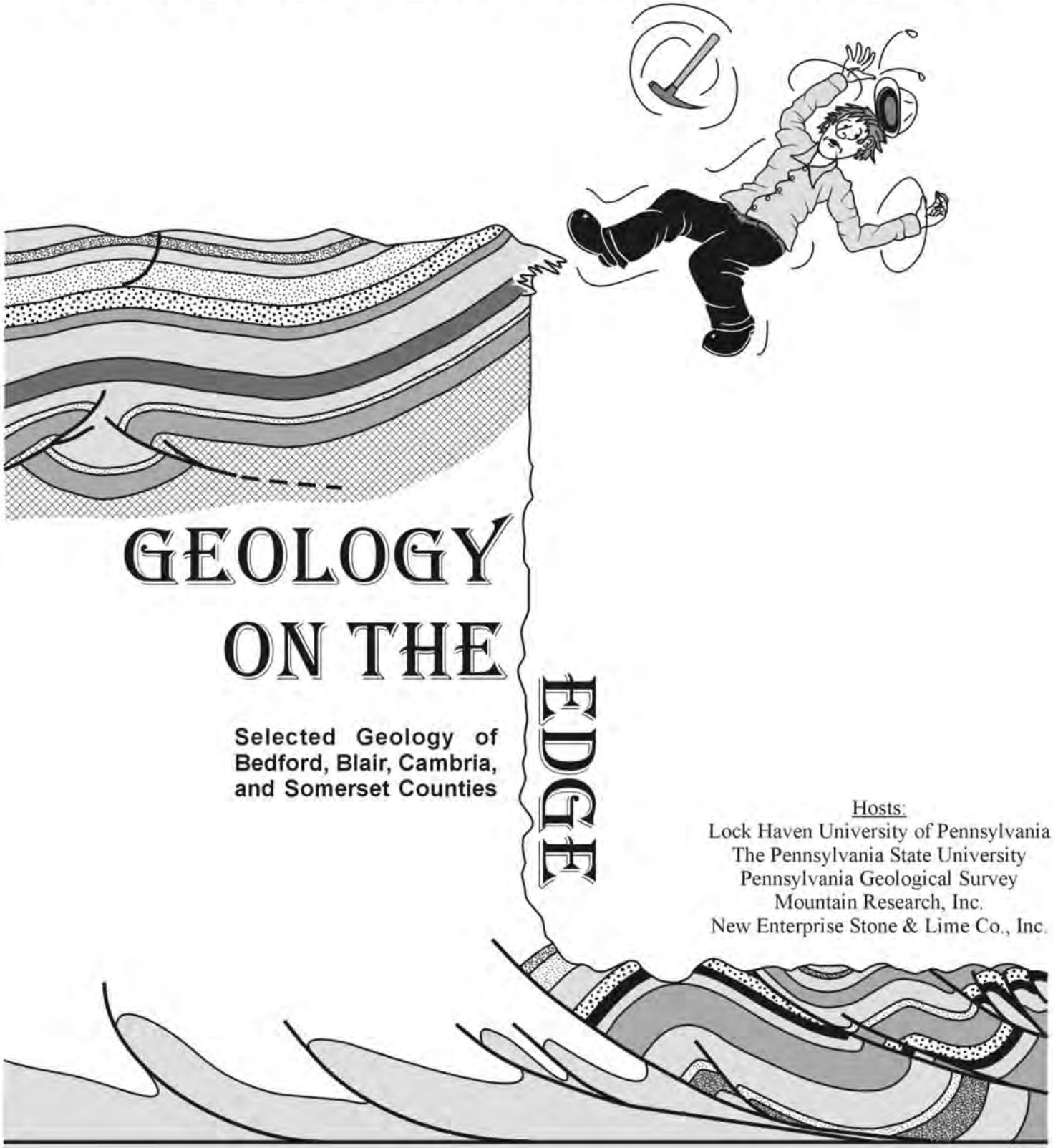
68TH ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

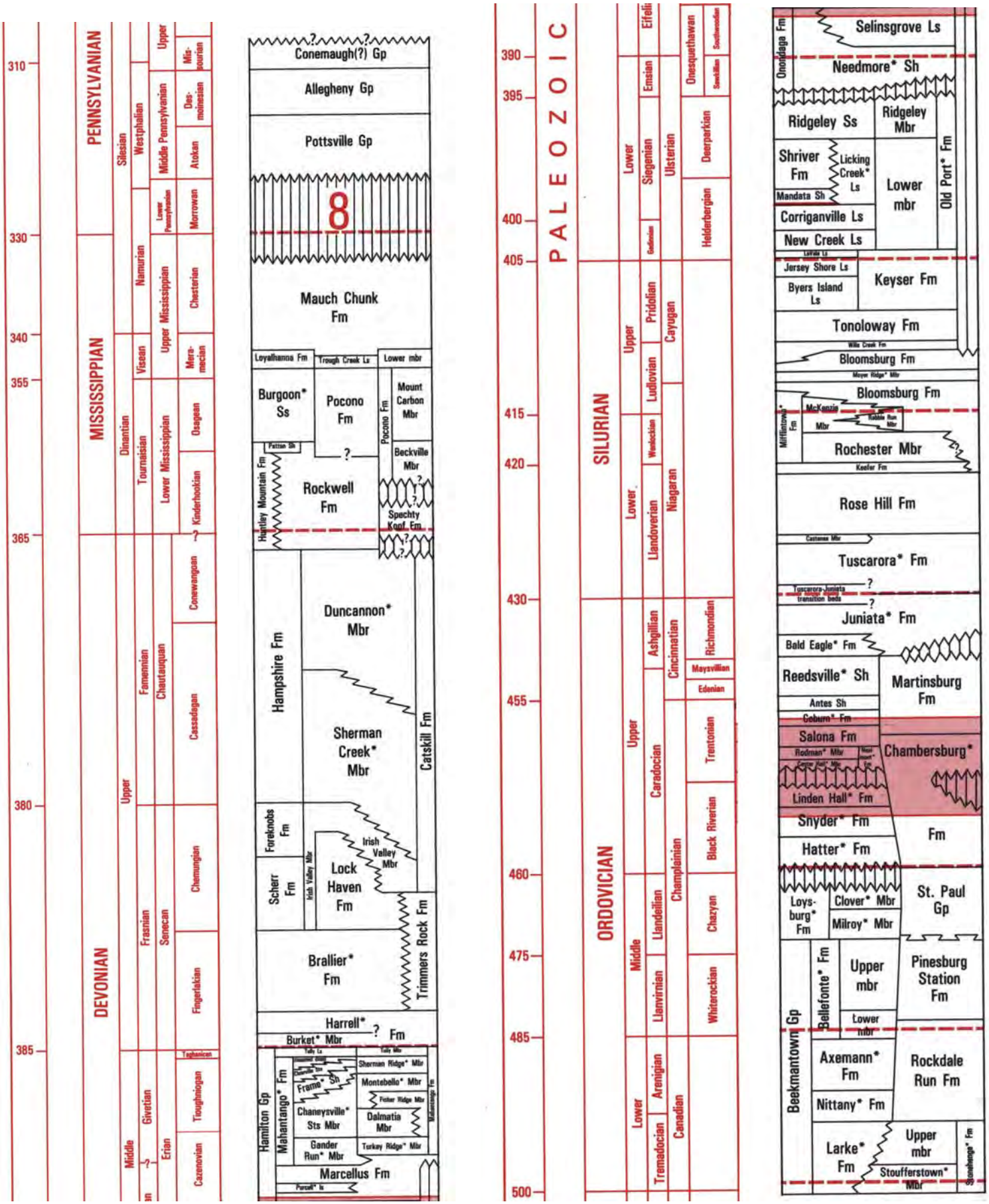


GEOLOGY ON THE EDGE

Selected Geology of Bedford, Blair, Cambria, and Somerset Counties

Hosts:
Lock Haven University of Pennsylvania
The Pennsylvania State University
Pennsylvania Geological Survey
Mountain Research, Inc.
New Enterprise Stone & Lime Co., Inc.

October 2-4, 2003
Altoona, PA



Modified from Pennsylvania Geological Survey General Geology Report 75,
Stratigraphic correlation chart of Pennsylvania

68th Annual Field Conference of Pennsylvania Geologists Guidebook

Geology on the Edge

Selected Geology of Bedford, Blair, Cambria, and Somerset Counties

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Frontispiece- Group photo of the 2002 Field Conference of Pennsylvania Geologists, Starrucca Viaduct, Lanesboro, Pennsylvania

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INTRODUCTION

For the first time in its history, the 2003 Annual Field Conference of Pennsylvania Geologists will visit the Altoona area in west-central PA. Here, the Ridge and Valley to the east meets the Appalachian Plateaus to the west. A transition zone, the Allegheny Front, lies between the two. "Geology on the Edge" addresses stratigraphy, structure, paleontology, and the environmental geology of the greater Altoona-Bedford-Johnstown region with four, pre-conference trips on Thursday, and nine conference stops Friday and Saturday.

For those with the flexibility to take advantage of a pre-conference trip, the range of options is wide. Trip A focuses on the geology of the Johnstown area specifically for elementary and secondary Earth and Space Science teachers (leader--Steve Lindberg). Trip B is an excursion into two Devonian basins, one to the east, the other to the south of Altoona (leader--Robert Altamura). Trip C visits an active aggregate quarry in Middle Ordovician carbonates (leaders--Duff Gold, Arnold Doden, Todd Lowrey, Keith Van Horn). Trip D provides participants with an opportunity to visit a Pleistocene fissure/cave that has yielded 51 species of vertebrates and more than 9000 individuals (leader--Shirley Fonda).

The main theme for Friday focuses on the detailed sedimentology, stratigraphy (Edwin Anderson, Peter Goodwin and Cheryl Sinclair, John Taylor and Frank Hall), paleontology (Charles Miller), and economic geology of the Keyser Formation (Duff Gold, John Taylor, Arnold Doden, William Bragonier) with 5 stops planned between Altoona, Blair Co., and New Paris, Bedford Co. The site of the once strategic entrepôt depot in Hollidaysburg (John Harper) can be viewed from the lunch stop at the scenic overlook at Chimney Rocks.

Saturday, the focus is on the Allegheny Front (Michael Scanlin and Terry Engelder) as viewed from two different perspectives. One is the contrast in stratigraphy, structure, and geologic history as they relate to the mineral resources in each of the two adjacent physiographic terranes (Robert Smith, Stop 6; Steve Lindberg, Stop 9). The other involves consequences that are more direct. You will be able to contemplate the impact of the escarpment's geomorphology on the social fabric of the area as we ride the train up the escarpment and through the historic Horseshoe Curve onto the Allegheny Plateau (Jon Inners, Vic Skema, and Gary Fleeger, Stop 7), and as we visit the Allegheny Portage National Railroad historic site at the top of the Front (John Harper, Stop 8).

DAY 1

Stops on the first day of the Conference involve the nature and depositional environment of the Keyser Formation in west-central Pennsylvania. This assessment is timely because of a renewed interest in the Devonian carbonates as a potential source of limestone. It will become apparent as we visit 5 different localities that the complexity of the facies architecture in the Keyser requires an advanced degree of sophistication and attention to detail to effectively explore for exploitable deposits of both high and uniform grade limestone. In contrast to the Ordovician limestone formations in the Nittany Valley, the Silurian/Devonian limestones are thin and highly variable in composition and texture, both along strike and down dip. The former are remarkably uniform in composition, thickness, and grade over distances of tens of miles. Facies changes and perhaps unconformities in the latter lead to variable thickness and composition over short distances along the paleo-shoreline and downslope. The spatially complex and rapidly changing depositional environments that produce the Keyser created deposits that are not only erratic in grade, but are difficult to establish as exploration targets.

Aside from its economic potential, the Keyser Formation is an extraordinary resource for the study of Mid-Paleozoic marine communities and sea-level history. The base of the formation represents a significant sea-level rise that reintroduced normal marine conditions to a basin that had experienced evaporite deposition through much of the Late Silurian. A highly diverse invertebrate fauna, including

impressive stromatoporoid-coral reefs in the middle of the formation, marks the peak of the transgression prior to the return of stressed peritidal conditions, represented by the upper member of the Keyser. We will debate different interpretations of the depositional environments, where each facies is located within a hierarchy of orders of cycles, and what may be driving the changes in lithology. Despite the fall in sea level represented by the upper member, sediment accumulated continuously through the end of the Silurian into the Early Devonian. Conodont biostratigraphy (Denker and Harris, 1988) places the Devonian/Silurian System boundary near the middle of a continuous sequence of muddy limestone beds that represent a prograding mud-flat setting within the upper part of the Keyser. This contrasts strongly with the clear division apparent in the European section, where this boundary is marked by a physical change, a consequence of the initiation of the Caledonian Orogeny. Cheryl Sinclair and Edwin Anderson will address the age, stage, and setting in more detail.

A distinctive carbonate package of ten mappable units has been identified in the New Paris Quarry (this volume). Throughout this region, the Keyser Formation is underlain by more than 1000 feet of the Tonoloway Formation, which is dominated by finely laminated lime mudstones, and is overlain by the Old Port Formation. The latter consists of thin limestone units with the New Creek (=Coeymans) and Corriganville (=New Scotland) members at the base, through the Mandata Shale member up-section into the chert and shaly limestone of the Shriver Member, and into the Ridgeley Sandstone Member. Robert Altamura will lead Field Trip B on Thursday to examine some of these units (this volume).

The Keyser Formation is approximately 180-feet thick in this region, and consists of at least 8 distinctive units with markedly different textures and compositions. Amongst the more distinctive of these "units" are the stromatoporoid beds by virtue of both abundance and size of these large coralline sponges, some as much as a foot in diameter and two feet in length. Charles Miller has summarized the taxonomy of the large fossils as well as their habitat. Edwin Anderson, Peter Goodwin and Cheryl Sinclair will relate these to shallow marine basins with fluctuating sea level. They will examine Milankovitch cycles as a possible forcing function for the meter-scale depositional cycles in the middle of the formation.

John Taylor, Frank Hall, and William Bragonier examine the stratigraphy of the Keyser at two localities, interpret the reefal environment through modern-day analogs, and will propose a new member (the Chimney Rocks Member) for the interval formerly called Byers Island Member in this area. John Taylor will demonstrate the importance of knowledge of the Keyser stratigraphy to detect low-angle faults that locally duplicate the lower Keyser units at the Eldorado Quarry. He will also show us that the unique morphology responsible for Chimney Rocks has both stratigraphic ("calico rock") and structural components (high-angle faults). Arnold Doden and Duff Gold will use the Osterburg and New Paris areas to emphasize the difficulty of mapping the Keyser members and in targeting specific units for economic evaluation. A drill core of the entire Keyser section at New Paris will be on display.

Dissolution of the "sweet" units in the Keyser is another factor to affect sustainable quarry operations. One of these "sweet" units, the "calico" rock of the early quarrymen, is a massive lime mudstone with orange-colored fenestrae (similar in color to calico cats). It was quarried locally as a source of lime, and was touted amongst the miners for the abundance of caves.

The question comes down to whether or not any of the Keyser units have both the grade and volume for sustainable production to satisfy the long-term needs of a modern power plant. If so, what are the limitations for an exploration program and what are the requirements for the exploration geologist? Clearly, the geologist should be a competent field-person. The geo-person should have expertise in facies, setting, and stratigraphy of the Keyser Formation in this area. It would also help if he/she were an expert in modern reefal environments, paleontology, marine carbonate sedimentology, and marine biology, as well as have an understanding in planetary mechanics. Perhaps only the Great

Devonian Geologist, Professor Rashmani Singh would be competent to handle such an assignment (see posters).

DAY 2

The field trip stops on Saturday have both geological and social components, and serve to illustrate contrasts between the two adjacent, yet distinctly different regions in west-central Pennsylvania. We will compare the differences in the nature of the lithologies, structures, and mineral resources exposed in the Ridge and Valley physiographic province with those in the Allegheny Plateaus terrain. In each province, a mineral resource comes into focus. Stop 6 provides a glimpse at the lead (and zinc) mineralization in the Ordovician carbonates of Southern Sinking Valley (Robert Smith) and its role in the colonial history of Pennsylvania. In contrast, later in the day we descend to the base of a coal-stripping pit, Stop 9, and address the coal and clay resources in the Allegheny Plateau Province, their economic benefits to the region, as well as the down-stream pollution problems they have generated (Steve Lindberg).

In addition, we spotlight the Allegheny Front, the bounding zone between these two adjacent, yet contrasting, physiographic and structural provinces. In calling this feature to your attention, we wish to address not only the geologic nature of this escarpment, but also its social impact as well. As a loosely defined boundary drawn between these two terrains, the Allegheny Front is unlikely to be a reproducible mappable entity. Here, it occurs somewhere within Bald Eagle Valley; its exact position is likely to vary and be a function of the discipline of the observer. To a geomorphologist, it is a laid-back, eastward-dipping scarp marking the western edge of Bald Eagle Valley. Intuitively, one would have to define its position temporally because of on-going headward erosion and scarp-retreat. Stratigraphically, there is a radical jump from Devonian strata to Pennsylvanian across the “front.” In a structural sense, it marks a change in fold style from relatively narrow, tight fold hinges to gentle folds. The geophysical interpretation (Scanlin and Engelder, this volume) suggest it is a ramped step over a basement fault that has caused a series of stacked anticlines to be propagated to the surface. They advance the case that the Allegheny Front is a broad zone of disturbed strata stacked above a fault that displaces Precambrian rocks in the basement approximately 8 km below the surface, and make the analogy to “highway speed bumps.” The Devonian outcrop width in this zone varies from less than one mile near Skytop, Centre Co., to tens of miles farther south near Blue Knob, Blair Co.

As we traverse the Allegheny Front, first by rail and then by highway, try to develop a concept of this escarpment from the perspective of its daunting magnitude. It imposed tremendous hardships on westward expansion and the early colonial trade routes. The “front” represents the eastern slope of a ridge that is the drainage divide separating the Susquehanna River system flowing east to the Atlantic from the Ohio River system flowing ultimately into the Gulf of Mexico. Barge transport on the extensive canal system that developed in eastern Pennsylvania stopped in Hollidaysburg because of these mountains (see historical note by John Harper). We will hear details of the engineering challenges of constructing the first railroad over the Allegheny Mountains—the Allegheny Portage Railroad. This inclined-plane rail bed, designed to “portage” canal barges over the divide and into the Ohio system of canals, operated between 1834-1854 and was considered a technological wonder in its day. It played a critical role in opening the interior of the United States to trade and settlement.

During the time the canal system was in use, the newer, competing rail systems were rapidly expanding westward. Moreover, just as it did for the canals, the Allegheny Front served as a significant obstacle for the railroads as well. Built in 1845, Horseshoe Curve was the railroad’s solution to this problem. Horseshoe Curve permitted rail travel between New York City and Chicago, giving Pennsylvania a major role in the development of the still young country. Virtually unchanged in design since its initial construction, the curve is located at the end of a long "U" gradually sloping up two sides of a steep valley. As we ride the train up and over the escarpment on the rail line (Jon Inners , Vic

Skema, and Gary Fleeger), marvel at this engineering accomplishment, and contemplate the implications of this feat upon the social fabric of American history.

APPENDICES

TRIP A. Printed separately.

TRIP B: The Thursday radargeology trip visits two Devonian-cored structural basins within the Ridge and Valley Province of the central Appalachians near Hollidaysburg and Everett, PA. Interpretation of the stratigraphy and structures as portrayed in side-looking airborne radar (SLAR) imagery has resulted in the identification of distinct and mappable lithofacies within geologic units that were previously undivided. We will observe selected outcrops of these new lithofacies and associated structural features during the field trip. The trip provides the opportunity to collect Devonian marine fossils from a radargeological unit that is designated as a member of the Mahantango Formation.

TRIP C: The excursion to the New Enterprise Stone and Lime Company quarry at Roaring Spring examines the stratigraphy of the middle Ordovician carbonates in the steeply overturned limb of the Roaring Spring anticline. The quarry exposes a continuous section: Bellefonte, Loysburg, Hatter, Snyder, Linden Hall, Nealmont, Salona and lower Coburn formations, including a number of bentonite marker beds. The field stops will focus on the mesoscopic-scale structures and the complex deformation in the hinge zone of the anticline.

TRIP D: The 40 feet of cave sediments excavated in the Frankstown Fissure Bone deposit yielded bones from 9319 individuals, representing 52 species of mammals as well as many reptiles and amphibians. The prize-wining find was the fragmentary skeleton of a young Mastodon (*Mammut americanum*) dated by amino acid recemization as 10,000-12,000 ybp. Changes in the types of species and number of individuals at levels throughout the forty-foot column reflects the transition between a boreal to a more temperate climate.

ACKNOWLEDGEMENTS

The organizers and editors graciously thank the many professionals whose time, energy, and personal contributions all came together for this year's field conference. We gratefully acknowledge the substantial efforts of the authors, field-trip leaders, individuals involved in logistics and coordination, and those shouldering last-minute editing and production responsibilities. Both Arnold Doden and Gary Fleeger cut a broad swath through the technological maze greatly lessening the trauma of the publishing experience and, for that, we are deeply appreciative. We also thank the Pennsylvania Geological Survey, as the Field Conference's umbrella organization, for supporting fieldwork and data gathering, and for facilitating the production of this guidebook.

In particular, we thank New Enterprise Stone and Lime Company, Inc., for making field-trip sites available and for releasing propriety data. We wish to acknowledge the cooperation and support of these hosting institutions--Lock Haven University of Pennsylvania, The Pennsylvania State University, Indiana University of Pennsylvania, Temple University, and the University of Pittsburgh at Johnstown—for the role of their faculty, use of their libraries and access to their facilities. Thanks to guest speaker Timothy C. Van Scoyoc, Director, Blair County Historical Society, Altoona.

We greatly appreciate the cooperation of the following individuals and entities who facilitated and contributed to this field conference: the PA State Police, Troop G, Hollidaysburg, for accommodating our parking needs; the Borough of Hollidaysburg for use of the Chimney Rocks State

Park; the Altoona Bible Church and Christian Science Reading Room for access to their parking lots; Grannas Brothers for access to their quarries; Executive Director Margaret Goodman, Fort Roberdeau Historic Site; Altoona Railroaders Memorial Museum, Allegheny Portage Railroad National Historic Site; and Mark Blaisdell, Cooney Brothers Coal Company, Cresson.

Last, but not least, we are very appreciative to New Enterprise Stone and Lime Company, Inc., and Mountain Research, Inc., for their generous contributions, to Sheetz, Inc., for providing lunches for the participants, to Groundwater & Environmental Services, Inc. and Fairway Laboratories, Inc. for the coffee and doughnuts, and to Eichelbergers, Inc. for the water and soft drinks provided on the trip.


Harpes '03

FACIES AND PALEOENVIRONMENTS OF THE KEYSER FORMATION IN THE CONTEXT OF ITS CYCLIC STRUCTURE

by
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INTRODUCTION

The Keyser Formation of the Helderberg Group in central Pennsylvania, Maryland and West Virginia (Fig. 1) consists of shallow-marine and tidal-flat limestone, dolomite and locally quartz arenite facies (Bowen, 1967; Head, 1969; Makurath, 1977; Barwis and Makurath, 1978; Dorobeck and Read, 1986). These rocks are Late Silurian and Early Devonian in age and occur in the upper half of the Pridolian and lowermost Gedinnian Stages (Fig. 2). Based on its internal cyclic structure the Keyser Formation is interpreted as two 3rd order (2 Ma) sequences at its type locality near Keyser, WV. Here, at the type locality, the formation nearly reaches its thickest point, 87 m (285 feet), as measured in the quarry and roadcut just east of the village of Keyser (Figs. 2 and 3). The formation thins to 27.5 m (90 feet) in the abandoned quarry in the village of Tyrone, PA, 150 km to the north. At Tyrone, the lower half of the Keyser Formation (the lower 3rd order sequence) is missing and the Keyser is unconformable with the underlying Tonoloway Formation (see Sinclair et al., this volume). At Tyrone the upper half of the Keyser Formation (the upper 3rd order sequence) is 20 m (65 feet) thinner than at Keyser, WV. Most of the lost section is accounted for by differential subsidence (Anderson et al., 1986) that results in less accommodation space at Tyrone than to the south in Maryland and West Virginia. However, a few meters of the Keyser section at Tyrone are lost in an erosional unconformity at the overlying Keyser - New Creek formational boundary (as compared to the type locality in West Virginia). At other localities in the Altoona area, the upper Keyser sequence is the main unit preserved, but small remnants of the top of the lower Keyser occur below the unconformity that defines the 3rd order sequence boundary at the base of the upper Keyser.

The Helderberg Group (Pridolian, Gedinnian and Siegenian) in the Appalachian Basin is divisible into meter-scale rock cycles (PACs, see Fig. 4) that are in turn bundled into a multi-tiered hierarchy of cycle sets or sequences (see Goodwin et al., 1986; Goodwin and Anderson, 1988; Anderson and Goodwin, 1989; 1990a; 1990b; 1991; Goodwin et al., 1992). These cycles and sequences are the product of 'Croll-Milankovitch' orbital forcing (Croll, 1875; Milankovitch, 1941) where the smallest-scale cycles (6th order) are the product of precession and three orders of cycle bundles (sequences) are produced by modulation of precession by variation in the degree of eccentricity of the Earth's orbit (Fig. 5, and see Goodwin and Anderson, 1985; Goodwin and Anderson, 1997). The Keyser Formation at its type locality is divisible into two relatively complete 3rd order (2 ma) sequences that in turn consist of 4th order (400 ka) and 5th order (100 ka) sequences. All levels of this hierarchy are recognized by asymmetry in their patterns of facies distribution (Fig. 6). Larger facies changes occur at the bases of cycles lowerin sequences whereas smaller facies changes occur at cycle boundaries higher in sequences. In addition coarser-grained skeletal limestone is the dominant facies near the bases of cycles and low in cyclic sequences whereas finer carbonates with restricted faunas and dolomites frequently containing microbial structures (stromatolites and thrombolites) characterize the upper parts of cycles and sequences.

Anderson, E.J., Goodwin, P.W. and Sinclair, C.J., 2003, Facies and paleoenvironments of the Keyser Formation in the context of its cyclic structure, *in* Way, J.H. and others, eds., Geology on the edge: selected geology of Bedford, Blair, Cambria, and Somerset Counties, Guidebook, 68th Annual Field Conference of Pennsylvania Geologists, Altoona, PA, p. 1 - 18.

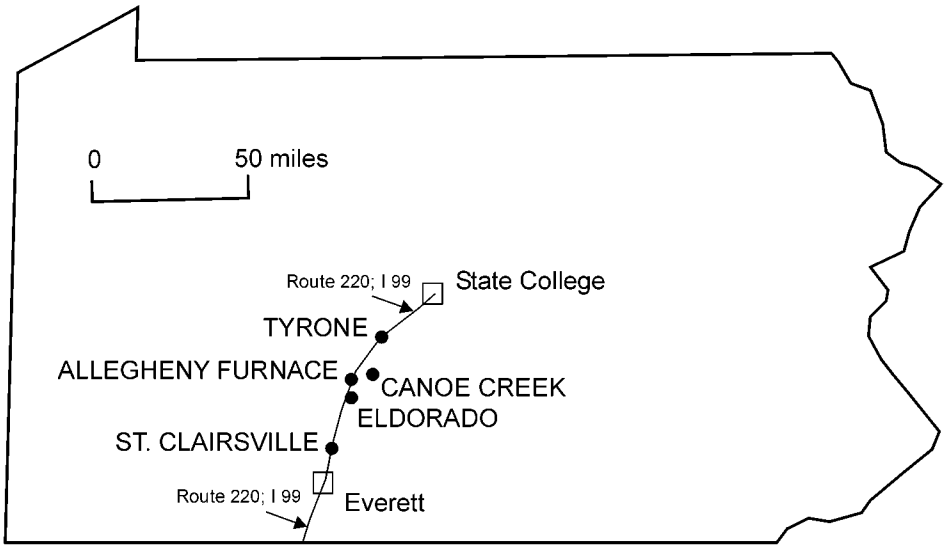


Figure 1. Location of five sections of the Keyser Formation between state College and Everett, PA.

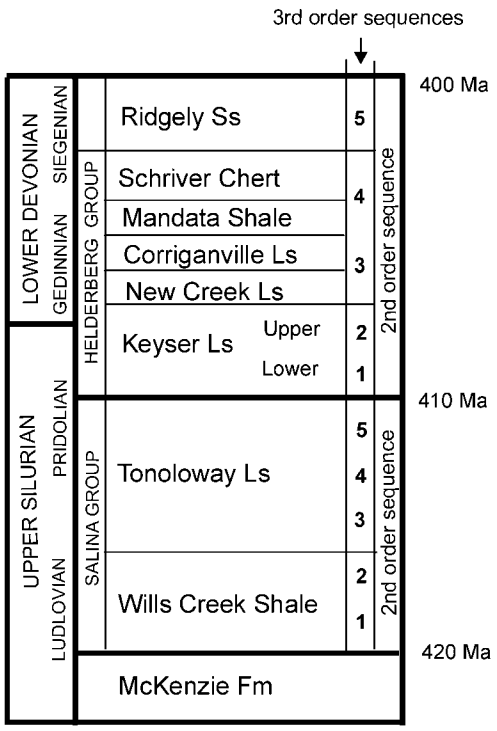


Figure 2. Stratigraphic position of the Keyser Formation and interpreted position of 2nd and 3rd order sequence boundaries with estimated age dates in the Salina and Helderberg Groups.

THE GENETIC HIERARCHY

2nd Order	10 ma	Tectono-eustasy
3rd Order	2 ma	Eccentricity ?
4th Order	400 ka	Long Eccentricity
5th Order	100 ka	Short Eccentricity
6th Order	20 ka	Precession

Figure 3. The genetic hierarchy of cycles and sequences adopted in this study (from Goodwin and Anderson, 1997).

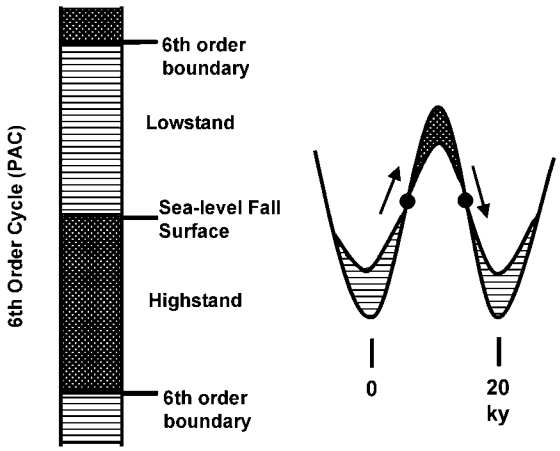


Figure 4. The relationship between precessional eustasy and 6th order cycles. Sixth order boundaries are produced at times of non-depostion associated with maximum rate of sea-level rise (see dot at the inflection point on the sea-level rise curve). Sea-level fall surfaces may be produced at times of maximum rates of sea-level fall (Goodwin and Anderson, 1997).

In the Altoona area, including sections at St. Clairsville, Eldorado (Altoona Bypass), Allegheny Furnace, Canoe Creek Quarry and Tyrone (Fig. 2), most of the lower Keyser 3rd order sequence is either lost in an unconformity or represented by a facies change into Tonoloway-like tidal-flat facies. Evidence for lateral facies change between lower Keyser shallow-shelf facies and tidal-flat facies is seen in the intertonguing of these facies at several localities between Keyser, WV and Altoona, PA, including Hyndman, Everett, Cessna and St. Clairsville (all in PA). At these localities, Tonoloway facies are interbedded with Keyser facies and Tonoloway tidal-flat facies thin and finally pinch out to the south. A marked erosional unconformity truncates lower Keyser mud-mound or reefal facies defining the 3rd order boundary between the lower and upper Keyser 3rd order sequences in the Altoona area (see stratigraphic columns Figs. 7-11; Sinclair et al., 1998 and Sinclair et al., this volume).

ASSUMPTIONS IN THE CYCLIC ANALYSIS

In this paper, the term **cycle** (or 6th order cycle) is used to describe the smallest-scale rock cycle in the studied stratigraphic interval. In this usage, a cycle is the same as a 'punctuated aggradational cycle' (PAC) defined by Goodwin and Anderson (1985), Anderson and Goodwin (1990b) and an 'elementary sequence' defined by Strasser (1994). A 6th order cycle (PAC or elementary sequence) is defined as a meter-scale sedimentary rock package bounded by surfaces marked by abrupt change to deeper facies (see Fig. 4). These rock cycles typically shallow upward and may contain sea-level-fall surfaces. These cycles are interpreted as the product of the 20 ka precessional signal (Anderson and Goodwin, 1992; Strasser, 1994). The term **sequence** is used in this paper to describe bundles or sets of 6th order cycles. Periodic variation in the degree of eccentricity of the Earth's orbit bundles 6th order cycles into 100 ka sets (5th order sequences), 400 ka sets (4th order sequences) and 2 Ma sets (3rd order sequences) as mentioned above (see Fig. 5).

Deductive methodology

In this study, the first and most fundamental assumption is adoption of a deductive methodology. Specifically the hypothesis is adopted (and tested by ongoing application) that 'Croll-Milankovitch' type orbital-forcing processes impose a hierarchic, allocyclic structure on the stratigraphic record. This hypothesis is derived from 25 years of experience in measuring and interpreting cyclic patterns, primarily in Silurian and Devonian strata in the Appalachian Basin. The model subsequently has been tested and supported by analysis of cyclic structure in the Carboniferous of Wales (Anderson and Goodwin, 1990b), evaluation of the cyclic structure of the Sierra del Pozo section in southern Spain (Jimenez de Cisneros and Vera, 1993) and analysis of the cyclic structure of Berriasian strata in the French Jura by Strasser (1994) and Strasser and Hillgärtner (1998). Most recently Anderson and Terry (2003), Terry and Anderson (2003) and Anderson (2004) documented a similar cyclic hierarchy in the Lower Cretaceous

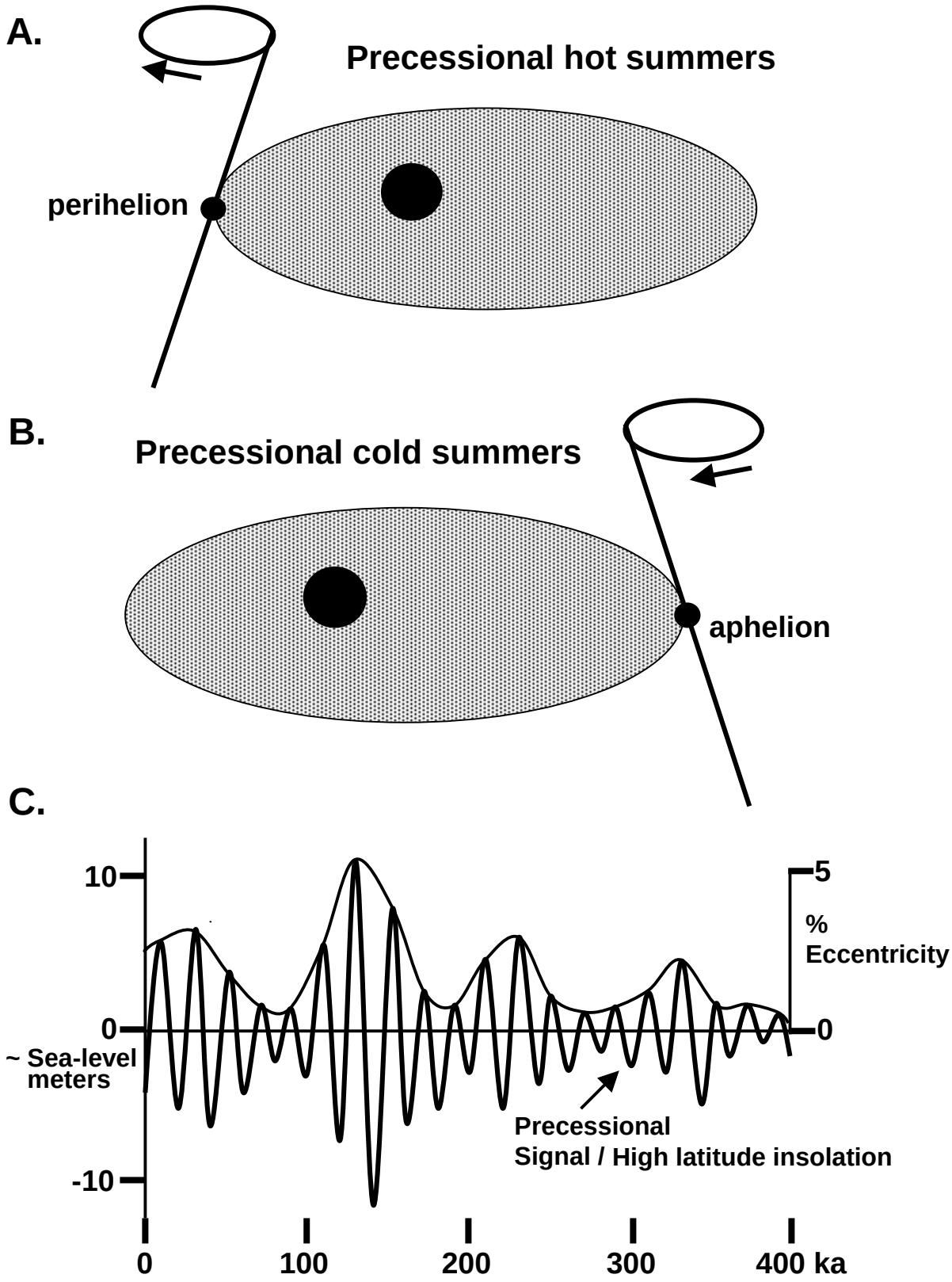


Figure 5. The Croll - Milankovitch orbital forcing mechanism. A. Continental glacial ice melts during perihelion summers; B. Continental glacial ice accumulates during aphelion summers; C. The magnitude of the precessional signal (insolation), ice volume and sea-level vary directly with eccentricity bundling precessionally forced rock cycles into sequences at two or more scales.

Purbeck Group in Dorset, England where well-developed paleosol profiles commonly occur at cycle and sequence boundaries.

The assumed hypothesis is/will be sustained and reinforced to the degree that strata of the Helderberg Group are consistent with the model. The hypothesis is to be adjusted, revised or even rejected if new observations are in significant and inexplicable conflict with the model. This method is the same as that expressed in Goodwin and Anderson (1985, p. 515) who stated "Our deductive approach is consistent with the hypothetico-deductive interpretation of the scientific method (Popper, 1959) and with the views of Kuhn (1962) that science advances principally through generation and testing of paradigms. In agreement with Medawar (1964), Eldredge and Gould (1972), and Laudan (1977) we think that ideas precede detailed observations so that all observations are to a large degree made under the influence of some previously formulated hypothesis."

Precession and eccentricity

In this study it is assumed that the fundamental process in producing a cyclic stratigraphic record is the precessional signal (Berger, 1988; Anderson & Goodwin, 1990b; 1992; Fischer and Bottjer, 1991; De Boer and Smith, 1994 and House and Gale, 1995). The strength of the precessional signal is directly related to the degree of eccentricity of the Earth's orbit (Fig. 5). As eccentricity increases and summers occur near perihelion (in the precessional cycle), insolation at high latitudes reaches a maximum. If those summers are in a hemisphere with large areas of continent at high latitude, then high insolation values may trigger the melting of significant amounts of accumulated continental glacial ice. When summers occur near aphelion with high eccentricity, the resulting long series of cool summers may trigger renewed build up of high-latitude, continental glacial ice. Read et al. (1986) stated that even low-amplitude sea-level oscillations of a few meters generate tidal-flat cycles in their modeling experiments. Thus, variations in ice volumes only 5%-10% of that demonstrated for the Pleistocene could be recorded in the stratigraphic record. Grotzinger (1986) discussed the role of low amplitude (orbitally forced) sea-level fluctuations in the production of small-scale carbonate cycles and links the origin of such cycles to decreased surface area of high-latitude land masses on which continental glaciation might develop.

If fluctuation in sea level is primarily a response to precession of the position of the summer solstice in the Earth's orbit, then the magnitude of sea-level rise and fall would be proportional to the degree of eccentricity of the orbit (Fig. 5c). When eccentricity is high, there would be large changes in summer insolation between perihelion and aphelion and therefore larger sea-level fluctuations. When the Earth's orbit is nearly circular, the amount of change in insolation through a precessional cycle would be minimized, resulting in more stable sea levels. The degree of eccentricity of the Earth's orbit varies periodically. It varies from nearly circular to as much as 5% eccentric and back to circular with a period of about 100 ka (see Berger, 1988 p. 634, Fig. 9). Croll (1875) recognized the significance of this phenomenon and showed that at a maximum eccentricity the difference in distance between the Earth and the Sun in the aphelion versus the perihelion positions would be some 22 million km. This number is closer to 14 million km at 5% eccentricity and 5.5 million km at the Earth's current eccentricity (~1.7%). In addition, the 100 ka eccentricity maxima in the Earth's orbit are more enhanced at 400 ka intervals and possibly at 2 million-year intervals (Berger, 1988; Fischer, 1991). These periodic patterns in degree of eccentricity of the Earth's orbit modulate the strength of the precessional

CROLL - MILANKOVITCH STACKING PATTERNS

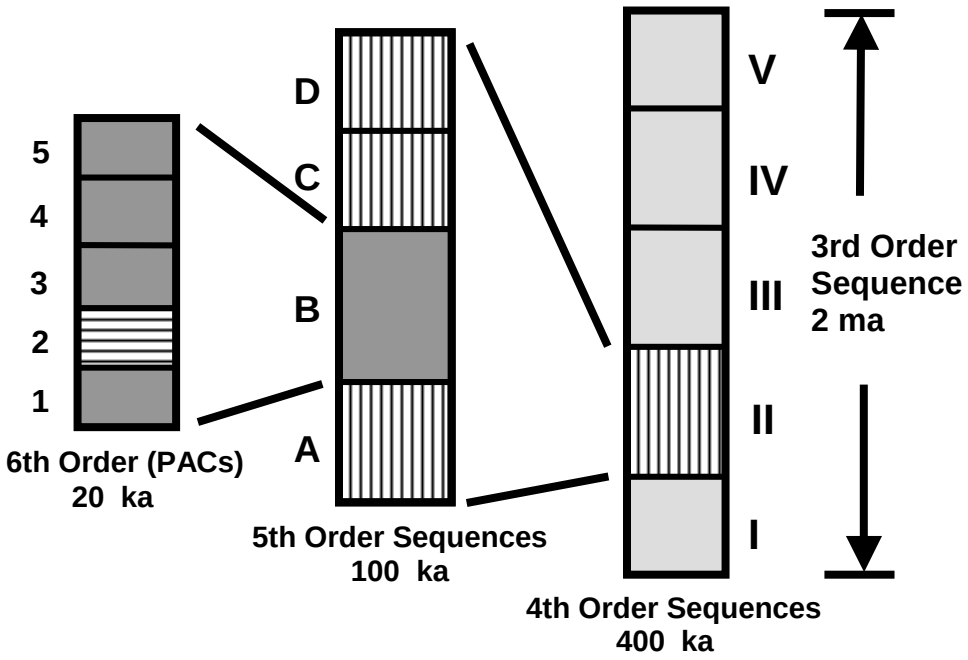
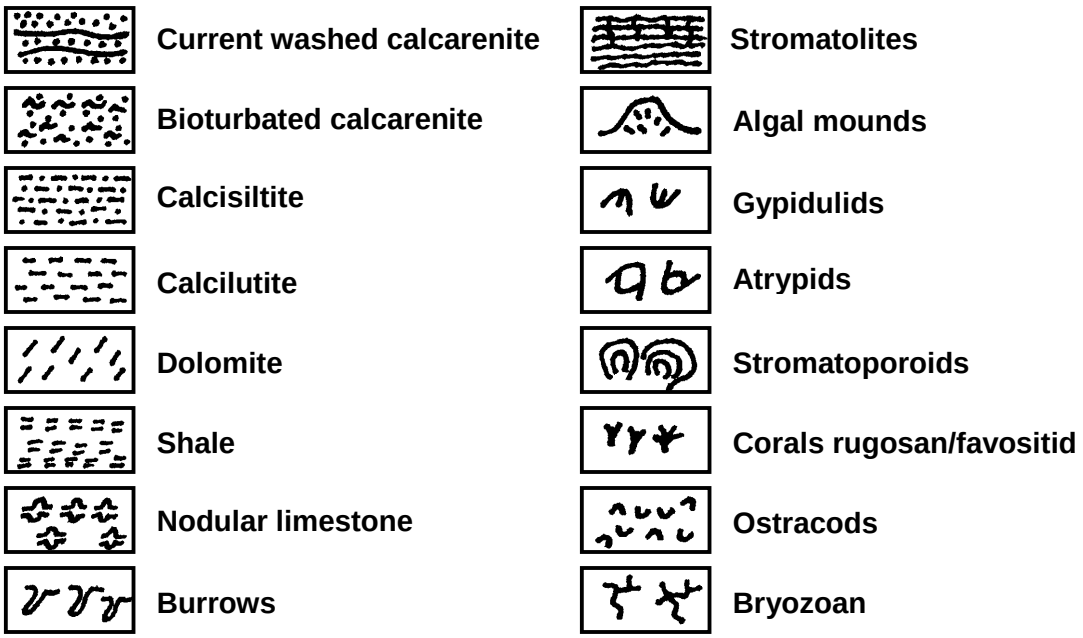


Figure 6. Stacking patterns of cycles and sequences derived from assumption of the orbital-forcing model. With complete preservation, five 6th order cycles (PACs) may occur in one 5th order sequence and four 5th order sequences in one 4th. The largest facies contrasts or most open marine facies tend to occur in the second unit in each order resulting in sequence asymmetry (Goodwin & Anderson, 1997; Anderson, 2004, in press).



Legend for all stratigraphic columns.

signal (forcing changes in ice volume and associated sea-level fluctuations), thus producing 100 and 400 ka bundles of rock cycles, i.e. 5th and 4th order sequences (see Fig. 6).

Obliquity

The role of obliquity (the 41 ka obliquity cycle) in the assumed orbital-forcing model is limited to modulating the magnitude of insolation changes through the precessional cycle. For example, if a maximum precessional sea-level rise were in phase with maximum tilt, the magnitude of this rise would be amplified, but 20 ka later the next precessional rise would occur at minimum tilt and be muted. This could lead to a cyclic stratigraphic record where the first precessional rise (in a 100 ka sequence of rises) produced a marked facies change at the associated precessional (6th order) cycle boundary but where the next 6th order boundary might be difficult to detect.

The origin of cycle boundaries

A final working hypothesis is that all rock cycle boundaries are surfaces produced by rates of (precessional) sea-level rise that exceed a critical value (Anderson and Goodwin, 1992; Anderson, 2004). At rates above the critical value of sea-level change, sedimentation is thought to effectively stop (see Tipper, 1997; 2000). Tipper (1997) predicted that the critical variable for the production of lag is colonization rate and that it produced the lag phenomenon during both sea-level rise and sea-level fall. In this manner, higher-amplitude sea-level rises produce discontinuities between lowstand and highstand facies at rock-cycle boundaries representing longer time intervals and displaying larger facies contrasts across the boundary. During lower- amplitude sea-level rises, the time interval of discontinuity would be shorter and the facies change across the cycle boundary (= depth difference) would be less. This concept of a mechanism for producing cycle boundaries in all facies is distinct from modeling methods that artificially generate lag-time or lag-depth (e.g. Read et al., 1986) and (the concept) explains the genesis of cycle boundaries in totally subtidal deposits. The critical value for rate of sea-level change may also be exceeded during (precessional) sea-level falls (also predicted by Tipper, 1997), producing sea-level-fall surfaces between highstand and lowstand facies within 6th order cycles (Fig. 4). Sea-level-rise surfaces are more marked and better preserved stratigraphically than sea-level-fall surfaces because rates of relative sea-level rise are amplified by subsidence while rates of relative sea-level fall are diminished.

In summary, in the assumed model, all orbitally-forced sea-level rises, and therefore all surfaces at allocycle boundaries, are the product of the precessional signal (Anderson and Goodwin, 1992; Goodwin and Anderson 1997). The term **PAC** (punctuated aggradational cycle) is exclusively equated to precessionally forced 6th order rock cycles (Goodwin and Anderson, 1985; 1988; 1997; Goodwin et al., 1986). As stated earlier, these rock cycles are equivalent to Strasser's (1994) elementary sequences. Variation in the degree of eccentricity of the Earth's orbit bundles these 6th order cycles (into 5th and 4th order sequences or cycle sets) by periodically varying the magnitude of the precessional signal (Fig. 5c).

Genetic hierarchy and stacking patterns

The hierarchy of cycles and sequences applied in this study is genetic (see Busch and West, 1987; D' Argenio et al., 1997) in the sense that each rank in the hierarchy is related to a specific stratigraphic process (Fig. 6). In particular, as described above, 4th, 5th and 6th order sequences (or cycles) are each related to a particular orbital-forcing process involving the

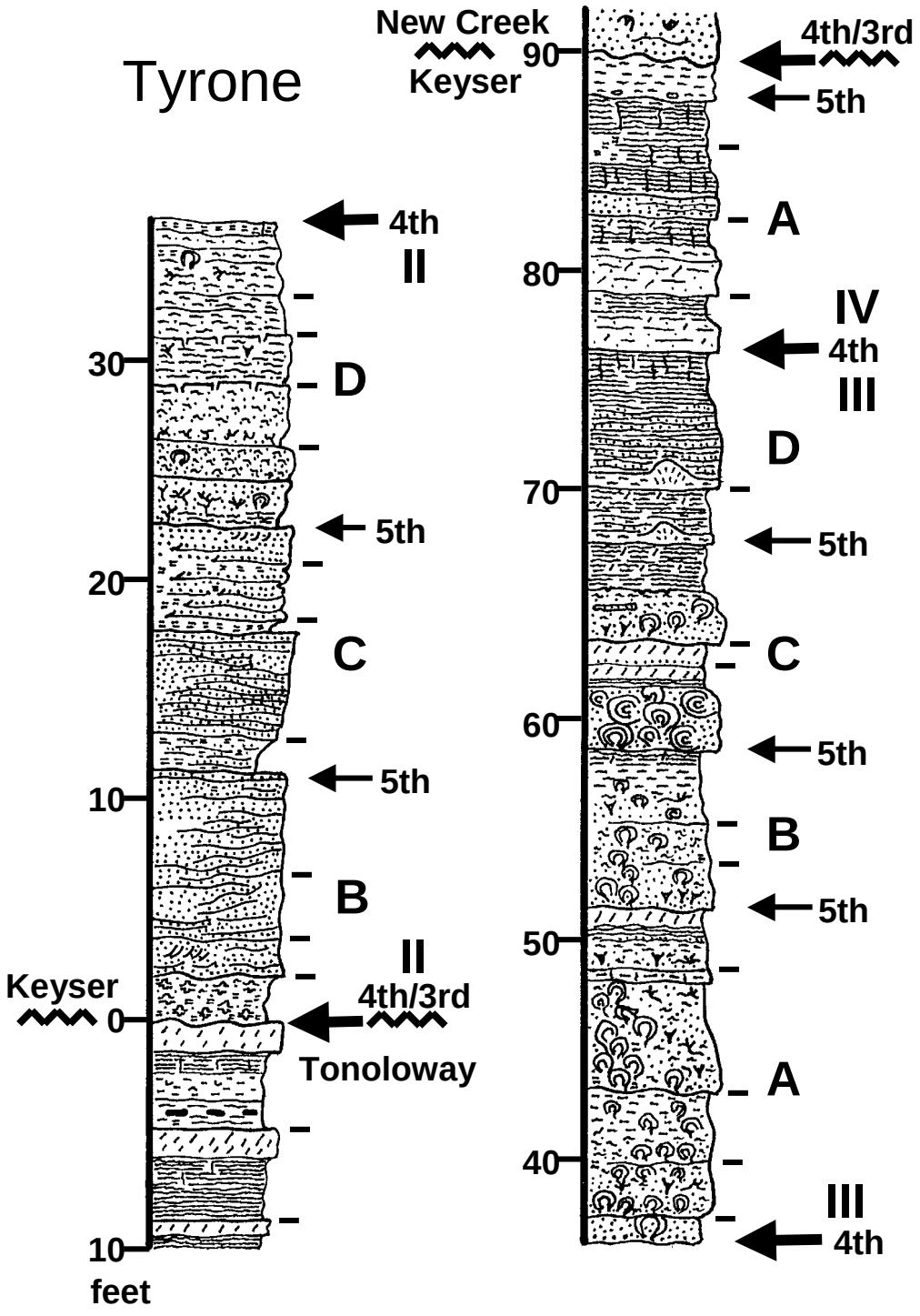


Figure 7. Stratigraphic column of the Keyser Formation at the Tyrone section.

interplay of precession and eccentricity (Goodwin et al., 1992). In this scheme, the terms 2nd and 3rd order sequences are adopted and modified from the usage of seismic and sequence stratigraphy in which the fundamental unit of sequence stratigraphy is the '3rd order sequence' (a genetically related set of strata bounded by unconformities and their correlative conformities, Van Wagoner et al., 1988).

Although 3rd order sequences were not defined in terms of duration (Van Wagoner et al., 1988), in practice 3rd order sequences commonly are 1-2 Ma in duration and 2nd order (b), supersequences, tend toward 10 Ma in duration. For this reason, the 3rd order rank in the genetic cyclostratigraphic hierarchy defined here is assigned to the 2 Ma sequence. Note that when sequences of less than 2 million years duration are identified by the practitioners of the sequence stratigraphic model (and called 3rd order), the boundaries of such shorter duration sequences could have been placed at prominent 400 ka sequence boundaries within a 2 Ma sequence. However, the sequence stratigraphic model does not recognize an orbitally forced hierarchic structure internal to 3rd order sequences. Furthermore, the cyclic structure used in this study is conceptually distinct from both parasequences and parasequence sets and thus from the hierarchy of stratal units employed in the sequence stratigraphy model (Van Wagoner et al., 1988; Kamola & Van Wagoner, 1995).

If complete preservation of the orbitally forced hierarchy occurs, the predicted stacking pattern consists of five 6th order cycles in each 5th order sequence. At the next level, four 5th order sequences would occur in each 4th order sequence and at a larger scale, five 4th order sequences are predicted in a 3rd order sequence (Fig. 6). The largest facies changes occur at the bases of 6th order rock cycles and (by arbitrary definition) in the lower part of the second cycle or sequence in each of the larger-scale bundles in the hierarchy. Experience demonstrates that the basic cycle and the bundled sets of these cycles (sequences) are asymmetric in facies distribution; it is then most parsimonious to have the bundled sets reach a shallowest point (or a minimal facies contrast across cycle boundaries) at or near the top of cycles and larger-scale sequences.

CYCLIC STRUCTURE OF THE KEYSER FORMATION

The Upper Keyser 3rd order sequence

In the Altoona area (Tyrone to St. Clairsville, Fig. 1) only the upper half of the Keyser Formation is well preserved. The lower half, well exposed at the type locality in West Virginia, is replaced by lateral facies change into Tonoloway facies and in part is lost in a 3rd order unconformable sequence boundary between the lower and upper parts of the Keyser Formation. Based on their internal cyclic structure, these two parts of the Keyser are interpreted as 3rd order sequences of 2 Ma duration. This time estimate for the duration of the stratigraphic interval represented by the Keyser Formation (based on its internal cyclic structure) is consistent with the time shown for the Keyser Formation on the *Stratigraphic Correlation Chart of Pennsylvania* (Berg et al., 1983). In the rest of this article the cyclic structure of five well-exposed stratigraphic sections of the Keyser Formation in the Altoona area will be described and interpreted in terms of patterns of facies change. Stratigraphic logs show the correlation of 3rd, 4th and 5th order sequence boundaries at all localities in the study area. Small tick marks at the right margins of the columns indicate 6th order cycle boundaries.

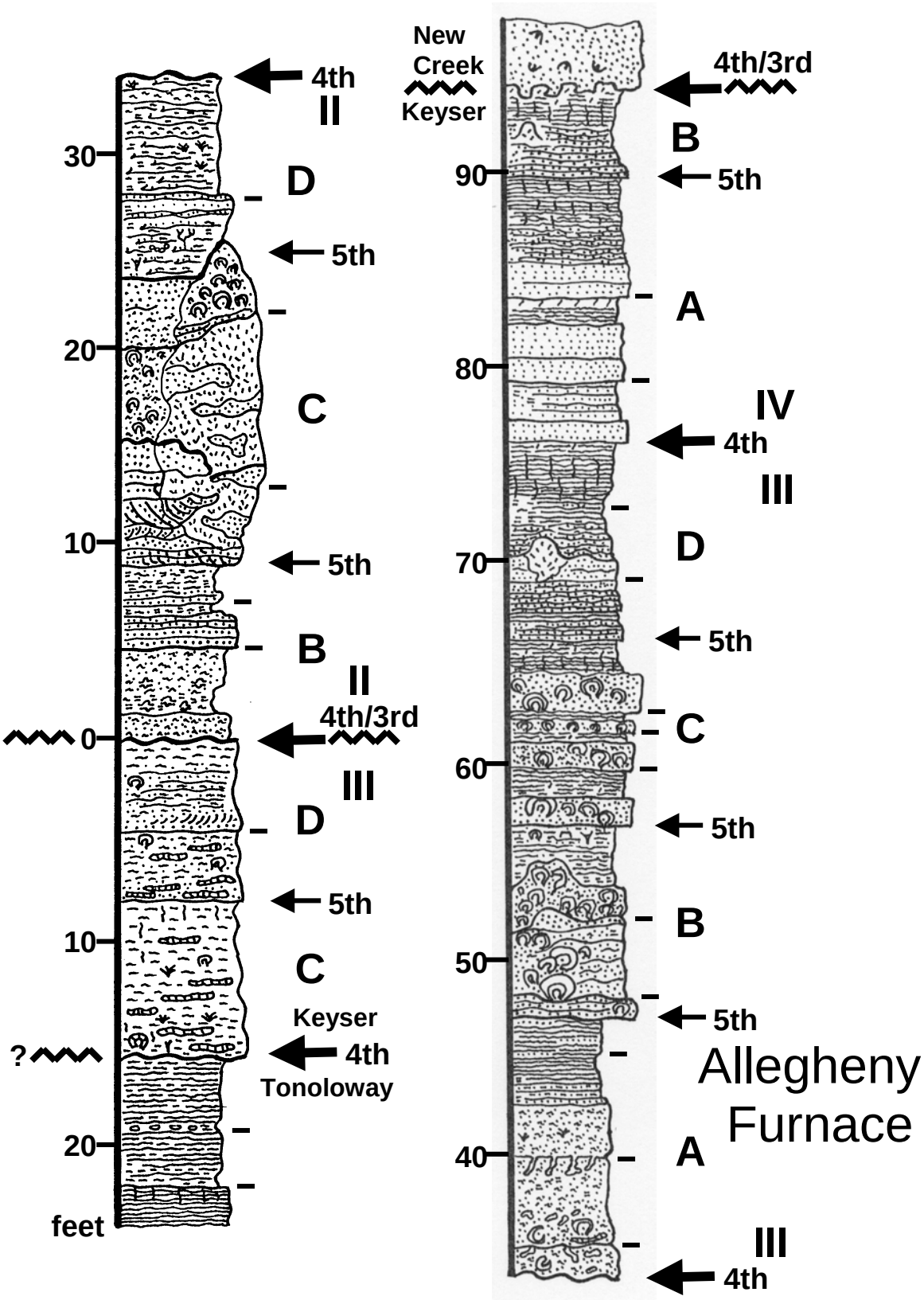


Figure 8. Stratigraphic column of the Keyser Formation at the Allegheny Furnace section (Altoona).

Tyrone

In the Altoona area the upper Keyser 3rd order sequence is thinnest and least complete at Tyrone where both the boundaries of the sequence are marked unconformities (Fig. 7). The upper Keyser sequence overlies limestone and dolomite facies of the Tonoloway Formation at an erosional surface. There is no evidence of subtidal Keyser facies below this boundary. At the top of the sequence, subtidal gypidulid brachiopod-bearing crinoidal limestone of the New Creek Formation overlies the Keyser at an erosional unconformity. At Tyrone, third order sequence 2 (the upper Keyser) consists of 4th order sequences II and III and just the base of sequence IV. Sequence I and 5th order sequence II - A are missing in the unconformity at the lower boundary of the Keyser Formation.

At Tyrone, as elsewhere in the Altoona area, sequence II is dominated by coarse shallow-marine calcarenite facies. The defining facies asymmetry of sequence II is seen in the deposits of fine carbonate in 5th order sequence D at the top of this 4th order sequence. PAC boundaries in these finer grained deposits are marked with vertical (*Monocraterion*) burrow structures suggesting exposure in the high intertidal zone (see Goodwin and Anderson, 1974). However the lower part of sequence II remains in persistently subtidal and current-washed paleoenvironments.

The overlying 4th order sequence (sequence III) is dominated by more restricted, massive stromatoporoid-rich facies that commonly grade upward into mudcracked stromatolitic limestone and dolomite facies (see 5th order sequences A, B and C, Fig. 7). In sequence D, at the top of 4th order sequence III, subtidal stromatoporoid-rich facies are replaced by more restricted fine laminated calcarenite facies containing thrombolitic algal mounds overlain by thick deposits of mudcracked cryptalgal laminites. This progressive but stepwise change to more restricted facies defines the asymmetry of the second 4th order sequence preserved at Tyrone. The overlying remnant of sequence IV continues this trend and is even more restricted as reflected in the fine dolomitic calcarenites and mudcracked stromatolites of sequence IV - A and B.

The unconformity at the Keyser New Creek boundary is a continuation of the unconformity at the Manlius - Coeymans formational boundary in the Hudson Valley of New York (Goodwin et al., 1986) where erosion on the unconformity has cut less deeply. The Rondout and Manlius formations in eastern New York State are thought to be correlative with the upper Keyser 3rd order sequence. In this interpretation the Wilbur/Rosendale and the Glasco/Whiteport members of the Rondout are condensed correlative stratigraphic equivalents to 4th order sequences II and III in the upper Keyser Formation.

Allegheny Furnace

The stratigraphic section of the Keyser Formation at Allegheny Furnace (Fig. 8) is similar to that at Tyrone in that 4th order sequences II, III and IV are represented by a coarse calcarenite-dominated sequence, a stromatoporoid / algal mound / algal laminated sequence and an upper sequence consisting predominately of tidal-flat facies. This last sequence is truncated by a marked erosional unconformity. The equivalent stratigraphic section (based on placing the zero meter point on the log at the 3rd order boundary in all sections) is five feet thicker at Allegheny Furnace than at Tyrone. A significant facies change occurs in sequence II - C where a 10-15 foot high bioherm laterally replaces the bedded calcarenites seen in this sequence at Tyrone. A second major change is the addition of two 5th order sequences (C and D) below the 3rd order boundary between the lower and upper parts of the Keyser Formation. These two sequences contain abundant flat 'pita bread' stromatoporoids in a calcisiltite to micrite matrix. The preservation of these lower Keyser units is explained by increased subsidence at

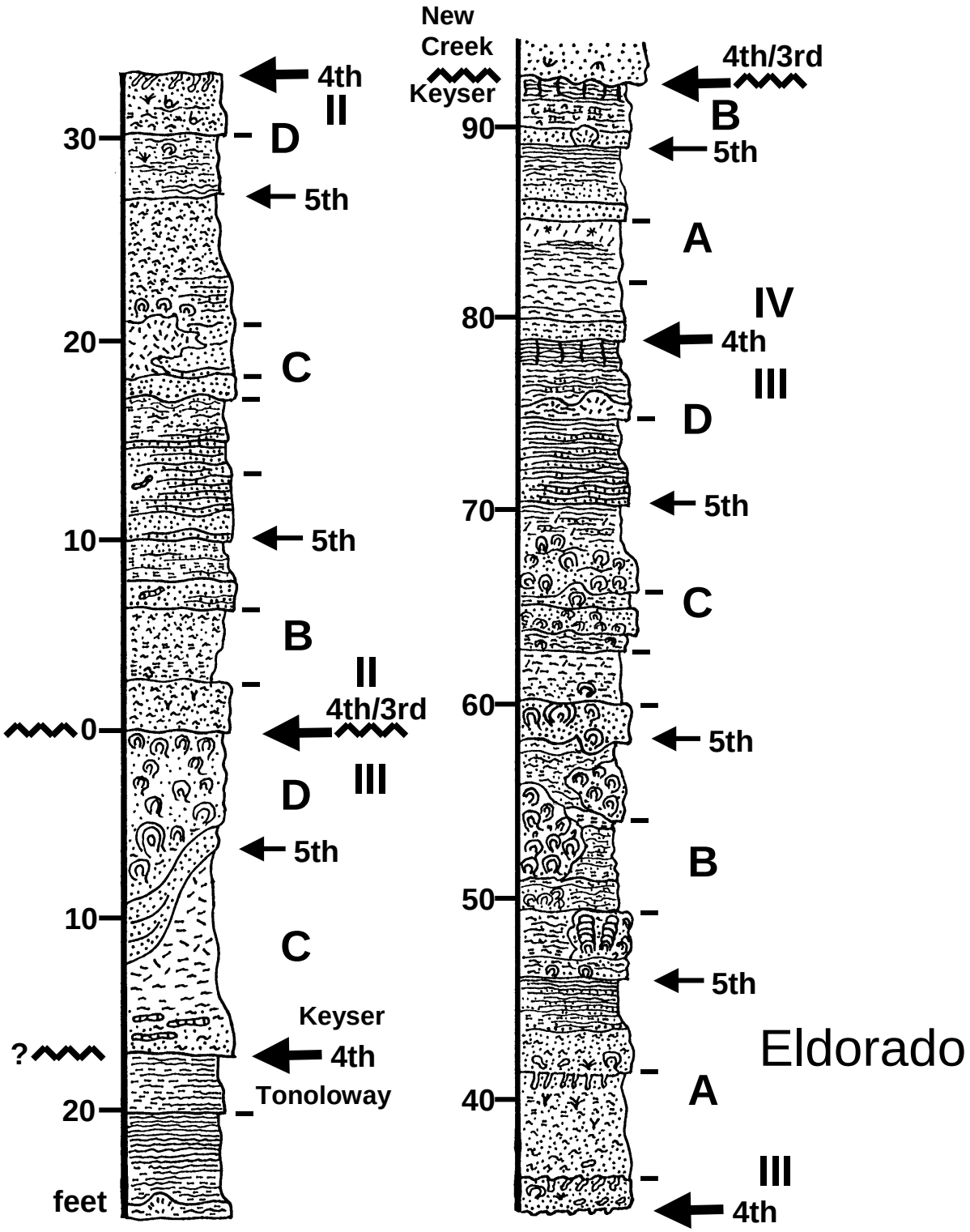


Figure 9. Stratigraphic column of the Keyser Formation at the Eldorado section (I-99 Altoona Bypass).

Altoona compared to Tyrone, with Tyrone being at a position nearer to the basin margin when the Keyser was deposited. Excellent examples of sea-level-fall surfaces occur in sequence III - C (58-62 feet on the log) where large stromatoporoid heads were eroded off prior to deposition of overlying dolomitic laminites. Late Silurian stemmed plant fossils occur in laminated tidal-flat facies at 45 feet on the log.

Eldorado (Altoona Bypass I - 99)

This section is very similar to the Allegheny Furnace section. A bioherm is again developed in sequence II - C and sea-level-fall surfaces are indicated by the erosion of the tops of stromatoporoid beds at approximately 60 feet on the log in sequence III - C (Fig. 9). Two 5th order sequences in Keyser facies again occur below the unconformable 3rd order boundary. The surface between these two units appears to show depositional relief, suggesting that a mud mound developed in sequence C. However, the thickness of these two sequences, as well as that of the entire section, is very close to that measured at Allegheny Furnace.

St. Clairsville (south exit ramp off I - 99)

The section at St. Clairsville continues the trend seen between Tyrone and Altoona (Fig. 10). The correlative elements (sequences) of the Keyser are progressively thicker and more components of the section are preserved. Specifically sequence II increases in thickness from 35 to 47 feet, sequence II - A is now present, suggesting the sea flooded St. Clairsville whereas Altoona (25 km to the north) persisted as a land area and a small part of sequence I is preserved above the unconformable 3rd order boundary. Together these observations indicate a trend toward greater subsidence to the south suggesting that the axis of greatest basinal subsidence in the late Silurian was to the south and east whereas the Tyrone locality was nearer the northwest basin margin. Sequence III is also 10 feet thicker here than at Allegheny Furnace and the remnant of sequence IV is some 4 feet thicker.

These interpreted paleogeographic and subsidence trends are also reflected in sedimentary facies when correlative sequences are compared between onshore and offshore areas. Sequences II - B, C and D contain less coarse-grained calcarenite, less bioherm development and more diversely fossiliferous fine calcarenite and calcisiltite deposits. In particular, gypidulid brachiopods are now found in 5th order sequence B (the *Gypidula prognostica* peak zone of Bowen, 1967) and large atrypid brachiopods are common in sequence II - D. In addition, rugose and favositid corals are now more abundant in sequence III - B which is dominated by stromatoporoids to the north at Altoona and Tyrone.

Canoe Creek Quarry

While 4th order sequences II, III and IV are only slightly thicker at the Canoe Creek Quarry compared to their thicknesses at Allegheny Furnace, and the same sequences are present at both, there are marked facies changes at three stratigraphic levels (Fig. 11). First a prominent stromatoporoid bioherm is developed directly below the 3rd order sequence boundary (at 0 feet on the log). The combined thickness of 5th order sequences C and D varies between 20 and 40 feet across the width of the quarry. The size of these bioherms and the diversity of corals associated with them suggests a more open marine paleoenvironmental position (and greater subsidence) than that in which these sequences were deposited at Altoona.

The calcarenites in sequences II - B and C are finer in grain size and have no large bioherms associated with them as is seen in these sequences at Allegheny Furnace and Eldorado. Finally,

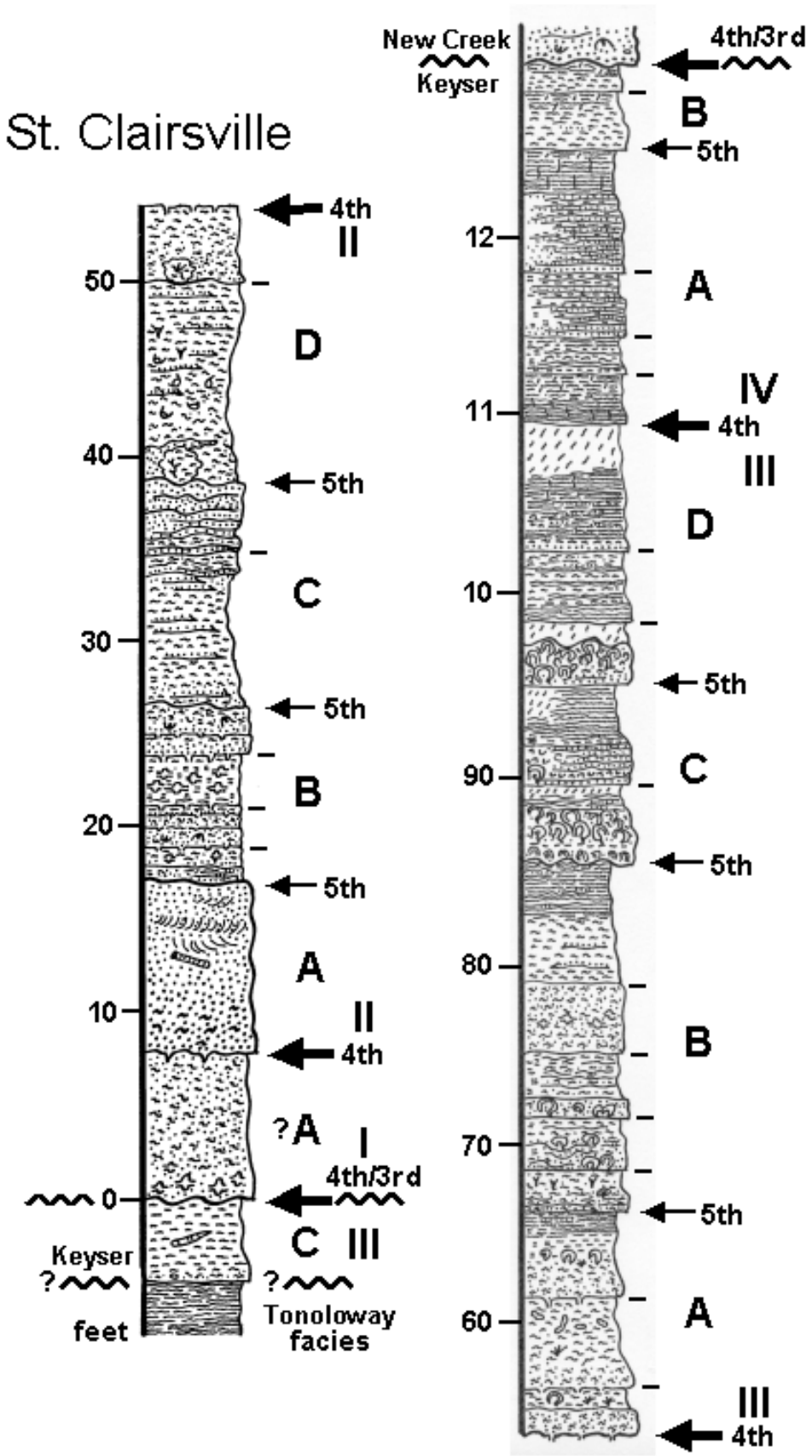


Figure 10. Stratigraphic column of the Keyser Formation at the St. Clairsville section (I-99 off ramp south).

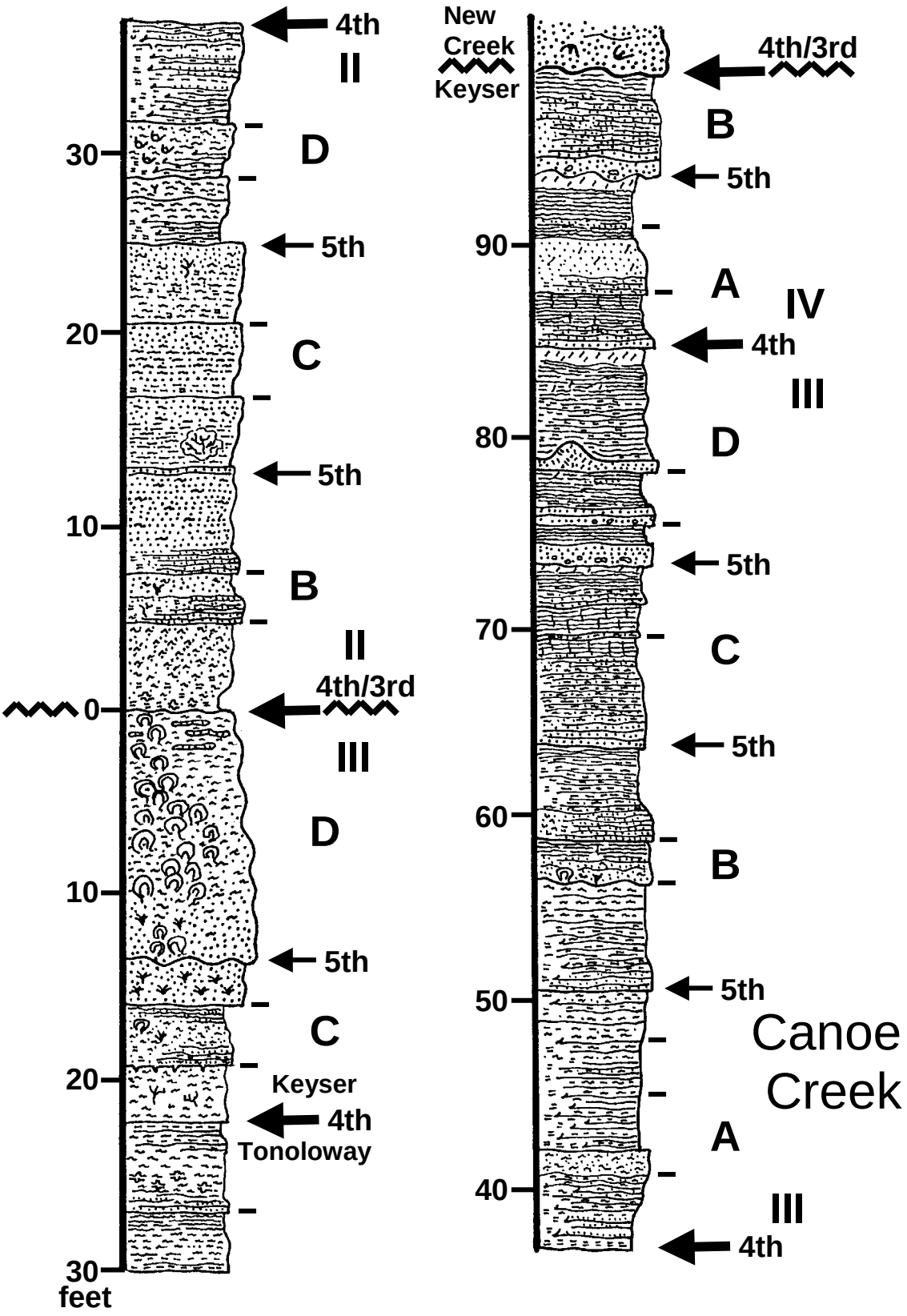


Figure 11. Stratigraphic column of the Keyser Formation at the Canoe Creek Quarry.

sequences III - A, B and C, that are dominated by stromatoporoid biostromes at Tyrone, Allegheny Furnace and Eldorado, are here represented by thin lime mud beds separated by shale partings. Nearly all stromatoporoids are missing. These marked facies changes suggest that the Canoe Creek locality is in a more offshore paleogeographic position than the localities in Altoona. However the 3rd order unconformable boundary was not flooded as early as the same surface at St. Clairsville; thus more section is missing at the 3rd order boundary.

CONCLUSIONS

Description and analysis of the hierarchical cyclic structure of the Keyser Formation leads to several new stratigraphic and paleoenvironmental interpretations. First, it is now possible to correlate rock units throughout the study area down at least to the level of 5th order (100 ka) sequences. These correlations demonstrate loss of cycles and sequences into basin-margin areas and define previously unrecognized unconformities. Patterns of decreasing stratigraphic thickness, in stratigraphic intervals where the cyclic structure is complete, provide evidence for differential tectonic subsidence and help define the northwestern margin of the Appalachian Basin at the end of the Silurian. Marked facies changes that occur within single 100 ka sequences provide new evidence of detailed lateral paleoenvironmental changes. This evidence makes it possible to assess paleoecologic positions of gypidulid and atrypid brachiopods, rugose and favositid corals and different stromatoporoid morphotypes. Finally, documentation of the correlative cyclic hierarchy throughout the study area confirms the validity of applying the 'Croll-Milankovitch' orbital-forcing model.

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MAPPING OF THE TONOLOWAY-KEYSER FORMATIONAL BOUNDARY WITH ASSUMPTION OF AN ORBITALLY FORCED CYCLIC HIERARCHY

by
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INTRODUCTION

At the type locality near Keyser, WV, the Tonoloway-Keyser formational boundary is drawn at a major facies change between laminated peritidal and nodular subtidal facies. At this locality the Keyser Formation is 87 m or 285 feet thick (Bowen, 1967; Head, 1969) and is interpreted as two 3rd order (2 Ma) sequences (see Dorobek and Read, 1986; Anderson et al., this volume). These sequences are the first two 3rd order sequences in the 2nd order Helderberg Supersequence (Anderson et al., Figures 2 and 3, this volume). The first 3rd order sequence (i.e. the lower Keyser) is 40 m (130 feet) thick, measured from the contact with the underlying Tonoloway to the base of the *Gypidula prognostica* peak zone, and is entirely subtidal. This lower Keyser 3rd order sequence grades laterally into peritidal Tonoloway facies between Keyser, WV and Altoona, PA.

At localities between Keyser and Altoona (i.e. Hyndman, Everett, Cessna and St. Clairsville, PA), subtidal (Keyser) facies and peritidal (Tonoloway) facies are interbedded in the stratigraphic interval correlative with the lower Keyser 3rd order sequence described above. At localities near Altoona (i.e. Hollidaysburg, Eldorado, Canoe Creek Quarry and Allegheny Furnace) the formation boundary is also drawn at a facies change from peritidal to subtidal carbonate facies, but this surface is now a 5th order boundary a few meters below the top of the first 3rd order sequence (see Figure 3, the boundary between 5th order sequence III-B and III-C). Further north, near the basin margin (Tyrone and Jersey Shore, PA), the Tonoloway-Keyser formational boundary is again marked by an abrupt facies change (Swartz, 1939; Head, 1969) from peritidal algal laminated or dolomitic facies to subtidal calcarenite facies (Figures 1 and 3). However, at these localities the formational boundary is the unconformable boundary at the top of the first 3rd order sequence, where at least an entire 4th order (400 ka) sequence is missing (Sinclair et al., 1998; Sinclair, 1999).

The complexity of the Tonoloway-Keyser formational boundary in the Appalachian Basin is revealed by application of a hierarchical allocyclic model of stratigraphic analysis (Goodwin and Anderson, 1985; 1997; Anderson and Goodwin, 1990). Applying this model of cycles and sequences (Anderson et al., this volume) to the stratigraphic interval encompassing the formational boundary not only suggests a new genetic explanation of the boundary but reveals Siluro-Devonian basin dynamics not discernible from a gradualistic perspective. For example, the degree of unconformity at the 3rd order sequence boundary between the lower and upper Keyser sequences is shown to be a product of both a major sea-level fall resulting in widespread erosion and differential subsidence resulting in progressive onlap of Keyser facies over the unconformity (Anderson et al., 1986). Erosion associated with the 3rd order boundary is indicated by truncation of 5th order (100 ka) sequences at the top of the lower Keyser. In turn, differential subsidence is indicated by stepwise flooding over the erosion surface at the 3rd order boundary where two 5th order sequences were deposited between Everett and St. Clairsville before the entire Altoona area was flooded leading to deposition of sequence II-B (see Figures 2 and 3). Differential subsidence also was responsible

Sinclair, C.J., Anderson, E.J. and Goodwin, P.W., 2003, Mapping of the Tonoloway-Keyser formational boundary with assumption of an orbitally forced cyclic hierarchy, *in* Way, J.H. and others, eds., Geology on the edge: selected geology of Bedford, Blair, Cambria, and Somerset Counties, Guidebook, 68th Annual Field Conference of Pennsylvania Geologists, Altoona, PA, p. 19 - 23.

Figure 1: The Unconformable Third-Order Sequence Boundary at Tyrone. The unconformity at Tyrone is marked by an abrupt change from Tonoloway peritidal facies to subtidal Keyser facies. The arrows point to the sequence boundary.

Figure 2: The Unconformable Third-Order Sequence Boundary at St. Clairsville. The unconformity at St. Clairsville is a surface of high relief across which there is a facies change from micritic limestone below to coarse brown calcarenite above. Each section of the scale is one foot long. The arrows all point to the 3rd order boundary. The bedding is nearly vertical.

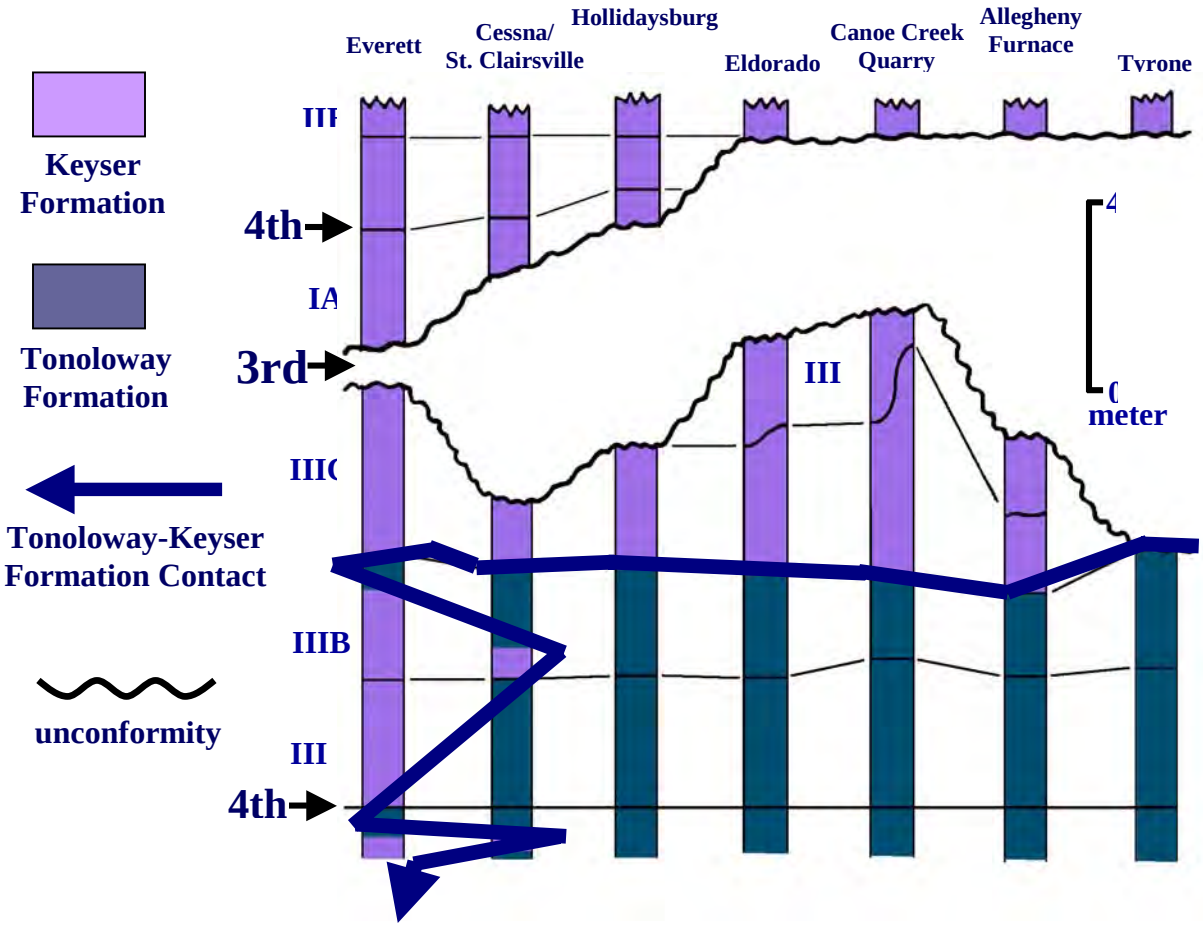

Figure 3: The Tonoloway-Keyser Formational Contact The formation boundary superimposed over a hierarchic cyclic framework shows a complex relationship between the Tonoloway and Keyser Formations. The gap in the columns at the third-order sequence boundary represents section missing due to vacuity and/or hiatus.

for the increase of subtidal facies in correlative 5th order sequences within the lower 3rd order sequence to the south (i.e. the lateral Tonoloway - Keyser facies transition, Figure 3).

There is thus a complex stratigraphic relationship produced by the superposition of hierarchic eustatic sea-level fluctuations on a differentially subsiding basin. Toward the basin margin at Tyrone, the formational boundary is an unconformable 3rd order (2 Ma) sequence boundary at which open-shelf Keyser carbonate facies lie directly on peritidal carbonates of the Tonoloway formation. Basinward, at St. Clairsville and Everett, PA, additional Keyser cycles are preserved above the unconformity (Figures 2 and 3), indicating varying amounts of hiatus due to differential subsidence and/or uplift (Anderson and Goodwin, 1989). Below the unconformity at these localities, higher subsidence rates toward the basin center resulted in decreasing vacuity and caused peritidal Tonoloway facies to the north to grade laterally into subtidal Keyser facies to the south within correlative individual 5th order (100 ka) sequences. Farther south, at Keyser, WV, where subsidence is even greater, the formational boundary is at another 3rd order unconformity, one that formed 2 Ma earlier than the basal Keyser unconformity at Tyrone.

Key 5th order sequences

Below the Unconformity

Fifth-order sequence III-B is the sequence directly below the unconformity at Tyrone (Figures 1 and 3). At Tyrone, III-B is composed entirely of dolomitic laminites of the Tonoloway Formation. This sequence can be traced between exposures throughout central Pennsylvania by mapping the internal cyclic structure. Additionally, at St. Clairsville, the faunal content of this sequence (III-B) is considerably more diverse than the sequence below. At Allegheny Furnace, III-B appears to have been truncated by erosion, and discrimination of internal PACs is more problematic. At St. Clairsville, the base of III-B contains more massive, cherty, micritic limestone that resembles Keyser facies, and the top of the sequence consists of the typical peritidal laminites of the Tonoloway Formation.

Fifth-order sequence III-C is not preserved at Tyrone. It is the sequence directly below the unconformity at exposures closer to the basin center in Pennsylvania (e.g. St. Clairsville and Everett, PA). This sequence is, like III-B, dominated by micritic limestone that contains diverse and abundant fossil material. Stromatoporoids, ostracods, and brachiopods, as well as several corals, are observed in this sequence. Sequence III-C usually has an erosional upper boundary, and ranges in thickness from 8 to 26 feet in central Pennsylvania. Fifth-order sequence III-D is preserved only in the immediate Altoona area at Eldorado, Canoe Creek Quarry and Allegheny Furnace. This facies is coarser, fossiliferous limestone with a more abundant and diverse faunal content. At Eldorado the internal cycles consist of approximately fifty-percent spherical stromatoporoid material, whereas at Allegheny Furnace, flat 'pita bread' stromatoporoids are common.

Directly below the third-order unconformable sequence boundary, except at basin margin localities such as Tyrone, the facies are fossiliferous micritic limestone typical of the Keyser Formation. At basin margin localities, a distinct erosional sequence boundary separates peritidal Tonoloway and subtidal calcarenite Keyser facies. Basinward, at localities between St. Clairsville and Hyndman, PA, the transition from Tonoloway to Keyser facies is more complex. At these localities, basal cycles (PACs) within 5th order sequences contain subtidal nodular calcarenite facies typical of the Keyser, but these sequences shallow upward into typical Tonoloway peritidal laminite and dolomite facies (see Figure 3).

Above the Unconformity

Fifth-order sequence I-A is a distinctive coarse, brown, crinoidal calcarenite with a lower boundary marked by high erosional relief. At St. Clairsville and Cessna (2 miles to the south), this massive, bioturbated sequence is lithologically distinct from the facies below the marked erosional unconformity (Figure 2). The upper surface of this brown calcarenite is also erosional and as a consequence this unit is interpreted as a remnant of a separate 4th order sequence. At localities closer to the basin margin, this sequence is missing.

A major facies change occurs in 5th order sequence II-A as compared to sequence I-A below. Sequence II-A is a very coarse grayish white, sparry calcarenite containing abundant and diverse fauna such as crinoids, arthropods, bryozoans and brachiopods. This sequence is only present at those localities where I-A is also preserved, i.e. offshore from the basin margin. Sequence II-A is the first 5th order sequence in a 4th order sequence that is well preserved throughout the Altoona area. The upper part of sequence II-A is less fossiliferous than its base. Fifth-order sequence II-B is a nodular, argillaceous calcarenite that is easily recognizable and correlative throughout central Pennsylvania. It is deposited as a consequence of the largest sea-level-rise event in this part of the Keyser Formation. This sequence contains the *Gypidula prognostica* peak zone described by Bowen (1967), which is a traceable key bed for hundreds of miles from central Pennsylvania to West Virginia. In addition, sequence II-B contains several other brachiopods species, crinoids, bryozoans and arthropods. Sequence II-B lies directly on the third-order unconformable sequence boundary at Tyrone, Eldorado and Allegheny Furnace. The magnitude of the sea-level event that led to the deposition of sequence II-B determines the asymmetric structure of 4th order sequence II (see Anderson et al., this volume).

CONCLUSIONS

The Tonoloway-Keyser Formational boundary is complex. To the south, at the type locality near Keyser, WV, the boundary is at an erosional surface below the lower Keyser 3rd order sequence. That is, it occurs at a surface at the *base* of the first 3rd order sequence in the 2nd order Helderberg Supersequence. At Tyrone, 150 km to the north, the formational boundary is at a similar erosional surface between Tonoloway and Keyser facies, but this surface is at the *top* of the first 3rd order sequence in the Helderberg Supersequence. That is, the surface is approximately 2 Ma younger at Tyrone than the one marking the formational boundary at Keyser, WV. In the intervening areas (St. Clairsville to Hyndman, PA), Tonoloway and Keyser facies are interbedded within this 3rd order sequence, with Keyser facies occurring at the bases of 5th and 4th order sequences and Tonoloway facies being deposited at the tops of these sequences. If one defined the Tonoloway-Keyser formational boundary at the base of the first occurrence of subtidal calcarenite facies or the top of the last occurrence of peritidal facies at these intermediate localities, the formational boundary would be progressively younger to the north toward the basin margin. In this sense, the Tonoloway-Keyser boundary, which is drawn at different surfaces in a series of cycle boundary surfaces at different localities, is similar to other apparently diachronous formational boundaries in the Helderberg Group (Anderson et al., 1984).

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STROMATOPOROIDEA: AN OVERVIEW

by

Charles E. Miller, Jr., P.G.

INTRODUCTION

The stromatoporoids are an extinct group of Paleozoic marine sponges, some sufficiently large enough to be termed "colonial." This group of sponges formed some of the largest reef complexes in the fossil record. Among the largest are those of the Silurian of Gotland, Sweden, where reef masses measure 20 m high and 200 m in diameter (Clarkson, 1986, p. 78). These fossils prove to be valuable in paleoecologic and chronstratigraphic studies, in stratigraphic correlation, facies analysis, and petroleum exploration (Galloway and St. Jean, 1956; Lecompte, 1956; Stock and Holmes, 1986).

Stromatoporoids were filter feeding, sessile, benthic macro-organisms, most commonly associated with corals. These sponges probably lived in clear, shallow, agitated tropical to subtropical waters. Stromatoporoids were less tolerant of muddier and deeper water than were the corals that were associated with them. In addition, stromatoporoids replaced corals as the upper surface of a reef became progressively more subject to wave action (Galloway, 1957; Lowenstam, 1957).

Lower Paleozoic stromatoporoids were important contributors to massive bioherms, comprising as much as 90% of the organic complex (Kershaw, 1988). Reoriented or transported fragments occur in bedded limestone. They rarely occur in calcareous shale. These lithologic associations represent a variety of shelf facies ranging from intertidal to shallow subtidal environments (Head, 1969; Kershaw, 1998). They are not seen in deep-water deposits or sandy clastic facies; thus, they did not occur close to paleo-shorelines characterized by substantial hinterland relief and consequent heavy clastic input (Kershaw, 1988). Stromatoporoids grew in a variety of reef settings including barrier, fringing, patch, platform, and even atoll reefs.

Stromatoporoids range from the Lower Ordovician through the Upper Devonian; however, they are most abundant in the Silurian and Devonian. They reached their maximum areal distribution, abundance, and diversification in the Devonian (Galloway and St. Jean, 1956). Currently, Cambrian "stromatoporoids" are regarded as archaeocyaths (Stock, 2001). Fossils found in Carboniferous through Tertiary rocks that have been referred to as stromatoporoids appear to represent a polyphyletic grouping of several organisms that have evolved by convergence on the basic stromatoporoid morphology (Stock, 2001).

Over the past 130 years, experts rigorously debated stromatoporoid affinities. They have been assigned to a variety of taxa including hydrozoans, bryozoans, and even to an extinct phylum with no modern counterparts (Clarkson, 1979, p. 58). A brief, albeit interesting, attempt was made to ally stromatoporoids with the foraminifera (Stock, 2001). Since the 1970's, Kazmierczak (1976) argued that stromatoporoids were actually cyanobacterian stromatolites. However, most workers today believe that stromatoporoids are calcified sponges (Kershaw and Brunton, 1999; Stock, personal communication, 2002). Stromatoporoid taxonomy: Phylum Proifera, Subphylum Cellularia, Class Stromatoporoid (Stearn & Carroll, 1989, p. 82).

STROMATOPOROID MORPHOLOGY

Stromatoporoids secreted a calcareous skeleton comprising sheet-like laminae or lamellae parallel to the surface separated by vertical pillars. The upper few millimeters of this reticulate arrangement of galleries supported the soft tissue. Typically, these galleries are filled with calcite cement. Unlike most modern sponges, Paleozoic stromatoporoids are not composed of spicules and no trace of spicules has been found in their skeletons (Stearn and Carroll, 1989).

Miller, Jr., C. E., 2003, Stromatoporoidea: an overview, *in* Way, J.H. and others, eds., Geology on the edge: selected geology of Bedford, Blair, Cambria, and Somerset Counties, Guidebook, 68th Annual Field Conference of Pennsylvania Geologists, Altoona, PA, p. 24 – 29.

They are recognizable in outcrop based on their generally large size, overall growth morphology, and internal macroscopic elements including a laminated appearance (Kershaw et al., 1999). At first glance, stromatoporoids superficially resemble stromatolites, tabulate corals, and bryozoans – all of which can have similar dome-shaped masses with microscopic structures not easily visible to the naked eye. However, stromatoporoids have the characteristic laminae and pillar structure in vertical sections of the specimen shown in Figure 1. Although commonly found together with tabulate corals, the structural differences are clearly visible with a hand lens (Kershaw, 1988).

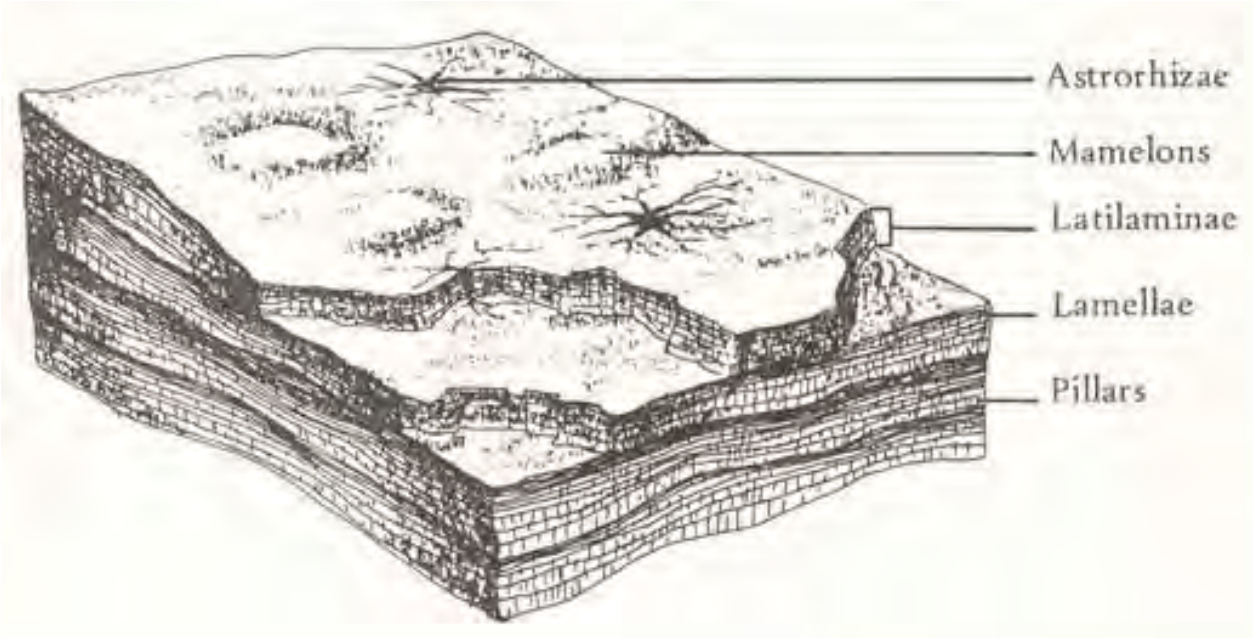


Figure 1. Macroscopic skeletal elements of stromatoporoids (from Petersen and Rigby, 1973, p. 67).

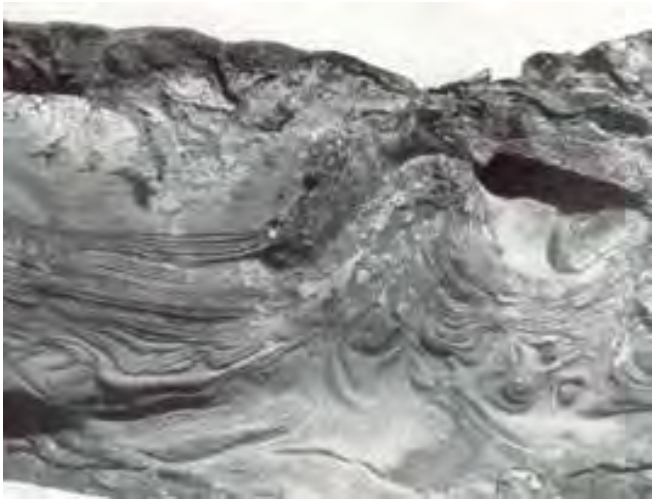
Diagnostic taxonomic characters for recognizing stromatoporoids include: encrusting or bulbous masses with thin concentric laminae parallel to the surface and bundled into latilaminae; and presence of pillars (forming a grid-like pattern), and astrorhizae (small radiating channels) on the mamelons (small bumps) (Figure 1).

"Banding" is one feature that distinguishes stromatoporoids in the field, crudely analogous to layering in tree-rings. Each band, called a latilamina, comprises several lamellae (Figure 1). Latilaminae suggest periodicity in the environment of the stromatoporoids. Galloway (1957) attributed the latilaminae to seasonal changes. The spacing and thickness of the lamellae may reflect annual, seasonal, or diurnal influences or perhaps more subtle variations in nutrient availability, temperature, currents, or storm events. Wide spacing suggests more stable environmental conditions fostering optimal growth, whereas, more closely spaced lamellae reflect slower growth rates (St. Jean, 1969).

Despite their common occurrence, stromatoporoids tend to be less familiar to geologists and amateurs than many other fossils. Their variability and irregularity result in less consistent appearances compared to discrete shells produced by organisms such as brachiopods, molluscs, arthropods, and echinoderms. At first glance, a number of organic (domal stromatolites, oncolites, thrombolites) and inorganic structures (laminites, convolute lamination, liesegang banding) might be mistaken for stromatoporoids. For example, the highly domical masses illustrated in Figure 2a from the Altoona Bible Church locality, thrombolites, occur in the same exposure as abundant stromatoporoids. Differentially weathered and naturally etched samples facilitate tentative megascopic identification, however, fresh carbonate surfaces tend to mask the presence of internal structures.

a

b



c

Figure 2. (a) High domical thrombolites in the Keyser Jersey Shore Member; Altoona Bible Church (Allegheny Furnace) locality; Altoona, Pa. (b) Convolute lamination; Mymon, central Carpathians, Poland; (c) Convoluted beds as seen from above; Italy. (b and c are from Pettijohn and Potter, 1964, plates 106A and 106B)

Detailed study of the internal structures of these fossils is essential for their identification. Sample preparation and analysis is labor-intensive. Polished surfaces tangential and perpendicular to the growth surfaces, and thin-section microscopy are requisite. Multiple thin sections are often necessary to clarify three-dimensional structures to verify identification (St. Jean, 1969). Additionally, calcite twinning sometimes compromises identification using thin sections even when good field specimens are available (Stock and Holmes, 1986). Often, stromatoporoid structures in thin-sections appear vague and obscure compared with bryozoan and brachiopod skeletal fragments; this suggests recrystallization or inversion from an original skeletal mineralogy of aragonite or high-magnesium calcite.

STROMATOPOROID GROWTH FORMS

Stromatoporoids range from only a centimeter in diameter to a meter or more across (Cuffey, personal communication, 2003). The frequent large size and growth forms are the most striking external features of these fossils. Kershaw (1988) shows that four basic shapes describe the growth forms: laminar, domical, bulbous, and dendroid (branching) (Figure 3). Prior to Kershaw's classification, no consistent system of nomenclature had emerged for describing stromatoporoid external morphology. Rounded forms have been called massive, globular, bulbous, domal, nodular, or hemispherical; flat forms have been called

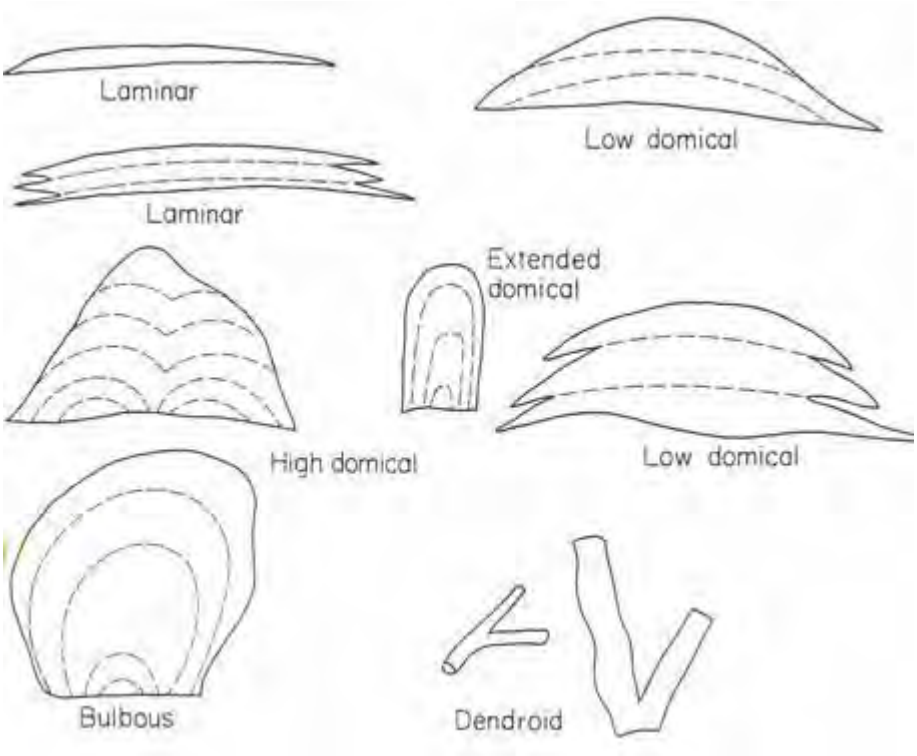


Figure 3. Cross sections illustrating the range of stromatoporoid morphology (Kershaw, 1988).

lamellar, laminar, sheet-like, or tabular; and subcylindrical forms have been called dendroid, branching, ramose or twig-like (Stearn, 1982; Stock, 2001; Lecompte, 1956).

PALEOECOLOGY OF STROMATOPOROIDS

Before the 1970s, little was published on stromatoporoid skeletal shape and its possible relationship to the paleoenvironment (Stock, 2001). Initially, paleobiologic investigations were used as broad paleoenvironmental indicators in oil-related work on the Devonian (Kershaw, 1988). Such studies involved careful plotting of the exact distribution of stromatoporoid growth forms among the observable lithofacies developed within well-studied reef complexes.

Stromatoporoid growth forms, in part, reflected their paleoenvironmental setting (Figure 4).

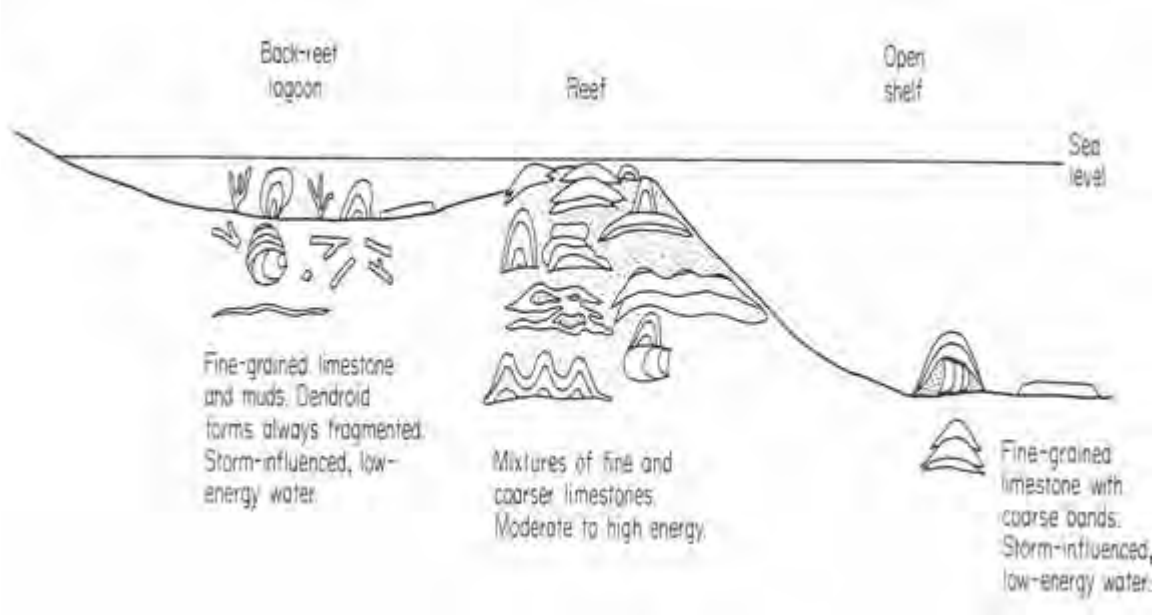


Figure 4. Typical environmental distribution of stromatoporoid growth forms. (From Kershaw, 1988)

Generally, delicate branching (dendroid), stem-like, and unstable bulbous forms occupied quiet water environments, such as in back-reef areas (Kershaw, 1988). However, if the back reef area became stagnant, there tended to be a preponderance of thin, irregularly laminated forms (St. Jean, 1969). Large domical and laminar types dominated higher-energy conditions in reefs, where the stromatoporoids formed huge sheets and masses. From a hydrodynamic viewpoint, these are appropriate shapes for such environments: dendroid and bulbous forms are suited to low-energy conditions; a laminar form is streamlined to allow water to pass

smoothly over it; and domical forms are stable on the substrate, difficult to dislodge by storms. Yet, stromatoporoid growth forms may also be interpreted in other ways. Laminar types that grew in low-energy muddy sediments may have been spreading their weight outwardly, so that they did not sink in the sediment.

However, exceptions do occur. Kershaw (1998) observed that fluctuating energy levels as well as sediment types and accumulation rates influenced growth form and could force change during their lifetime. A stromatoporoid could began as a laminar shape, change into domical form, and then later change yet again into a bulbous form. In deep-water fore-reef or inter-reef platform environments, stromatoporoid forms are similar to those found in the back reef. Thus, based on growth habit alone, it is not always possible to define the depositional setting (St. Jean, 1969).

Some stromatoporoid growth forms were inherent to the species; genetic programming was independent of the paleoenvironment. For example, in one Silurian reef, domical forms occur adjacent to laminar ones. Thus, two different species inhabited the same low-energy environment. What circumstances caused one species to grow tall while another species grew laterally? One possibility is that the laminar forms out-competed the other species for space and the only place the latter could go was up (Kershaw, 1988). Another example of species control on growth form is the presence of both bulbous and dendroid stromatoporoids in low-energy back-reef environments, where clearly different species maintained different growth forms, independent of environmental conditions.

Evidence for sedimentation and disturbance caused by water turbulence are commonly preserved in stromatoporoids. In some instances, hiatuses in skeletal growth caused sediments to interfinger with the edges of the stromatoporoid structure. The specimens had been periodically subjected to partial burial by sedimentation. They then re-grew out over the new sediment surface. This re-growth resulted in a ragged appearance that is clearly indicative of episodic sedimentation. Stromatoporoids, therefore, can show several events during their lives, and can indicate the frequency of such depositional events. Noting that low-profile forms suggest low sedimentation rates, and abundant ragged specimens of any growth form indicate regular depositional events, it is inferred that the specimens grew in conditions of very little deposition, punctuated by events of rapid sedimentation. Raggedness on one side only of a group of stromatoporoids, if consistent, may indicate the down-current direction and thus serve as a useful paleocurrent indicator (Kershaw, 1988).

Stromatoporoid forms also illustrate periodic reorientation. For example, some specimens display initial normal growth, overturning, and subsequent continued normal growth. In some cases, delicate edges snapped off during such movement. Thus, these animals recorded high-energy events, again, probably related to storms. Several events within the lifetime of a single animal give some idea of the frequency of catastrophic events affecting the seabed.

It is widely assumed that stromatoporoids required a hard surface, such as a shell fragment, for initial larval settlement before spreading across neighboring areas of soft substrate. However, many examples show that no hard object underlies initial growth, and published cases from the Ordovician and Silurian suggest growth directly on soft substrates, e.g., clay-rich lime mud to sand-sized skeletal grains; rarely are they associated with siliciclastic sand and mud (Kershaw, 1998). Stromatoporoid success in reefs is presumed to be due, partly, to the presence of stable substrates of debris of previous reef builders, as well as their apparent wide tolerance of substrate texture (Kershaw, 1998).

Large stromatoporoids reflect long periods of growth and thus highlight their ability to survive and record events affecting the sea. As such, stromatoporoids have the potential to reveal regional and even global processes and events (Kershaw, 1998). In a study of the Devonian Iberg reef in Germany, stromatoporoid growth forms aid recognition of facies patterns, which suggest influence of southeast trade winds and indicate interpretation of the reef as an atoll (Gischler, 1995). Webby (1980) suggested the potential value of stromatoporoids in plate reconstructions because of their warm, stenothermal character, which apparently was retained throughout the Ordovician, Silurian, and Devonian. Stock (1986) suggests that in the absence of other critical fossils, stromatoporoids are useful for placement of the Silurian-Devonian boundary in the Keyser Limestone in the Appalachian Basin (Virginia).

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PALEOECOLOGY OF THE KEYSER LIMESTONE AND ITS STROMATOPOROIDS IN CENTRAL PENNSYLVANIA

by

Charles E. Miller, Jr., P.G.

INTRODUCTION

The Keyser Limestone was deposited in Late Silurian-Early Devonian (Late Cayugan-Early Helderbergian) time in a shallow sea that transgressed from the southwest to the northeast across the Valley and Ridge Province of Virginia, West Virginia, Maryland, and Pennsylvania (Harper, 1969; Head, 1969; Head et al., 1969). Keyser equivalents were also deposited in New Jersey and New York. Paleogeographic reconstructions suggest that eastern North America was at approximately 30° south of the equator then (Ziegler et al., 1977).

The Keyser in central Pennsylvania (Figure 1) includes a variety of lithofacies deposited during relative tectonic quiescence in depositional environments ranging from supratidal to open marine that were part of a gently sloping carbonate shelf. Slopes are estimated at 10 to 15 cm/km and maximum-water depths in the basin were about 60 m (Dorobek, 1984). Keyser deposition occurred over four million years (E. J. Anderson, personal communication, 2002). Integration of the sedimentology, paleontology, stratigraphic position (refer to guidebook cover 2), paleogeographic location, and comparisons to similar ancient and recent analogs provides a basis for understanding Keyser paleoecology. In most cases, there is no single sedimentological or paleontological observation that definitively identifies a particular depositional environment. Rather, paleoenvironmental interpretations are based on the sum of numerous observations.

Figure 1. Keyser Limestone distribution in central Pennsylvania (modified from C. E. Miller, 1979).

Miller, Jr., C. E., 2003, Paleoecology of the Keyser Limestone and its stromatoporoids in central Pennsylvania, *in* Way, J.H. and others, eds., Geology on the edge: selected geology of Bedford, Blair, Cambria, and Somerset Counties, Guidebook, 68th Annual Field Conference of Pennsylvania Geologists, Altoona, PA, p. 30 - 41.

In recent years, the paleoecologic aspects of the Keyser Formation, both in central Pennsylvania and adjacent state have been the focus of many studies, including: Anderson, 1971, 1972; Anderson and Makurath, 1973; Bliss, 1983; Brezinski, 1981; Brezinski and Kertis, 1982; Chapman, 1979; DeVries, 1977; Epstein, 1971; Goodrum, 1976; Head, 1969; Makurath, 1977; M. Miller, 1971; C. Miller, 1979; Nagle, 1964; Rickard, 1955; Smosna and Warshauer, 1979; Stock, 1997; Stock and Holmes, 1986; Thiel, et al., 1996; Travis, 1971; Warshauer, 1977; Wong, 1985. Similar studies of Keyser equivalents in New Jersey and New York include Anderson, 1971, 1972; Epstein, 1971; Harper, 1969; Head, 1969.

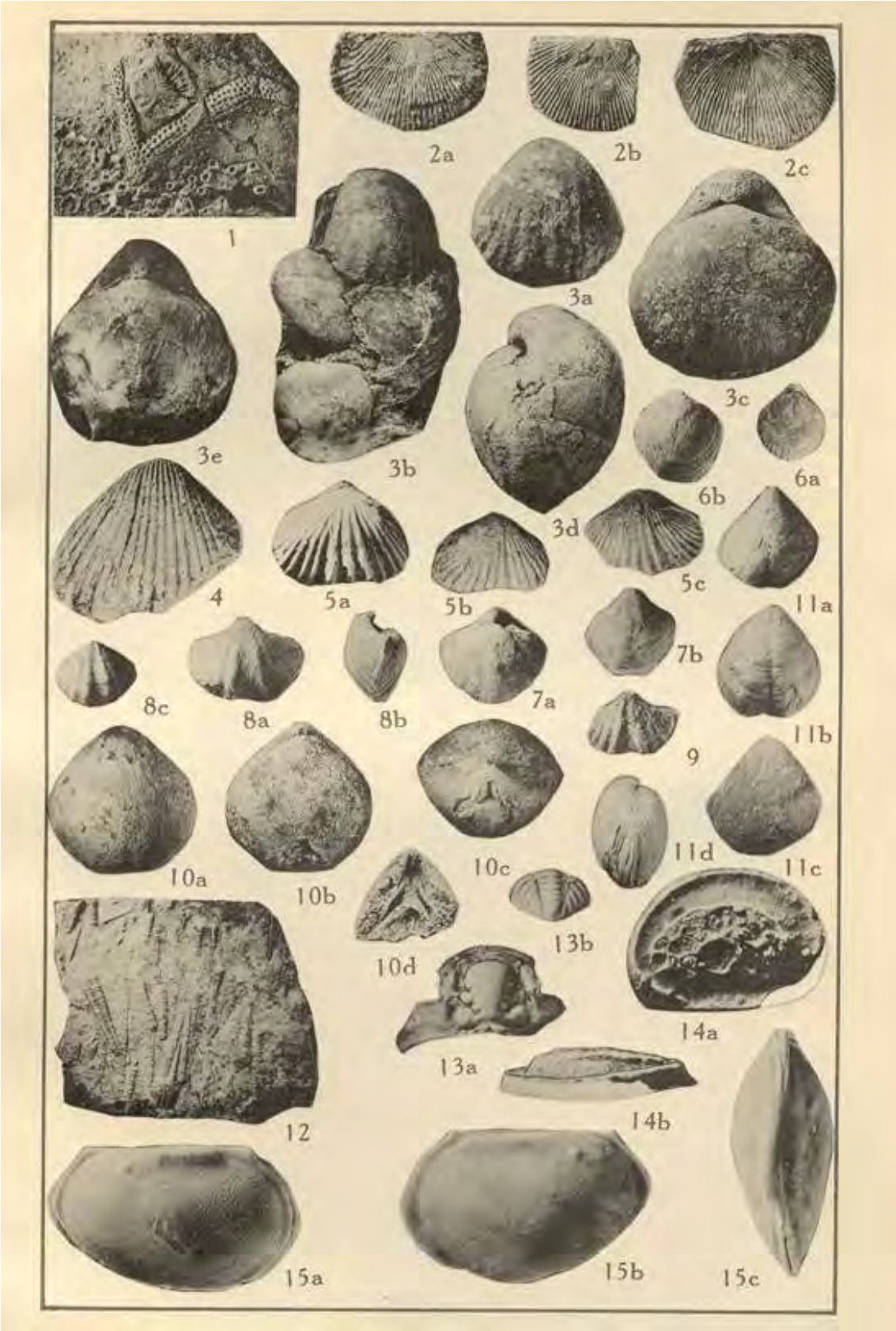
Figure 2. Two examples of bulbous stromatoporoid growth form from the Jersey Shore Member of the Keyser Limestone, Eldorado Quarry, Altoona, PA.

Most Keyser outcrops contain beds in which fossils are prolific, both in numbers and in taxa (Plate 1, Figure 2). This availability has allowed workers in the Keyser to use a wide variety of fossils in biostratigraphic and paleoecologic studies, principally brachiopods, corals, cystoids, crinoids, conodonts, and ostracods (C. E. Miller, 1979). Typically, bryozoans and stromatoporoids have been under-utilized as paleoecological tools owing to the extra labor involved in species-level identification (refer to C. E. Miller, in this guidebook). Where they have been used, the studies have tended to be more biostratigraphic and less paleoecologic in nature.

LITHOFACIES, FAUNA, AND DEPOSITIONAL ENVIRONMENTS

Lithofacies and faunal descriptions provide a sound basis for interpreting Keyser depositional environments and paleoecology in central Pennsylvania. The following summary of the major Keyser lithofacies, their faunas and depositional environments largely integrates the findings of DeVries (1977), Dorobek (1984), Head (1969), Makurath (1975, 1976, 1977), Travis (1971), and Wong (1985). Although there is considerable overlap, different sections of the Keyser are described in different studies. Therefore, some lithofacies in one study may not be present in others; and the descriptions themselves vary from

PLATE 1. KEYSER FOSSILS



study to study. For example, Makurath's (1975, 1977) "Thin-bedded muddy calcarenite lithofacies" refers to the "Regressive, Restricted, Barrier, and Open Water Lithofacies" of DeVries (1977). Consequently, correlation of one lithofacies scheme to another is not always readily apparent.

The following list summarizes the lithofacies that occur in the Keyser of central Pennsylvania. These lithofacies reflect the various marginal-marine, carbonate depositional environments illustrated in Figure 3.

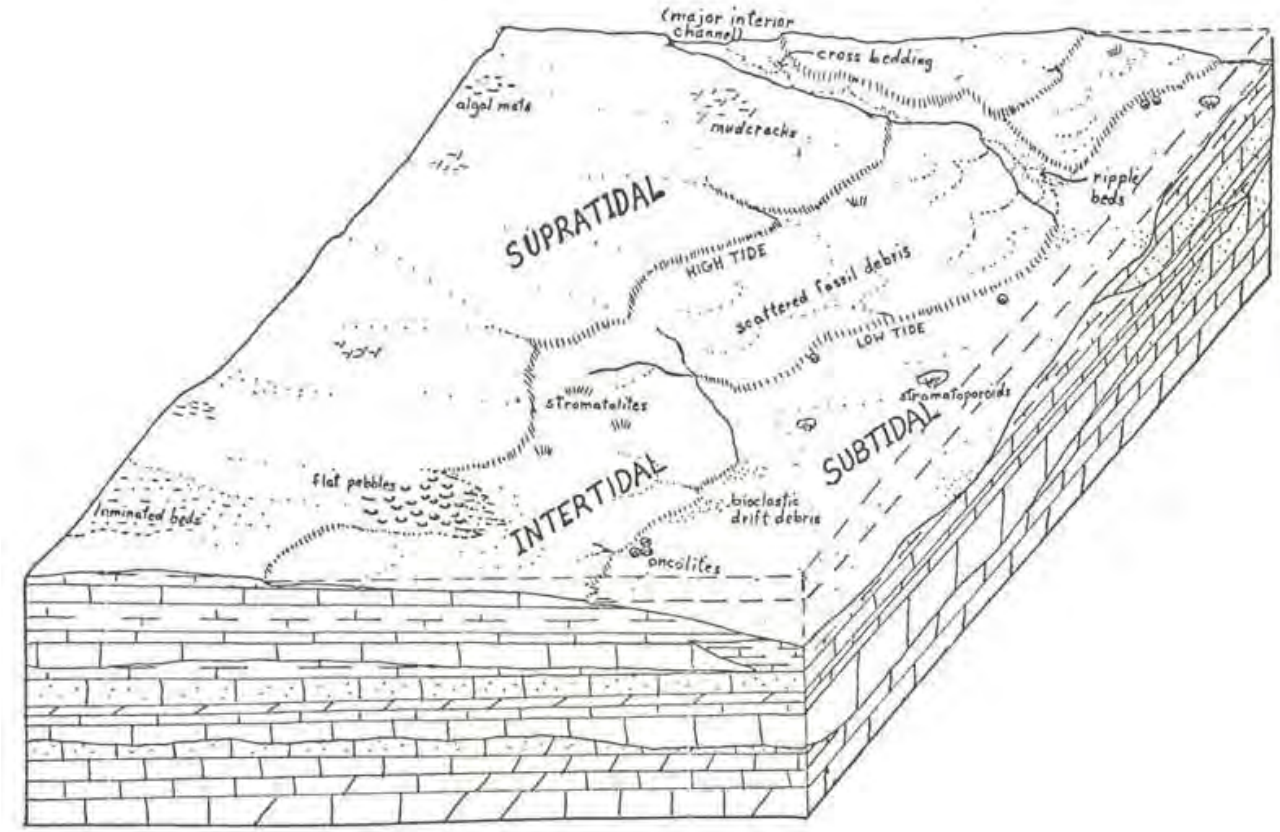


Figure 3. Diagrammatic scheme of supratidal, intertidal, and shallow subtidal environments of low-energy carbonate deposition. (From C. E. Miller, 1971)

1. **<u>Laminated lithofacies</u>** -- very thinly bedded calcisiltites and calcilutites containing a sparse fauna, mostly ostracods. There is very little evidence of burrowing. Makurath (1975, 1977) indicates that similar laminated carbonates have been described from a number of other ancient deposits and have been widely used as criteria for interpreting supratidal environments.
2. **<u>"Banded" lithofacies</u>** -- thin interbeds of micrites, calcarenites, and calcisiltites, containing a few shelly fossils. This lithofacies is interpreted as intertidal to very shallow subtidal. A small branching trepostome bryozoan is common in this lithofacies, paralleling the dominance of branching zoarial growth forms in low intertidal to very shallow subtidal deposits in the Kansas Permian (Cuffey, 1967).
3. **<u>Stromatoporoid biostrome lithofacies</u>** -- beds with tabular masses of stromatoporoids that do not project into overlying units and sparse or nonexistent associated fauna, suggesting deposition in tidal flat/intertidal/shallow-subtidal environments.

4. **Coral-stromatoporoid bioherm lithofacies** -- flat-based, vertical accumulations of various corals (favositids, halysitids, head-like rugose corals, *Cladopora* branches) and stromatoporoids (typically bulbous and dendroid) in a matrix of pelmatozoan fossil-hash calcarenite and calcisiltite, and some brachiopods. These sites must have been local topographic highs, possibly wave resistant, and lying in a rather shallow subtidal area of good circulation, slightly offshore of the tidal flat complex, but shoreward of the open shelf environments.

5. **Coral-stromatoporoid calcarenite lithofacies** -- massive to medium-bedded, crinoidal fossil-hash calcarenite and biomicrites, containing favositids, halysitids, auloporoids, *Cladopora*, stromatoporoids and some brachiopods. The larger stromatoporoids commonly are seen encrusting favositids. Many of these coral-stromatoporoid accumulations were probably marginal to and less dense than the biohermal buildups; they must have been subtidal, and may have accumulated a micritic matrix because of a position in shallow, protected environments or in a deeper environment of low mechanical energy.

6. **Calcilutite-calcisiltite lithofacies** -- variably bedded biomicrites containing brachiopods, bryozoans, trilobites, ostracods, with some bioturbation. This lithofacies represents a subtidal depositional environment, either shallow and protected, or deeper and low-energy.

7. **Calcarenite lithofacies** -- consists of thick-bedded to massive biosparites commonly containing crinoidal debris as well as abundant brachiopods and some bryozoans. The depositional environment is subtidal, probably highly agitated because micrite is generally lacking. Pentamerid brachiopods are represented in the Keyser by one genus (*Gypidula*), which is mostly restricted to the calcarenite lithofacies. This genus is biconvex and subglobose, which may represent an adaptation to the higher energy of the calcarenitic environment (Head, 1969).

8. **Nodular lithofacies** -- consists of argillaceous limestone massive to shaly bedded, composed of oblong nodules of calcilutite, calcisiltite, or fine calcarenite. Brachiopods are dominant, accompanied by echinoderm fragments, gastropods, corals, ostracods, stromatoporoids, trilobites, and bryozoans (C. E. Miller, 1979), including locally conspicuous bryozoan nodules (Thiel et al., 1996). The fossils are largely unbroken, however, bioturbation is extensive. Primary current-generated sedimentary structures (ripples, cross beds, graded beds) are conspicuously absent. These features suggest a subtidal, low-energy, lagoon paleoenvironment (Barnett, 1970; Head, 1969; Makurath, 1975, 1977). Strophomenid genera of the Keyser are most abundant in the nodular lithofacies. In this lagoonal lithofacies, the substrate was probably rather plastic or fluid and strophomenid morphology takes on new significance. Their flattened shapes would better rest on top of the soft bottom, in snow-shoe-like fashion (Head, 1969)

KEYSER MEMBERS

Based on variations in lithology and fauna, Head (1969) divided the Keyser into five members. In central Pennsylvania, three of those members are present in complete sections of the Keyser: the lower Byers Island Limestone, the middle Jersey Shore Limestone, and the upper LaVale Limestone. The respective lithofacies of each member are indicated in Table 1.

Byers Island Limestone -- the lowest member is distinguished by the nodularity of the great percentage of its beds.

Table 1: Lithofacies distribution in Keyser members in central Pennsylvania.

Lithofacies	Keyser Limestone Members		
	Byers Island	Jersey Shore	LaVale
Laminated			X
Banded			X
Stromatoporoid biostrome	X	X	X
Coral-stromatoporoid bioherm		X	
Coral-stromatoporoid calcarenite		X	
Calcilutite-calcisiltite	X		
Calcarenite	X		
Nodular	X		

Jersey Shore Limestone -- the middle member is distinguished by its abundant corals and stromatoporoids (Head, 1969). In places, stromatoporoids dominate the Jersey Shore fauna to the extent that, in some cases, they totally constitute well over one-half of the volume of the rock (Stock, 1997).

LaVale Limestone -- the upper member is distinguished by the laminated or banded aspect of these beds (Head, 1969).

However, William Bragonier, Frank Hall, and John Taylor (Field Trip Leaders), who have worked in the Altoona-Hollidaysburg-Bedford area over the past decade, suggest a modification to this stratigraphy (personal communication, 2003). While they continue to recognize the Jersey Shore and LaVale members as valid in this area, Taylor indicates that the lower member of the Keyser in this part of the Ridge and Valley, the Byers Island Member, differs dramatically from exposures in the type locality in the central part of the state. Taylor and his co-workers will be formally proposing the name Chimney Rocks Member for this part of the Keyser throughout this area. This new member comprises three parts: a lower, massive, lime-mudstone to wackestone- (the "calico rock") lithofacies; a middle nodular limestone lithofacies with lumps of fine, bioclastic grainstone surrounding by shaly material; and an upper echinoderm grainstone lithofacies. The sharp, basal contact of the lower member is marked by the disappearance of the fine laminae of the Tonoloway and the appearance of well-developed bedding in the Keyser. Its top is marked by the appearance of a more diverse, open marine fauna of the Jersey Shore Member.

PALEOECOLOGICAL ROLES OF KEYSER STROMATOPOROIDS

Little has been written about stromatoporoid paleoecology in the Keyser of central Pennsylvania despite the abundance of these fossils at many localities. This dearth of information is largely attributable to the difficulty of working with these fossils. Like most bryozoans, but unlike other common shelly fossils, species-level identification of stromatoporoids requires careful thin-section microscopy. As a result, few Keyser workers in Pennsylvania, or elsewhere, have utilized these fossils at the species level. For example, Head's classic study of the Late Cayugan and Helderbergian of the central Appalachians devoted only a single sentence to the paleoecological role of Keyser stromatoporoids: "Stromatoporoids play the major role in many biostromal developments and are important associates in the biohermal and surrounding interbiohermal facies" (Head, 1969, p. 174).

Most commonly, Keyser stromatoporoids in central Pennsylvania occur as biostromes, and, less frequently, as stromatoporoid bioherms which are known from only a few localities, including Jersey Shore

and Altoona. Only the Jersey Shore and one of the Altoona stromatoporoid bioherms (Allegheny Furnace) have been described in detail. Elsewhere in the Keyser, including adjacent states, stromatoporoid bioherms have rarely been described (see following sections).

Ulrich and Bassler (1913a, 1913b) describe and illustrate what appear to be the commonest Keyser stromatoporoids as *Stromatopora constellata* (Hall). However, additional detailed thin-section work is needed to confirm that identification on a regional scale.

Altoona (Eldorado Quarry) patch reef

Hall (1989, 1990) briefly mentions stromatoporoid reefs in the upper Jersey Shore Member (Upper Silurian) of the Keyser in the remains of the Eldorado Stone Quarry (along I-99) south of Altoona, Pennsylvania. The 1.8-meter-high bioherms are exposed in the uppermost portion of the quarry. They have not yet been described in detail; however, they are mentioned here for future comparison to the other described bioherms in the Keyser. Of all Keyser localities examined by this author in central Pennsylvania, the largest stromatoporoids occur at the Eldorado Stone Quarry. At highway level, some boulders, up to 15 feet in length, are largely comprised of stromatoporoids, with individuals up to a meter in diameter. Based on thin-section analyses, these all appear to represent the common species *Stromatopora constellata* (Hall) previously identified in the Keyser by Ulrich and Bassler (1913a, 1913b).

Altoona Bible Church (Allegheny Furnace Section) patch reef

A complete section of the Keyser Formation occurs adjacent to the parking area behind the Altoona Bible Church (Union Avenue, PA Route 36, Altoona). This stratigraphic section is also referred to as the Allegheny Furnace Section (Faill et al., 1989, p. 173). The Altoona Bible Church patch reef (Figure 4) is discussed by Brezinski and Kertis (1982); Cuffey, Abdo, and Taylor (1986); and Cuffey and Taylor (1989). This small, uppermost Silurian bryozoan-coral-stromatoporoid patch reef is unusual in that its lower part is a bryozoan bioherm, of which very few are known anywhere in the Mid-Paleozoic. This reef occurs within a pelmatozoan or crinoidal grainstone facies near the top of the Byers Island Member, below the Silurian-Devonian boundary, and thus of late Pridolian age (Cuffey and Taylor, 1989). Reef development was in or adjacent to a tidal channel cutting through a carbonate-sand barrier island complex separating somewhat restricted lagoonal environments from open, shallow shelf environments within the Appalachian Basin, an ecologic setting very similar to that of present day Bahamian bryozoan reefs (Cuffey et al., 1977).

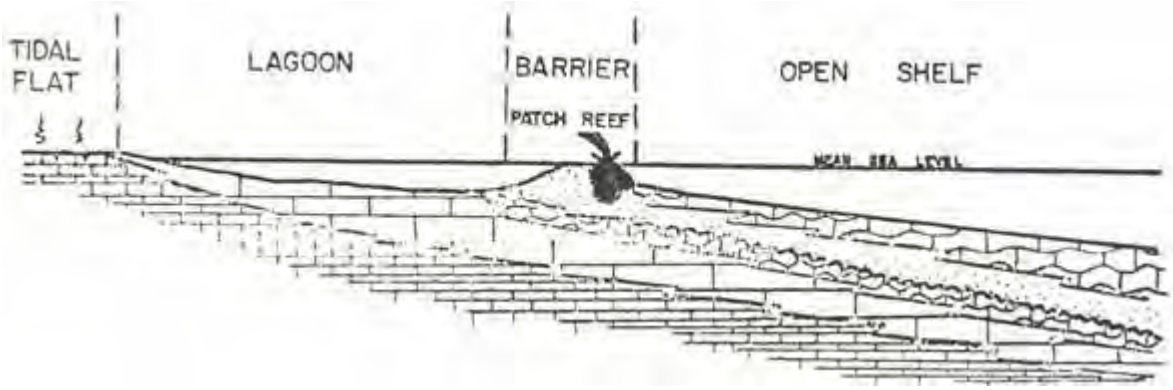


Figure 4. Schematic facies relations of the lower Keyser Formation in the Altoona area with inferred location of the Altoona Bible Church patch reef. (Modified from Brezinski and Kertis, 1982)

Bryozoans, in the lower portion of the reef, formed a framework, which was later infilled with micrite. Later, they were encrusted by stromatoporoids, specifically the species *Stromatopora constellata* (Hall) as recorded by Ulrich and Bassler (1913a, 1913b). Some of the stromatoporoids developed a vertical columnar morphology, a growth form not reported at other Keyser localities, possibly in response to rapid accumulation of the enclosing skeletal sand (Cuffey and Taylor, 1989). Reef growth terminated when

erosion truncated the reef top. Subsequently, the reef was buried under additional shallow marine carbonate sediments that contained a more diverse fauna suggesting open shelf conditions.

The Allegheny Furnace reef consists of a boundstone or framestone mound, 3 m high by 10 m wide. A bryozoan "lettucestone" (Cuffey, 1985), comprising foliaceous sheets of cystoporate bryozoans, makes up the lower part of the reef. The upper part of the reef is coral-stromatoporoid bindstone, "coverstone" and "globstone" (Cuffey, 1985). Unlike stromatoporoid biostromes elsewhere in the overlying Jersey Shore Member, this upper portion does not display the dominance of framebuilders, inasmuch as the stromatoporoid columns are all growing upward in parallel. Brezinski and Kertis (1982) recognized these features and suggested that they represented continued upward growth into more turbulent, near surface waters. The reef top is planed off at an erosional surface and is overlain by open marine carbonates (grainstones to lime-mudstones).

Jersey Shore

An abandoned quarry, adjacent to Pine Creek, near Jersey Shore, Pennsylvania, exposes a late Silurian coral-stromatoporoid bioherm in the type section of the Jersey Shore Limestone Member of the Keyser Limestone. Sedimentary structures, textures, faunal diversity, and vertical faunal zonation show that the transgression was interrupted by a local, stable period of sea level (Bliss, 1983), during which the reef mass grew. Corals (Favosites, Halysites, *Cladopora*) and stromatoporoids were the primary frame builders. Other associated organisms include brachiopods, crinoids, rugose corals, bryozoans, and ostracods. A stromatoporoid boundstone overlies a crinoidal packstone. The bioherm grew among a variety of marginal and shallow marine environments associated with a transgressing sea. Growth appears to have been terminated by increased sedimentation and consequent burial.

Both the Byers Island and Jersey Shore Limestone members are reported here. These units suggest a shallow subtidal (lagoonal) environment, superceded by a more wave-agitated, shallower tidal zone offshore. Presence of a diverse fauna, coarse sediment, a paucity of micrite, jumbled stromatoporoids, and broken fossils suggest the bioherm was associated with a wave-agitated environment.

The Jersey Shore bioherm began growth on a crinoidal fossil hash foundation. Tabulate corals then stabilized the sediments after which stromatoporoids encrusted the corals. Corals and stromatoporoids trapped sediments and provided protected niches for other organisms. In the upper bioherm zones, stromatoporoids became dominant and continued that role until reef growth ended when sedimentation became too great, burying the bioherm in calcareous mud (micrite). This replacement of corals by stromatoporoids at Jersey Shore follows broader observations by Galloway (1957) and Lowenstam (1957) that stromatoporoids replaced corals as the upper surface of a reef grew progressively upward.

Bliss (1983) reported the following general trend of stromatoporoid growth forms within the Jersey Shore bioherm: uppermost – bulbous, with thick branches; middle – domal, as large heads with broad bases; lowest – laminar, as small, encrusting, tabular forms. Growth forms became sturdier as turbulence increased with decreasing water depth. This trend follows observations by Riding (1980) of Silurian reefs at Gotland (Sweden) in which tabular stromatoporoid forms are replaced by domal and bulbous forms as part of a shallowing-upward sequence from upper fore reef to reef crest.

Mustoe bioherm

At Mustoe, Highland County, Virginia, a 13-m thick stromatoporoid-dominated patch reef is exposed in the Jersey Shore Limestone Member (Smosna and Warshauer, 1979; Stock, 1986; Stock and Holmes, 1986). Although the patch reef is the most distinguishing feature at this locality, stromatoporoid biostromes, representing inner-platform blanket sediments (Stock, 1997), were also identified here. In the bioherm, hemispherical and spherical stromatoporoids were the major frame builders, accounting for 80% of the reef volume. Corals, *Cladopora* and *Favosites*, and crinoids lived as reef dwellers in small crevices between the stromatoporoids and within reef-flat pools. Reef growth was terminated by a slight drop in sea

level as evidenced by a wave-cut erosion surface. The regression continued and inner-platform muddy sediments buried the surface. Small, sediment-binding globular and tabular stromatoporoids dominated minor corals and rare brachiopods in the quiet water behind the reef. The uppermost Keyser Limestone, a laminated micrite with *Leperditia*, tabular stromatoporoids, and rare brachiopods, was deposited on a near-shore shoal after reef termination. The overlying New Creek Limestone, a cross-bedded crinoidal calcarenite of a shallow shelf environment, indicates an ensuing slight rise of sea level (Smosna and Warshauer, 1979).

Similar to their Devonian counterparts elsewhere, stromatoporoids at Mustoe are very large and growth forms vary (Smosna and Warshauer, 1979; Wilson, 1975). Large frame builders with hemispherical and spherical shapes dominated the Mustoe patch reef. Growth was primarily upwards on the firm substrate of the reef proper, resulting in their characteristic shape. Smosna and Warshauer (1979) noted a marked increase in stromatoporoid size with upward growth of the reef. Through time, the reef rose higher above the adjacent sea floor into shallower, more agitated water that was richer in nutrients, oxygen, and sunlight. Growth-form distribution at Mustoe follows that of other Devonian stromatoporoid-dominated reefs in that large, robust stromatoporoid growth forms are generally found in shallow, moderate-to high-energy environments; whereas, smaller forms occur in lower-energy areas (St. Jean, 1969). In these lower-energy environments, water circulation was more restricted than on the patch reef.

Some other observations of the Mustoe stromatoporoids have sedimentological implications. Evidence of regression within the over-all transgressive cycle of the Keyser appears as wave-cut surfaces produced when erosion terminated upward growth of the patch reef. Large stromatoporoids at the top of the reef were overturned and planed. As regression continued, progradation of near-shore sediments of the LaVale Limestone Member eventually buried the patch reef (Holmes, 1980; Smosna and Warshauer, 1979).

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THE PLATEAU CLIMB-OUT ZONE BENEATH THE ALLEGHENY FRONT AND DEER PARK ANTICLINE, SOUTHWESTERN PENNSYLVANIA: CHARACTERISTICS OF A GEOLOGIC SPEED BUMP

Michael A. Scanlin and Terry Engelder

ABSTRACT

The transition between the Appalachian Valley and Ridge and the Appalachian plateau in southwestern Pennsylvania is reflected in the hybrid architecture of three structures: the Allegheny structural front plus the Deer Park and Negro Mountain anticlines. This transition, the plateau climb-out zone, is characterized by the transfer of major detachment slip from the Waynesboro Shale in the Valley and Ridge upward to the Reedsville shale under Deer Park anticline and finally up to the Salina Group on the hinterland side of Laurel Hill anticline. At Deer Park and Negro Mountain, the Appalachian Plateau detachment sheet is passively folded above a roof thrust in the Salina Group. Further toward the foreland, the detachment sheet actively deforms in a three-tiered manner with the Salina Group acting as the major detachment surface. The Allegheny structural front is located above a 700-meter step in basement that disrupts tectonic transport between the Valley and Ridge and Plateau provinces, thus acting like a large geologic speed bump.

INTRODUCTION

A regional network of modern seismic data offers compelling evidence that the location and subsequent growth of anticlines on the Appalachian plateau of southwestern Pennsylvania is a direct consequence of deep-seated basement faults offsetting an otherwise flat décollement (Scanlin and Engelder, 2003). Because of this mechanical coupling between basement and Appalachian Plateau folding, it is reasonable to hypothesize that the Allegheny structural front, the boundary between the Appalachian Plateau province to the WNW and the Valley and Ridge province to the ESE, might also have a strong element of basement involvement. Specifically, the Allegheny "front" sits over a step in the basement with a down-thrown hinterland block, an idea that is present in the literature but somewhat vague (e.g., Cooper, 1964; Wagner, 1976; Beardsley and Cable, 1983; Beardsley et al., 1999; Harper et al., 1999). If such a step exists, it acts as a huge geologic speed bump against which and over which rocks of the Paleozoic from the Valley and Ridge were pushed during the Alleghanian orogeny. High-resolution seismic data are the best means of confirming the presence this geologic speed bump.

The geological analogy to the roadway speed bump is appropriate because the continent-continent convergence of Africa against North America during the Alleghanian Orogeny pushed the Appalachian foreland toward the northwest a distance well in excess of 100 km at the Blue Mountain structural front (Geiser, 1988). This lateral transport was accomplished with the development of high-amplitude, fault-related folds stacked across the Valley and Ridge terrane. Stacking of these first order folds comes to an abrupt halt at the Allegheny structural front. Tectonic transport across the Allegheny structural front was less than 25 km (Engelder, 1979). Assuming that motion of the Appalachian detachment sheets at both structural fronts was quasi-synchronous, the rate of tectonic transport at the Blue Mountain structural front was four times that at the Allegheny structural front. Aside from internal shortening, something else impeded the rate of tectonic transport across the Allegheny structural front. Our hypothesis is that faulted basement produced a significant offset at the basement-cover contact and that this step up of basement to the

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northwest was not only figuratively but literally a geologic speed bump over which the Allegheny structural front developed.

The Allegheny Front marks the boundary between two provinces of distinct structural styles (Figure 1). The differences arise primarily from transport on different detachment zones and differences in mechanical stratigraphy, mainly the presence of a significant thickness of Silurian salt in the Plateau region (Hatcher et al., 1989; Faill, 1998). As the result of the transfer of detachment up section near the Allegheny structural front, there are significant differences in the thickness of the detachment sheets on either side of the structural front. Northwest of the structural front the plateau detachment sheet consists primarily of a Silurian-Pennsylvanian sequence (Davis and Engelder, 1985). Southeast of the structural front the detachment sheet includes carbonates of the Cambrian-Ordovician section with Silurian-Devonian clastics uncoupled along a passive roof-thrust detachment (Onasch and Dunne, 1993). Lateral shortening of the detachment sheet, although an order of magnitude greater in the valley and ridge than the plateau province, has been accomplished by similar tectonic imbrication acting in the mechanically strong portions of the stratigraphic sequence (Scanlin and Engelder, 2003).

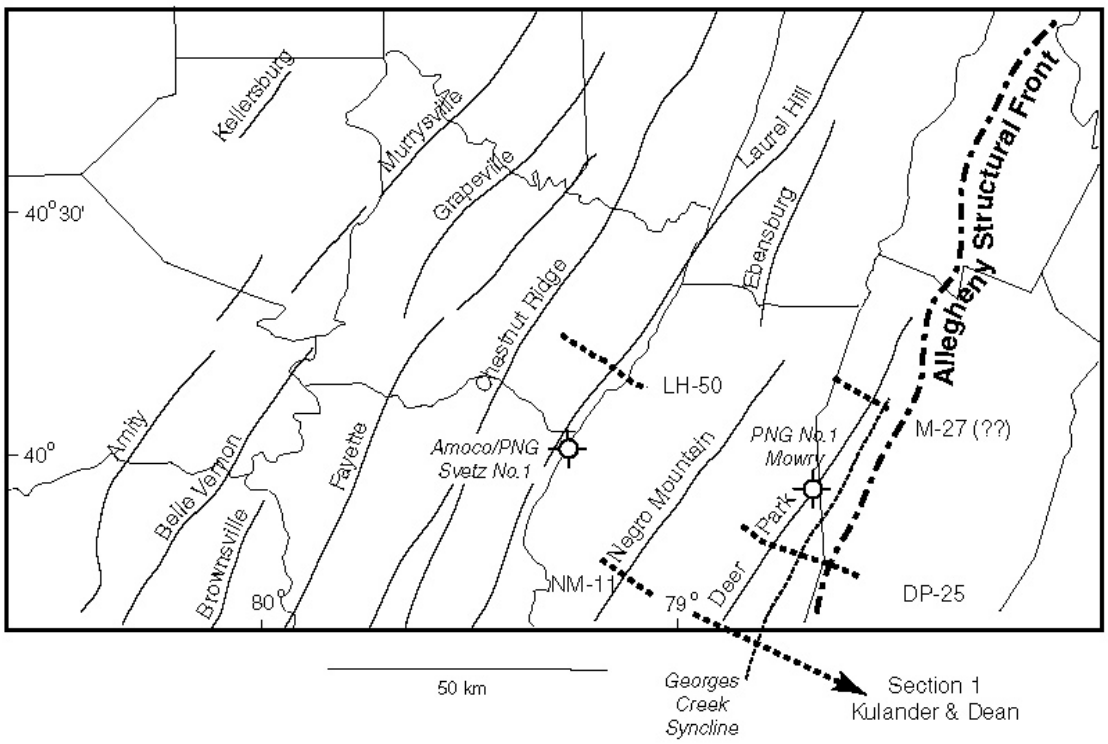

Figure 1. Structural geology of southwestern Pennsylvania. Important structural elements include: Allegheny structural front (thick dashed line), surface traces of Appalachian Plateau anticlines (solid lines), Georges Creek syncline (thin dashed line). Data elements include three key reflection seismic profiles and one schematic cross-section (adapted from Kulander and Dean, 1986) (thick dashed lines) plus location of two deep exploration wells used for stratigraphic correlation.

In the Pennsylvania salient, the Cambrian Waynesboro Shale facilitates detachment above the Precambrian basement complex southeast of the structural front and the detachment zone ramps upward stratigraphically to the northwest where the Silurian Vernon shale accommodates detachment above the topographically irregular Lockport Dolomite surface (Scanlin and Engelder, 2003). The rate of this climb from Waynesboro "shale" to Silurian Vernon "shale" is not as abrupt as may be assumed given the abrupt change in structural style at the structural front. The climb-up from the Waynesboro is accomplished throughout a zone including the two most proximal anticlines on the Appalachian Plateau, the Deer Park

and Negro Mountain anticlines. This climb-out process is not apparent in recent cross-sections of the Allegheny Front (e.g., Beardsley et al., 1999; Harper et al., 1999).

When seen in map or plan view, Deer Park anticline is positioned immediately west of the Allegheny structural front. As a result of its geographic location on the foreland side of the Allegheny structural front, the Deer Park anticline is logically labeled as the easternmost and largest amplitude fold in the Appalachian Plateau province (e.g., Rogers, 1970). However, its position immediately west of the structural front permits the possibility of structural similarities to the Allegheny Front and structural differences relative to its sibling plateau anticlines farther WNW toward the foreland. Until now the nuances of its subsurface architecture as well as its tectonic relationship to both adjacent plateau anticlines and the Allegheny structural front to the east have yet to be accurately characterized.

With the support of high-resolution seismic data (see Appendix 1 for details concerning data source and resolution), the objective of this paper is to provide a unifying tectonic model that accommodates the interrelated structural elements of the adjacent Appalachian plateau structures, Deer Park anticline, and the Allegheny structural front in the vicinity of Somerset County, Pennsylvania. Advances made in this research include (1) improved delineation of the subsurface structural architecture of the Allegheny structural front and Deer Park anticline, (2) a clearer understanding of the mechanical stratigraphy and tectonic mechanisms within these structural elements, (3) improved understanding of the nature of the transition from the Valley and Ridge to the Plateau, and (4) explicit documentation of the spatial and kinematic relationship between all the Plateau province structures and the structural front.

THE APPALACHIAN PLATEAU DETACHMENT SHEET

The growth of detachment sheet anticlines in the Bedford-Pittsburgh region of the Appalachian Plateau is a direct consequence of tectonic thickening of a three-tiered mechanical stratigraphy that comprises the Siluro-Devonian interval (Scanlin and Engelder, 2003). The general architecture includes a basal detachment zone, a lower imbrication zone, and an upper wedge zone (Figure 2). The detachment zone is predominantly disturbed shale of the Silurian Vernon Formation. Salt horizons within the Syracuse Formation of the imbrication zone host secondary detachments responsible for imbrication and the development of triangle zones in the core of the anticlines. The Upper Silurian through Lower/Middle Devonian constitutes a tectono-stratigraphic layer thickened by imbrication. This stratal package acts as a thick competent strut that deforms in unison. Locally, it breaks into multiple layers of imbrication along several detachment surfaces. In these cases, each mechanical unit detaches along both roof and floor thrusts as in a passive-roof duplex. Regardless of the thickness of the mechanical struts, triangle zones form as a consequence of vergence from both sides toward the central core of the anticline. Some fold amplification is also achieved by extensive, smaller-scale wedge thrusting and concomitant tectonic thickening of the less competent Upper Devonian wedge zone.

Each detachment sheet anticline is situated above prominent, periodically spaced structures in the footwall of the detachment sheet (Scanlin and Engelder, 2003). Footwall structures are principally reactivated Late Proterozoic extensional normal faults. Most show structural inversion. Beneath Negro Mountain, a zone of thrust imbrication at the Ordovician Trenton level underlies the Siluro-Devonian and overlies the inverted normal faults. Tectonic inversion is seen in the development of buttress anticlines in the Cambro-Ordovician section. The superposition of hanging wall anticlines on footwall structures strongly suggests that these anticlines were produced by westward translation of the detachment sheet over syn-sedimentary basement growth faults that propagated vertically by recurrent tectonic activity including Alleghanian inversion.

The regular spacing of these anticlines is a direct consequence of periodic fracturing and concomitant lateral collapse at deformed steps in the detachment sheet. Evidence suggests that basement faults not only controlled the distribution of Lower Paleozoic stratigraphy but also provided the localized

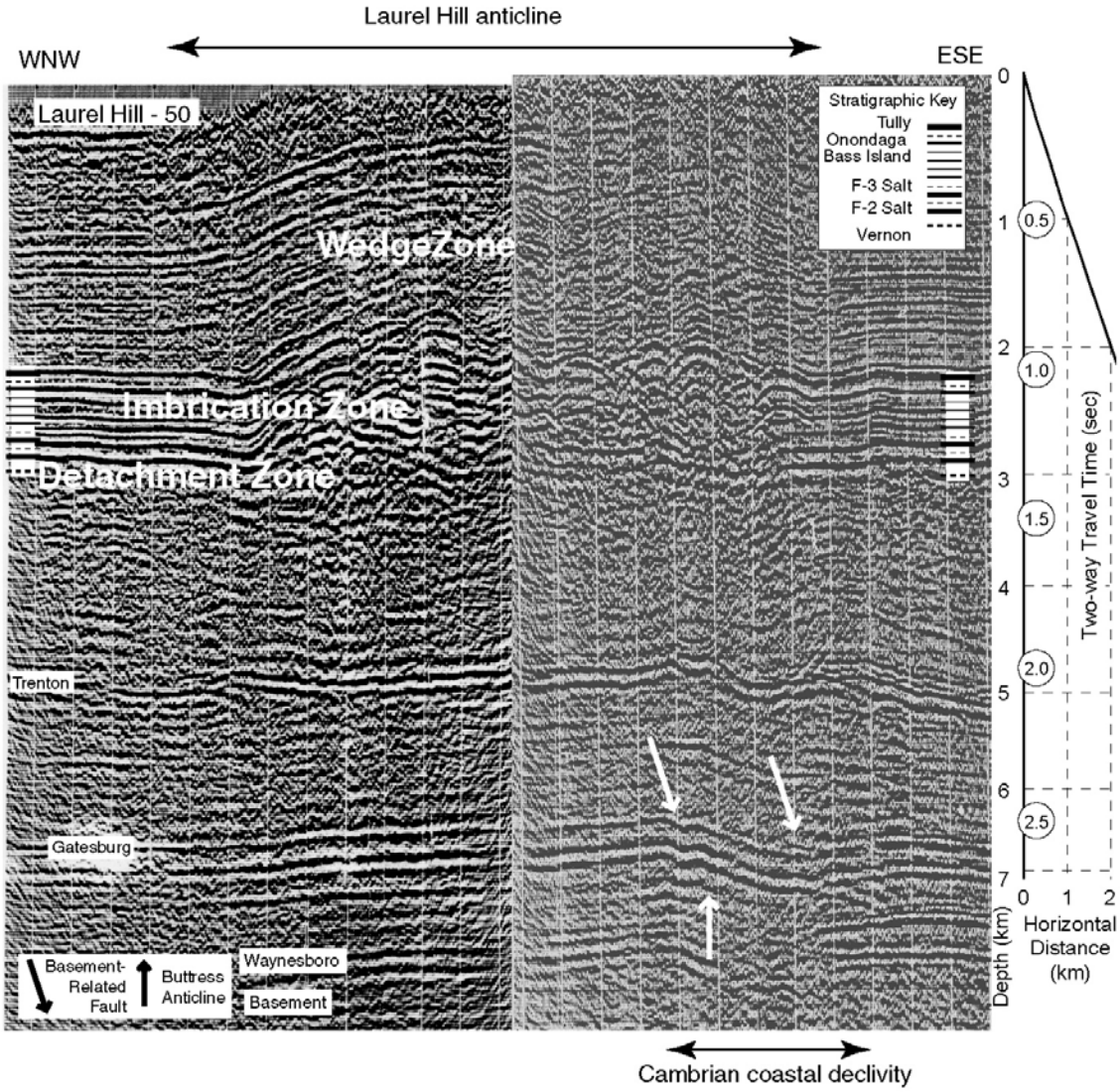

Figure 2. Interpretation of structural style within the detachment sheet as found in seismic profile LH-50 (migrated time section) through Laurel Hill anticline (see Figure 1 for location). The components of the three-tiered model annotated in their appropriate position on seismic profile (migrated time section). Approximately 3:1 vertical exaggeration.

stress concentration that generated the periodic collapse and fold growth in the over-riding detachment sheet. The response of the detachment sheet to periodic collapse is the growth of a Coulomb wedge that gives rise to a local tectonic thickening within the weakened section. In extrapolating this model toward the hinterland of the Appalachian Mountains, it permits the hypothesis that Deer Park anticline and the Allegheny structural front are both coupled to basement steps as well.

DEER PARK ANTICLINE

We focus first on the Deer Park anticline largely because it is, comparatively speaking, less structurally complicated than the Allegheny Front (Figure 3). The front contains more steeply dipping beds that are more difficult for the seismic reflection method to resolve and consequently offer a more challenging interpretation problem. Our strategy is to use the lessons learned from Deer Park as well as anticlines further toward the foreland to interpret the structures at the Allegheny structural front. Our premise in taking this approach is that the mechanical development of the structural front is as closely

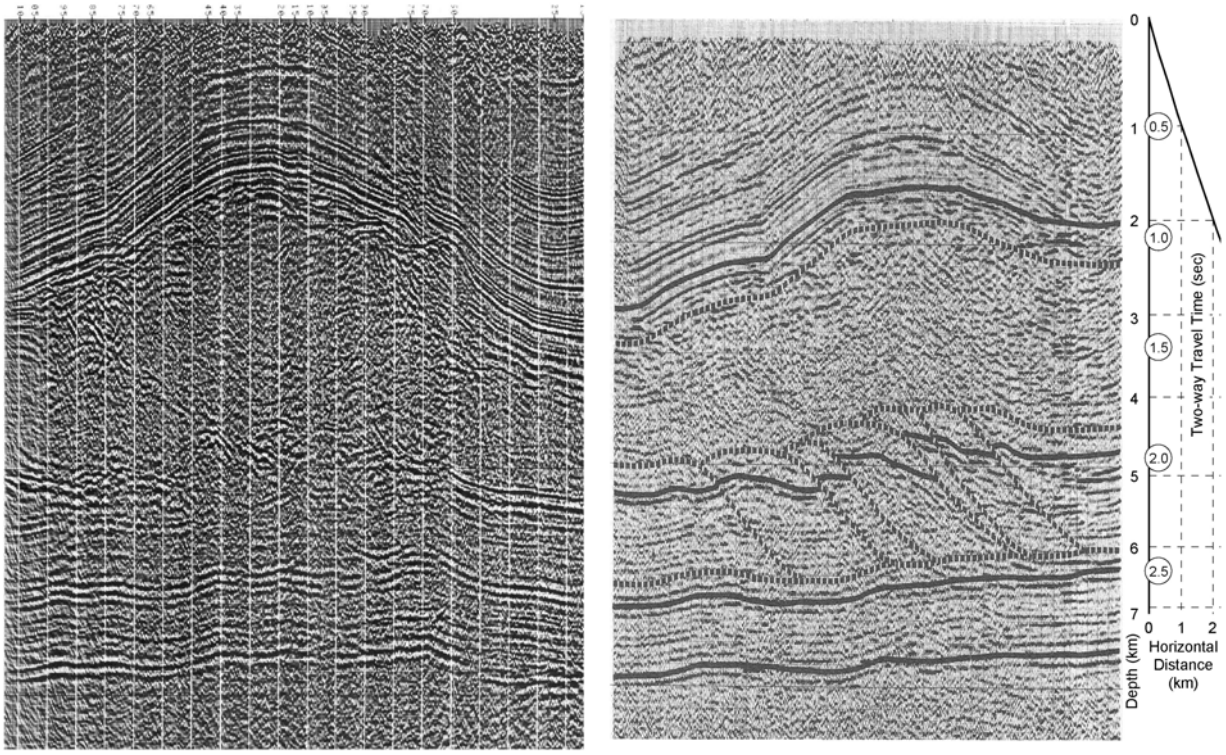

Figure 3. Two migrated-time seismic profiles across Deer Park anticline (see Figure 1 for locations). Seismic section DP-25 provided for academic research by Amoco Production Company and UGI Development Company. Seismic section M-27 (from Mitra, 1986).

related to the development of Appalachian Plateau anticlines as it is to the fault-related folding of the Valley and Ridge. This lesson is best illustrated using a cross-section drawn to the SSW of seismic sections DP-25 and M-27 (Figures 1 and 4). In this interpretation, both the Deer Park anticline and the structural front are drawn with splay faults ramping toward the foreland from a detachment in the Upper Ordovician Reedsville shale. The difference is that the Reedsville detachment at the structural front is fed by a master ramp from the Waynesboro shale under the Wills Mountain anticline (Kulander and Dean, 1986). The major structures that are missing from the Kulander-Dean interpretation of the Deer Park anticline are the stacked ramps from Waynesboro to the Reedsville as identified in the interpretation of seismic section M-27 (Figure 4 vs. Figure 3B). Only one blind thrust is shown in the Kulander-Dean interpretation.

Deer Park anticline is the first structure west of the Allegheny structural front (Figure 1). Based on seismic images (Figure 3), the Deer Park exhibits structural attributes characteristic of both the Plateau detachment sheet anticlines and the fault-related folds of the Valley and Ridge province. Valley and Ridge structures consist of a duplex thrust system developed in the Cambro-Ordovician section with a passive roof thrust developed in the overlying Siluro-Devonian section. In the Appalachian Plateau at Laurel Hill anticline duplex thrust systems are developed in the Siluro-Devonian section according to the three-tiered mechanical model (Scanlin and Engelder, 2003).

At Deer Park, the Siluro-Devonian section displays the passive roof thrust architecture characteristic of Valley and Ridge structures. The Lower Paleozoic section forms a stack of at least two and maybe more duplex thrust systems quasi-synchronously cutting the Lower Silurian Tuscarora, Ordovician Trenton, and the Cambrian Gatesburg sections (Figures 5-7). We interpret this partitioning of tectonic imbrication and duplex development to be a mechanical response to a dramatic difference in tectonic transport across the Allegheny structural front that necessitated detachment at multiple stratigraphic levels. Detachment and

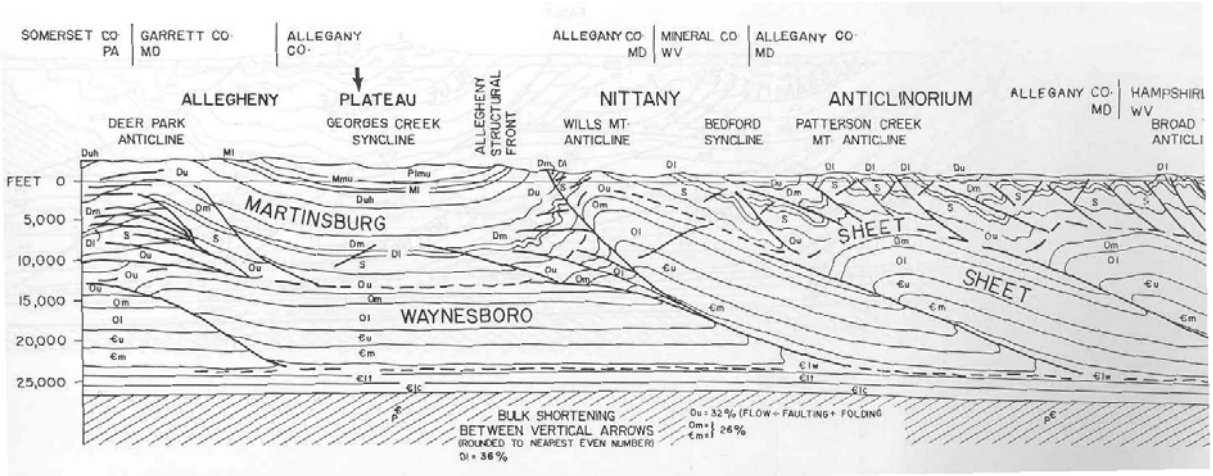

Figure 4. Structural cross section through Allegheny structural front (see Figure 1 for location) (from Kulander and Dean, 1986).

imbrication at multiple levels not only accommodated the large tectonic transport from the east but also facilitated the progressive stratigraphic climb of the basal detachment zone from the Waynesboro Shale in the Valley and Ridge to the Silurian Vernon Shale in the Plateau province. Deer Park anticline is part of the Plateau climb-out zone with slip being transferred upward from the Waynesboro Shale in the Valley and Ridge to Vernon Shale under the Appalachian detachment sheet at Laurel Hill anticline. Climb-out ramps through the Gatesburg, Trenton, and Tuscarora levels all possess a common vergence toward the foreland.

It is particularly noteworthy that Deer Park Anticline is situated in the immediate vicinity of and above ancient basement faults (Figure 7). The recurrence of this remarkable structural pattern is not only consistent with our tectonic model for adjacent plateau anticlines (i.e., a major ancient basement fault located at the trailing edge of each anticline) but also presents a reason for presuming that basement faulting is responsible for the structural front as well. Consistent with other Plateau detachment sheet structures, the surface trend of Deer Park appears to follow and be localized by these basement features. The basement fault at the trailing edge of Deer Park manifests a structural relief in excess of 500 m at both the Waynesboro and the Gatesburg levels.

Independent confirmation of the general structural architecture at Deer Park is derived from the interpretation of a seismic section (Mitra, 1986) traversing Deer Park approximately 30 km NE along strike (Figure 1: M-27). The position and orientation of the seismic line were not explicitly provided in the published paper; however, the position and dimensions of critical structural components within the subsurface landscape facilitated a fairly reliable line location and orientation with respect to the Deer Park structure. It is noteworthy that the surface expression of Deer Park anticline merges with the Allegheny structural front approximately 60 km along strike to the northeast. Side-by-side presentation of DP-25 and M-27 facilitates not only comparison of the structural elements displayed in each seismic image but also the imaging attributes of each seismic profile (Figure 3). M-27 contains interpretive markings on key stratigraphic horizons that could not be removed from the published image. DP-25 does not contain interpretive markings at this point to emphasize the presence of a sizable step in basement that was largely covered by a interpretation line in M-27. Also note that the southeastern side of DP-25 has been cropped horizontally to match the horizontal dimension of M-27, the cropped portion of the line is restored on all other Figures showing DP-25 (Figures 5-7).

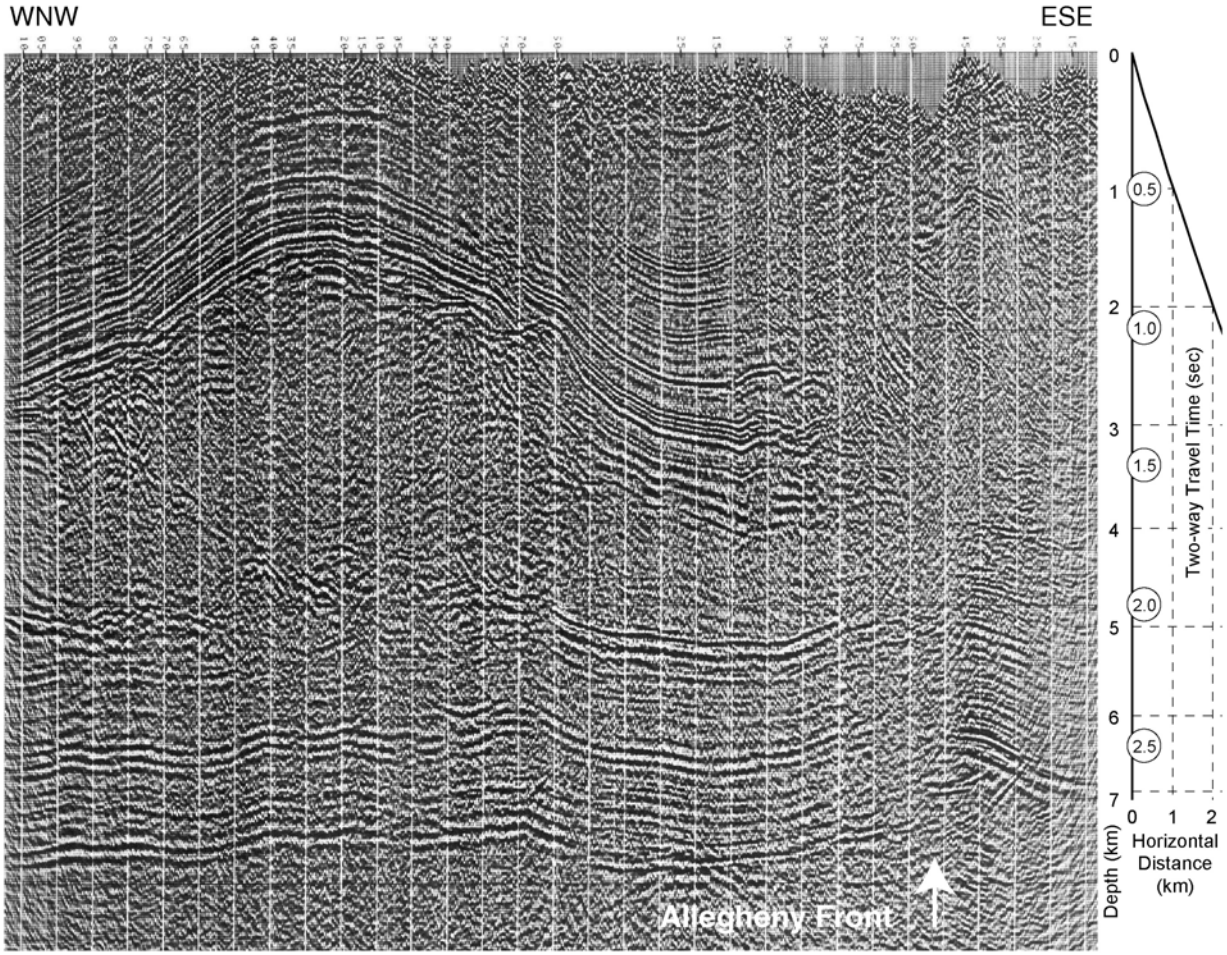

Figure 5. Seismic profile DP-25 showing the complete section cutting across the Allegheny structural front (migrated-time section).

Notable differences in the structural architecture portrayed in the two seismic lines from top to bottom include: (1) M-27 displays a Siluro-Devonian passive roof thrust section that appears to be substantially narrower toward the ESE than DP-25, (2) M-27 appears to exhibit a thicker mouth or tectonic feed zone between the Siluro-Devonian passive roof thrust and the top of the Trenton imbrication zone, and (3) the Gatesburg imbrication zone on M-27 seems to portray a diminished level of imbrication relative to our interpretation of DP-25 for this zone (Figure 7).

Closer examination of the seismic reflection events beneath the interpretive markings that have been superimposed reveals that the reflection picks beneath the Siluro-Devonian roof thrust are not consistent on the WNW and ESE flanks of the anticline. Our interpretation of M-27 would place the roof thrust boundary on the ESE side of Deer Park several hundred milliseconds below the level marked on the published section. This reinterpretation moves a portion of the roof thrust section to a zone of tectonic thickening in the core of Deer Park and erases significant differences between the sections. We also believe that the interpretive markings at the Gatesburg level have smoothed through seismic expressions of a much more intense level of imbrication in this zone that created the appearance of a difference where none exists.

Also at the Gatesburg and Waynesboro levels, the interpretive markings on M-27 have smoothed through unmistakable seismic signatures of major basement discontinuities including a major basement fault at the trailing edge of the anticline.

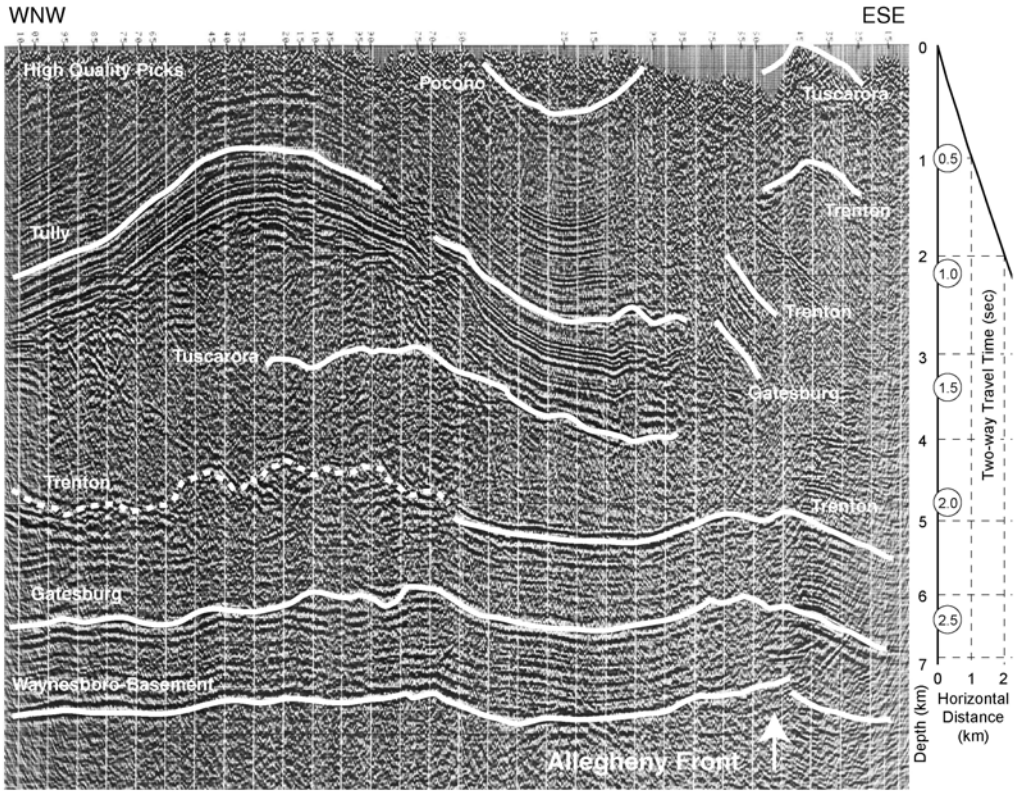

Figure 6. Prominent seismic reflections that correlate with key stratigraphic horizons on seismic profile DP-25 (migrated-time section).

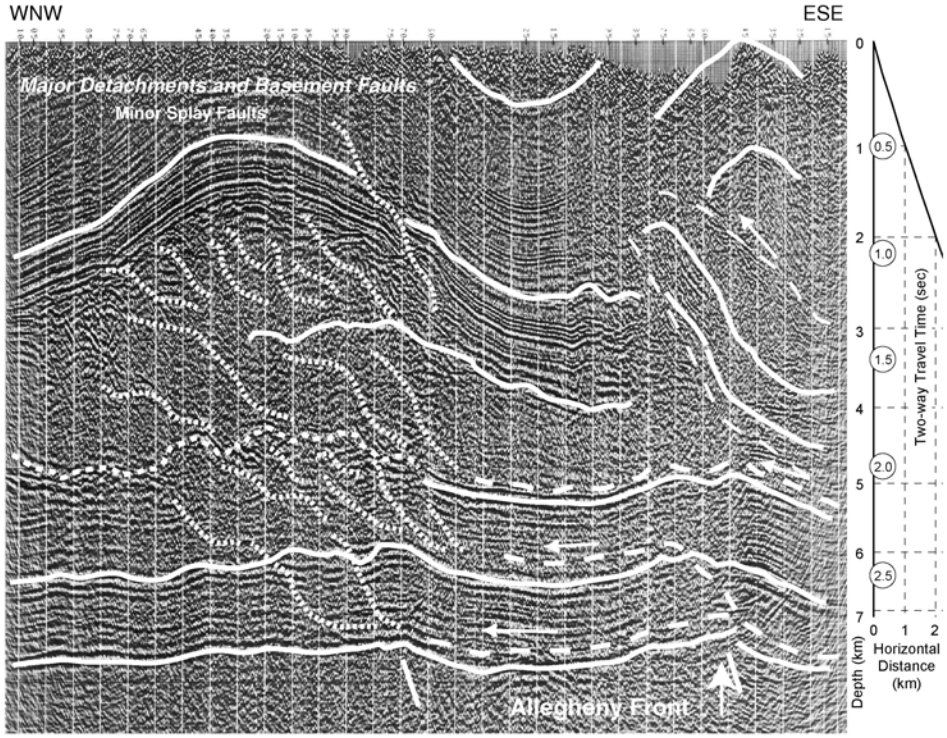

Figure 7. Final geological interpretation of the structural elements on seismic profile DP-25 (migrated-time section).

In summary, high-resolution seismic images confirm that Deer Park anticline exhibits an architecture that more closely resembles the Valley and Ridge structural pattern but differs in that tectonic imbrication and duplexes are stacked independently at the Tuscarora, Trenton, and Gatesburg levels as a result of a dramatic decrease in tectonic transport in moving from the structural front to the more foreland anticlines of the Appalachian Plateau. This architecture contains structural elements that reflect an initial transition from the fault-related folds of the Valley and Ridge to the three-tiered tectonic model of Plateau anticlines. A more mature transition is exhibited at Negro Mountain anticline, the Plateau anticline immediately west of Deer Park (Figures 1 and 8). Here the east flank of the anticline shares the architecture described above for Deer Park whereas the west flank of the anticline exhibits the three-tiered model architecture (Scanlin and Engelder, 2003) that is fully expressed beneath Laurel Hill anticline, the Plateau anticline immediately west of Negro Mountain (Figures 1 and 2).

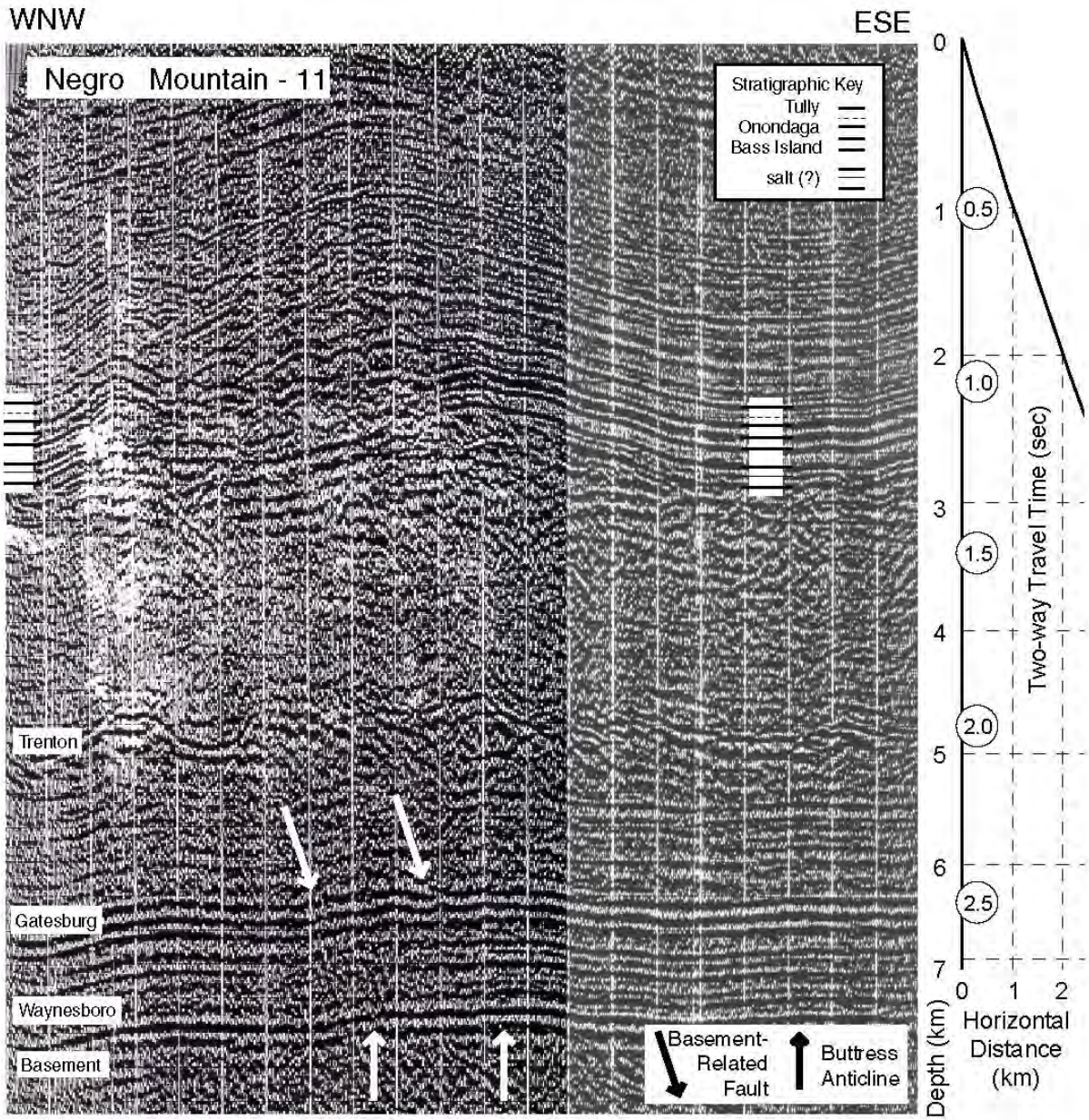

Figure 8. Thrust imbrications at the level of the Trenton horizon and basement-related faults on seismic profile NM-11 across Negro Mountain anticline (see Figure 1 for location). Approximately 3:1 vertical exaggeration.

ALLEGHENY STRUCTURAL FRONT

The east flank of Deer Park dips ESE into a broad relatively undeformed syncline, the Georges Creek syncline that strongly resembles other undeformed synclines between Plateau detachment sheet anticlines to the west. This recurrent structural feature between Plateau anticlines is the structural signature that ultimately led to the recognition of basement faults as the nucleation mechanism in the growth of detachment sheet anticlines (Scanlin and Engelder, 2003). Here, beneath the Allegheny structural front, we encounter perhaps the preeminent Appalachian basement fault with a structural relief in excess of 700 meters. Structural displacement that persists through the Trenton horizon suggests recurrent activity along this fault zone. Intense deformation of the overlying stratigraphic section is testimony to its potential as a nucleating mechanism for the development of tectonic imbrication of the overlying stratigraphic section.

The structural elements present above the fault-related disturbance at the Trenton level exhibit the classic architecture of a fault-propagation fold (Figure 4). Based on the seismic signature correlated with various stratigraphic marker horizons (Figure 6) and the dip of these units, we interpret the arrangement of stratigraphic units displayed to represent the upper portion of two stacked fault-propagation folds. Keeping in mind that the seismic sections are plotted with a 3:1 vertical to horizontal exaggeration, the dip on the beds portrayed in these fault-propagation structures is approximately 30 degrees. Therefore, the structural arrangement of the units and the dip of the beds are consistent with the mechanical constraints associated with fault-related structures. Our interpretation also suggests the strong possibility of the major detachment climbing from Cambrian Waynesboro Shale into the Ordovician Reedsville Shale, thereby facilitating the tectonic transport of the Upper Ordovician-Silurian section across the structural front and carried by imbrication systems into the core of Deer Park. Therefore, the first structure west of the Allegheny Front in the Plateau province displays architecture more akin to structures in the Valley and Ridge. Whereas the typical Valley and Ridge structures are duplexes that involve the entire Cambro-Ordovician carbonate section with a passive roof thrust, the first structure to the northwest of the Allegheny front shows considerable imbrication of the Upper Ordovician-Silurian section in the core of the anticline.

Consistent with our basement tectonic model for Plateau structures to the WNW, structures developed along the Allegheny Front appear to follow and be localized by basement features. The lack of structural continuity at all levels indicates foreland structural transport at all levels. In addition structures on either side of the Allegheny Structural Front exhibit some architecture characteristics consistent with sibling adjacent structures within both the Valley and Ridge and the Plateau.

CONCLUSIONS

Our model for the Allegheny front is consolidated and expressed most effectively by a schematic cross-sectional diagram through the region (Figure 9). Our cross-section begins in the WNW at the first three-tier model, detachment sheet anticline of the Plateau province, Laurel Hill anticline, and progresses ESE through the Plateau anticlines of Negro Mountain and Deer Park and ends at the Valley and Ridge structures of the Allegheny structural front. The two hinterland anticlines of the Plateau (i.e., Negro Mountain and Deer Park) together with the fault-related fold at the Allegheny structural front collectively constitute the Plateau climb-out zone (Figure 9).

Several significant and recurrent architectural themes emerge from an examination of these structures. First, the three structural features that comprise the Plateau climb-out zone are developed immediately above significant basement faults. These basement discontinuities exhibit structural relief that ranges from 300 m at Negro Mountain to > 700 m at the Allegheny structural front. Progressing from east to west the structural elements common to Valley and Ridge architecture evolve in phases through the development of structures across the Plateau climb-out zone into the architecture common to Plateau anticlines further toward the foreland. The passive Siluro-Devonian roof thrust of the climb-out zone evolves into the three-tier structural architecture on the west flank of Negro Mountain. The active Cambro-

Ordovician section common to the climb-out zone is left behind in the floor of Appalachian Plateau detachment sheet beneath Laurel Hill anticline and further to the foreland.

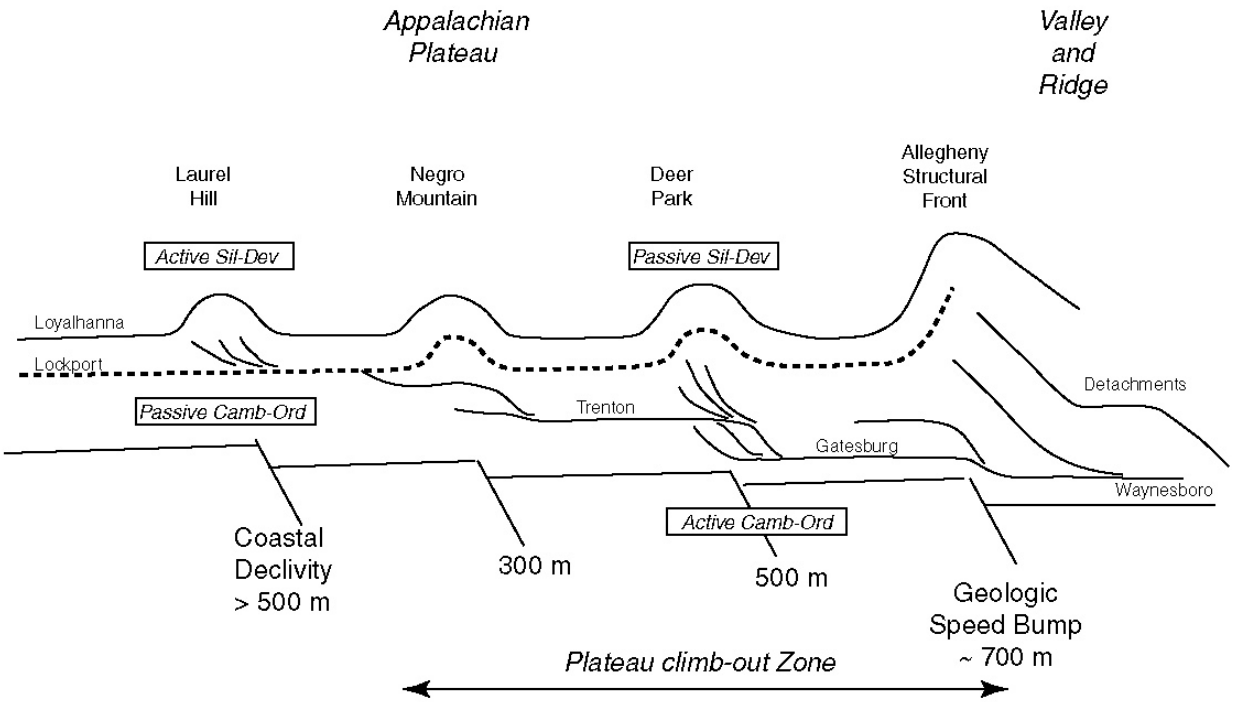

Figure 9. Model for the Plateau climb-out zone between the Allegheny structural front and the Laurel Hill anticline.

In summary, the evolution of the Plateau climb-out zone facilitated the reduction in tectonic transport across the Allegheny structural front relative to transport in the Valley and Ridge during the Allegheny orogeny. High-resolution seismic imagery accurately delineates the remarkable periodic occurrence of major basement faults or 'geologic speed bumps' that are, indeed, responsible for suppressing tectonic transport toward the foreland.

APPENDIX 1

Data Sources

Our analysis of the Deer Park anticline and Allegheny structural front is based on a high-resolution seismic reflection profile 26 km in length acquired by Amoco Production Company in the mid 1980's (Fig. 1). The seismic line traverses the structures being evaluated across strike from WNW to ESE. Geophysical well log information and a velocity survey from the P.N.G. Eberly and Snee, Mowery #1 exploration well, drilled to a depth of 2828 m, provided critical stratigraphic information for the correlation of seismic reflection data and stratigraphy. The seismic data utilized in this study are 24-fold CMP post-stack migrated time sections recording 4 sec of two-way travel-time that yields a penetration depth in excess of 8 km, well below the base of the Paleozoic strata. The data have a temporal sampling interval of 4 msec and a horizontal spatial sampling interval of 45.7 m. Recording instrumentation used in data acquisition was a 48 trace cable system deployed in a split spread configuration with a long offset of 2400 m. Record filters had a low frequency cutoff of 18 Hz and a high frequency cutoff of 90 Hz. The energy source used in acquisition was an explosive source that consisted of single shot holes drilled to a depth of 15 m and detonated using 44 kg explosive charges. The processing stream has maximized signal to noise and migration image quality through pre-stack deconvolution, refraction statics, surface consistent reflection

statics, velocity analysis/normal moveout correction, residual statics corrections, residual normal moveout corrections, CMP stacking, time-variant band pass filtering, and wave equation migration. Final data are presented as standard seismic profiles displaying horizontal distance and vertical two-way reflector time corrected to a horizontal datum 485 m above sea level. The seismic profile display scale shows a vertical to horizontal exaggeration of approximately 3:1 to facilitate visual perception of the very broad, low relief structures characteristic of the plateau. Stratigraphic interval thickness was calculated using interval velocities that were specific to individual stratigraphic units. These interval velocities were derived from a combination of sonic logs and velocity analysis software.

Well logs for our analysis are archived at the Oil and Gas Division of The Pennsylvania Topographic and Geologic Survey in Pittsburgh, Pennsylvania (e.g., Heyman, 1977). Several key geophysical well logs for each well were utilized for stratigraphic correlation and seismic interpretation. The gamma ray log is primarily used to correlate lithology between individual boreholes. Sonic and density logs define an impedance record from which the synthetic seismograms are calculated.

Resolution Limit in the Seismic Data

Seismic resolution of structural features is dictated by the signal-to-noise level and frequency of the seismic data combined with the knowledge and experience of the interpreter. Vertical resolution is controlled by the frequency of the seismic signal that decreases with depth, resulting in a depth variant decrease in resolution. Horizontal resolution is more difficult to quantify but is strongly affected by the signal-to-noise level of the data and the horizontal sampling interval. Conventional limitations on seismic resolution can be overcome to some extent when a structural model, consistent with the mechanical behavior of the stratigraphy, is used to guide the seismic interpretation process.

The majority of the seismic signal in the Upper Devonian interval is 35 Hz, providing a conventional vertical resolution of 33 m; the Lower Devonian interval is traversed by seismic wavelets in the 25-30 Hz range yielding resolution of 42 m; and the Cambro-Ordovician section is imaged by 20 Hz energy with a resolution of 56 m. Average velocities used for time to depth conversion can be calculated using the Depth-Horizontal Distance Chart (Figure 2). The conventional limits set forth above pertain to the vertical resolution of stratigraphic layering. Vertical faults offsetting flat-lying strata can be detected at one-half of the above interval, whereas shallower dipping faults have somewhat lower resolution. The necessary and sufficient condition for recognition of features in the horizontal domain is two samples per apparent wavelength. The majority of this seismic data set has a subsurface sample interval of 50 m and therefore represents the smallest feature resolvable in the conventional sense. Even though many smaller structures in the Upper Silurian and Lower Devonian are below the conventional limits of resolution, our experience from drilling and outcrops of similar structure guides our interpretation.

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RADARGEOLOGICAL MAPPING IN THE RIDGE AND VALLEY PROVINCE, SOUTH-CENTRAL PENNSYLVANIA

by

Robert J. Altamura

INTRODUCTION

This paper reports the results of a radargeological-mapping project in the Ridge and Valley physiographic province in south-central Pennsylvania using side-looking airborne radar (SLAR) imagery. This mapping technique, supplemented by field checking, generates geological maps of sizeable areas. In addition to geologic units, it has been shown to be of value for mapping faults and lineaments (Altamura, 1985; Altamura and Quarrier, 1986; Altamura and Gold, 1992; Altamura, 2000). In the Mesozoic basin of central Connecticut, it was possible to apply radargeological mapping to the stratigraphy in the non-metamorphosed Newark Supergroup using SLAR imagery. However, it generally did not apply to the highly metamorphic terranes elsewhere in the state.

Subsequently, work in the folded sedimentary terrane here in the Valley and Ridge province of Pennsylvania, demonstrated that SLAR images were useful in tracing lithologies over considerable distances, subdividing previously undifferentiated stratigraphic intervals, and in identifying and mapping structural discontinuities. This technique promises to be applicable not only in geologic mapping, but also in water and oil and gas exploration in this terrain.

Geological Setting

The study area includes Ridge and Valley portions of the Bedford, Everett, and Hollidaysburg 15-minute quadrangles (Figure 1). Exposed in the region are folded and faulted Paleozoic sedimentary units ranging in age from Cambrian to Pennsylvanian. To the west, this area is adjacent to the mildly deformed Appalachian plateaus containing sedimentary units ranging from Devonian to Permian in age. Together, these terranes comprise the Appalachian foreland basin or foredeep. The Cincinnati arch defines the western margin and its eastern margin is buried beneath thrust sheets of the Piedmont in southeastern PA. Figure 2 illustrates the outline of the entire Appalachian basin (from Milici and De Witt, Jr., 1988).

The Appalachian foreland basin originated as an extensive, water-filled sedimentary basin that formed on the continent-side of a fold-thrust belt as part of Appalachian mountain building. Foreland basins form due to material thrust onto the continental plate, resulting in a terrane commonly referred to as the fold-thrust belt (FTB). The FTB is the geological terrane in which upper crustal shortening is accommodated by the development of a system of thrust faults and related folds in allochthonous cover rocks separated from autochthonous rocks by regional décollement ("thin-skinned tectonics" of Rodgers, 1949). The allochthonous cover rocks comprise a ductile layer, mostly sandstone, siltstone, and shale units, and an underlying stiff layer, principally carbonate units. Anticlines resulted from the imbricate stacking of carbonate units by ramping thrust faults, and synclines formed in the intervening regions. Folds developed in this manner are referred to as fault-bend folds (e.g. Hatcher, 1995, p. 208). As a result of the thin-skinned tectonics and differential erosion, the surface expression of fold limbs and noses is usually well defined by resistant orthoquartzite, sandstone, and siliceous and cherty carbonate ridges with intervening valleys underlain by shale and carbonate units (Figure 3). These are the structures and strata that were interpreted using the SLAR data.

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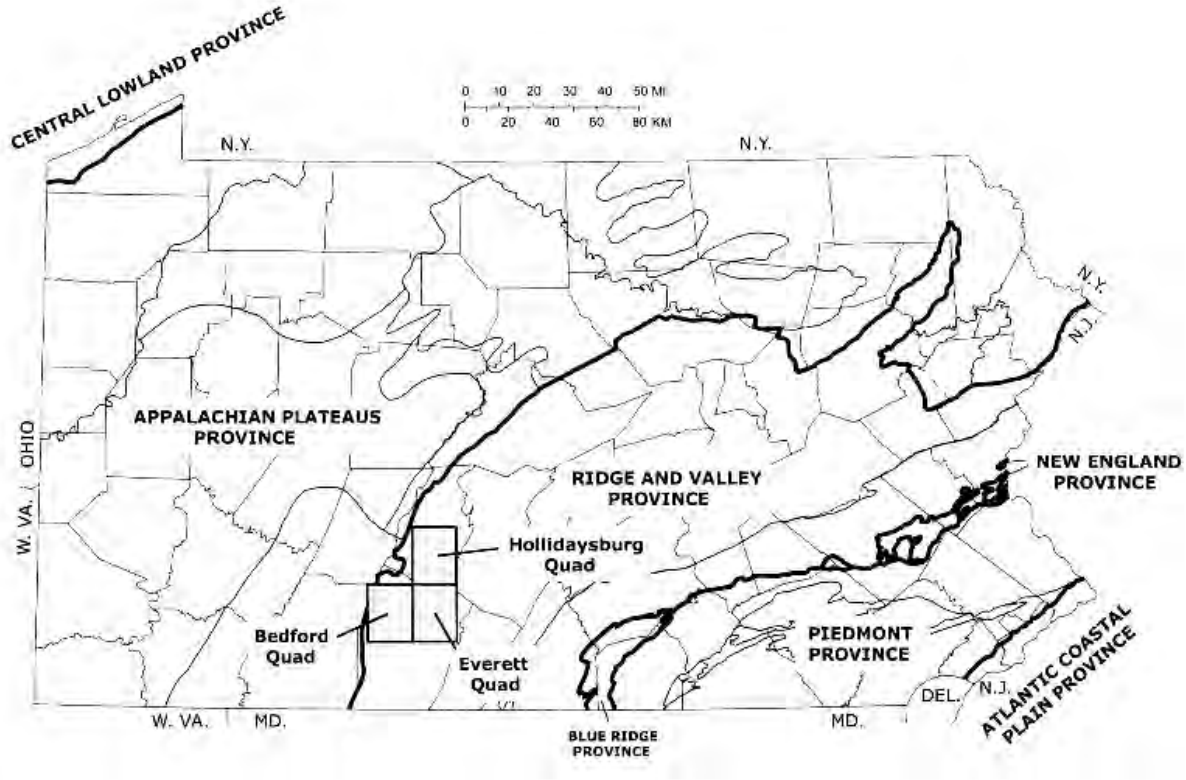

Figure 1. Map indicating the locations of the Hollidaysburg, Everett, and Bedford 15' quadrangles (shaded rectangles), the areas of radargeological study by the author.

Methodology Employed Using SLAR Imagery

Imagery used for this study was obtained from Motorola Airborne Remote Sensing (MARS) and the U.S. Geological Survey (U.S.G.S.). SLAR data, from which the imagery was prepared, was acquired by transmitting a radar beam perpendicular to the ground track of the aircraft. The result of this process is an illuminated view of the land that enhances subtle surface features and facilitates geological interpretation. SLAR is an active system that provides its own source of illumination in the form of microwave energy; thus, imagery can be obtained either day or night. And, because SLAR penetrates most clouds, it can be used to prepare images of cloud-covered areas as well.

Radargeological mapping involves the interpretation of geomorphology, structures, and lithologies using radar imagery stereoscopically and monoscopically. Stereo strips and a composite (base map) image were prepared from the synthetic aperture radar data by MARS (Everett quad) and the U.S.G.S. (Hollidaysburg and Bedford quads). Lithologies and structures (i.e., faults, lineaments, etc.) were compiled on a transparent overlay registered to SLAR strips at 1:250,000 scale. This information was then transferred to a second clear overlay atop the SLAR mosaic base map, and that overlay became the radargeological map. Selected interpretations were then field checked for accuracy. SLAR images incorporate some aberration effects as a result of computer compilation of the energy data. Consequently, the final radargeological map of the Everett 15-minute quadrangle was corrected to a U.S.G.S. topographical base map. The position of lines on the final map is believed to have a maximum error of less than 15 m.

Figure 2. Generalized geologic map of the Appalachian basin along the eastern coast of North America (from Milici and de Witt, Jr., 1988).

Geologic lines bounding the radargeological units and structures were digitized in the laboratory of Dr. Eric Warner, Office of Remote Sensing of Earth Resources (ORSER), The Pennsylvania State University. Digitized geologic data are registered to both the SLAR images and to digital U.S.G.S. topographic base maps (Digital Raster Graphics or DRGs).

RADARGEOLOGICAL INVESTIGATION IN THE PENNSYLVANIA RIDGE AND VALLEY

Geological mapping using SLAR in Pennsylvania began with the Everett 15-minute quadrangle (scale 1:62,500), Pennsylvania. The Ridge and Valley physiographic setting was ideal for using remote-sensing techniques to map stratigraphy and structure. Dr. John Gardner of Motorola Airborne Remote

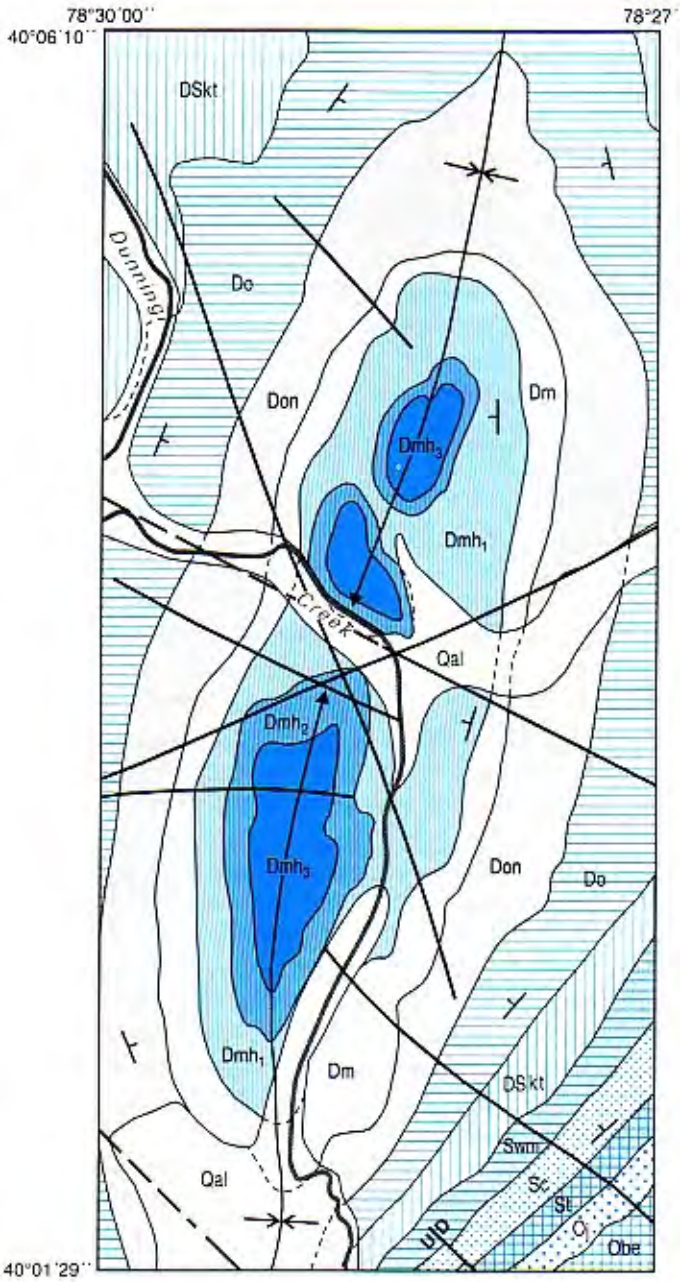

Figure 3. Radargeologic map of a portion of the Everett West 7.5' quadrangle. Explanation is provided in Field Trip B in the Appendix of this guidebook.

Sensing (MARS) provided a SLAR base map of the Everett 15 minute quadrangle and guidance. Using textural, tonal, and topographic variations, geologic units were interpreted and delineated on an overlay (Figure 4). In general, depending on vegetation and land-use, ridges and topographic highs were interpreted as being underlain by coarse-grained clastic units (e.g., conglomerates and sandstones), slopes underlain by shale units, and valleys underlain by carbonates (limestone and/or dolostone). The distribution of a particular unit was traced throughout the quadrangle and integrated with the other units.

The structural attitudes of particular formations and fractures were deduced using classic morphotectonic inferences (as in field mapping) of "v" patterns at stream intersections with unit contacts or trellis drainage patterns. Structures are inferred from the attitude of stratigraphic units. Mirror-image repetition of the same bed across strike implied folds, whereas, lateral offsets of radargeologic units along linear valleys implied faults. Movement sense of the horizontal component (right- or left-lateral) can be determined for these faults assuming essentially strike-slip motion.

Most units on the radargeological maps prepared as part of this investigation correspond to units on the Geologic Map of Pennsylvania (scale 1:250,000; Berg et al., 1980). However, for the Devonian interval, the more detailed information provided by the Stratigraphic Correlation Chart of Pennsylvania (Berg et al., 1986) aided in correlating between the radar units and previously mapped stratigraphy. Five radargeological units were recognized corresponding to the interval designated as undifferentiated Devonian Hamilton Group (e.g. Berg et al., 1980; Altamura and Gold, 1992). These units permitted the subdivision of this interval (Figure 5). Field work revealed that these radargeological units represent repeating, coarsening-upward marine cycles defined by sequences of shale (Dm_1, Dmh_1, Dmh_3, Dmh_5) and siltstones/sandstones with minor fossiliferous coquinites and structure-less marls (Dmh_2 and Dmh_4).

Figure 4. SLAR image of the Frankstown structural basin showing examples of interpreted geologic contacts (just below the center of the image). (North is to the top; width is approximately 30 km.)

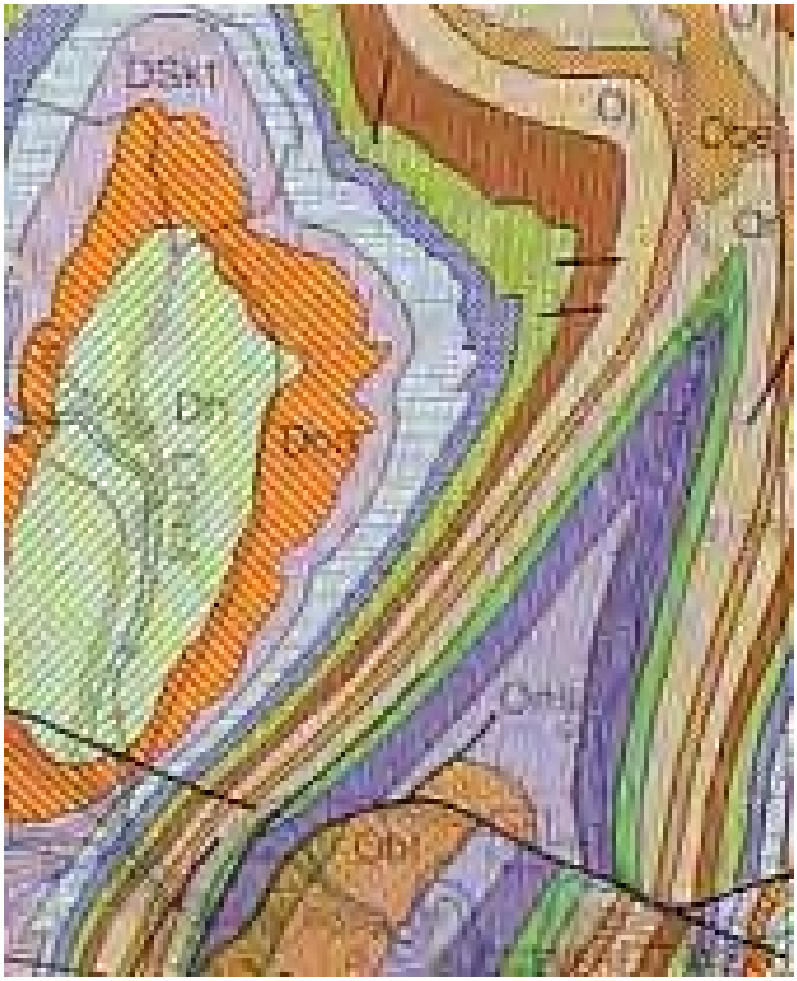

Figure 5. Portion of the Geologic Map of Pennsylvania showing the core of the Everett structural basin. (Devonian Hamilton Group undivided = Dh; Old Port and Onondaga formations = Doo) Compare with Figure 3.

The base of Dm_1 is a slope-maker and relatively well-exposed. Its physical characteristics are consistent with the Middle Devonian Marcellus Formation. Radar units Dmh$_1$ through Dmh$_5$ correspond with depositional cycles previously recognized in the Middle Devonian Mahantango Formation (Dennison and Hasson, 1976; Duke et al., 1991). Beneath Dm$_1$ is bedrock that underlies a valley between outcrops of the Marcellus Formation and a ridge underlain by the Ridgeley Member of the Lower Devonian Old Port Formation. This valley is interpreted as being underlain by the Onondaga Formation, based on stratigraphic sequence and topographic expression. The floor of a borrow pit in this area reveals abundant fragments that probably represent the Needmore Shale, a member of the Onondaga Formation. This area is designated as *Don* on the radargeological map (e.g. Figure 3).

Radargeological investigations in the eastern part of the Everett 15-minute quadrangle revealed N-S trending belts that consist of ridge-making and slope- and valley-forming units. Field checks show the former to be dominated by sandstone/conglomerate and the latter by siltstone/shale redbeds. These radar units underlie land that has been mapped on the state map as the Devonian Foreknobs and the Catskill formations.

Radar faults and lineaments are interpreted where the radar expression of units shows clear offset of radar stratigraphy, in spite of lack of exposure for field confirmation. Of particular note is the Everett-Bedford lineament (EBL) (Abriel, 1978; Gold et al., 1978) of which ~40 km of its ~100 km length is present in the Bedford and Everett 15' quadrangles. The apparent abrupt termination of the Broad Top syncline in the eastern portion of the Everett East 7.5' quadrangle may be related to its alignment with this lineament. A similar situation exists immediately north of the Hollidaysburg 15' quadrangle where the elongate northern nose of the Frankstown structural basin (that constraining Beaverdam Valley) is apparently truncated by the Tyrone-Mount Union lineament. Kowalik and Gold (1976) suggested that lineaments defined by alignments of abruptly plunging ends of long, continuous folds within the Ridge and Valley are due to structures within the cover rocks. On the other hand, Southford (1986) has identified the EBL as a cross-strike structural discontinuity with an origin in the basement.

The lineaments (and fracture traces) in the study area are potential targets for ground-water supplies (e.g., Lattman and Parizek, 1964). At locations where two or more lineaments intersect, such as in the central part of the map area, there is added likelihood for ground-water resources. The use of lineaments has also been advanced for gas exploration in Devonian shale units (Wheeler, 1980; Southward, 1986) elsewhere in the central Appalachians. Potential targets for gas exploration exist in the southeastern part of the Everett 15' quadrangle and the southeastern part of the Bedford 15' quadrangle map where the Everett-

Bedford lineament transgresses Devonian shale units. A potential target area in the Hollidaysburg quadrangle exists in the northeastern portion where the Canoe Valley fault transgresses the Middle Devonian black shale units. Both ground-water prospecting and gas exploration rely on the assumption that lineaments represent fracture zones, and high fracture permeability is expected.

CONCLUSIONS

Side-looking airborne radar (SLAR) imagery is a useful tool for discriminating lithologies and structures that are manifest by changes in slope and tonal variations in vegetation. SLAR images are particularly useful in geologic mapping in sedimentary terranes (e.g., the Newark Supergroup, CT, and Ridge and Valley, PA). Previous work by the author using SLAR in Connecticut permitted recognition of previously unmapped structures and provided new interpretations of the geology.

Radargeological work in the Ridge and Valley Province of Central Pennsylvania resulted in some refinement to the local geology based on new interpretations and field checking. The Hamilton Group and the Brallier, Harrell and Sherr formations were subdivided into lithofacies that correlate to the published stratigraphic column for south-central Pennsylvania. Because these lithofacies are cyclic, coarse- and fine-grained clastic rocks, their alternating slope aspect allows them to be distinguished as radargeological units that are mappable over considerable distances. These radarstratigraphic units correlate throughout the Bedford, Everett, and Hollidaysburg 15' quadrangles, and they appear to be transportable to other areas in the Ridge and Valley province. Lineaments and fracture traces identified on SLAR imagery within the study area are potential targets for ground-water resources, and where they transgress Devonian-age shale, may be targets for natural gas exploration.

The *Radargeological Map of the Everett 15-minute Quadrangle* in digital form is planned to be included on the conference CD ROM. *Radargeological Maps of the Valley and Ridge portion of the Bedford and Hollidaysburg 15-minute quadrangles* is in preparation. The general success of the radargeological-mapping project in the Ridge and Valley encouraged additional mapping in this terrane. New lithofacies, identified during these investigations in Pennsylvania, may prove to be regionally correlated to other areas elsewhere in the Appalachians. Future radargeological investigations in the Ridge and Valley province will target areas underlain by Middle Devonian strata because of the possibility to identify potential gas reservoirs where fractures transgress black shale units such as the Marcellus Formation.

ACKNOWLEDGEMENTS

Radargeological mapping in Pennsylvania has been conducted in cooperation with the Geologic Mapping Division of the Pennsylvania Geological Survey. I am particularly grateful to Survey geologist Dr. Jon Inners for his continued encouragement and support. Radar mapping in the Everett 15' quadrangle was funded initially by the Connecticut Geological and Natural History Survey. Dr. D. P. Gold, The Pennsylvania State University, took a particular interest in the project and provided encouragement and suggestions as to the nature of the physical interactions of the radar incident beam with rocks and soils. Drs. D. P. Gold and A. G. Doden reviewed the original manuscript. J.H. Way did substantial editing for the final version.

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Lead and Zinc in Central Pennsylvania

by

Robert C. Smith, II, Pennsylvania Geological Survey

INTRODUCTION

As noted elsewhere in this guidebook (Way, 2003), lead was mined in southern Sinking Valley as early as 1778. Miller (1924, p. 13-14), for example, notes:

> 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 [Figure 1]. 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. Several letters from General Roberdeau and others concerning these operations are in the Pennsylvania Archives, (First Series) especially in Vols. 6, 7, and 8. At one time 1,000 pounds of lead was sold to the State at $6.00 a pound in the depreciated currency of the 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 laborers in the Wilderness, as it was called, and the guards that were necessary on account of hostile Indians.

Reports about interactions between early colonists, Native Americans, and lead and silver abound. Eckman (1927), Price, L.F.D. (1947), and Loose (1972) fairly well document enslavement of Conestoga tribe Native Americans by Thomas Penn, son of the Proprietor, to work lead-silver mines in the Pequea and Burnt Mills areas of Lancaster County.

A widespread genre of reports about lead in central Pennsylvania survived into the late 1960s. The basic theme of these fanciful stories is that an early colonist provides a service or rescue for a Native American. As a means of showing gratitude, the Native American leads the colonist blindfolded to an outcrop where pure natural lead can be cut or carved from the rock. The colonist collects for a day, is blindfolded again, and conducted safely back home. The crafty colonist, of course, isn't satisfied with a day's production and leaves red threads or breaks twigs on the way home. When he tries to relocate the lead deposit, he finds that the even craftier Native American has left scores of red threads or broken twigs in all directions (Richard Hammon, personal communication, 1973). Rather interestingly, some of those who passed on the genre were skilled amateur prospectors. Richard Hammon's father, Peter, *z.b.*, did some skilled lead prospecting at Silver Mine Knob, Huntingdon County, which wasn't rediscovered by geochemists until the late 1960s (Smith et al., 1971).

At $6.00 per pound, lead produced from the Fort Roberdeau area is likely the highest unit value mineral resource ever produced in central Pennsylvania. Interest in zinc was slower to develop but continued at least into the 1980s when a major corporation unsuccessfully attempted to lease the area of the old Soister Iron Mine (Smith, 1978, p. 120-124).

MINERALIZATION IN SINKING VALLEY

Minerals found in the Sinking Valley area include: the Pb species galena, anglesite, cerussite, and jordanite; the zinc species sphalerite, hydrozincite, and smithsonite; and the gangue minerals barite and dolomite. It is generally thought that only galena was recovered in the area of Fort Roberdeau and only

Smith, R. C., II, 2003, Lead and zinc in central Pennsylvania, *in* Way, J.H. and others, eds., Geology on the edge: selected geology of Bedford, Blair, Cambria, and Somerset Counties, Guidebook, 68th Annual Field Conference of Pennsylvania Geologists, Altoona, PA, p. 63 – 72.

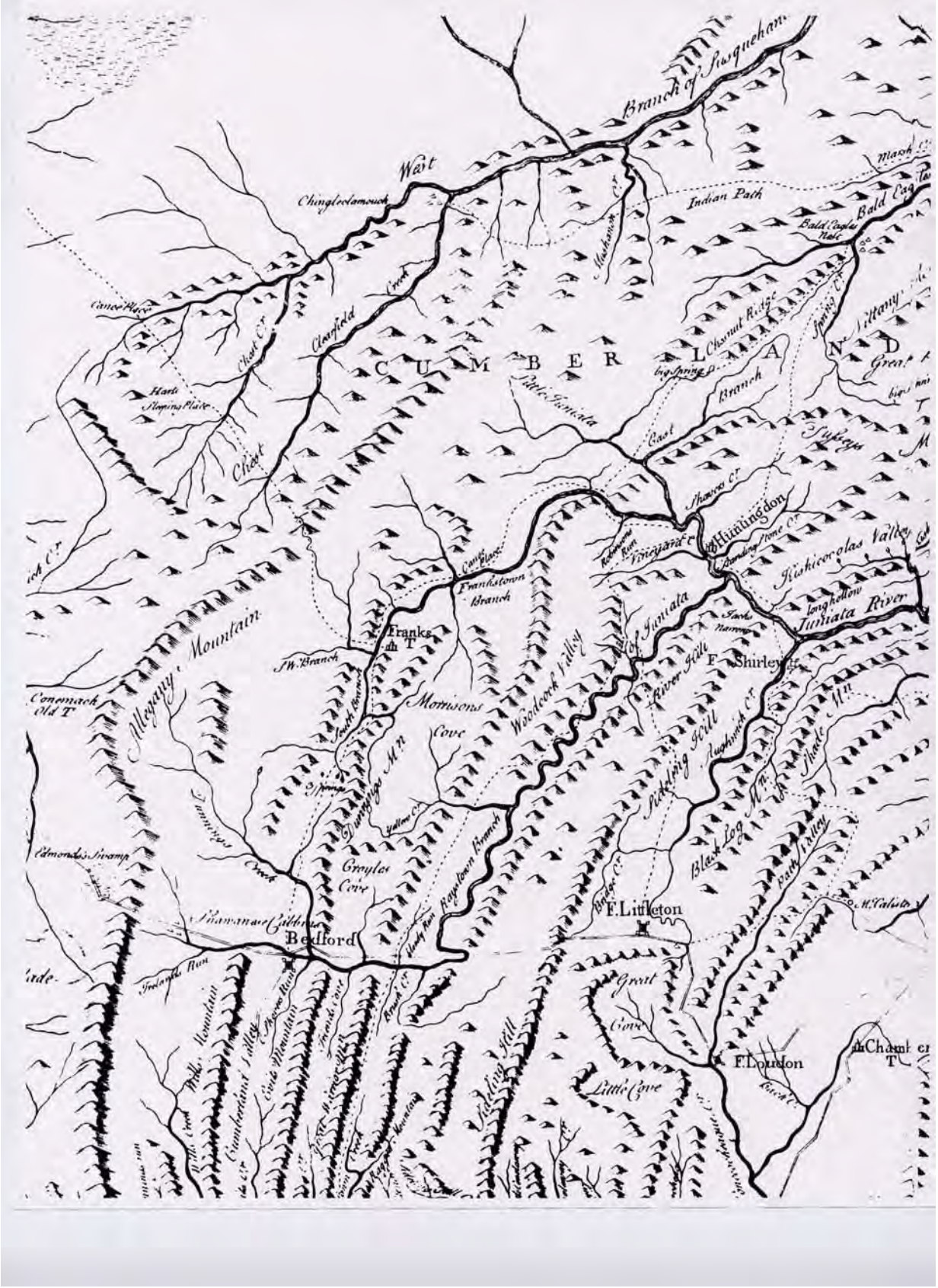


Figure 1. Early map of the Sinking Valley area NNE of Franks T and NW of Huntingdon. Forts Littleton, Loudon, Shirley, as well as a fort at Bedford shown, but Fort Roberdeau not yet built (Scull, 1770).

sphalerite in the Keystone Mine of northern Sinking Valley. Core drilling by the New Jersey Zinc Company yielded some zinc ore intercepts beneath the Keystone Mine (Noel Moebs, personal communication, circa 1960). Rose (1999), in his overview of lead and zinc in Pennsylvania, estimated a production from Sinking Valley of 3,500 tons of ore having a combined grade of 12% zinc plus lead.

Figure 2 (Smith, 1978, Figure 49) shows the locations of some of the then-known mines, prospects, and significant occurrences in southern Sinking Valley. Locations A through G were mines relocated as of 1976; whereas, H through N were reported, but unlocated. The Bellefonte Formation dolomite contact with the overlying Milroy Member of the Loysburg interbedded limestone and dolomite is approximated in Figure 2, but more accurately located in Plate 1 of Faill et al. (1989). Using the locations on Figure 2 and Faill et al.'s geology, the occurrences in southern Sinking Valley appear to be hosted in dolomites and dolomitic limestones from the upper Bellefonte Formation up to the Snyder Formation. In northern Sinking Valley in the Keystone Mine area, significant mineralization is located in Upper Cambrian Mines dolomite, Lower Ordovician Larke-Stonehenge dolomite-limestone, and at the Keystone Mine itself, limestones, possibly from as high as the Snyder or even Linden Hall formations.

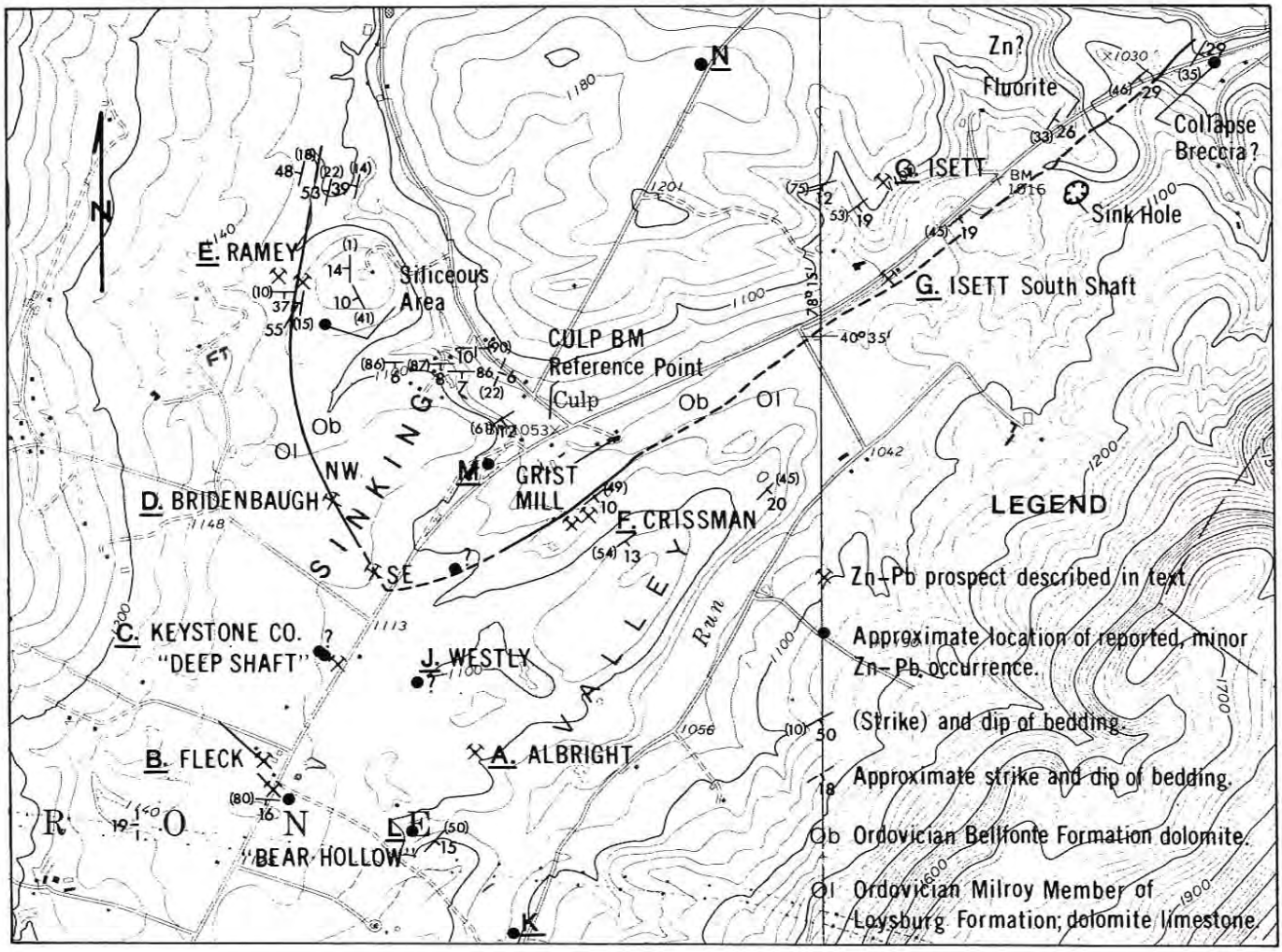


Figure 2. Zn-Pb mines, prospects, and significant occurrences in southern Sinking Valley from Smith (1978, Figure 49). See Plate 1 of Faill et al. (1989) for more accurate geology.

Except for a few, less brittle limestone beds observed in the Keystone Mine that were richly replaced by sphalerite and galena, nearly all of the ore in Sinking Valley is in open spaces in brittle fault breccias (A. W. Rose, personal communication, 1975). The vein-faults at the Fleck occurrences trend N48W, those at Bridenbaugh N30W and the Albright Mine may be on the extension of this latter fault. However, Reed

(1949, p. 5) found that at least one vein at the Albright Mine had a strike of nearly east and dipped 80 to 85 degrees to the north.

Based, in part, on the deformation of main stage galena from many prospects in central Pennsylvania, it can be reasonably hypothesized that such lead-zinc mineralization is a product of the Alleghanian orogeny. It is proposed herein that saline fluids that transported the metals were expelled from shaly units such as the Antes Member of the Reedsville Formation as a result of the Alleghanian orogeny. These fluids migrated along a northwest-trending zone (Smith et al., 1971) and other structures in upper Ordovician and lower Silurian clastics, and were deposited where the transporting saline fluids encountered pyrite of sedimentary origin in black shaly interbeds in the Tuscarora or in pyritic algal mats in the sabka facies of the Tonoloway Formation or possibly the Milroy Member of the Loysburg Formation. Where the fluids became oxidized or encountered sulfate-bearing ground water, barite also precipitated. This latter was very fortunate for early lead prospectors as barite associated with the galena in Southern Sinking Valley provided a nearly indestructible, readily recognized residue. Early settlers were used to the concept of "tracking" and it would have only been a small leap for them to have become Pennsylvania's earliest exploration geochemists.

From several other data sets, the maximum heating and subsequent cooling associated with the Alleghanian orogeny can be established. From laboratory studies of sphalerite and galena samples, the temperature of formation of lead and zinc mineralization can be determined. As shown below, an Alleghanian cooling curve can be combined with the temperature of formation of sulfides to estimate the time of formation of the lead and zinc deposits for Southern Sinking Valley and central Pennsylvania in general (Smith and Faill, 2000). Still other data sets establish a gentle, Mesozoic Thermal Pulse (MTP of Smith and Faill, 2000) that reheated the Sinking Valley area and far beyond, possibly to Montmorency Falls, Quebec. The MTP also helps explain the origin of zinc-lead-copper veins in southeastern Pennsylvania (Smith, 1977).

Logically, these same thermal histories and fluid movements also controlled oil and gas generation and migration. Indeed, it is possible for two blind men to hold different parts of the same elephant. Below follows a somewhat simplified version of a portion of Smith and Faill (2000) which they plan to update.

ALLEGHANIAN UNLOADING

In the past two decades, a wealth of data has been obtained in central Pennsylvania from thermal history indicators such as fission track annealing, vitrinite reflectivity, and various measures of hydrocarbon maturity. Michael L. Hulver's (1997) thesis, for example, is a *tour de force* compilation, recalibration, and interpretation of such data, and is highly recommended. However, for purposes of developing a simple model, those data may be overwhelming.

In contrast, Mary Roden Tice (in Way, Smith and Roden, 1986, and Roden and Miller, 1989) created an elegantly simple fission track data set for apatite crystals for the Ridge and Valley of Pennsylvania. These she separated from Tioga Ash Bed B using samples supplied by J. H. Way and the present author . These apatites were carefully collected from channel samples cut through the 390.0 +/- 0.5 Ma ($^{207}Pb/^{235}U$ date on monazite, Roden et al., 1990) Tioga Ash Bed B in central and eastern Pennsylvania. By making detailed, centimeter-scaled measurements of sections of the Tioga Ash Beds at many localities, Way and Smith found that positive identification of each bed was possible at many localities. Thus, they were assured of sampling the same ash bed at each locality. This identity was confirmed when George H. Shaw et al. (1992) analyzed splits of these same apatites and found them to have notably uniform ratios of La/Tb and Ce/Tb. Thus, Roden and Miller were able to work with a population of synchronously deposited apatite that would likely have minimal variation in composition.

Roden and Miller (1989) analyzed some of the Tioga Ash Bed B apatite samples for Cl. They found a small, but significant fraction: 0.2 for Cl/(Cl + F). Recent research published by Carlson et al. (1999)

included a study of Tioga Ash Bed B apatite from Old Port, PA, presumably from the same ash bed sampled by Way and Smith [confirmed, Ray A. Donalick, personal communication, 2002]. Carlson et al. (1999) found this apatite to contain 0.17 Cl atoms per formula unit and that it was the most resistant to annealing of nine normal apatites they studied (their Figure 3). Various studies have suggested that such moderately Cl-rich apatites are likely to anneal over geologic time at temperatures of ~120ºC. Thus, we now have a simple but elegant tool indicating when the Ridge and Valley had cooled to 120ºC following Late Alleghanian tectonism (circa 278 +/- 6 Ma, Smith and Faill, 1994). Except for areas near the thicker anthracite overthrusts (MacLachlan, 1985), Roden and Miller's Tioga B data show that much of the Ridge and Valley had cooled to 120ºC by the late Triassic. This yields a cooling rate of ~1.6ºC/Ma based on a maximum Alleghanian temperature of 200ºC at 278 Ma and cooling to 120ºC by 225 Ma. Roden's median Tioga Ash Bed B fission track age for samples distant from the anthracite region is 225 Ma, as was shown in Figure 1 of Way, Smith, and Roden (1986).

As inferred below, this cooling rate of ~1.6ºC/Ma likely continued until intrusion of the Quarryville Diabase, perhaps at ~ 205 +/- 5 Ma (?), at which time the temperature in the Ridge and Valley of central Pennsylvania might have been 90ºC. This would imply that normal fluorapatites in the Ridge and Valley would have ***first*** "set" at ~212 +/- 5 Ma.

A significant corollary of this cooling of much of the Ridge and Valley away from the anthracite region to 120ºC by 225 Ma is that the region had a cover of 4.2 km of sediment at 225 Ma. {Closure temperature (120ºC) minus current ambient temperature (15ºC) / geothermal gradient (25ºC/km) = ~ 4.2 km.} This appears to be consistent with Hulver (1997) who shows a maximum of 4 km of cover for this same region using a recalculated CAI (Figure 2.11) calibration and 4 km using coal volatile matter (Figure 3.09). It should also be noted that Lacazette and Engelder (1988) estimated an overburden thickness above the Reedsville shale of 4 km using fluid inclusion pressure estimates for an unspecified location.

Nearer the anthracite region, Roden obtained Tioga B apatite fission track ages as young as 152 Ma. These, as others (especially David B. MacLachlan, Pennsylvania Geological Survey) have suggested, likely represent the additional time required to erode the additional thickness of the anthracite overthrusts and, as discussed below, sediment eroded from the rebounded Mesozoic basins. This is consistent with the work of Orkan and Voight (1985), who reported a depth of ~ 5 km for the western anthracite region using H_2O-CH_4 fluid inclusions in quartz.

Far more complex patterns of Alleghanian unloading-cooling reported by others are believed, in part, to represent 1) variation in the compositions of the apatites studied (possibly including carbonate-fluorapatites) which would have different inherent annealing temperatures, 2) a residuum of significant dates of 141 Ma over a wide area [as discussed under The Mesozoic Thermal Pulse, below], and 3) the chance of a few samples being near hot springs related to deep circulation of meteoric water in a porous sandstone such as the Ridgeley.

SUGGESTED FURTHER ALLEGHANIAN UNLOADING RESEARCH

Carefully collected samples of apatite from other single ash beds should also yield useful, comparably smooth data. The ideal candidate may be Bentonite bed 13 of Smith et al. (1986) at the Union Furnace Section. Warren D. Huff (personal communication, 6/16/92) reports that B13 is likely the Deike K-bentonite of mid-continent terminology and that it is "loaded" with apatite and zircon at Union Furnace. Because Ordovician and Devonian sections are locally quite close to one another, a result of steep folding and faulting, cross calibration or at least comparison of data from the Ordovician and Devonian ash beds should be possible. Because Ordovician outcrops are more widespread and are frequently well exposed in commercial limestone quarries, an excellent data set should be obtainable. Further confirmation of the usefulness of apatites from a single ash bed might be possible by continuing study of the apatite and zircon-rich Bald Hill Bentonite C (Smith, et al., 1988) at the top of the Lower Devonian Helderberg Group. Such a study was begun by Roden and Miller (1989) who looked at two samples labeled "Kalkberg." The apatite in

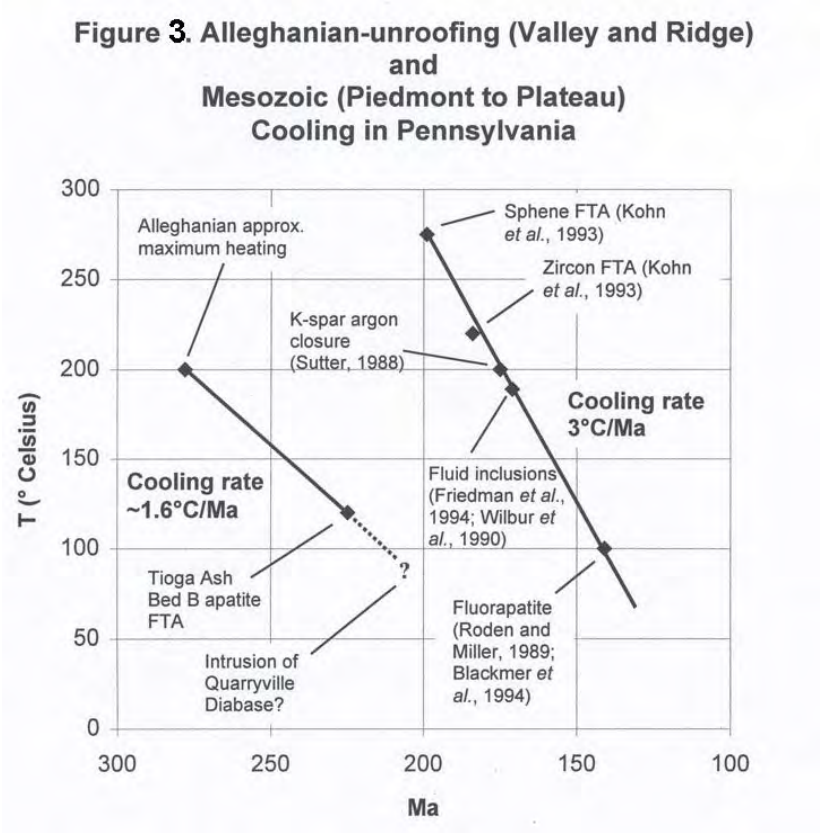
those was also found to have a Cl/Cl+F ratio of 0.2 and yielded apatite fission track ages of 203 and 246 Ma for a mean of 225 Ma. Now approximately 6 additional localities are known for Bald Hill Bentonite C and further study is encouraged. [See also Smith et al., 2003, this guidebook]

Roden and Wintsch (1992) tried to interpret fission tracks in zircons from some of the same Tioga Ash Bed B samples. However, based on the 200ºC Alleghanian maximum temperature for central Pennsylvania (vitrinite reflectivity, M.L. Hulver, 1997, Figure 3.20), it appears that the zircons from most of central Pennsylvania were never reheated to the 225 degrees needed to anneal zircon fission tracks after their original magmatic cooling. The exceptions occur nearer the anthracite overthrusts, where the sections were tectonically thickened more than elsewhere. For this area of zircon resetting, a two-point rate of Alleghanian cooling over the range of ~225º to 120ºC would be quite interesting.

MESOZOIC THERMAL PULSE

Just as the apatite FTA data of Roden provide a key to Alleghanian unloading, so FTA data on sphene and zircon, when combined with a few other small data sets, provide a relatively simple key to a Mesozoic Thermal Pulse (MTP) and rapid cooling. We envision this MTP as being caused by crustal thinning related to initiation of rifting. As always, the MTP and symptomatic diabase intrusions at ~ 200 Ma are the result of radiogenic heat released by decay of K, U, and Th in the mantle. This same heat flow attenuated the crust and provided for an elevated heat flow that extended well beyond the present boundaries of the Mesozoic basins.

The sphene and zircon FTA data were obtained for the Reading Prong, Newark Basin, and Piedmont of Pennsylvania and adjacent Maryland and Delaware by B. P. Kohn, M. E. Wagner, T. M. Lutz, and G. Organist (1993). They concluded that 1) there was a substantial MTP over their study area, 2) that cooling had progressed to a sphene-annealing temperature of ~275ºC by 199 Ma, 3) cooling had progressed to a zircon-annealing temperature of ~220ºC by 184 Ma, but that 4) away from Mesozoic diabase, heating never exceeded ~300ºC, based on lack of argon loss in biotite.



We concur with these conclusions, but note the even more widespread, normal fluorapatite FTA dates representing cooling to ~100ºC by 141 +/-3 Ma obtained by Roden and Miller (1989, 4 of 14 non-ash apatites) and by G. C. Blackmer, G. I. Omar, and D. P. Gold (1994, 8 of 29). As shown in Figure 3 (this paper), these dates fall on the sphene-zircon cooling trend following the MTP, but not on the trend for Alleghanian unroofing. Indeed, wide aerial distribution of the 141 Ma cooling milestone does not appear consistent with Alleghanian tectonic thickening. Thus, we are proposing that northwest of the failed Newark-Gettysburg Rift Basins, the MTP expressed itself as a broad, diffuse heating to less than ~120ºC (Cl-bearing Tioga B apatite not reset) but to more

than ~100ºC (normal fluorapatites reset). In a sense, this is a ~110ºC degree mirror image of the ~275 to <300ºC MTP found by Kohn et al. (1993) in the area between the failed and successful Mesozoic rifts.

Although frequently interpreted as a separate heating event, it seems reasonable to consider Sutter's (1988) 200ºC argon closure in potash feldspar at 175 Ma (Figure 3, this paper) as part of the cooling from the same MTP called upon by Kohn et al. (1993) to explain sphene and zircon FTA data and herein for fluorapatite FTA data. When all such data known to us are considered, a rapid, linear cooling at rate of 3ºC / Ma (Figure 3) seems appropriate for the period 200 Ma to 141 Ma.

Although preceded by the Triassic Quarryville Diabase, the Jurassic York Haven Diabase plus Rossville Diabase seem to represent the peak manifestations, but not the cause of the MTP. Three lateral equivalents of the York Haven Diabase were dated by Sutter (1988) using $^{40}Ar/^{39}Ar$, yielding a median of 201.2 +/- 1.3 Ma. Dunning and Hodych (1990) dated the Palisades Sill, a lateral equivalent of the York Haven Diabase, and obtained a median $^{206}Pb/^{238}U$ age of 201.2 Ma, probably +/- 1.0 Ma (avg. of 2 dates) for the best clear fragments of zircon. Similarly, they obtained an age of 201.0 +/- 1.0 (median of their 7 preferred analyses) for a small Rossville Diabase sheet (the D-263 body of Smith, 1973). The age of the York Haven Diabase is also well constrained by the position of the Jacksonwald basalt flow of that formation to a position 7 m above (Smith, et al., 1988) the *Corollina* zone used by Cornet (1977) to position the base of the Jurassic.

POSSIBLE AGES OF ZINC-LEAD MINERALIZATION BASED ON THERMAL MODEL

The best studied sphalerite and galena occurrences in the Ridge and Valley of central Pennsylvania occur in the Ordovician Bellefonte through Snyder formations and the uppermost Silurian Tuscarora Formation. Smith et al. (1971), Smith (1977), and Howe (1981) emphasized that much of this mineralization occurs in Alleghanian structures and that much main-stage mineralization is thoroughly deformed. (For example, galena from the Motel 22 occurrence, Huntingdon County, PA.) Howe (1981) also emphasized that the regionally consistent mineralization "…can be divided into six paragenetic stages, each separated by an episode of tectonic disturbance…." We would go so far as to speculate that the distinct stages of mineralization might be the result of tectonic realignment of the hydrothermal plumbing system, implying that there were six substantial pulses of tectonism over the course of mineralization. From this, is seems reasonable to assume, as others have done, that the mineralization is late Alleghanian. Combining this with the proposed cooling history (which seems to eliminate widespread Mesozoic reheating to 120ºC in central PA) and estimates of the temperature of formation of the sphalerites and galenas done by others, one can now approximate the age of the fluid migration and resulting mineralization. We suggest, however, that these are only approximations because the temperatures of hydrothermal systems might have exceeded regional temperatures at a given level if fluids came from great depth.

An example of how data on Alleghanian sphalerite-galena mineralization might be further interpreted and used to understand the Alleghanian orogeny itself follows. We will use one of Howe's (1981) two preferred intergrown sphalerite-deformed galena intergrowth samples, supplied as RS-04-07 from Albright occurrence A (Smith, 1977, p. 127) from southern Sinking Valley, Blair County. It yields a delta co-existing sphalerite-galena S^{34} temperature of formation of 137ºC and a sphalerite fluid inclusion temperature of 139.5ºC, perhaps suggesting little hydrostatic or lithostatic pressure. When plotted on Figure 3, this yields an estimated age of ~235 Ma. In general, Howe's sphalerite fluid inclusion temperatures range from 160ºC for the more southerly deposits studied in central Pennsylvania such as Woodbury (Smith, 1977, p 149-162) to 140ºC for the more northerly such as Milesburg Gap (Smith, 1977, p. 208-218). These would correspond to ages of ~260 and 240 Ma, respectively, suggesting that mineralization advanced from south to north. This is consistent with Stamatakos et al. (1996) paleomagnetic data suggesting fold development at 255+/-19 Ma and, indeed, hydrothermal solutions may have initiated the mineralization recorded by the

paleomagnetic data. If they were part of this system, hydrocarbons along the Allegheny Front might have been emplaced shortly thereafter, perhaps at ~225 Ma.

Likely, most of the significant Ridge and Valley sphalerite-galena occurrences were formed by one hydrothermal megasystem. This is suggested by the small, but systematic, variation in Howe's sphalerite fluid inclusion temperatures and by the fact that the vast majority of his sphalerites had uniform salinities of 24 to 25 weight percent equivalent NaCl. Likewise, Howe found that many sulfide minerals have delta S^{34} compositions close to +26 per mil. Recently, R. C. Smith and R. P. Nickelsen used this to establish a possible tie between the zinc-lead mineralization and a Tuscarora Formation tectonic breccia containing pyrite from the Mt. Pleasant Bank iron mine located at the intersection of the "late" Cowans Gap and Path Valley faults (Nickelsen, 1996, p. 8). They predicted 27 per mil for pyrites from the Hares Valley Zn-Pb district and Mt. Pleasant Bank, and obtained values of 25.6 and 26.6 delta S^{34}, respectively, suggesting the possibility of a common source fluid. Kessler et al. (1994) studied the same suite of Bellefonte through Snyder and Tuscarora-hosted sphalerite and galena samples supplied by Smith and found an extremely small spread of $^{206}Pb/^{204}Pb$ isotopes clustered at about 18.55, again suggesting a common hydrothermal system for deposits in the two different host rocks. In this study of paleoaquifers, Kessler et al. called this "…significant cross-formational flow."

Jeanne Passante Lawler (1981) studied fluid inclusions in sphalerites provided by B.C.S. II from the three Zn-Pb districts in the Newark Basin of eastern Pennsylvania. These are the Audubon, New Galena, and Phoenixville Districts (Smith, 1977, p. 226-270), each hosted in different units. (The only diabase observed by the senior author at any of these was irrelevant Catoctin equivalent metadiabase observed on a dump and in cores from one of the Phoenixville District mines, Smith and Barnes, 1994.) She found that most inclusions in sphalerite contained fluids having 11 to 16 equivalent weight percent NaCl, with the higher percentages from New Galena. The fluid inclusion homogenization temperatures for the most typical sphalerite samples from Phoenixville ranged from 175 to 185ºC, those from Audubon ranged from 160 to 170ºC, and those from New Galena from 135 to 145ºC. This cooling from south to north may also represent the direction of fluid migration. Using our Mesozoic cooling curve (Figure 3, this paper) and Lawler's homogenization temperatures, then typical sphalerites from Phoenixville appear to have formed at ~167 Ma, those from Audubon at ~ 163 Ma, and those from New Galena at ~155 Ma. Lawler calculated hydrostatic pressure corrections, but they do not seem to be appropriate for the uplifted southern portion of the Newark Basin.

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Bald Hill Bentonites A, B, and C
History and New Data Since 1988

By
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and John H. Way, Lock Haven University

History

Observing that both the Tioga Ash Beds (Way et al., 1986) and Ordovician bentonites of central Pennsylvania followed substantial periods of carbonate deposition, Smith hypothesized that the top of the Helderberg Group might include volcanic layers as well. Accordingly, J.H. Way and family visited L. Rickard's "Kalkberg Bentonite" at Cherry Valley, N.Y. on 3/31/86. Smith and Way then recognized the equivalent layers at Bald Hill, Frankstown, Blair County, on 4/2/86. These became known as the "Bald Hill Bentonites" (BHB) because "Kalkberg" was well established as a formation name. On 5/2/86, they found the three BHB's in the Clites quarry at Hyndman, Bedford County, PA. Smith and family then visited Cherry Valley 6/26/86 where he recognized BHB B and C and prepared a preliminary stratigraphic section and again on 8/11/86 to refine the stratigraphic section and take photographs. On 8/23/86 Smith returned to Cherry Valley with Berkheiser who provided bed by bed carbonate descriptions and depositional environments. This and other field work by all three authors resulted in the paper published in 1988.

Since then, Roden and Miller (1989) used apatite from two samples of BHB C for fission track analyses. Berkheiser and Smith found and described an excellent section at Black Oak Ridge, Bedford County (Smith and Berkheiser, 1992. Abstract herein as Figure 1.) Combinations of Smith and Berkheiser and/or Way found and described additional usable sections Jersey Shore, Lycoming County; Selinsgrove Junction (SE limb of anticline), Northumberland County; and Monterey, Highland County, Virginia. Benjamin Hanson (1995) attempted to study melt inclusions in phenocrysts from the Bald Hill and other bentonites as noted below. Also, Tucker et al. (1998) dated Bald Hill Bentonite A at Cherry Valley.

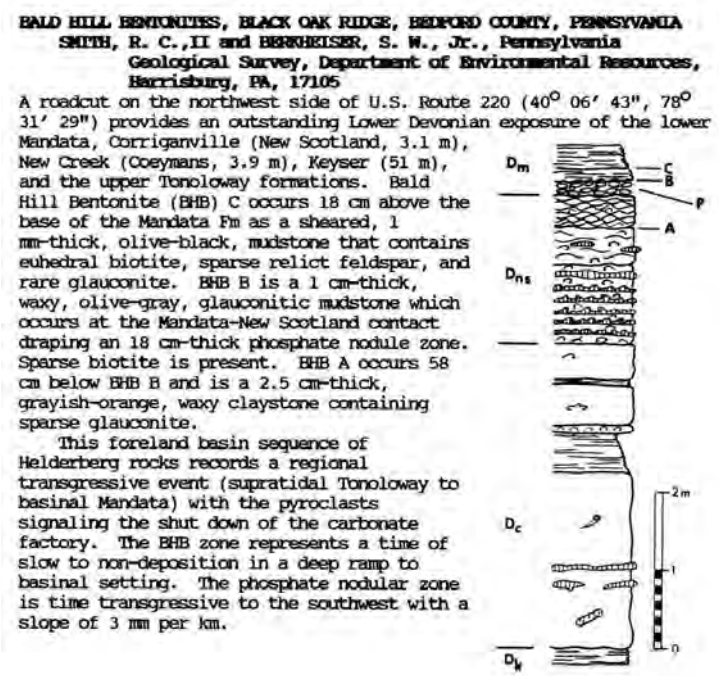


Figure 1. Black Oak Ridge, Bedford County, PA, description and section from Smith and Berkheiser (1992).

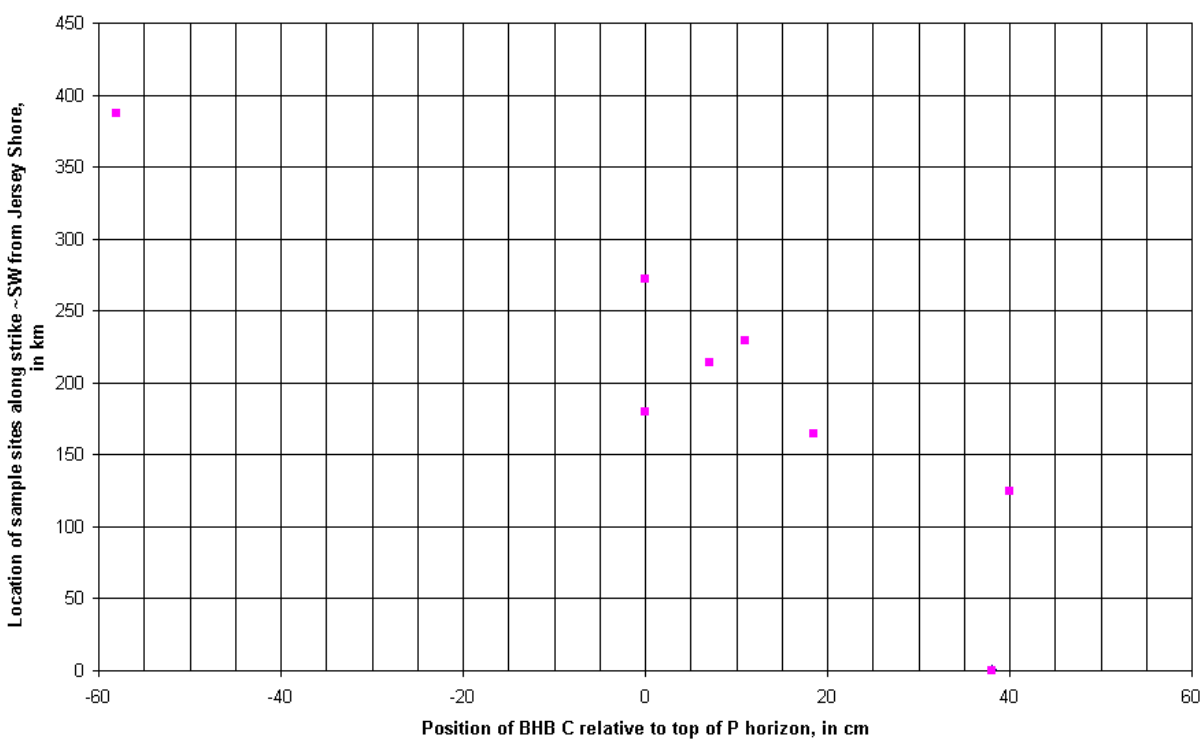
Smith, R.C II, Berkheiser, S.W., and Way, J.H. (2003) Bald Hill Bentonites A, B, and C- history and new data since 1988, *in* Way, J.H. and others, eds., Geology on the edge: selected geology of Bedford, Blair, Cambria, and Somerset Counties, Guidebook, 68th Annual Field Conference of Pennsylvania Geologists, Altoona, PA, p. 73 – 77.

New Data

Roden and Miller (1989) separated apatites from BHB C at Hyndman and Bald Hill supplied by Way and Smith. They were found to have Cl/F + Cl ratios of 0.21 and 0.20, respectively. This is similar to what Roden and Miller found for apatites from Tioga Ash Bed B suggesting, that with some caution, fission track unloading data from BHB C might be included with data from Tioga B. Roden and Miller did this and found an average cooling to ~120^0 C by 225 Ma in complete agreement with data for Tioga Ash Bed B away from the anthracite overthrust (Smith, 2003, this guidebook).

One of the primary uses of bentonites (mostly clay, commonly including smectite) or ash beds (mostly quartz, feldspars, and micas), is as time lines for correlation and as datum to test various theories of deposition. In the case of the Tioga Ash Beds (Way et al., 1986), seven layers not uncommonly can be excavated at one locality, tend to alternate in relative thickness, and to have an individual character. To date, exposures of the Bald Hill Bentonites yielded three, field-recognizable layers at any one locality: BHB A tends to be a few cm thick and consist of light-colored smectite-illite clay having a soapy feel and which contains glauconite grains, especially near the base., B which tends to be about 1 cm thick and to contain biotite having a slightly purplish color and sub-mm glauconite; and C which tends to be about 1 cm thick, coarser than the others, and to contain euhedral biotite and not uncommonly feldspar. In addition, bentonitic layers of material apparently reworked by storms from highlands now appear as pronounced reentrants weathered back into the outcrop, as for example, one 23 cm above C at Cherry Valley, New York. At all but the Cherry Valley section, the phosphate nodule horizon adds a fourth marker, but it is not a time line. For example, see Figure 2, which shows how facies, represented by the phosphate nodule horizon, slopes at 3mm/km (which equals only 3 ppm) and even cuts BHB C. Smith et al. (1988, p 221), noted that equivalence of A, B, and C from New York and West Virginia had not been proven and encouraged the finding of additional localities and verification of the identity of the individual beds.

Figure 2. Slope of phosphate nodule horizon relative to BHB C



Considering the depositional environment and wide geographic spread, the 4 additional sections observed by Smith, Berkheiser, and Way generally fit the patterns they reported earlier. They also collected, to the degree possible in such thin layers, true channel samples of each accessible layer. These were dried, disaggregated to – 1 cm, hand-picked to remove any rootlets, visible calcite, etc., and ground in an agate mortar and pestle to –100 mesh. These were commercially analyzed for, among others, TiO_2, an element believed to be relatively immobile since eruption and likely to differ from one layer to another. Because of the potential for contamination by calcite, all TiO_2 data were recalculated to a somewhat arbitrary 1 % CaO. The results are shown in Table 1.

Table 1. TiO_2 analyses for Bald Hill Bentonite beds from 10 localities in New York, Pennsylvania, Maryland, West Virginia, and Virginia. All analyses calculated to 1% CaO in an attempt to correct for dilution by carbonate mud and/ or hydrothermal calcite.

Locality	BHB A % TiO_2	BHB B % TiO_2	BHBC % TiO_2	Stratigraphic position of BHB C relative to phosphate nodule horizon
Cherry Valley, Otsego Co., NY	0.38	0.84	0.62	
Jersey Shore, Lycoming Co., PA	0.51???	0.80	0.72	38 cm above top
Selinsgrove Junction, (SE limb of anticline) Northumberland Co., PA	0.37	N.A.	N.A.	
Bald Hill, Blair Co., PA	0.36	0.79	0.48	40 +/-1 cm above top
Black Oak Ridge, Bedford County, PA	0.37	0.80	0.75	18.5 +/-1 cm above top
New Paris, Bedford Co., PA	0.56???	0.84	0.53	directly on top
Hyndman, Bedford Co., PA	0.44	0.82	0.60	7 cm above top
Corriganville, Allegany Co., MD	0.36	0.54???	0.66	11 cm above most pronounced P nodule layer in shale , but most faulted of sections used.
New Creek, Mineral Co., WV	0.36	0.56???	0.57	directly on top
Monterey, Highland Co., VA	0.62???	0.61???	0.58	30 cm below base of 28 cm P nodule–bearing bed
Apparent range for correctly identified samples	0.37 +/- 0.01	0.81 +/-0.03	0.62+/- 0.14	

In general, layers believed to be BHB A contained 0.37+/- 0.01% TiO_2, BHB B 0.81 +/- 0.03, and C 0.62 +/- 0.14. C has a much larger TiO_2 range than desired, but is coarser and was deposited in a higher energy environment which locally might have selectively winnowed light vs. heavy minerals. Three samples of BHB A appear to be problematic: Jersey Shore, New Paris, and Monterey. Three samples of BHB B also appear to be problematic: Corriganville, New Creek, and Monterey. It should be noted that the 6 problematic samples have %TiO_2 contents of: 0.51, 0.56, 0.62, 0.54, 0.56, and 0.61 or 0.56 +/-0.05 %. General appearance and a limited range for TiO2 suggest that this represents one pyroclastic layer and not just random shaly partings. It now seems likely to be a previously unrecognized, distinct bentonite or bentonitic layer, perhaps with a southerly source. It is hoped that a locality might be found where four

layers were deposited and are preserved well enough for sampling and analyses. Difficulty in finding B at the three most southerly sections studied suggests that it may have a more northerly source. BHB C remains a preferred time line because it is typically easiest to locate in the field. However, the odds of samples containing 0.37 +/- 0.01 % TiO_2 not being BHB A are remote as are the odds of samples containing 0.81 +/- 0.03 % TiO_2 not being BHB B. As a package that includes the phosphate nodule horizon, the Bald Hill Bentonites are a robust correlation tool.

On the Th-Hf/3-Ta classification diagram of Wood (1980) all of the BHB's plot in the field for destructive plate margins magmas such as those produced by island arcs. This, the 395 Ma date reported for biotite from BHB A by $^{87}Rb/^{87}Sr$ (Miller and Senechal, 1965, on the Kalkberg bentonite of Rickard found by D.W. Fischer circa 1955 and identified by W.E. Brownell), and the recent reconstructions of C.R. Scotese suggest the possibility of island arcs in the sea being closed between eastern North America and Africa near the end of the Helderbergian.

Within routine sampling analytical error, chondrite-normalized diagrams for the BHB's typically show an increase in lanthanides from BHB A to B to C for each locality. This suggests the possibility that the crustal magma chambers evolved over time. Raw lanthanide data for some of the critical sections are summarized in Table 2. The possibility of fractionation within BHB C is suggested by a plot having K/Rb on the ordinate and Sm/Nd on abscissa. For most samples, this plot looks very much like a location map. It may be a statistical fluke or reflect some combination of fractionation within a crustal magma chamber and air elutriation by prevailing wind during eruption.

	A	A	A	A	A	C	C	C	C	C
	Cor.	Hynd.	B.O.R.	B.H.	C.V.	Cor.	Hynd.	B.O.R.	B.H.	C.V.
La	6.3	10.5	8.1	10.7	8.8	24.1	33.5	27.2	22.9	21.6
Ce	10	13	12	15	19	44	57	43	41	29
Lu	.11	.29	.24	.21	.27	.39	.55	.39	.43	.31

Table 2. Selected lanthanide data in ppm for Bald Hill Bentonite sections: Corriganville, Hyndman, Black Oak Ridge, Bald Hill (BHB A resampled and reanalyzed since 1988.), and Cherry Valley.

Hanson (1995) attempted to fingerprint several sets of bentonites including the BHB's. This was attempted primarily by analyzing rhyolitic melt glass trapped in quartz crystals growing in the magma. This is a potentially elegant approach as long as only relatively pure bentonites are sampled. Unfortunately, such quartz-encased glass also survives moderate transport and can be redeposited from highlands into the next storm-generated bentonitic parting. Despite detailed, measured sections, photographs, telephone conversations and a FAX provided by the authors, Hanson did not sample the type BHB layers. Figure 2-7 of Hanson (1995) indicates that at Cherry Valley he sampled a pronounced parting 23 cm above BHB C. Indeed, there is a pronounced parting 3.68 m above BHB A at Cherry Valley, NY, but BHB C is 3.43 m above BHB A. Hanson's Figure 2-43 of the Bald Hill, PA, indicate that he attempted to sample BHB C 1.14 m too high and did not use the significant updates Smith and Berkheiser prepared for the 1992 GSA NE meeting: C unchanged, B chemically recognized in the 9-cm subunit of the .38 m unit below C, and A chemically recognized 0.80 m below C in what was originally field-identified as B As a result of these changes and his preference for more pronounced partings or PAC's (?), his correlations are not useful for the BHB's. If the other bentonites he studied in NY are associated with pronounced partings, then that work likely has more utility. Hanson was successful in finding a new exposure of BHB's near Smoke Hole, VA.

In a study of the Devonian Period, Tucker et al. (1998) sampled the ~8 cm Bald Hill Bentonite A at Cherry Valley, NY. Ten zircon fractions were separated and analyzed from this bed within the *Icriodus woschmidti* lowest Devonian conodont zone. Four yielded concordant $^{207}Pb/^{208}Pb$ dates and 5 others were only 2 to 3 % discordant. They report a weighted mean for the nine of 417.6 +/- 1.0 Ma. Further conodont

and radiometric dates of the Bald Hill Bentonites at Bald Hill and Black Oak Ridge are recommended to further resolve this apparent very old beginning of the Devonian.

Though it is hard to reconstruct the evolution of the concept, it appears that groups of bentonites and ash beds may have influenced the Alleghanian deformation of the Ridge and Valley. Excavations of bentonites in the Antes black shale at the base of the Reedsville Formation near Cito, Fulton County, by R.P. Nickelsen and the senior author suggested that they were observing a jump in the level of a major decollement there. Earlier, the same geologists observed countless duplexes in Tioga Ash Bed B in a crosscut to a Ridgeley Formation glass sand open cut near Mapleton, Huntingdon County. Field work in BHB sections suggests the possibility that there has been much deformation at that level at Bald Hill, Blair County. Thus, the hypothesis should be considered that a major decollement follows the Ordovician ash beds until a belt following Alleghanian curvature is reached, perhaps at approximately 65 km W to N of Gettysburg, that it then follows the Tioga Ash Beds to somewhere beyond 100 km, and then possibly jumps to the Bald Hill Bentonites at a distance of 125 km. In a wider sense, these same three zones include massive amounts of highly deformed Reedsville, Marcellus, and Mandata black shales in their hanging walls that might have been source areas for both hydrothermal ore solutions and hydrocarbons.

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ROCKS, RAILS, CANALS, AND FOSSILS: THE GEOLOGY OF THE ALLEGHENY PORTAGE RAILROAD

John A. Harper
Pennsylvania Geological Survey

Introduction

Before the middle of the 1800s, traveling westward from the Atlantic coast presented a host of difficulties for the average person. The Allegheny Mountains presented a formidable barrier to westward travel, proving to be THE boundary between civilization and the great western frontier. Originally pioneers, then soldiers, then those who saw a better life away from the main population centers paved the way. Slowly, people began following the pioneers westward as tales of vast stretches of fertile farmland, great rivers, abundant forests and game, and troves of mineral resources found their way back east. There were lots of tracks and trails, but there were very few established roads at the time. Turnpikes first began to be built early in the 1800s. The Huntingdon, Cambria and Indiana Turnpike (now US 22) was completed in 1819. This road (actually a dirt track) crossed the Allegheny Mountains within the deeply etched valley called Blair Run Gap between Hollidaysburg and Cresson (Jacobs, 1945). Roads such as these often had little to recommend them; canals, on the other hand, offered a better, faster, and safer means of transportation.

On March 31, 1824 the Pennsylvania Legislative Assembly appointed a Board of Canal Commissioners to investigate possible canal routes between Harrisburg and Pittsburgh (Wilson, 1897).

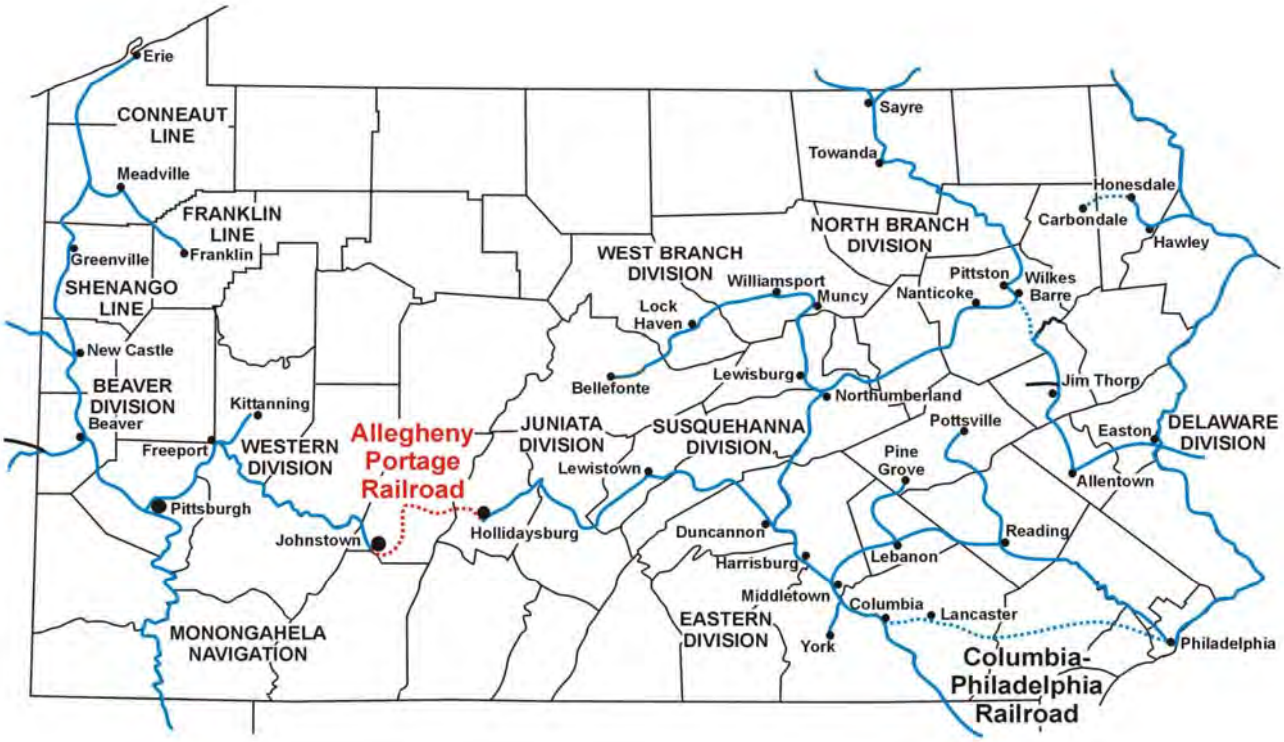

Figure 1. Map of the Pennsylvania canal system and associated railroads (dotted) (modified from Shank, 2001). The Juniata Canal, a division of the Pennsylvania Mainline Canal, ran 127 miles between Duncan's Island in the Susquehanna River and Hollidaysburg, and had 86 locks. It remained in operation from 1832 until 1888.

Harper, J.A. (2003) Rocks, rails, canals, and fossils: the geology of the Allegheny Portage Railroad, *in* Way, J.H. and others, eds., Geology on the edge: selected geology of Bedford, Blair, Cambria, and Somerset Counties, Guidebook, 68th Annual Field Conference of Pennsylvania Geologists, Altoona, PA, p. 78 - 89.

The Board favored the Juniata and Conemaugh rivers as the best route, especially because the Conemaugh flowed into the Allegheny and, eventually, into the Ohio River. Construction of the Pennsylvania canal system began in 1826 and continued until about 1840 without interruption. The system eventually became a hybrid of public and private canals and railroads (Figure 1), but for travelers trying to get to Pittsburgh from Philadelphia the entire journey was made in canal boats. The boats were loaded onto Columbia-Philadelphia Railroad cars in Philadelphia (the CPRR was the forerunner of the Pennsylvania Railroad), and then they were unloaded on the Susquehanna River in Lancaster County at Columbia. The journey continued northward in a canal constructed along the Susquehanna River to the mouth of the Juniata River north of Harrisburg. The canal boats then traveled westward along the Juniata River canal as far as Hollidaysburg at the foot of the Allegheny Mountains. At this point, the boats were loaded onto the Allegheny Portage Railroad, which took them over the mountains and deposited them into the Conemaugh River canal at Johnstown. The Conemaugh linked Johnstown with the Allegheny River, Pittsburgh, the Ohio River, and the great western frontier. The Pennsylvania Main Line Canal, as it was called, opened in 1834 and operated for 20 years.

The Allegheny Portage Railroad was the first railroad over the Allegheny Mountains. Considered a technological wonder in its day (1834-1854), the railroad played a critical role in opening the interior of the United States to further settlement and additional trade. It allowed settlers and traders to travel from the east coast to the center of the North American continent without major interruption by forming a link between the Juniata River canal of the Pennsylvania Mainline Canal System in central Pennsylvania and the Ohio River drainage (via the Conemaugh and Allegheny rivers). Thousands of people made the journey on the Portage Railroad, including Charles Dickens who traveled to America in 1841-1842 (Dickens, 1842).

The Allegheny Portage Railroad went through two iterations (Old and New Allegheny Portage Railroads), then was bought and dismantled by the Pennsylvania Railroad in 1854. Today, only parts of the railroad remain. See Stop 8 for more information on the Allegheny Portage Railroad.

Early Geological Investigations

The geology of the Portage Railroad route, and of the area around the railroad, was first explored during the initial surveys for the right-of-way. Early (i.e. pre-Revolutionary War) explorations for mineral resources were limited and very much confined to lead, zinc, iron ore, and coal deposits. Some early settlers made use of coal and iron ore throughout the Johnstown and Hollidaysburg area, but we don't actually know when that first occurred. We do know that coal had been found at least as early as 1769, and probably used at that time. And from the journal of Joshua Gilpin, a businessman from Philadelphia who owned property in western Pennsylvania, we learned that iron mills existed in Johnstown by 1809, and that limestone and aluminum-rich claystones cropped out in the hillsides around the town (Brice, 1989).

The numerous surveys for the Pennsylvania Mainline Canal made prior to 1831 were more concerned with topography than with geology. However, geology undoubtedly became important when the canal tunnel was first proposed, and later when local natural resources became necessary for actually building the railroad.

Edward Miller – Engineer and Geologist

Edward Miller was the Portage Railroad's Principal Assistant Engineer, and he made quite a name for himself during his career. J. Peter Lesley, Director of the Second Geological Survey of Pennsylvania, called Miller "a Civil Engineer of great ability" (Lesley, 1876, p. 48). Miller later served as Chief Engineer of the Pennsylvania Mainline Canal in 1838-39, became an Associate Engineer of

the Pennsylvania Railroad under J. Edgar Thompson in 1847, and eventually established his own company in 1862. Wilson (1899) described Edward Miller & Co. as a "firm whose name was a synonym for ability, energy, integrity and boundless resources."

Edward Miller made the first geological report of the Blair and Cambria County area at the 1835 meeting of the Geological Society of Pennsylvania in Philadelphia (Miller, 1835). Although, quite busy with his duties, serving in the main office with Principal Engineer Sylvester Welch, Miller spent much of his "leisure" time examining rock outcrops, gathering specimens, taking instrument readings, and speculating on what he found:

> The deep excavations made for the Portage, and the bold ravines and gorges with which the mountain is serrated, afford every opportunity which can be desired for an examination, and I have endeavored to procure results which may be depended upon as accurate, so far as they extend. The dip and bearings of the various strata were ascertained by proper instruments; and the topographical details from correct manuscript maps, and other data belonging to the state, and now in the engineer's office at Johnstown. (Miller, 1835, p. 251)

Miller's (1835) contributions included: 1) an outline map of about 200 square miles of what are now Cambria, Blair, Bedford, and Huntingdon counties at a scale of 1:63,360; 2) a cross section along the railroad from the west side of Hollidaysburg (near the present-day Fort Fetter/Gaysport boundary) to the area around Cassandra at Inclined Plane No. 3; and 3) specimens presented to the society that were studied by prominent geologists and paleontologists of the day.

The map showed, among other things, the crest line of Allegheny Mountain, the courses of all the streams, the Portage Railroad right-of-way, and the dip and strike of the strata. The cross section is by far the most interesting and informative contribution (Figure 2). Miller's original was 10 by 5.5 inches and had a horizontal scale of 1 inch = 3,000 feet and a vertical scale of 1 inch = 300 feet (Figure 2 is a redrafted version, so the scales aren't exact). Miller apologized for the distortion – "Allowance must of course be made for the distortion caused by so great a difference between the scales." (Miller, 1835, p. 252) He divided the cross section into areas numbered 1 to 4 and included detailed information on the types of strata, dip of beds, bed thicknesses, and total thicknesses of each. The cross section contained letter designations used to reference the various strata and the specimens collected in them. But Lesley had only slight praise for Miller's report:

> Had he not, in obedience to the taste of the eastern geologists, and from habit as a constructing engineer, *exaggerated the vertical scale to eight times that of the horizontal scale,* so as to distort all the dips, this section would be not only of the highest interest as a classic in the science, but would stand us in capital stead in our annual report this year (1874-'5); comparing it, as we then could, with the elaborate section which Mr. Platt has had made for his report on the Clearfield and Jefferson district, along the Snow Shoe and Bellefonte railroad. Mr. Platt will give Mr. Miller's text in his report on Cambria and Somerset counties, (Report of Progress in 1875,); but the section as Mr. Miller published it is worthless . . . (Lesley, 1876, p. 49)

Miller took dips and strikes along the whole railroad right-of-way and found that the dip direction did not vary greatly from "W.N.W". He also found that the dips between Inclined Plane No. 3 and Inclined Plane No. 6 did not vary much from 3.5^{o}, but that eastward from Inclined Plane No. 6 the dip gradually increased to 23° at Hollidaysburg.

No. 1 on the left side of Figure 2 included what we now map as Rose Hill (Lower Silurian) to beyond the top of the Onondaga Limestone, probably into the Marcellus Formation (Middle Devonian).

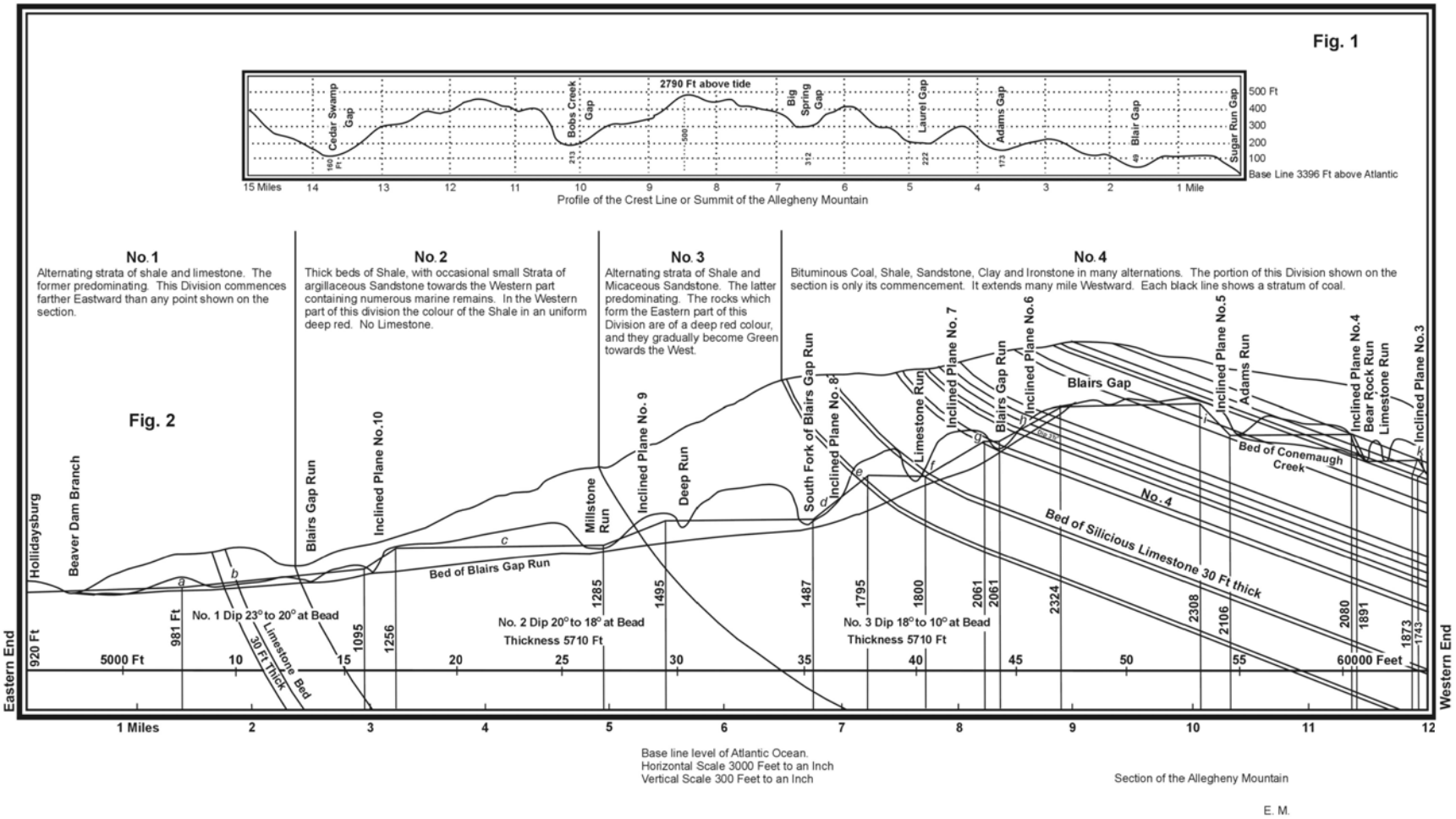

Figure 2. Cross section of the Allegheny Mountains, showing prominent strata and the locations of the inclined planes (redrawn from Miller, 1835).

He noted that a limestone bed at *b* in Figure 2 (Onondaga Limestone) was about 50 feet thick but wasn't very fossiliferous except where it had been weathered. Other limestones (probably Wills Creek and Tonoloway) contained beds as thin as one inch and were fossiliferous.

No. 2 included the Hamilton Group through the lower half of the Catskill Formation, measured at 5,710 feet thick. Although predominantly shale, the number and thickness of sandstones increased westward (Brallier to Scherr to Foreknobs). The western edge of No. 2 contained the red shales of the lower Catskill Formation.

No. 3 included the upper Catskill Formation and at least a portion of the Rockwell Formation, measured at 3,370 feet. The color of the rocks changed gradually from red to green traveling westward. Miller noted that the sandstones could be easily quarried in thin slabs of large size.

Miller called No. 4 "The coal measures." He determined that the starting point for this sequence of rocks was at *e* on Figure 2 ". . . because there is at this place a decided change in the character of the rocks, and we find, for the first time, sandstone containing vegetable remains of a kind which, I believe, is never found except in the immediate vicinity of coal." (Miller, 1835, p. 253-254) In fact, he started the "coal measures" too low in the section. The plant fossils he found probably occurred in the upper Rockwell or, perhaps, the Burgoon. Swartz (1965), Inners (1987) and Faill and others (1989) all described plant remains in this portion of the section. Lesley (1876, p. 49) stated, ". . . his fourth, or Coal Measure division . . . commences as low as No. X ["Pocono" = upper Rockwell and Burgoon], no doubt to the satisfaction of our western geologists . . ."

No. 4 also contained a quartzose limestone bed about 30 feet thick (*f* in Figure 2) – the Loyalhanna Formation. The Loyalhanna, which is commonly called Loyalhanna Limestone even where it is actually calcareous sandstone, is highly recognizable to anyone who has studied the geology of western Pennsylvania. Miller (1935) apparently was the first to describe it:

> At *f*, is a bed about 30 feet thick of limestone, containing so large a proportion of silex, that it forms good mortar without any admixture of sand. It is exceedingly hard, and full of irregular seams and fissures. (Miller, 1935, p. 254)

As Miller observed, the Loyalhanna is very hard. It is difficult to excavate, especially with primitive means (picks and shovels, and black powder), but it has good cut-slope stability (Geyer and Wilshusen, 1982) so the railroad should have had little trouble with rockfalls. It is also a good source of construction aggregate and road material. I've often wondered if some of the stone rail supports ("sleepers") on the Portage Railroad, particularly between Inclined Planes No. 7 and No. 6, might have been worked out of Loyalhanna boulders.

The first true coal appeared at the top of Inclined Plane No. 7 (*g* on Figure 2), probably the Mercer coal (Pottsville Group), or, less likely, a well-developed seam in the Mississippian Mauch Chunk Formation. It was only a few inches thick, and since Incline Plane No. 7 passes through the Burgoon, Loyalhanna, and Mauch Chunk (Berg and Dodge, 1981), it probably was found upslope from the plane, rather on it.

> From this place, we find the usual strata which form the coal measures of England. Bituminous coal, shale, sandstone, clay and iron stone, in many varieties and numerous alternations. The coal strata are numerous, from one inch to six feet in thickness, and very various in quality; differing materially sometimes in the same stratum. I have designated [on Figure 2] all that I am acquainted with, which occur within the limits of the section, by black lines. Some of those shown are too small to be worked advantageously, and there are probably several which have escaped observation. (Miller, 1835, p. 254)

He found that the ironstone (siderite nodules) was abundant and reminded him of that found in the coal measures of England. He found only three limestone beds cropping out in No. 4: 1) the Loyalhanna, mentioned above; 2) a light blue limestone in a bed three feet thick along Bens Creek near Cassandra (Inclined Plane No. 3), which is probably the Upper Freeport limestone; and 3) a limestone in the bed of Limestone Run, a small creek between Lilly and Cassandra. He assumed it was the same limestone as the one in Bens Creek.

Sandstone varied both in appearance and quality, with outcrops showing a lot of jointing, probably due to valley stress relief (Ferguson, 1967). Miller found the best quarries typically occurred within stream valleys where large blocks lay strewn upon the ground. Considering the amount of sandstone needed for "sleepers" and construction of foundations, bridges, and culverts, it was extremely important to make note of this.

Miller stated that rare minerals would not be found along the railroad, and that his specimens were valuable only to illustrate the geology of the Allegheny Mountains, but ". . . alas! the suite of specimens which he sent . . . to the museum of the society in 1833, cannot now, perhaps, be recovered." (Lesley, 1876, p. 49) Some of these specimens, if not all, probably reside in a variety of collections around the state, but no one knows where. This valuable historical collection appears to have been lost for all time. But at least we have published reports with illustrations that can help us deduce what Miller provided to science.

Miller's Collected Specimens

The first paper concerning specimens collected by Miller was a report on some plant fossils by Richard Harlan, a well-known physician and paleobotanist of the early 1800s. These came from the surface of a coal bed at the top of Allegheny Mountain (Harlan, 1835), but there is no further information as to stratum or location. He claimed Miller told him that marine fossils occurred both above and below the plant fossils, but how this is possible I don't know. Miller might have meant that marine fossils occur both above and below the coal bed, referring to separate marine zones in the Allegheny Group. Lesley (1876) interpreted Harlan's statement to mean "layers of rock holding marine shells lay over and under the shales with plants". Harlan described only three plants from the Portage Railroad, *Pecopteris obsoleta*, *Pecopteris milleri* (named in honor of Edward Miller), and an unnamed species of *Neuropteris* (also, he included an illustration and discussion of *Lycopodiolites dichotomus* Sternberg from the anthracite fields of Schuylkill County, Pennsylvania). Modern paleobotanists (e.g. Darrah, 1969) do not recognize any of these names.

Thomas G. Clemson, who had been with the Royal School of Mines in Paris, France, and later became superintendent of the Flemington Mines in New Jersey (Lesley, 1876), performed chemical analyses of coal, charcoal, and siderite specimens supplied by Miller. Clemson (1835) expounded profusely on the importance of these specimens to the iron industry in the United States. Unfortunately, his analyses are greatly lacking by today's standards. Lesley (1876, p. 50) stated that the analyses ". . . show how crude were the ideas of chemists then, respecting the demands which a future coal trade would make on their art; not a word about sulphur, phosphorus, potash, soda, magnesia, - merely volatile matter, 15; ashes, 8; carbon, 77 = 100." But Lesley says nothing of Clemson's physical descriptions of his specimens, which, in fact, were quite good. Clemson also described a specimen of iron ore ("siderose or, lithoid spathic iron"), and a specimen of mineral charcoal, which Miller frequently found disseminated in some of the coal beds.

Inclined Plane No. 3 Fossil Locality

My particular interest in Miller's collections involve the invertebrate fossils found at the head of Inclined Plane No. 3 near Bens Creek and Cassandra (Figure 3).

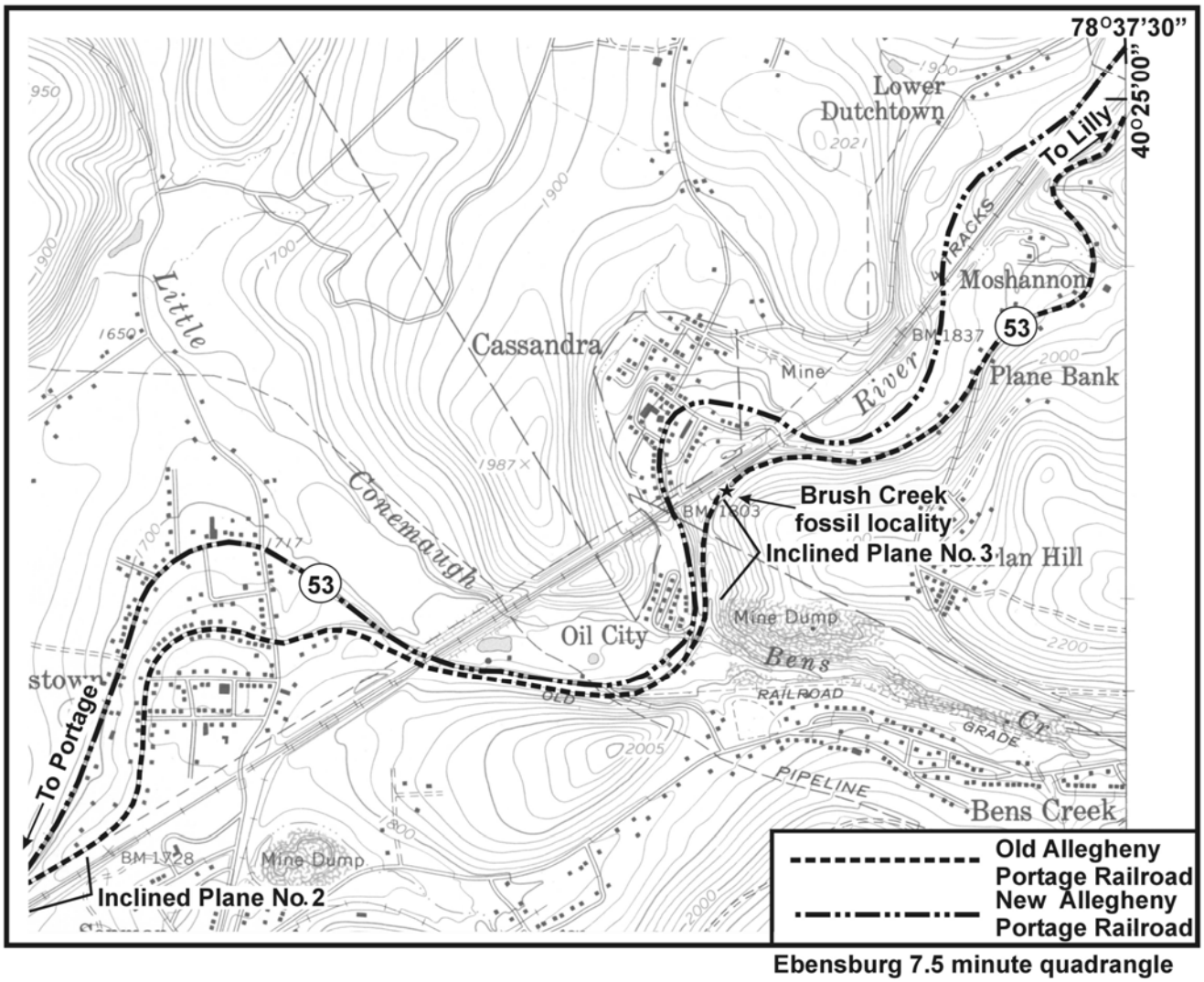

Figure 3. Location of Edward Miller's Inclined Plane No. 3 fossil locality on the Ebensburg 7.5-minute quadrangle.

> The most interesting specimens found in this quarter, are in the deep cuttings at the head of inclined plane No. 3, locality *k* [on the right side of Figure 2]. A stratum of good coal 2 feet thick is found at this place, having a roof of black shale 4 feet thick, upon which is an unstratified bed of argillaceous rock, containing a great variety of shells and other marine remains, with sulphuret of iron and balls of iron stone. The upper part of the stratified shale also contains marine impressions, and some of the more delicate remains have been replaced by sulphuret of iron. In breaking these rocks to pieces to facilitate their removal, great numbers of shells were loosened and fell out. Specimens 16 to 24, locality *k*. (Miller, 1835, p. 254-255)

The section, minimally described by Miller, occurs within the Brush Creek cyclothem of the Glenshaw Formation, Conemaugh Group (Figure 4). The coal is called the Gallitzin coal in Cambria County, but it has also been called Mason coal and Brush Creek coal. It lies 107 feet above the Upper Freeport coal in Cresson where it is 15 inches thick (Butts, 1905), and crops out in the railroad cut west of the eastbound tunnel at Gallitzin, where it is 6 inches thick. Butts (1905) indicated that it is exposed in the railroad cuts near Cassandra (adjacent to Inclined Plane No. 3). In this vicinity, it is 100 feet above the Upper Freeport coal and about 15 inches thick. The Gallitzin is not an economical coal by

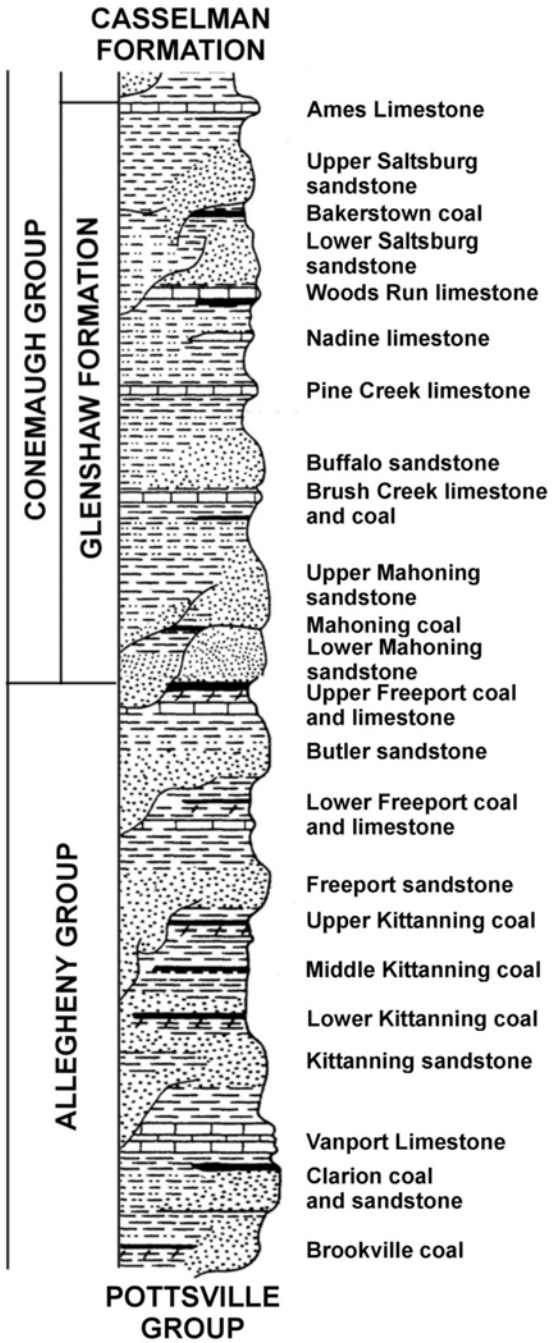

Figure 4. Generalized stratigraphic section of the upper part of the Allegheny Group and the Glenshaw Formation (lower half of the Conemaugh Group). Modified from Harper and Laughrey (1987).

Figure 5. Photograph of a piece of Miller's (1835) "unstratified bed of argillaceous rock" (Brush Creek limestone) from the roadcut at the top of Inclined Plane No. 3 with a fragment of the gastropod *Worthenia tabulata* (at arrow). Dime for scale.

modern measures, but it has been worked between Lilly and Cassandra (Butts, 1905). The outcrop Miller described is mostly covered by colluvium and vegetation now, but if the coal were still exposed you would see that it is about 15 inches thick, not the 2 feet Miller (1835) described. The shale above the coal should be the lower marine shale of the Brush Creek, but I haven't been able to find any fossils in it. It is best seen on the northwest side of the road. I have found the "unstratified bed of argillaceous rock" on the southeast side of the road, but only as float (Figure 5) containing some poorly preserved but very recognizable, typical Brush Creek fossils. Unfortunately, not even digging in the colluvium has turned up the Brush Creek in place. I've also examined the railroad cuts at Cassandra and found nothing even remotely fossiliferous above the Gallitzin coal. It is possible that this far east the marine zone is found only as remnant pods of black, argillaceous limestone.

Timothy Abbott Conrad published descriptions of the better specimens, all of which were marine shells (Conrad, 1835). Conrad was a well-known naturalist affiliated with the Academy of Natural Sciences of Philadelphia and, according to Lesley (1876), one of the most active members of the Geological Society of Pennsylvania. He is now recognized as one of the pioneers of paleontology (Wheeler, 1935). His expertise on Cenozoic shells from the southeastern states, particularly Eocene fossils from Alabama, made him the most suitable candidate available to describe the new Carboniferous fossils.

According to Weller (1898), Conrad's was only the fourth published paper containing

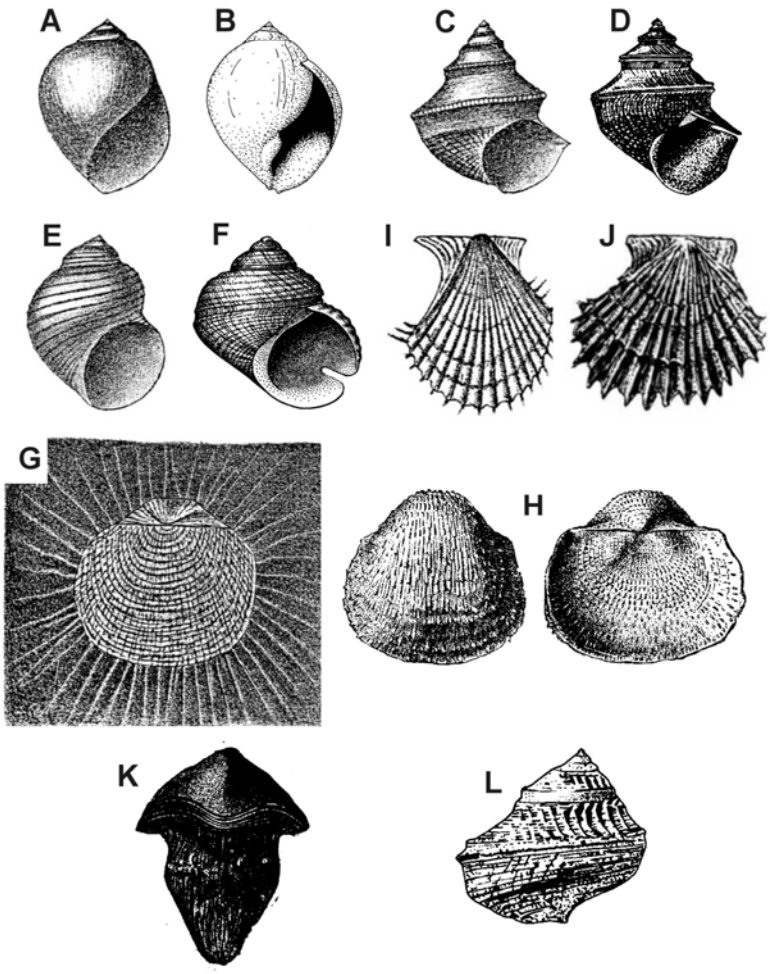

Figure 6. Fossils from the Brush Creek marine unit (Glenshaw Formation) at the head of Inclined Plane No. 3. Compare Conrad's (1835) original illustrations (A, C, E, G, and I) with the more modern ones (B, D, F, H, and J). A – *Stylifer primogenia.* B – *Strobeus primogenius* (Conrad). C – *Turbo tabulatus.* D – *Worthenia tabulata* (Conrad). E – *Turbo insectus.* F. *Shansiella carbonaria* (Norwood and Pratten). G – *Pecten armigerus.* H – *Acanthopecten carboniferus* (Stevens). I – *Productus confragosus*. J – *Juresania nebrascensis* (Owen). K – *Petalodus allegheniensis* Leidy. L – *Raphistomella* (*Raphistomella*) *grayvillense* (Norwood and Pratten).

descriptions of Carboniferous invertebrate fossils from North America. Raymond (1910) claimed it was the first published report describing fossils from the Coal Measures, but this isn't true because many plant fossils had already been described by 1835. However, it ***is*** the first published report of invertebrate fossils from the Coal Measures of North America. As a result, the locality at the top of Inclined Plane No. 3, now on PA 53, is of historic importance in geology because it is the location from which the first marine fossils described from the Pennsylvanian of North America were obtained, and some of the specimens described have become very recognizable as characteristic of Middle Pennsylvanian strata in North America. It is truly a sight worth preserving for historical purposes.

Conrad's (1835) paper included three new species of snails, a brachiopod, and a bivalve (Figure 6). Unfortunately, Conrad's type specimens have been lost, but many of them are so recognizable from the illustrations that there is no question of their identification:

Stylifer primogenia (Figure 6A) is now known as *Strobeus primogenius* (Figure 6B). This species is quite common throughout the marine zones of the Allegheny and Conemaugh groups of western Pennsylvania, as well as other Pennsylvanian strata across the country.

Turbo tabulatus (Figure 6C) is now known as *Worthenia tabulata* (Figure 6D), and is one of the more recognizable Pennsylvanian fossils from North America. It occurs commonly in the Brush Creek marine zone throughout southwestern Pennsylvania.

Turbo insectus has not been redescribed or reillustrated since Conrad's original report. However, the illustration (Figure 6E) probably refers to *Shansiella carbonaria* (Norwood and Pratten), described originally from Illinois. *Shansiella*, like *Worthenia*, is one of the more recognizable fossils commonly found in the Brush Creek marine zone throughout southwestern Pennsylvania (Figure 6F). Conrad's illustration shows a snail somewhat more high-spired than *S. carbonaria*, but 19th century fossil illustrators commonly exaggerated specimens, or added details that did not exist. Also, there has never been a report of any other species of snail from the Brush Creek having similar features.

Productus confragosus (Figure 6G) is probably *Juresania nebrascensis* (Owen) (Figure 6H), the most common productid brachiopod found in the Brush Creek marine zone in southwestern Pennsylvania. In fact, *J. nebrascensis* is the only productid listed by Raymond (1910) from collections he made in the Brush Creek near this locality (see below). Miller had provided Conrad with numerous distorted and pyritized specimens, but Conrad's description is inadequate for a scientific description. Conrad seems to have been struck more by the preservation of the spines illustrated in Figure 6G than in how the species differed from known European forms.

Pecten armigerus (Figure 6I) is probably *Acanthopecten carboniferus* (Stevens) (Figure 6J). The only specimen Conrad had to work with was "the interior of the left valve" (probably an external mold). *Acanthopecten carboniferous* occurs throughout the Pennsylvanian marine rocks of the Appalachian basin.

Conrad (1835) also listed nine other fossils from the Brush Creek at Inclined Plane No. 3, but failed to describe or illustrate them. Being familiar with the scientific literature of Europe, Conrad considered most of them to be at least similar, if not conspecific, with well-known European forms. Raymond (1910) first identified the fossiliferous rock as the Brush Creek limestone, and listed numerous other fossils collected from the first cut west of Bens Creek Station on the Pennsylvania Railroad (Inclined Plane No. 3 was east of Bens Creek Station). These included (using updated nomenclature):

Brachiopods:	*Chonetinella plebeia* (Dunbar and Condra)
	Derbyia crassa (Meek and Hayden)
	Juresania nebrascensis (Owens)
Bivalves:	*Nuculopsis girtyi* Schenck
	Palaeoneilo oweni (McChesney)
	Astartella concentrica (Conrad)
Gastropods:	*Strobeus primogenius* (Conrad)
	Raphistomella (*Raphistomella*) *grayvillense* (Norwood and Pratten)
	Worthenia tabulata (Conrad)
	Knightites (*Cymatospira*) *montfortianus* (Norwood and Pratten)
	Pharkidonotus percarinatus (Conrad)
	Soleniscus typicus (Meek and Worthen)
Cephalopods:	*Pennoceras seamani* Miller and Unklesbay

All of these listed species are common in the Brush Creek and Pine Creek marine zones in other localities around western Pennsylvania, northern West Virginia, and eastern Ohio.

The Inclined Plane No. 3 locality is also the type locality of the shark tooth *Petalodus allegheniensis*, described by Joseph Leidy (1856) (Figure 6K). This is arguably the most recognizable vertebrate fossil to be found in the marine rocks of the Glenshaw Formation.

The specimens of rock I've been able to find and take home to examine for fossils have yielded only a very sparse fauna. The snail, *Raphistomella* (*Raphistomella*) *grayvillense* (Norwood and Pratten) (Figure 6L) appears to be the most common recognizable fossil. This fossil is very common in all of the Glenshaw marine units but the Ames.

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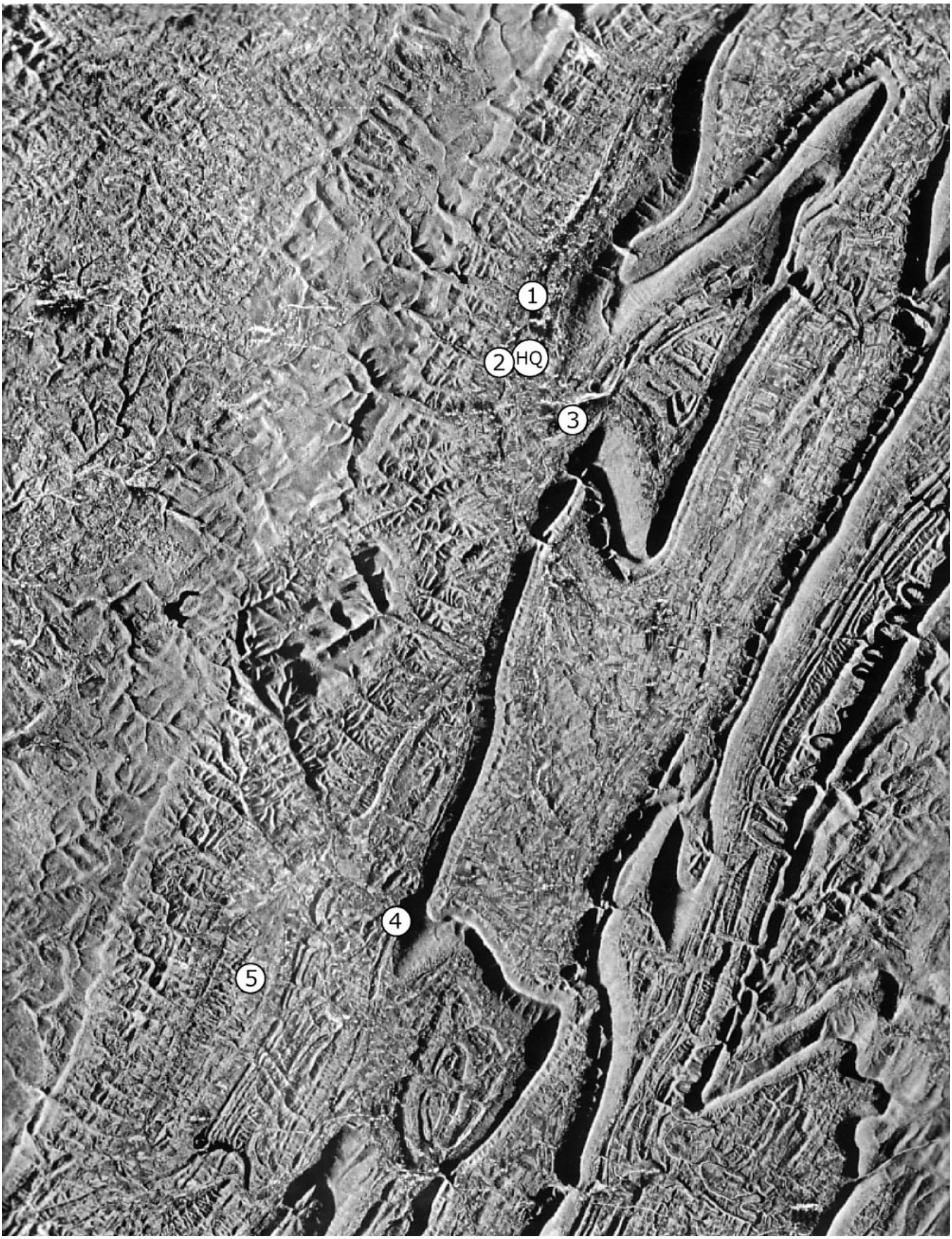


Stop locations for Day 1 of the 2003 Field Conference of Pennsylvania Geologists

FIELD TRIP # 1 Friday, October 3, 2003

Theme: STRATIGRAPHY AND DEPO-ENVIRONMENT OF THE KEYSER FORMATION

Leaders: Edwin "Andy" Anderson, Peter Goodwin, Cheryl Sinclair, John Taylor, Frank Hall, Willian Bragonier, John Harper, Robert Altamura, Arnold Doden, Keith Van Horn and David "Duff" Gold

Itinerary: Assemble in parking lot of Ramada Inn. Busses 1 and 2 will proceed to Stop # 1 (Allegheny furnace quarry); busses 3 and 4 will drive directly to Stop # 2 (Eldorado Quarry). After approximately 1 ½ hours busses 1 and 2 will drive to Stop # 2, and busses 3 and 4 will ferry their participants to Stop # 1. The itinerary is detailed for consecutively numbered stops, with an inset on odometer settings for those going to Stop # 2 first.

The Eldorado Quarry (Stop # 2 excursion) Road Log

0.1	0.1	Left out of parking lot, then right onto Plank Road (Rte 220 BUS).
1.6	1.7	Spring Road Traffic Light.
0.7	2.4	Right onto Rte 22.
0.4	2.8	I-99 underpass.
0.9	3.7	Right on Rte 746N/ 22 BUS.
1.4	5.1	Exit right to I-99.
0.9	6.0	Follow Rte 22 W to I-99 exit.
1.4	7.4	Left on Rte 220 N.
0.6	8.0	Join I-99.
1.3	9.3	**Stop # 2, Eldorado Quarry.** Disembark on road side and cross guard rail into floor of abandoned quarry. Pick up in 1 ½ hours.
0.9	10.2	Exit 31 to Plank Road, south on Rte 22 BUS.
0.3	10.5	Turn off right to Ramada Inn.
0.1	10.6	Ramada Inn parking lot. Follow itinerary below to **Stop # 1, Allegheny Furnace Quarry.**
5.4	16.0	All vehicles reassemble in Ramada Inn parking lot.

The Normal Road Log (Stops # 1, 2, 3, 4 and 5, in sequence)

0.1	0.1	Left and left again (north) onto Plank Road (Rte 220 BUS to Rte 36).
1.7	1.8	Left on Rte 36 N (Sign post to Altoona, on Union Avenue).
0.8	2.6	Right into parking lot behind Altoona Bible Church.
0.1	2.7	**Stop # 1, Allegheny Furnace Quarry.** Disembark in parking lot behind church, the floor of the abandoned quarry. Assemble for an introduction and instructions. Then please distribute yourselves amongst the 5 poster stations to learn what can be seen at each control point on the quarry face. Please take care on the steep slopes, and do not overcrowd the observation points. Departure in 1 ½ hours.
0.9	3.6	Retrace route, left on Union Road (Rte 36 S) and right (south) onto Plank Road.
1.7	5.3	Exit right at Ramada Inn turn off.
0.1	5.4	Ramada Inn parking lot. **Stop # 2. Eldorado Quarry.** Follow itinerary above.
10.6	16.0	All vehicles reassemble in Ramada Inn parking lot.

Itinerary for Stops #3, # 4 and # 5.

0.1	16.1	Left and right from Ramada Inn parking lot onto Plank Road (Rte 220 S).
1.6	17.7	Junction with N. Juniata Road.

0.8	18.5	Left on Rte 22.
1.5	20.0	Right on Rte 36.
0.7	20.7	Left on Chimney Rocks Road.
0.3	21.0	Left on Clupper Lane.
0.2	21.2	**Stop # 3. Disembark at Chimney Rocks Municipal Park, for lunch.** The Keyser - Tonoloway contact is exposed in the quarry wall. You can get a closer view of the basal "calico" member of the Keyser Formation by following the trail above the quarry to the "chimneys". You should spend some time at the "look-out" parapet, at the western side of the park, to learn more about the Devonian Basin to the southwest and the Allegheny Front, to the northeast.
0.2	21.4	Rejoin the busses, and retrace route and turn right on to Chimney Rock Road.
0.3	21.7	Turn left on to Catfish Road (Rte 36 S).
4.5	26.2	Turn right (west) on Rte 164/220 to I-99 S.
0.9	27.1	Join I-99S.
13.6	40.7	Osterburg to right (breached anticlinal valley, exposing deformed Tonoloway strata).
0.4	41.1	Reclaimed Osterburg Quarry (grassy ridge-top).
2.2	43.3	Turn right on Exit 7, to St. Clairsville and Osterburg.
		Stop # 4. St Clairsville Road-cut. Disembark on exit ramp and examine steeply dipping Keyser beds in road-cut**.**
0.4	43.7	Turn right off exit ramp.
0.1	43.8	Then turn left onto William Penn Highway (Rte 220 S).
3.8	47.6	Turn right at Cessna, onto Rte 56 W.
0.3	47.9	Underpass beneath I-99.
2.8	50.7	Apple Bin Restaurant on right.
0.4	51.1	Left on Crissman Road.
0.6	51.7	Cross Valley Road.
1.3	53.0	Crest of ridge (anticline).
0.9	53.9	Left onto Quarry Road
1.1	55.0	Left into New Paris Plant
0.1	55.1	**Stop # 5. New Paris Quarry.** Park near scale station, and walk up and into quarry to the east.
0.1	55.2	Return to busses, exit quarry and turn left onto Quarry Road.
0.2	55.4	South on Quarry Road, then left (east) onto Cuppett Road.
1.0	56.4	Left on Ridge Road (TR-490).
0.3	56.7	Cross Orchard Road.
0.1	56.8	Top end of Quarry.
0.8	57.6	Right onto Crissman Road.
1.3	58.9	Cross Valley Road
0.6	59.5	Right onto Rte 56 (Quaker Valley Road).
3.2	62.7	Left onto I-99/220
3.9	66.6	Exit 7 to St. Clairsville and Osterburg.
2.2	68.8	Reclaimed Osterburg Quarry on left.
14.3	83.1	Exit to McKee's Gap.
7.3	90.4	Exit 31 to Plank Road, south on Rte 22 BUS.
0.3	90.7	Turn off right to Ramada Inn.
0.1	90.8	Ramada Inn parking lot.

STOP 1. FACIES AND CYCLIC STRUCTURE AT ALLEGHENY FURNACE.

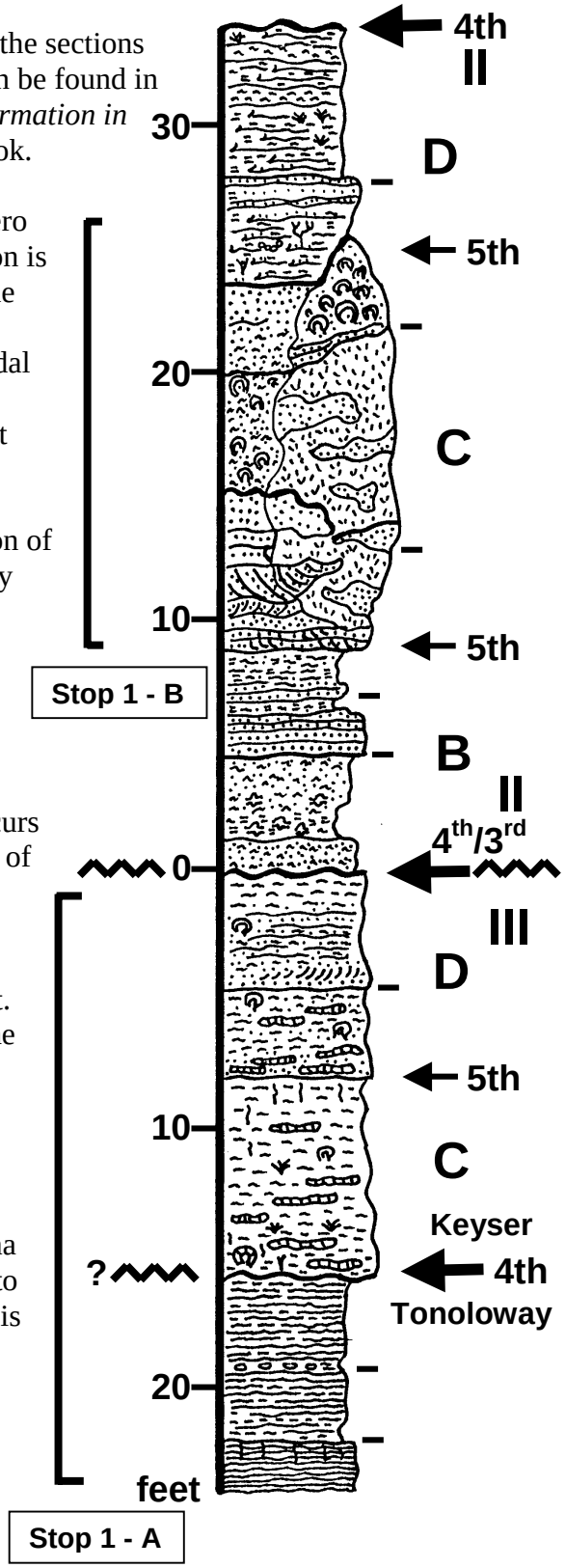
Leaders: Edwin J. Anderson and Cheryl Sinclair

The complete stratigraphic column and legend for each of the sections discussed in the field trip stop portion of the guidebook can be found in the article *Facies and paleoenvironments of the Keyser Formation in the context of its cyclic structure* elsewhere in the guidebook.

A. The 3rd order unconformable boundary occurs at the zero mark on the log. At this position in the section attention is focussed on the two 5th order sequences at the top of the lower Keyser directly beneath the unconformity (Plate 1A). The facies in these sequences are restricted subtidal carbonates containing 'pita bread' stromatoporoids. Tonoloway facies are represented by high intertidal flat dolomitic stromatolites. At St. Clairsville (Stop 4), sequence II - A is well preserved as a thick, coarse crinoidal calcarenite facies in addition to a small portion of sequence I above the 3rd order unconformable boundary (Plate 1C). To the east at the Canoe Creek Quarry, 5th order sequences D and C under the unconformity are nearly doubled in thickness and are represented by a large stromatoporoid bioherm (Plate 1B).

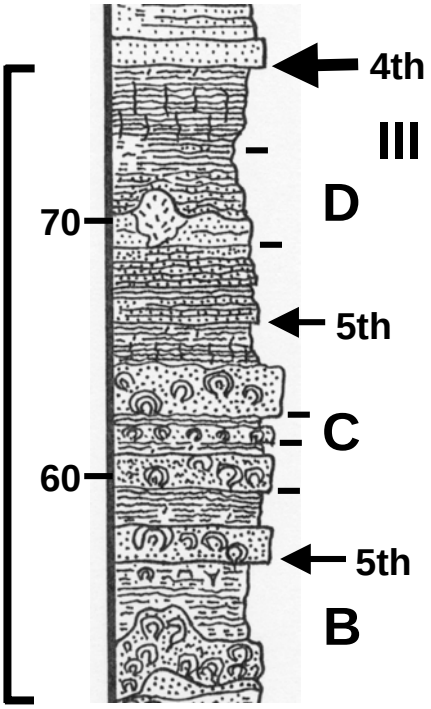
B. A well developed micritic stromatoporoid bioherm occurs between 10 - 25 feet on the log. Note the interbedding of micritic facies with coarse crinoidal calcarenite in the lower half of the mound. This interval, 5th order sequence C, to the north at Tyrone is represented by coarse current bedded calcarenite and to the south at St. Clairsville by finer shelf facies with tempestites. To the east at the Canoe Creek Quarry, 5th order sequence C contains very fine calcarenite with small patches of bryozoans.

C. The lower parts of 4th order sequence III contain abundant stromatoporoids at all localities in the Altoona area except at the Canoe Creek Quarry which appears to have been an a more offshore position. This sequence is more restricted than 4th order sequence II below it and most 5th order sequences within it shallow up to dolomitic intertidal and supertidal facies. Plate 1E (St. Clairsville); Plate 2A and D (Allegheny Furnace) and Plate 2C (Eldorado).



C. continued

At **Stop 1 - C** focus attention first on 5th order sequence C. This sequence consists of four 6th order cycles (PACs), each of which is represented by a carbonate - dolomite couplet. The carbonate portion in each case is a massive Stromatoporoid-bearing calcarenite bed. The lower surface of each of these beds is a sea-level-rise surface or PAC boundary. The upper surface of each is a sea-level-fall surface where dolomitic laminites overlie subtidal facies. At places on these surfaces, stromatoporoids in life position are erosionally truncated. This evidence leads to the interpretation that these surfaces were first subaerially exposed and eroded, and then gradually submerged by ongoing subsidence into the high intertidal zone where the dolomitic laminites were deposited (see Plate 2D).



Stop 1 - C

The base of 5th order sequence D, beginning at 66 feet on the log, is initiated by a finely laminated calcarenite PAC. The second PAC has a series of prominent thrombolitic algal mounds in its basal bed (Plate 2B). These algal mounds (a restricted subtidal facies can be traced laterally to Tyrone and Canoe Creek Quarry (see logs in Anderson et al., this volume and Plate 2E). Sequence D ends in a three-foot-thick interval of flat-laminated, mud-cracked stromatolites deposited in the high intertidal zone. Continue up section through another seventeen feet of tidally dominated cycles to the Keyser-New Creek formational boundary. This boundary is a marked erosional surface that can be traced to an erosional surface at the Manlius-Coeymans formational boundary in the Hudson Valley of New York state. This surface is interpreted as a 3rd order sequence boundary.

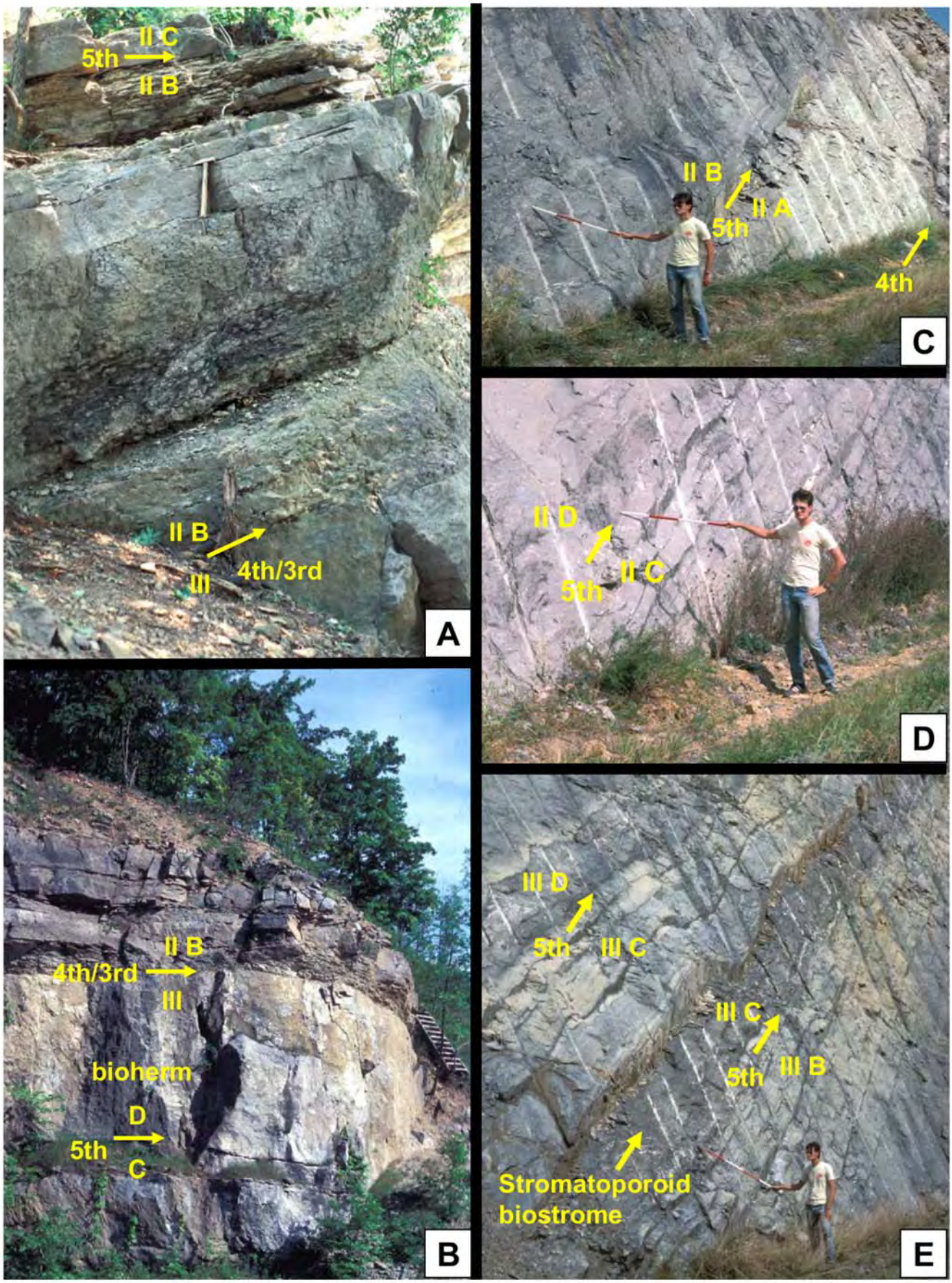

II C
5th
II B
II B
4th/3rd
III
A
II B
5th
II A
4th
C
II D
5th
II C
D
II B
4th/3rd
III
bioherm
D
5th
C
B
III D
5th
III C
III C
5th
III B
Stromatoporoid
biostrome
E

Plate 1

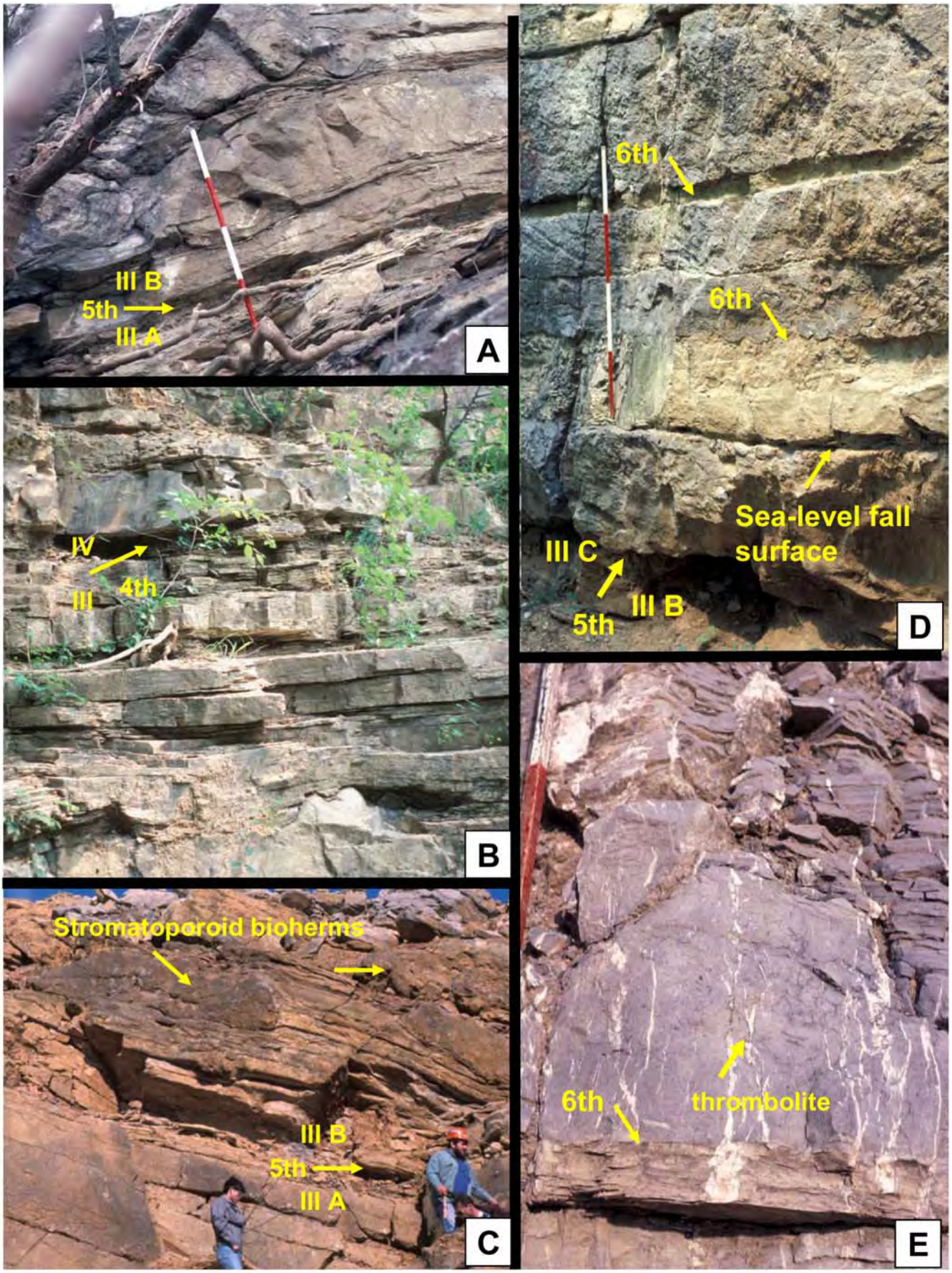

III B
5th
III A
A
IV
III
4th
B
Stromatoporoid bioherms
III B
5th
III A
C
6th
6th
Sea-level fall
surface
III C
5th
III B
D
6th
thrombolite
E

Plate 2

STOP 2 ELDORADO SECTION

Discussants: Frank W. Hall, John F. Taylor, William A. Bragonier

The Eldorado Section is located in the southern outskirts of the city of Altoona, and approximately 3 miles east of the Allegheny Topographic Front, which is easily visible from the section. The section is accessible from the northbound lanes of Interstate 99 (with the safest parking near the Plank Road exit sign). However, parking along the interstate requires prior notification of the State Police (Hollidaysburg barracks). Prior to construction of I-99, the section was part of the east wall of the Eldorado Stone Quarry, located in the Hollidaysburg 15 minute quadrangle studied by Butts (1945). The section consists of cliffs of Silurian and Devonian carbonates and younger siliciclastics dipping gently to the southeast. The following rock units (from the base upward) may be examined at this stop: the uppermost part of the Silurian Tonoloway Formation, the Silurian-Devonian Keyser Formation (Chimney Rocks-proposed, Jersey Shore and LaVale Members) and the Devonian New Creek, Corriganville, Mandata, and Shriver Formations (Figure 1). The latter four units and the overlying Ridgeley Formation are treated collectively by some workers as the Old Port Formation.

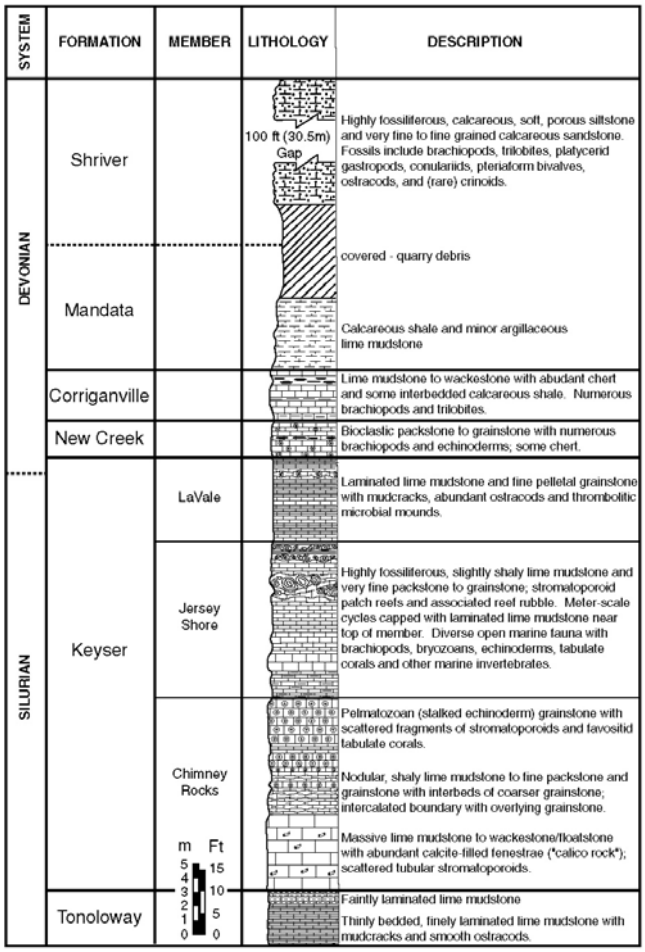


Figure 1. Stratigraphic column for Eldorado measured section along Interstate 99. After Hall (1990).

Four sites (A-D) have been selected at this stop to allow participants to examine specific units and features. Site A is at the base of the cliffs slightly east and just down-slope from the highway. The cliffs are unstable and no attempt should me made to climb them. The physical stratigraphy and structures are best seen from a distance, from the road. The many fallen blocks of rock provide an opportunity to examine all lithologies represented in the cliffs. A footpath ascending the steep slope to the south of the section leads to Site B, where stromatoporoid patch reefs and reef talus in the Jersey Shore Member can be examined. For those choosing not to make the steep climb to Site B, some fallen boulders derived from the reef interval are marked to allow you to examine this facies. From Site B, the path continues south along the slope to Site C, a low cliff where the highest beds of the LaVale Member and sharp contact with the overlying New Creek Limestone are completely exposed. The succession continues at Site C to afford a view of the Corriganville Limestone and lower part of the Mandata Formation. A short distance up the abandoned quarry road to the east is Site D, where cliffs in the Shriver Formation can be sampled for a diverse Lower Devonian fauna. The best collecting is in the talus blocks rather than the cliff itself. A less difficult (although still fairly steep) footpath farther to the south than the one that leads from Site A to Site B allows access to Site D for those not wishing to make the steeper climb.

The dominant structures in the vicinity of the Eldorado Section are thrust faults and third order folds produced by the Alleghenian Orogeny (see Hall, 1990, geologic map and structure section). The strata at

this locality dip gently southeastward toward the hinge of a gentle syncline located about 1,000 feet southeast of the Eldorado Section. The southeast limb of the syncline and an anticline are cut by a thrust trending about N30ºE and dipping about 50º SE, with a stratigraphic throw up to approximately 300 feet (Hall, 1990). Northwest of the section, the strata of the quarry are folded into an anticline verging to the northwest, with the northwest limb dipping 50º to 90º. The hinge of this fold, which plunges 25º S10W, is exposed in the Tonoloway Formation immediately west of and below the southbound lanes of I-99 (Hall, 1990). Numerous joints occur in the section, and contribute to the sliding of the blocks. Some joints are filled with calcite. Near the top of the section, the Shriver Formation is cut by a zone of closely spaced, subvertical joints. The zone is about 10 feet wide, trends N50ºW, and may represent a fracture trace (Gold, 1984).

SITE A: TONOLOWAY AND LOWER KEYSER FORMATIONS

Figure 1 is a stratgraphic column showing the physical stratigraphy of the section at this stop. Figure 2 is a photograph on which the formations and their constituent lithofacies are labeled. Only the uppermost part of the Tonoloway Formation, approximately 12 feet, is exposed here. It consists of well-bedded, laminated lime mudstone, containing mud cracks and little fauna aside from scattered smooth-shelled ostracods. The uppermost subunit, approximately three feet thick, is faintly laminated and is in sharp contact with the overlying Keyser Formation. The Tonoloway was deposited in peritidal enivironments, including arid mudflats, during the Late Silurian sea level lowstand that created evaporites in deeper parts of the Appalachian Basin to the west and north. The massive, pervasively burrowed lime mudstone at the base of the overlying Keyser records a rise in sea level that reduced the salinity, allowing at least some more normal marine organisms to thrive in the area.

The Keyser in this section is about 105 feet thick and is divided into three members, from oldest to youngest: the Chimney Rocks Member (new), Jersey Shore Member, and LaVale Member.

Chimney Rocks Member (proposed) - Formerly misidentified as the Byers Island Member (see discussion for Stop 3 – Chimney Rocks Park), this unit is approximately 46 feet thick here. Depositionally, the Chimney Rocks Member is a transgressive package that represents the regional deepening that submerged the Tonoloway tidal complex and ultimately resulted in normal, open marine deposition that produced the overlying Jersey Shore Member. At the base of the Chimney Rocks Member is a lime mudstone, about 18 feet thick in this section, speckled with numerous calcite-filled veins and fenestrae (vugs). This very high quality limestone, called the “calico rock” by quarrymen, also contains scattered stromatoporoids including a tubular form (*Idiostroma*) that is silicified and weathers in relief in some places to form the “hobnail rock” of quarrymen (Butts, 1945). The calico rock is overlain by shaly, nodular lime mudstone to wackestone that grades upward into pelmatozoan (echinoderm) grainstone. Brachiopods and bryozoans are common; a few favositid tabulate corals are found. In some sections the echinoderm grainstone at the top of the member contains bryozoans, corals and stromatoporoids. Locally these organisms form patch reefs that display well-developed faunal succession (Brezinski and Kertis, 1882; Cuffey and Taylor, 1989). The well-winnowed echinoderm grainstone at the top of the Chimney Rocks Member is also of fairly high quality. This interval, along with the exceptionally pure calico rock, has made this member the prime interval for quarrying historically. Note that in this section, a thrust fault, sub-parallel to the strata with a stratigraphic throw up to approximately 55 feet (Hall, 1990, Figure 9), repeats the Chimney Rocks Member (and locally a small part of the Jersey Shore Member) (Figure 2). All lithologies of the Chimney Rocks Member can be seen at the base of the old highwall and in the many fallen blocks.

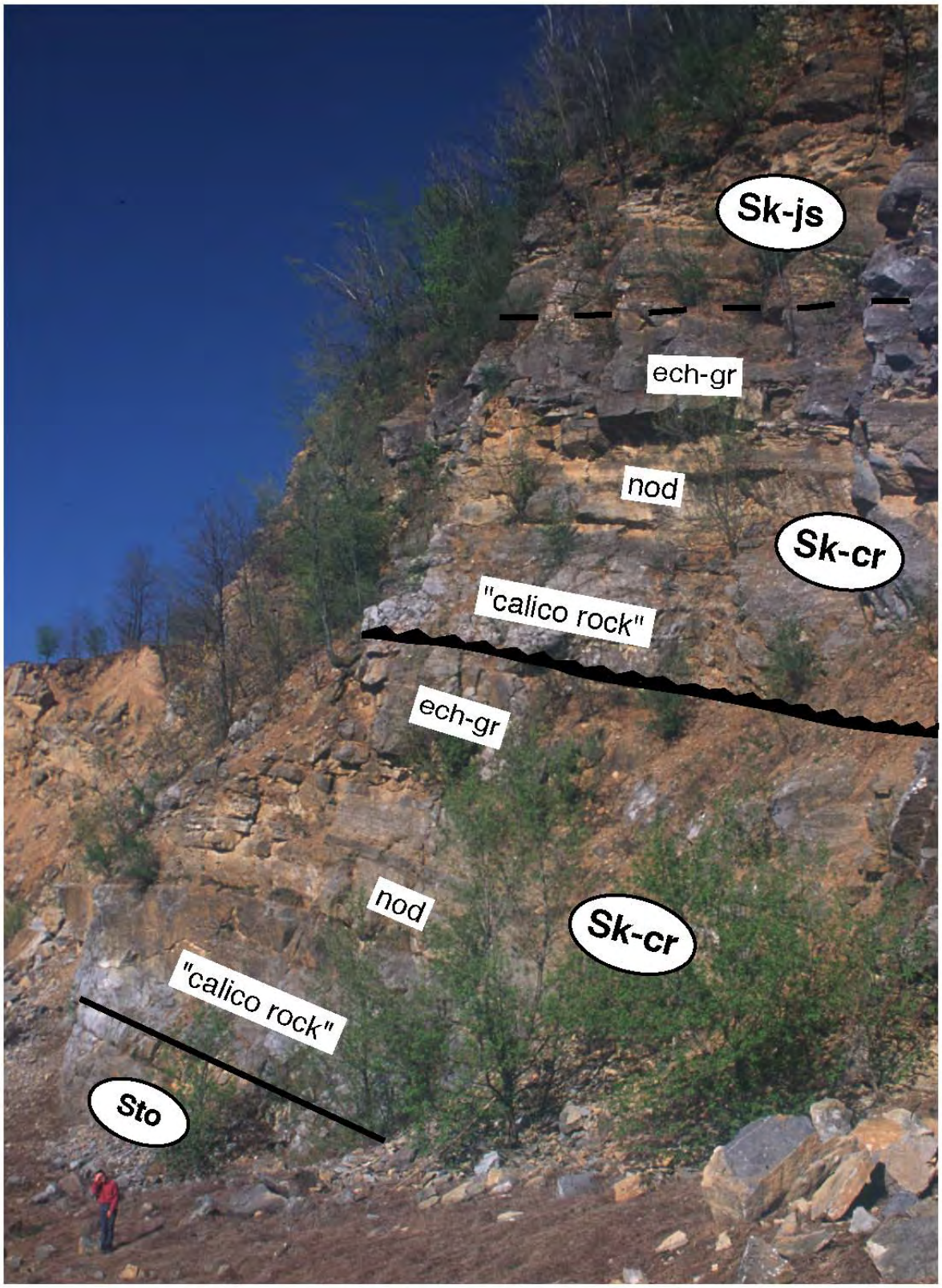


Figure #2 - Physical stratigraphy of the lower part of the Eldorado section along Interstate 99, including the highest beds of the Tonoloway Formation (Sto) and the Chimney Rocks (Sk-cr) and Jersey Shore (Sk-js) Members of the Keyser Limestone. Note intraformational thrust fault that repeats the Chimney Rocks Member.

SITE B: STROMATOPOROID REEFS AND REEF TALUS

The contact between the Chimney Rocks and Jersey Shore Members, marked by the appearance of yellowish shaly partings and a much more diverse fauna, is exposed in the cliff face at this site, as are splendidly preserved small stromatoporoid-dominated patch reefs and some associated reef talus (Figure 3) in the higher member. The Jersey Shore is about 39 feet thick in this section, and comprises abundantly fossiliferous lime mudstone, packstone, boundstone, and some calcareous shale. Fossils include stromatoporoids, brachiopods, bryozoans, echinoderms, favositid tabulate corals, and the slender branching tabulate coral *Cladopora*. A few meter-scale cycles that grade from stromatoporoid boundstone/rudstone at the base to finely laminated lime mudstone caps occur at the top of the member. Directly south of the stromatoporoid reef exposures, a northwest-trending, subvertical fault drops the contact of the Jersey Shore with the overlying LaVale Member about 10 feet.

SITE C: LAVALE MEMBER AND BASAL PART OF OLD PORT FORMATION

The LaVale Member at the top of the Keyser records a relative drop in sea level and return to peritidal deposition similar to that which created the Tonoloway Formation. The LaVale is approximately 20 feet thick in this section and, as elsewhere, consists of finely laminated lime mudstone and fine pelletal

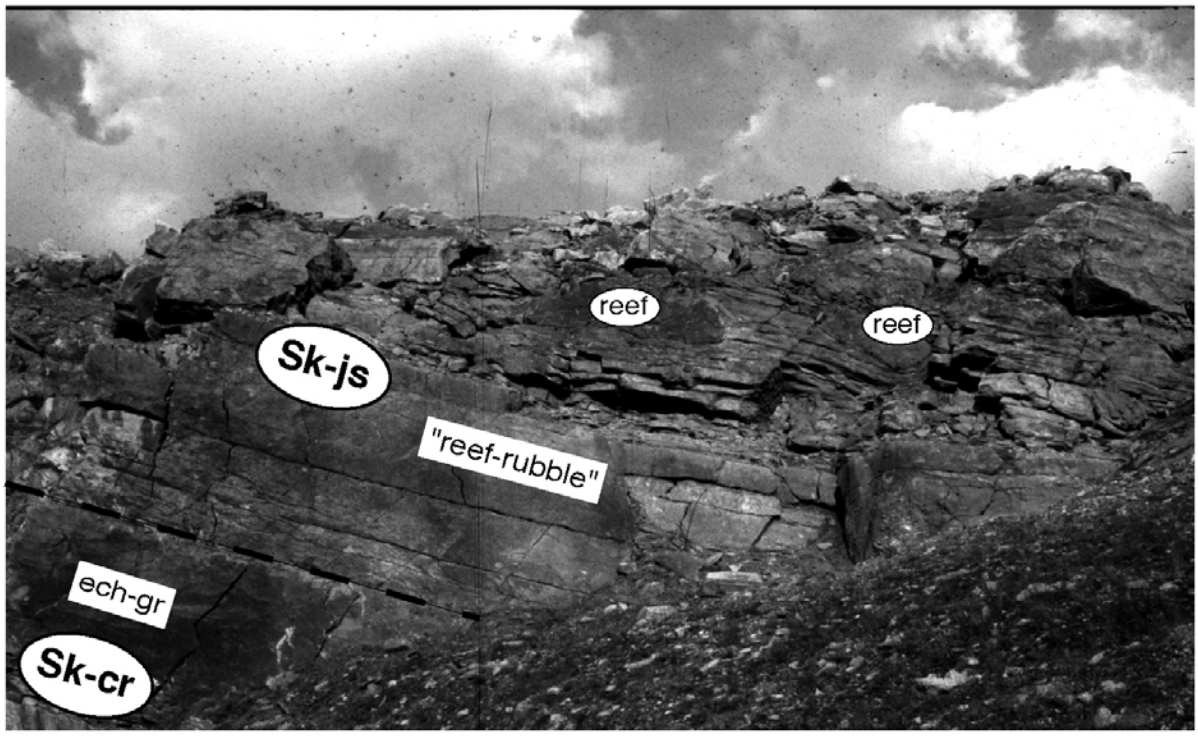


Figure 3. Cliff exposing echinoderm grainstone (ech-gr) at top of Chimney Rock Member (Sk-cr) and isolated stromatoporoid patch reefs and associated reef rubble facies in Jersey Shore Member (Sk-js) at site B.

grainstone with prominent mud cracks and ostracods. In isolated exposures, the LaVale is easily mistaken for the Tonoloway. In some sections, the LaVale contains tall, slender, conical microbial mounds (Figures 4 and 5). Because the internal fabric is clotted, rather than laminated as in stromatolites, these are considered thrombolites. At its sharp, welded contact with the overlying New Creek Limestone the LaVale displays burrows filled with grainstone of the New Creek. Depressed laminae adjacent to some of the burrows suggest that the LaVale was not lithified when the burrows and grainstone were formed; it appears to have been a “firmground”, rather than a well-cemented “hardground”. The Silurian-Devonian boundary is believed to lie not at the formation boundary, but within the upper part of the LaVale Member. In a regional study of conodonts from the Keyser Limestone and its equivalents from New Jersey to West

Virginia, Denkler and Harris (1988) reported the basal Devonian conodont *Icriodus woschmidti* from the highest few feet of the LaVale Member in West Virginia. Although diagnostic Devonian conodonts have not been recovered from the LaVale in central Pennsylvania, they have been from the basal bed of the New Creek. Considering the stressful environments represented by the LaVale and resulting poor yield of conodonts from that unit, it seems likely that the base of the Devonian lies somewhere within the highest part of the Keyser here as well.

The New Creek and Corriganville Limestones are exposed in their entirety at Site C. The New Creek consists of 9 feet of bioclasitc grainstone to packstone, locally lensoidal bedded, and contains some chert lenses and beds. Brachiopods, especially gypidulids, and stalked echinoderms dominate the fauna. The New Creek represents a return to higher energy marine conditions and more normal marine salinity.

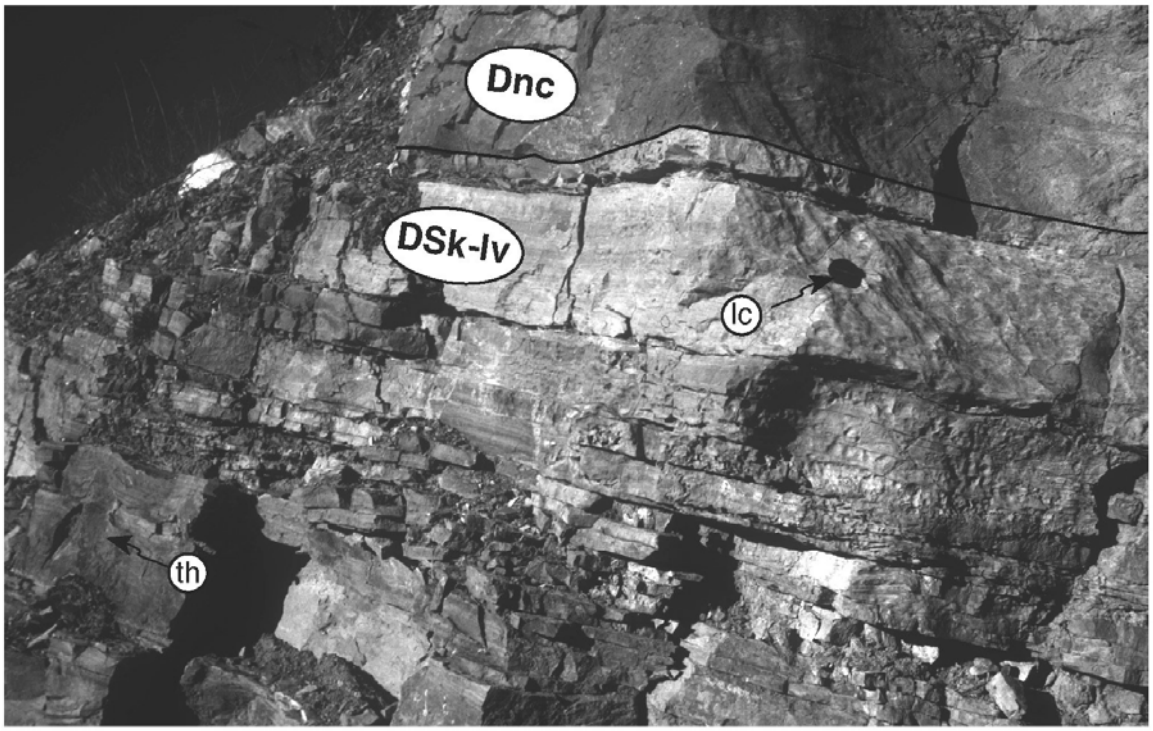


Figure 4. Exposure of contact between Keyser Limestone and overlying New Creek Limestone (Dnc) at site C of Stop 2 showing laminated lime mudstone of Lavale Member (Dsk-lv) of the Keyser, sharp welded contact between the formations, and tall thrombolitic microbial mound (th) in the LaVale. Lens cap (lc) for scale.

Directly overlying the New Creek is the Corriganville Limestone, which consists of 12 feet of lime mudstone to wackestone with abundant lenses and laterally discontinuous beds of chert and some interbedded calcareous shale. The Corriganville yields an abundant and diverse fauna dominated by brachiopods, including *Leptaena rhomboidalis* and *Macropleura macropleura*. Trilobites are also present in modest numbers with dalmanitacean and phacopacean genera dominant. Although they are fairly common and some are large, individual pygidia measuring 3-4 inches across, the trilobites of the Corriganville are not easily extracted from the dense, cherty limestone. Excellent trilobite specimens can be much more easily collected from the Shriver Formation at Site D.

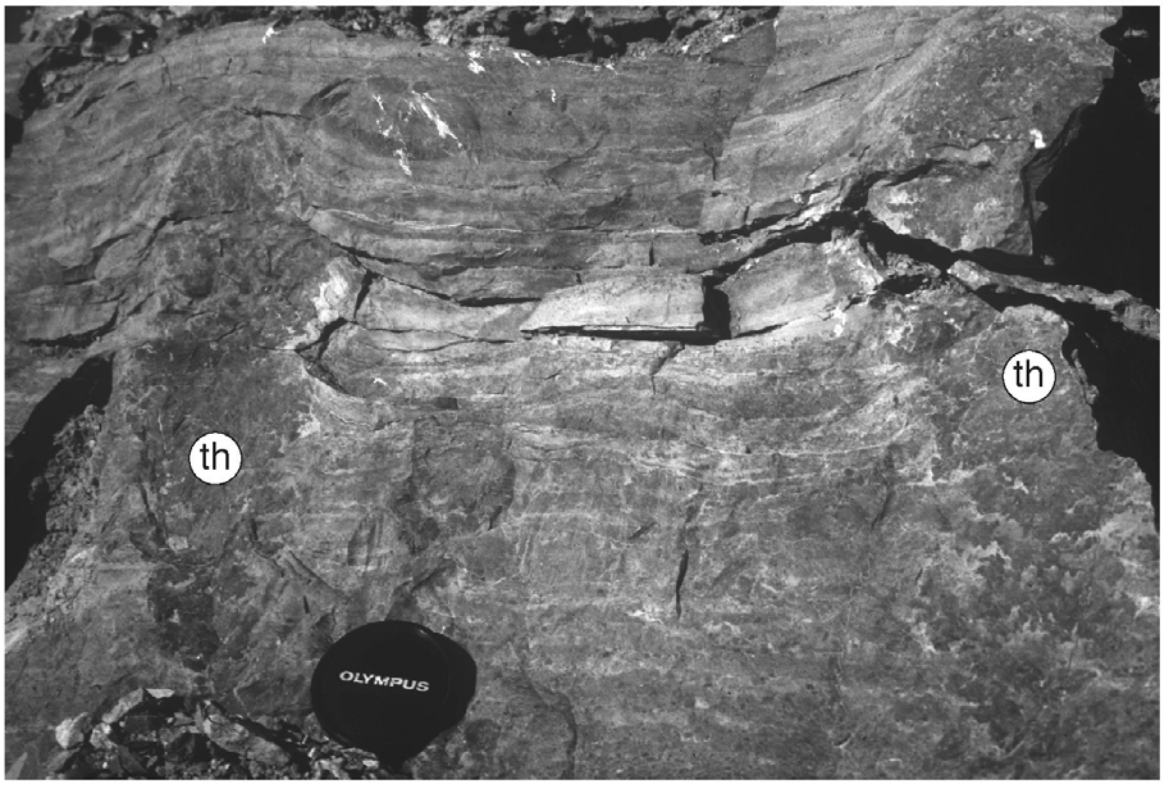


Figure 5. Close-up of thrombolitic microbial mounds (th) in LaVale Member of Keyser Formation at site C in the Eldorado section. The mound at the left is the one shown in Figure 4.

The Corriganville also contains several altered volcanic ash beds or "bentonites". Bald Hill Bentonites A and B (Smith et al., 1988) have been tentatively located within shaly intervals 2.0 and 10.5 feet (respectively) above the base of the Corriganville in this section. Bald Hill Bentonite C (Smith et al., 1988) is tentatively located 1.65 feet above the base of the Mandata in the section. Metcalf (1993) traced these altered volcanic ash beds southward from Bald Hill in Blair County to Black Oak Ridge in Bedford County, a distance of approximately 25 miles. She found that the bentonites, which can be distinguished by their trace element compositions established by X-ray fluorescence, climb in the section from north to south, demonstrating that the boundary between the Corriganville and overlying Mandata Formation is not isochronous as predicted by Goodwin and Anderson (1985, 1986) who interpreted that contact as one of their PAC boundaries.

The Mandata Formation is estimated to be approximately 30 feet thick in this area. Only the lower 17 feet of the dark calcareous shale and minor argillaceous limestone that compose this unit are exposed at Site C. It clearly represents significantly deeper depostion than the underlying carbonate units, thus continuing the deepening trend reflected in the contrast in lithologies between the New Creek and Corriganville. However, the Mandata contains fossils of benthic (bottom-dwelling) marine invertebrates, some of which are pyritized. This indicates that the bottom waters still contained sufficient oxygen to allow some animals to survive there, although the preserved organic matter in the dark shales confirm anoxic conditions within the sediment. In other words, the environmental conditions on the sea floor during Mandata deposition were dysaerobic, rather than anaerobic.

SITE D: THE SHRIVER FORMATION

Approximately 120 feet of the Shriver Formation are exposed in the cliffs at this site. In this section the Shriver consists of very weathered (originally calcareous), yellowish brown, soft, porous siltstone and fine grained sandstone. Some parts of the formation, which clearly represents shallower conditions than the Mandata, are highly fossiliferous. The diverse macrofauna includes calcareous and phosphatic brachiopods,

numerous trilobites, platycerid gastropods, conulariids, pteriamorph bivalves, and a few crinoids. The fossils are most easily recovered by breaking up blocks from the talus. The commonest trilobite is a large dalmanitid, but a few other groups are also represented, specifically at least one phacopid, one proetid, and the aberrant calymenid *Dipleura*. The spririferids dominate the brachiopod fauna. Although the coarser grain size of the sediment suggests higher energy conditions, the fossil preservation indicates minimal disturbance and reworking of bioclasts. Most brachiopods remain articulated, some articulated "molt ensembles" (intact but slightly displaced thorax/pygidium arrays) have been found, and ellipsoidal clusters of ostracod valves (of uncertain origin but unlikely to survive much disturbance of the sediment) are common. In contrast to the minimal biostratinomic overprint, the fossils reflect an active and taxon-specific diagenetic history. The trilobites are entirely moldic; all skeletal calcite has been dissolved away. The brachiopods and large platycerid gastropods have much of the calcitic shell material preserved but other parts are silicified, usually displaying well-developed "beekite rings". Surprisingly, a very small number of the platycerid gastropods display thin longitudinal bands that probably are preserved original color banding. The upper part of the Shriver and the overlying Ridgeley Formation (sandstone) are not exposed in this section.

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STOP 3 and Lunch. CHIMNEY ROCKS PARK

Leaders: John F. Taylor, William A. Bragonier, and Frank W. Hall

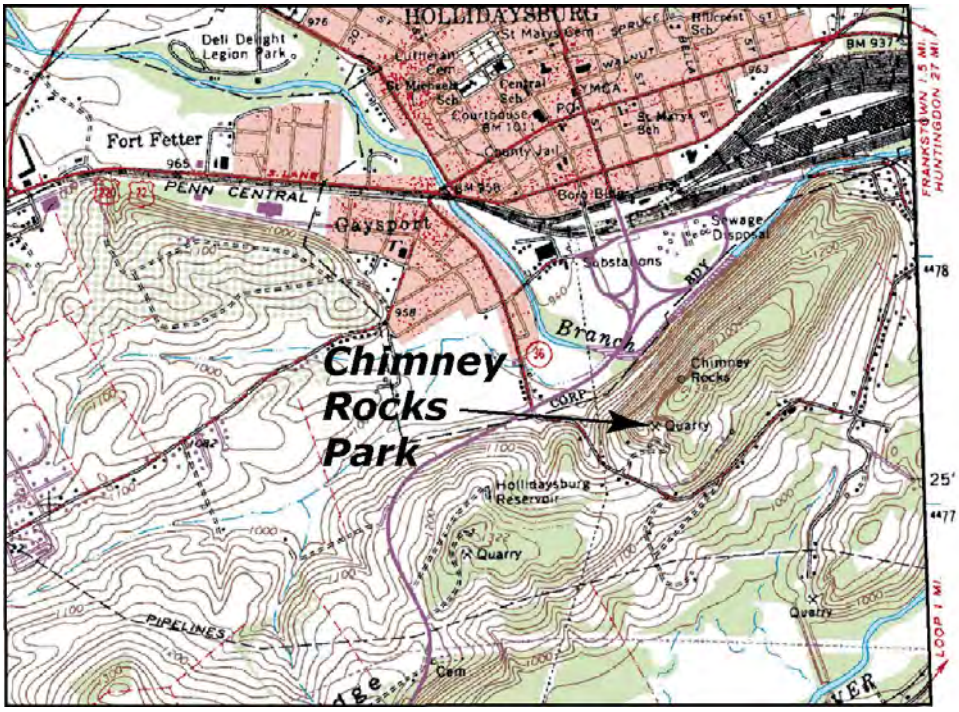

Figure 1. Location map for Chimney Rocks Park (Stop 3).

The Chimney Rocks, a series of limestone spires that adorn the western flank of Catfish Ridge, 0.7 miles south-southeast of Hollidaysburg, are prominent features visible from a distance at all times of the year. The ridge is supported by the Keyser Limestone, which is somewhat more resistant than the underlying Tonoloway Formation and overlying Old Port Formation. The Chimney Rocks themselves, and an abandoned quarry in the Keyser and Tonoloway Formations at the south end of the ridge, have been incorporated into a city park that will serve as our lunch stop. The old quarry wall, preserved at the north end of the picnic area, provides an opportunity to discuss relatively fine-scale lithostratigraphy within the Keyser and some small, intraformational faults, one of which is responsible for the development of the Chimney Rocks. There are three sites within the park that are described below. Site A is the main quarry/picnic area where the entire group will have lunch and be introduced to the lithofacies and members of the Keyser at this location. Sites B and C, accessible for individuals who are able and willing to hike roughly a quarter mile up a steep gravel road that winds its way to the top of the ridge, will allow you to examine the Chimney rocks from their base and top, respectively. Many of the lithologies that characterize the units described and illustrated in Figures 2 and 3 can also be seen in the large blocks that have been lined up between the picnic area and the old highwall, as well as the boulder on which the commemorative plaque has been mounted at the entrance. Because this is a park, no hammering or collecting is permitted. All units that we will see here can be sampled at other stops. For safety sake, please also refrain from climbing the old highwall.

SITE A: THE HIGHWALL

Exposed in the highwall are the highest beds of the Tonoloway Formation, all of the basal member of the Keyser and the basal beds of the middle (Jersey Shore) member of the Keyser. A photograph of the eastern two thirds of the highwall, with the units labeled, is provided as Figure 2.

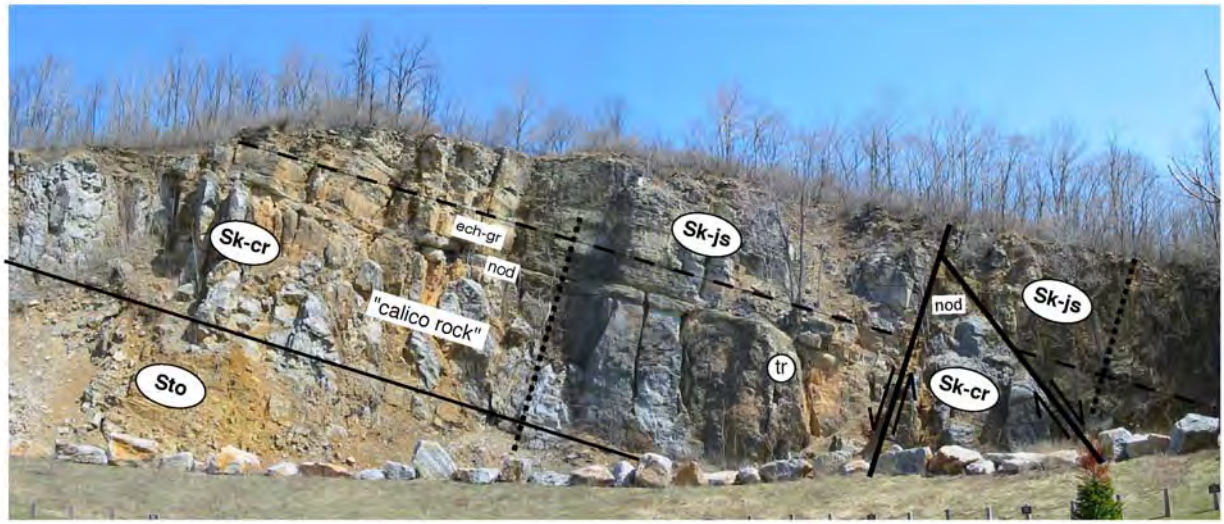

Figure 2. Chimney Rocks Park section in highest Tonoloway Formation (Sto) and Chimney Rocks (Sk-cr) and Jersey Shore (Sk-js) members of the Keyser Limestone. Vertical (stratigraphically) dashed lines denote line of measured section provided in Figure 3. Three components of the Chimney Rocks Member (new), in ascending order, are "calico rock", nodular shaly limestone (nod), and echinoderm grainstone (echin-gr). A small area of the highwall is coated with travertine (tr) from a small cave exposed when this was an active quarry.

Figure 3 is a stratigraphic column showing the lithologic packages recognized in this section. The primary target of the quarry was the lower member of the Keyser Formation, a unit that has been incorrectly identified as the Byers Island Member in earlier studies (Brezinski and Curtis, 1985; Denkler and Harris, 1988; Cuffey and Taylor, 1989; among others). Although it occupies the same stratigraphic position, above the Tonoloway Formation and below the Jersey Shore Member of the Keyser, and does contain some intervals of nodular limestone, which dominates the true Byers Island Member farther to the east and south, this basal package in the westernmost valley of the Valley and Ridge Province in Pennsylvania is distinctly different lithologically (and faunally) and is here referred to as the Chimney Rocks Member.

Throughout its area of exposure, roughly from Tyrone to St. Clairsville (north to south), the member is a persistent triad comprising (1) a very pure, massive basal lime mudstone to wackestone with numerous calcite-filled vugs (the “calico rock” in miners’ terminiology), (2) a middle nodular, shaly interval (“lumpy limestone”) with minor bioclastic grainstone interbeds in some sections and (3) an echinoderm grainstone package of variable thickness at the top of the member. The lower two units are well-developed at this location, but the capping grainstone is anomalously thin and more fine-grained than it is in most sections. For this reason, this section was not selected as the type section. Instead, the Altoona Bible Church (Allegheny Furnace) section in Altoona, whichwe visited this morning, is designated as the type section for the Chimney Rocks Member. The basal contact with the Tonoloway Formation, marked by the disappearance of the characteristic fine laminations and well-developed stratification of that formation, is fairly sharp. The upper contact with the Jersey Shore Member, defined by a significant increase in the amount of yellowish shaly material and by the appearance of a much more diverse marine invertebrate fauna, is sharp in some sections but in others is gradational and less easily placed. That boundary was particularly difficult to place here in the Chimney Rocks section where the capping grainstone interval is not as well-winnowed as it is in most sections and the dashed lines in Figure 2 mark the approximate location of the base of the Jersey Shore Member on either side of a small horst of the Chimney Rocks Member near the eastern end of the highwall. The higher concentrations of shaly material, and the appearance of significant

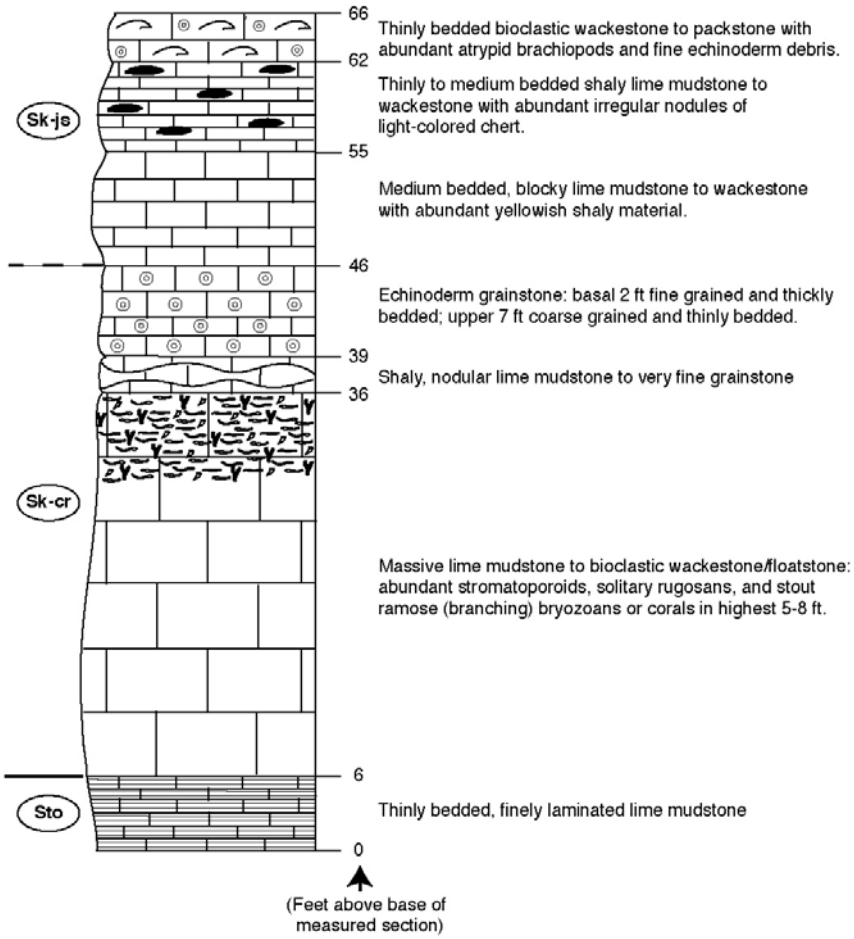

Figure 3. Stratigraphic column of highest Tonoloway and lower Keyser Formations at Chimney Rocks Park measured along line of section indicated in Figure 2.

quantities of chert in the beds assigned to the Jersey Shore Member appreciably diminish the quality of that part of the formation for mining at this location. The relatively thin interval assigned to the Jersey Shore Member here requires some climbing to examine and is rather unremarkable as compared to the strata that represent that member in the other sections included in today's intinerary. For these reasons, we will examine only the Tonoloway and Chimney Rocks Member at this locality.

The calico rock is approximately 30 feet thick here and displays some internal variation in lithology and fauna. As elsewhere, it contains a fauna whose diversity is intermediate between that of the impoverished to non-existent fauna of the Tonoloway and the rich, open marine assemblage of the Jersey Shore Member. Fossils are most abundant in the highest 5-10 feet of the calico rock where stromatoporoids of various size and shape and numerous corals and bryozoans weather out on the surface. It is this restricted distribution of fossils that led to the discovery of a small intraformational fault that is responsible for the development of the Chimney Rocks. The small fault strikes approximately N50-60ºE and is nearly vertical at the surface. Figure 4 is a cross-section that depicts one of the Chimney Rocks and its relationship to the small fault that bounds it on the upslope (southeast) side.

The Chimney Rocks, referred to as the Tower Rocks in some early publications (e.g., Butts, 1945), are composed of the highest 8-10 feet of the Tonoloway Formation and the lower 15-20 feet of the resistant overlying calico rock on the upthrown, northwestern side of the fault. Although the vertical offset along the fault is at most only 15-20 feet, it was sufficient to place the more easily eroded nodular bed and overlying grainstones of the upper Chimney Rocks Member on the southeastern side opposite the resistant calico rock. Over time, the grainstones down-wasted more rapidly, leaving the resistant, relatively narrow sheet of calico rock standing in relief. Dissolution along a well-developed set of joints that strike N15ºW led to the isolation of portions of the resistant, upthrown sheet of rock into the "chimneys" that exist there today. Without the very detailed, sub-member scale description of the units, which allowed recognition of upper calico rock faulted against lower calico rock, the structural control on the development of the Chimney Rocks would not have been discovered.

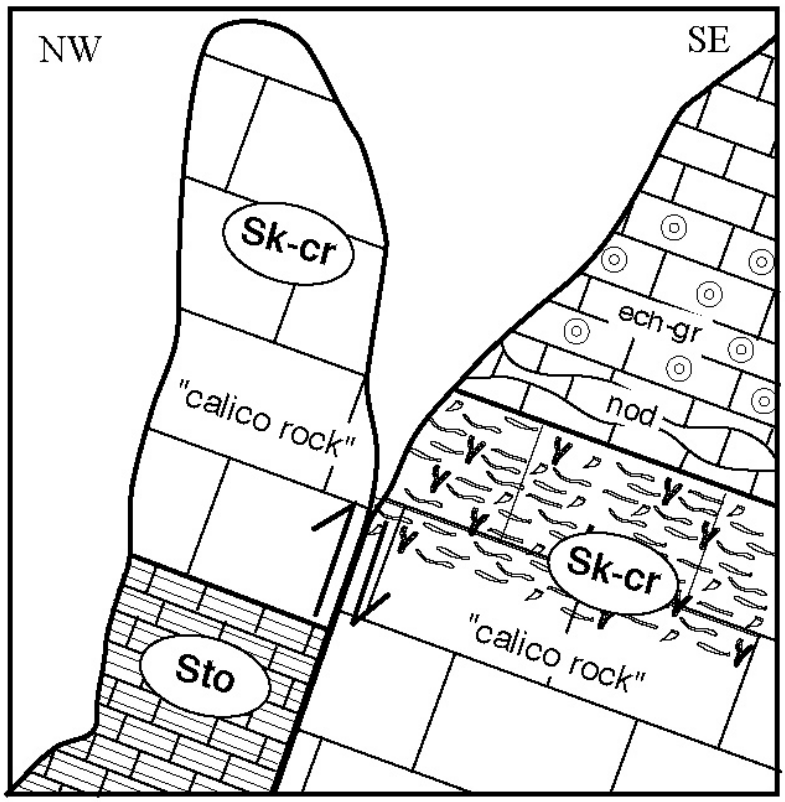

Figure 4. Cartoon cross-section showing the relationship of the formations and members across the small, high-angle fault that led to the development of the Chimney Rocks where the massive beds at the base of the Chimney Rocks Member (Sk-cr) were uplifted to lie opposite less resistant overlying grainstones at the top of the member. See Figure 5 for actual photograph of this chimney.

SITE B: BASE OF THE CHIMNEY ROCKS

Following the steep winding road that leads from the southeast end of the picnic area up toward the top of the ridge, you will find a side-trail that is marked as leading to Site B. (It is actually the second trail to the left; the first one leads to an overlook at the top of the highwall.) At Site B you can examine the base of the more southerly of two isolated, cylindrical chimneys (Figure 5) and see the contact between the Tonoloway and Keyser Formations near its base. This is the chimney depicted in Figure 4.

The footpath immediately above (uplsope from) the chimney marks the location of the fault. The beds cropping out in the slope behind the chimney are fine grainstone of the upper Chimney Rock Member. To the south is another outcrop that does provide a view of the fault itself (Figure 6). Although not developed into a full, towering chimney, the spur of rock to the northwest of the fault exposes the Tonoloway-Keyser Contact and the basal 10-12 feet of the calico rock. That stratigraphy does not carry over to the southeast across the vertical fracture that bounds the spur on the upslope side; rather, the abundance of stromatoporoids visible on the weathered surface of the rocks to the southeast identify them as the uppermost part of the calico rock, as do the grainstones that crop out on the slope immediately above them. The vertical fracture is the small “Chimney Rock Fault”, which extends out into the air to the south as the northwest face of the ridge curves farther to the east. Understandably, from this point south there are no more chimneys because erosion has removed all the calico rock on the northwest side of the fault.

SITE C: TOP OF THE CHIMNEY ROCKS

Returning to the winding road up onto the ridge, complete the climb to the overlook on top of the northernmost calico rock outcrops where you’ll find a metal railing and a plaque describing the anthropological significance of this overlook. Visible on the upper surface of this portion of the upthrown northwestern block is the concentration of stromatoporoids and corals at the top of the calico rock that you saw on the downthrown side at Site B. The northeast-striking joints along which dissolution has been concentrated to isolate the chimneys to the south are conspicuously displayed here as well.

Figure 5. View looking northeast at the more southerly of two isolated, cylindrical "chimneys" composed of the lower part of the "calico rock" (Sk-cr) at the base of the Keyser Limestone and the highest few feet of the underlying Tonoloway Formation.

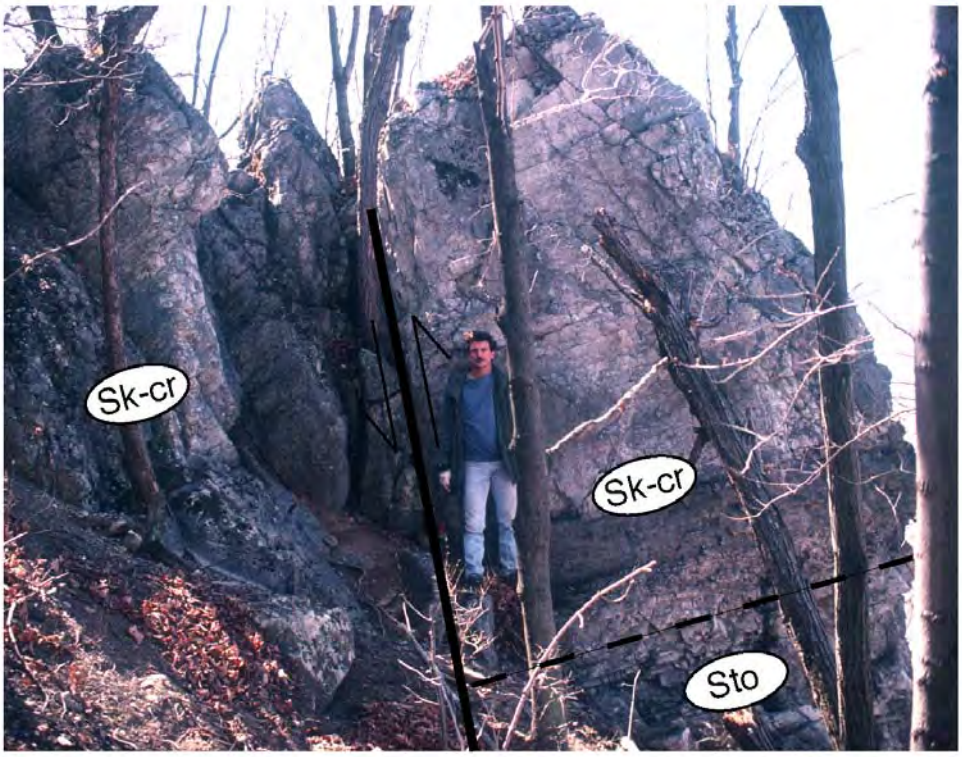

Figure 6. View (looking southeast) of the outcrop at Site B, directly south of the "chimney" shown in Figures 3 and 4, in which the very steeply dipping fault (thrust/reverse? - dip angle and direction not established with certainty) that created the Chimney Rocks is exposed. Note how the fault has brought the lowest 10-15 feet of the Chimney Rocks Member on the northwest up to the level of the highest, stromatoporoid-coral-rich 5-10 feet of the "calico rock" on the southeast.

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Chimney Rocks Scenic Overlook (lower level), Hollidaysburg, PA
(and lunch)

General Geology and Physiography of the Allegheny Front

Discussant: Robert J. Altamura

Two of the 6 areas of distinct geology and physiography in Pennsylvania can be seen from the Chimney Rock overlook near Hollidaysburg: the Ridge and Valley and Appalachian Plateaus provinces.. These provinces are characterized by landscapes that resulted from millions of years of erosion, principally by running water, but also from the effects of glaciation. Variations in topography reflect the differences in resistance to erosion and structural deformation of different lithologies and structural deformation. Each area, in addition to being a physiographic province, is a geological region (*i.e*., terrane) that reflects the role of plate tectonics in the geologic history of Pennsylvania.

From about 450 to 250 million years ago, during the Paleozoic Era, several crustal plates, including Africa and Laurasia, collided with the Proto-North American plate to create the Appalachian Mountains and the supercontinent Pangea. The collision deformed and even metamorphosed both the continental rocks of Proto-North America and the oceanic rocks and sediments of the intervening ocean (the Iapetos Ocean) between. Mountains that were created by the collision yielded large volumes of sediment which were deposited in the Appalachian forearc basin. These sediments were folded and faulted during the Allegheny orogeny.

Shortly after the collisions ended, at the beginning of the Mesozoic Era about 235 million years ago, plate-tectonic processes reversed. Pangea began to break apart, initiating the embryonic opening of the Atlantic Ocean. During the early stages of breakup, rift basins formed along and on both sides of the zone where the Atlantic finally opened. The Gettysburg-Newark terrane in southeastern Pennsylvania is the eroded remnant of one of these rift basins. It contains 200-million-year-old sedimentary rocks (including brownstone) and intrusions of diabase (trap rock).

The theme of this year's field conference, "Geology on the Edge," refers to the terrane boundary that also serves as the physiographic boundary between the Ridge and Valley and Appalachian Plateaus province. From the overlook, one can look west from the Valley and Ridge province to the Appalachian Plateau, across the Allegheny front. Plate collision during the later stages of Appalachian mountain-building resulted in folding and thrust faulting of the sedimentary rocks of the Appalachian basin. This deformation was greatest in the Valley and Ridge province, but also affected rocks of the Appalachian Plateau, although to a much more limited extent.

The "Allegheny Front" separates the two terranes and is believed to represent the subsurface ramping of a regional horizontal detachment plane (or décollement) from deeper Cambrian strata in the Valley and Ridge to the Silurian salt beds of the Salina Group. It is this transition that is largely responsible for the distinct change in both structural and physiographic characteristics across the "Front" (see Scanlin and Engelder, this volume).

LUNCH

The Juniata River Canal and Hollidaysburg Canal Basin

Discussant: John A. Harper

Hollidaysburg, established in 1796, was essentially a tavern stop on the Huntingdon, Cambria and Indiana Turnpike in the early 1800s when the Pennsylvania Canal Commission began to plan for the cross-state canal system. It was too far out in the frontier area to be of any significance. Frankstown, which lies about two miles northeast of Hollidaysburg, was to be the original selection for the western terminus of the Juniata River Canal. But that all changed because of one reluctant farmer.

Frankstown lies at the confluence of the Little Juniata and Frankstown Branches of the Juniata River* and was a natural location for a canal basin. As Jacobs (1845) tells the story, the most advantageous place for the basin was on the farm of Jacob Wertz but, for whatever reason, he refused their offer of $10,000 for the land. Perhaps he was greatly attached to the land, or didn't like progress, or was holding out for a larger sum. Whatever the reason, Wertz refused to sell. John Blair, who lived at Blair's Gap at the foot of Allegheny Mountain (about 2½ miles west of Hollidaysburg), used his influence as a member of the Pennsylvania Legislature to have the basin relocated to Hollidaysburg. Many people argued that there wasn't enough water in the Beaverdam Branch at Hollidaysburg to operate the canal. However, in 1831 the Canal Commission agreed with the new location for the basin, and hundreds of laborers and builders, engineers, and stonemasons poured into the area to dig the canal, build the Portage Railroad, and cut the stone for the numerous related structures.

When the Western Division of the Pennsylvania Mainline Canal opened in 1831, Hollidaysburg (Figure 1) developed into an important inland shipping terminal and transfer point. Within five years it grew from a tiny frontier village with a population of 76 to an inland seaport with a population of about 3,000. The town became a major commercial gateway between the Atlantic seaboard and the western frontier. Hollidaysburg became the county seat of Blair County in 1846. Altoona soon became more important commercially, thanks to the Pennsylvania Railroad, which established a major base of operations there in the 1850s. However, Hollidaysburg continued to play an important role through most of the 20th century as a commercial, industrial, and governmental center for the region (Borough of Hollidaysburg, 2001a). Many of the canal-era buildings still survive in Hollidaysburg, providing interesting studies for historical architecture buffs.

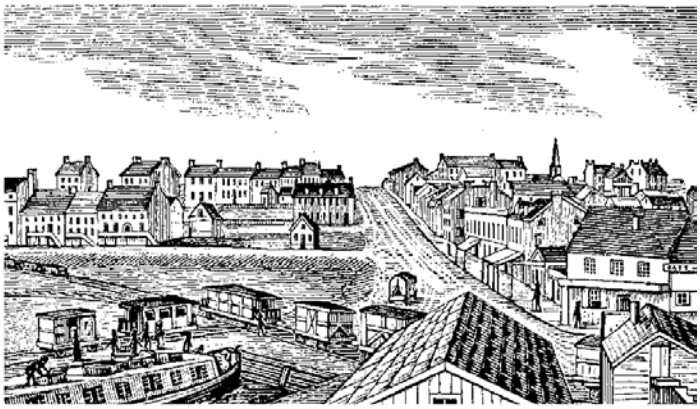


Figure 1. Old lithograph of Hollidaysburg, circa 1840, showing the canal basin and Portage Railroad in the lower left quarter (from Baumgardner and Hoenstine, 1952).

The Juniata Canal came into Hollidaysburg along Juniata Street (Figure 2, A), parallel to US 22. The Hollidaysburg Canal Basin consisted of three interconnected basins (Jacobs, 1945). The main basin, which was 1,695 feet long, 120 feet wide, and six feet deep, extended along South Juniata Street from Montgomery Street to Jones Street (B) (approximately where PA 36 now

*"Juniata" is a corruption of "Oneida," an Indian word meaning "standing stone." Tradition says the Oneida tribe revered a l4-foot high ceremonial stone decorated with engraved petroglyphs.

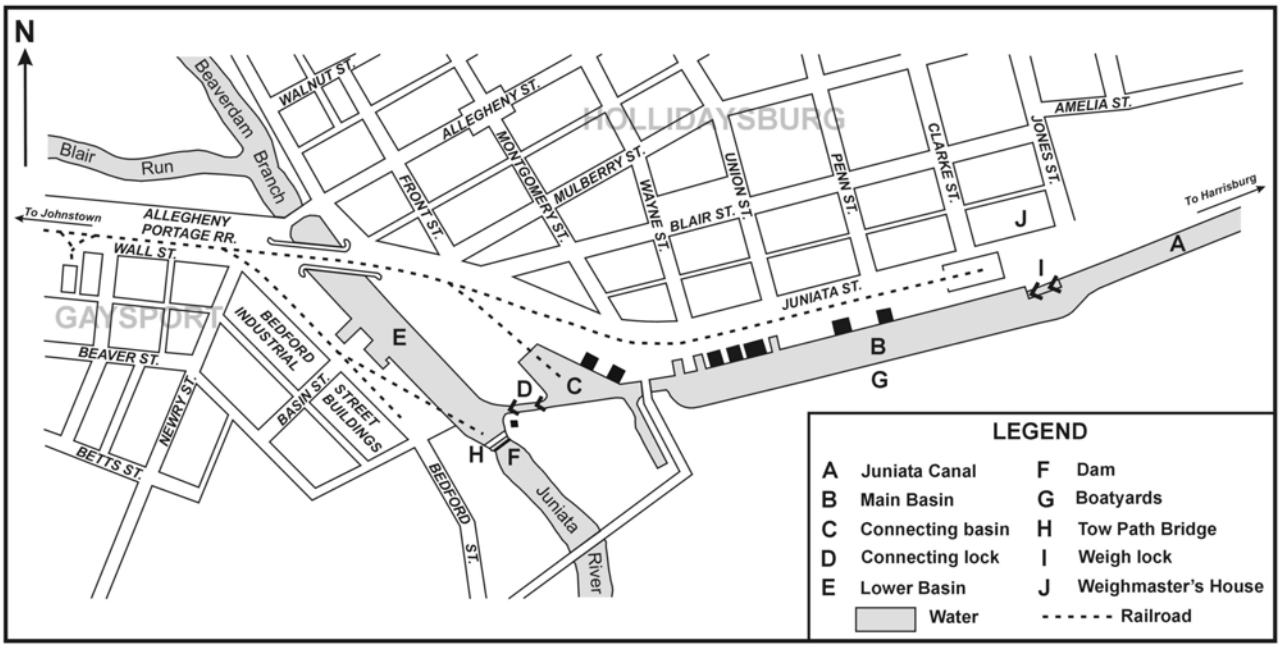


Figure 2. Map of the Hollidaysburg canal basins(courtesy of the Allegheny Portage Railroad National Historic Site).

crosses the Conrail yards). A 600-foot canal segment with a small basin situated at the west end of the main basin, just below the present day intersection of Juniata and Montgomery Streets (C), connected these two basins with a lock to a smaller basin located just below what is now Juniata Street (D). This small basin and canal segment connected to a lower basin by a lock. The lower basin, which was situated along Bedford Street in Gaysport, essentially where the Canal Basin Park is now located (E), was about 1,100 feet long and 120 feet wide. A dam or weir on the Juniata River just downstream from the upper basin (F) helped maintain the water level in the basins and the canal.

Canal boats proceeded into the main basin along the canal. At the main basin, the boats were either unloaded onto the various wharves that were located along the basin margin or passed into one of the other basins for unloading onto the Portage Railroad. Railroad tracks actually ran down into these two canal basins in order to facilitate the easy transferral of boats to the railroad (Jacobs, 1945). The south side of the main canal basin (near the present PA 36 cloverleaf) was occupied by three boatyards where boats were built and repaired (G). The towpath crossed a bridge over the Juniata River just northwest of the dam (H). The canal weigh lock (I) was situated at the foot of Jones Street, and the weighmaster lived in the brick house on the northwest corner of Juniata and Jones Streets (J) (Jacobs, 1945). A boat was weighed by running it into a lock at either end and fastening the lock gates to make them as watertight as possible. Then they drained the water. At that point, the boat would be resting on large scales where it could be weighed as accurately as it could be on land. The section adjacent to the canal was a typical seaport, with businesses servicing the canal workers and travelers.

Juniata canal boats could carry 60 to 80 tons of freight and/or people. The typical boat was about 80 feet long, 14 feet wide and 7½ feet deep. The horses and mules that pulled the boats along the canal were stabled in the bow of the boats, the cabin and bunks were in the stern, and the cargo was stored in the hold in the center. A new Juniata boat cost about $1,000 (Jacobs, 1945).

The port of Hollidaysburg was a very busy place, with one boat arriving about every 20 minutes (Jacobs, 1945). The number of passengers and the amount of freight coming into Hollidaysburg required the building of boat slips and docks, large warehouses and freight-forwarding houses, and hotels and taverns that catered to boatmen and travelers alike. At the height

Figure 3. Canal boats were built in sections to allow them to be moved relatively easily from canal to railroad and back. This illustration, by Philip J. Hoffman, shows the railroad crossing the Ebensburg Branch Viaduct near the village of Wilmore, Cambria County (from Shank, 2001).

of the canal's popularity there were five large forwarding warehouses on the north bank of the basin. In the early days of the canal, boats were unloaded at the docks and the freight and passengers transferred to railroad cars for the trip across the mountains. The invention of sectional canal boats (Figure 3) improved this process immeasurably by allowing the boat sections to be hauled out of the water, disassembled, and placed on trucks (railroad undercarriages). After the trip to Johnstown the boat sections were reassembled and continued down the canal to Pittsburgh.

Freight shipped separately was loaded onto boxcars (similar to the passenger car shown in Figure 4) by brute strength. Railroad workers often worked all night loading cars. And then, in the morning they traveled by rail the 36 miles over the Allegheny Mountains to Johnstown where they had to unload the cars. At times they must have worked 72 hours with their only rest, if you can call it that, being the ride to Johnstown. One canal boat loaded with freight could fill as many as 12 boxcars, making two trains of five or six cars each (Jacobs, 1945).

Passengers and freight weren't the only things the canal brought to Hollidaysburg. Many cases of ague, euphoniously called the "Juniata Jigs" by some newspaper wags, arrived during warm weather; and when it took a strong grip on a man "he shook 'til his teeth rattled." Hollidaysburg's apothecaries kept busy selling quinine and bitters as cures for the disease (Jacobs, 1945).

During the apex of its operation, the canal basin and railroad handled between 215 million and 255 million tons of freight annually, bringing about $115,000 per year to the state coffers

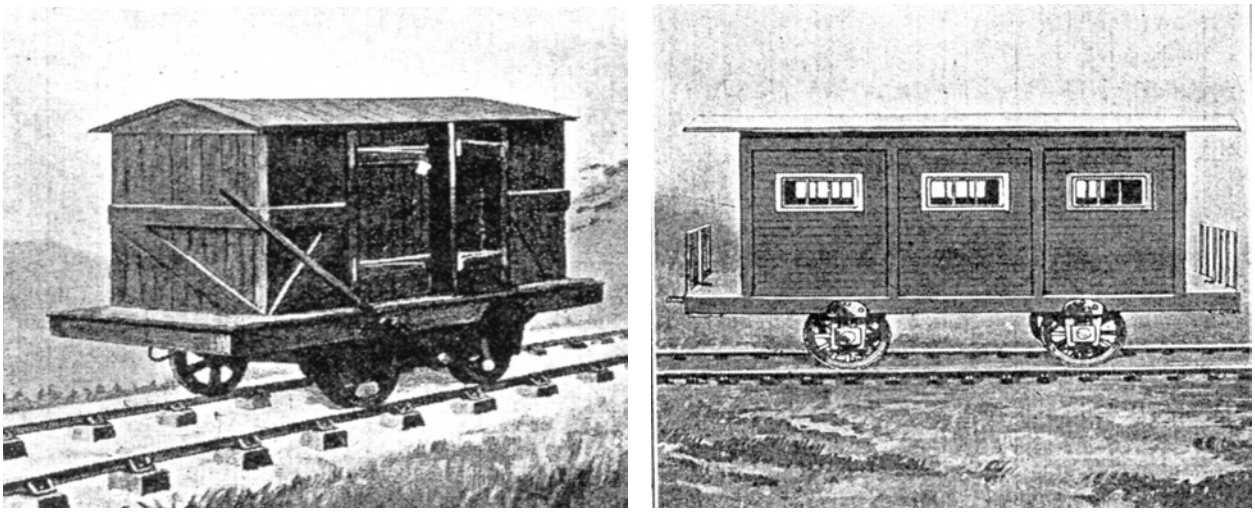


Figure 4. Early rail cars on the Portage Railroad (from Shank, 1975). Left - A box car. Right – A passenger car.

(Jacobs, 1945). Tens of thousands of people passed through Hollidaysburg during the canal era. By the late 1850s, however, the canal system was obsolete.

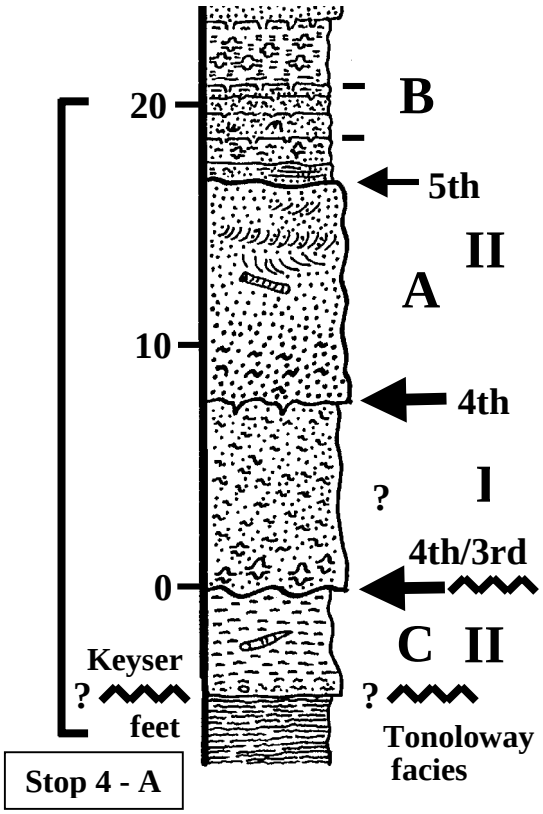
Although the Pennsylvania Railroad bought the Pennsylvania Mainline Canal system in 1857 and dismantled the Portage Railroad, the Hollidaysburg canal basin continued in limited operation, serving the needs of area farmers and manufacturers. Eventually, the last canal boat, the "William A. Fluke," left Hollidaysburg on April 22,1872 (Jacobs, 1945). The canal between Hollidaysburg and Williamsburg was abandoned that year. Necessary repairs had been largely ignored, and frequent flooding caused extensive damage to the infrastructure. The feeder reservoir for the canal basin, for example, had been a beautiful, 500-acre body of water that became a favorite resort for fishermen. The farmers in the river valley below Hollidaysburg feared that the dam would eventually break and drown them (Johnson, 1889). When the canal was abandoned in 1872, the Pennsylvania Railroad cut the breast of the dam to prevent the water from overflowing and flooding the adjoining land. On February 10, 1882, the dam finally gave way and the water flowed into the Juniata River. Wagonloads of stranded fish were gathered and sold in Hollidaysburg (Jacobs, 1945). The dam was never repaired. Since that time the land has been used for other purposes.

The canal bed became the right-of-way over much of its distance for a branch of the Pennsylvania Railroad between Hollidaysburg and Huntingdon. In Hollidaysburg the canal basin was filled with cinders; it is now part of the rail yard south and east of the borough. East of Huntingdon the canal was so greatly damaged by a flood in 1889 that it also was abandoned (Borough of Hollidaysburg, 2001b) Traces of the once busy waterway can be seen still at several places in the Juniata River valley, east of Hollidaysburg.

In the late 1980s, plans for restoration of the canal and canal basin in Hollidaysburg began to take shape. After several years of research and fundraising, the borough began to study creating a linear park, connecting the Legion Park on North Juniata Street to the original site of the Canal Basin. Eventually, the plan encompassed Chimney Rocks. The newly built Canal Basin Park lies along the Beaverdam Branch of the Juniata River in the Gaysport section of Hollidaysburg. For anyone interested in studying the canal basin in further detail, Canal Basin Park has a museum (fee charged), which, when completed, will illustrate the transfer of canal boats from the canal to the Allegheny Portage Railroad.

STOP 4. THE ST. CLAIRSVILLE EXIT ROAD CUTS AND OSTERBURG ANOMALY

PART 1: **FACIES AND CYCLIC STRUCTURE AT ST. CLAIRSVILLE/ OSTERBURG**.
Leaders: Edwin Anderson and Cheryl Sinclair



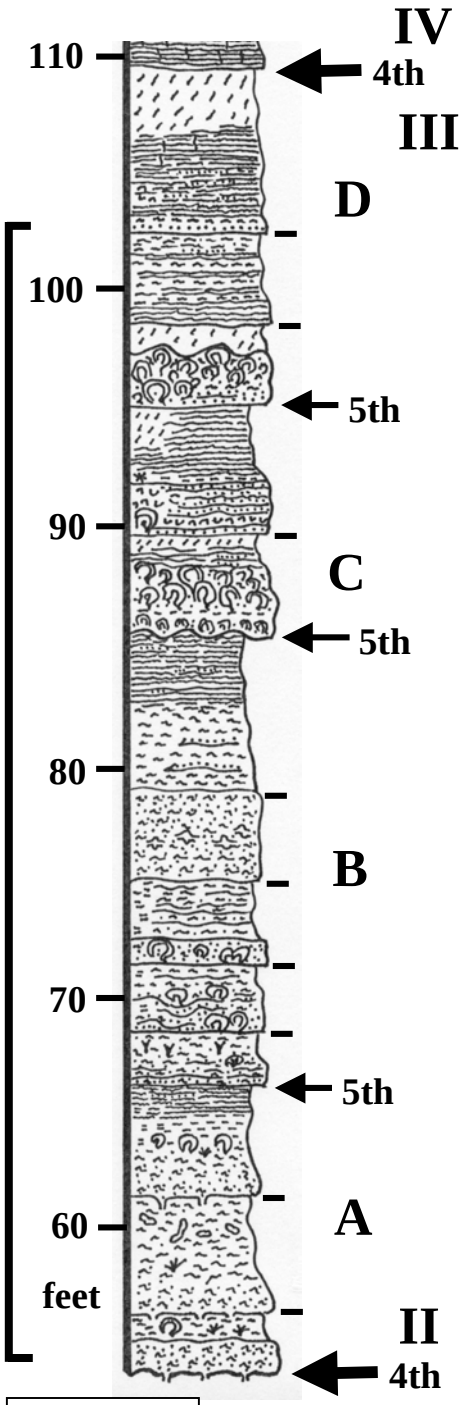
A. The 3rd order unconformable boundary occurs at the zero mark on the log. As compared to Allegheny Furnace, 4th order sequence II is now complete. 5th order sequence A, a very coarse crinoidal calcarenite, is now present (see Plate 1C). The largest magnitude sea-level-rise event is marked by the occurrence of the *Gypidula prognostica* peak zone at the base of 5th order sequence B. A diversely fossiliferous, coarse, brown calcarenite, not observed further north in the basin occurs directly below sequence II. This unit is interpreted as an erosional remnant of 4th order sequence I. An erosional surface, the 3rd order boundary, separates this brown calcarenite from a gray micrite below containing cephalopods. The highest Tonoloway tidal-flat algal laminite facies occurs just below this 4-foot thick micritic unit. At Allegheny Furnace the micritic interval, the last subtidal facies in the lower Keyser 3rd order sequence, is represented by two 'pita bread' stromatoporoid bearing 5th order sequences. At the Canoe Creek Quarry the same unit contains large stromatoporoid-bearing micritic mounds (labeled bioherm in Plate 1B).

B. In this part of the St. Clairsville section, 4th order sequence III is fully preserved. This section provides an excellent example of the typical asymmetry of 4th and 5th order sequences. The most open marine 5th order sequence is sequence B. Sequence B contains a diversity of corals including rugosans and branching favositids. Each of the 5th order sequences grades upward into tidal-flat algal laminite and/or dolomite facies. A sea-level-fall surface is seen in the scalloped surface in the middle of the first PAC in sequence D at 98 feet on the log. The paleoenvironmental preferences of stromatoporoids are suggested by the degree of their development in 5th order sequences B, C and D as compared to that seen earlier at Allegheny Furnace in the same sequences.

In general, St. Clairsville was in a more offshore (or basinward) position than Allegheny Furnace. In that stromatoporoids appear to be adapted to more restricted onshore, subtidal paleoenvironments, the most robust stromatoporoid patch reefs occur onshore at Allegheny Furnace and Eldorado in sequence B (the most open sequence, see Plate 2A and 2C). However, as conditions become more restricted upsection, stromatoporoid biostromes are well-developed in sequences C and D at St. Clairsville (Plate 1E), but they disappear in sequence D at Allegheny Furnace (Plate 2B).

Not only are there more open marine faunas at St. Clairsville, compared to those in equivalent sequences at Allegheny Furnace, but also 4th sequence III is some ten feet thicker here, suggesting a higher rate of subsidence southward toward the basin axis.

The unconformable 3rd order sequence boundary at the Keyser-New Creek formational boundary is well exposed at the south end of the section.



Stop 4 - B

PART 2: THE OSTERBURG ANOMALY
Leaders: Arnold G. Doden, David P. Gold, and Keith Van Horn

The St. Clairsville road-cut provides the only conveniently exposed section of the upper Tonoloway, Keyser, and overlying members of the Old Port Formation viz., (Mandata "shale", Shriver "limestone, shale and chert", and Ridgley "sandstone") in the Osterburg area. A description of the geology of the area is included to illustrate the difficulty of evaluating the economic potential of the Keyser Formation in the Allegheny Front transition zone. Mapping is complicated by the presence of local facies changes, unconformities, omissions, and lack of continuity of beds, as well as an extensive and deep pervasive alteration to saprolite. The geology is further complicated a complex structural pattern of faulted 3rd order folds in a disharmonic relationship with the underlying Tonoloway strata, exposed in the core of the breached anticline. These 3rd order folds are open and plunge

approximately 20º southwest. In contrast, the folds in the core are tight, 4th to 5th order folds, with sharply oppressed hinge zones. The development of saprolites, in the upper units, but particularly in the Shriver member attest to a late hydrothermal event that may have been localized in a complex structural anomaly. A more formal report on the regional geology is given below.

GEOLOGY AND ECONOMIC RESOURCES OF THE OSTERBURG AREA, BEDFORD COUNTY, PENNSYLVANIA

by
Arnold G. Doden, David P. Gold, and Keith Van Horn

INTRODUCTION

The village of Osterburg lies within northwestern Bedford County, King Township, near the common boundary of the Alum Bank and New Enterprise 7.5 minute quadrangles. Approximately one mile north of Osterberg is a small limestone quarry once owned by G.G. Exline (Miller, 1934). One of many quarries in the region that mined Helderberg limestones, the Exline quarry had a working face 225 feet long and 50 feet high in 1929 (Miller, 1934). Miners removed the best limestone from a 15 foot-thick section of the Keyser Formation and burned it in two stone lime kilns near the quarry. Now owned by New Enterprise Stone and Lime Co., Inc. (NESL), the defunct quarry hosts a small bee keeping operation and overlooks a fish hatchery alongside the William Penn highway (old Route 220). Approximately 150 m east across the highway lies the smaller Defenbaugh pit, abandoned by 1929 (Miller, 1934). Thin-bedded limestones of the upper Tonoloway Formation had been mined here. More recently, New Enterprise Stone and Lime Company quarried Keyser Formation limestones from the hills on the eastern side of the map area to supply road material for construction of the local freeway.

Approximately four square miles were mapped at a scale of 1 inch = 500 feet to better define the stratigraphy and structure of the area as part of a resource evaluation project. Limestones of the Keyser and lower Old Port Formations were of particular economic interest, given their generally thick beds and favorable lithologic character. Field mapping data were supplemented with diamond drill cores taken from three holes west of the William Penn highway.

The most recent map of this region provides a generalized summary of the geology, given in the Alum Bank and New Enterprise quadrangles of Hoskins (1976). The Keyser and Tonoloway Formations are grouped as undivided (Dkst), as are units from the Old Port and Onondaga Formations (Doo). Previous work in the region includes mapping by Turley (1952) of upper Devonian sediments in the northwest corner of the Alum Bank quadrangle, and mapping by Penn State University field camp students in the southeastern part of the quadrangle (unpub. map, probably prior to 1965).

GEOLOGIC SETTING

The Osterburg map area lies between the Valley and Ridge and Appalachian Plateau physiographic provinces in the transition zone of the Allegheny Front (the boundary between the Appalachian Plateau and the Valley and Ridge structural provinces (Figure 1)). The general area encompasses Silurian and Devonian sediments that have been folded into a 3rd order anticline and syncline, plunging approximately 20° southwest, with disharmonic 4th and 5th order folds in the breached core of the anticline.

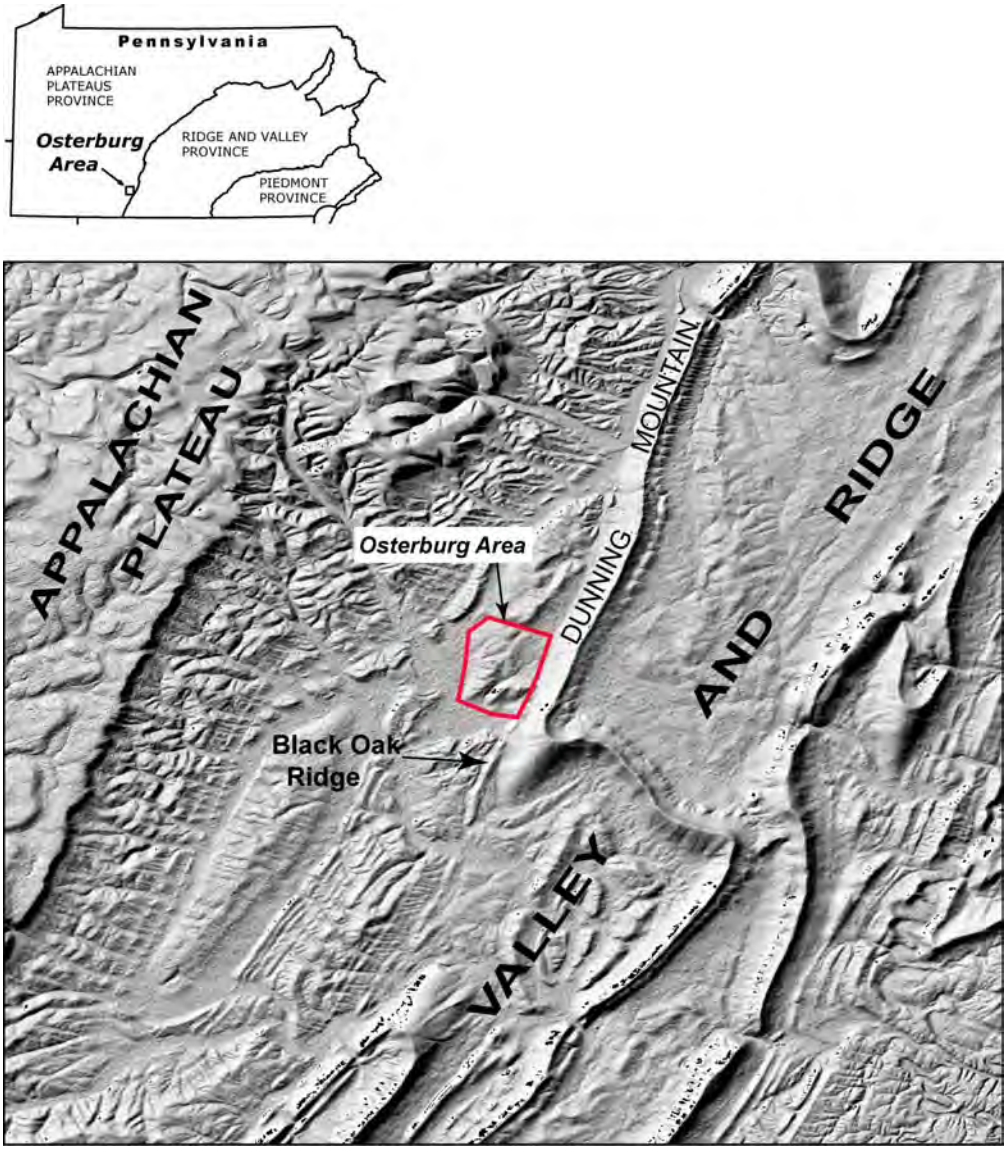


Figure 1. NED image of the Osterburg region, northwestern Bedford County. The Osterburg map area lies west of Dunning Mountain, at the western margin of the Valley and Ridge province.

The terrain south and west of Osterburg is highlighted by prominent northeast-trending ridges separated by flat-bottomed stream valleys. Local relief exceeds 400 feet in places. Near Osterburg and farther northeast the valley marking the boundary of the Allegheny Plateau and Valley and Ridge provinces converge, leaving a narrower zone of low hills (Figures 1 and 2).

On a local scale a north/northeast-trending valley divides the map area roughly into two parts (Figure 2). Hills that continue northeast along strike from Black Oak Ridge comprise the southeast side of the map area. The eastern part of the map area is dominated by steep-sided hills, the western sides of which along the William Penn highway are prone to land slide activity. The western part of the map area consists of gentle, west-dipping hill slopes that reflect the general dips of bedrock. The hills terminate abruptly at the eastern side of the Scrubgrass Creek floodplain (Figure 2).

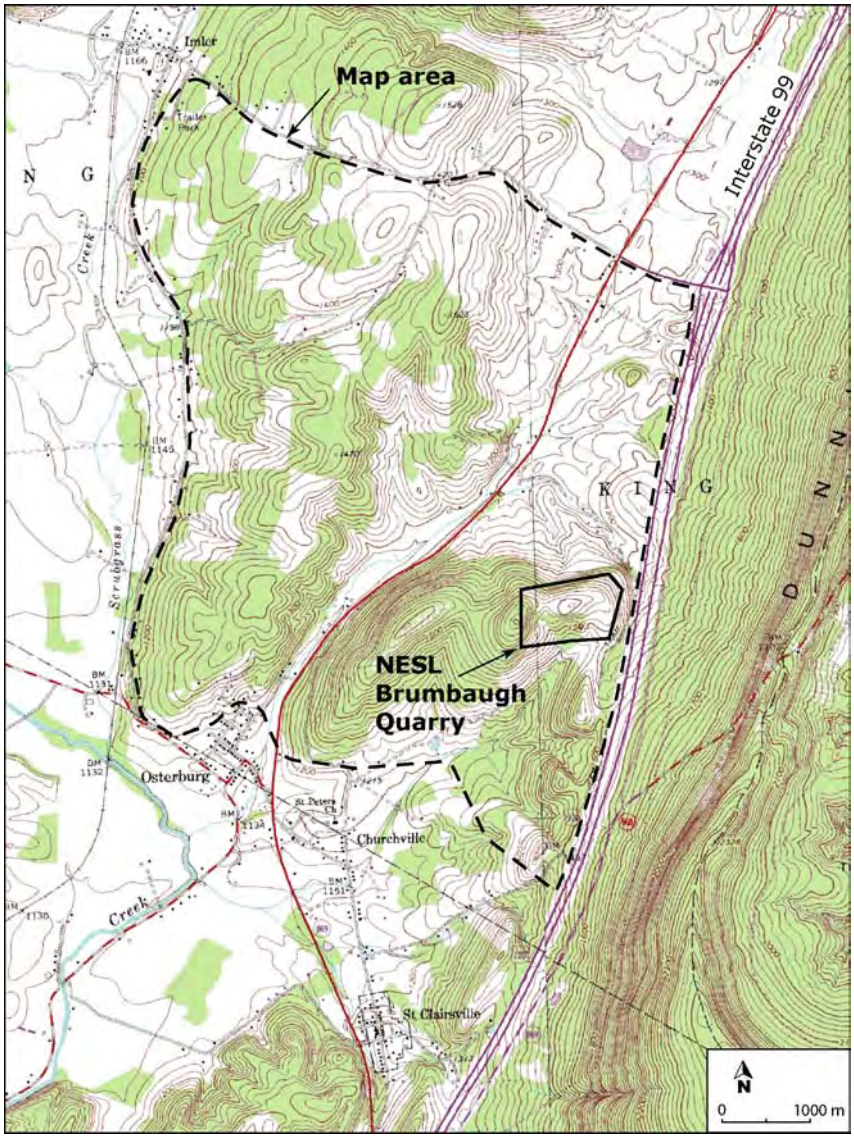


Figure 2. Topographic map showing boundaries of the map area (dashed line), Dunning Mountain on the east side and Scrubgrass Creek floodplain on the west side.

The abundance and quality of bedrock outcrops varies considerably throughout the map area. Small outcrops are scattered through local fields and steep wooded hillsides. Aside from exposures in the old quarry, larger outcrops (2 meters +) are rare, but some occur as "palisades" on the north side of hills in the eastern map area. A few outcrops of prominent stromatoporoid-rich beds of the Keyser Formation are exposed in the central and eastern parts of the map area and proved to be critical marker horizons for mapping. However, in much of the central map area no outcrops were found and mapping was based on "float" and three drill cores. A few additional exposures of bedrock were found in local pits dug by farmers. Exposures near but outside the map area, such as the road-cut on I-99, south of St. Clairsville on Black Oak Ridge, provide important control on the stratigraphic section. Here, 110 feet of the section from the upper-most Tonoloway Formation, to the top of the Keyser Formation (Anderson and Sinclair, this volume) are exposed, along with part of the Shriver Member of the Old Port Formation in the off ramp road-cut. Poorly resistant units such as the shales and siltstones of the Mandata and Shriver are preserved in the Black Oak Ridge road-cuts; these were not found in outcrop in the map area.

STRATIGRAPHY

Bedrock in the Osterburg area consists of sedimentary rocks of Upper Silurian to Lower Devonian age. The lower part of the section is dominated by limestones whereas the upper part has a considerably greater proportion of clastic sediments. Carbonate rocks dominate the bedrock exposures in the eastern two thirds of the map area, comprising the open valley in the northeast as well as higher ridges in the southeast area. Siltstones and sandstones occur in the western third of the map; carbonate rocks are not exposed at the surface in this part. Siltstones and chert of the Shriver Member (Old Port Fm.) cap the highest ridges in all parts of the map area. The geologic map and cross-sections for Osterburg are shown in Figures 4 and 5.

The stratigraphic section for Osterburg is presented in Figure 6. Lithologic descriptions were taken from outcrop observations and from cores logged from three diamond drill holes (see Figure 4). The following descriptions are in order of the oldest to youngest formations in the map area. Formation and member abbreviations (e.g., St) correspond to those given on the geologic map (Figure 4).

Figure 3. View north from the reclaimed Brumbaugh quarry, east side of the map area. Dunning Mountain (Valley and Ridge) is on the right-hand skyline and the Allegheny Plateau is on the left in this photograph.

Tonoloway Formation (St)

Mostly thin-bedded to finely laminated, micritic algal limestones near the top of the formation, with alternating cycles of thin bedded dolostones and limestones in the middle.

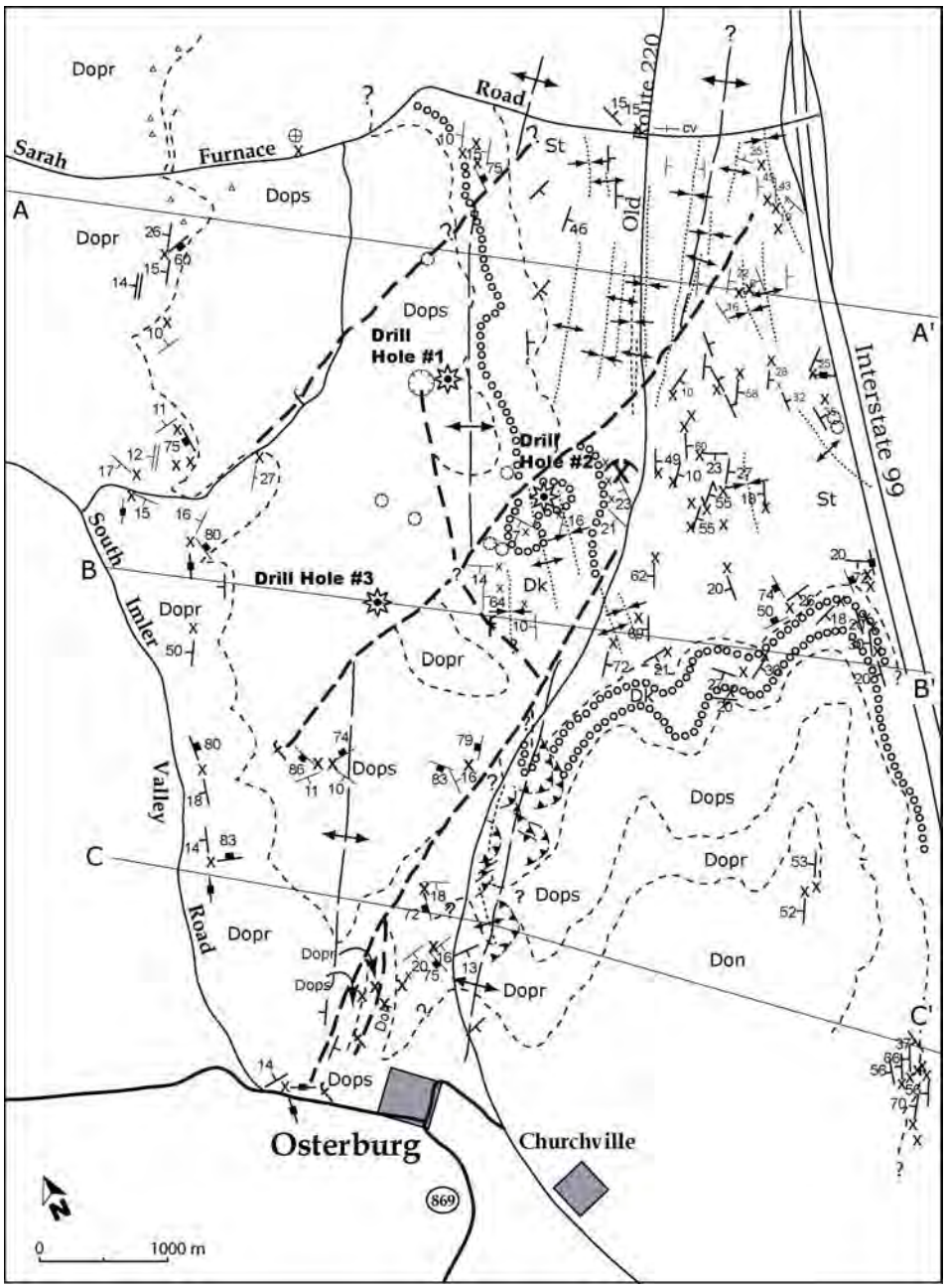
Keyser Formation (Dk)

Generally a thick-bedded limestone with two stromatoporoid horizons, common chert, nodular horizons with chert or micrite nodules, and upper and lower "calico" horizons.

Old Port Formation

New Creek (Coeymans) Member (**Dopnc**)
Coarse-grained, thin- to medium-bedded limestone with abundant chert nodules, minor argillaceous horizons, and a minor "calico" (micrite with sparry calcite) bed.

Corriganville (New Scotland) Member (**Dopc**)
Fine to coarsely-crystalline, massively bedded limestone with algal colonies. Black chert beds 1-2 inches thick are common.



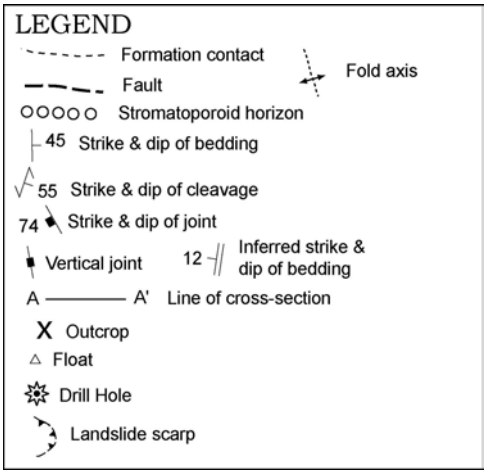


Figure 4. Geologic map of the Osterburg area.

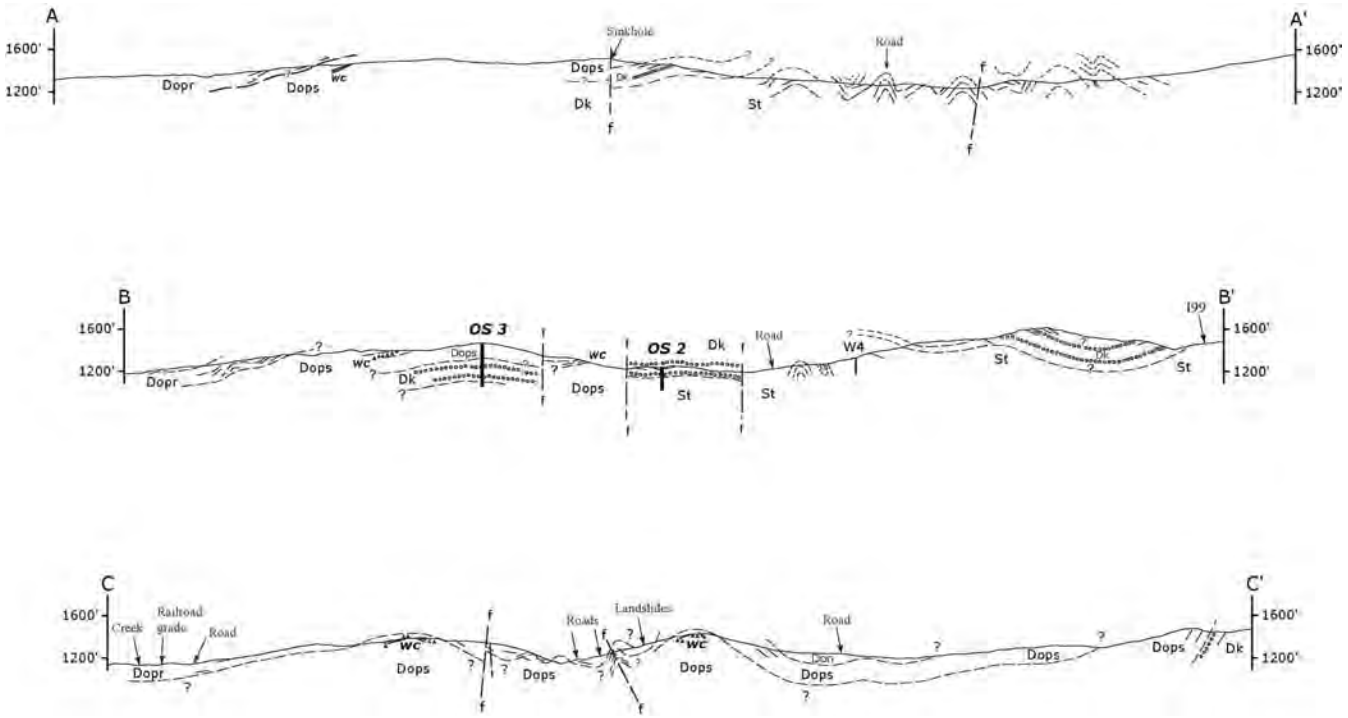


Figure 5. Cross-sections A-A', B-B', and C-C' for Figure 4. No vertical exaggeration.

Mandata Member (**Dom**)

The Mandata was examined only in a few road cuts southeast of Churchville on Black Oak Ridge and in drill cores; no naturally occurring outcrops were found in the map area (presumably they are concealed by colluvium). In the Osterburg area this unit consists of shale with subordinate amounts of chert and is approximately 36 feet thick. The shale is mildly calcareous in places, medium- to dark-gray and may weather into a dark yellow saprolite. The chert is typically nodular and grayish-black.

Shriver Member (**Dops**)

The Shriver Member of the Old Port Formation consists of siltstone, chert, shale, and limestone, but is rarely found in outcrop. The best exposures are found at the I-99 exit road-cut to the southeast in Black Oak Ridge. The siltstone ranges from siliceous to calcareous with regard to its matrix composition. When fresh, the silicified siltstone resembles a dark gray chert, hence the original name Shriver Chert (e.g., de Witt, 1974). This rock tends to weather white or gray. Other Shriver siltstone near Osterburg is a dark-gray to nearly black rock with a calcareous matrix that weathers to a soft, spongy-textured porous rock. Most of the resulting weathered "ridge gravels" derived from the Shriver are dominated either by calcareous orange, spongy fragments or by siliceous white fragments. However, weathered Shriver siltstone includes a wide range of colors: white, tan, gray, brown, orange, or lavender. It is possible to map this unit by the abundant presence of chert and a vari-colored weathered siltstone and limestone as float, including the locally known "ridge gravels" that cap most of the ridges in the map area.

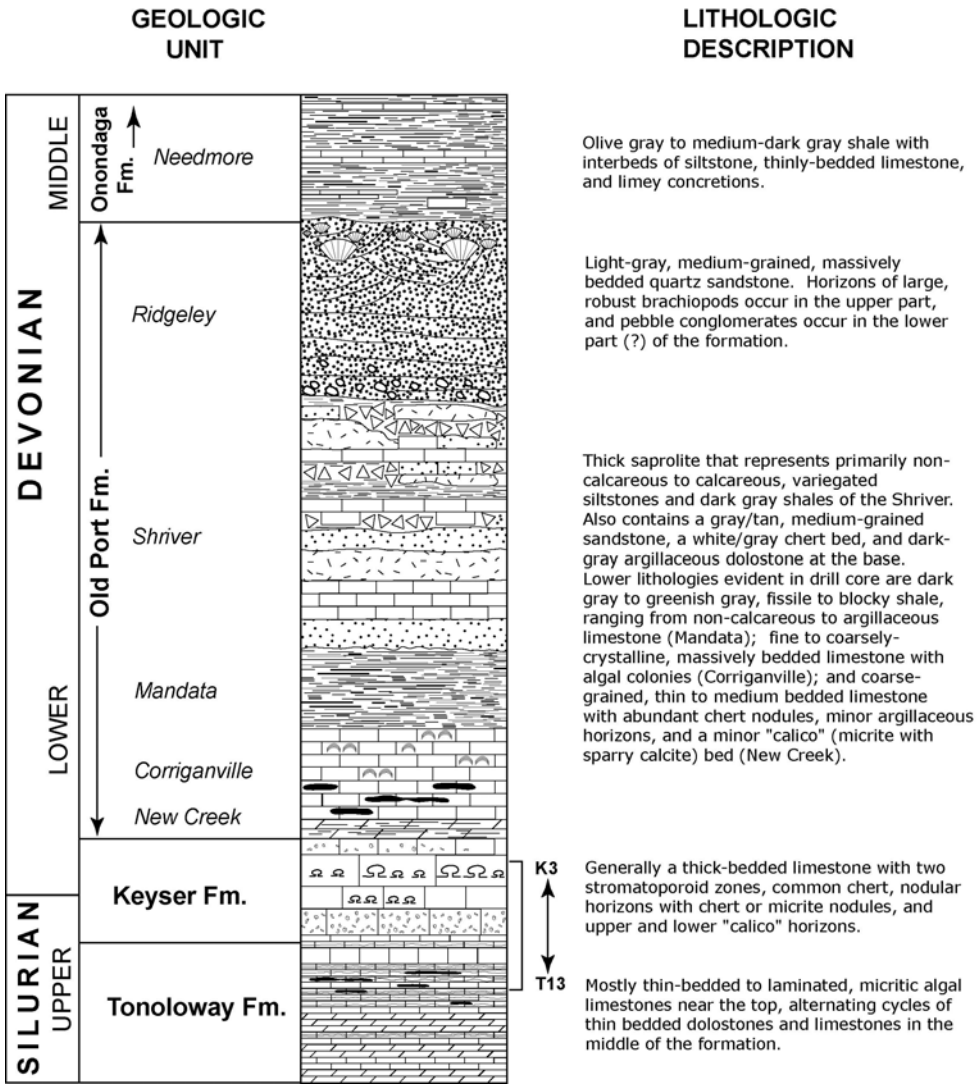


Figure 6. Stratigraphic column for the Osterburg map area. Mining evaluation units discussed for the New Paris Quarry (see STOP 5) are indicated for parts of the Tonoloway and Keyser Formations (T13-K3).

The Shriver Member varies considerably in its lithology throughout central and south-central Pennsylvania. At its type locality at Shriver Ridge near Cumberland, MD the unit is a dark gray, siliceous shale with chert interbeds (Lane, 1956). In central Pennsylvania the Shriver contains a greater proportion of limestone. The Shriver in Mifflin County, for example, is a predominantly dark gray, siliceous limestone with interbeds of calcareous chert and subordinate shale beds (Lane, 1956). In other localities the Shriver is almost entirely a dark gray chert (R.C. Smith, pers. comm., 2002).

Ridgeley Member (**Dopr**)

The Ridgeley Sandstone (also known as the Oriskany) is predominantly a light- to medium-gray cross-bedded sandstone that weathers white, light gray, tan, or orange. The sandstone ranges from fine- to coarse-grained and is thin to massively bedded (layers up to 6-8 feet thick). Most outcrops and blocks of float in the map area tend to be massively bedded. Bedding ranges from planar to lenticular, and steep-angle planar and trough crossbeds are abundant. Conglomeratic horizons occur locally. Fossils are especially abundant, but poorly preserved as the molds of large robust brachiopods that may include *Costispirifer arenosa(?), Renesselaeria marylandica(?) and Acrospirifer muschisioia(?)* in the upper sandy beds. Parts of the Ridgeley are exposed as large (up to 1 m) sandstone blocks on the surface, dominantly on the west side of

the map area. Ridgeley appears generally competent in rare outcrops (e.g., junction of Route 869 and the South Imler Valley road), but the formation tends not to be much of a ridge former in this area.

Onondaga Formation

Needmore Shale (**Don**)
Isolated outcrops of the Needmore Shale were mapped in the flat terrain south and east of Osterburg. It is exposed in the road-cuts 100 m east of Osterburg and 800 m southeast on Route 220, as an interbedded shale, mudrock, and limestone. The shales are generally medium olive-gray to dark-gray and grayish-black, thin-bedded in layers 10 cm or less in thickness. The black shale tends to weather rusty brown. The mudrocks are olive to dark gray, massive, calcareous in places and moderately fossiliferous. Limestone horizons in the lower Needmore are typically dark-gray, argillaceous calcilutites that weather to light tan, sharp-edged spalls. Limestone concretions up to 15 cm across are present in the southern-most road-cut.

SAPROLITIC WEATHERING

Saprolites are a common weathering phenomenon in Pennsylvania (e.g., Sevon, 1999) and are also present near Osterburg. Field mapping, supplemented by diamond core drilling in the central part of the map area, revealed that hilltops in this limestone terrain consist of (in descending order): very weathered Shriver siltstone fragments near the surface, a zone of soil/saprolite, and alternating zones of weathered limestone and saprolite to a depth of 27 m (as measured in one drill hole). Some of the core sections reveal that a transition, though abrupt, is present where the limestone grades into saprolite.

STRUCTURAL GEOLOGY

The Lower Devonian/Upper Silurian section of the Osterburg area is located in the transition zone of the Allegheny structural front, whose geomorphic expression is the eastern edge of the Appalachian Plateau (Faill and Nickelsen, 1999). In the eastern part of this zone the structural style is one of close asymmetric 3rd and higher order folds, that become open and more symmetric westward. The rocks of the Osterburg area are part of a 3rd-order anticline and syncline plunging 20° southwest. A disharmonic relationship exists between the thicker “strut units” in the Keyser and Old Port formations, and the thinly-bedded carbonates of the middle to upper Tonoloway Formation exposed in the core of the 3rd order anticline (see Figures 4 and 5). These Tonoloway strata are deformed into close to tight 4th order upright to slightly inclined folds with sharp hinge zones. A suspected thrust fault near the Tonoloway/Keyser boundary may account for the disharmonic nature of the deformation.
Three high-angle, east/northeast-trending faults are inferred from offsets (right lateral) of fold axes and the prominent stromatoporoid marker beds, and the occurrence of aligned sinkholes. The apparent movement on another north-trending high-angle fault is not clear.

ECONOMIC POTENTIAL

As local miners recognized over a century ago, the “Helderberg limestones” in Bedford County have high $CaCO_3$ contents (> 95 wt.%; Miller, 1934). Local kilns burnt the high quality limestone extracted from a number of small quarries in the basal Keyser and upper Tonoloway formations during the 1930’s (Miller, 1934). Exploration for these high-grade limestones in this area is rendered difficult by the thin and variable nature of the Keyser units, their lack of continuity, the presence of a late pervasive and unpredictable degree of alteration, and their distribution in complex fault and fold structures.
During the 1970’s NESL developed a quarry in the upper Keyser units on the hill top east of Route 220, to provide aggregate for interstate I-99. The gentle southwesterly bedding dips, minimal overburden, and easy access to I-99 contributed to the economic viability of the Brumbaugh quarry (see Figure 2). Limestones of the Keyser and lower Old Port Formations offer the best potential for carbonate aggregate products.

Figure 7. Part of a stromatoporoid-rich horizon in the Keyser Formation, Osterburg area.

Figure 8. Photograph of bedded black chert (below blue pencil) in the Corriganville limestone.

The thin-bedded nature and abundance of chert in the Tonoloway Formation would probably make these limestones generally unattractive as a potential source of aggregate. However, the lithologic characteristics, general thickness, and lateral persistence of Keyser and lower Old Port limestones makes these rocks more promising in terms of raw tonnages. Keyser limestone also exists west of the William Penn highway and comprises much of the prominent northeast-trending ridge (a third order anticline) in the central map area. However, most of the Keyser strata dip toward the west beneath increasing amounts of overburden. Compounding this problem is the existence of a thick saprolite developed on the limestones, as well as chert and siltstones of the Shriver ridge gravels that cover the hilltops. Consequently, a considerable amount of overburden would have to be removed before suitable limestone for aggregate could be mined in the western part of the map area. In addition, the chert horizons would have to be avoided by selective mining practice.

Elsewhere in the region the Ridgeley (Oriskany) sandstone has been used in the mineral industry as a source of silica sand (especially from friable rocks) or as aggregate, where it is better cemented. Some outcrops of Ridgeley on south side of the Osterburg map area exhibit a fairly hard and resistant sandstone with massive beds of relatively uniform lithology. Much of the mapped area, however, has friable sandstone that appears to be deeply weathered in many places.

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STOP 5: New Paris Quarry.

Leaders: David P. Gold, Arnold G. Doden, and Keith Van Horn

The New Paris Quarry is a small limestone pit located in western Bedford County, Pennsylvania and is operated by New Enterprise Stone and Lime Co., Inc. Located two kilometers northeast of the village of New Paris, the quarry is accessed from local roads that connect to State Route 96 (Figure 1).

The quarry was originally opened by J.S. Taylor in 1929. It was one of seven local quarries within a few miles of New Paris that were mining the "Helderberg" limestones. Limestone was being burned in a stone kiln and in open heap (Miller, 1934).

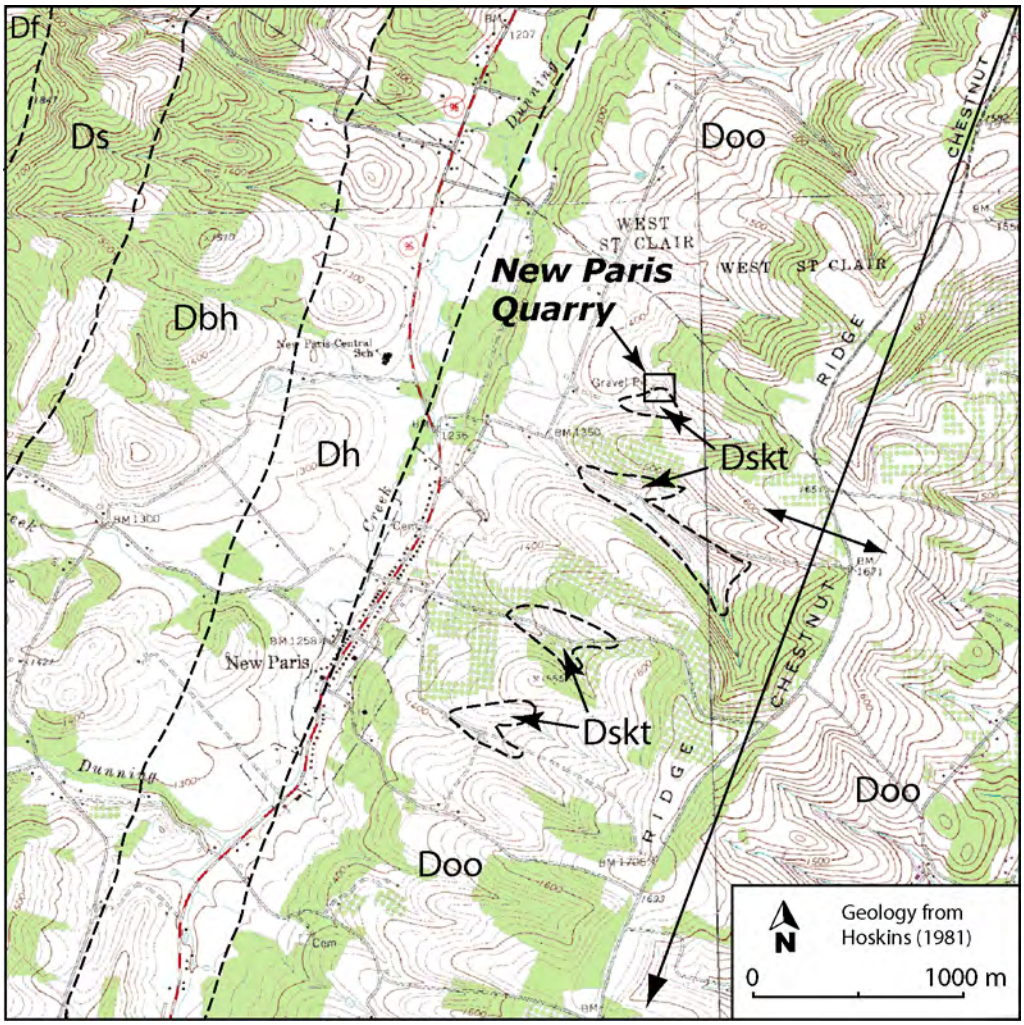

Figure 1. Location map for the New Paris Quarry. Geological units are: Dskt = Keyser/Tonoloway; Doo = Onondago/Old Port Fms; Dh = Hamilton Gp; Dbh = Brallier/Harrell; Df = Fore Knobs Fm. After Hoskins, 1981.

GEOLOGIC SETTING

The quarry is cut into the gentle west-facing slope of Chestnut Ridge in the eastern part of the Allegheny Plateau. Chestnut Ridge forms a topographic high along the fold axis of an open third order anticline that plunges gently to the south/southwest and is cored by Upper Silurian and Lower Devonian sediments. At the surface most of the core consists of the Onondaga and Old Port Formations (Hoskins, 1981). However, several small inliers are developed on the west side of Chestnut Ridge which reveal older Keyser and Tonoloway carbonates (Figure 1; Dskt). It is in one of these inliers that the New Paris quarry was developed in order to mine limestones from the Keyser Formation.

The gently dipping limestones typically strike 190° and dip 5-7° west. Calcite veins, 10-20 feet apart, coincide with the dominant joint set oriented 010°/85°. These veins range from 1-10 cm in thickness, and contain mainly coarse crystalline calcite with minor amounts of fluorite. Secondary vein sets occur at 045°-055°/80° and 110°/90°.

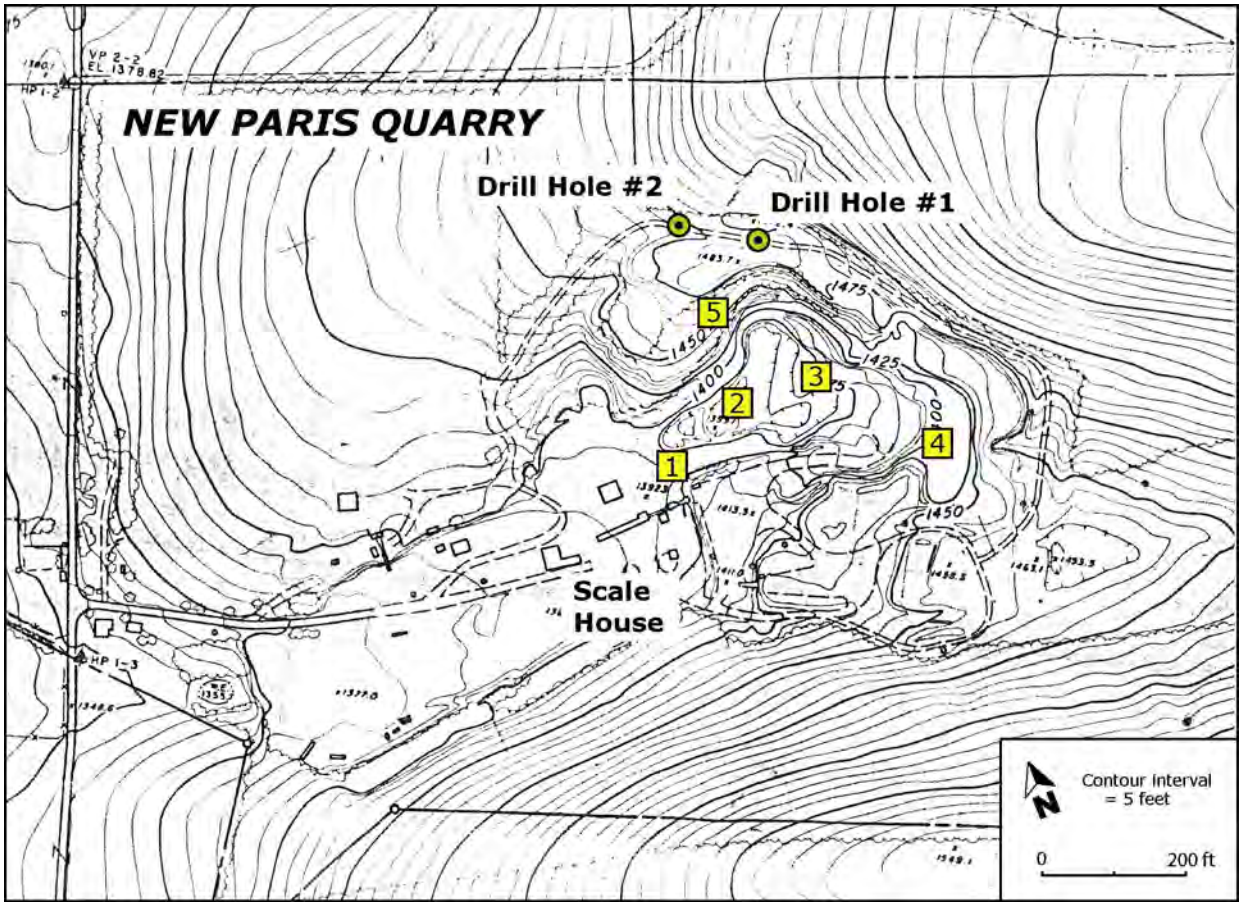

Figure 2. Topographic map of the New Paris Quarry showing locations of drill holes and field stops (numbers in squares).

The quarry gate is located at 40°17’13.8”N and 78°37’53.5”W. From the scale house walk east 200 feet to the top of the ramp (Figure 2, quarry station # 1) for an overview of the quarry. The highwall (see Figure 3) is developed in the La Vale Member of the Keyser Formation (see Figure 4); the floor exposes only the upper beds of the Jersey Shore Member. The New Creek (Coeymans Member), Corriganville (New Scotland Member), and the Mandata Shale Member of the Old Port Formation are exposed only in the 1st (upper) quarry bench.

Walk down the ramp to examine the highly fossiliferous upper beds of the Jersey Shore Member at stations 2, 3, and 4 (see Figure 2).

For those interested in the overlying New Creek, Corriganville and Mandata units, walk around the quarry to the west and follow the trail to station # 5 on the upper bench. Note the bentonites Bald Hill B and Bald Hill C, respectively below and above the New Creek Limestone beds (R.C. Smith, pers. comm.), as well as the phosphatic nodules on the weathered surface at the top of the Corriganville Member.

A more complete stratigraphic section is available in drill core (Drill Hole # 1 in Figure 2) on display on the quarry floor. This core is keyed into the potential mining units labeled in Figure 6. Some of the chemistry of these units is shown in Figure 6.

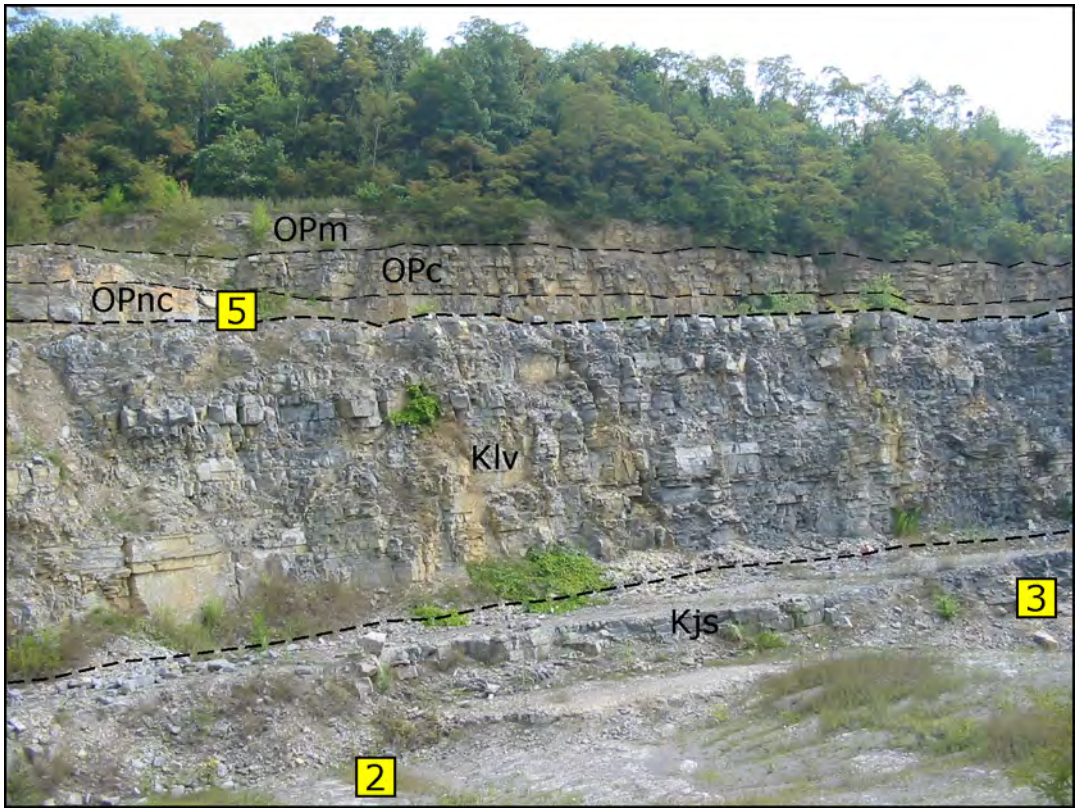

Figure 3. Photograph of quarry highwall showing members of the Keyser Formation (Kjs = Jersey Shore, Klv = La Vale) and members of the lower Old Port Formation (Opnc = New Creek, Opc = Corriganville, Opm = Mandata). Approximate positions of field stops 2, 3, and 5 are also shown.

QUARRY STRATIGRAPHY

Past mining operations have removed Upper Silurian and Lower Devonian age limestones, primarily from the Keyser, New Creek, and Corriganville Formations (Figure 4).

Most of the following discussion on the fossils and paleoenvironments for the New Paris Quarry is taken from Beuthin (1999). Only the uppermost part of the Jersey Shore Member of the Keyser Formation is exposed at New Paris. The Jersey Shore comprises the quarry floor and the highwall extending up to the first bench. Many of the strata are fossiliferous and the member contains isolated stromatoporoids and stromatoporoid reefs, tabulate corals (the chain coral *Halysites* and the honeycomb coral *Favosites*), and several beds contain bryozoans, crinoid columnals, and brachiopods (Figure 5).

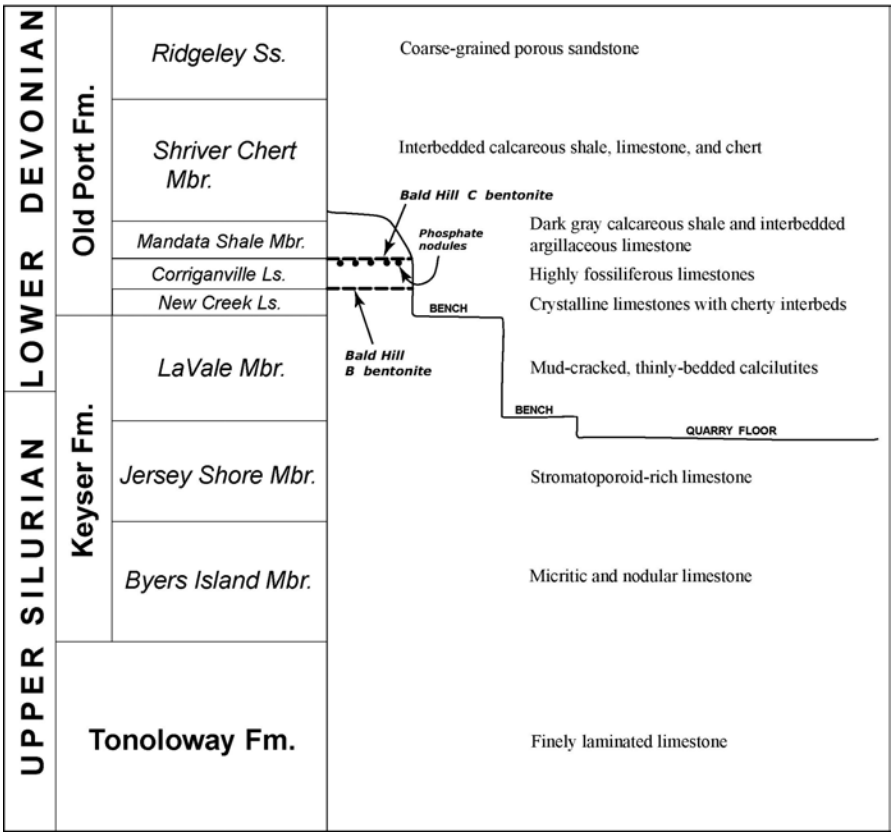

Figure 4. Stratigraphic column for the New Paris Quarry (modified from Hall (1990) and Beuthin (1999)).

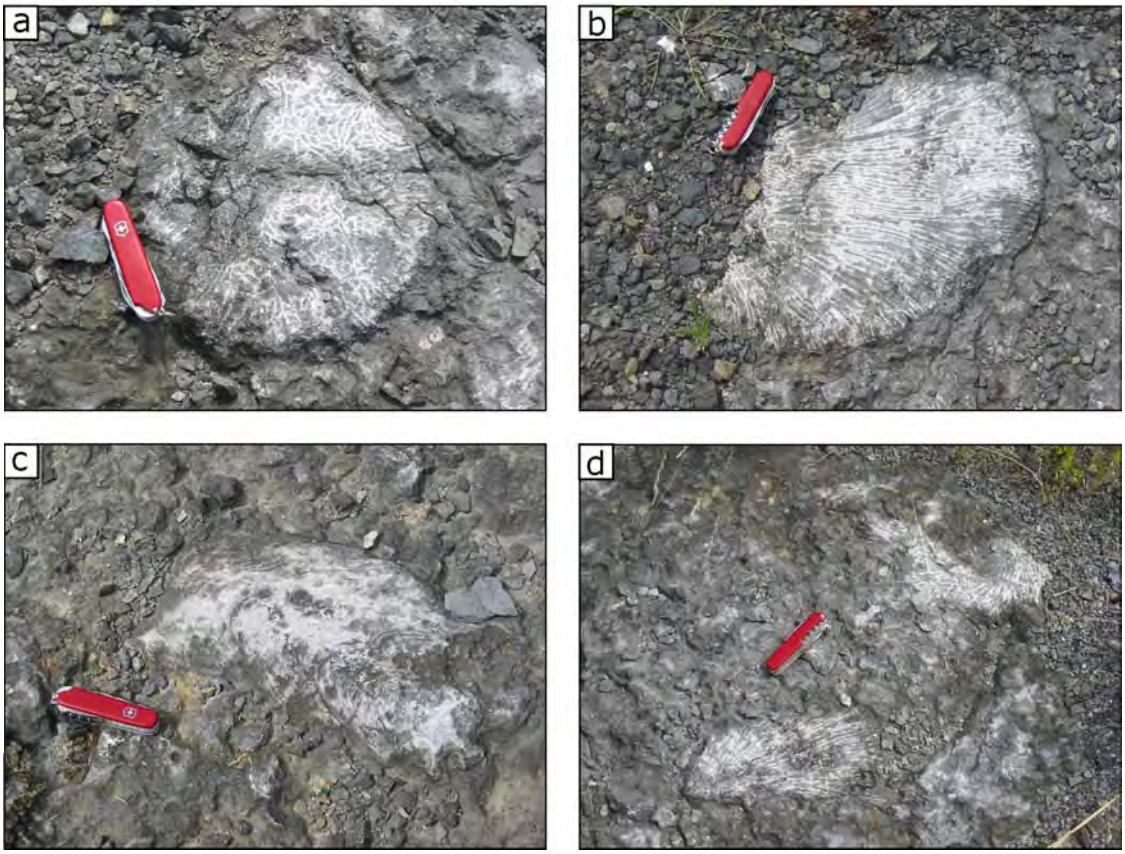

Figure 5. Examples of fossils exposed in the quarry floor. (a) Tangential view of a halysitid ("chain coral"); (b) Longitudinal (vertical section) view of a halysitid (?); (c) Cross-sectional view of a stromatoporoid (?); (d) Longitudinal (vertical section) view of a halysitid (?). Identifications courtesy of Roger Cuffey, Penn State University.

The LaVale Member forms the main part of the highwall at New Paris Quarry (Figure 3). According to Beuthin (1999), beds in this unit generally exhibit internal stratification but stromatoporoid reefs are absent. Many bedding planes host large lepriditid ostracods, although in contrast to the Jersey Shore Member, the LaVale Member lacks a rich and diverse shelly fauna. The numerous mudcracks in the La Vale clearly indicate occasional subaerial exposure, suggesting peritidal deposition, probably on the intertidal region of a tidal flat. The abundance of ostracods but the absence of a diverse fauna in the La Vale suggest an ecologically stressed environment. Many of the laminations may be biogenic, having resulted from growth of sediment-binding algal mats on a tidal flat (Beuthin, 1999).

The New Creek and Corriganville formations consist of interbedded fine-grained limestone (mudstone and wackestone) and coarse-grained limestone (packstone and grainstone). Generally coarser grain sizes and the presence of robust fossil shells and nodular chert in the 8-foot thick New Creek unit reflect relatively energetic depositional conditions. Beds in the 13-foot section of the Corriganville Member are finer-grained, with interbeds of nodular argillaceous limestone and chert, suggesting a shallow marine environment compared to that of the New Creek Member. Brachiopods are abundant, including the genera *Leptaena* and *Macropleura*. Crinoid columnals are also common. Bryozoas are present, but sparse. These beds also contain remains of the trilobites *Dalmanites* and *Calymene* (Beuthin, 1999). Many of these fossils can be observed at field stop #5. The diverse fossil assemblage in these formations suggests deposition in an open shelf environment. A peritidal environment was being replaced by more offshore, shallow marine environments (Beuthin, 1999).

Phosphatic nodules 1-5 cm across are scattered on the weathered, excavated upper bench, a fossil-rich surface on or slightly below the Bald Hill C bentonite. These nodules are thought to be coprolites.

The bentonites at New Paris Quarry have not been studied in detail, but elsewhere in the region Bentonite B is reported to contain calcite, glauconite, traces of chlorite, and possible potassium feldspar (Smith et al., 1988). According to R.C. Smith (pers. comm.), the upper bentonite at New Paris Quarry (Bentonite C) represents a feldspathic vitric tuff. At its type area this bentonite contains trace to abundant amounts of volcanic quartz, biotite, glauconite, plagioclase, potassium feldspar, chlorite, and zircon (Smith et al., 1988).

WHOLE-ROCK CHEMISTRY

Samples of representative core sections were analyzed for whole-rock major and trace element compositions as part of a resource evaluation study of limestones in the New Paris Quarry. Drill core from 15 resource evaluation units in Drill Hole # 2 (see Figure 2) were split, sampled and analysed for their major, minor and trace element content.

The results are summarized in Figure 6, which shows the variations in major element oxide and trace element concentrations with depth in Core Hole #2 at New Paris Quarry. Some of the oxides and elements have been omitted for clarity; either their concentrations were extremely low or the inter-sample variations were considered insignificant for purposes of the present study.

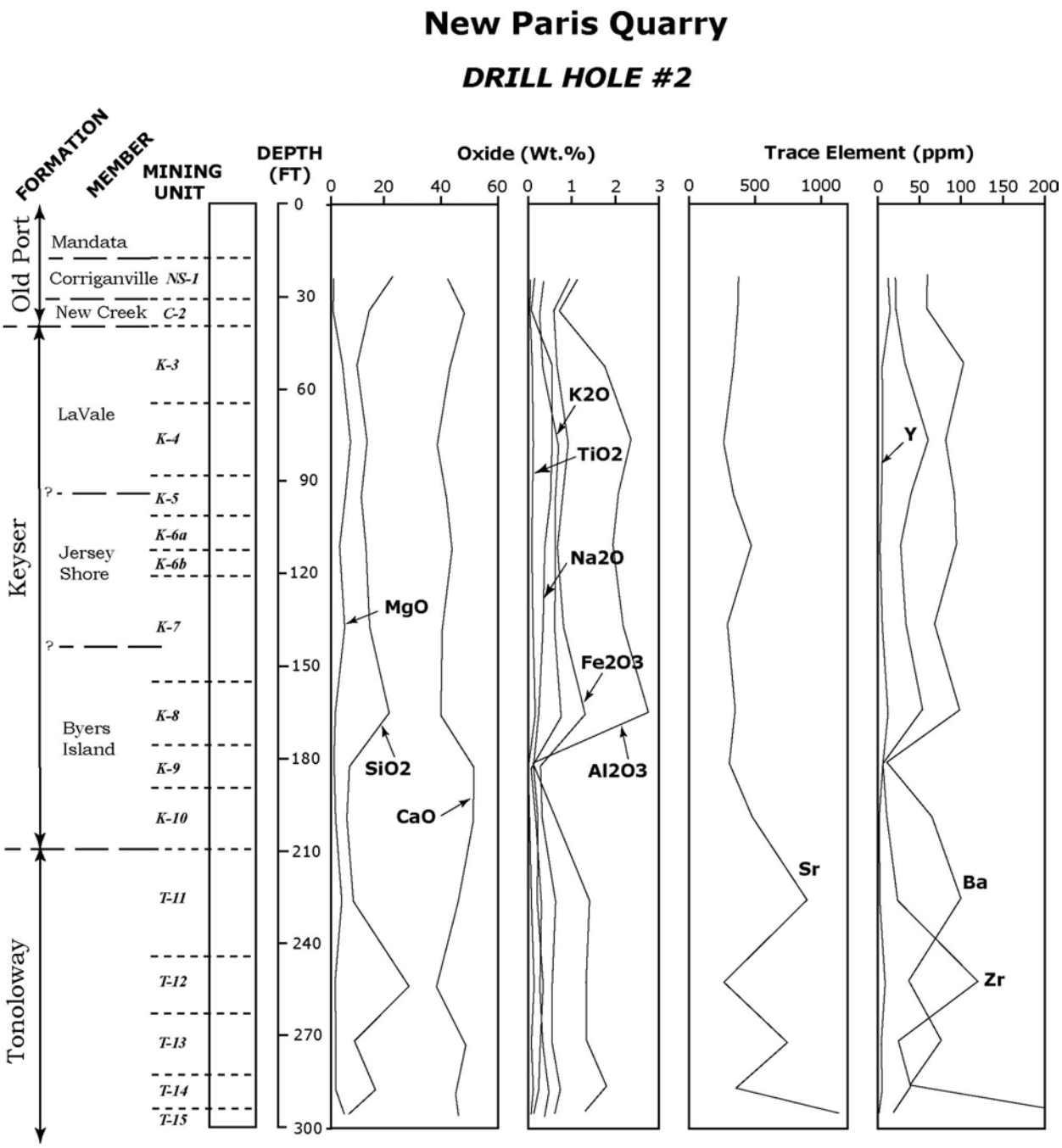

Figure 6. Diagram summarizing stratigraphy, mining units, and whole-rock geochemistry of the New Paris Quarry.

Figure 6 reveals several notable characteristics of the data. Concentrations of CaO are generally high throughout the section, whereas those of MgO are mostly low, reflecting the high proportions of calcite in these rocks. There exists a mild overall decrease in CaO with increasing levels of MgO, suggesting that minor amounts of dolomite may have formed at the expense of calcite in some of the units. The curves in Figure 6 suggest that units with lower concentrations of CaO have higher levels of SiO_2. These relationships are confirmed when the drill core data are cast into bivariate plots of CaO vs. SiO_2, CaO vs. MgO, and MgO vs. SiO_2 (not shown). The major components offset each other as expected from constant sum effects. Hand specimen observations indicate significant amounts of chert in some of the New Paris

Quarry limestones. The units with relatively high values of SiO_2 are those in which chert has replaced calcite. Thus, CaO values are reduced in these units proportionally to the amount of chert that formed. No correlation appears to exist between SiO_2 and MgO; the minor amount of dolomite present was not affected by chert formation, or vice versa.

Units NS-1 and K-8 have relatively high levels of SiO_2, K_2O, and Fe_2O_3 compared to other units in the section. This combination of elements may be attributable to anomalous amounts of clays, although their presence has yet to be confirmed by petrographic or x-ray analysis. Unit K-9 is a remarkedly clean, porous, medium- to coarse-grained bioclastic limestone. This calcarenite unit is equivalent to Taylor's (this volume) "echinoderm grainstone". Unit K-10 has markedly low values of essentially all chemical components except for CaO, suggesting a rock that consists primarily of $CaCO_3$ (calcite). Such a composition is expected, as unit K-10 is the well-known "calico" rock mined throughout central Pennsylvania for its pure limestone.

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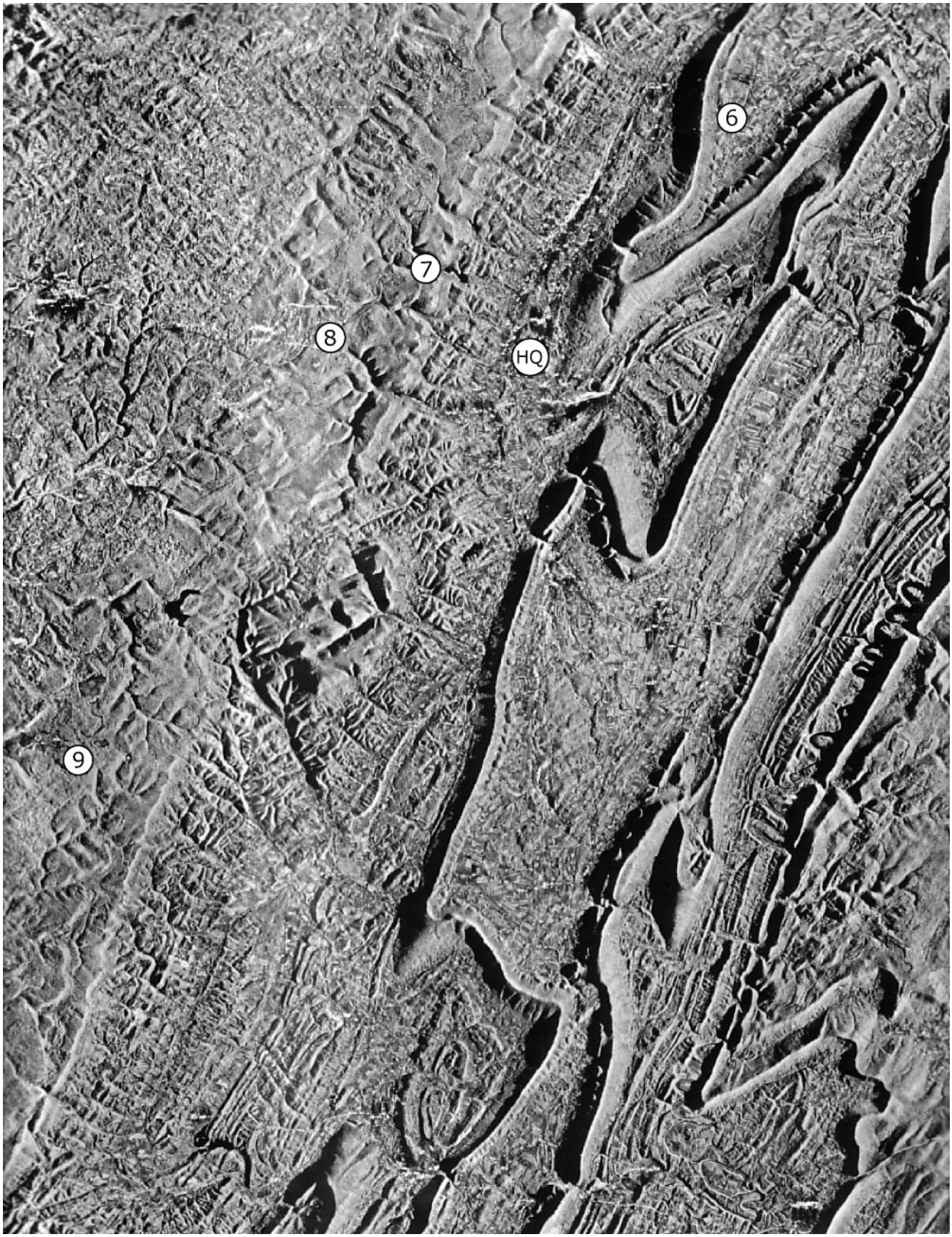


Stop locations for Day 2 of the 2003 Field Conference of Pennsylvania Geologists

ROAD LOG AND STOP DESCRIPTIONS

DAY 2

Miles

Int.	Cum.	Description
0.0	0.0	Leave parking lot of Ramada Inn, Altoona, and turn left onto access road.
0.1	0.1	Turn left at traffic light onto Business US Route 220 north. Move into right lane.
0.2	0.3	Bear right onto entrance ramp for I 99 / US Route 220 north.
1.1	1.4	Blair County Ballpark on right. The home of the Altoona Curve, a AA affiliate of Pittsburgh, opened in 1999. The team's name refers not only to a curveball but also to the 220º arc that forms the nearby Horseshoe Curve, a National History Landmark.
1.4	2.8	Take the 17th Street Exit (I 99 Exit 33) ramp and continue west toward Altoona.
0.4	3.2	Several dozens of rock bolts or rock anchors stabilize the slope along this ramp.
0.9	4.1	Bear right onto Valley View Blvd. (Business US Route 220 north).
1.6	5.7	Turn right onto Kettle Street.
0.5	6.2	Cross over I 99.
0.9	7.1	Tuscarora boulder colluvium on left.
0.2	7.3	Altoona City Authority's Kettle Reservoir dam breast and lake on right. Outcrop of Juniata Fm. on left.
2.3	9.6	Beginning of series of Bald Eagle Fm. outcrops and boulder colluvium on left.
1.5	11.1	Last of Bald Eagle Fm. outcrops on left.
0.2	11.3	Borrow pit exposing Reedsville and Bald Eagle colluvium on left.
2.8	14.1	Plaque on left marks one of the area's lead mines. Smith, 1977, p. 124, identified this as the J. G. Fleck prospect, one of many throughout southern Sinking Valley.

Figure 1. A bronze plaque commemorates the area's mining efforts to supply General Washington with lead for the Revolutionary War (erected by the Colonel John Proctor Chapter, SAR, in 1925).

0.5	14.6	Turn left onto Fort Roberdeau Road.
0.4	15.0	Bear right and continue on Fort Roberdeau Road. (Pistol Club Road to left.)
0.3	15.3	Turn left into parking area at entrance to Fort Roberdeau Historic Site and Natural Area.

STOP 6. FORT ROBERDEAU—THE LEAD MINE FORT
Leaders: Peggy Goodman and Robert C. Smith, II.

Leave STOP 6. Turn right out of parking area and follow Fort Roberdeau Road to Kettle Road.

0.6 15.9 Turn right and retrace route to Altoona. (*For those interested in karst features of southern Sinking Valley, two additional stops, Tytoona Cave and Arch Spring, are provided in the Supplemental Road Log at the end of the formal Day-2 Road Log.)

8.9 24.8 Turn left at traffic light onto Pleasant Valley Blvd. (Business US Route 220 south).

1.6 26.4 Bear right at traffic light onto 17th Street.

0.9 27.3 Turn right at traffic light onto 9th Avenue. Move into left lane.

0.3 27.6 Turn left into entrance of Railroaders Memorial Museum, 1300 9th Avenue.

Figure 2. The Master Mechanics Building, completed in 1882, was built to house the labs and facilities of the Pennsylvania Railroad's testing department. As late as 1984, the building was still in use by Conrail. Today it serves as the home of the Railroaders Memorial Museum. (Photos from the Museum's web site. http://www.railroadcity.com/vtour/index.htm)

STOP 7. A GEOLOGICAL RAILROAD EXCURSION THROUGH THE HORSESHOE CURVE AND SUMMIT TUNNELS.
Leaders: Jon D. Inners, Viktoras W. Skema, Gary M. Fleeger

Leave STOP 7. Turn right out of parking area onto 9th Avenue. Move into left lane and proceed to traffic light.

0.3 27.9 Turn left onto 17th Street.

1.5 29.4 Bear right onto I 99 /US 220 south.

1.5 30.9 Mifflintown Fm. along ramps of Exit 32.

1.9 32.8 Eldorado Quarry, STOP 2 adjacent to northbound lane.

1.4 34.2 Take Exit 28 right lane and follow US Route 22 west toward Ebensburg.

We begin the ascent across the Allegheny Front (elevation ~1000').

1.3 35.5 Brallier Fm. exposed on vegetated slopes.

1.3 36.8 Lock Haven Fm. exposed on vegetated slopes.

0.8 37.6 Catskill Fm. exposed on vegetated slopes.

1.4 39.0 Extensive (~0.3 mi) vertical cut in Burgoon Fm. adjacent to eastbound lanes. Drop zone fills with large angular blocks.

2.7 41.8 Cambria/Blair county line.

0.1 41.9 Take Gallitzin Exit.

0.2 42.2 Turn right at exit ramp stop sign.

We are near the top of the Allegheny Front (elevation ~2400').

0.4 42.6 Enter Allegheny Portage Railroad National Historic Site.

0.5 43.1 Visitor Center.

STOP 8. ALLEGHENY PORTAGE RAILROAD NATIONAL HISTORIC SITE
Leader: John A. Harper

Leave STOP 8. Turn right out of parking area and retrace route to US 22.

0.9 44.0 Turn left onto US Route 22 west toward Ebensburg.

Road cuts along this stretch of the route expose siliciclastic sequences from the Pennsylvanian Glenshaw and Glenshaw formations.

10.0 54.0 Cambia & Indian Railroad bridge carries a pipeline from the Cambria CoGen Company. The company exports steam to Laurel Crest Rehabilitation and Special Care Center and electricity to Penelec. Using two circulating fluidized-bed boilers, the plant burns approximately 650,000 tons of bituminous coal waste a year and removes more than 90% of the sulfur dioxide from the emissions. Limestone reacts with the sulfur in the coal to form gypsum. Operating since 1991, the plant generates 98 megawatts of electricity and produces 820,000 pounds of steam per hour.

3.7 57.7 Take Exit leading to US Route 219 south.

7.4 65.1 Bridge crosses the Little Conemaugh River, immediately upstream from confluence with the South Fork Branch at South Fork.

2.0 67.1 Bridge crosses the South Fork Branch and railroad tracks. The breached South Fork Dam is visible immediately to the southeast. This dam failed catastrophically at 4:00 p.m., May 31, 1889, sending 20 million tons of water down the narrow valley of the Little Conemaugh River, here, to the northwest. Moving at 40 miles per hour and boiling with huge chunks of debris, the wall of water grew at times to 70 feet high. These floodwaters swept away steel mills, houses, livestock, and people. Americans awoke the next day to the news that Johnstown had been devastated by the worst flood in the Nation's history with over 2,200 dead. Meteorological data indicated that the region experienced 5 to 6 inches of rain over a 26-hour period. East of the Allegheny Front, this same storm brought record flooding to the Juniata River valley, and floods devastated regions surrounding the Genesee River in NY, and the James and Potomac River basins in MD and VA. However, it is the flooding in Johnstown that is remembered to this day. (Refer to stops 9 and 10 in the 54th Annual Field Conference, Johnstown, PA.)

7.4 74.5 Take Exit leading to PA Route 56 east. NOTE: this is a tight turn, proceed slowly.

0.3 74.8 Merge onto PA Route 56 east.

9.6 84.4 Left turn onto gravel haul road (Babcock Creek Trail).

2.5 86.9 Gate at entrance to Cooney Brothers property.

STOP 9. COONEY BROTHERS COAL COMPANY, POT RIDGE STRIP MINE
Leader: Stephen R. Lindberg

Leave STOP 9. Retrace route to PA Route 56.

2.5 89.4 Turn right onto PA Route 56 west.

9.6 99.0 Bear right onto entrance ramp for US Route 219 north.

16.0 115.0 Bear right onto entrance ramp for US Route 22 east.

23.7 138.7 Bear right onto exit ramp for Plank Road, Altoona.

0.4 139.1 Bear right and merge onto Business US Route 220 south.

0.3 139.4 Bear right onto road leading to Ramada Inn.

0.1 139.5 Ramada Inn parking lot.

END OF DAY-2 ROAD LOG.

Thanks for joining us. Have a safe journey home!

*SUPPLEMENTAL ROAD LOG: The following log directs those interested in the karst of southern Sinking Valley to two local, well-know features: Tytoona Cave and Arch Spring.

0.0 0.0 Begin at the intersection of Fort Roberdeau Road with Kettle Road. Proceed north on Kettle Road.

3.6 3.6 Turn left onto Morrow Road. Follow this narrow winding road a short distance to the northwest.

0.3 3.9 Pull-off area on left by barrels at entrance to Tytoona Cave. The road is narrow; use caution.

TYTOONA CAVE PRESERVE

Shown on early county maps, the history of this cave dates back to 1788. Currently, this 6.8-acre cave preserve is owned by the National Speleological Society (NSS). The heavily wooded cave entrance is located at the bottom of a large collapsed sinkhole. It is surrounded on two sides by nearly vertical bedrock, mapped as Coburn through Loysburg undivided. This cave contains about a mile of trunk passage, a portion of which is divided by water sumps, and a few large dry rooms. Very delicate and significant formations occur in one of the sump-protected rooms. At low water, the first 1000 feet of passage offers easy access for visitors. Downstream, the master conduit system exits at Arch Spring. (Refer to the NSS website for details of the history of this site.)

Figure 3. Kiosk on access path a short distance from Morrow Road.

Figure 4. Gently sloping roof at entrance to Tytoona Cave, southern Sinking Valley, Blair County, PA.

0.3 4.2 Retrace route and turn left onto Kettle Road.

0.7 4.9 Pull-off on right side of Kettle Road, just past small bridge.

ARCH SPRING

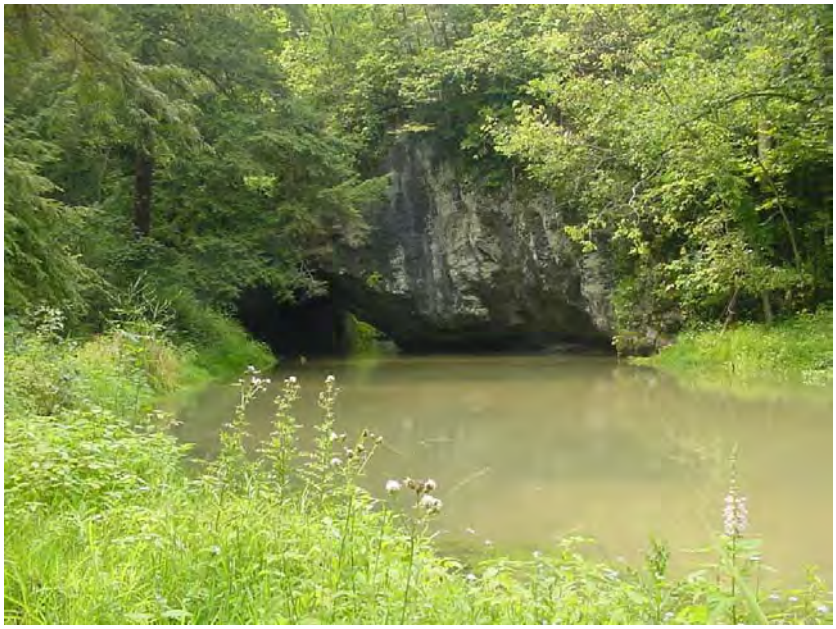


Figure 5. View of Arch Spring from Kettle Road, southern Sinking Valley, Blair County, PA.

This limestone arch, visible from the road, is a much smaller version of the famous Natural Bridge in VA. It is 40 to 50 feet high, and the opening is 20 to 25 feet in diameter, with Sinking Run flowing through it. Upstream from the arch is a small pond in a large, steep-sided collapsed sinkhole. This sink is a least 100 feet long, 50 feet wide, and perhaps more than 30 feet deep. At the far side, a 4-foot diameter opening serves as the resurgence of water flowing into Tytoona Cave, a straight line distance over 4000 feet. Arch Spring, the source of this part of Sinking Run, is the eighth largest spring in the state, discharging from 2000 to an estimated maximum of 30,000 gallons per minute. Arch Spring is privately owned and the area is posted. Little remains of the village to which the spring gave its name. However, the adjacent limestone homes and the Sinking Valley Presbyterian Church, about a half mile farther north, serve as superb examples of period architecture.

Figure 6. Limestone house adjacent to Arch Spring, southern Sinking Valley, Blair County, PA.

Figure 7. Sinking Valley Presbyterian Church, Arch Spring, Blair County, PA.

END OF SUPPLEMENTAL ROAD LOG.

STOP 6: FORT ROBERDEAU—THE LEAD MINE FORT

Leaders: Margaret J. Goodman, *Fort Roberdeau Association* and Robert C. Smith, II, P. G., *Pennsylvania Geological Survey*

INTRODUCTION

Bullets and war go hand-in-hand, as do bullets and lead, especially as we look back in history. During the American Revolutionary period, most everyday commodities to support the revolution were in short supply, including ammunition for the patriot army. There were only a few lead mines in operation when the war started, and their output was insufficient to meet the demand.

On March 23, 1777, Major General John Armstrong, a decorated military officer, wrote to Thomas Wharton, Jr, the President of the Supreme Executive Council of the State of Pennsylvania, bringing to his attention the fact that “the veins of lead that lay near Frankstown would be advantageous to the Patriot cause.” He recommended that the mine on the Proprietaries' Sinking Valley tract of 9,056 acres, which occupied roughly the entire valley formed by the “V-shaped” Brush Mountain, should be seized by the newly declared state of Pennsylvania for its use in the war effort. Acting favorably upon the recommendation, the General Assembly of Pennsylvania gave approval to Brigadier General Daniel Roberdeau to pursue mining operations there. Roberdeau agreed to undertake the responsibility of verifying the report and starting a mining operation.

Daniel Roberdeau, a prosperous merchant and lawyer in Reading and Philadelphia, fervently advocated American independence. As an elected representative from Pennsylvania to the Second Continental Congress, he served as a member of the intelligence committee and the committee that procured supplies for the Continental Army. He was fully aware of the shortages of supplies for the Army, and he strongly advised increasing the production of lead in the colonies wherever possible. Clearly, this meant finding new resources as well.

Roberdeau requested and received a leave of absence from the Continental Congress, then located in York, Pennsylvania. Congress had fled Philadelphia following the 1777 defeats at Brandywine and Germantown and the occupation of the city by the British under General Howe. From York, he proceeded to the military depot at Carlisle, PA, to gather soldiers and supplies. Following the Juniata River, he made his way to Huntington, and, after a brief stay there, reached Sinking Valley on April 27, 1778. Soon after he arrived, Roberdeau confirmed the report of lead in the area. Some historians suggest that both the French as well as local native tribes recovered lead here prior to this period.

At this time, the area bounded by the three tributaries of the Juniata River (the Little Juniata, the Frankstown Branch, and the Raystown Branch) was part of Bedford County. This included Sinking Stream Valley, where streams rose from and disappeared into limestone. The picturesque valley surrounded on three sides by mountains was sparsely settled, and the residents there were more interested in farming and surviving than in mining lead. The French and Indian War (1754-1760) had served to stem the tide of white settlers and turn back many of those who had already endured extreme difficulties to establish settlements in the frontier. After the war, the boldest of the pioneers began returning to try to reestablished their homes and farms. In the late 1700s, there was no formal authority in this remote western frontier, and Native Americans hostile to the colonists, traveled effortlessly across the wooded mountains and attacked settlements in the valley at will.

Roberdeau also became aware of the threat of attacks from the native population. He found that many local residents were heading back east in response to rumors of imminent raids by a large force of British Rangers, Iroquois, and loyalist sympathizers. Roberdeau decided to "erect a stockade to protect the reducing works," and did his best to persuade the locals to stay to defend the frontier.

THE FORT

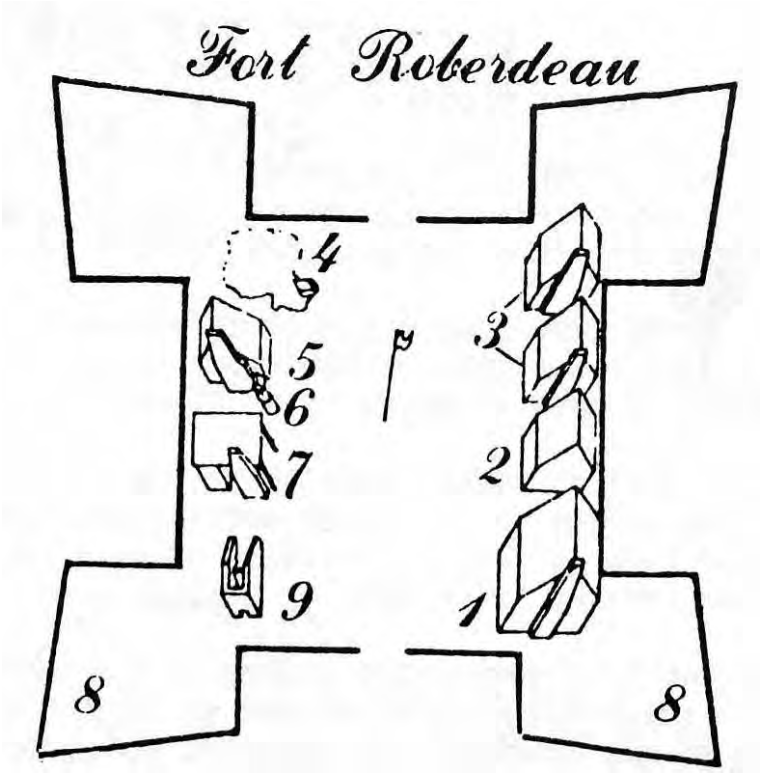
The site selected for the original fort was located on Sinking Spring Valley Manor, one of William Penn family's large tracts of land. This "manor" was valued for its fertile soil, abundant water, and serene beauty. Clearly, an additional benefit was the lead ore that lay hidden beneath its gently rolling countryside. If enough of this strategic metal could be recovered, it would not only yield much needed ammunition for the war effort, but it might turn out to be profitable for the entrepreneurs and landowners as well.

With growing concern over reports and rumors of surprise Indian attacks throughout the region, and an acute awareness that the miners would require a secure environment, Roberdeau directed that work begin immediately on a fortification near the center of mining activity. Construction began in April and continued through the summer of 1778, and by the fall, the fort was completed. Members of the Cumberland and Bedford counties militia and the Bedford Co. Ranging Companies as well as local settlers aided in this effort.

Typical palisade construction for frontier forts involved a stockade built using long, upright logs partially buried in a backfilled trench. Here, however, carbonate bedrock is often near the surface, and soil, in places, is thin to absent. Out of necessity, Roberdeau built the stockade by placing logs horizontally, one on top of the other, reaching a height of 12 to 14 feet (Figure 1).

Figure 1. The front entrance of reconstructed Fort Roberdeau as it appears today. Note the horizontal logs forming the stockade.

This stockade formed a hollow square and bastions secured each corner. The interior of this garrison comprised several buildings listed below. The numbers correspond to those on the sketch map shown here. (Note: the fort's plan outline is similar to others noted in Scull's 1770 map of the central Pennsylvania region, e.g., F. Littleton; see Smith, this guidebook.)



1. Officers Quarters – used both as living quarters and the administrative office.
2. Store Room – used as a secure storage area for the fort's stores and equipment, as well as personal items for the soldiers. This building, without windows or fireplace, was located purposely between the enlisted men's barracks and the officers' quarters.
3. Barracks – served as the living quarters for 12 men. Buildings were equipped with wood-plank bunks and fireplaces, and contained a minimum amount of furniture. The space above the ceiling beams provided additional storage.
4. Powder Magazine – an underground facility for storage of powder and shot. The angular entrance was designed to prevent damage to adjacent buildings in the event of an explosion.
5. Kitchen – served as the center for meal preparation and cooking, complete with an oven and hooks for dry-aging meat.
6. Well – this source of water was located within the fortification, and therefore was available anytime.
7. Blacksmith Shop – sheltered one of the most important services at the fort. The bellows are identical to period equipment. A lean-to and storage building provided additional protection in the event of an attack.
8. Firing Platforms – located in the bastions. These elevated floors enabled soldiers to see and fire over the wall. The fortification was outfitted with four, double-fortified, four-pounder cannons mounted on traveling carriages. In addition, portholes, cut at shoulder height into the connecting curtain walls, afforded access to soldiers firing small arms.
9. Lead Smelter – lead-production activity centered on this furnace. Ores, brought to this site, were reduced to generate the metal. Molten lead was formed into ingots and sent east for additional processing.

Although the primary purpose for building Fort Roberdeau was to protect those associated with the mining and smelting operations, it frequently provided a safe haven for local residents during periods of unusual Indian unrest. Those who were unwilling or unable to take advantage of this protection frequently fell victim to the periodic attacks. Many others, upon returning to their homesteads, found their homes burned and their possessions destroyed. The fort itself, according to records, was never subjected to an Indian attack.

However, in retrospect, several factors combined to impede the mining operation, and thus nullify the principal purpose of this fortification. The value of the lead ore had been substantially over estimated. Operating costs proved far greater than any profits generated by the operation. It was difficult to retain miners who were willing to dig and break the ore and smelters to process it (Figure 2). Moreover, the volume of lead extracted from the area never achieved the expectations of the initial reports.

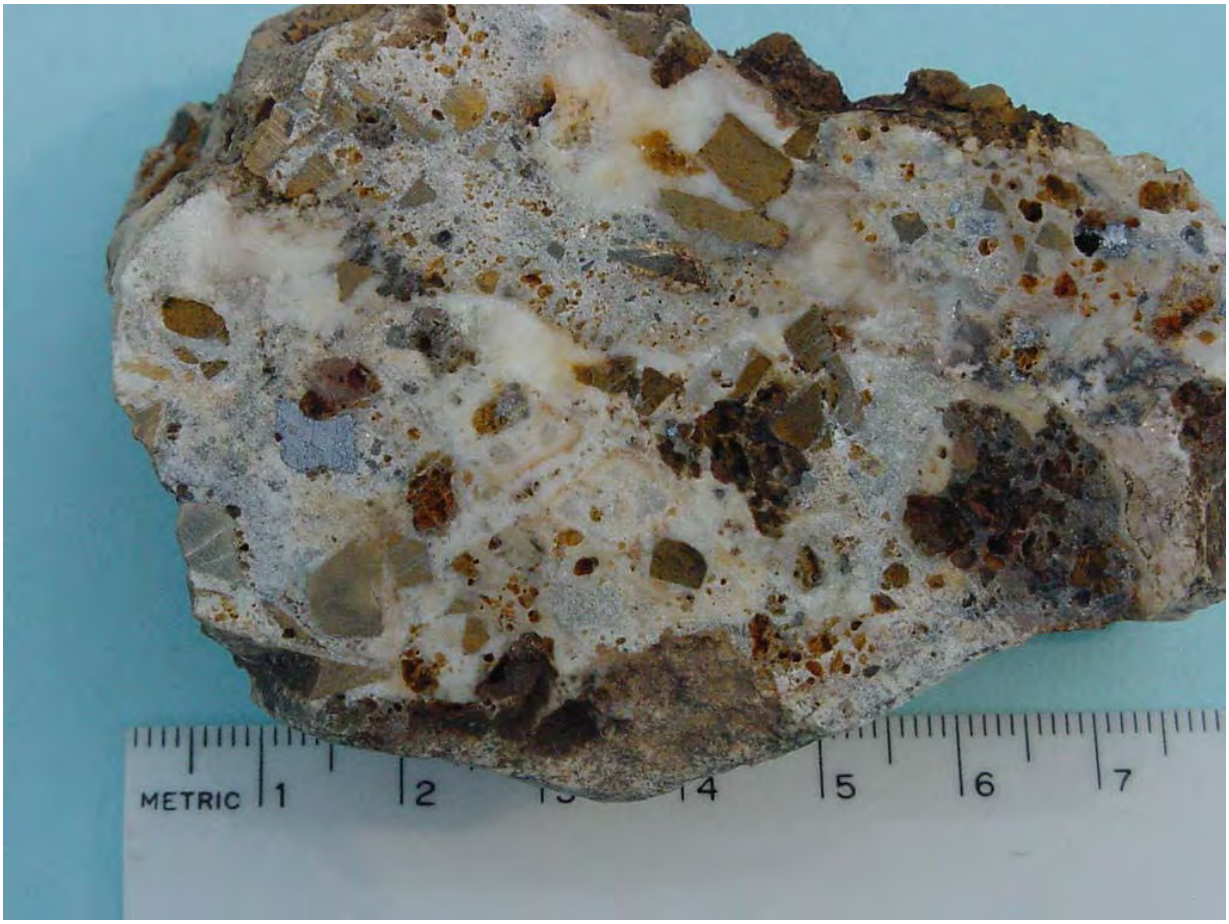


Figure 2. A slabed hand sample of Bellefonte Fm. vein "lead ore" from farm fields near the Bridenbaugh prospects (Smith, 1977, p. 128; Smith, 2003, Fig. 2 this guidebook). This area is near the present location of Fort Roberdeau. The majority of the sample is barite with sparse galena cleavages. Note the spongy nature of the matrix as well as the angular carbonate clasts. Sphalerite, present here as well as in some other sites in the Southern Sinking Valley region, is far less common and was not sought as ore for this colonial smelting operation.

Perhaps the most important elements in this entire equation were those taking place on foreign soil, far removed from the western frontier. Two accords reached between America and France proved to have profound effects on the nation's strained resources devoted to the war effort, and ultimately upon this central Pennsylvania lead-mining operation.

France began providing aid to the colonies in May 1776, when it sent 14 ships with war supplies to America. In fact, most of the gunpowder used by the American armies came from France. After Britain's defeat at Saratoga, France saw an opportunity to seriously weaken its ancient enemy and restore the balance of power that had been upset by the French and Indian War (the Seven Years' War).

As Minister to France, Benjamin Franklin negotiated and signed two treaties on February 6, 1778. In the first, the Treaty of Amity and Commerce, France recognized America and offered trade concessions. In the second, the Treaty of Alliance stipulated that if France entered the war, neither country would lay down its arms until America won its independence, that neither would conclude peace with Britain without the consent of the other, and that each guaranteed the other's possessions in America. The bottom line: this new, formal Franco-American alliance meant that a supply of arms and ammunition sufficient to address the needs of the struggling continental army would be forthcoming. Suddenly, the pressure to generate massive supplies of lead from the colonies was relieved.

Thus, the venture responsible for the construction of Fort Roberdeau was brought to a close only a year after it began. Because there were more pressing needs for the militia, the fort was not maintained as an active regional garrison. It served as a storage depot for ordnance and ammunition for the Bedford County area until March 1780. Subsequently, it fell into disuse and progressively deteriorated.

THE LEAD

During the colonial period, lead was produced from operations in New York, North Carolina, and several New England states; there is scant mention of lead being mined in Pennsylvania. Smith (1977, p. 124-140) provides a comprehensive review of the location, mineralogy, and geochemistry of these early lead prospects throughout southern Sinking Valley. Refer also to Smith, 2003 (this guidebook), for insights regarding lead-zinc geochemical history in central and eastern PA.

Throughout the brief history of the mining operation during this time, reports indicated that a thousand pounds of lead was processed in 1778. Most of the lead produced here was packed on horses and donkeys and hauled to Water Street nearly ten miles to the east. There, the ingots were transferred to flat boats and, using the Juniata and Susquehanna Rivers, sent on for additional refining and manufacturing into bullets.

In 1780, Roberdeau entered into a partnership with owners of lead mines in Virginia. His letters reveal high hopes for continuation of the lead production in Sinking Valley. Although lead mining operations continued for several years, the outcomes were disappointing. In addition to the likelihood that initial yields were exaggerated, the ores here were too lean to be economic. The operations apparently did cover Roberdeau's investment and he was reimbursed for his initial expenses.

Interestingly, it is reported that British loyalists interfered with the smelting operations through bribery and terrorism. Roberdeau knew that the British were aware of the lead production, and in one of his letters he stated, "We are now an object with the enemy." In 1780, he offered a bonus of $100 to a smelter who would finish the ore that was "on the ground," but to no avail. Although the British never played a military role here, they apparently were successful in slowing lead production by secretly paying the smelting crew to leave the valley.


Hey, look pal - if you wanna be a lead weight, galena gainst someone else!
Harper '03

STOP 7. A GEOLOGICAL RAILROAD EXCURSION THROUGH THE HORSESHOE CURVE AND SUMMIT TUNNELS.

Leaders: Jon D. Inners, Viktoras W. Skema, and Gary M. Fleeger.

This "STOP" is actually a 22-mile, non-stop train trip from Altoona to Gallitzin and back (Figure 1), sponsored by the Railroaders' Memorial Museum as part of their annual Rail Fest celebrations. The first weekend in October is normally the only time in the year that excursion trains travel this scenic and historic route around the Horseshoe Curve, up the Allegheny Front, and through the "summit tunnels" at the crest of the Front—and we Field Conference participants are fortunate in the timing! While the highlight of this excursion is undoubtedly the trip around the Horseshoe Curve, the most famous railroad landmark in Pennsylvania (and arguably in the entire nation), the route also includes a spectacular run high along the north side of the Sugar Run Valley and through the Allegheny Tunnel, the oldest tunnel through the Front in the Commonwealth.

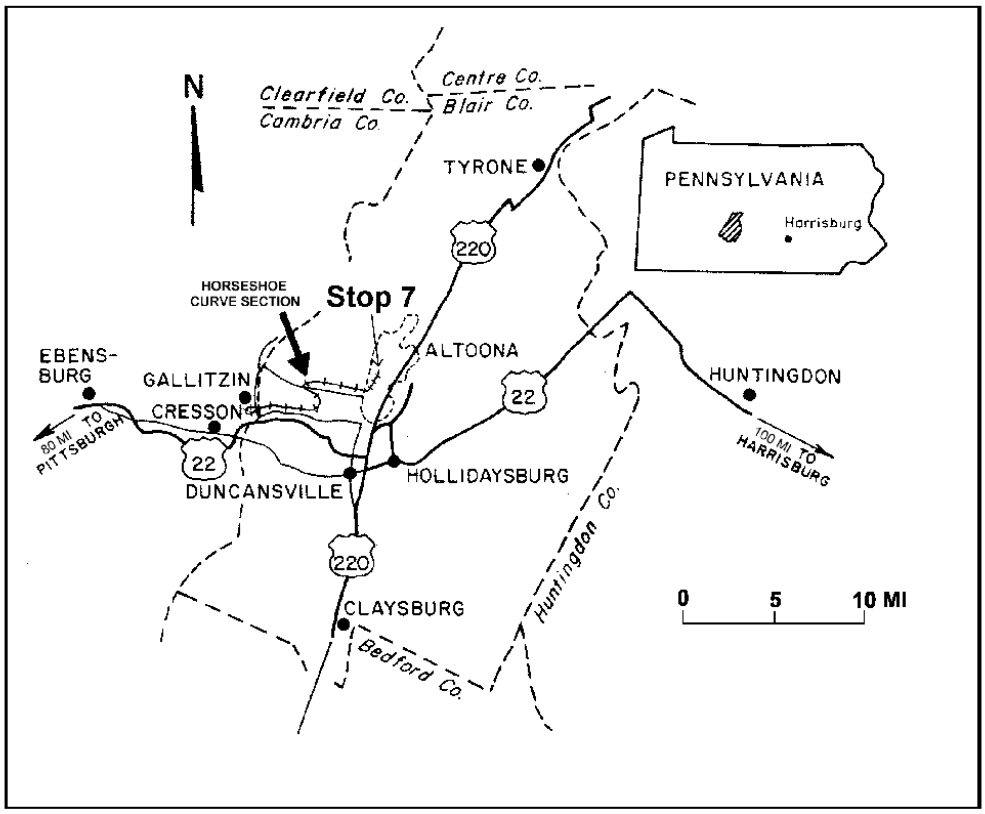


Figure.1. Location map for STOP 8, showing general route of train excursion.

Construction of the railroad also created one of the most complete upper Paleozoic stratigraphic sections in the Northeast—through Upper Devonian, Mississippian, and Pennsylvania marine and terrestrial strata more than 6600 feet thick. So make yourself comfortable, but look out the window! As excursionists enjoy the spectacular autumn scenery of the Front, and as geologists take a veritable trip back in time—not merely a hundred years to the halcyon days of rail travel in America, but more than 300 million years to the sultry days of Carboniferous coal swamps and the Devonian Catskill Delta.

Our train trip today though the Horseshoe Curve and up the Front recapitulates an important event in Field Conference history. The geologists of the very first Field Conference in 1931 took the train from Altoona to the Allegheny/Gallitzin Tunnels on the morning of Memorial Day, May 30, and then WALKED from there back to Altoona. Although the "Pennsy" apparently had no problem with such a group expedition along the tracks 70 years ago (when there were actually many more trains than now passing up and down the Front), Norfolk Southern would certainly frown on it today.

Physiography and engineering. A paragraph in a recently republished book by Dan Cupper of Harrisburg, PA, probably captures the "essence" the Horseshoe Curve as well as anything ever written:

> For all the natural beauty that surrounds it, Horseshoe Curve is a symbol of conflict. Every time a wheel turns on a train rounding the curve—whether going up or down the mountain—that fact is re-established. From the very day it opened in 1854, trains pushing westward struggled to overcome gravity, and crews coming down the mountain still fight to hold back gravity's pull (Cupper, 2002, p. 1).

Figure 2. View of the Allegheny Front from Chimney Rocks (STOP 3) about 6 miles to the east. The steep escarpment at the Front marks the boundary between the Allegheny Plateau and the Ridge and Valley. The right arrow points to the Burgoon Run valley (Horseshoe Curve) and the left arrow to the Sugar Run valley (Summit Tunnels).

The topographic barrier that is the root of this transportational conflict with gravity is the imposing Allegheny Front, the great erosional escarpment (Figure 2) that separates the Ridge and Valley fold mountains from the Allegheny Plateau—with its much gentler folds but even more rugged topography.

During the colonial and early national periods of American history, the Allegheny Front was the major topographic barrier to westward expansion in Pennsylvania. It kept Pittsburgh and the rest of western Pennsylvania isolated from markets to the east. In contrast to the long narrow mountains of the Ridge and Valley, where deep water gaps allowed fairly easy travel from one transverse valley to another, the Front in central and western Pennsylvania is broken through only by the West Branch of the Susquehanna River near Lock Haven, 70 miles northeast of the Horseshoe Curve—and the terrain bordering the river behind the Front in that area is still some of the wildest and most rugged in the Commonwealth. Little wonder that the West Branch "gate" offered little enticement for westward movement.

Spurred by the successful completion of the Erie Canal through central and western New York, Pennsylvania embarked on a great public works program in 1826, the keystone of which was the Pennsylvania Main Line Canal. The canal extended westward across the state and joined the Susquehanna and Ohio River valleys. Its route passed over the Allegheny Front at Blair Gap, about 4 miles southwest of Horseshoe Curve, through an ingenious system of inclined planes and stationary steam engines known as the Portage Railroad (see Harper, this guidebook, STOP 8).

Though the Pennsylvania Railroad (PRR) was incorporated in 1846, work on a railroad link between Harrisburg and Pittsburgh was begun much earlier. In 1840, Col. Charles L. Schlatter surveyed three routes—northern, middle, and southern—connecting the two cities. In the late 1840's, John Edgar Thomson (1808-1874), who at the time was Chief Engineer of the PRR, designed and surveyed a route over the Alleghenies, generally following Schlatter's middle route along the Juniata and Little Juniata Rivers to Sugar Run Gap. This route had a maximum grade of only 21 feet per mile for the 134 miles from Harrisburg to the foot of the mountains. But grades over the Allegheny Front would have to be substantially higher, as nearly a thousand feet of elevation had to be overcome in less than six miles—an average grade of more than 150 feet per mile (Burgess and Kennedy, 1949).

Thomson's final design utilized two engineering structures to overcome the problem of excessive grades at the Front. The first was the Horseshoe Curve in Burgoon Run valley, a mile and a half north of Sugar Run (Figure 3; see excursion log between *Sites 7* and 8). As well described by Ward (1980):

> Thomson ran his rails into a valley and then back again to gain distance to achieve higher elevations with acceptable grades. In the process his crews [450 Irish laborers using picks and shovels, wheelbarrows, and black powder] hacked out ledges along two mountains and dug and transported millions of cubic feet

of fill dirt to build up the roadbed across two valleys. The result was not only an engineering triumph that saved the road millions of dollars in transport costs over the years, but a vista of awesome beauty….

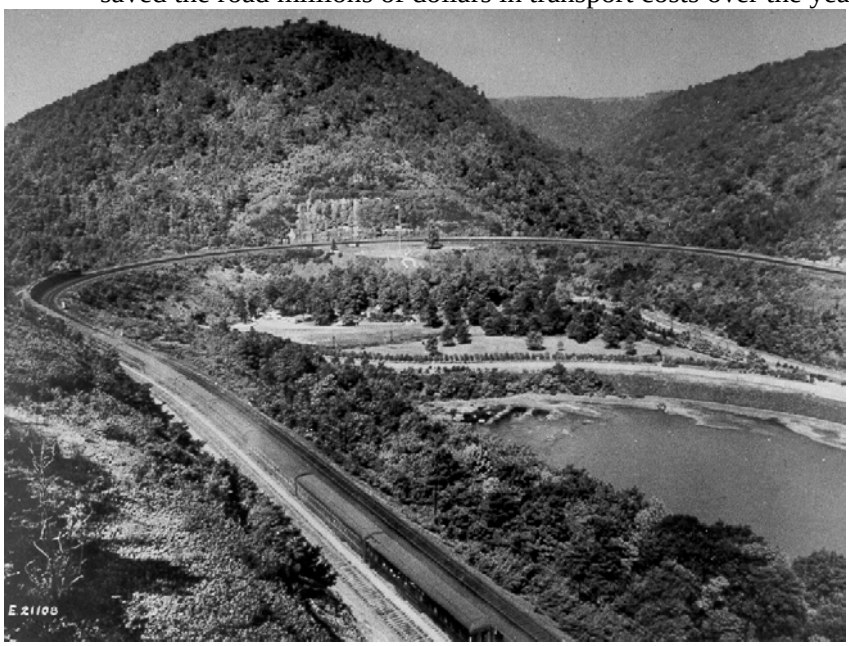


Figure 3. J. Edgar Thomson's Horseshoe Curve as seen from the southeast side of Burgoon Run valley. The high cut in the Mississippian/Devonian-age Rockwell Formation at Kittanning Point (*Site 10* of the excursion log) marks the head of the Curve. (Photo courtesy of Altoona Public Library and Railroaders Memorial Museum.)

The second was a tunnel located about 100 feet below the crest of the Front at what is now Tunnel Hill (see Figure 29 and excursion log *Site 25*). This was the first tunnel through the rocks of the Allegheny mountain barrier, and its construction was fraught with difficulties. When it was finally completed in early 1854, the way was open for the first train to pass over the route on February 15 (Cupper, 2002). Chief engineer at the time of the opening of the line across the mountains was Herman Haupt (1817-1905), who had succeeded Thomson when the latter became President of the Pennsylvania Railroad in 1852 (Ward, 1973). (Haupt later gained fame as the Union's railroad "czar" through much of the American Civil War, and as the engineer most responsible for the construction of the ill-fated Hoosac Tunnel in western Massachusetts.)

At the same time that the railroad was being constructed over the Front, Altoona was founded as an important way station on the western section of the PRR. (J. Edgar Thomson himself apparently named the community after Allatoona Pass in northern Georgia, where he had done railroad work early in his career [Ward, 1980].) The Pennsy established its major locomotive and car shops there—and the extensive rail yards at Altoona were the place where long westbound trains stopped to add pusher engines for the long climb to Gallitzin (Faill et al., 1989).

Except for widening to three tracks and then four tracks between 1898 and 1900 and the reopening of the New Portage Tunnel in 1904 (Cupper, 2002), the present railroad route over the Allegheny Front is virtually unchanged from Thomson's original design 150 years ago. The same cannot be said concerning the route's ownership. The Pennsy maintained control until its disastrous merger with the New York Central in 1968. Conrail took over in 1976, and in 1998 Norfolk Southern inherited the route on Conrail's demise.

Traffic on the route has declined from as many as 168 trains a day in 1904 to only about 60 a day at present. The decline in passenger service has been even more drastic, with only two trains—the *Pennsylvanian*, a Philadelphia-Pittsburgh daily, and the *Three Rivers*, an overnight run between New York and Chicago and vice versa—currently operating.

Stratigraphy and structure. Figure 4 shows the litho- and chronostratigraphic framework of the bedrock formations in the Horseshoe Curve area and indicates the *Sites* along the train trip where the rock units are exposed. Figure 5 shows details of the stratigraphic sections in the Burgoon Run valley (A) and the Sugar Run valley (B).

"AGE"				UNIT	THICKNESS FT	LITHOLOGY
PENNSYLVANIAN	Upper	WESTPHALIAN	MISSOURIAN	CONEMAUGH GROUP GLENSHAW FM.	75+	Interbedded gray claystone, shale, and sandstone, with nodules and discontinuous beds od siderite limestone. *Sites 24, 26, 27, & 29.*
PENNSYLVANIAN	Middle	WESTPHALIAN	DESMOINESIAN	ALLEGHENY GROUP	345	Irregularly cyclic sequences of clastic rocks and coal beds (to 1.8 meters thick). Some fresh-water limestones. Mostly gray and olive colors. *Sites 21, 24, & 29.*
PENNSYLVANIAN	Middle / Lower	WESTPHALIAN	ATOKAN / MORROWAN	POTTSVILLE GROUP	105	Light gray quartzose sandstone, clay shale, coal (not exposed), and underclay. Somewhat cyclic. *Sites 19 & 21.*
				?		
MISSISSIPPIAN	Upper	NAMURIAN	CHESTERIAN	MAUCH CHUNK FM.	165	Gray quartzose sandstone and conglomerate; red and green silty claystones at top and bottom. *Site 18.*
MISSISSIPPIAN	Upper	VISEAN	MERE-MECIAN	LOYALHANNA FM.	50	Gray, strongly cross-bedded calcareous sandstone. *Site 16.*
MISSISSIPPIAN	Lower	TOURNAISIAN	OSAGIAN	BURGOON SS.	300	Gray, cross-bedded quarzitic sandstone, pitted at top. Siltstone, shale, and coal in middle. *Sites 15 & 16.*
MISSISSIPPIAN	Lower	TOURNAISIAN	KINDER-HOOKIAN	ROCKWELL FM.	300	Predominantly gray sandstone, but also containing considerable siltstone and silty clay shale. Fine clastics locally purplish red; Patton "red beds" at top. *Sites 10 & 14.*
DEVONIAN	Upper	FAMENNIAN	CONEWANGOAN	CATSKILL FM. — DUNCANNON MBR.	600	Fluvial fining-upward cycle(s), consisting of basal gray sandstone grading up into red silty claystone. *Sites 8, 12, & 13.*
DEVONIAN	Upper	FAMENNIAN	CASADAGAN	CATSKILL FM. — SHERMAN CREEK MBR.	1400	Interbedded grayish-red silty claystone, siltstone and sandstone; some greenish-gray beds of these same lithologies. Fining upward cycles common. *Sites 6 & 7.*
DEVONIAN	Upper	FAMENNIAN	CASADAGAN	CATSKILL FM. — IRISH VALLEY MBR.	450	Interbedded gray and red sandstone, siltstone, and silty claystone, mostly arranged in marine-nonmarine motifs. *Site 5.*
DEVONIAN	Upper	FRASNIAN	CHEMUNGIAN	LOCK HAVEN FM.	1975	Interbedded gray silty clay shale, siltstone and sandstone, minor quartz pebble conglomerate. Lower part thinner bedded and finer grained than upper. *Sites 2, 3, & 4.*
DEVONIAN	Upper	FRASNIAN	FINGERLAKIAN	BRALLIER FM.	900+	Interbedded silty clay shale, silt shale, and siltstone. *Site 1.*

Figure 4. Upper Paleozoic (Upper Devonian to Pennsylvania) bedrock units exposed along the excursion route (keyed to *Site* descriptions). Modified from Inners, 1997.

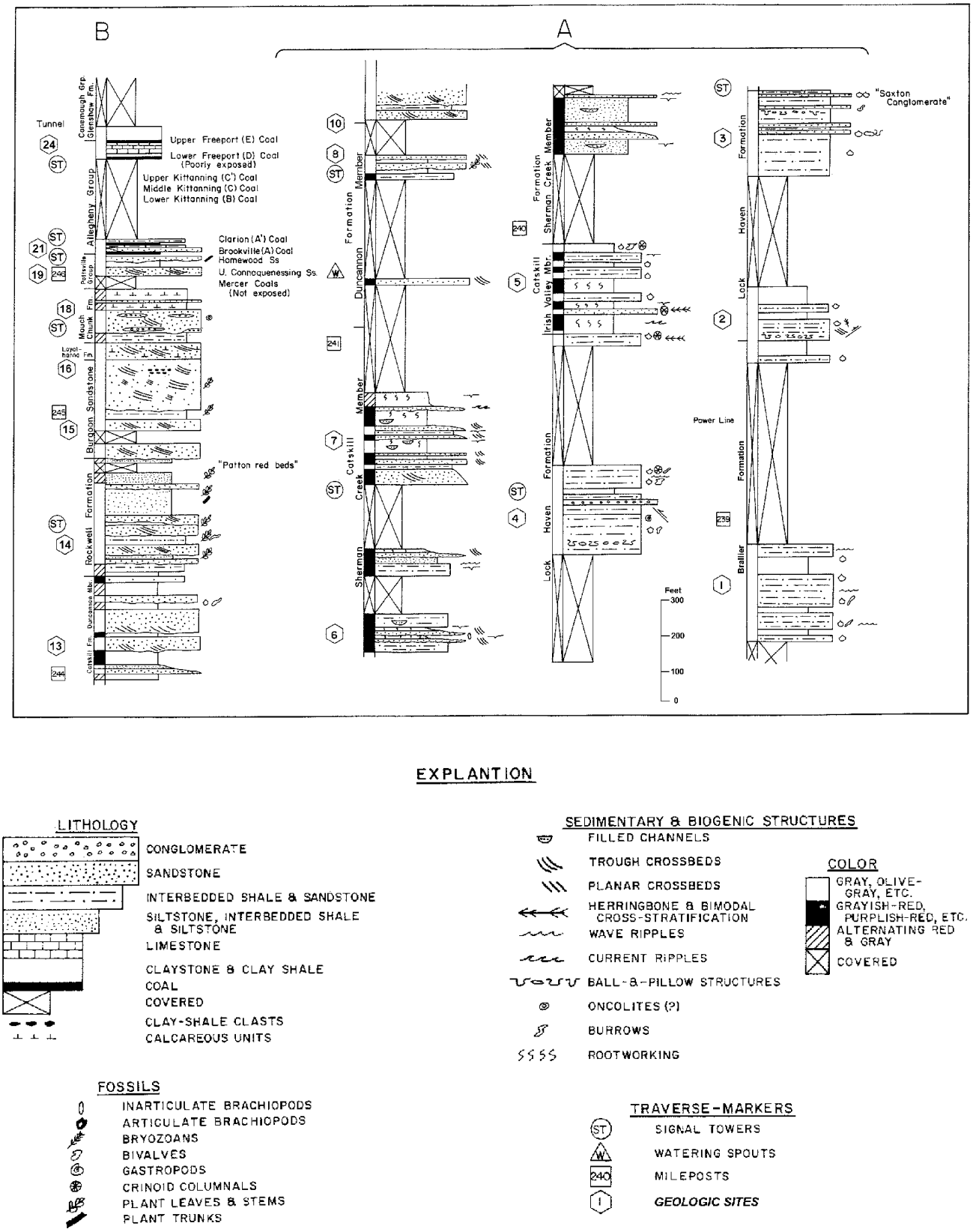


Figure 5. Stratigraphic sections along the excursion route, showing positions of *Sites*: A. north side of Burgoon Run valley; B. north side of Sugar Run valley. (Modified from Inners, 1987).

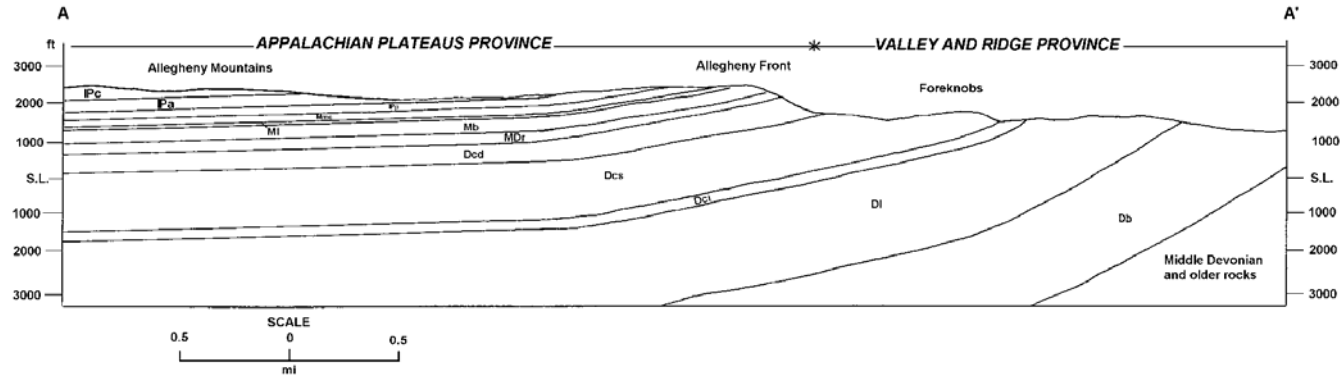


Figure 6. Generalized geologic cross section across the Allegheny Front at Altoona.

Figure 6 is a somewhat generalized NNW-SSE cross-section across the Allegheny Front in the vicinity of the Horseshoe Curve. The gradual decrease in bedding dip shown on the section (from about 20° northwest in the Foreknobs area to less than 10° northwest on the Plateau) is clearly evident on the railroad traverse.

Log of Train Trip from Altoona Amtrak Station through the Horseshoe Curve, Sugar Run Valley, and Allegheny Tunnel to Gallitzin:

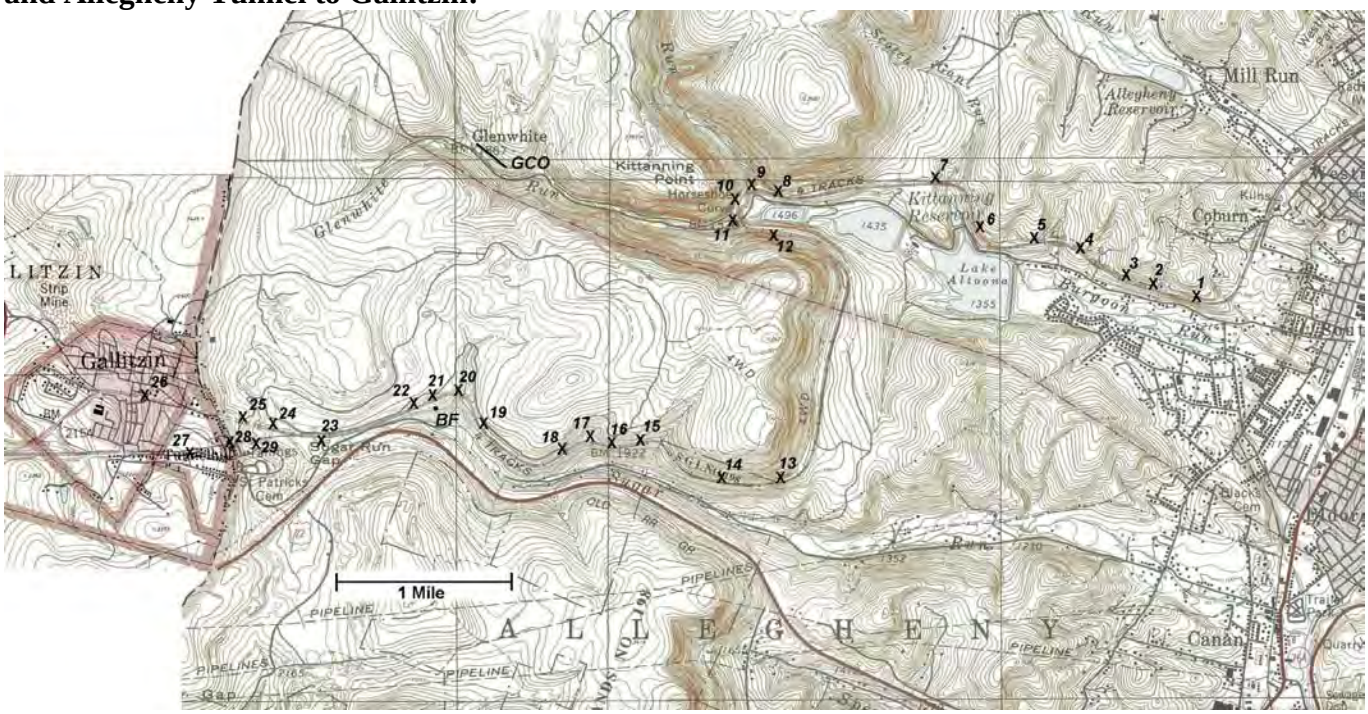


Figure 7.Detailed map of train excursion (STOP 8), showing geologic and historic *Sites*, viewpoints, and other significant features along the route.

The following log is a major expansion (with some corrections) of a Geological Society of America Centennial Field Guide (Inners, 1987). Much supplemental information is from a poster session prepared for the 1989 meeting of the Northeastern Section Geological Society of America (Inners, 1989). The geologic and historic *site* descriptions along the route are divided into two parts. The first describes what can actually be seen from the train, while the second (indented, smaller type) gives details visible only on close "field" examination. (There may be some exceptions to this ideal!) *Sites 1* to *12* are in the Burgoon Run valley, with *Sites* 8 to *12* within the Curve itself; *Sites 13* to *24* and *29* are in Sugar Run valley; and *Sites 26* and *27* are at the west portals of the Summit Tunnels; *Sites 25* and *28*

are tunnels through the summit of the Front (Figure 7). All *sites* are to the right of train unless indicated otherwise.

The new $4.5-million ***Altoona Passenger Station*** opened in July 1986, about 12 years after the old PRR brick station was demolished. Just to the west of the station is the site of the once famous Logan House (built by the PRR in 1855), which served not only as a hotel but also as the train ticket office and indoor waiting room for railroad passengers (Van Horne and Drelick, 2002; Treese, 2003).

Figure 8. Altoona Railroaders Memorial Museum. (Postcard photo, copyright Thomas Pollard Photography.)

To the east of the Altoona Station is the ***Railroaders Memorial Museum*** (Figure 8). The museum occupies the former Master Mechanics Building (c. 1880), one of over 120 buildings that made up the Pennsylvania Railroad's Altoona Works—at its height the greatest railroad shop complex in the world. The original 12th Street Shops in this vicinity were established in 1850 as mainly locomotive and car repair shops. Later the Pennsy expanded operations here to include the design and construction of locomotives and railroad cars. (More than 6500 steam locomotives were built at Altoona, the first in 1866, the last in 1946.) In 1888-90, the Juniata Erecting Shops were built in the Juniata section of Altoona, about a mile to the north. By the turn of the 20th century, the combined 12th Street/Juniata Shops sprawled over 218 acres (88 acres under-roof) and took up the entire center of Altoona. The complex then included roundhouses; iron foundries; locomotive and car shops; airbrake, paint, and wheel shops; and several buildings housing test facilities for everything from drinking water and light bulbs to locomotives. In 1904 the South Altoona foundries complex opened two miles southwest of the main shops—and all foundry work previously done in the machine shops was transferred there. During the halcyon days of steam railroading in the first third of the 20th century, the PRR train works extended for three miles along the tracks in Altoona and South Altoona. Peak employment at this time was about 17,000 workers. In 1931, early in the Great Depression, a devastating fire swept the air brake, paint, and wheel shops at 12th Street; they were never rebuilt—and all locomotive work was gradually switched to the Juniata Shops—a process that was completed on August 1, 1938. Following World War II, the entire PRR railroad complex at Altoona entered upon a slow but steady decline as the grand era of steam railroading passed into the diesel-electric age. The last steam locomotives were manufactured in 1946. As mergers, bankruptcies, and takeovers took place over the next several decades, the former PRR shops were successively run (and gradually downsized) by the Penn Central Railroad (1968), Conrail (1976), and Norfolk Southern (1998). Only the Juniata Shops are still in operation, constituting an important Norfolk Southern locomotive heavy repair and manufacturing facility.

Site 1. Brallier Formation (at Milepost 239). The interbedded gray and olive sandstone, siltstone, and clay shale exposed where the railroad bends around to the west to enter the Burgoon Run valley (Figure 9) occur in the upper part of the Brallier Formation of Faill et al. (1989), or the basal part of the "Chemung Formation" of Butts (1945) and Swartz (1965). The prominent sandstones in the cut may be turbidites. The beds dip about 25° to the west-northwest.

Figure 9. Interbedded shale and sandstone in the upper part of the Brallier Formation at *Site 1*.

Sedimentary features include thin (0.4 to 6 inch) siltstone-sandstone beds with planar bases and rippled tops; horizontal, fucoidlike burrows on the bases of some beds; and locally intense bioturbation. Common fossils include the brachiopods *Productella*, *Ambocoelia*, *Cariniferella*, and *Atrypa* (Swartz, 1965). (Figure 10 illustrates some of these fossils.) The 68-foot-thick shale unit of Swartz (1965) near the east end is covered with rusty iron oxide and white sulfate mineralization weathered from iron pyrite.

Site 2. Brallier and Lock Haven Formations (just west of power-line crossing). Exposed near the east end of this cut is the probable contact between the "shaly" Brallier Formation and the overlying "sandy" Lock Haven Formation. A steeply west-dipping thrust fault containing mesoscopic kink folds (Figure 11) cuts the uppermost Brallier.

Many of the fine-grained sandstone beds in both formations exhibit small-scale cross-laminations. About 15 feet above the fault zone are several small ball-and-pillow structures. Swartz (1965) noted the occurrence of brachiopods (*Douvillina*, *Productella*, *Atrypa*, *Tylothyris*, and *Ambocoelia*) and bryozoans at several horizons.

Site 3. Lock Haven Formation (at easternmost railroad signal tower in valley). This second Lock Haven cut exposes five sandstone packets that form distinct ledges separated by recessed intervals of silty clay shale.

Ball-and-pillow structures (Figure 12), load casts, bioturbation (large fucoid-like burrows), climbing ripples, and symmetrical ripples characterize the sandstone beds. The brachiopods *Orthospirifer*, *Ambocoelia*, and *Camarotoechia* occur throughout. At the top of the exposure is a coquinite composed of the disarticulated shells of *Orthospirifer*. Butts (1945) correlated the sandy, brachiopod-coquinite at the west end of the exposure with the "Saxton conglomerate," one of several, coarse offshore-bar or tidal-channel deposits better developed in the Lock Haven to the east of the Horseshoe Curve area.

Site 4. Lock Haven Formation (at second signal tower). This westernmost cut in the Lock Haven is one of several *sites* along the excursion route that are themselves worthy of Field Conference STOPS. The most obvious feature here is a large rippled-sandstone bedding plane that marks the site of a destructive rockslide on April 2, 2002 (Figures 13a and b, see below). The rock sequence consists predominantly of interbedded olive-gray sandstones and silty shales, with one 20-foot-thick interval of purplish-gray, silty clay shale near the top. The 2-foot-thick resistant bed (about 75 feet east of the signal tower) is a flat-pebble quartz conglomerate. Cutting this bed at track level and extending diagonally upward through the cut is a reverse fault that dips 50° to the east or southeast and has about 6 feet of displacement (see Figure 13c).

On the April 2002 rockslide: At about 4:30 PM, while a construction worker operating a backhoe was helping to shave back the cut, a large slab of well-jointed sandstone and shale slid onto Track #3 at the same time that an empty hopper train was passing westward. The slide—carrying along the backhoe—derailed that train, which hit the side of an eastbound double-stack container train, derailing it. A few of the container cars of this second train, in turn, hit a loaded coal train traveling eastbound on Track #1, knocking one loaded hopper off the rails. The second derailment caused a small fire, which was extinguished by water dropped from helicopters. The backhoe operator was trapped in the wreckage and suffered disabling injuries. Tracks #'s 1and 2 were opened the next day, but Track #3 remained closed for another day or two. The stereogram of Figure 13b summarizes the geologic "cause" of the slide.

Current and interference ripples, bioturbation, flaser bedding, herringbone cross-stratification, shallow scour-and-fill structures, isolated ball-and-pillow structures, and invertebrate coquinites occur at various horizons (Swartz, 1965; Rahmanian, 1979). The bedding plane on which most of the April 2002 rockslide took place exhibits beautiful current and interference ripple marks, the current ripples being oriented approximately N20^{o}E-S20^{o}W, with

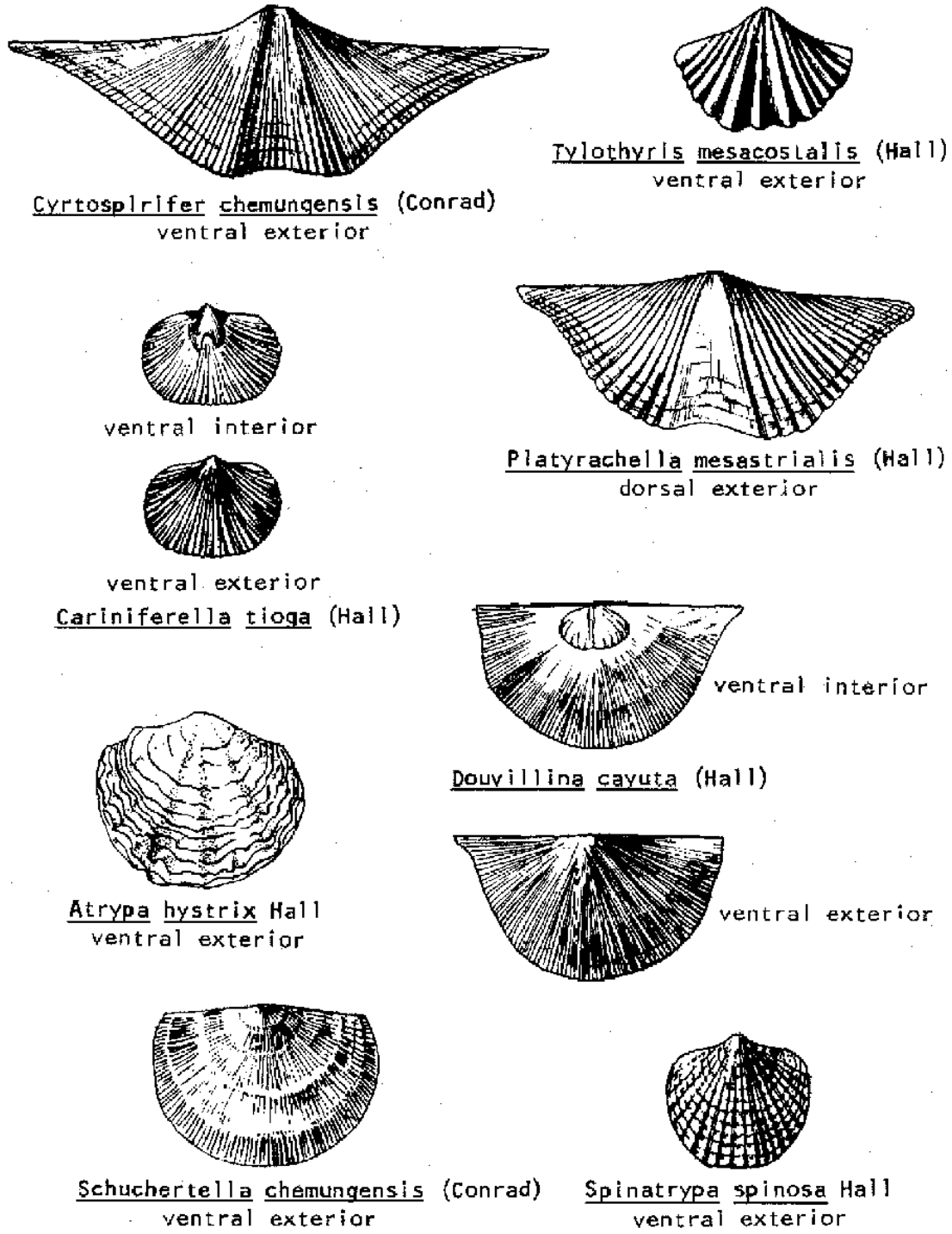


Figure 10. Some common brachiopod fossils in the Brallier and Chemung Formations (slightly modified from Swartz, 1965).

Figure 11. Contact of the Lock Haven and Brallier Formations (arrow) at *Site 2*. The uppermost Brallier is cut by a west-dipping thrust fault associated with numerous small kink folds.

Figure 12. Large sandstone ball-and-pillow structures in the Lock Haven Formation at *Site 3*.

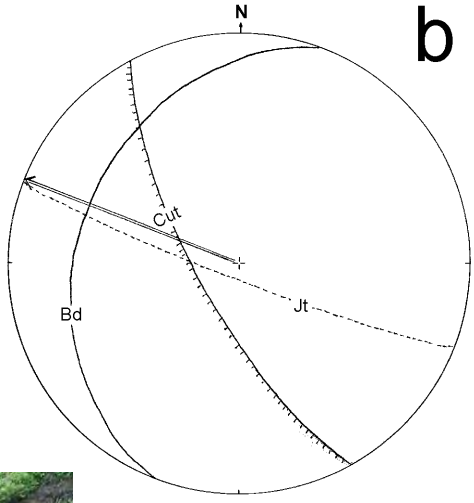


Figure 13. Rockslide and fault in Lock Haven Formation at *Site* 4. (a.) Site of April 2002 rockslide. (b.) Stereogram showing elements of rock structure at site of rockslide: bedding (Bd) = N20^{o}E/30°NW; joint (Jt) = N80^{o}W/85°N; and cut (face) = N30^{o}W at 75° SW (1/4 to 1). The "daylighted" arrow indicates that the slide was "caused" by undercutting of the dip by the steep angle of the cut face, with the smooth joints breaking the rock mass into potentially unstable blocks. (c.) Reverse fault in western part of cut.

flow to the southeast. The coquinites are composed mostly of brachiopod (*Cyrtospirifer*, *Atrypa*, etc.) and bivalve shells and crinoid ossicles.

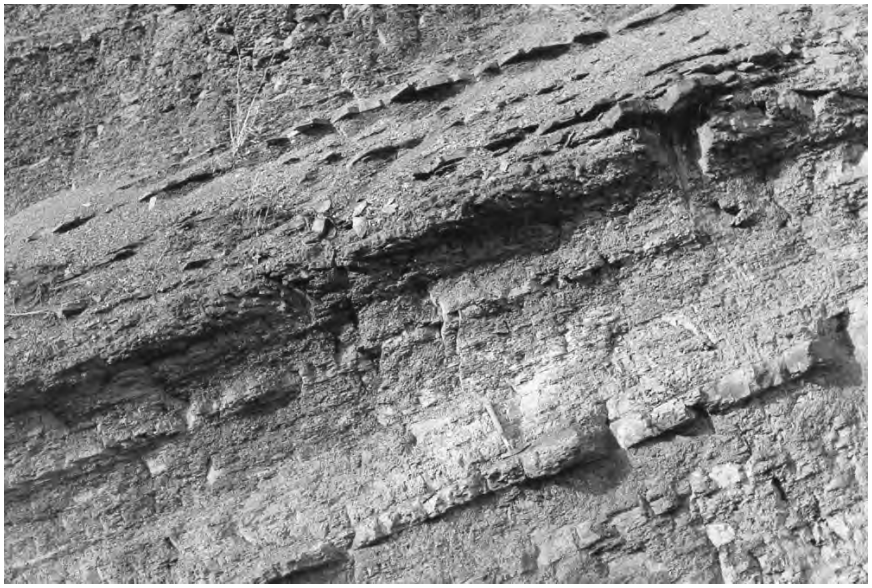


Figure 14. Fining-upward motif in Irish Valley Member of Catskill Formation at *Site 5*.

Site 5. Irish Valley Member of Catskill Formation (east of Milepost 240). The greenish-gray and grayish-red silty clay shales, siltstones, and sandstones here are organized into fining-upward "motifs" (Figure 14; Walker and Harms, 1971). Four such motifs are exposed (Rahmanian, 1979). Sedimentary structures include symmetrical and asymmetrical ripples, herringbone cross-stratification (in a 16-foot-thick sandstone bed 50 feet above the base), flaser bedding, mudcracks, bioturbation, and rootworking (Rahmanian, 1979). Brachiopods, bivalves, and crinoid ossicles are diagnostic of the marine portions of the motifs. According to Rahmanian (1979), the sedimentary environment is shallow marine shelf-shoreface (locally containing tidal sand waves or tidal deltas) grading upward into tidal and supratidal mudflats.

Views of reservoirs just west of Milepost 240. As we round "Miller's Curve" at this point, the view to the left shows three of the City of Altoona's water-supply reservoirs in the Burgoon Run valley. All three were built by the PRR, not only as sources of water for its operations in Altoona but also as a municipal supply for the city. The upper reservoir lies within the Horseshoe Curve and was built in the 1880's. The somewhat larger Kittanning Reservoir in the middle dates from the 1890's or very early 1900's, and Lake Altoona, the easternmost and largest, was built somewhat later. The existence of the village of Glenwhite on Glenwhite Run (see *Site 11*) and numerous coal mines on both Glenwhite and Kittanning Runs upstream of the Curve caused long-term water quality problems for all three reservoirs—problems which were solved by rather complicated engineering works starting as early as the turn of the 20th century.

Because Glenwhite and Kittanning Runs (which we will cross in 1½ miles) were degraded by coal mining, an extensive series of stone and concrete channels and a tunnel were built to divert the water from these streams around the water supply reservoirs. They are designed so that the water from either or both streams can be diverted around or into the reservoirs.

In recent years, surface mine reclamation and the construction of a passive treatment system have improved the quality of the water in Glenwhite Run. Its pH has increased from about 3.5 to near 7. As a result, water from Glenwhite Run now runs into the upper reservoir across the road from the Horseshoe Curve Visitors' Center. However, Kittanning Run remains diverted around the reservoirs. The concrete and stone channels carrying Kittanning Run have that distinctive orange "yellow-boy" coating characteristic of many streams impaired by acid mine drainage.

Site 6. Sherman Creek Member of Catskill Formation (north of Lake Altoona). The 250 feet of grayish-red sandstone, siltstone, and shale here consists of about four fining-upward alluvial cycles.

Trough crossbedding, parting-step lineation, and symmetrical ripples occur in the red sandstones. The red claystones are intensely rootworked and bioturbated. Carbonaceous plant remains are common in the basal parts of a few pale red sandstones. In the red claystone beneath the most prominent sandstone, the inarticulate brachiopod *Lingula* is common. The occurrence of *Lingula* suggests a distal setting on the alluvial plane, subject to brief brackish water incursions.

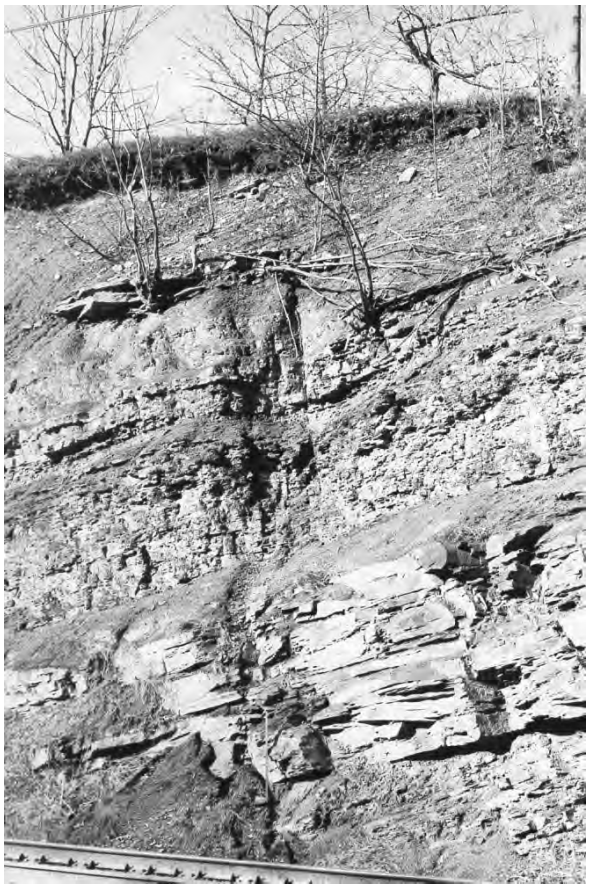


Figure 15. Fining-upward alluvial cycles in the Sherman Creek Member of the Catskill Formation at *Site 7*.

Site 7*. *Sherman Creek Member of Catskill Formation (just west of signal tower and east of Milepost 241). The fining-upward cycles at this *Site* (Figure 15) differ from those at the previous one in containing a few thin olive-gray sandstone and clay shale beds. Trough crossbedding is well developed in the basal sandstones of the cycles. Facing the tracks near the west end of the cut is a loose block of grayish-red sandstone that displays beautiful current ripples.

Many in-place sandstone beds also exhibit current ripples, as well as basal erosional scour. Mudcracks, bioturbation, and rootworking characterize the red claystones. Carbonaceous plant remains are abundant in the sandstones.

Just past *Site 7* the excursion train enters the Horseshoe Curve.

According to Cupper (2002), the Curve is 1800 feet across and about a half a mile long (i.e., from the open end of the "horseshoe" to the head at Kittanning Point). The actual curvature at Kittanning Point (*Site 10*) is 2375 feet long and the degree of curvature is $9^{o}25'$, the sharpest on the Harrisburg to Pittsburgh route. Since the "west end" is 122 feet higher than the east end and the length of track around the Curve is about 6800 feet (1.29 miles), the average gradient is about 95 feet/mile (or 1.8%). Thomson's "switchback" is elegant in its simplicity. But, according to Herman Haupt, his assistant (and later successor as chief engineer), "…[M]ore than a dozen lines were required to be run at the Horseshoe Curve to equalize gradients before the final location was decided upon" (Ward, 1980).

Site 8. Duncannon Member of Catskill Formation (at Signal Tower just before curve). Three fining-upward alluvial cycles (each 25 to 50 feet thick) occur along the tracks and on the hillside above. The sandstones are thick bedded, light olive gray, and locally crossbedded; the intervening shales and claystones vary from grayish red to olive gray, the red being especially evident at the east end of the cut. The well-exposed channel sandstone in the cut exhibits erosional scour at the base. Note that the 13° northwest dip of the beds here (and at *Site 12*) is much less than at *Site 1*. (Swartz [1965] and Inners [1987] included much of this interval in the Rockwell Formation.)

As is typical of the Duncannon (Faill et al., 1989), the sandstones here are fine grained and micaceous.

Site 9. Kittanning Run valley. The huge fills here and across the valley of Glenwhite Run (*Site 11*), each nearly 100 feet high, were constructed from the immense amounts of rock and soil excavated from cuts on the east and west sides of the Curve and from the high cut at Kittanning Point (*Site 10*).

In the latter part of the 19th century, the S. E. Baker Coal Co. ran a railroad spur up this valley to its coal mines. The line later became a common carrier known as the Kittanning Run Railroad. It was abandoned in 1917 just after the Baker mines closed (Cupper, 2002).

At this point, the "Kittanning Path" (a local name for the Frankstown, or Allegheny, Path, one of the most important of Pennsylvania's Indian trails) left the Burgoon Run valley and proceeded up the valley of Kittanning Run to cross the Allegheny Front. Colonel John Armstrong and his band of 300 frontiersmen used this path to reach the Delaware Indian stronghold of Kittanning, about 60 miles farther to the northwest, which they successfully attacked and destroyed on September 8, 1756 (Wallace, 1965; Hunter, 1962).

Site 10. Rockwell Formation (at Kittanning Point, the head of the Horseshoe Curve). The thick-bedded greenish- gray sandstones exposed in the deep cut at Kittanning Point occur near the base of the

Figure 16. Probable Murrysville Sandstone (base of the Rockwell Formation) at Kittanning Point (*Site10*). Note the thick lenticular shaly unit a few feet above track level.

Pocono Formation of Butts (1945), or the Rockwell Formation of more modern usage (Faill et al., 1989). This massive unit probably represents the Murrysville Sandstone of areas farther west on the Plateau (see *Site 14*) (Figure 16). The resistant rock layers here were one of the major obstacles to the construction of the Curve: in the early 1850's, blasting though such thick-bedded, indurated quartz-sandstone was a major undertaking. Once "constructed," however, the high rockface, with beds dipping northwestward into the cut, was very stable—and formed a picturesque backdrop for paintings and photographs of Thomson's masterpiece (see Figure 3).

The spectacular view to the left (Figure 17) encompasses the three Altoona water reservoirs in the valley of Burgoon Run (seen earlier at "Miller's Curve"), incised deeply into the Front in the foreground and cut through the "foreknob" ridges in the middle distance. Far off on the horizon is Brush Mountain (Early Silurian-age Tuscarora Formation) at the plunging nose of the Nittany Mountain (Sinking Valley) anticline (Faill et al., 1989). A few dozen yards east of the railroad is the "funicular" and inclined plane used to carry visitors from the Horseshoe Curve Museum below to track level at Kittanning Point. The current Museum was built in 1992; it succeeded earlier, less elaborate facilities. The diesel-electric locomotive on display in the foreground is GP9 #7048. It replaced the K-4 steam locomotive #1361 in 1985, after the latter had been at this site for 29 years. The K-4 is being restored for display at the Railroaders Memorial Museum.

Figure 17. View east from *Site 10* showing the Altoona Reservoirs and Brush Mountain in the distance.

The Pennsylvania Railroad converted from steam to diesel between 1948 and 1957 (Cupper, 2002). Although the larger steam locomotives were more powerful than diesels, they were much more difficult to keep running. According to a plaque in the Horseshoe Curve Museum, a steam locomotive—with its maze of tubes, valves, and bearings—had to be in the shop for 14 to 16 days a month, whereas a diesel ran 29 days out of every 30! The steamers also required more trainmen, as well as extensive coaling, watering, and turning facilities. (Diesels run equally well in forward or reverse.)

Trough and planar crossbeds and carbonaceous plant remains are common here. Swartz (1965) mistakenly cites this as the "type section" of the Burgoon Sandstone.

Site 11. Glenwhite Run valley. Across this valley is the second big fill of the Horseshoe Curve. Two railroad spurs, one on each side of the valley, at one time ran up the valley of Glenwhite Run from the head of the Curve to the mines, coke ovens, and company town of the Glenwhite Coal and Lumber Co. The grade of one of these is still well preserved on the north side of the run. Beneath the fill here are two stone-lined tunnels, both dating from about the time of the construction of the Curve. The one on

Figure 18. Former Survey coal geologist Albert D. Glover examines the ruins of several of the stone beehive coke ovens of the Glenwhite Coal and Lumber Co. about 1.25 mile north-northwest of the Curve.

the left carries the waters of Glenwhite Run, and the one on the right is for the road (SR 4008) up the valley of the run.

About 1.5 miles up this valley (on the hillside north of Glenwhite Run) are located the ruins of about 90 beehive coke ovens of the Glenwhite Coal and Lumber Co. (Figure 18). This bank of ovens was constructed in the last quarter of the 19th century to produce coke from the Lower Kittanning (B) coalbed mined nearby. Workers at the ovens and in the mines lived in the company town of Glenwhite, located just northwest of the ovens (see Patten 15' topographic map, dated 1902). The company went defunct about 1938, at which time the two railroad spurs, which formerly ran up from the Curve, were abandoned (Cupper, 2002). When mining ceased, the city of Altoona saw to it that the village of Glenwhite was dissolved, so as to remove the threat of pollution to its reservoirs in the Curve.

Site 12. Duncannon Member of Catskill Formation (on "west side" of Curve). The two sandstone exposures here—about 500 feet apart—are the most obvious remains of a "big" 75-feet-high cut that Thomson's construction crews gouged out of the mountain on the south side of the Curve. The bare cut is evident on historic photos up to at least the turn of the 20th century, but it is now largely covered with trees. (A few sandstone ledges can still be seen high on the hill.) The medium- to thick-bedded, locally crossbedded sandstones represent the channel phases of 50-feet ±- thick fining-upward alluvial cycles. About 25 feet of grayish-red shale and claystone occur at the top of the first (upper) exposed cycle.

As at *Site 8*, the sandstones are fine grained and micaceous. The channel sandstone nearest the head of the Curve contains a thin (1-2 feet) interval of very thin-bedded, very fine-grained, calcareous silty sandstone that exhibits honeycomb weathering.

Site 13. Duncannon Member of the Catskill Formation in vicinity of AG Curve (Milepost 244). The cuts at the entrance to Sugar Run valley expose the upper half-dozen or so fining-upward alluvial cycles (gray sandstones to red claystones) in the Duncannon Member of the Catskill Formation. (Swartz [1965] and Inners [1987] included much this 300-foot section of the upper Duncannon in the overlying Rockwell.) Out the windows to the left is a splendid profile view of the Front: The escarpment slope is underlain mainly by the Rockwell Formation and the caprock is typically the Burgoon Sandstone.

Trough cross-bedding and carbonaceous plant remains occur in the sandstones, and rootworking is profuse in the red claystones. A 70-foot-thick sandstone unit midway through the exposure contains a 1-foot ± thick bed of agglomerate composed of shale clasts, caliche fragments, etc., in a sandy matrix. Beautiful pyrolusite dendrites occur in thinly interbedded grayish-red siltstone and shale near the top of the member (about 1600 feet west of Milepost 244).

Site 14. Rockwell Formation (in vicinity of first, or easternmost, signal tower in valley). The Rockwell-Duncannon contact—well exposed here—occurs about 1600 feet west of Milepost 244, and marks the change from the meandering stream deposits of the Duncannon upper delta plain to the distributary deposits of the Rockwell coastal alluvial plain. The Rockwell consists dominantly of planar- and trough-crossbedded sandstones interbedded with several thick intervals of greenish-gray, silty clay shale. Thick sandstones about 820 feet east of the signal tower apparently correlate with the Mississippian Murrysville Sand, an important gas producing unit in western Pennsylvania (Bayles, 1949). The overlying 40 feet of greenish-gray silty shale with thin very fine-grained sandstone interbeds is probably the equivalent of the marine Riddlesburg Shale of the Broad Top region (Figure 19). Somewhat higher in the section and easily visible from the train (at the signal tower) is a sandstone

channel cut down into olive-gray shale. The Patton "red beds" at the top of the Rockwell (poorly exposed here) are a key marker horizon for surface and subsurface mapping along the Allegheny Front and in the eastern portion of the Allegheny Plateau.

Figure 19. Rockwell Formation at *Site 14*: contact of the fossiliferous Riddlesburg Shale with the underlying Murrysville Sandstone.

Identifiable plant remains reported from these beds include *Triphyllopteris*, *Rhodea*, *Adiantites*, *Lepidodendropsis*, and *Archaeopteris* (Swartz, 1965). The Riddlesburg Shale contains bivalves and rhynchonellid brachiopods (T. M. Berg, personal communication, 1986). Small, thin-shelled bivalves are present in shale interbeds approximately 110-160 feet above the Riddlesburg shale (Swartz, 1965). Fucoidlike horizontal burrows occur at the base of many of the sandstone beds.

Site 15. Burgoon Sandstone (at Milepost 245). Well exposed here are about 150 feet of typical crossbedded Burgoon sandstone overlying a 30-foot thick, greenish-gray shale interval (Figure 20). The shale in turn overlies 10 feet of crossbedded sandstone at the east end of the cut. This is the second cut in the Burgoon, the first being 800 feet to the east, where about 50 feet of medium-bedded, finer-grained, greenish gray-sandstone crop out. (See *Site 17*.)

In 1965 E. F. Koppe reported representatives of the upper Pocono *Triphyllopteris* fauna (including *Triphyllopteris* sp., and *Rhodea vespertina* (Read) in shale beds in the uppermost sandstone unit (see Swartz, 1965).

Figure 20. Strongly crossbedded sandstone in sharp erosional contact with underlying greenish-gray shale interval—Burgoon Sandstone at *Site 15*. This is probably the same horizon as the coal horizon overlain by sandstone that is exposed along new US 22 on the south side of Sugar Run Valley (see *Site 17*).

Site 16. Burgoon Sandstone and Loyalhanna Formation (at Milepost 245). The spectacularly cross-bedded, calcareous sandstones of the Loyalhanna Formation here abruptly overlie the thick-bedded, coarse-grained, trough and planar cross-bedded sandstones of the Burgoon Sandstone (Figure 21a).

Planar cross-beds in the Burgoon (Figure 21b) indicate a west-northwest transport direction. According to Adams (1970), the transport direction in the Loyalhanna was to the northeast and east-northeast. A few plant fossils (*Triphyllopteris*, *Rhodea*) can be found in the Burgoon (Swartz, 1965); no plant or invertebrate fossils are reported from the Loyalhanna.

Site 17* (left). *View—from vicinity of Allegrippus Curve—of deep cuts on new US 22 on south side of Sugar Run valley. Across the valley to the south (0.25 miles away) are two spectacular highway cuts in the Rockwell and Burgoon Formations (east) and Burgoon Formation (west). Allegrippus Curve is named for Allegrippus, a place name designating a few buildings on the railroad tracks that appears on the 1902 edition of the Ebensburg 15' topographic map.

The Rockwell on the highway consists of cyclic units of greenish-gray sandstone and siltstone and greenish-gray to pale-red or purplish-gray, silty shales and claystone; at the top of the formation is variegated shale and claystone of the Patton Member. The Burgoon Sandstone is thick bedded to massive and exhibits two distinct pulses of braided-stream alluviation (represented by sand bodies each about 150 feet thick), separated by a thin coaly layer in the lower middle part of the western cut. The base of the Burgoon in the eastern cut is marked by a spectacular

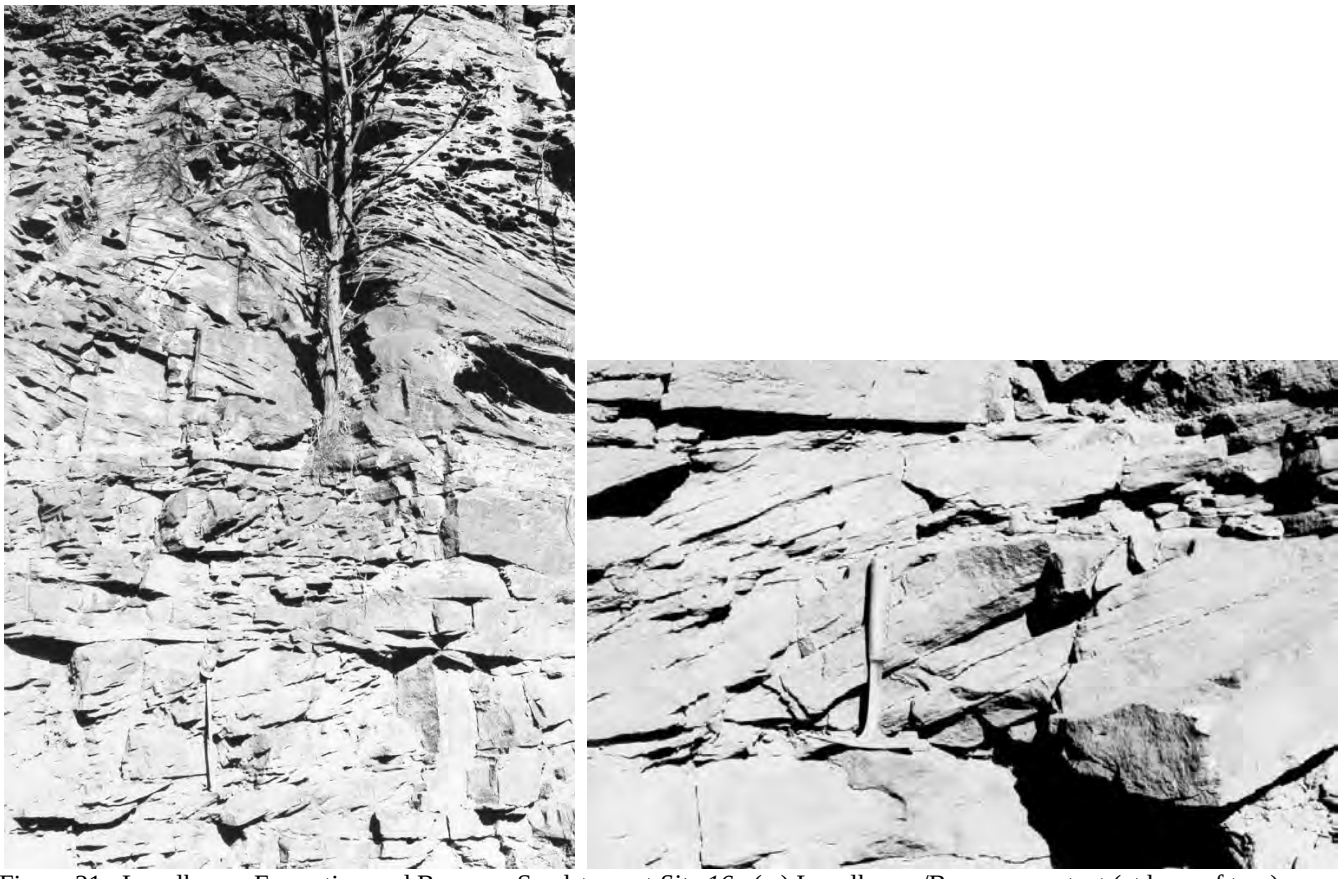


Figure 21. Loyalhanna Formation and Burgoon Sandstone at *Site 16*. (a.) Loyalhanna/Burgoon contact (at base of tree). Note the large-scale crossbedding in both units and the intense solutional weathering in the Loyalhanna. (b.) Planar-crossbed set in the Burgoon Sandstone.

erosional cutout, with relief of up to 16.4 feet. Pyrite nodules and lenses to 5 feet long and 1 foot thick occur in the lower part. Also characteristic of the Burgoon are pockets of gray shale-chip conglomerate containing rounded clasts to 0.5 feet in diameter. The sandstones of both formations exhibit both planar and trough crossbedding. Numerous casts of plant trunks and stems occur in the Burgoon sandstones, and comminuted plant debris is abundant in the coaly zone The coaly layer is 3.6 to 4.6 feet thick and consists of two high-ash "coal" beds (the upper of which is actually coaly shale) separated by 1 feet of rootworked claystone (A. D. Glover, Pennsylvania Geological Survey, personal communication, 1985).

In 1872 the famous western landscape painter Thomas Moran (1837-1926) made a woodcut of "Allegrippus" from a distant vantage point, showing the railroad hugging a wooded steep slope on the far side of a heavily forested valley (Panzer, 2002). William H. Rau (1855-1920), outstanding photographer of the PRR in the 1890's, took several photographs of Allegrippus, one of which clearly shows at least two sizeable buildings, both apparently on the north side of the tracks (Van Horne and Drelick, 2002, p. 144).

Site 18. Mauch Chunk Formation (at second signal tower). The thick-bedded, greenish-gray, calcareous sandstones (Figure 22) here locally display good trough crossbedding. About 300 feet farther west is a second cut in the Mauch Chunk, this one consisting of several 10- to 25-foot thick intervals of red and green silty claystone and crossbedded, tan-weathered sandstone. The lower sandstone unit in this second cut contains several cannonball-size siderite concretions that may be visible from the train.

At the base of the crossbedded sandstone outcropping directly at the signal tower is a 0- to-2-foot-thick bed of conglomerate containing pebbles of milky quartz, quartzite, and limestone (transported caliche or algal nodules). The quartz pebbles range up to 2-inches in diameter (Swartz, 1965). Several 1-foot-thick beds of somewhat finer-grained conglomerate also occur interbedded with the dominant sandstones in the eastern cut (see Faill et al., 1989, p. 53).

Figure 22. Thick-bedded, predominantly gray calcareous sandstone (above) overlying thinly interbedded red sandstone and shale (below)—Mauch Chunk Formation at *Site 18*.

Figure 23. Medium- to thick-bedded, trough crossbedded quartzose beds of the Upper Connoquenessing Sandstone (Pottsville Group) at *Site 19*.

Site 19. Upper Connoquenessing Sandstone of Pottsville Group (at Milepost 246). The prominent gray-sandstone unit exposed just east of the Bennington Curve is thick bedded and strongly trough crossbedded (Figure 23). Lenses of silty, dark-gray shale 1 to 2 feet thick occur locally, the most prominent of these gradually opening up between two braid-channel sandstones toward the east end of the cut.

The rock is medium to coarse grained, quartzose, and typically micaceous. Finely comminuted, carbonaceous plant debris is abundant throughout. Swartz (1965) called this the Lower Connoquenessing Sandstone.

Site 20. Bennington Curve ("Benny"). Historically, this has been the most dangerous spot on the old PRR route over the Front. At least three fatal wrecks have occurred here: January 1, 1921; August 29, 1927; and February 18, 1947. The last involved the catastrophic derailment of the *Red Arrow* passenger train, in which 24 died and 141 were injured.

At 3:35 AM, the *Red Arrow*, running one hour and eleven minutes late out of Pittsburgh bound for New York, leapt off the No. 2 track (the second from the outside of four tracks) and plunged down a 150-foot embankment on the convex (north) side of the curve. Several hundred feet of the Nos. 2, 3, and 4 tracks were torn up when the two K-4 steam locomotives at the head of the train and eleven of the fourteen cars left the tracks. (The engines and five cars ended up at the bottom of Gum Tree Hollow.) An Interstate Commerce Commission investigation a few month later concluded that the *Red Arrow* was going twice the authorized speed of 35 mph in approaching the Bennington Curve—but some surviving members of the train crew (significantly, not all) insisted that the train entered the curve at no more than 30 mph (West-Emerson, 1983; *Altoona Tribune*, February 19, 1947).

Figure 24. Crossbedded Homewood Sandstone (Pottsville Group) occupying a channel cut down into gray shale and claystone of the Mercer coal zone at east end of *Site 21*.

Site 21. Upper Pottsville Group (including Homewood Sandstone) and lower Allegheny Group (including Brookville and Clarion coals; in Bennington Cut at third and fourth signal towers). Well exposed just west of the Bennington Curve are two prominent channel sandstone beds and two coalbeds. The sandstones—the lower of which is the Homewood, the uppermost sandstone unit in the Pottsville Group (Figure 24)—are thin to thick bedded and display trough crossbedding and basal cutouts. Above

Figure 25. Unnamed sandstone overlying the Brookville coalbed of the lower Allegheny Group at west end of *Site 21*.

the Homewood in the lower Allegheny Group are the Brookville (A) (lower) and Clarion (upper) coalbeds. The unnamed channel sandstone resting on top of the Brookville coalbed (Figure 25) displays a common type of superposition in coal-bearing sequences. Since compacted peat is difficult to erode, downcutting streams and migrating delta distributaries that are able to remove overlying sediments cannot incise the peat. Thus, channel sandstones commonly lie directly above coalbeds in stratigraphic sections.

Lepidodendron casts and carbonized plant trunks are common in the Homewood, especially at the base. The olive-gray underclays beneath the coalbeds are extensively rootworked.

For various sedimentologic and petrographic reasons, Williams (1960) considered the 5-foot-thick coalbed, here called Brookville, to be a Mercer coalbed (older) and the lower sandstone, here called Homewood, to be the Upper Connoquenessing. However, the stratigraphic interval between this coal and the Lower Kittanning (reported to outcrop in the old Bennington Cemetery by F. Platt and W. Platt, 1877) is only about 52 feet, far too thin for the lower coal to be a Mercer (see also Butts, 1905). Recent drilling in this area indicates that locally mineable coals occurring approximately 60 feet lower in the section actually represent the Mercer seams.

Site 22. Bennington—village, cemetery, and furnace. The large cross in the old cemetery to the right marks the western part of the "ghost town" of Bennington, which had a population of 600 and boasted two churches in 1875 (Sipes, 1875). On the opposite side of the tracks, just south of Sugar Run, are the sandstone-ruins of the Bennington iron-furnace originally the "Henrietta" furnace), which was in operation from about 1846 to at least 1882. The ruins are not visible from the railroad, but you may be able to catch a glimpse of the eroded slag pile on the bank of Sugar Run.

In the 1870's and '80's, most of the male population of Bennington village worked for the Cambria Iron Co. (Blair Iron & Coal Co.), either at the furnace, in local coal mines, or in coking operations at *Site 23* (see below). The village must have had a fairly sizable population up to the time of World War I, as many of the headstones date from 1900 to 1920. (The majority of the headstones are white marble; most are badly weathered—partly due to proximity to the former steam railroad. There are also many wooden crosses.) The last burial in the cemetery appears to have been in 1959.

The blast furnace (9¾ feet at the bosh and 39.5 feet high; Figure 26) was originally built to utilize charcoal fuel, but was converted to coke when it was reconstructed in 1853. According to Lesley (1859), it made about 56 "tonnes" of iron a week from Clinton (Lower Silurian) "fossil ore" (see Inners, 1999) obtained from Frankstown, 9 miles to the east, mixed with "bog ore" mined nearby. The "bog ore" (probably nodular limonite) reportedly came from a horizon about 70 feet below the A coal in the deep ravine just east of the Bennington Cut (i.e., Gum Tree Hollow at *Site 20*; F. Platt and W. Platte, 1877). By 1880, the furnace was reportedly manufacturing 550 tons of pig iron per month (Sell, 1911).

Site 23* (left). *Coke ovens of Cambria Iron Company. On the hillside south of the tracks just before the Allegheny Tunnel-Old Portage Tunnel split in the tracks are the ruins of 100 beehive coke ovens (Figure 27a). Erected by the Cambria Iron Company, the ovens were initially fired-up on October 8, 1878 (F. Platt, 1881). Previous to this the coke had been burned in "open ricks," a very wasteful process involving loss of nearly one-quarter of the carbon contained in the coal (F. Platt and W. Platt, 1877; F. Platt, 1881).

Coke is the combustible residue remaining after the volatile parts of a bituminous coal have been expelled by heat. The chief purposes of coking are to obtain a fuel that (1) has higher calorific power and greater density and (2) does not agglomerate (or cement) in the furnace, as does most raw bituminous coal. Coking also drives out about 50 percent of the sulfur in the coal (Newton, 1884).

The ovens are about 10 feet in diameter, with a round 1±-feet hole at the top (for charging) and another opening in front (about 30 inches square) for discharging (Figure 27b). They are built back-to-back to facilitate

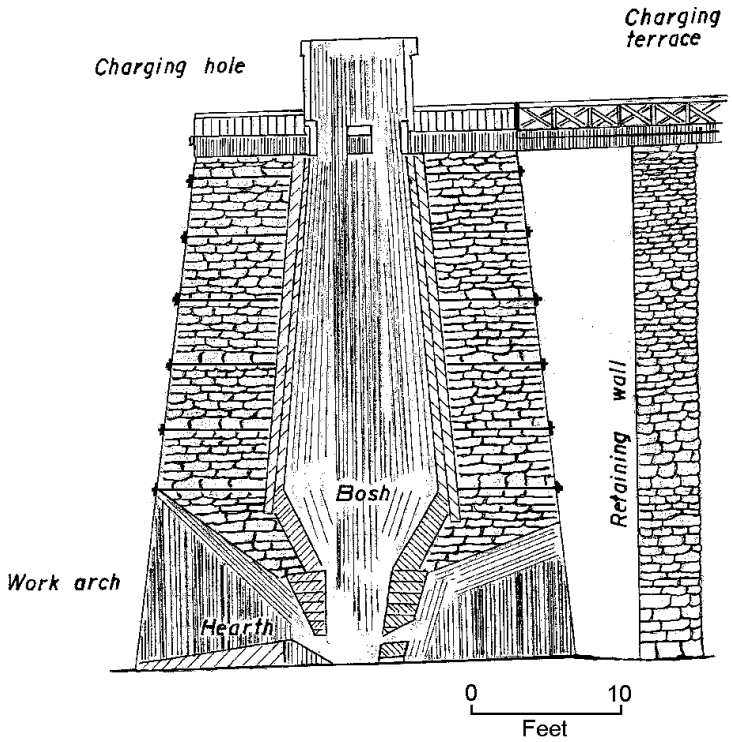


Figure 26. Generalized cross-section of the Bennington iron furnace (Inners, 1989).

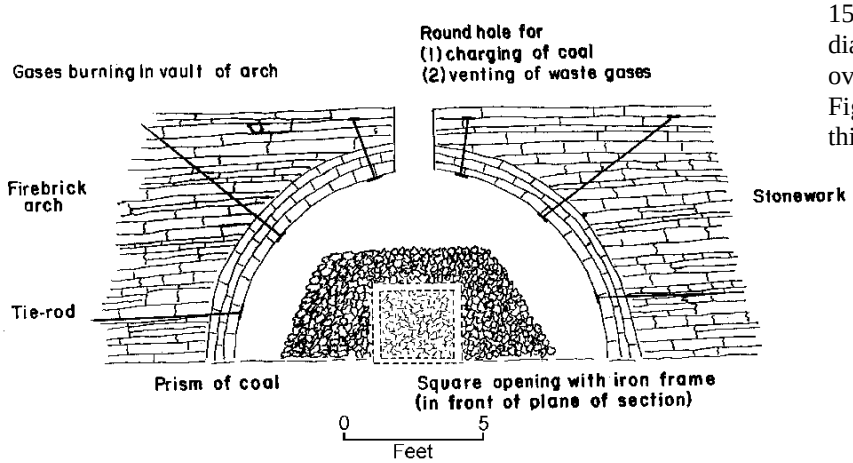


Figure 27. Beehive coke ovens of the Cambria Iron Company at *Site 23*. (a.) Ruins of four ovens on south side of long double bank south of railroad. The ovens are about 12 feet in diameter and rest on a sandstone foundation wall about 15 feet high. (b.) Generalized diagram of a typical beehive coke oven. (The stone ovens shown in Figure 18 are built very much like this.).

charging from above. Daily output was about 160 net tons, yielding coke weighing about 65 percent of the gross weight of coal charged (F. Platt, 1881). (An excellent description of the operation of such ovens is given in Newton, 1884.) The coal was obtained mainly from the Lower Kittanning (B) bed in the vicinity of Bennington. Prior to construction of the ovens here, only about half the mined coal was coked locally (see above), the rest being shipped to Hollidaysburg to be coked in Belgian ovens and used in the Cambria Iron Co.'s Hollidaysburg furnaces (F. Platt and W. Platt, 1877). (In Belgian ovens, the bottom or the walls, or both, are heated by the combustion of fuel on the outside [Newton, 1884].)

Figure 28. Cut on north side of tracks at east portal of Gallitzin Tunnel at *Site24*. The Upper Freeport coalbed is at the very top and the Upper Freeport limestone is at the bottom.

Site 24. Lowermost Glenshaw Formation and uppermost Allegheny Group--including Upper Freeport, or E, coalbed (at east portals of the Allegheny/ Gallitzin Tunnels). Well exposed here (adjacent to the Gallitzin Tunnel portal on the right) is a portion of a typical Allegheny sedimentary cycle composed (from base upward) of freshwater limestone; greenish-gray, thinly interbedded silty clay shale and fine-grained sandstone; underclay, and a 5-feet coalbed (the Upper Freeport, or E) (Figure 28). The greenish-gray shale directly overlying the coalbed is the basal unit of the overlying Glenshaw Formation (Conemaugh Group).

The limestone (Freeport) is medium dark gray and finely crystalline. The underclay is intensely rootworked. Poorly exposed at the base of the cut is the Lower Freeport (D) coalbed.

Although the Upper Freeport was extensively mined in the 19th century and into the 20th, it was not highly prized. The E yielded "a good steam coal, tolerably well adapted for iron making," but it was "undeniably inferior to…Bed B" (F. Platt and W. Platt, 1877). The two Platts also noted that the Mahoning sandstone crops out near the top of the hill over the Allegheny Tunnel (see below) and that this sandstone was quarried out in "handsome blocks" a short distance to the north.

Site 25. Allegheny Tunnel. The Allegheny Tunnel (at the left on Figure 29) is the original "summit tunnel" on the Mountain Division of the Pennsylvania Railroad. It was begun in 1851 and completed just in time for the first train to pass around the Horseshoe Curve and through the tunnel on February 15, 1854. Approximately 500 feet to the south (at a slightly higher level) is the New Portage Tunnel (see *Site 28*). Directly to the north is the Gallitzin Tunnel (at the right on Figure 29), the newest of the three summit tunnels, having been completed on June 14, 1904 (Cupper, 2002). In 1994-95, both the Allegheny and New Portage Tunnels were enlarged for ocean-going container cars (the clearance was increased from about 17 feet to 20 feet 8 inches)—and the Gallitzin Tunnel was converted to service-road use (essentially abandoned).

Figure 29. East portals of the Allegheny (left) and Gallitzin Tunnels at *Site 25*, as they appeared in 1989, prior to enlargement of the former and abandonment of the latter in 1995. The plaque above the Allegheny Tunnel states that it was "commenced" on October 14, 1851 and completed in 1854. Among others mentioned, it notes J. Edgar Thomas as president (of the Pennsylvania Railroad) and E. Miller and H. Haupt as chief engineers. The stone and concrete work in front of the tunnels apparently represents remnants of the housings of large fans for aerating the tunnels during the steam era.

The Allegheny Tunnel is 3600 feet long according to a plaque at the west portal. (Burgess and Kennedy [1949] give the length as 3,570 feet, and Sell [1911] says it is 3612 feet long.) Its original height above grade was 22 feet (Sell, 1911). Construction of the tunnel occasioned considerable problems because of the weak nature of the shale, claystone, and coal encountered—especially at the east end where the Upper Freeport, or E, coalbed and its underclay "cropped out" in or just above the roof. Frequent rock falls occurred due to these treacherous tunneling conditions.

The tunnel was driven from both ends and from two intermediate shafts. A third shaft was started, but was abandoned before completion; and a fourth shaft was sunk in the winter of 1853-54 to facilitate the operations of masons and bricklayers constructing the lining. (The Mahoning coalbed was encountered 80 feet above the Upper Freeport coalbed in these shafts [Rogers, 1858].) In the two main shafts, steam pumps capable of discharging up to 175 gpm of water were installed. At the time the tunnel was opened, 800 feet of the roof (mostly sandstone) was not arched with brick—though 200 feet of this length was timbered. A rockfall occurred in this latter section in March 1856, so this too was arched shortly thereafter. The arching of the entire tunnel was finally completed in 1869.

Site 26. Lower Glenshaw Formation (at west portals of Allegheny/Gallitzin Tunnels). Exposed on both sides of the tracks here are about 25 feet of lower Conemaugh strata, the basal beds of which occur about 120 feet above the Upper Freeport coalbed (see Glover, 1990, and Butts, 1905). Note that the bedding dip here is less than 5° to the northwest, as compared to 25° at *Site 1* in the Brallier Formation and 13° at *Sites 8* and *12* in the Duncannon Member (Horseshoe Curve). Note also that water is flowing out of the rock strata on the south (right) side of the cut, a reflection of the bedding dip to the northwest—obliquely toward the tracks in this case. Just west of the tunnel cut is the highest point on the old PRR "main line"—2,192 feet A.T.

A generalized section here is as follows:

Interbedded shale and sandstone, medium gray	8 feet
Clay shale, dark gray, fissile	0.5
Underclay, light gray, rootworked	1
Silty clay shale, medium gray, with siderite nodules	15
Sandstone, medium light gray, fine grained	3

Butts (1905) reports a six-inch coal in the cut "west of the east bound tunnel" at Gallitzin, which he identifies as the Gallitzin coal. The coal is presently not exposed in the cuts near the tunnel portal. It may be covered by the concrete curtain constructed to stabilize the southeast corner of the cut. The fissile clay shale and underclay on the north side of the tracks probably represents the horizon of this coal. The Gallitzin coal is a name used only in this area. Regionally, the coal at this stratigraphic position, approximately 100 feet above the Upper Freeport coal, is referred to as the Brush Creek. The sandstone at the base of the cut is the Upper Mahoning sandstone (see *Site 27*).

From the west portals of the Allegheny/Gallitzin tunnels to the "U-turn" just past Union Cemetery 0.5 miles ahead and back nearly to *Site 27*, the railroad route lies within the borough of Gallitzin.

Gallitzin was named for Russian Prince Demetrius Gallitzin (1770-1840), the Catholic "Missionary of the Alleghenies." He came to the United States in 1795 and was the first Catholic priest to receive all his orders in this

country. He served the Allegheny settlements for more than 40 years and laid out the village of Loretto, Cambria County, 5 miles to the northwest of Gallitzin.

During its heyday in the decades immediately before and after the turn of the 20th century, Gallitzin was a coal-mining and coke-manufacturing town with a large Irish and (later) Italian population (Excursion Guide, Altoona Railroaders Memorial Museum).

The "U-turn" was constructed early in the 20th century when the Pennsylvania Railroad reopened the New Portage Tunnel (see *Site 28*). It allowed for easy turnaround of pusher locomotive used on westbound trains through the Horseshoe Curve and over the Allegheny Front—and is still used for that purpose today.

Site 27. Lower Glenshaw Formation (at west portal of New Portage Tunnel). The splendid, long cut here exposes a 45-foot-thick, gently (< 5°) northwest-dipping section of lower Conemaugh strata, the base of which lies about 65 feet above the Upper Freeport coalbed (see Glover, 1990, and Butts, 1905). The thin, discontinuous, dark-reddish-brown sideritic limestone and underlying gray claystone in the middle of the cut (particularly visible to the left) probably mark the horizon of the Mahoning coalbed. The sandstone at the top is probably the Upper Mahoning (possibly exposed at the base of the section at *Site 26*). Although several of the other individual units noted in the section below can probably be picked out from our slowly moving train, the description does little justice to the complexities of the stratigraphy. What on first impression looks like a west-dipping thrust fault (with attendant drag on underlying beds) is actually a combined penecontemporaneous slump and channel cut-out (Figure 30)!

Figure 30. Penecontemporaneous slump and superimposed channel cut out in the Glenshaw Formation (above the horizon of the Mahoning coalbed) on the north (left) side of cut at *Site 27*.

Note the steep grade as the tracks descend toward the tunnel just beyond the steel-truss highway bridge. Long, heavy trains sometimes come to a complete stop here so as not to pick up too much momentum in passing through the tunnel and continuing down the "Slide" toward "Benny."

A simplified, generalized section (measured on the north side of the cut) is as follows:

Sandstone, medium to thick bedded, medium light gray, fine grained (channel in part; Upper Mahoning?).	10 feet
Silt shale, with thin sandstone beds, light olive gray, abundant irregular siderite masses (locally slumped).	15
Clay shale, medium gray, fissile to platy, numerous nodules and thin beds of siderite.	4
Sideritic limestone, unevenly bedded, light brownish gray, rootworked, pinches out locally.	0-1
Claystone, non-bedded, medium gray, rootworked.	5
Shaly claystone, medium gray, with large irregular masses of siderite.	4
Shaly claystone, soft, medium gray, with a few very thin beds of light-gray, very fine-grained sandstone; abundant small siderite nodules near top. (Smooth surface at base of cut at east end.)	6

Site 28. New Portage Tunnel. Opened for traffic in 1856, this is the second oldest of the three tunnels on the former "Broad Way" of the Pennsylvania Railroad. It is 1,629 feet long and was originally part of the New Portage Railroad, built by the Commonwealth of Pennsylvania to replace the "old" Portage Railroad (STOP 8, this Guidebook).

After purchasing the entire Main Line canal-and-railroad network from the Commonwealth of Pennsylvania in 1857, the Pennsylvania Railroad abandoned the New Portage Railroad and its tunnel. In 1898, the tunnel was reopened and connected to the "main line." The entire route of the New Portage Railroad to Duncansville at the entrance to Blair Gap, about 6 miles to the southeast, was reopened on June 14, 1904, the same day that the first trains passed through the newly constructed Gallitzin Tunnel (Cupper, 2002).

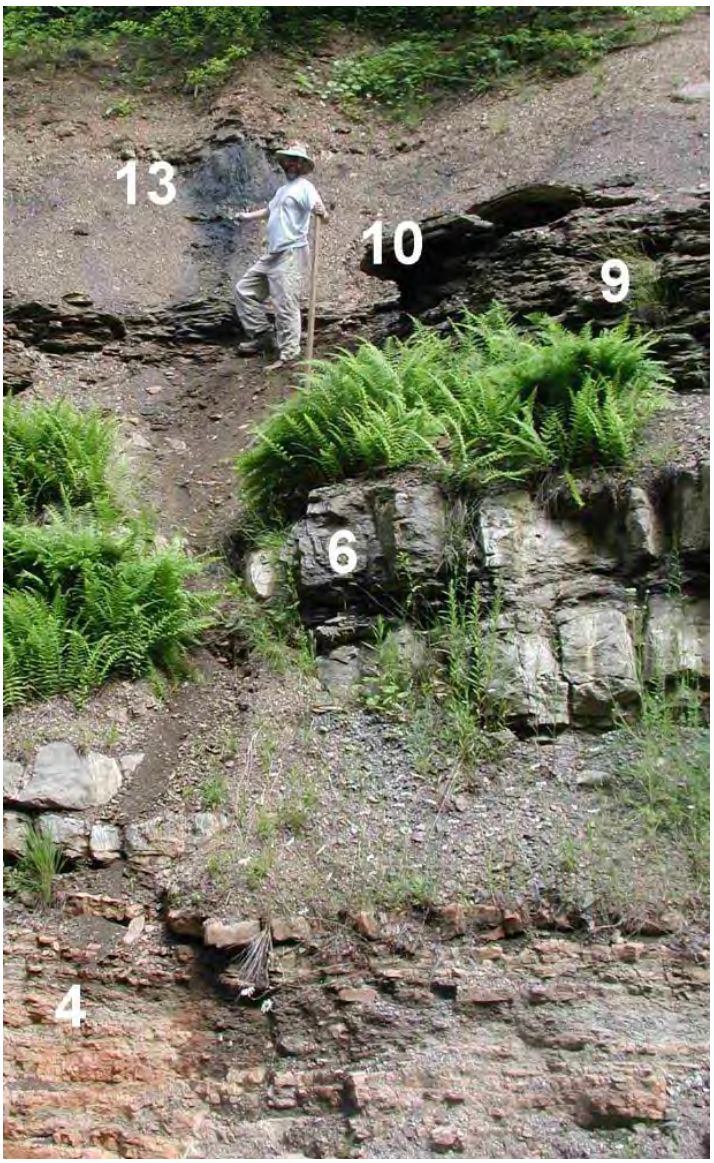


Figure 31. Uppermost Allegheny section exposed at *Site 29*. The numbers on the units correspond to those of the measured section in the text.

Site 29. Uppermost Allegheny Formation--including Upper Freeport coalbed (at east portal of New Portage Tunnel). The section exposed on both sides of the tracks just beyond the tunnel—and clearly visible from the train—is the same as that at *Site 24*—but even better (Figure 31):

Glenshaw Formation (part)

14. Shale, platy to fissile, brownish-gray weathered	6+ feet

Allegheny Formation (part)

13. Coal, with 0.1-feet-thick parting 1.6 feet above base and 0.5 feet of "boney" at top (Upper Freeport, or E, coalbed).	5.3
12. Hard clay, medium dark (brownish gray).	0.6
11. Silty claystone, medium dark gray, rootworked.	0.7
10. Silty sandstone, thin bedded, medium gray, coarsens upward.	1.4
9. Sand-silt laminite, weathers rusty, contains carbonaceous laminae and coarsens upward.	4.3
8. Carbonaceous claystone, black, shaly in upper part. (Upper Freeport "leader").	0.9
7. Silty claystone, medium dark gray, poorly fissile.	1.1
6. Limestone, medium to thick bedded (0.5- to 2-feet beds), medium dark gray, fine grained, fossiliferous (*Spirorbis*, ostracodes, fish parts-isolated scales, plates, etc.), with 2- to 6-inch-thick, calcareous shale interbeds. Upper limestone beds show parallel laminations (fine ribbing on weathered surfaces).	7.3
5. Interbedded clay shale and limestone, medium dark gray. Limestone is fine grained, pyritic, in irregular beds and nodules, fossiliferous (*Spirorbis*, ostracodes).	0.2
4. Interbedded clay shale and sideritic limestone, thin bedded, 1- to 4-inch thick beds). Shale, medium gray; limestone, medium brownish gray, fine grained, argillaceous.	4.4
3. Calcareous claystone, medium dark gray to brownish gray, grades up into overlying unit.	0.8
2. Claystone, dark gray, poorly fissile, with a few walnut-size sideritic limestone nodules at top.	2.4
1. Sandstone, top exposed in drainage ditch.	

Just after leaving *Site 29*, the excursion train begins a second steep descent, known to local railroaders as the "Slide." The tracks drop on a 2.27 percent grade to "Benny". Because of the steep grades, engineers receive extensive train-handling instruction before being allowed to operate between Gallitzin and the Bennington Curve (Excursion Guide, Altoona Railroaders Memorial Museum). Anyone who has ridden the "Three Rivers" or "Pennsylvanian" east from Pittsburgh will recognize this stretch!

Now just sit back and enjoy the ride—and take in the "big picture" as we return to Altoona, passing again around the Horseshoe Curve.

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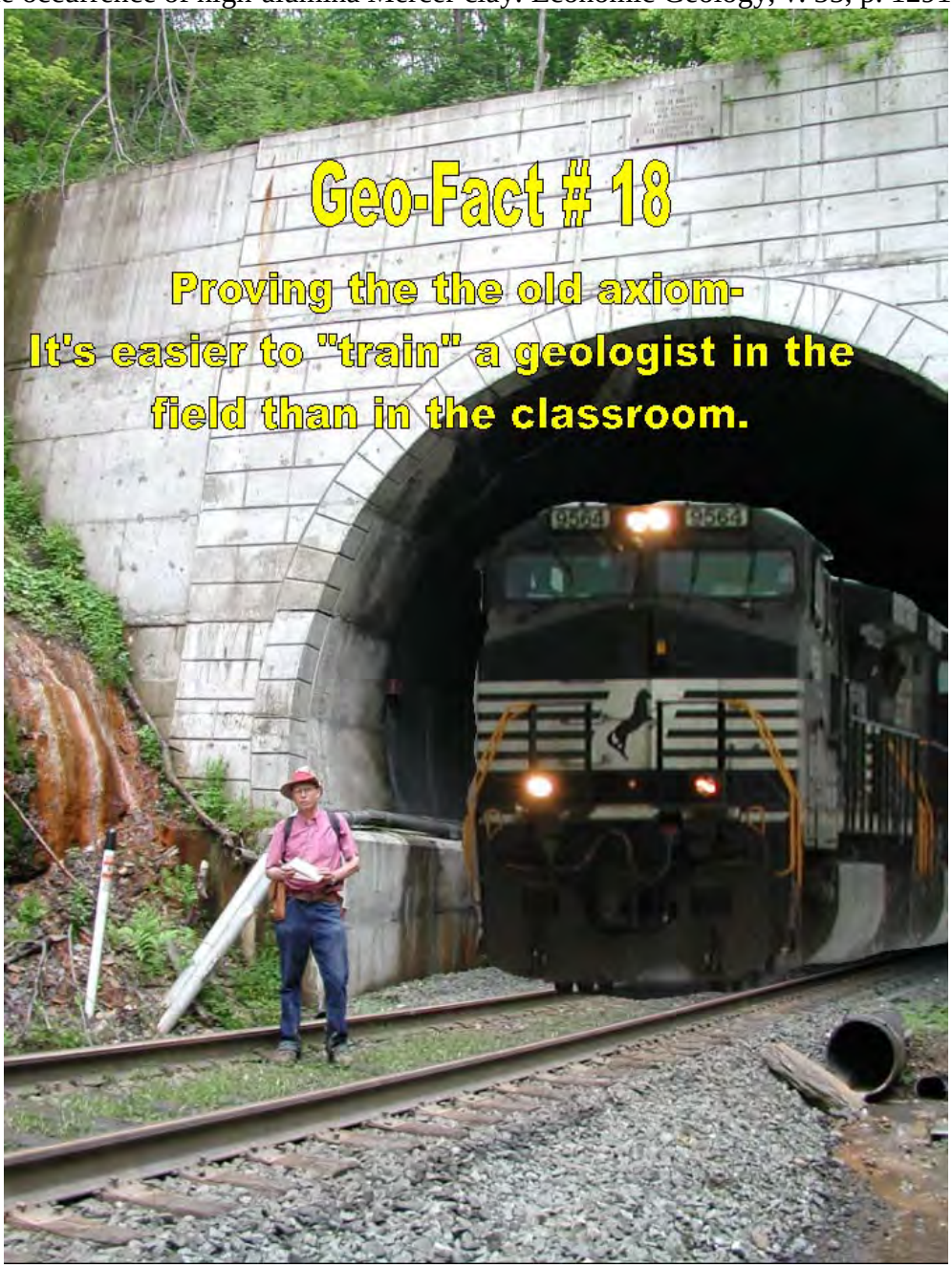

Photo by Vik Skema, modified by Gary M Fleeger
Geo-Fact text by A. Nonymous

STOP 8. ALLEGHENY PORTAGE RAILROAD NATIONAL HISTORIC SITE (AND LUNCH)

Leader: John A. Harper

Introduction

The National Park Service established the Allegheny Portage Railroad National Historical Site (**Figure 1**) in 1964 to commemorate the first railroad crossing of the Allegheny Mountains. The park covers 1,500 acres of the site where the Allegheny Portage Railroad arrived at the top of Allegheny Mountain (**Figure 2A**). It includes:

- A Visitors Center, which has informative and educational exhibits, including artifacts and models, that help tell the story of the railroad. A full-scale model of the Lafayette, one of the locomotives used on the railroad, stands in one corner. The Visitors Center also has a 60-seat auditorium where they show a 20-minute orientation film about the Portage Railroad. Other amenities include a bookstore, restrooms, pay phones, and a water fountain.
- "Sleeper" quarries, accumulations of sandstone where the railroad's stone masons found and worked the sandstone blocks into the stone foundations for the rails ("sleepers"). Access to the quarries, and other outside historic exhibits, is easily obtained on a wheelchair-accessible boardwalk.
- The historic Lemon House (**Figure 2B**), an historic hotel and tavern on the railroad. It was a common rest and dining stop for railroad passengers. The National Park Service has restored

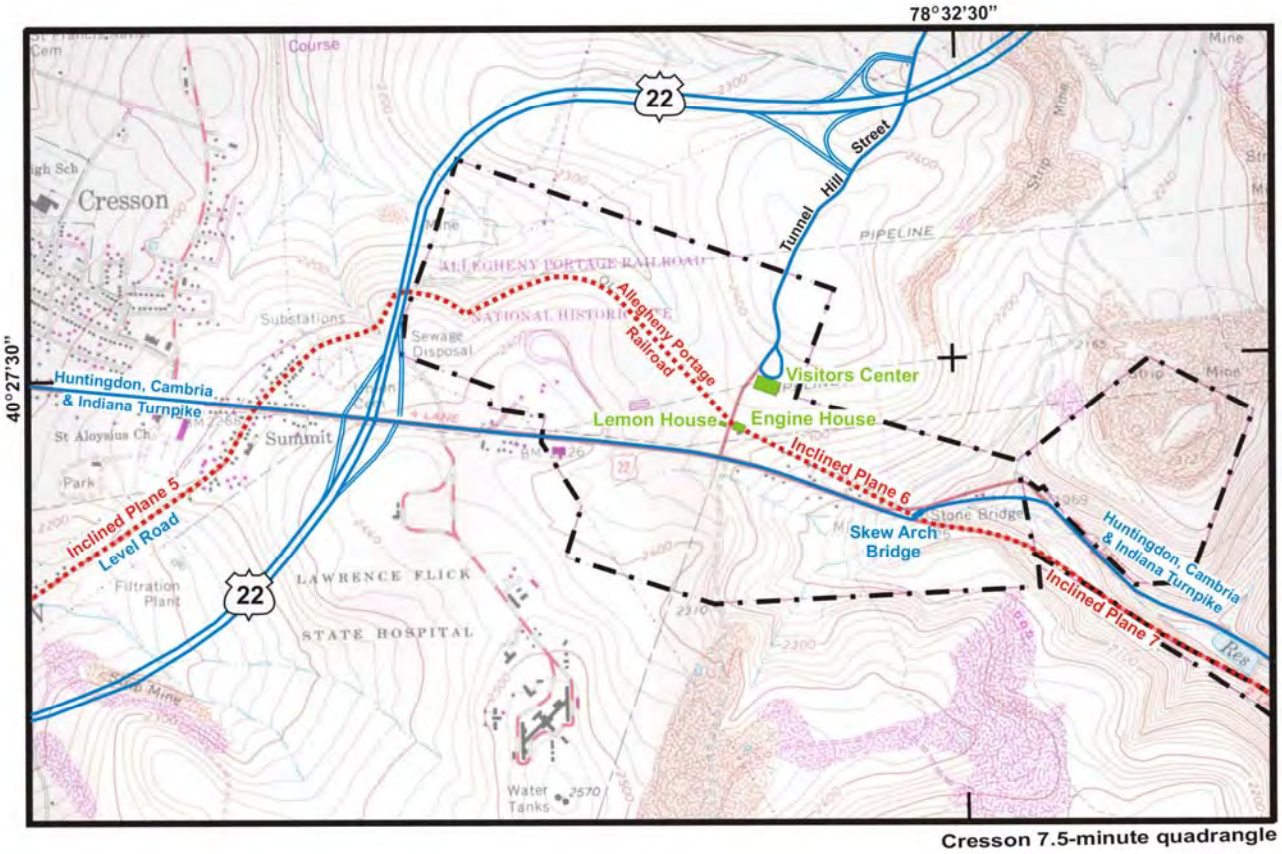

Figure 1. Location of the Allegheny Portage Railroad National Historic Site (outlined in black) on the Cresson 7½ - minute quadrangle.

A

B

C

D

E

F

G

H

this historic tavern's first floor to how it would have looked in 1840, using both reproduction and period furnishings. Docents can explain about the social and economic aspects of the railroad in the furnished tavern's bar room, dining room, parlor, and exhibit area.

- Inclined Plain No. 6 and Engine House No. 6 Interpretive Shelter. The inclined plain, which overcame 266.5 feet of elevation over its 2,713.85-feet length (Wilson, 1897), includes the restored right-of-way complete with reconstructed rails. The engine house includes the excavated original engine-house cut-stone foundation, as well as full-scale models of the stationary steam engines and boilers used in raising and lowering cars on the inclined plane. Informative and interactive exhibits help explain the workings.
- Skew Arch Bridge (**Figure 2C**) can be found down the inclined plane and across the westbound lanes of Old US 22. When the Allegheny Portage Railroad was being built, it became obvious that the Huntingdon, Cambria and Indiana Turnpike would cross the railroad about midway along Inclined Plane No. 6. The Skew Arch Bridge was built in 1832-33 to carry the turnpike traffic over the railroad (Hoenstine, 1952). The bridge was in continual for over 100 years until a new concrete road, now the eastbound lanes of Old US 22, was built. Amazingly, the bridge is still in a near perfect state of preservation. In 1928, the Blair County Historical Society erected a tablet on the bridge bearing an inscription by the Honorable Plymouth W. Snyder.
- The Allegheny Portage Railroad Memorial (**Figure 2D**) was erected and dedicated in 1934, in the presence of a large assemblage of Pennsylvania Railroad and Pennsylvania State officials, historians, and other interested persons, to commemorate the centennial of the completion of the Allegheny Portage Railroad. The monument originally was 10 feet high, erected from "sleepers" from the Portage Railroad.
- There are also a picnic area and hiking trails.

The park also oversees the Staple Bend Tunnel, the first railroad tunnel built in America, which is located approximately 4 miles east of Johnstown in Cambria County. Portions or all of the inclined planes and some of the railroad right-of-way west of Allegheny Mountain remain (**Figures 2E and F**), much of it being used as PA Route 53 between Summit and Johnstown.

This will also be our Lunch stop. After lunch, feel free to roam through the historic site. Hiking trails and the grass-covered inclined plane allow easy access to all of these features (if they are open. **PLEASE BE EXTRA CAREFUL** if you plan on crossing Old US 22 to visit the Skew Arch Bridge and railroad memorial. Traffic will be coming uphill (from the left), so be sure to look that way before crossing.

Construction of the Allegheny Portage Railroad

On March 21, 1831 Pennsylvania's Governor George Wolf signed a legislative act authorizing the building, without delay, of the Allegheny Portage Railroad (Wilson, 1897). Contractors set to work building ten inclined planes, a bridge over the Conemaugh River near present day Mineral Point (the Conemaugh Viaduct), a tunnel near Johnstown (the Staple Bend Tunnel), numerous culverts, and the railroad right-of-way. The right-of-way was 120 feet wide to accommodate any additional track that might be necessary in the future, and to ensure that any fallen trees would not

Figure 2 (opposite). Illustrations from the Allegheny Portage Railroad. A – "Lemon Inn on the Portage Railroad" by George Storm. This is an illustration of the Allegheny Portage Railroad at the top of Inclined Plane 6. The original painting is in the State Museum of Pennsylvania. B – The historic Lemon House. C – Skew Arch Bridge. D – Old Allegheny Portage Railroad Memorial. E – Muleshoe Curve Viaduct, built for the New Allegheny Portage Railroad, was still in used by the Pennsylvania Railroad until the 1960s. F- Stone masons' tool marks remain on this sandstone boulder at the stone quarries adjacent to the Visitors Center. G – Culvert below the remains of Inclined Plane No. 10 in Foot of Ten. H - Lilly Culvert, a Portage Railroad Bridge still being used on PA 53 in Lilly.

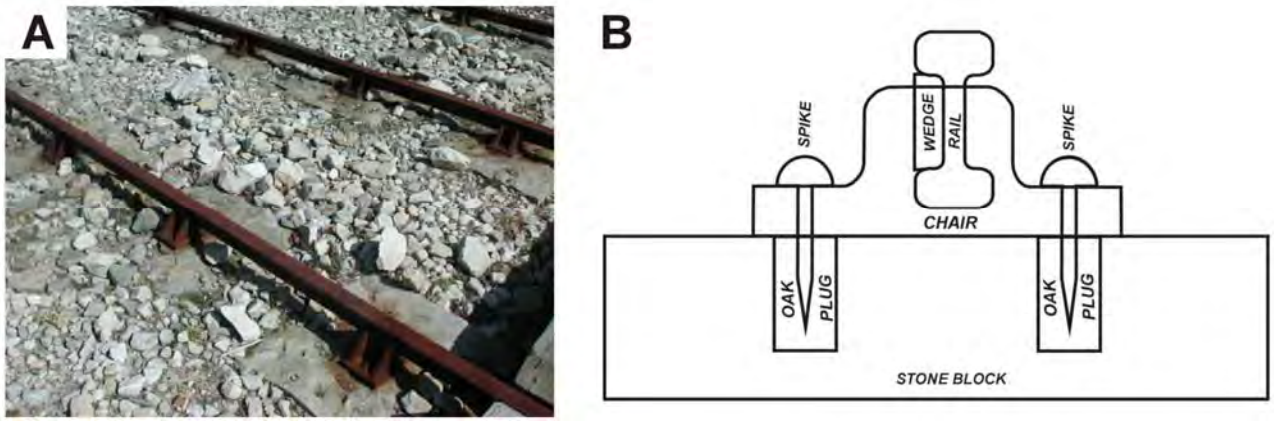

Figure 3. A - Photograph of stone "sleepers" along the Allegheny Portage Railroad right-of-way at the Allegheny Portage Railroad National Historical Site. B - Details of the edge rails and stone "sleepers" on the Allegheny Portage Railroad (redrawn from Shank, 1975).

block the tracks. The railroad bed was 25 feet wide, wide enough for two sets of tracks. One set of tracks was laid between the inclined planes and two sets were laid on the inclines so cars could be raised and lowered simultaneously, thus counterbalancing each other. The bed was constructed so that the steepest grade was no more than 10.25 percent.

Figure 4. John Roebling, inventor of wire cable that made traveling the inclined planes on the Portage Railroad safer. Roebling, a German native, settled in Saxonburg, Butler County, Pennsylvania and set up shop. He made his first wire rope in 1841 to replace the hemp ropes on the railroad. His wire cables later were used in his famous suspension bridges, such as the Brooklyn Bridge.

The tracks consisted of rolled iron rails, each 18 feet long and 237 pounds, set in cast iron "chairs" secured by iron wedges. The whole assembly was then attached to a set of cut stone blocks called "sleepers" (**Figure 3**). The "sleepers" were cut from local sandstone bedrock or float by stonemasons. Where such rock wasn't available, or would have cost too much, wooden ties replaced the "sleepers." The "sleepers" were spaced approximately every three feet along the road. The blocks tended to shift with weather and moisture variations, so the rails often separated, making it impossible for trains to move safely along the tracks. Eventually wooden cross ties, such as those seen on railroads today, replaced most of the "sleepers."

Originally, the ropes used to raise and lower canal cars on the inclined planes consisted of hemp that varied in length from 3,616 to 6,632 feet (Welch, *in* Shank, 1975). Unfortunately, as strong as these ropes were, they broke frequently. John Roebling (**Figure 4)**, the architect and engineer who built the Brooklyn Bridge, suggested using "wire rope," and by 1849 all of the Portage Railroad's rope had been replaced by metal cables.

The engines, boilers, and machinery for operating the ropes that hoisted and lowered the railroad cars on the inclined planes resided below track level in an engine house at the top of each incline. If you visit the reconstruction of Engine House 6 you will see a reproduction of the boilers and engines and learn how they operated. Two cast iron wheels, eight feet in diameter and with 6-inch grooves for the ropes, were placed

vertically in the center of each set of tracks 100 feet from the head of the incline. At the bottom of the incline, a similar horizontal wheel on a carriage was anchored in a similar fashion 40 feet from the foot of the incline. A double pulley block, rope, and windlass allowed it to be moved about 50 feet. The rope that hauled the canal cars ran a complicated pattern over the wheels, down the incline, around the wheel at the bottom, and finally back up the incline. Eighteen-inch wheels spaced 24 feet apart between the tracks supported the rope on the incline. Since the rope was moving down one track and up the other simultaneously, one car could be hauled up the incline while another was going down. If the weight of cars descending the incline exceeded that of cars ascending, or if there where no ascending cars at all, the engines were disengaged from the hoisting mechanism and gravity took over. A water brake regulated the velocity of the descending cars, keeping them from running out of control. An ingenious set of "safety cars," special trucks attached to the rope on the downhill side of the cars, provided additional braking ability (Wilson, 1897).

In the early years, horses pulled the railroad cars on the level surfaces and slight inclines. In 1835, the engine "Boston" became the first locomotive to run on the Portage Railroad. It did the work of 18 horses and proved so successful that over the next few years the railroad acquired 16 more locomotives. Eventually the use of horses was phased out completely (Wilson, 1897).

At the opening of the Allegheny Portage Railroad on March 18, 1834, there were 25 cars ready for use. Another 25 became available by April 1, and 30 more by April 18. These could be hauled by either horse or locomotive. Although designed specifically to haul canal boats, the Portage Railroad also hauled "standard" passenger and freight cars (**Harper Stop 3 Figure 4**). The canal boats were built in sections (**Harper Stop 3 Figure 3**) to make their movement overland practicable. Passengers and goods boarded a half or third canal boat section that was mounted on wheeled trolleys in Philadelphia. Horses or mules hauled the sections through the streets to the railway terminus where the boat halves were transferred to special railroad trucks. The canal cars were taken overland by locomotives on the Columbia-Philadelphia Railroad, the forerunner of the Pennsylvania Railroad. At the Susquehanna River, the sections were reassembled and drawn by horses to the Juniata River canal, then along the Juniata to Hollidaysburg. There they were transferred once again to railroad trucks and hauled over Allegheny Mountain on the Allegheny Portage Railroad. Finally, at Johnstown at the western end of the portage, the boats were reassembled to complete the journey to Pittsburgh on the Conemaugh River canal (Wilson, 1897).

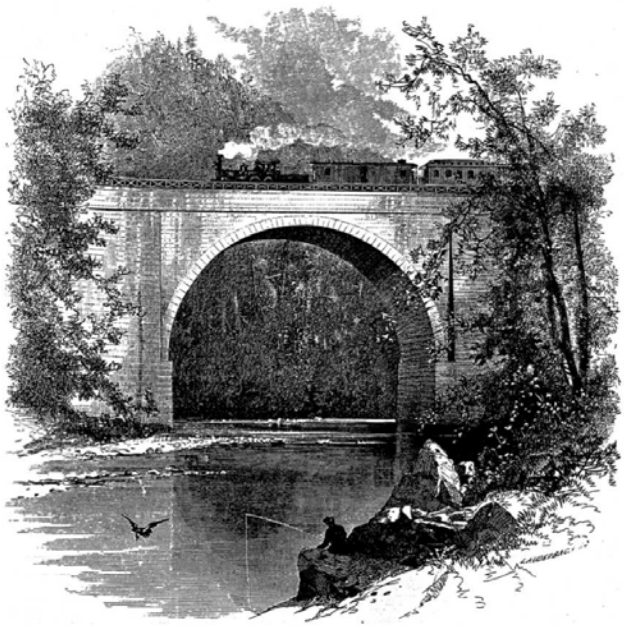

Figure 5. The Conemaugh Viaduct, built to carry the Portage Railroad over the Little Conemaugh River (from Shank, 1975). This historic structure was one of the victims of the great Johnstown Flood of 1889.

The first single track was completed and open for traffic March 18, 1834, less than three years after the final surveys had been done. The second track was finished in late spring of 1835. In all, he Allegheny Portage Railroad was completed in less than four years. It was 36½ miles long, and had a total rise and fall of 2,570 feet between Hollidaysburg and Johnstown. The inclination of the planes varied from about 0.07 percent to a little over 10 percent (Wilson, 1897; Welch, *in* Shank, 1975). The Conemaugh Viaduct over the Little Conemaugh River (**Figure 5**) eight miles east of Johnstown

Figure 6. The Staple Bend Tunnel, the first railroad tunnel built in America. Photo from Kennedy (2001).

comprised a single semi-circular, 80-foot arch 28 feet wide and standing 70 feet above the surface of the water. The Staple Bend Tunnel (**Figure 6**), four miles east of Johnstown, was the first tunnel built in America. It was 901 feet long, 20 feet wide, and 19 feet high at the top of the arched ceiling (Wilson 1897).

The Allegheny Portage Railroad, along with the rest of the Pennsylvania Mainline Canal system, served well those willing to travel west to make their fortunes for the next 20 years. The whole journey from Philadelphia to Pittsburgh, a distance of about four hundred miles that used to require months of hardship, could be covered in relative comfort in less than a week (Wilson, 1897).

The New Allegheny Portage Railroad

It didn't take long after the Portage Railroad opened before people were complaining about the lack of convenience and the safety of the inclined planes. Generally regarded as "nuisances," it cost no less than $10,000 per year to keep each inclined plane in repair, just about doubling the cost of operation as compared with the level or very low-grade parts of the railroad. The railroad was constantly being repaired. For example, every spring the tracks had to be repaired and readjusted because of frost heave. Landslides, foundation problems in the engine houses, and embankment failures caused almost daily problems along the railroad. Probably the biggest problem, however, was the ever-present problem of rotting wood in road and bridge superstructures. Repairs were done piecemeal on a daily basis and the railroad was never actually in good working order. The only important improvements made before 1850 were the changes to locomotives and metal cables (Wilson, 1897).

On June 16, 1836, just a year after the Allegheny Portage Railroad was completed, the State Legislature charged the Canal Commissioners with finding a better way of transporting travelers over Allegheny Mountain.

The engineers in charge of the railroad determined that by increasing the overall distance only slightly a new line could cross the mountain avoiding the inclined planes entirely. This would necessitate running the railroad along the banks of the Conemaugh River and digging a tunnel through Allegheny Mountain summit. The new railroad plan would make use of eight miles of the old grade, but with an increased distance of only one mile (Wilson, 1897).

The Board of Commissioners held off making any decisions until construction of the Pennsylvania Railroad began in 1847. At that time, the legislature began to understand that the "old" Portage Railroad had outlived its usefulness. This became especially apparent when the Pennsylvania Railroad hoped to use the Portage as part of its line until it could complete its own line over the mountains. Such economic interests had their impact. Governor William F. Johnson called the Portage Railroad "evil", and suggested spending $500,000 to bypass four of the five inclined planes between Summit and Johnstown. Because of cost, he did not suggest replacing the planes on the east side of the mountains – only repairing them. He felt the Pennsylvania Railroad would be able to make good use of the Portage for many years if these changes were made. But

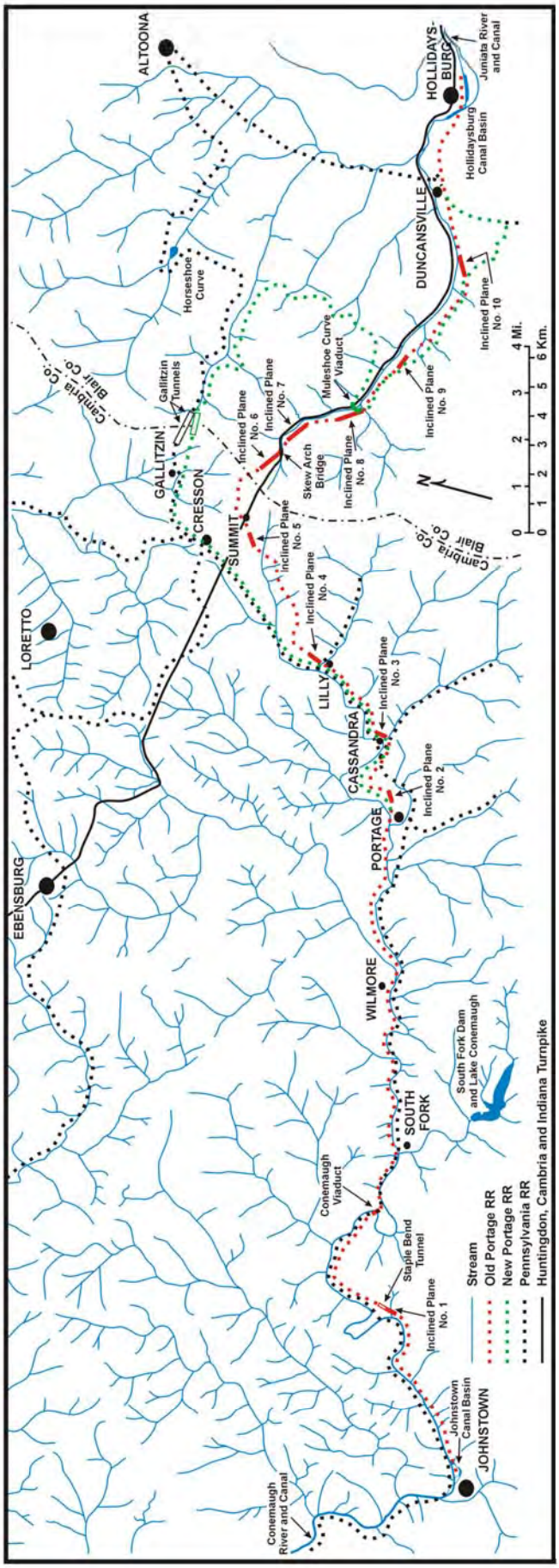

Figure 6. Map showing the routes of the various railroads between Johnstown and Hollidaysburg, and their relationships to the local streams. Based on an 1896 relief map of the Allegheny Mountains prepared for the Pennsylvania Railroad.

later that year the Legislature decided to bypass all of the inclined planes. After the appropriate surveys and report were completed, the Legislature authorized reconstruction that would avoid the planes on the western slope, and in June 1851 work began (Wilson, 1897).

The new railroad bypassed Inclined Plane Nos. 1 through 3 (**Figure 6**), by increasing its length slightly in order to enter the Staple Bend Tunnel and by following the Little Conemaugh River to Lilly. From there the road paralleled the Pennsylvania Railroad line north to a small branch of Clearfield Creek near Cresson, bypassing Incline Plane Nos. 4 and 5. The Pennsylvania line went through a 3,570-feet long tunnel through the summit, down the northern face of Sugar Run Gap and around the eastern face of Allegheny Mountain to Altoona via Horseshoe Curve (**Figure 6**). The New Portage Railroad also went through the summit via a tunnel, but it was only 1,800 feet in length. The railroad then ran down the southern face of Sugar Run Gap and curved around the eastern slope of Allegheny Mountain to Blair Run Gap, avoiding Inclined Plane Nos. 6 through 8. It crossed the old railroad and the Huntingdon, Cambria, and Indiana Turnpike at the foot of Inclined Plane No. 8 on the Muleshoe Curve Viaduct, which is still standing over old US 22 (**Figure 2E**). The new line paralleled, and occasionally crossed, the Old Portage Railroad, bypassing Inclined Plane Nos. 9 and 10, south of the final inclined plane. It eventually picked up the old railroad line in Duncansville (**Figure 6**). A six-mile-long branch railroad from Duncansville to Altoona provided access between the Pennsylvania and Portage lines. By February 1854 the Pennsylvania Railroad was ready to go over the mountain on its own road, and by July

1855 the New Portage Railroad, although incomplete, began operations (Wilson, 1897).

The New Portage Railroad was 45 miles long only 9 miles longer than the old one. The summit at Sugar Run Gap was 150 feet lower that at Blair Run Gap, reducing the total ascent and descent by 300 feet. The maximum grade for the new Portage road was 66 feet per mile on the western slope and 75 feet per mile on the eastern slope of the mountain. The summit tunnel was dug at the narrowest and lowest point at Sugar Run Gap, 135 feet below the summit. The Pennsylvania Railroad tunnel, by comparison, was as much as 200 feet below the summit, even though it was only a few hundred yards farther north. The Board of Commissioners pronounced the New Portage Railroad "superior to the New York and Erie, the Pennsylvania, or the Baltimore and Ohio Railroad" (Wilson, 1897, p. 79). Thus, the Old Allegheny Portage Railroad, once considered one of the "wonders of the age", had done its work, lived its history, and was decommissioned (Wilson, 1897).

The Demise of the Portage Railroad

Wouldn't you know it? No sooner had the New Portage Railroad gone into operation than the government decided to sell it, and the entire canal system along with it. The New Portage had cost over $2 million dollars to build, and there was no way that revenues from its use were ever going to equal, let alone exceed, its operating costs. The rest of the canal system was also in bad shape financially (as well as physically), and the advent of the cross-state Pennsylvania Railroad had put a serious crimp in any revenues the system could have generated (Wilson, 1897).

The cost of the state canal system from Philadelphia to Pittsburgh had been $16,504,655.84 (Jacobs, 1945). When the system went on the blocks, the Pennsylvania Railroad was the only bidder, making payment with bonds valued at $7,500,000, less than half of the total cost. On August 1, 1857 the Pennsylvania Railroad took possession of the Eastern, Juniata, and Western divisions of the Pennsylvania Mainline Canal, including the Portage Railroad, and began dismantling them. By 1858 the Portage was gone, and within six years the Pennsylvania Railroad had abandoned the entire Western Division of the Pennsylvania Mainline Canal. In 1866 they sold the remaining 178 miles of canal to the Pennsylvania Canal Company, a private enterprise, for $2,750,000.

The Pennsylvania Railroad cannibalized the Portage, using most of the rails on the Pittsburgh, Fort Wayne and Chicago Railroad in Illinois. Many of the stone "sleepers" were sent to Altoona for use in masonry for the railroad shops. A small side track allowed use of the New Portage tunnel as a subsidiary route, and portions of the tracks at Hollidaysburg and Lilly were used as sidings. The Staple Bend Tunnel was abandoned and left to rot. And the infamous Johnstown Flood of 1889 destroyed the great Conemaugh Viaduct, which was still being used by the Pennsylvania Railroad. The day of the Portage Railroads was finally over and done.

Long neglected by all but local historians, many of the inclined planes disappeared beneath a cover of forests and the railroad right-of-way in places was used, and eventually paved with asphalt, for road traffic. Eventually, however, the federal government realized the historic value of the Portage Railroads and acquired much of the land and remaining structures. They have been hard at work restoring much of the former glory.

Bedrock and Surficial Geology

The stonemasons hired to cut stones and construct "sleepers", culverts, engine house foundations, and the Skew Arch Bridge did much of their work within an easy walk of the Visitors Center. In fact, a leisurely stroll down the boardwalk through the quarry will provide a good view of the many small pits where the stone was extracted and cut. One sandstone boulder along the

boardwalk even features marks left by those historic masons (**Figure 2F**).

The bedrock at the park consists of the upper part of the Allegheny Group and the lower part of the Conemaugh Group (Glenshaw Formation) (**Harper Chapter Figure 4**). The Allegheny and Conemaugh groups both consist predominantly of variable sequences of rock types consisting predominantly of medium-gray silt shale and dark-gray clay shale with some light-gray sandstone, and red and gray claystone. The Allegheny contains numerous, thick, mineable coal seams such as the Upper Freeport and Lower Kittanning, whereas only thin, generally unmineable coals occur sparsely throughout the Conemaugh. Nonmarine limestones are common in the Allegheny but rare in the Glenshaw Formation. The Glenshaw has four or five marine zones (Figure 4), typically consisting of a central argillaceous limestone surrounded by fossiliferous shales, whereas Allegheny marine zones typically are more brackish and sparely fossiliferous (the major exception being the Vanport Limestone).

Inclined Plane No. 6 crosses the Upper Freeport coal (the group boundary) approximately 100 feet below the engine house. Glover (1990) showed the Upper Freeport has been mined extensively throughout the area, including beneath the park. A hike of only ½ mile northeast or southwest from Old US 22 will bring you to Upper Freeport strip mines.

Most of the area downhill from the Visitors Center is covered with a surficial deposit of regolith and colluvium consisting of sandstone boulders in an unsorted mixture of unconsolidated material. The boulders are Mahoning sandstone (lowermost Conemaugh) (**Harper Chapter Figure 4**), which is well developed in this area (Geyer and Wilshusen, 1982 indicated that it is well developed in the subsurface at Cresson, just west of the park). It is also conspicuous in the Patton area of north-central Cambria County where it forms a flat surface of considerable extent (Stone, 1932). It is typically a heavy, coarse, and, in places, conglomeratic sandstone that typically occurs in two sequences about 35 to 40 feet thick each, separated by shales, a minor coal, and/or sometimes a thin nonmarine limestone. In the subsurface of western Pennsylvania it often has no recognizable parting at all, forming one mass of sandstone up to 100 feet thick. Where exposed at the surface, it tends to break down into abundant boulders that seem to be strewn across the landscape in helter-skelter fashion. In Cambria County, such accumulations occur in the Patton area, near Cassandra about six miles southwest, and here at the park. Stone (1932) indicated that some blocks are 10 feet across and provided an excellent source of local building stone. It would have been relatively easy, even in the 1830s, to sift through the boulder field here at the edge of Allegheny Mountain to find suitable stone to cut.

Feel free to examine the boulder quarries, both along the boardwalk and down the slope from the engine house.

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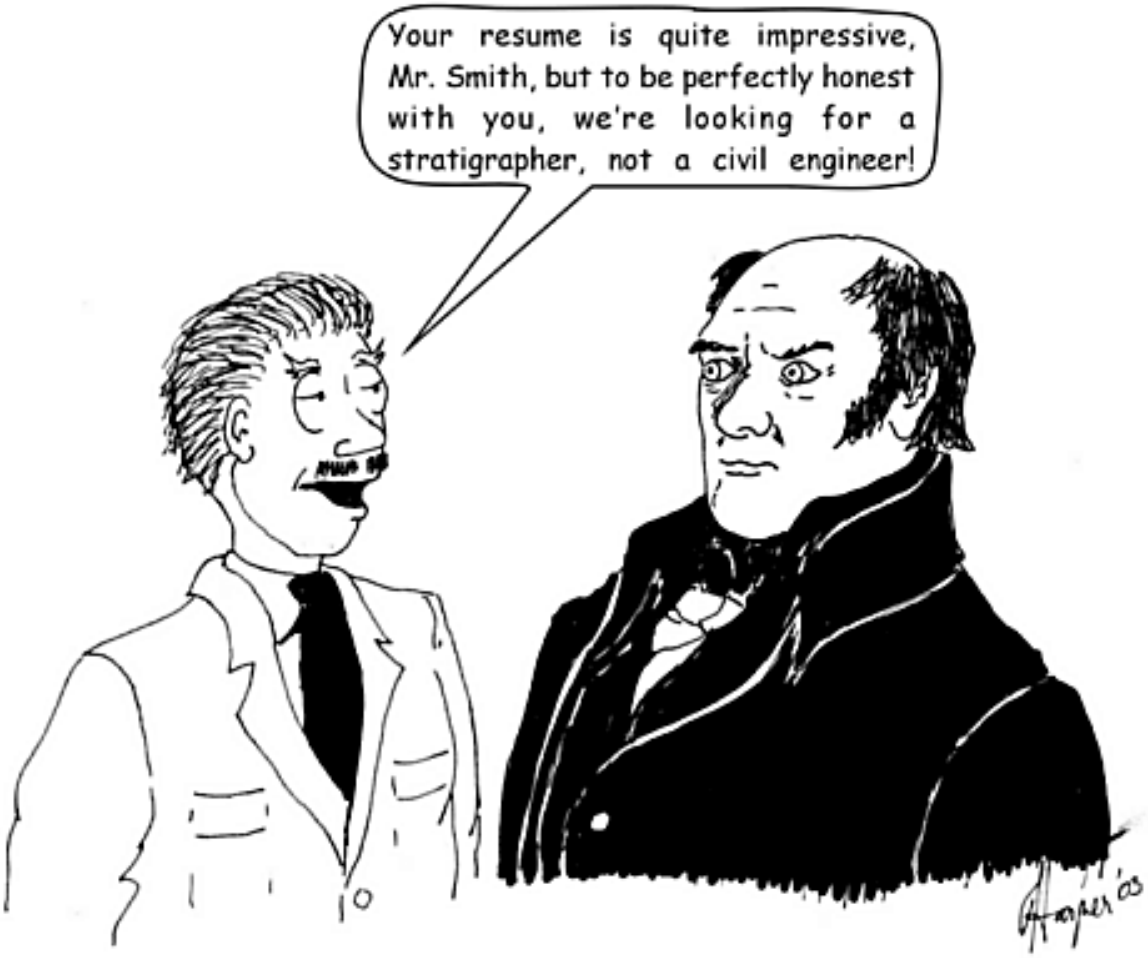


WHAT IF . . . William Smith were still living today?

STOP 9. COONEY BROTHERS COAL COMPANY--POT RIDGE STRIP MINE

Leader: Stephen R. Lindberg, University of Pittsburgh at Johnstown, Westmont Hilltop School District, Johnstown

INTRODUCTION

This field stop provides participants the opportunity to examine a classic example of surface mining in some of the bituminous coal sequences along the eastern edge of the Appalachian Plateaus. Cooney Brothers Coal Company has carried on continuous mining at this Pot Ridge site since 1956. This mine is the largest of the company's three active stripping operations on the plateaus at this time. Mining operations here are carried out by a work force of approximately 15, who work 10 hour shifts Monday through Friday. The current operations are within a year of completing all mining at this location.

The most recent data (2001) available from the Pennsylvania Department of Environmental Protection lists the Pot Ridge site as having 739.5 acres under mining permits with a total yearly production for 2001 of 60,262 tons. This production is down from 113,428 total tons (DEP, 2003) reported in 1999. Total 2002 production for all Cooney Brothers surface mines was approximately 250,000 tons (personal communication, Blaisdell, 9/15/03).

As we climb Pot Ridge and the active operation comes into view, the first-time visitor may be awe-struck at the scale of the workings before them. The amount of overburden that is blasted, bulldozed, and removed to access the coal seams is truly impressive. The piles of bare waste rock and the scale of the highwall combine to create a dramatic, almost surrealistic scene.

Figure 1. View looking northeast over the active strip pit. The "Mrs. C" dragline is visible on the ridge in the background atop previously mined land.

In addition to the physical scale of the open pit, the landscape is dominated by the largest piece of Earth moving equipment here at the mine--the 6400 series dragline. Fitted with a 12-cubic-yard bucket, the "Mrs. C" dragline (Figure 1) is one of the largest, tracked-dragline models that still operate on diesel engines. During normal operations, the dragline will remove overburden at an average fuel-consumption rate of 48 gallons per hour. A show-room-new 6400 model dragline represents an investment of about 1.6 million dollars.

All of the coal mined here at Pot Ridge is trucked to the Cooney Brothers coal-mixing facility located about 11 miles north in Portage, PA. There, the coal is custom blended to meet the specifications of both domestic and overseas customers. The coal produced at the Pot Ridge mine is used for steam production in coal-fired, electric generating plants along the eastern seaboard.

PHYSIOGRAPHIC AND REGIONAL SETTING

The Pot Ridge mine and all of Somerset County is located within the Allegheny Mountain section of the Appalachian Plateaus province. The highest elevation within the county (and in PA) is Mount Davis at 3,213' above sea level. Prior to mining operations, the highest point along Pot Ridge was 2,820'. On a clear day, an *avis raris* here, Laurel Hill is visible to the west as a prominent southwest-northeast trending ridge at a distance of about 20 miles. The city of Johnstown, approximately 15 miles to the northwest, lies at the junction of the Little Conemaugh and Stonycreek rivers.

Three miles directly east is the Allegheny Front. The Front marks the eastern boundary of the Main Bituminous field at the northern end of the Appalachian coal basin. Throughout this entire region, active

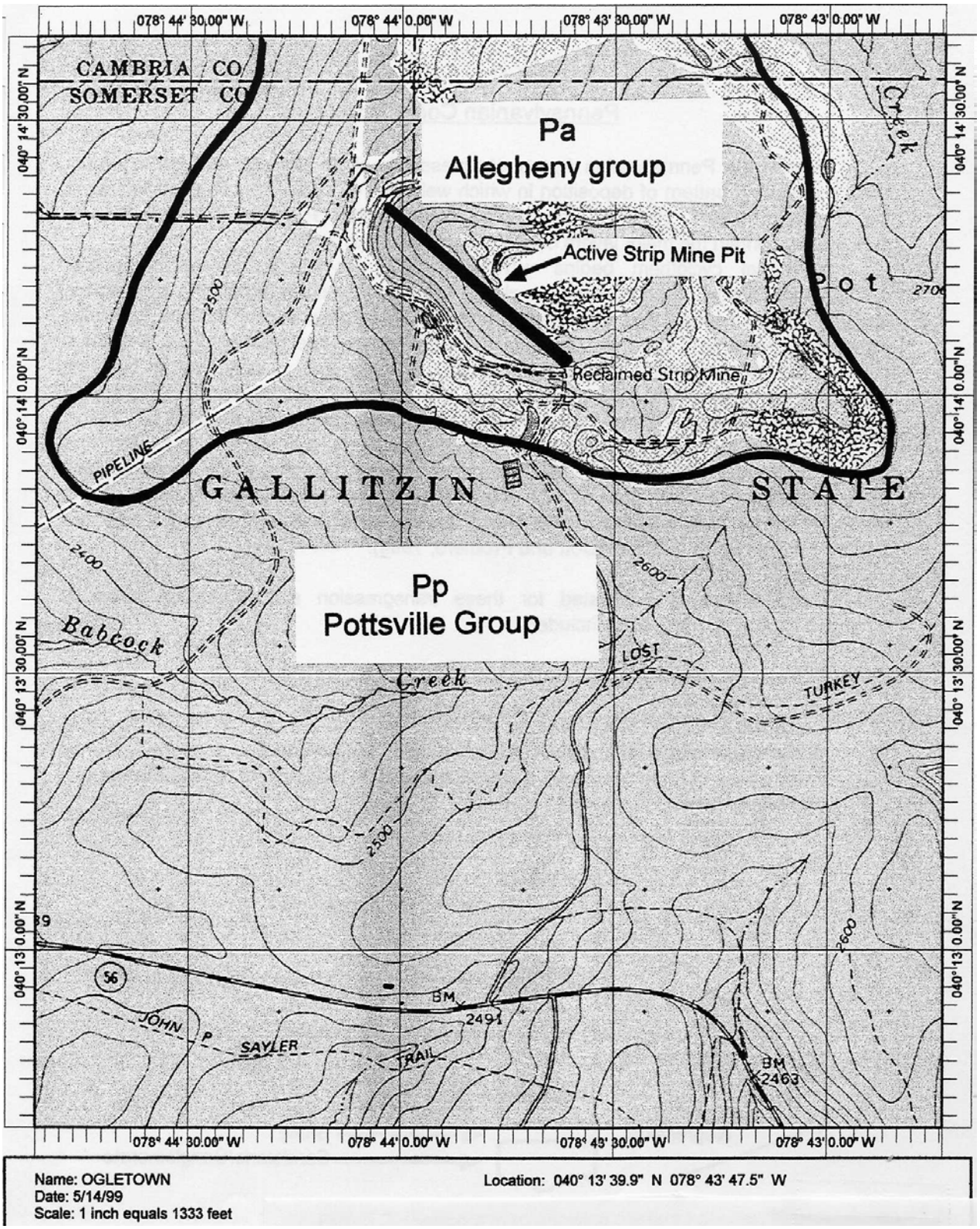


Figure 2. Geologic map showing the contact between the Pennsylvanian Allegheny and Pottsville groups. (Based on data from Cooney Brothers Coal Co., Portage, PA.)

operations as well as extensive reclaimed areas point to a long history of mining within the Ogletown 7.5' quad. The current, active strip pit lies within northernmost Somerset County, with reclaimed land extending about 0.5 mile north into Cambria County. Active mining is currently proceeding in a southwest direction, with the axis of the open pit (Figure 2) bearing approximately N40ºW.

GEOLOGIC SETTING

The Cooney Brothers Pot Ridge Mine exposes a middle Pennsylvanian stratigraphic sequence beginning at the top of the Pottsville Group and extending up through the lower third of the Allegheny Group (refer to guidebook Cover 3). Seams currently being mined here include the Mercer (within the Pottsville), Clarion 1 (Brookville), Clarion 2, and the Lower Kittanning. Here at Pot Ridge, the Mercer coal is economically the most important. The top of the Allegheny Group is marked by the Upper Freeport Coal, and its base corresponds to the Clarion 1 coal.

The total thickness of the Allegheny Group ranges between 220 to 290 feet. Originally known as the "Lower Productive Coal Measures" (Phalen and Martin, 1911), the Allegheny Group contains at least 5 major mined coal layers within this region. Within the open pit, the Lower Kittanning coal is located approximately 100 feet above the top of the Mercer coal.

COAL ANALYSES

Table 1 (Penn State, 2003) provides analyses of the four coal seams currently being mined at the Cooney Brothers Pot Ridge surface mine. Thee data are not specific to the Pot Ridge operation, but reflect testing done on samples from Somerset and adjacent counties. For the Lower Kittanning and Clarion coals, two different analyses are provided.

Table1. Analyses of selected coals from Somerset, Clarion, and Clearfield counties, PA. (Data from The Penn State University's coal sample bank and database)

RANK	SEAM	% Ash, dry	% Sulfur, dry	BTU / lb, dry	% Carbon, dry
lvb[1]	Lower Kittanning, Somerset County	10.63	3.10	13,745	90.91
lvb	Lower Kittanning, Somerset County	9.78	0.62	13,871	89.33
hvAb[2]	Upper Clarion, Clarion County	17.67	5.93	12,204	85.51
hvAb	Upper Clarion, Clarion County	8.91	4.82	13,390	83.67
hvAb	Lower Clarion, Clarion County	12.64	4.52	13,157	85.99
hvAb	Lower Clarion, Clarion County	10.08	5.64	13,557	85.12
mvb[3]	Mercer, Clearfield County	8.98	3.81	14,032	88.72

[1]lvb (low volatile bituminous)
[2]hvAb (high volatile A bituminous)
[3]mvb (medium volatile bituminous)

Figure 3. View looking northwest at the highwall of the Pot Ridge strip mine operation, Cooney Brothers Coal Co., Portage, PA. The Mercer seam is visible along the base of the highwall.

REFERENCES

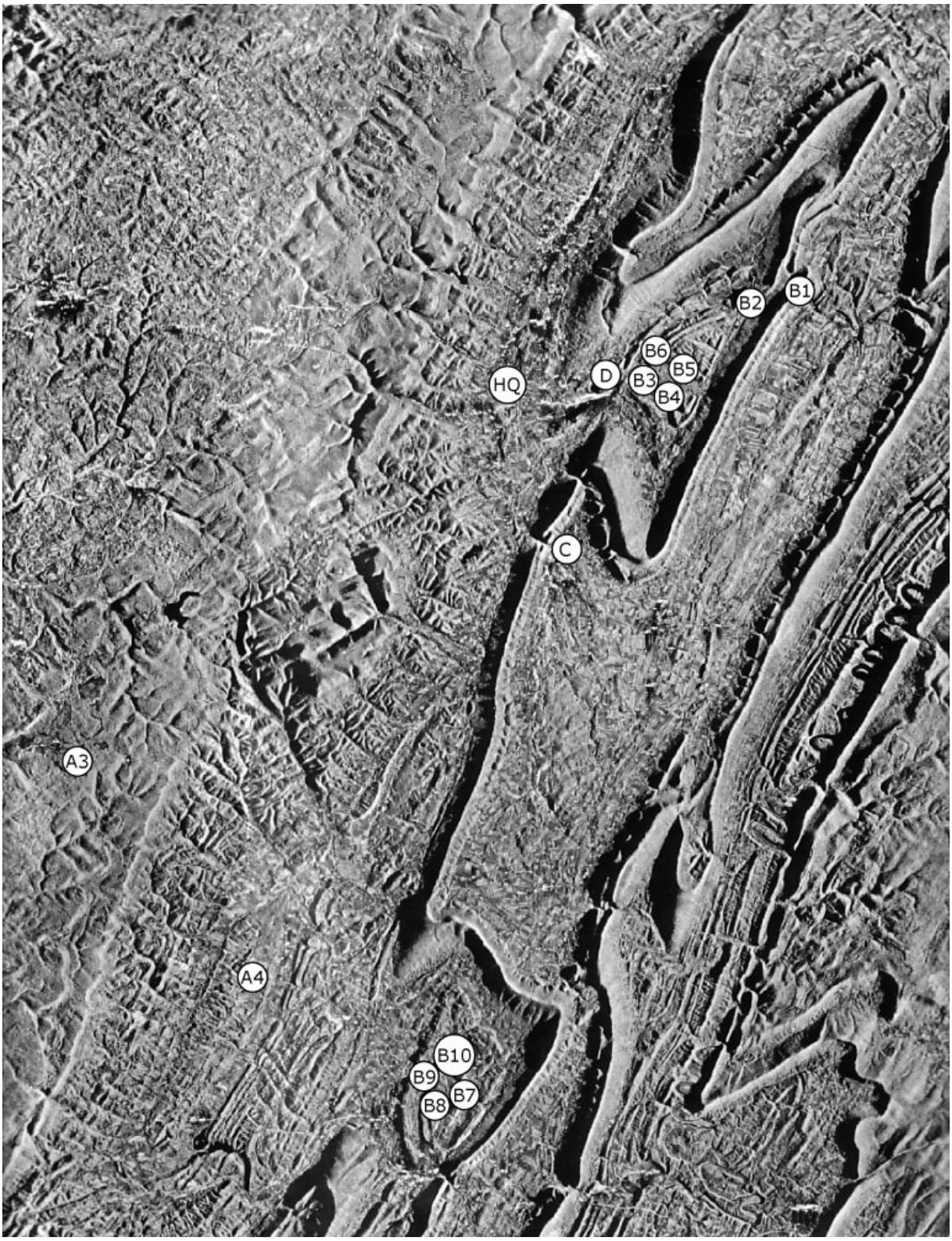
Pennsylvania Department of Environmental Protection, 2001, Annual Report on Mining: Site accessed September 9, 2003. http://www.dep.state.pa.us/dep/deputate/minres/bmr/annualreport/2001/contents.htm

The Pennsylvania State University Coal Sample Bank and Database, WWW subset.: Site accessed September 15, 2003. http://www.energy.psu.edu/COPL/coal.html

Phalen, W. C., and Martin, L., 1911, Mineral Resources of Johnstown, Pennsylvania and Vicinity: United States Geological Survey Bulletin 447.

Appendices

Pre-conference Field Trips B, C, and D



Stop locations for pre-conference field trips B, C, and D
of the 2003 Field Conference of Pennsylvania Geologists

Appendix B

SUBDIVISION OF LOWER TO MIDDLE DEVONIAN STRATA IN TWO STRUCTURAL BASINS IN THE RIDGE AND VALLEY PROVINCE, SOUTH-CENTRAL PENNSYLVANIA (BASED ON GEOMORPHIC AND TECTONIC INTERPRETATIONS OF SIDE-LOOKING AIRBORNE RADAR (SLAR) IMAGERY)

Robert J. Altamura

INTRODUCTION

The purpose of this field trip is to present some of the results of radargeological mapping in two Devonian-cored structural basins within the Ridge and Valley Province of the central Appalachians near Everett and Hollidaysburg, Pennsylvania (Figure 1). This field trip will visit localities of Keyser, Old Port, Onondaga, Marcellus, and Mahantango formations that confirm radargeology interpretations. It is possible to map radargeological units from distinctive patterns in Side-looking radar (SLAR) imagery (Figure 2). These patterns appear to be related to lithology, structure, and slope aspect. They make it possible to map lithofacies and units within previously undivided formations. The radargeological units (*i.e.*, new lithofacies) are correlated with the published stratigraphic column for the region (Berg *et al.*, 1986).

Observation of selected outcrops of the new lithofacies, originally identified as radargeolgical units, will be a major focus of the field trip, however we will also observe some evidence for structural deformation representative of the terrane. In the Hollidaysburg quadrangle, such evidence will include left-lateral offset of the Tuscarora ridge along the east limb of the Frankstown basin due to the Canoe Valley fault and possibly related fault zone breccia. In the Everett quadrangle, this will include exposures nearly on the fold axis of the 1st order fold that defines the Everett structural basin. Outcrops showing kink folds, closely-spaced cleavage, and meter-long tectonic "pencils" will also be observed. Finally there will be an opportunity to collect Middle Devonian marine fossils from a newly identified lithofacies of the Mahantango Formation in the study area.

Field Trip Area

The study area is underlain by a sequence of clastic and nonclastic sedimentary rocks of the Appalachian foreland basin. Formations in the study area range from Cambrian to Pennsylvanian (Berg *et al.*, 1983). Included are the coal measures of the Broad Top. The strata were folded during Appalachian mountain building. Consequent erosion during the Mesozoic Era resulted in a physiography of unusually long, narrow, nearly parallel ridges (resistant rocks) and valleys (soft rocks) that have led to the name the Valley and Ridge Province. The province extends from eastern Pennsylvania to Alabama. To west it is bounded by the Appalachian Plateau and to the east, the Blue and Piedmont provinces.

Altamura, R.J., (2003) Subdivision of lower to middle Devonian strata in two structural basins in the Ridge and Valley Province, south-central Pennsylvania (based on geomorphic and tectonic interpretations of side-looking airborne radar (SLAR) imagery), *in* Way, J.H. and others, eds., Geology on the edge: selected geology of Bedford, Blair, Cambria, and Somerset Counties, Guidebook, 68th Annual Field Conference of Pennsylvania Geologists, Altoona, PA, p. 188 - 210.

The study area is located in the nonglaciated southern portion of the state referred to as the Salamanca Re-entrant after Crowl and Sevon (1999). During glacial times, the study area was the site of extensive periglacial activity, erosion, and fluvial deposition. A tundra environment existed in the study area during the Pleistocene Epoch. The periglacial environment associated with the various glacial event of the Pleistocene caused considerable mass wasting in the nonglaciated portion of Pennsylvania, such that the portion of Pennsylvania, such that the crest of ridges may have been lowered by tens of feet (Crowl and Sevon, 1999). Freezing and thawing broke up rock, which accumulated as talus, such as one can observe on the west slope of Brush Mountain near Altoona. Pleistocene mammals such as mastodons, giant beavers, and bison roamed the area near Frankstown (see Fonda, this volume) during this time, many tens of kilometers from the front of a continental glacier located toward the northern part of the state.

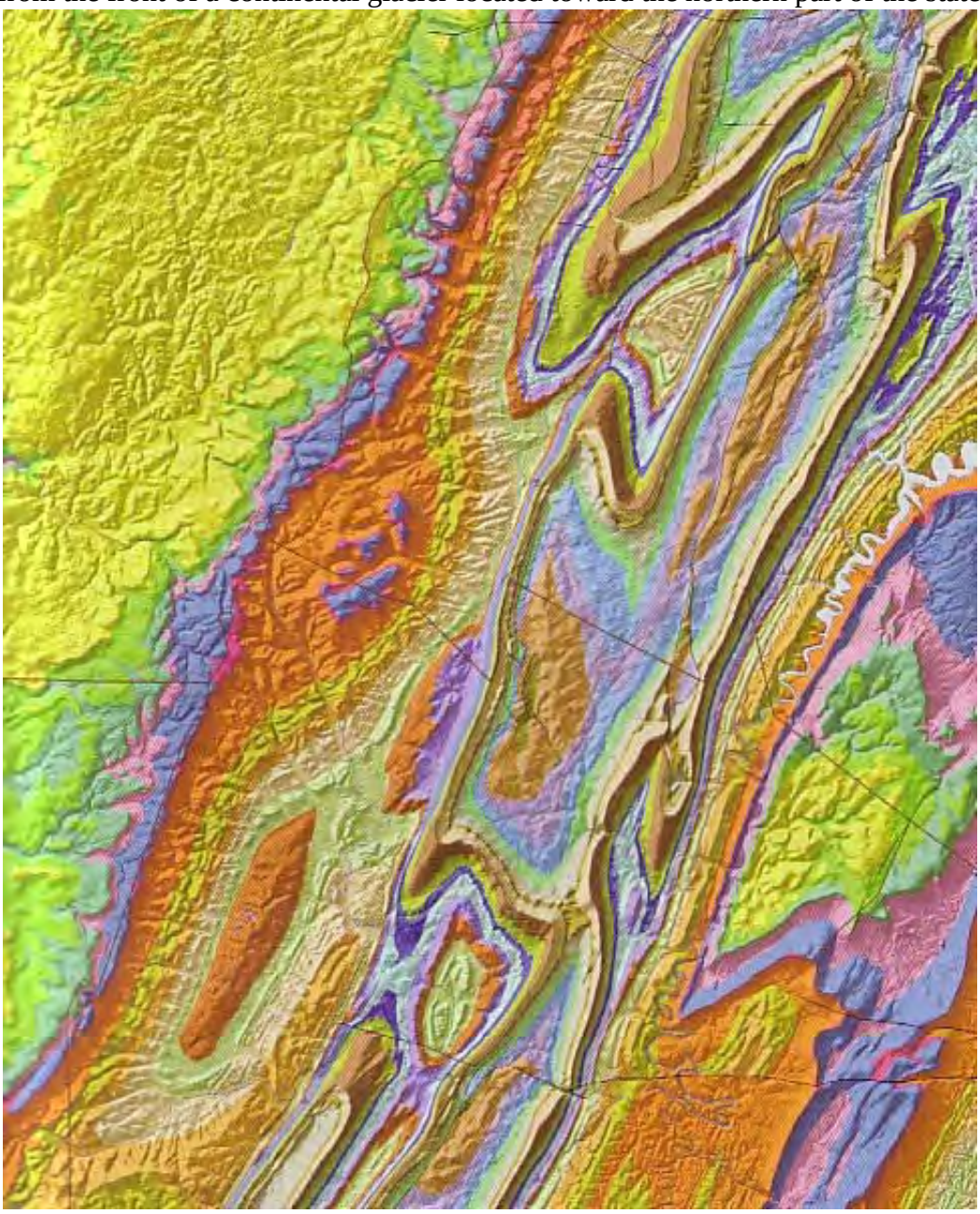


Figure 1. Regional geological map of south- central Pennsylvania (from Miles, 2003). Note the two structural basins within the Ridge and Valley terrane. These are cored by Lower to Middle Devonian strata that will be a focus of the field trip. The northernmost is referred to as the Frankstown basin and the southernmost as the Everett basin. (North is parallel to the side edge of the page, and the distance across the map from west to east is approximately60 km (or 37 mi.).

Figure 2. Side-looking airborne radar (SLAR) image showing the region of south-central Pennsylvania that will be the focus of study during the 68th Annual Field Conference of Pennsylvania Geologists. The Ridge and Valley image - separated from the "Ridge and Valley" by the "Appalachian Front," hence the theme of this year's conference: "Geology on the Edge." The two structural basins that will be foci of the radargeology field trip are portrayed in the northeastern quadrant of the image and in the south-central portion of the image. (North is parallel to the side edge of the image, and the distance from the western to eastern edges is approximately 55 kilometers [34 miles]).

Previous Work

Earliest geologic mapping in the Hollidaysburg's portion of the study area was by Platt (1881), as part of his report: the geology of Blair County. Butts (1918) first studied the stratigraphy in the Hollidaysburg area and elsewhere in south-central Pennsylvania shortly after World War I. However it was much later that his detailed geologic map of the Hollidaysburg 15-minute quadrangle was published as part of a U.S. Geological Survey folio. Butts' map was comprehensive and remains a valuable resource by geologists studying the area. Tregaski (1979) wrote a Penn State Master's thesis on the Woodbury zinc-lead occurrences of Bedford County and prepared a map that was used by Hoskins, who compiled a map of the Roaring Springs 7.5. Quadrangle for Map 61 of the Pennsylvania Geological Survey (Berg *et al.* (1981). Radargeological mapping of the Hollidaysburg area reveals that of some Middle Devonian formations can be subdivided and correlated to the Everett area (Altamura, 2003).

Rodgers (1858) was the first geologist to visit and report on geology of the Everett 15-minute quadrangle area. Stevenson (1882) mapped the area as part his report on Bedford and Fulton counties. Wilson (1952) prepared a map that was used by Hoskins to compile the New Enterprise quadrangle for Map 61. Knowles (1966) mapped a portion of the Everett 15-minute quadrangle as part of his study to map detailed stratigraphy and to genetically interpret geologic structures. Feathers (1974) studied the geology of the New Enterprise 7.5 minute quadrangle as part of a Master's thesis at Indiana University of Pennsylvania. Feather's results, along with a mineral resources report by Smith II (1977), and Wilson (1952) were all used by Hoskins in his compilation of the New Enterprise 7.5 quadrangle for Map 61. Radargeological mapping of the Everett area provide new interpretations that yield subdivision of some Middle Devonian strata (Altamura and Gold,1992; Altamura, 2000)

Acknowledgements

The topics of this field trip are part of a cooperative geologic mapping project by the author with the Pennsylvania Geological Survey. The Volunteers Program of the Geologic Mapping Division of the Survey funded Field expenses and acquisition of SLAR data. The Connecticut Geological and Natural History Survey funded early radargeologic studies in the Everett 15-minute quadrangle. Dr. John Gardner taught me the techniques of radargeology and introduced me to the geology of the Everett quadrangle. Field excursions with Drs. William "Bill" Duke, David "Duff" Gold, Jon D. Inners, and fellow Penn State graduate students Stuart Raeburn and Paul Richards were enlightening and very much appreciated. I thank Drs. Arnold Doden, Edwin "Andy" Anderson, and Duff Gold for their critical reviews of this manuscript. I would also like to thank Mrs. Kinney of Frankstown and Mr. Newcombe of Point View for allowing our field party access to their properties.

ROAD LOG

South-central Pennsylvania is still largely rural and has long been known for it beautiful mountainous scenery. However a major urban center is located at Altoona, and a popular truck haven at Bedford. Recent developments include the upgrade of the main north-south trending route PA Highway 220 to its new status as Interstate 99. Interstate 70, "The Pennsylvania Turnpike," is a major east-west corridor in the southern part of the region, located immediately north of the stateline.

The field stops for this field trip are covered on the U.S.G.S. Williamburg, Frankstown, and Everett West 7.5-minute topographic maps (1:24,000 scale).

0.0 mi Begin road log near the main entrance of the Ramada Inn - Altoona, 1 Sheratan Drive, Altoona, Pennsylvania. Turn *left* onto Plank Road.

0.6 Turn *right* onto Interstate 99 north.

1.9 Take Exit for Frankstown Road (*RIGHT TURN*)

5.3 Turn *left* on Highway 22 east.

11.8 Turn *right* on Highway 866 east.

12.3 Turn *left* onto Point View Drive.

12.4 Stop 1. Take first *right* turn up the hill to the gravel lot in front of the row of several green garages and park. This is the land of Mr. Jim Newcombe who lives in the nearby red house and permission is needed to park. Spectacular views of landforms associated with the Canoe Valley fault and a water gap will be visible depending on weather.

12.5 Return down Point View Drive, turn *right* on Highway 866 west.

13.0 Turn left on PA Highway 22 west.

14.5 Turn sharply *left* onto Flowing Spring Road (*n.b.*, 2nd turn for this road). This turn require crossing speeding traffic and caution is required to do this safely.

14.8 Stop 2. Turn *left* into the dirt lot across from the old metal shop and park.

The outcrop is at the rocky knob on the north side of Highway 22 beneath the power line poles. Extreme caution is needed when crossing Highway 22. Cross where full view of traffic in both directions is possible, and cross quickly. Transgressing an open field to the power line poles is requried. Entering the field near telephone pole #188 at the small crest of the hill in Highway 22 may allow for limited exposure to any poison ivy growing elsewhere along the roadside. The hike to the outcrop takes about 4 minutes.

15.0 Turn *left* onto Highway 22 west.

19.7 We will stop in the village of Frankstown (still on Highway 27) to obtain provisions for lunch.

19.8 Turn *left* onto Reservoir Road.

19.9 Turn *left* onto Locke Mountain Road.

21.0 Stops 3 and 4. Turn *left* into the gravel pull off across from the gate to the New Enterprise Stone and Lime Company rock quarry.

21.2 Turn *left* onto Sandbank Road.

21.4 Stop 5. Turn *right* into gravel drive way (T.E. Kinney on mailbox) and park.

21.7 Stop 6. Continue on Sandbank Road to a point where it bends left. Turn into the second gravel driveway and park. Bedrock is exposed along the right.

22.0 Turn *left* onto East Loop Road.

22.6 Turn *right* onto Locke (sic) Mountain Road.

23.0 Turn *right* onto Reservoir Road.

23.9 Turn *right* onto Highway 22 east.

24.0 Turn *left* onto Frankstown Road. This road is on the dip slope of the southerly plunging Brush Mountain anticline.

26.7 Turn *left* onto Interstate 99 south toward Bedford..

55.0 Take Exit 3 for Cessna and Highway 56 east.

55.3 Turn *left* at end of exit ramp onto Highway 56 east.

56.0 Turn *left* onto Business Highway 220 south.

57.1 Turn *left* onto Country Ridge Road.

58.7 Turn *right* onto Briar Valley Road.

58.8 Turn left onto Chalybeate Road.

58.9 Nearly 360˚ view of the skyline of the Everett physiographic basin. It is worth pulling over for a moment to note it. Continue on Chalybeate Road.

59.9 Turn left onto Rabbit Lane.

60.7 Stop 7. Turn right into the graveled area, turn around, and park. Radargeological units *Dm* (Marcellus Fm.) and Dmh_1 (Mahantango Fm., Gander Ridge Member) are exposed in the face of this borrow pit. Dmh_2 (Chaneysville Siltstone Member) is interpreted to underly the crest of the ridge.

61.6 Turn *left* on Chalybeate Road from Rabbit Lane.

61.8 Stops 8 and 9. Pull off on the right side of the road as much as possible and park. Cars sometimes travel relatively fast and visibility around this curve in the road is not the best. The dirt driveway on the right at the beginning of the curve is a preferred parking spot. Stop 8 and 9 are one continuous outcrop with Stop 8 at the southern most end and Stop 9 at the other. Exposed are Dmh_3 (Frame Shale) with Dmh_4 (Clearville Siltstone) at the top of the ridge. Turn car around.

62.3 Turn *left* onto Rabbit Road.

62.7 Turn left onto Yount Road.

63.0 Mahantango Fm. crops out along right side of road at fringes of farm field. This is mapped as Dmh_2 and is interpreted to be the Chaneysville Siltstone Member.

63.9 Stop 10. Pull over on the right side of the road and park. Dmh_3 is exposed in this abandoned borrow pit. This interpreted to be the Frame Shale member of the Mahantango Fm.

End of Field Trip. Return to Ramada Inn Altoona.

RADARGEOLOGY OF PORTIONS OF THE HOLLIDAYSBURG 15' QUADRANGLE

Leave Ramada Inn in Altoona: 10:00A

CANOE VALLEY FAULT

STOP 1. ***POINT VIEW DRIVE.*** A left lateral offset of the Tuscarora "ridge" and a water gap between Lock Mountain and Short Mountain exist at this locality. The Canoe Valley fault underlies Highway 22 as it passes through an erosional gap. The left-laterial offset is clearly shown of SLAR imagery, as is a NW-trending lineament, here called the Point View lineament (see Figure 2). A well-developed water gap comprises a portion of the lineament through which the Juniata River flows out of the basin.

Arrival: 10:30A

STOP 2. ***CANOE VALLEY FAULT? POWERLINE CUT ADJACENT PA HIGHWAY 22 NEAR CANOE CREEK.*** Mega-breccia comprised of limestone of the Siluro-Devonian Keyser Formation within a fracture zone. Fractures, breccia, and calcite veins are abundant. Could these features represent evidence that the trace of the Canoe Valley fault may be further to the west than shown on the state geological map (Berg *et al.*, 1980)? This location is along the trend of a NE-trending lineament and a presumed fracture zone.

Arrival: 10:45A

GENERAL DEVONIAN STRATIGRAPHY OF SOUTH-CENTRAL PENNSYLVANIA

Rocks of the Devonian in Pennsylvania were eloquently summarized by Harper (1999) as being primarily comprised of Lower Devonian marine carbonates, cherts, shales (*e.g.*, Laughrey, 1999), and Upper Devonian marine to nonmarine, coarse- to fine-grained terrigenous rocks deposited in a prograding Catskill delta (*e.g.*, Harper, 1999; Berg, 1999). The characteristic rocks of these two divisions interfinger in the Middle Devonian. It is this interfingering of rock-stratigraphic units or lithofacies that has made mapping of Middle Devonian rocks so challenging. The pinching and swelling of facies due to deposition alone (*i.e.*, no structural complications) has resulted in discontinuous outcrop belts. As a consequence of this discontinuity and a lack of exposures in the region near Hollidaysburg and Everett, earlier workers have been forced to "lump" some of the Lower and Middle Devonian strata together as undivided units (*e.g.*, Butts, 1945; Berg and Dodge, 1981, Berg *et al.*, 1980; Faill *et al.*, 1989).

Subdivision of some Middle Devonian, as well as Lower Devonian, units by using the radargeological technique advocated by Altamura (2000) has been possible in certain areas in south-central Pennsylvania (Figure 3). The refined Lower to Middle Devonian stratigraphy is portrayed well on radar imagery within two structural basins (see Figure 2) and stratigraphic interpretations have been field checked. Selected field exposures of these new lithofacies will be the focus of this field trip. Much of this radarstratigraphy can be correlated from one basin to another (Figure 4). It can also be correlated to the Bedford area and to exposures in the core of the Pigeon Hill syncline (Altamura, in preparation, 2003).

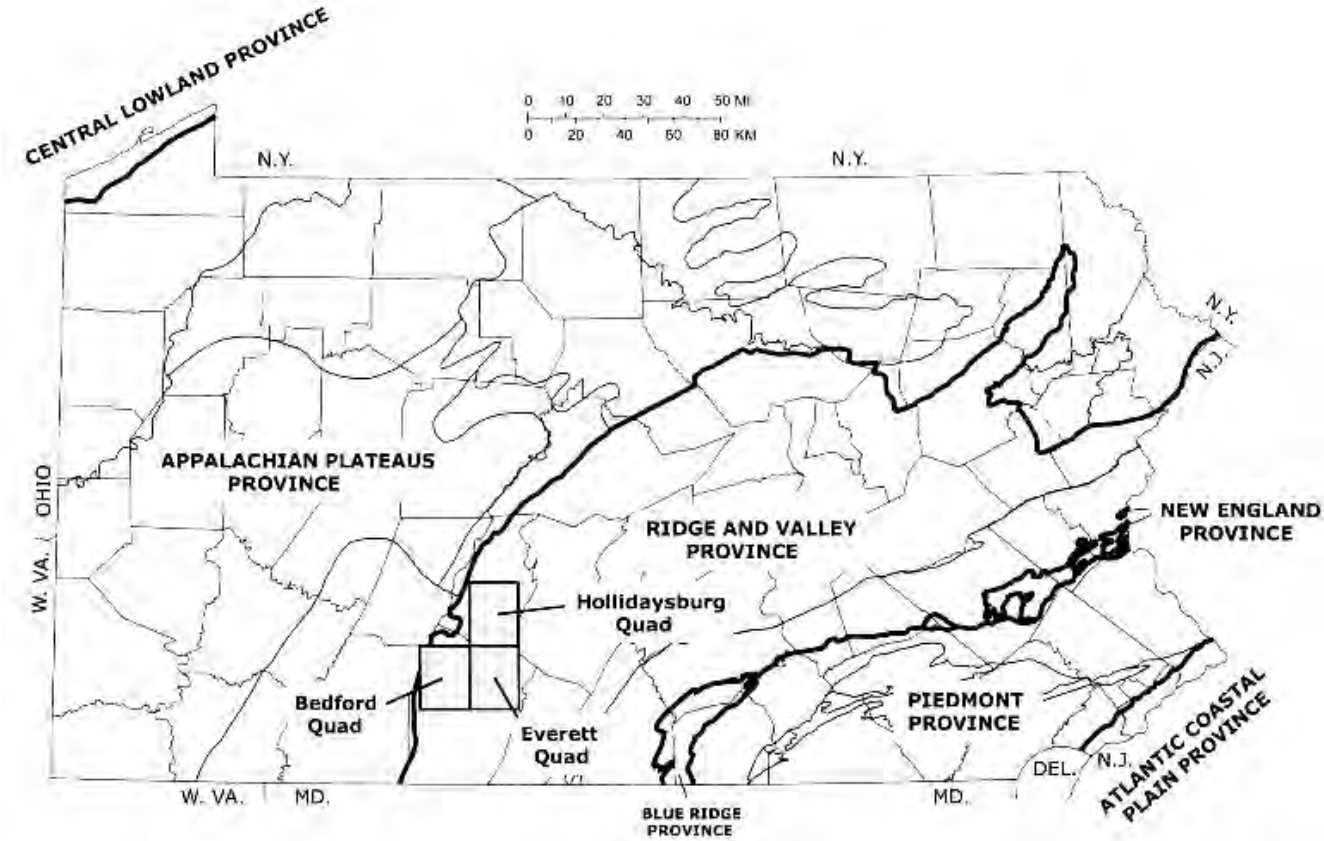


Figure 3. Location map showing the Holldiaysburg, Everett and Bedford 15-minute quadrangles (shaded rectangles), the areas of radargeological study by the author. Selected localities in the Hollidaysburg and Everett quads will be visited as part of the field trip. (previous pages)

Frankstown Structural Basin, Hollidaysburg Quadrangle

RADARGEOLOGICAL UNITS IN OUTCROP

Lower to Middle Devonian strata are exposed in an inactive rock quarry near Hollidaysburg. The Ridgeley Member of the Old Port Formation, the Onondaga Formation, Tioga Ash Bed Zone, and the Marcellus Formation are well exposed. Actual stratigraphic contacts between units mapped on the basis of attributes identified on remotely-sensed imagery (*i.e.*, SLAR) can rarely be "pin-pointed" to outcrops on the land. The radar contact between the Old Port Formation and the Onondaga is confined to a narrow rubble-filled gorge at this locality. A little digging has the potential to expose the contact.

The Lower Devonian Old Port Formation (Conlin and Hoskins, 1962) includes units represented by the interval between the Keyser and Onondaga formations. It includes what were earlier called the "Helderberg" and "Oriskany" groups. Units included in these groups are: the Coeymans (now known as New Creek), New Scotland (Corrigaqnville), Mandata, Shriver, and Ridgeley. Each of these has been applied to a separate lithic or faunal assemblage that can be thin or absent in different parts of the Ridge

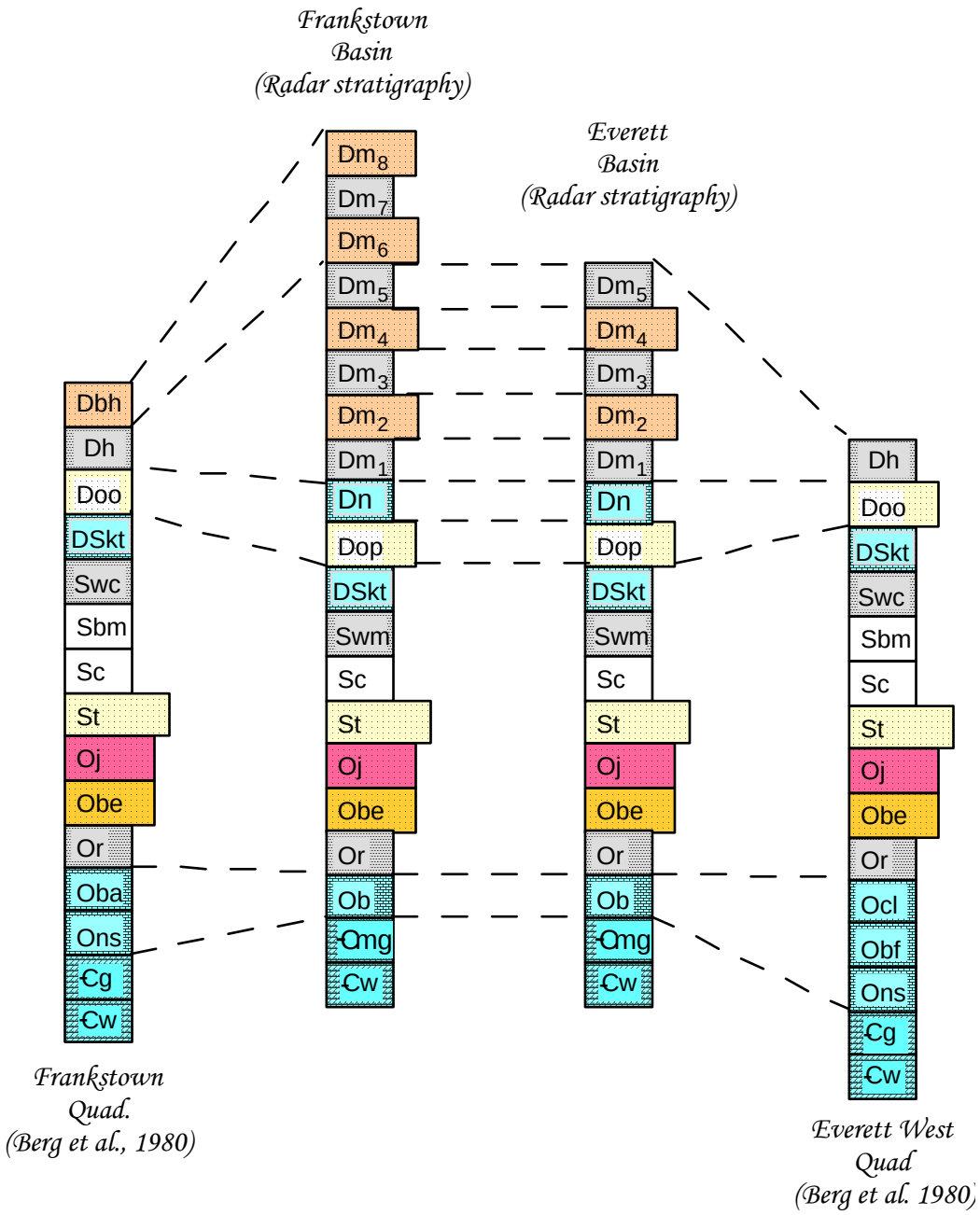
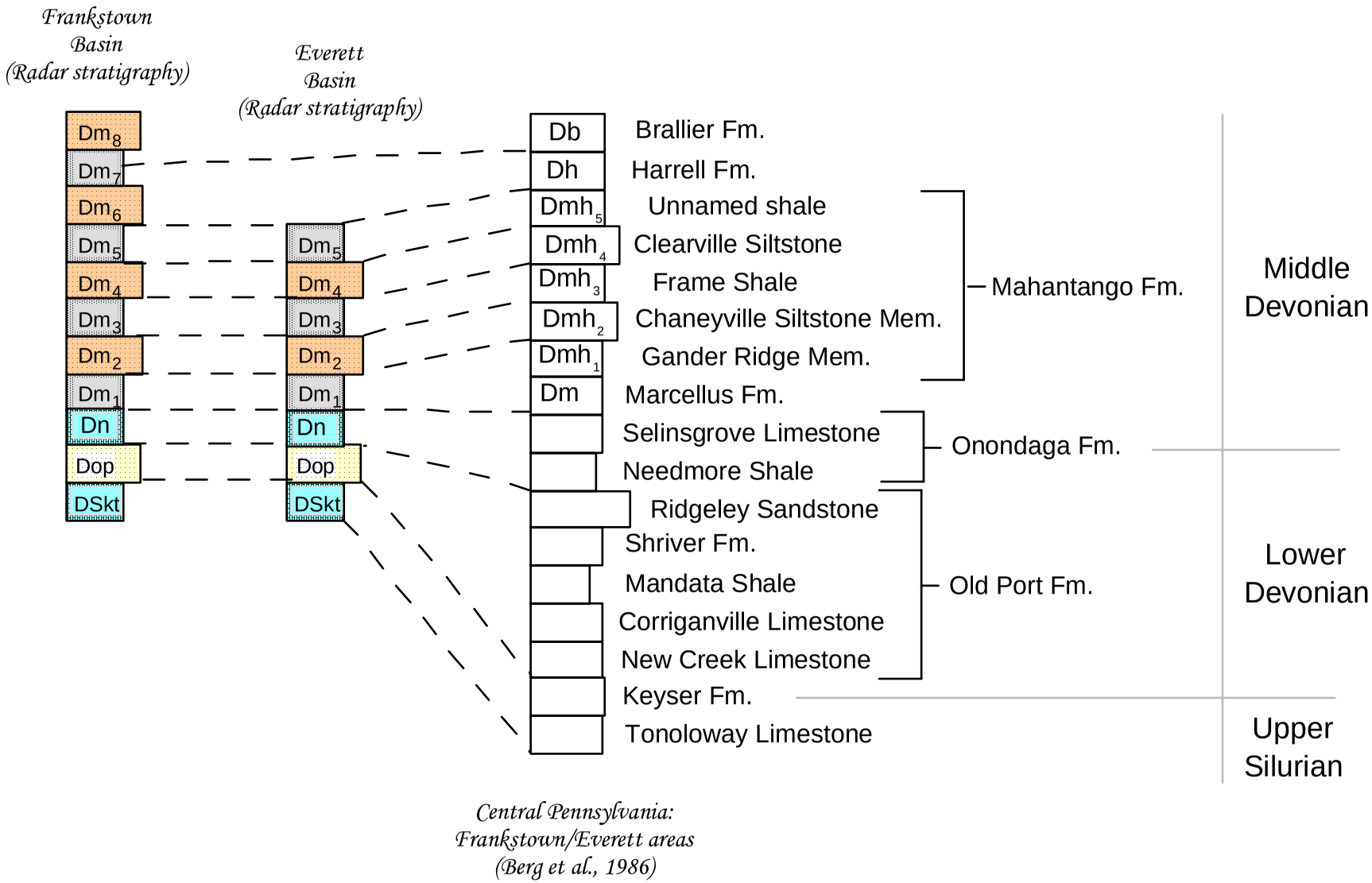


Figure 4. (a) Radar-stratigraphic columns for the Hollidaysburg (Frankstown basin) and Everett (Everett basin) 15-minute quadrangles compared to general stratigraphic column from Berg *et al.* (1980). (b) Correlation of radarstratigraphy to Lower and Middle Devonian units of central Pennsylvania (from Berg *et al.*, 1986). (next pages)

Figure 4b.


Frankstown Basin (Radar stratigraphy)
Everett Basin (Radar stratigraphy)
Dm8
Dm7
Dm6
Dm5
Dm4
Dm3
Dm2
Dm1
Dn
Dop
DSkt
Db
Dh
Dmh5
Dmh4
Dmh3
Dmh2
Dmh1
Dm
Brallier Fm.
Harrell Fm.
Unnamed shale
Clearville Siltstone
Frame Shale
Chaneyville Siltstone Mem.
Gander Ridge Mem.
Marcellus Fm.
Selinsgrove Limestone
Needmore Shale
Ridgeley Sandstone
Shriver Fm.
Mandata Shale
Corriganville Limestone
New Creek Limestone
Keyser Fm.
Tonoloway Limestone
Mahantango Fm.
Onondaga Fm.
Old Port Fm.
Middle Devonian
Lower Devonian
Upper Silurian
Central Pennsylvania: Frankstown/Everett areas (Berg et al., 1986)

and Valley province and that generally cannot be separately mapped (Fail *et al.*, 1989). The Ridgeley is exposed as outcrops and may be mappable, whereas the other units are not. As a result Knowles (1966), for example, reduced the Old Port to two mappable units: the Ridgeley Member at the top and a lower unit that combined all the others. Berg and Dodge (1981) showed Onondaga and Old Port as a combined undivided unit in the Everett and Hollidaysburg areas. Faill *et al.* (1989) mapped all the above-mentioned Old Port subunits as a single unit, which was also done on radargeological maps prepared in the region by Altamura (2000; Figure 5). Because the Old Port can largely be mapped on the basis of a continuous topographic ridge on the radar imagery, the dominant stratigraphic unit responsible for the landform is probably the Ridgeley Sandstone member.

Stop 3. Radargeologic unit *Dop* (Old Port Formation) at the inactive New Enterprise Stone and Lime Company sand quarry near Frankstown, Pennsylvania. The Old Port Formation is in part a ridge former in the study area and can be mapped from side-looking airborne radar imagery by its geomorphic expression and textural and tonal characteristics on radar imagery. The upper portion of the Old Port Formation is exposed in an inactive silica sand quarry near Frankstown (Figure 6). It is sandstone of the Ridgeley Member. Numerous abandoned stockpiles of specialty refractory brick can be observed from the days when the site was active.

Arrive: 11:00A

LOWER/MIDDLE DEVONIAN ONONDAGA FORMATION

The Onondaga Formation was first described for rocks in New York State by Hall (1839) and is comprised of the limestones and calcareous shales that occur between the Ridgeley Member and the black shales of the Middle Devonian Marcellus Formation. The Onondaga occurs as a narrow belt in the Hollidaysburg and Everett study areas. It is a dark-gray and greenish shale, some of which may be calcareous. These shales are interstratified with layers of thin-bedded, dark-gray limestone and shaly limestone (Figure 7).

Berg *et al.* (1986) subdivided the Onondaga of central Pennsylvania into Selinsgrove Limestone and the Needmore Shale for the region east of the study area. Ver Straeten (1996) replaced the name Onondaga with that of the Needmore Formation of Willard (1939) for central Pennsylvania. Ver Straeten then subdivided the Needmore Formation into the Selinsgrove, Hare Valley, and Beaverdam members. The term Onondaga is retained here for the radargeological unit between the Old Port and Marcellus; however in the field, shales of Needmore and limestones of the Selinsgrove can be observed.

MIDDLE DEVONIAN MARCELLUS FORMATION

Tioga Ash Bed Zone

Brown micaceous bentonite shales that regionally occur near the top of the Onondaga and the base of the Marcellus have been extensively studied (*e.g.*, Fettke, 1952; Dennison and Hasson, 1976; Dennison and Textoris, 1978; Conkin and Conkin, 1984; Way *et al.*, 1986). These have been interpreted to be of volcanic origin (*e.g.*, Fettke, 1952; Dennison and Hasson, 1976, Dennison and Textoris, 1978). Originally designated the "Tioga Bentonite" by Fettke (1952) while drilling for oil and natural gas in Pennsylvania, the "Tioga" was reported by Dennison (1961) throughout the Valley and Ridge province of the central Appalachians. A

summary of regional stratigraphic and petrologic analyses of the Tioga bentonite within the Valley and Ridge from Tennessee to Pennsylvania was presented by Dennison and Textoris, (1978), who proposed an eroded igneous terrane near Fredericksburg, Virginia as a possible source for the Tioga eruptions.

Way *et al*. (1986) refined the "Tioga Bentonite" of Fettke into at least 6 or more separate layers or laminae. The bentonite layers exposed at this field stop were highlighted by Way *et al*. (1986). These workers gave special emphasis to the Tioga ash layers as time markers to better view time-trangressive characteristics of Onondaga carbonate-bearing rocks and Marcellus clastic rocks. Ver Straeten (1996) noted a 390 ±5 Ma age for the Tioga ash beds in his report on the Lower and Middle Devonian strata of the central Appalachian basin in Pennsylvania.

The radar contacts of the Old Port, Onondaga, and Marcellus formations are mapped through this field locality (see the Radargeologic Map of the Hollidaysburg 15-minute quadrangle on the Conference CD-ROM). The field contact of the Old Port (*i.e*., Ridgeley) and Onondaga is represented by a narrow ravine at this site (Figure 8).

STOP 4. ***ONONDAGA FORMATION (RADARGEOLOGIC UNIT DON) AND MARCELLUS FORMATION (RADARGEOLOGIC UNIT DM) AT THE INACTIVE FRANKSTOWN SAND QUARRY.*** A thin but distinct slope-forming radar unit is identified in the field as olive-gray to black shale with interbeds of limestone. The unit is the Onondaga Formation, and it is well exposed towards the base of the south-facing quarry wall. It is comprised of gray shale with interbeds of limestone. The gray shale is believed to belong to the Needmore Formation (*e.g*., Ver Straeten, 1996). The limestone interbeds are believed to represent the Selinsgrove Limestone (*e.g*., Ver Straeten, 1996).
The contact of the Onondaga with the underlying Ridgeley Member is constrained between two closely-spaced outcrops. It is believed that a little digging will expose the contact.

The term Marcellus Formation (Hall, 1839) in Pennsylvania traditionally has been applied to all lower Hamilton Group organic rich black shale facies. The Marcellus (black shale) Formation is exposed near the top of the quarry wall. Note the distinct "poker-chip" character where the Marcellus has weathered. Tioga bentonite beds are especially well exposed in quarry walls and were described at this site by Way and Smith (1986).

Arrive 11:15A

LUNCH BREAK (~11:30P)

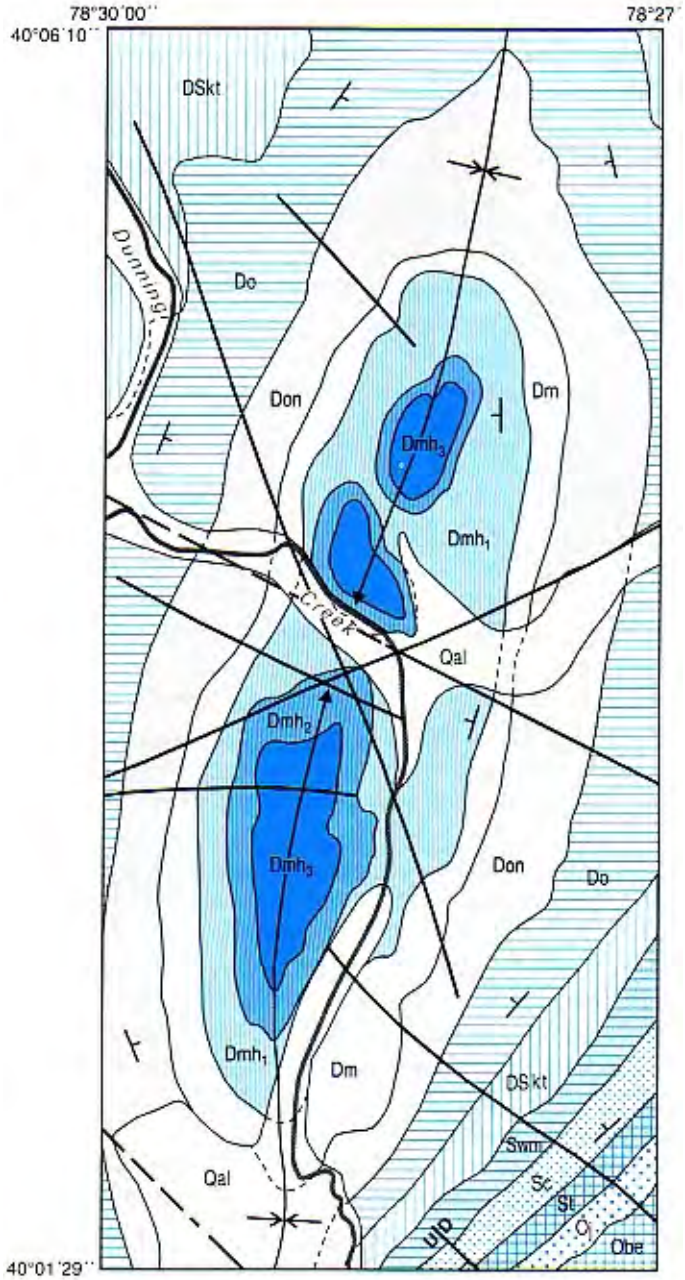


Figure 5. Enlargement of part of the geologic map derived from SLAR imagery of the Everett area (from Altamura, 2000). The structural basin shown is in the western half of the Everett West 7.5-minute quadrangle. Map explanation is provided on the adjacent page.

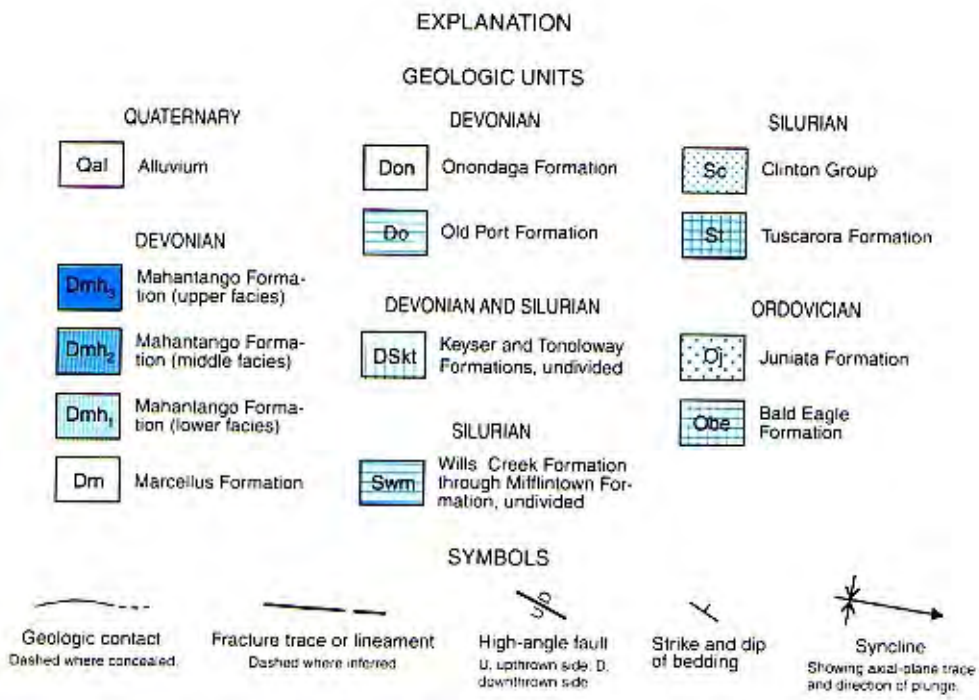


Figure 6. Lower Devonian Ridgeley Sandstone of the Old Port Formation near Frankstown, Pennsylvania. The "Ridgeley" is most probably responsible for the well-expressed ridge on side-looking airborne radar imagery. The ridge helps define the closure of the Frankstown basin (or doubly plunging syncline). Although the Old Port is subdivided into five members (Berg *et al*., 1986), it is the Ridgeley that is most consistently mappable in central Pennsylvania. At this locality, past quarrying has enhanced exposures. The quartz sandstone is friable here, perhaps due to partial dissolution of a calcite cement. The sandstone was excavated for the purpose of producing refractory bricks (Fail *et al*., 1989) and possibly silica sand, as for example, the U.S. Silica Company has done at Mapleton Depot.

Figure 7. Contact of the Onondaga and Marcellus formations revealed in a quarry face at an inactive sandstone quarry near Frankstown, Pennsylvania. The Marcellus occurs towards the top of the outcrop, and the Onondaga towards the base. Darker layers within a zone of alternating dark and medium gray layers within the Marcellus represent some of the "Tioga ash beds."

Figure 8. Contact between the Lower to Middle Devonian Onondaga Formation and the underlying Middle Devonian Ridgeley Sandstone at the inactive sandstone quarry near Frankstown, Pennsylvania. Although the foliage obscures a perfect view of the contact, only several feet separate outcrops of the two units. A change in texture and tone as well as a break in slope between the units is portrayed clearly on the SLAR image.

Stop 5. ***MIDDLE DEVONIAN MAHANTANGO FORMATION (RADARGEOLOGIC UNIT DM) EXPOSED IN MRS.***

KINNEY'S FLOWER GARDEN OFF OF SANDBANK ROAD. This slope-former is interpreted to be the Gander Ridge Member of the Mahantango Formation. Based on the SLAR signature alone it is not distinguishable from the SLAR signature alone from the Marcellus. The rock is olive-gray shale. It possesses a fissile character that results in the distinct "poker chip" weathering, which is recognizable elsewhere in the basin. At the top of the slope, the ridge is underlain by a coarser-grained facies (siltstone/sandstone) which may be the Chaneysville Siltstone Member (equivalent to the Montebello sandstone in eastern Pennsylvania).

Arrive: 12:15P

STOP 6. ***MAHANTANGO FORMATION (RADARGEOLOGIC UNIT DMH$_1$) EXPOSED IN CUT NEAR SANDBANK ROAD.*** This outcrop is located on the opposite side (northeast) of the same ridge as the previous stop. The bedrock is dominantly comprised of a fine-grained sandstone/siltstone, which is noticeably massive. It is interpreted to be the Chaneysville Siltstone Member of the Mahantango. In a few places the bedding is disrupted by kink folds that reflect a vergence compatible with the major 1st order fold in the Hollidaysburg quadrangle: the Frankstown structural basin.

Fractures include minor faults and strike-parallel and cross-strike joints (Figure 9). It is interesting to note that cross-strike fractures tend to possess plumose fan textures whereas strike-parallel fractures do not. The intersection of a closely-spaced cleavage and bedding has resulted in tectonic lithons or "pencils" up to 1 m in length (Figure 10). These occur within *Dmh1* at other localities, but have not been observed in the other coarse-grained clastic units in the study area.

Arrive: 12:30A

Leave Hollidaysburg area: ~1:00P.

Arrive in Everett field area: about 2:00P

RADARGEOLOGY OF PORTIONS OF THE EVERETT 15' QUADRANGLE

Everett Structural Basin, Everett Quadrangle

RADARGEOLOGICAL UNITS IN OUTCROP

STOP 7. ***MARCELLUS FORMATION (RADARGEOLOGIC UNIT DM) AND THE MAHANTANGO FORMATION (DMH$_1$) ALONG RABBIT LANE ROAD NEAR THE VILLAGE OF YOUNT.*** The Marcellus and Mahantango formations are exposed in a borrow pit. The rather distinct fissile character of bedding in this dark-gray shale slope-maker should be familiar. At the top of the slope, a ridge is underlain by a coarser-grained sedimentary rock (siltstone/sandstone) that we will observe in outcrop shortly. Carbonaceous black shale at the base of the outcrop is characteristic of the Marcellus shale. This "poker chip" character is similar to *Dm* in the Frankstown basin and

correlation of units between the two basins is implied. *Dm* is believed to be equivalent to the Marcellus Formation and the Gander Ridge Member of the Mahantango Formation.

The ridge is capped by the coarser-grained unit that is mapped as radargeologic unit Dmh_1. This rock is predominantly comprised of fine-grained sandstone/siltstone which is noticeably more massive and not fissile. Dmh_1 is correlated to the Chaneysville Siltstone Member of the Mahantango Formation.

Dmh_1 is cut by two sets of joints whose intersections with partings along the bedding have generated tectonic "pencils" that are similar and comparable in size (1-m lengths) to those found in Dmh_1 in the Hollidaysburg map area.

Arrive: 2:15P

STOP 8. ***RADARGEOLOGIC UNITS DMH2* AND *DMH3* IN THE CORE OF THE FOLD NEAR YOUNT.** This site is on the eastern limb of the 1st order fold (wavelength greater than 10 km) that defines the Everett basin. The site is approximately 300 meters east of the fold axis and dips are gentle to the west. A shale and massive fine-grained sandstone are exposed along the south side of a broad E-W trending valley. The shale and sandstone represent radargeological units Dmh_2 and Dmh_3, respectively. The valley cuts across the strike of the formations and is relatively linear. No faults are exposed., and the feature is referred to as the Rabbit Farm lineament after, you guessed it, a nearby rabbit farm.

Unknown fossil. Unusual cylindrical forms that cut across the gently dipping bedding surfaces in the shale facies are inferred to be of biological origin. They appear to be filled-in holes (Figure 11). These features are numerous with more or less concentric ridges that have an cross-sectional outline that is more elongate than circular. They seem to be widely distributed and are believed to be some sort of ichnofossil. Elsewhere in the study area *Zoophycus* is a characteristic ichnofossil in the Mahantango.

Dmh_2 is correlated to the Frame Shale of the Mahantango Formation, and Dmh_3 is possibly equivalent to the Clearville Siltstone of that unit. The Clearville is the equivalent of the Montebello sandstone elsewhere in Pennsylvania (see Berg *et al*., 1986).

Arrive: 2:45P

Figure 9. Exposure of radargeological unit Dmh_1 of the Middle Devonian Mahantango Formation along Sand Bank Road near Frankstown, Pennsylvania. The rock type ranges from siltstone to a fine-grained sandstone. It is interpreted to be the Chaneyville Siltstone Member. The high-angle fracture is oriented 355/90 and exhibits an east-down sense of displacement based on bedding markers and drag.

Figure 10. "Tectonic pencils" up to one meter in length occur within radargeological unit Dmh_2 of the Middle Devonian Mahantango Formation (Chaneysville Siltstone Member) near the village of Yount. "Pencils" are formed by the intersection of planes of parting along bedding and a closely-spaced cleavage that is pervasive throughout the study area. Tectonic pencils of similar length and appearance are found in the equivalent radargeological unit within the Frankstown basin.

Unknown fossil. Unusual cylindrical forms that cut across the gently dipping bedding surfaces in the shale facies are inferred to be of biological origin. They appear to be filled-in holes (Figure 11). These features are numerous with more or less concentric ridges that have an cross-sectional outline that is more elongate than circular. They seem to be widely distributed and are believed to be some sort of ichnofossil. Elsewhere in the study area *Zoophycus* is a characteristic ichnofossil in the Mahantango.

Dmh_2 is correlated to the Frame Shale of the Mahantango Formation, and Dmh_3 is possibly equivalent to the Clearville Siltstone of that unit. The Clearville is the equivalent of the Montebello sandstone elsewhere in Pennsylvania (see Berg *et al*., 1986).

Arrive: 2:45P

(A)

(B

(C)

Figure 11. Unusual cylindrical forms (fossil, trace fossil, or concretion?) within radargeological unit *Dmh*$_2$, which is interpreted to represent the Frame Shale member of the Middle Devonian Mahantango Formation. Locality is along Chalybeate Road near the village of Yount

STOP 9. ***RADARGEOLOGIC UNITS DMH2 AND DMH3 IN ROAD-CUT ALONG CHALYBEATE ROAD.*** This locality is close to the core of the NNE-trending fold axis of the elongated basin. The bedrock here is a dark-gray fissile shale with a pervasive penetrative cleavage that results in some pencil shape lithons. The shale contains large 6-cm spiroid brachiopods characteristic of the Middle Devonian facies in New York State. Crinoids and streptolasma coral have also been found. Unidentified tubular and ellipsoidal concretions (?) also occur. *Dmh2* is considered to be the Frame Shale member of the Mahantango Formation as is the shale at the previous stop.

Fold axis. The bedding attitudes are near horizontal at the western end of this long outcrop because this is near the location of the 1st order fold axis of the basin.

Radargeologic unit *Dmh3*, another fine-grained sandstone/siltstone, was mapped at the top of the ridge on the basis of float and topographic expression. The radargeologic unit possesses distinctive textural and tonal variations on the imagery. It is correlated to the Clearville Siltstone member of the Mahantango Formation.

In places thin beds of limestone including coquinites occur within the shale. The Tully Limestone, which is near this position in the stratigraphic column, is a possible candidate.

Arrive: 3:15P

STOP 10. ***RADARGEOLOGIC UNIT DMH2 ALONG YOUNT ROAD SOUTH OF IMLERVILLE.*** Here is one last look at the variation in this unit. The shale bedrock making up the slope at this locality has been excavated (presumably for road metal), and a vertical cliff face of several meters exposes the unit. This clastic sedimentary rock is highly fossiliferous. It is interpreted to be the Frame Shale Member of the Mahantango Formation.

Fossil collecting. The fossiliferous hash is suggestive of an ancient beach environment. As at Stop 8, we are not far below the contact with *Dmh3*. The fossil hash may be correlative with the coquinites found at Stop 8. Fossils found include spiroid brachiopods, crinoids and streptolasma coral. The Middle Devonian guide fossil *Mucrospirifer mucronatus* (Conrad) is a common fossil and occurs in large numbers. This spiriferid is recognized by its mucronate cardinal extremities and its low fold and shallow sulcus. Happy hunting.

Arrive: 4:15P

RETURN TRIP : 4:45P

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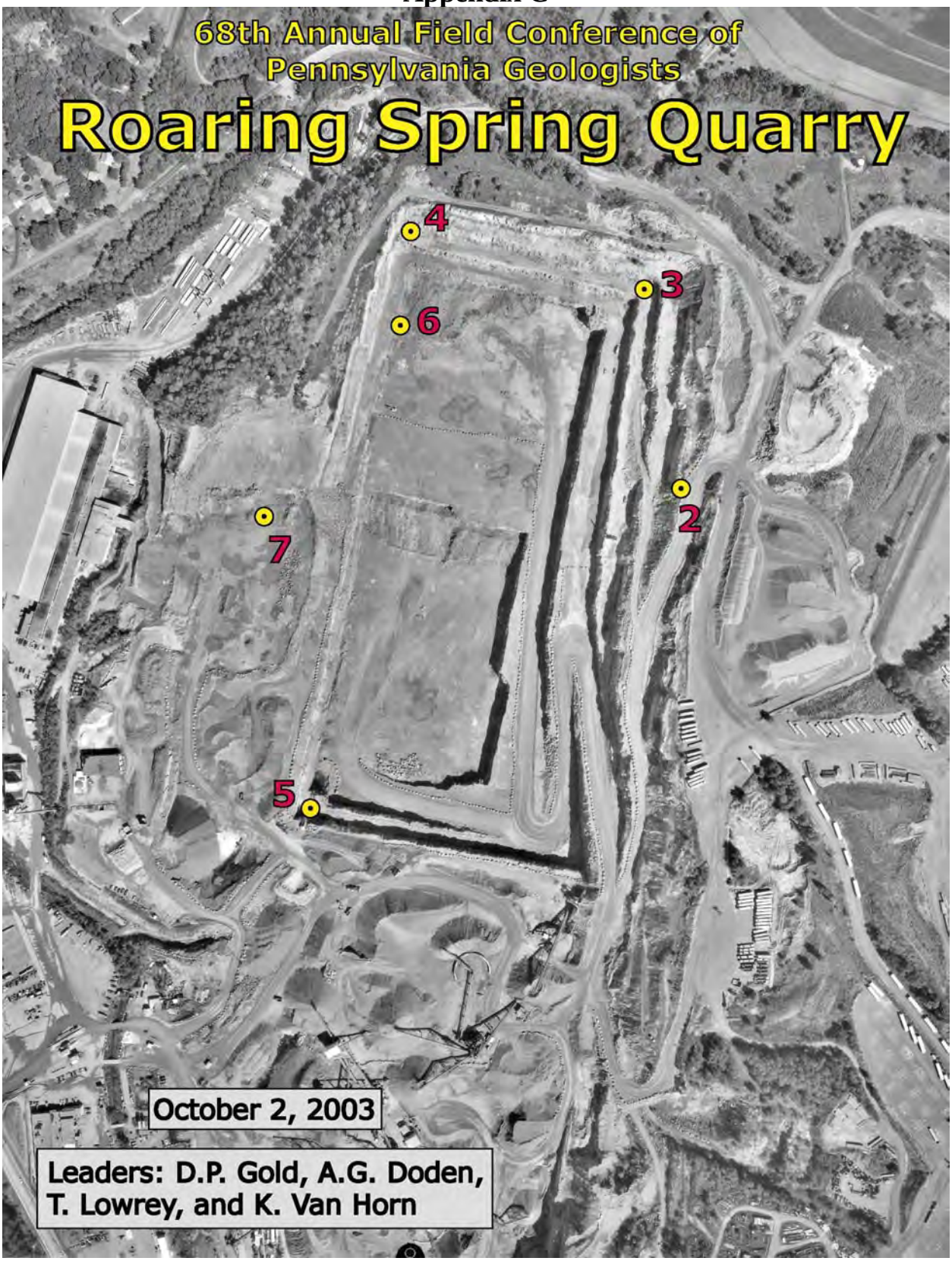
Appendix C



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FIELD TRIP GUIDE TO ROARING SPRING QUARRY

by

David P. Gold, Arnold G. Doden, Todd A. Lowrey and Keith Van Horn

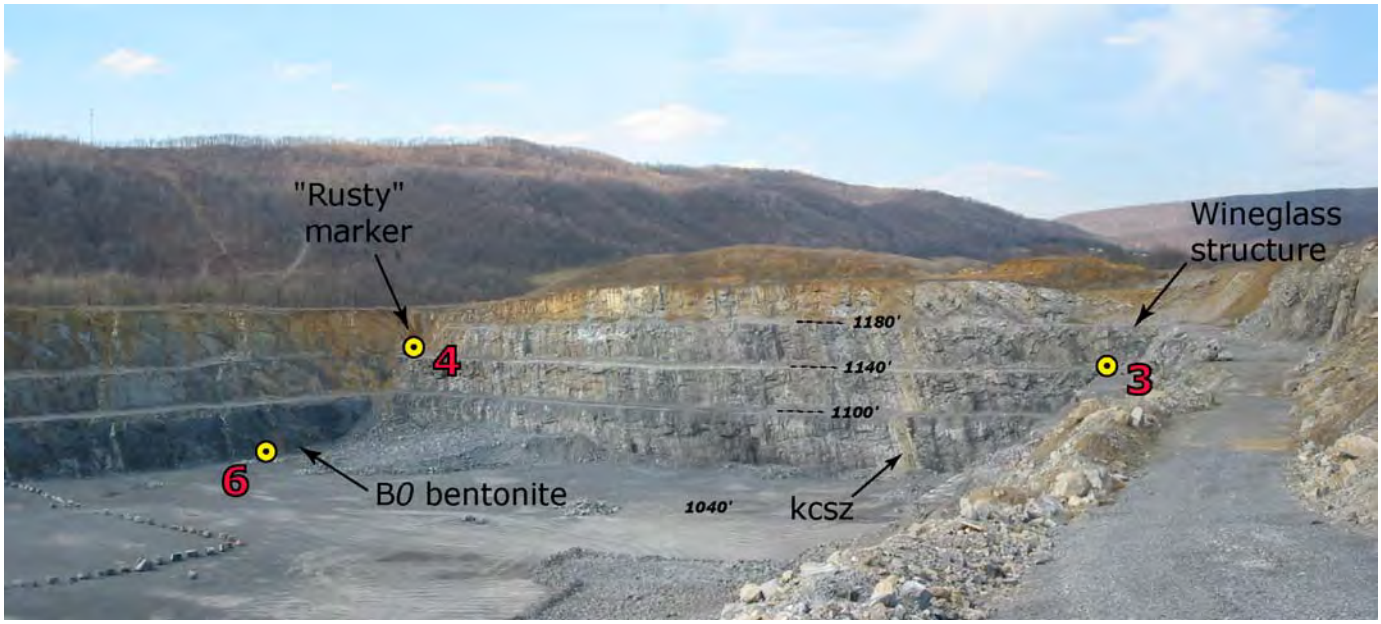

Figure 1. Panoramic view of the north end of the Roaring Spring quarry showing the B 0 bentonite and the "rusty" marker in the Loysburg Formation, the khaki-colored stromatolite zone (kcsz) approximately 400 feet above the base of the Bellefonte Formation, and the "wine glass" structure carrying Axemann strata over steeply dipping Bellefonte. (Photograph taken July, 2003).

INTRODUCTION

The Roaring Spring quarry lies within the northwest corner of Morrisons Cove, a strategic location in central Pennsylvania for a major aggregate producer. Owned by New Enterprise Stone and Lime Co., Inc. since 1930, the Roaring Spring operation produces annually approximately 1.8 million tons of aggregate, and 200,000 tons of limestone, suitable for co-generation power plants. The town of Roaring Spring is well known for its namesake, a 6 million-gallon-per-day natural spring whose flow and quality is closely tied to the local geology.

GEOLOGIC SETTING

The Roaring Spring area lies within the Valley and Ridge structural setting, due east of Dunning and Short Mountains. The quarry is developed on the northwest limb of an asymmetric, closed, overturned anticline, plunging 21º/041º (Lowrey, 1993). This 2nd order anticline represents the major structure in this part of Morrisons Cove (Figure 2). The core has been breached to expose Ordovician and older formations in the valley to the south, with Silurian clastic rocks comprising the bounding mountain ridges. Near the northern closure of the anticline, a thrust fault ramps Ordovician Axemann strata over the Bellefonte Dolostone. Three other low-angle thrust faults to the south of Roaring Spring carry elements of the upright eastern limb over progressively older rocks exposed in the core. A lineament of unknown origin traverses the Roaring Spring area (Figure 2) and crosses the town at approximately the location of the Spring.

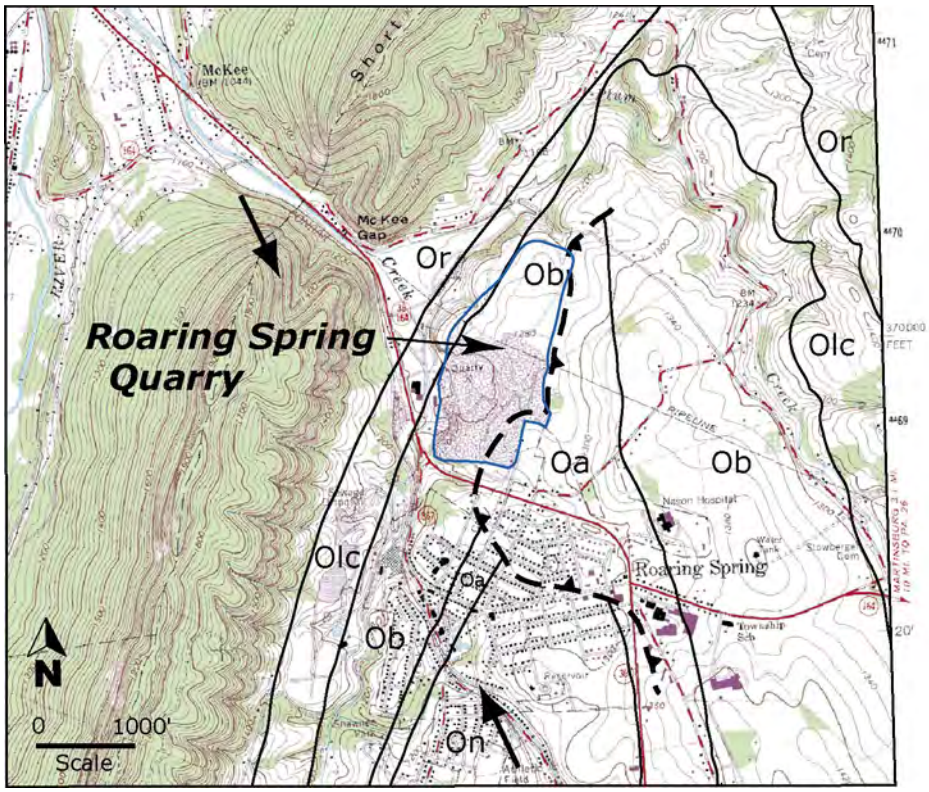

Figure 2. Geologic map of the northwestern part of Morrison's Cove. The present-day outline of the Roaring Spring Quarry is shown by the blue line. Opposing arrows indicate approximate position of lineament. (Key to symbols in Figure 3).

GEOLOGY OF THE QUARRY

The local stratigraphic column consists of Ordovician limestones and dolostones (Figures 3 and 4). Cambrian age rocks (Mines, Gatesburg, and Warrior formations) that form the core of the anticline are exposed farther south of Roaring Spring on Ore Hill Ridge and beyond. The quarry has been developed in steeply dipping (030º/70º) beds from the Salona down to near the base of the Bellefonte formations. These overturned beds expose the lower beds of the Bellefonte Dolostone near the unexposed core of the anticline to the east of the southeast quarry wall. Relatively shallow dipping (350º/24º), cyclically interbedded limestone (bioturbated grainstone) and dolostone (finely laminated dololutite) of the Axemann Formaton crop out in the Route 36 road-cuts to the southeast and in isolated patches along and to the east of the southeast wall. These isolated outcrops are interpreted as klippe to account for the temporal and spatial discordance (Gold, 1993). The small thrust slice that carries Axemann strata over the hinge zone of the fold is shown in Figure 2, and conceptually in the cross-section (Figure 4).

Although the Axemann is oldest formation exposed in the quarry it is not in correct stratigraphic position. The formation typically is 180 feet thick and consists of cyclical interbeds limestone and dolostone. A typical cycle consists of medium- to coarse-grained, dark gray coquina, overlain by bioturbated calcilutites and finely laminated light gray to buff dololutite. These 8-15 feet thick cycles are interpreted to represent a peritidal/tidal depositional environment. Some of the beds contain nodular chert. High spired gastroods and crinoids have been recovered from the bioclastic linestones, and vugs in these and the micritic limestone beds have yielded crystals of calcite and fluorite.

The large quarry is developed mainly in rocks of the Bellefonte Formation, 870 feet of which can be seen in the northeast high-wall on the 1140 ft bench. These consist mainly of 5 to 15 feet thick cycles of light to dark gray fine-grained dolostones. At least 8 cycles of coarse-grained bioturbated dolostone (pisolitic-textured grainstone), grading upward to light gray fine-grained dolostone, that occur near the base represent a change to Nittany-type lithology. A wormy textured dolostone bed with dispersed, irregular clasts of chert is used locally as a marker. This vermicular chert marker bed, 2-3 feet thick, can be seen on the 1140 ft bench near station 250. Another marker, identified as the khaki colored stromatolite zone (kcsz) (Figures 1 and 3) is exposed near station 600. A main zone 8-9 feet thick (Figure 11b), is composed of thinly bedded silty limestone and dolostones, some bedded chert and large (meter scale) stromatolite heads (Figure 8a). However, the "rusty" weathering extends over approximately 50 feet of stratigraphy.

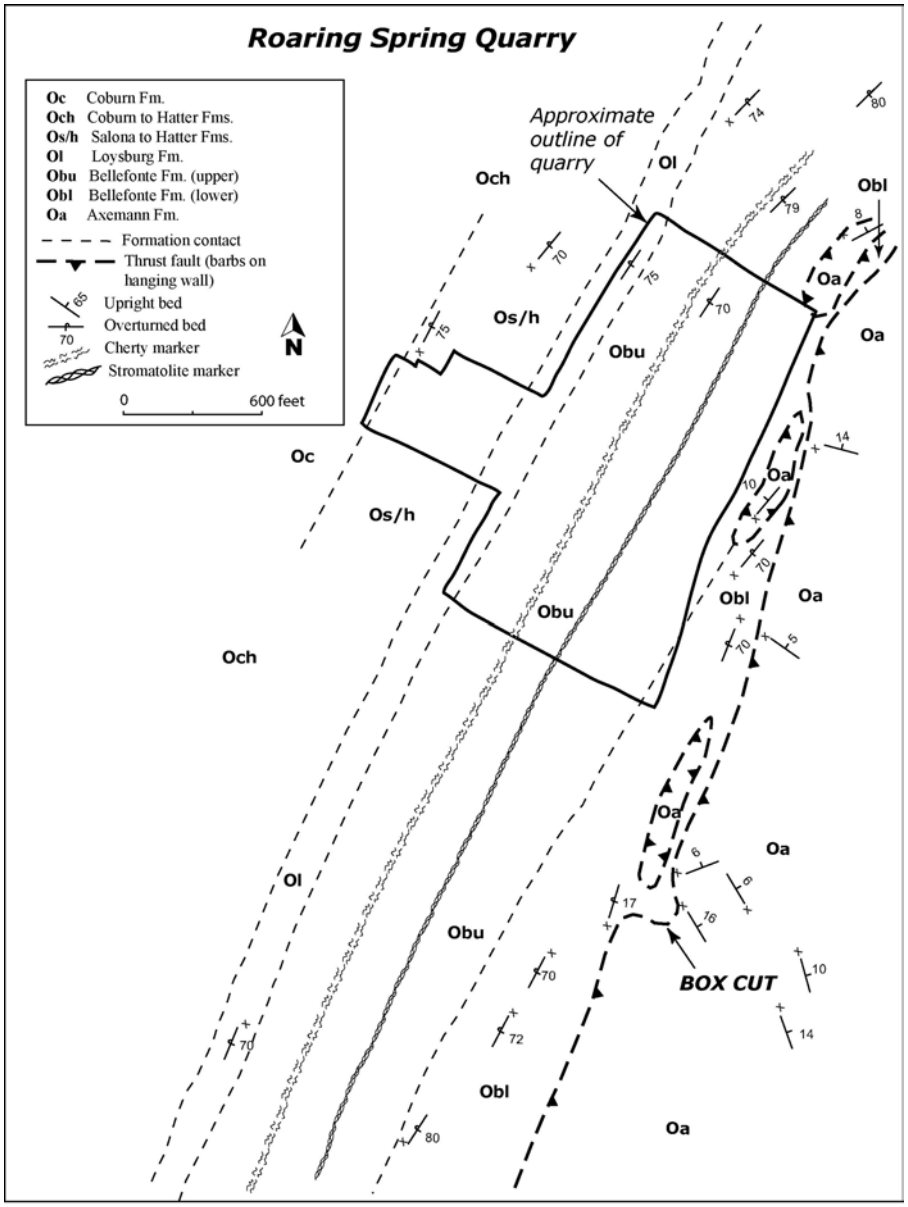

Figure 3. Detailed geologic map of the Roaring Spring Quarry. (Updated from Lowrey 1993).

The Bellefonte dolostones grade into the overlying Loysburg Formation (Milroy Member) with the appearance of a few meter-scale limestone beds. For mining purposes the contact is taken as the 4-ft thick rusty/silty limestone marker approximately 50 feet above the thin (5-10 cm) B*0*? bentonite bed (Figure 10a). Perhaps the contact should be taken as the base of a poorly developed bed 2 feet thick with internal cm-scale limestone/dolostone layers (a poorly developed "tiger stripe" rock) that occurs 23 feet stratigraphically below the bentonite. However, the subtleness of this "tiger stripe" bed and the paucity of limestone in the section below the bentonite makes this an awkward and impractical criterion for field use.

Another 600 feet of Middle Ordovician limestones to the base of the Coburn Formation is exposed on the 1140 ft bench to the west of the main quarry. The change in composition also is reflected in the nature of the quarry operation (from an aggregate and crushed stone operations, to high quality limestones, suitable for co-generation plants, blast furnaces and agricultural lime). The formations successively

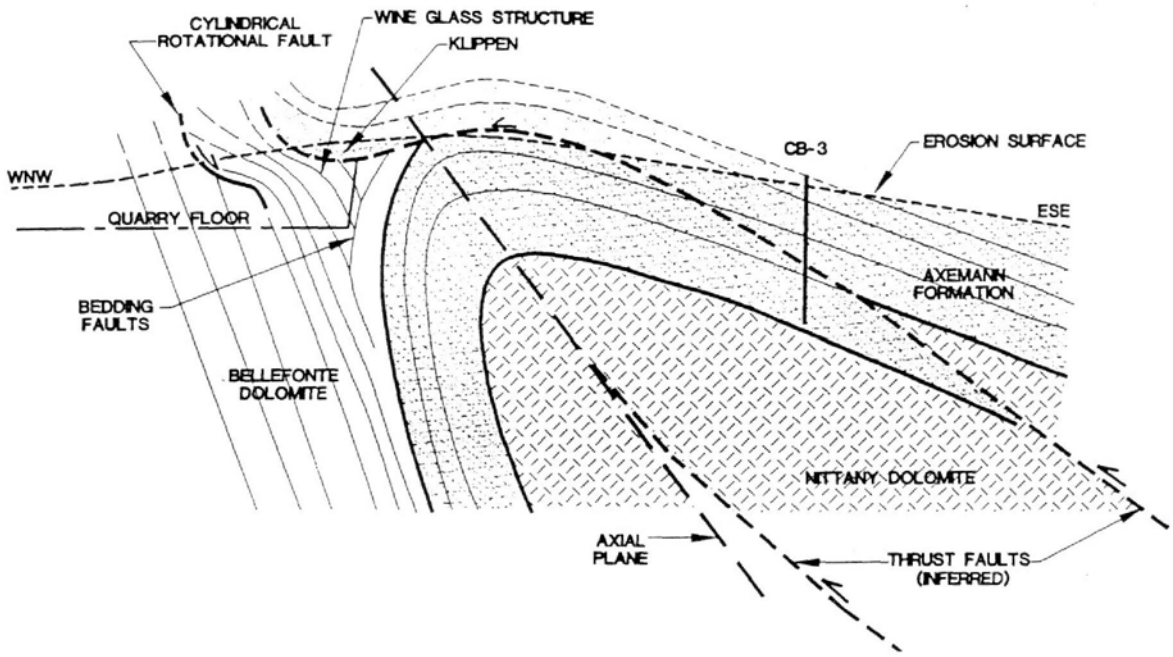

Figure 4. Cross-section of the Roaring Spring anticline, showing a low angle thrust fault duplicating the eastern limb, with Axemann strata over-riding the hinge zone. Note the thickened section of Axemann strata in drill hole CB-3. (From Gold and Lowrey, 1993).

exposed are Hatter, Snyder, Linden Hall, Nealmont, Salona and Coburn. Not all the bentonites mapped at Union Furnace have been recognized in the Roaring Spring Quarry. Only the B11, B12, B13, B14, B15,and B16 are exposed and serve to demarcate the boundary between the Nealmont and Salona formations (Figure 5).

STRUCTURAL GEOLOGY

The dominant structure is the overturned Roaring Spring anticline, plunging 21º northeast (see Figure 7a for geometric properties). The relatively flat-lying Axemann strata exposed in the northeast corner on the 1180 ft (upper) bench has the form of an open syncline, as do similar isolated patches to the south (see Figure 3). These discordant Axemann units overlie steeply dipping beds of Bellefonte Dolostone in the hinge zone of the Roaring Spring anticline. This temporal and spatial discordance is interpreted as a thrust slice ramping off the upright limb (Figure 4) that has been eroded to leave behind the small *klippe* shown in Figure 3.

Apart from this 2nd order Roaring Spring anticline and associated macroscopic scale thrust fault, all of the other structures mapped were mesoscopic scale features that did not appear to extend far from the host outcrop. The style of these local structures (faults, joints, calcite- and dolomite-bearing veins and tension cracks) is non-penetrative. This observation is reinforced by the remarkable paucity of water in the quarry despite steep gradients in the adjacent ground-water table.

Several faults were mapped in the north high-wall. In general, the westerly dipping faults are reverse in sense with displacements ranging from a few inches to only several feet. Some of the easterly dipping faults are dip-slip normal; others are low angle reverse faults (Lowrey, 1993). Many faults have transgressive curved surfaces, reflecting a cylindrical rotational component. Bedding faults are common along the east wall, exhibit slip vectors that are approximately perpendicular to the axial line of the Roaring Spring anticline. A flexural-slip mechanism is evoked for these bedding faults; the other mesoscopic scale

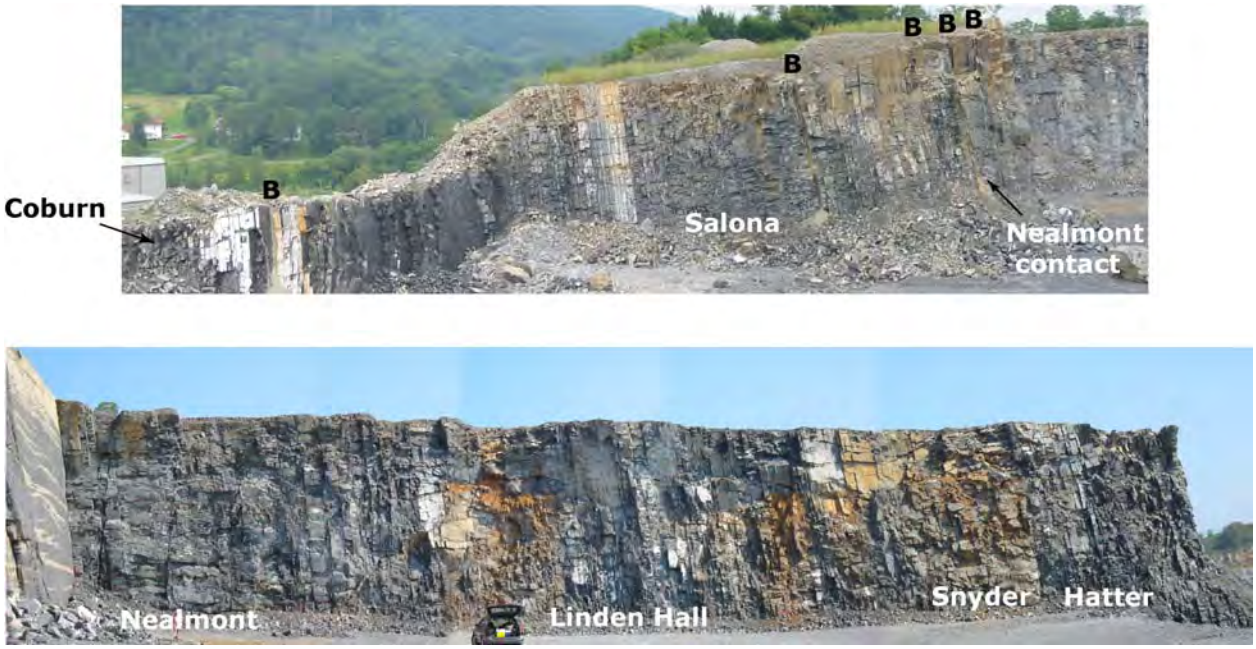

Figure 5. Panoramic view of the "co-gen quarry" wall looking north-northeast. Formations exposed are Coburn (extreme left) to Hatter (extreme right). Photograph taken August, 2003.

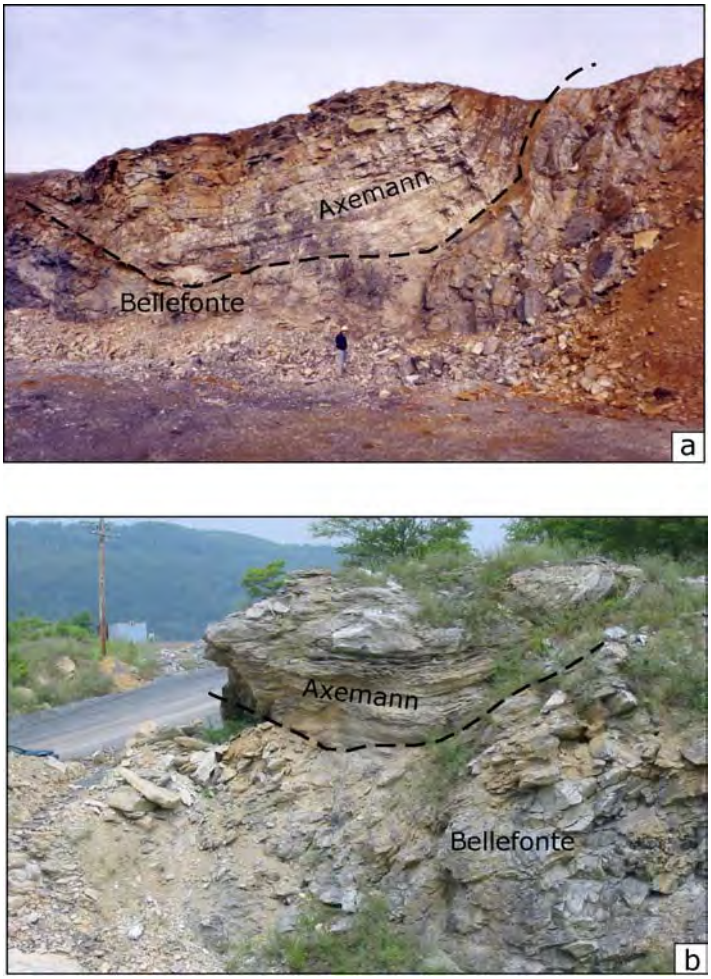

Figure 6. (a) "Wine glass" structure in the northeast corner of the quarry (photograph taken in 1994). (b) Outcrop exposed in box cut, southeast corner of quarry, showing strata of the Axemann Fm. thrust over the Bellefonte Fm (photograph taken in 2003).

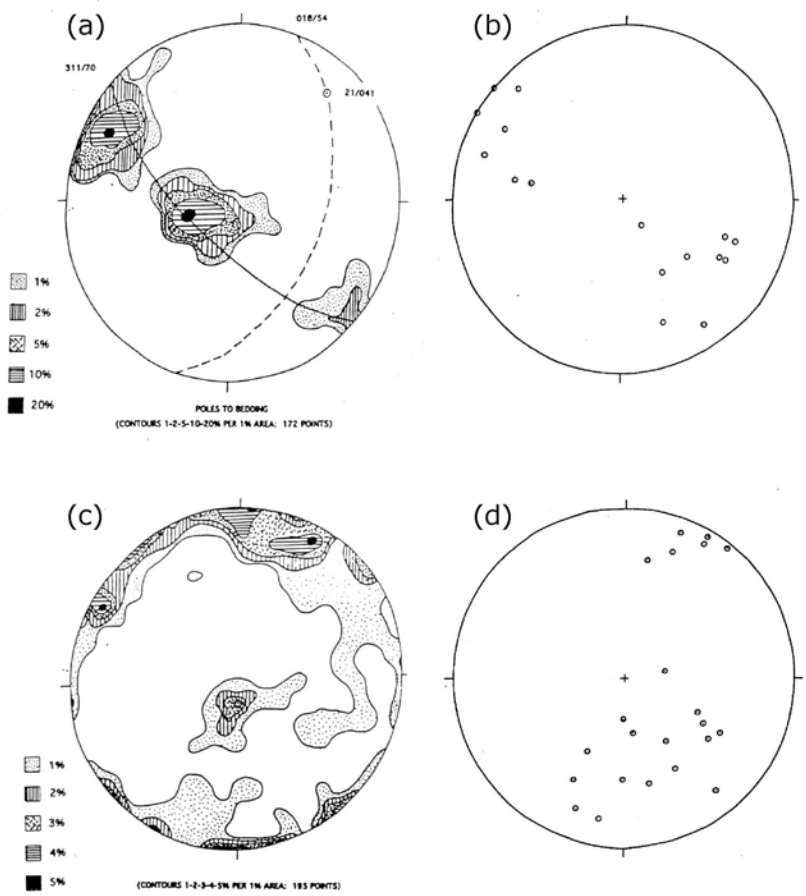

Figure 7. Orientation diagrams for structures in the Roaring Spring Quarry (from Lowrey, 1993): (a) Contoured S-pole diagram of bedding surfaces; (b) S-pole diagram of faults (16 points); (c) Contoured S-pole diagram of joint surfaces; (d) S-pole diagram of calcite veins (22 points).

faults in the hinge zone probably represent the space accommodation problem associated with concentric folds. The attitude of some of the faults is shown in Figure 7b.

Small displacement wedge faults are common (Figures 8b and 9). Most of these verge to the west and show a sense of footwall underthrusting from the southeast when rotated to a horizontal upright attitude. The antithetic nature implies a stress couple similar in nature to flexural slip deformation and may be fold-related. Conversely, they may reflect an unusual form of an early layer parallel shortening event. Another similar and possibly related structures are the small displacement ramps that originate as bedding faults, change direction and break through one or more beds and terminate into another bedding fault. In similar manner to the wedge faults the sense of these is compressional underthrusting. In contrast there are a number of small displacement, northerly dipping faults with stratigraphic offset to both east and west. One such fault at Stop 6 (260º/58º with slickenlines plunging 54º NNE) offsets the *Bo* bentonite 3 feet to the east (Figure 10b). The rusty marker, beneath the sump pump at Stop 5, is offset by a similar amount but in the opposite sense (Figure 8c).

The dominant joint sets are reported by Gold and Lowrey (1993) as 118º/80º, 076-094º/90º, 026º/8º, and 040-062º/90º and are depicted spatially in Figure 5c (after Lowrey, 1993). A sheeting joint set apparent in the upper benches dips 15-30º to the north and is clearly the latest structure to develop. Calcite veins are ubiquitous, but occur in greatest concentration in the hinge zone along the eastern wall. Their dominant orientations are 030º/45-55º and 115º/68-80º (see Figure 5d, after Lowrey, 1993).

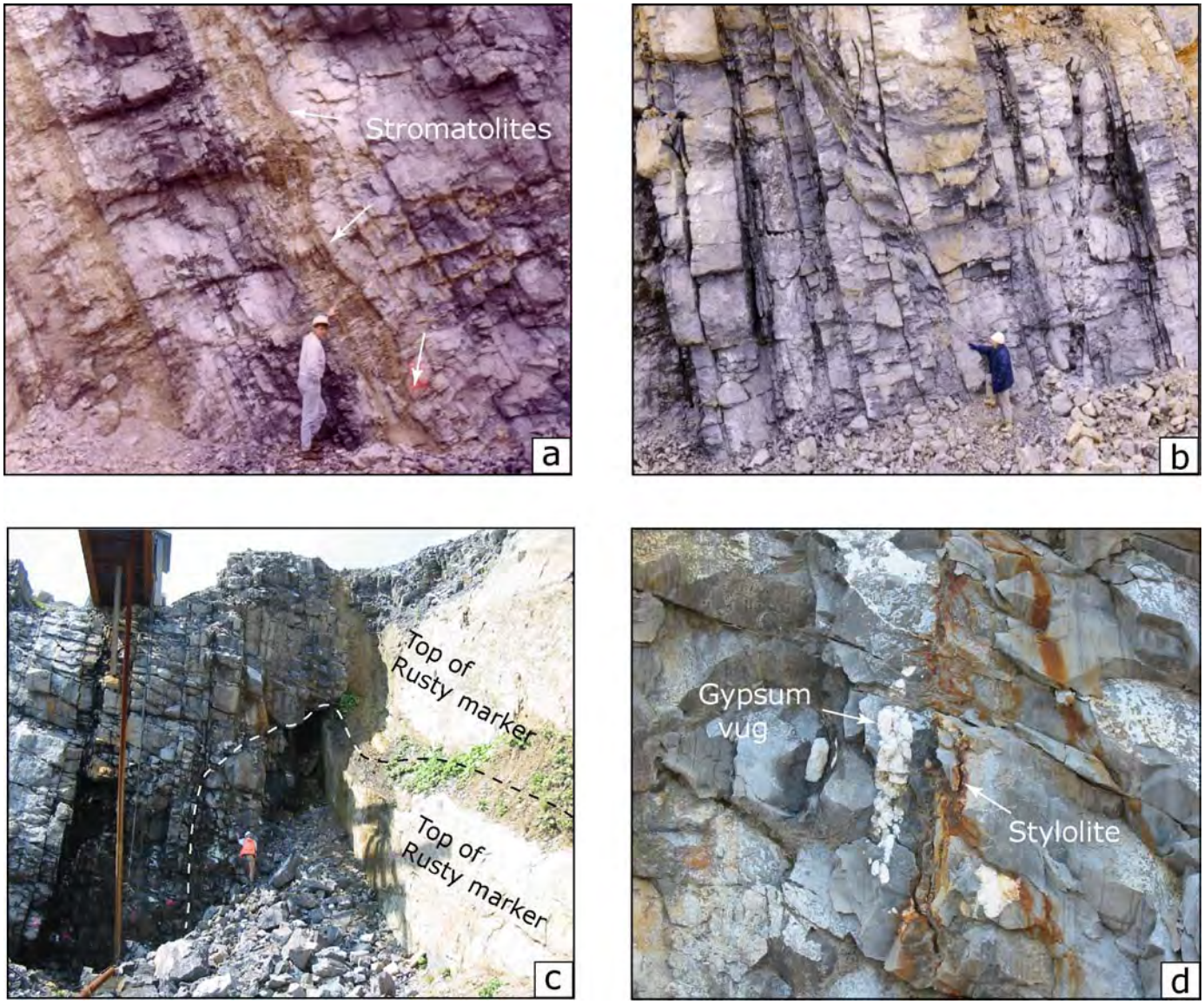

Figure 8. (a) Stromatolites at base of khaki colored stromatolite zone (kcsz); (b) wedge faults in north highwall; (c) Trace of bedding ramp fault (dashed line) near stop 5 below sump pump, displacing rusty marker 3 feet westward; (d) Rusty stain from oxidizing pyrite in stylolite, near stop 5 in lower Loysburg Formation. Photographs (a) and (b) taken in 1994; (c) and (d) taken in 2003.

Stylolites are present in most of the units exposed, particularly in the interbedded limestones and dolostones of the Loysburg Formation. They range from millimeter to many decimeters in intercusp distance, with corresponding amplitudes in the millimeter to centimeter range (Figures 8d and 11a, c, and d). Transgressive stylolites are very rare. Most of the bedding parallel stylolites host insoluble residues (some with shale) that may be up to 5 cm thick. These act as aquicludes. Bedding parallel stylolites are inferred to have formed by dissolution due to superincumbent vertical load while the beds were still horizontal, i.e., prior to folding. The transgressive stylolites reflect a change in the maximum principal stress axis during deformation.

Figure 9. Multiple wedge faults in Hatter Formation on Bench 1140, near Stop 7. View to the north-northeast, photograph taken August, 2003.

The fold and associated mesoscopic scale structures are ascribed to Alleghenian deformation (Butts, 1963; Faill et al., 1989). Most of the mesoscopic scale structures are related to "space accommodation" in the core of an evolving anticline. Although the veins, joints and some faults are clearly post folding phenomena, the wedge and small displacement ramp faults are expected to have formed while the beds were still in a horizontal position (i.e., pre-initiation of folding). The sheeting joints appear to associated with stress relief due to erosion.

ACCESSORY MINERALOGY

Although high-quality carbonate rocks are the focus of quarry operations at Roaring Spring, an impressive array of accessory minerals has been discovered in the pit over the years. Some general quarry localities are described below, but these are taken primarily from Gold et al. (1993). Quarry size and configuration has changed since the time of that publication. Geyer et al. (1976) reported the presence of calcite, celestine, dolomite, fluorite, goethite, kaolinite mineral group, pyrite, quartz as agate and black chert, sphalerite, strontianite and zircon. Dolomite, calcite (satin spar and dog tooth spar), strontianite, celestite and fluorite have been reported in the vugs and veins in the Milroy Member of the Loysburg Formation, which forms the western highwall of the main quarry. Similar mineralization has been reported (Joseph Dague, pers. comm., 2002) along the southeast bench of the quarry, where limestone and dolostone of the Axemann Formation are fractured and sheared in the hinge zone of the Roaring Spring anticline (Gold et al., 1993). Sphalerite occurs as orange-brown blebs in silicified dolomite beds (Geyer et al., 1976) in the northeast high-wall. In the northwest part of the quarry microcrystals of rutile, zircon, apatite and biotite occur in metabentonites exposed in the Salona Formation. Wafer thin, fluorescent calcite (flattened perpendicular to the c-axis) has been found in the lower Bellefonte Formation, near the southeastern part of the quarry (Gold et al., 1993). Gypsum, much of which has been replaced by calcite, occurs in the vugs in the Upper Bellefonte and Lower Loysburg beds. These statabound vugs probably represent thin pockets of evaporite during deposition of the host dolostone (Figures 8d, 10a, and 12).

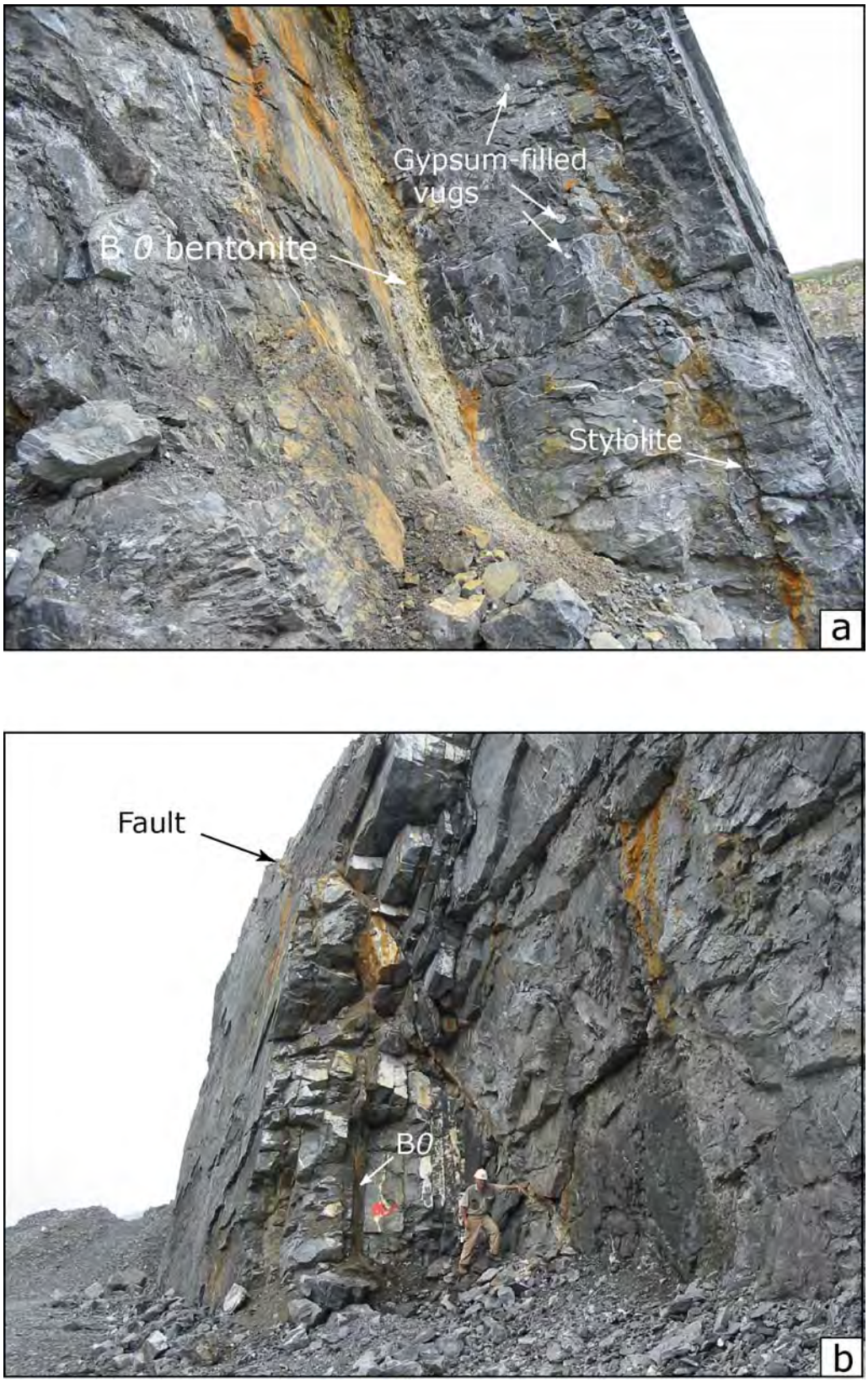

Figure 10. (a) Bentonite B *0* at Stop #6, northwest corner of quarry. (b) Bentonite B *0* exposed north of previous location (along strike). Geologist is pointing to a fault that cuts the bentonite. Photographs taken August, 2003.

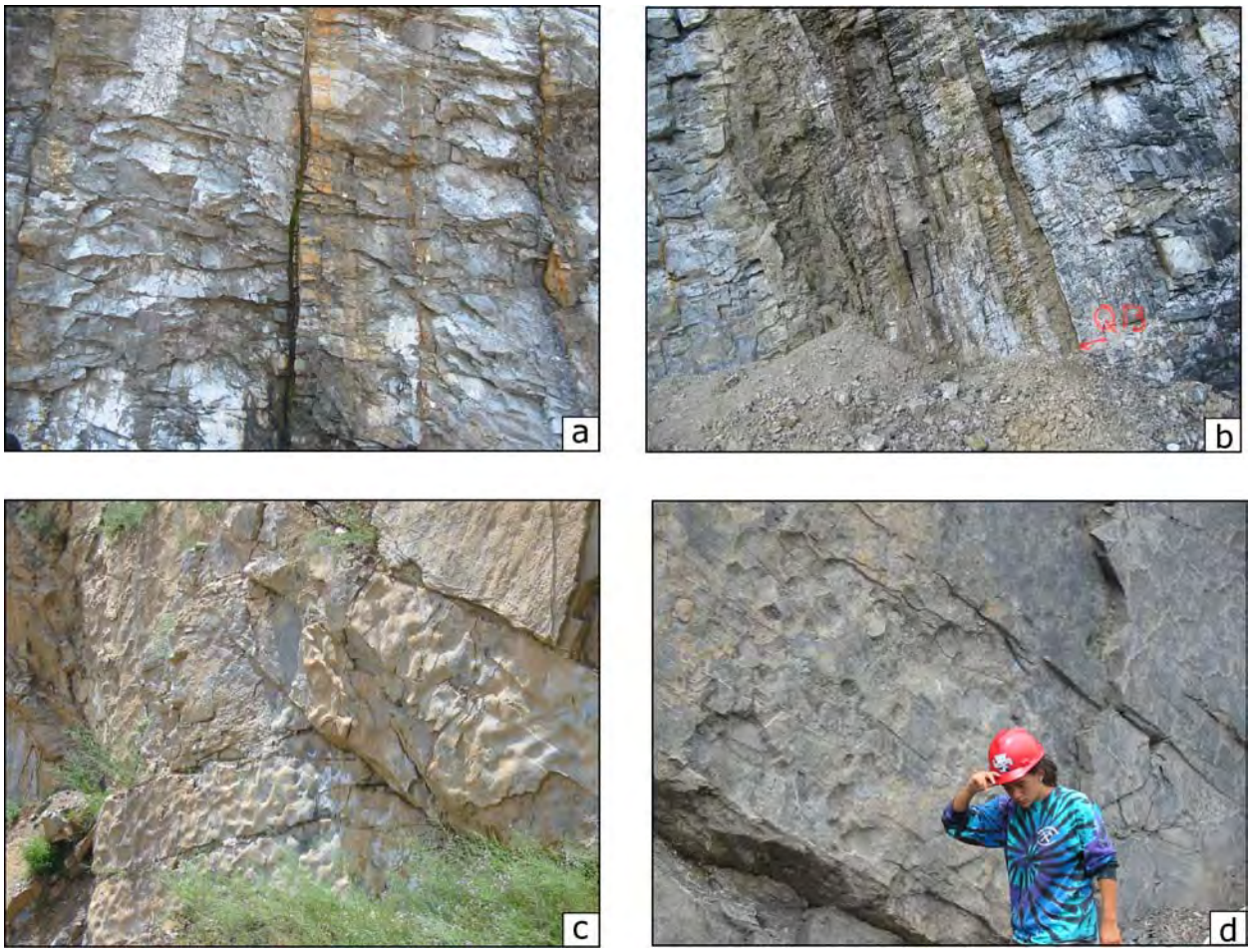

Figure 11. (a) Stylolites, dark colored layer is insoluble residues. (b) Khaki colored stromatolite zone (kcsz), station Q13 on 1100' bench, north wall of quarry. (c) Bedding surface of "mega-stylolites". (d) Bedding surface showing mud cracks and "mega-stylolite" cusps in the Loysburg Formation. Photographs taken July, 2003.

QUARRY PRODUCTION

The Roaring Spring quarry was acquired by New Enterprise Stone & Lime Co. from Snowberger & McGee in 1930. At that time the quarry face was only 200 feet long and 60 feet high (Miller, 1934). Two stone lime kilns were used to burn approximately 500 tons per year for local farm use. A gyratory crusher at the quarry produced 10,000 tons of crushed stone a year (Miller, 1934).

From the present day size of the pit it should be apparent that the production of aggregate and other products far exceeds the 1930 output. The Bellefonte dolostone is the mainstay of the aggregate operation in 2003. It is used as high density cement aggregate in the manufacture of molded products, bituminous aggregate, road base and agricultural aggregate (Faill et al., 1989). The Roaring Spring quarry produces annually approximately 1.8 million tons of dolostone aggregate. Higher in the stratigraphic section limestones from the Hatter through Nealmont formations are mined for high-grade material suitable for use in co-generation power plants. Currently production of limestone is approximately 200,000 tons a year.

ACKNOWLEDGEMENTS

We thank the management of New Enterprise Stone and Lime Co., Inc. for permission to conduct the field trip in the Roaring Spring quarry. ***Note that unauthorized mineral collecting is not allowed in the Roaring Spring quarry.***

Figure 12. Large drusi-form vug, partially replaced by calcite. Upper-most Bellefonte Formation. Photograph taken August, 2003.

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Appendic D
THE HOLLIDAYSBURG FISSURE BONE DEPOSIT

Shirley Fonda, Ph.D. State College

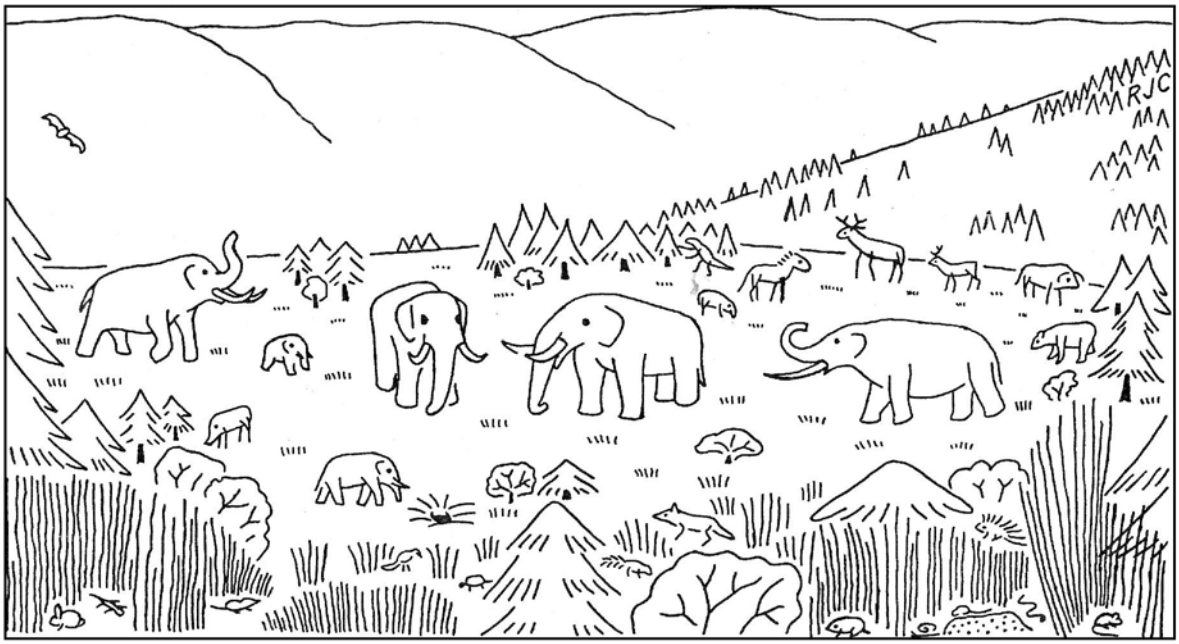

Figure 1. Artist's rendition of the Frankstown hilltop during late Pleistocene time (Cuffey et al., 1976).

INTRODUCTION

The excavation of a fissure in a quarry near Frankstown, Pennsylvania provides a record of the numerous animal species which inhabited the area in the late Pleistocene period. Changes in the types of species and numbers of individuals at levels throughout the 40-foot column reflect probable transitions between a boreal and a more temperate environment.

THE SITE

A fissure in an abandoned quarry in a hill between Hollidaysburg and Frankstown, Blair County, Pennsylvania has yielded abundant bones of late Pleistocene age (Figure 2). The quarry is one of a series in Catfish Ridge which trends northeast. It lies in the westernmost part of the Valley and Ridge Province, immediately adjacent to the Allegheny Plateau. Mid-Paleozoic shales, limestone, and sandstone were thrusted and folded in the late Paleozoic Allegheny Orogeny and were later eroded to form the present landscape.

The quarry is shown on the USGS Frankstown Quadrangle 7.5-minute series topographic map near 40°26'40"N and 78°21'30"W. It consists of gray limestone of the late Silurian/early Devonian Keyser Formation, gently sloping southeastward. The limestone contains many fossils of coral, bryozoa, brachiopods, and algae.

Fonda, S., (2003) The Hollidaysburg Fissure Bone Deposit, *in* Way, J.H. and others, eds., Geology on the edge: selected geology of Bedford, Blair, Cambria, and Somerset Counties, Guidebook, 68th Annual Field Conference of Pennsylvania Geologists, Altoona, PA, p. 224 - 240.

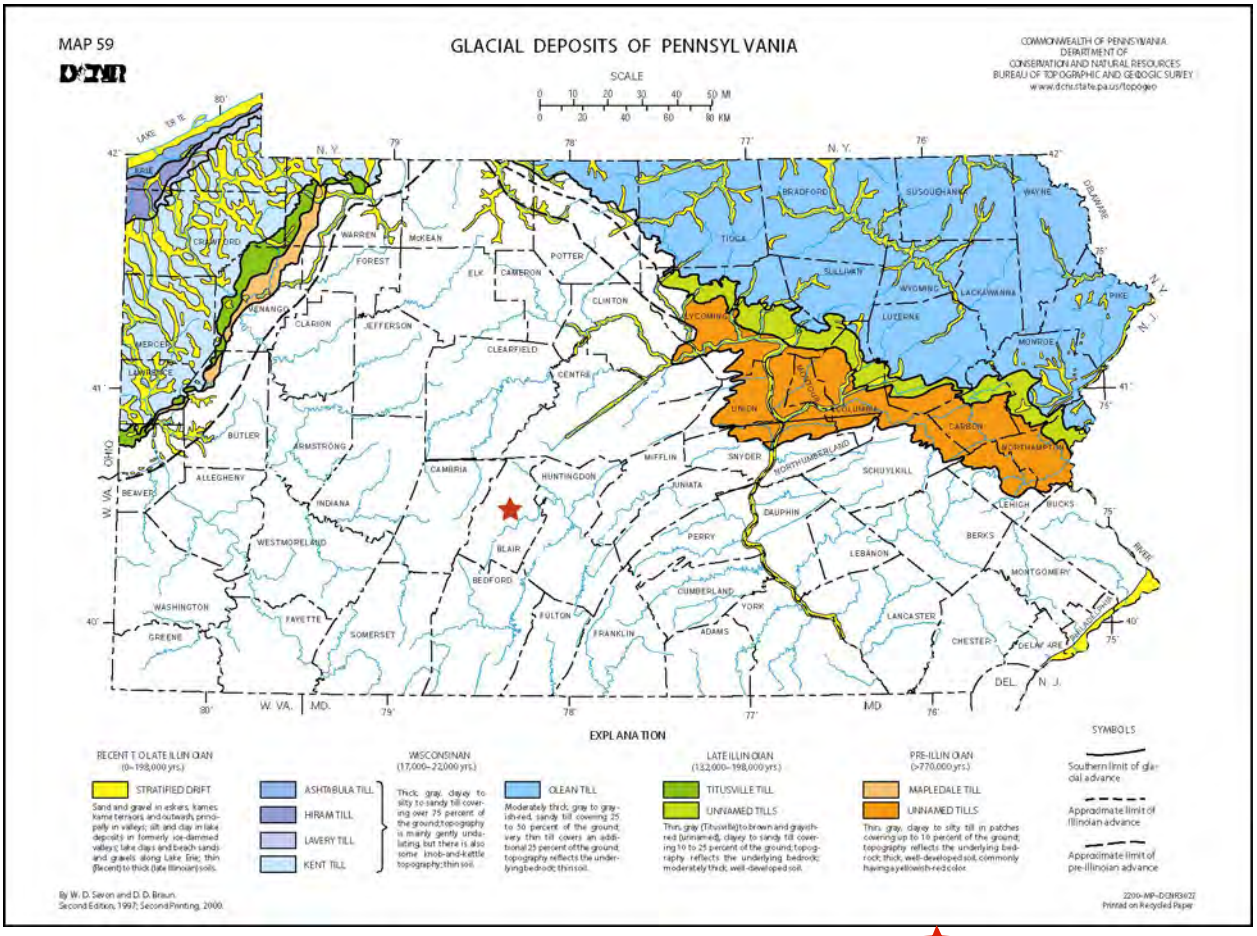

Figure 2. Map showing the southern extent of the glaciated region in Pennsylvania (★ = Hollidaysburg fissure).

The fissure is a vertical opening on the southeast wall of the quarry approximately 300 feet above the valley floor (Figure 3). It descends at least 40 feet, is 6 feet wide, and extends 18 feet into the quarry wall. Some sediment had eroded from the fissure and accumulated on the quarry floor as a talus cone approximately 15 feet high. The walls of the fissure are covered with a 1- to 2-inch layer of travertine which forms stalactites and longitudinal folds. The travertine is a humic brown color of Sagamon Age (according to William White of the Pennsylvania State University Department of Geology). The fissure was filled with rubble from cave breakdown, red-brown clay, and bits of charcoal. The upper 1/3 of the fissure was filled with large limestone blocks.

The middle section (Figure 4), containing many blocks embedded in red-brown clay, yielded fragments of a young mastodon (dated by amino acid racemization to be 10,000 to 12,000 years B.P.) and numerous smaller animals. The bottom portion was filled with horizontally-bedded, varicolored clays, cave rubble, and well-weathered limestone blocks. Several large pockets of fossils and many individual remains are scattered throughout. At 27 feet, an adjacent small cave was encountered on the front north face of the fissure. It is tear-drop shaped, 10 feet high with a 3 foot diameter floor. Many fossils were tightly packed in this small cave and a wide variety of species was found, including numerous skulls and mandibles, some still articulated. Also, a number of pockets within the travertine drapes contained abundant small vertebrate bones.

Figure 3. Fissure and cave in southeastern wall of quarry, view to the southeast. Photograph by Shirley Fonda, 1982.

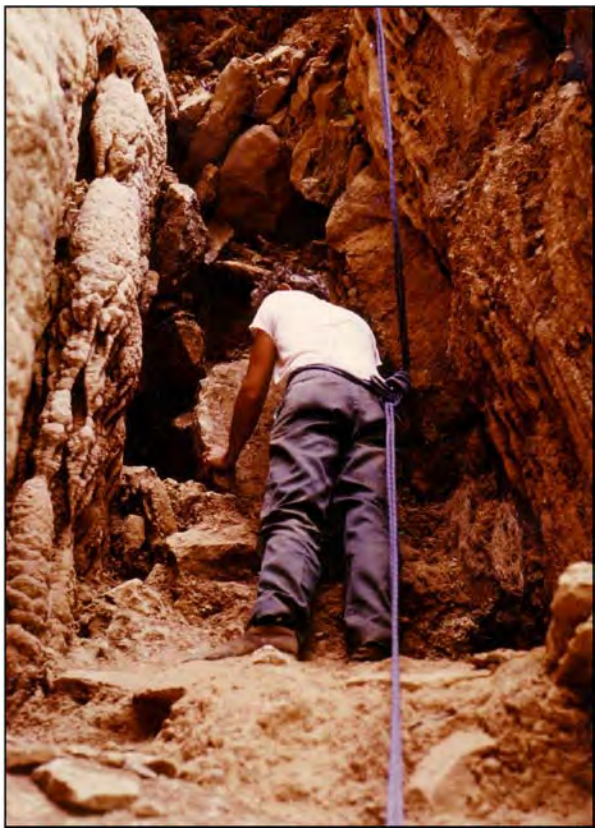

Figure 4. Middle section of fissure with Tom Fonda in the foreground. Photograph by Shirley Fonda, 1982.

The fissure may have originally been open to the top of the hill, providing a natural trap into which animals from the area could accidentally fall. The fissure might also have been a habitat for snails, amphibians, reptiles, birds, small rodents, and insectivores as well as a hibernation place. These groups of animals were observed living at the present time in the cave and there are signs that predators, i.e. foxes, have also used the cave as a den. When they were excavated, some of the bones were found to be rodent-gnawed.

Travertine formation at the top of the fissure suggests the possibility that the fissure might have continued back into the side of the hill. Since the rubble filling this area consists of very large, loosely-packed boulders, it was not safe to explore this possibility.

The area around the quarry is partly old cultivated fields with apple orchards and partly deciduous forest. Many of the animals found in the fissure as fossils are present in the area today. Deer, grouse, foxes, woodchucks, skunks, weasels have been seen in these areas near the quarry. To the east, a branch of the Juniata River runs through the valley at the foot of the hill alongside the small town of Frankstown and swamps fill in low spots between the river and the hill. Fish, muskrat, and beaver might inhabit these areas.

HISTORY OF THE SITE

The fissure was brought to our attention in 1973 when several men from the nearby town of Hollidaysburg were sighting in their rifles in the old quarry. They noticed large bones protruding from a filled fissure in a wall of the quarry and summoned police to the site.

After determining that these were not human bones but of a large fossil animal, Dr. Roger Cuffey, Professor of Paleontology at the Pennsylvania State University, was contacted. He identified the bones as ones from a young mastodon. With several of his students, Dr. Cuffey dug out many of the bones but

stopped the excavation when it was determined that further digging might dislodge the loose overhanging rock. When I later investigated the site, some of the loose rock overhead had fortunately dislodged and fallen out of the fissure. I then spent the next 12 years excavating this fissure with the help of my family, friends, and students from the Pennsylvania State University.

The Carnegie Museum of Pittsburgh, Pennsylvania excavated a Pleistocene bone site from this quarry in 1907. It was probably eventually quarried out but contained many fossils. This site is reported in the literature as the Frankstown Cave. To prevent confusion, we have named our site the Hollidaysburg Fissure.

The Frankstown Cave was 40 feet long, 7 feet wide and up to 12 feet high. The floor was 30 feet above the floor of the quarry and was covered with two feet of red clay mixed with limestone rubble, travertine, and bones. There was no evidence of an opening to the surface of the hill but the upper part of the cave was filled with blocks of limestone cemented together with cave calcite. The entrance of the cave through which the animals entered was probably collapsed and sealed. Fossils of wolves, birds, snakes, frogs, bats, bear, bison, deer, musk ox, peccary, tapir, sloth, mastodon and small rodents were found. Many of the bones were broken by falling rock and no articulated skeletons were found.

There are also a number of small caves in the southeast wall of some of the nearby old quarries but no bones have been found in the sediment on the floor. Perhaps some of these caves had once been connected to each other but no evidence of that has survived subsequent quarrying operations.

A present-day quarry at the north end of the series of abandoned quarries may expose new fissures in the future that could contain bones.

PROCEDURE

The excavation of the fissure began with making a mark 17 feet from the top of the fissure and 28 feet from the top of the hill. It was at this level that the mastodon jaw was located and therefore where our excavation began. A nail was driven into the side of the fissure and a black line was spray-painted adjacent to the nail. Similar lines were sprayed on the wall at two-foot intervals as we dug through the matrix. This allowed us to describe the enclosed material in each two-foot level.

Bones were carefully removed from the clay with small trowels, picks and fingers. The clay was tossed out onto the talus and the bones were carefully wrapped in newspaper to be taken back to our home base in State College, Pennsylvania. Often the great abundance of small bones in the sediment necessitated bringing the matrix back in buckets to be screened later for bones.

A number of ingenious methods were used to remove large rocks from the clay. Using crowbars, car jacks, pick axes and logs (for leverage), we managed to free or break up these rocks and get them out onto the talus.

When several snakebone layers were encountered, an effort was made to keep skulls, jaws, and adjacent vertebrae together. Dr. J. Allan Holman of Michigan State University had made a key to identify many species of snakes by their vertebrae and this will be used in an attempt to identify the jaws and skulls after identifying the vertebrae.

The matrix brought back in buckets was set out on window screens and gently sprayed with water to remove the clay. Upon drying, the bones were picked out and placed on other screens to be sprayed, along with the large bones already removed from the site with polyurethane spray.

The bones were identified by comparisons with drawings in Mammalian Osteology by B. Miles Gilbert, skeletons in the Smithsonian and Carnegie Museums, and skeletons we retrieved from roadkills. John E. Guilday, paleontologist at Carnegie Museum, set up a reference collection of a number of species for my use. Clark Olson of the Smithsonian Institute helped with bird identification and musk ox teeth were identified by Gerald H. McDonald. The minimum number of individual animals in a species was determined using skull and jaw material.

An assessment was made of possible size differences between fossil and recent individuals. Post-cranial material was identified as much as possible.

Specimens were catalogued and stored by stratigraphic levels. The mastodon bone was dated and it is hoped that bones from the lowest level of the fissure will be dated in order to determine the length of time the fissure was being filled.

Samples of the clay/soil were taken and processed for pollen analysis.

TABLE 1

FAUNAL LIST FROM THE HOLLIDAYSBURG FISSURE

MOLLUSCA
- **GASTROPODA**

ARTHROPODA
- **INSECTA**

CHORDATA
- **PISCES**
- **AMPHIBIA**
  - **URODELA** (Salamanders/Newts)
  - **ANURA** (Frogs/Toads)
- **REPTILIA**
  - **CHELONIA** (Turtles)
  - **SQUAMATA**
    - *Lampropeltis triangulum* (Eastern Milk Snake)
    - *Coluber constrictor* (Northern Black Racer)
    - *Heterodon platyrhinos* (Eastern Hognose)
    - *Crotalus cf. horridus* (Timber Rattlesnake)
    - *Agkistrodon contortrix* (Copperhead)
    - *Thamnophis sirtalis* (Common Gartersnake)
- **AVES**
  - **ANSERIFORMES**
    - *Anas sp.* (Teal)
    - *Mergus sp.* (Merganser)
  - **STRIGIFORMES**
    - *Bubo sp.* (Great Horned Owl)
  - **PICIFORMES**
    - *Dendrocopos sp.* (Hairy Woodpecker)

MAMMALIA
- **INSECTIVORA**
  - **TALPIDAE**
    - *Parascalops breweri* (Hairy-tailed Mole)
    - *Condylura cristata* (Star-nosed Mole)
  - **SORICIDAE**
    - *Blarina brevicauda* (Short-tailed Shrew)
    - *Sorex fumeus* (Smoky Shrew)
    - *Sorex cinereus* (Masked Shrew)
    - *Microsorex hoyi* (Pygmy Shrew)

CHIROPTERA

VESPERTILIONIDAE

Eptesicus fuscus (Big Brown Bat)
Myotis sp. (Little Brown Bat)

RODENTIA

SCIURIDAE

Marmota monax (Woodchuck)
Citellus tridecemlineatus (13-lined Ground Squirrel)
Tamias striatus (Eastern Chipmunk)
Glaucomys sp. (Flying Squirrel)
Tamiasciurus hudsonicus (Red Squirrel)

CASTORIDAE

Castor canadensis (Beaver)
* *Castoroides ohioensis* (Giant Beaver)

CRICETIDAE

Peromyscus maniculatus (Deer Mouse)
Neotoma floridana (Eastern Woodrat)

ARVICOLIDAE

Phenacomys cf. ungava (Spruce Vole)
Synaptomys cooperi (Southern Bog Lemming)
Synaptomys borealis (Northern Bog Lemming)
Dicrostonyx hudsonius (Collared Lemming)
Clethrionomys gapperi (Red-backed Vole)
Microtus pennsylvanicus (Meadow Vole)
Microtus chrotorrhinus (Rock Vole)
Microtus xanthognathus (Yellow-cheeked Vole)
Pitymys pinetorum (Pine Vole)
Ondatra zibethicus (Muskrat)

ZAPODIDAE

Zapus hudsonicus (Meadow Jumping Mouse)
Napeozapus insignis (Woodland Jumping Mouse)

ERETHIZONTIDAE

Erithizon dorsatum (Porcupine)

LAGOMORPHA

LEPORIDAE

Sylvilagus transitionalis (New England Cottontail)
Lepus americanus (Snowshoe Hare)

CARNIVORA

MUSTELIDAE

Martes americana (Pine Marten)
Mustela rixosa (Least Weasel)
Mustela frenata (Weasel)
Mustela vison (Mink)
Mephitis mephitis (Striped Skunk)

URSIDAE

Ursus americanus (Black Bear)

CANIDAE

Canis latrans (Coyote)

* *Canis dirus* (Dire Wolf)

Canis lupus (Gray Wolf)

Urocyon cinereoargenteus (Gray Fox)

FELIDAE

Lynx sp. (Bobcat)

ARTIODACTYLA

TAYASSUIDAE

***** *Mylohyus nasutus* (Long-nosed Peccary)

CERVIDAE

Cervus elaphus (American Elk)

Odocoileus virginianus (White-tailed Deer)

Rangifer tarandus (Caribou)

* *Cervalces sp.* (Stag-Moose)

BOVIDAE

***** *Bootherium bombifrons* (Wood Musk Ox)

PERISSODACTYLA

TAPIRIDAE

***** *Tapirus cf. veroensis* (Vero Tapir)

EQUIDAE

Equus sp. (Horse)

PROBOSCIDEA

MAMMUTIDAE

* *Mammut americanum* (Mastodon)

* Now extinct

FAUNAL DISCUSSION

Three of my objectives for this project were: 1) to identify the species found, 2) to compare them with their modern counterparts, and 3) to try to interpret the environment existing in that area during that period of time.

Fifty-two species of mammals were identified (Table 1). Six of these species are now extinct -- *Castoroides ohioensis* (Giant Beaver), *Canis dirus* (Dire Wolf), *Mylohyus nasutus* (Long-nosed Peccary), *Cervalces sp.* (Stag-moose), *Bootherium bombifrons* (Wood Musk Ox), *Tapirus cf. veroensis* (Vero Tapir), and *Mammut americanum* (Mastodon).

The identification of *Equus sp.* (Horse) extended the time period it existed in North America before becoming extinct. The species was reintroduced to North America by the colonizing Spaniards.

We collected every fossil found and noted its stratigraphic level. Many other studies of Pleistocene animals have focused on a specific group of animals, generally the small vertebrates, which are a better indicator of the environment. I was interested in studying the entire community in that area at that time and seeing if this community changed through the time period represented by the column.

The upper section of the fissure contained abundant large limestone blocks embedded in red-brown clay. The bones of a young mastodon were scattered in the matrix in this section between depths of 9 and 18 feet (Figure 5) and either fell with accumulating debris or were churned up within the fissure. Beneath this, the clay was stratified and the majority of the fossils were located in the levels between depths of 21 and 38 feet (Table 2). Not only were the greatest number of species (Figure 6) recovered at this depth interval, but also the majority of individuals (Figure 7). These stratified clays with embedded fossils, rock, and bits of

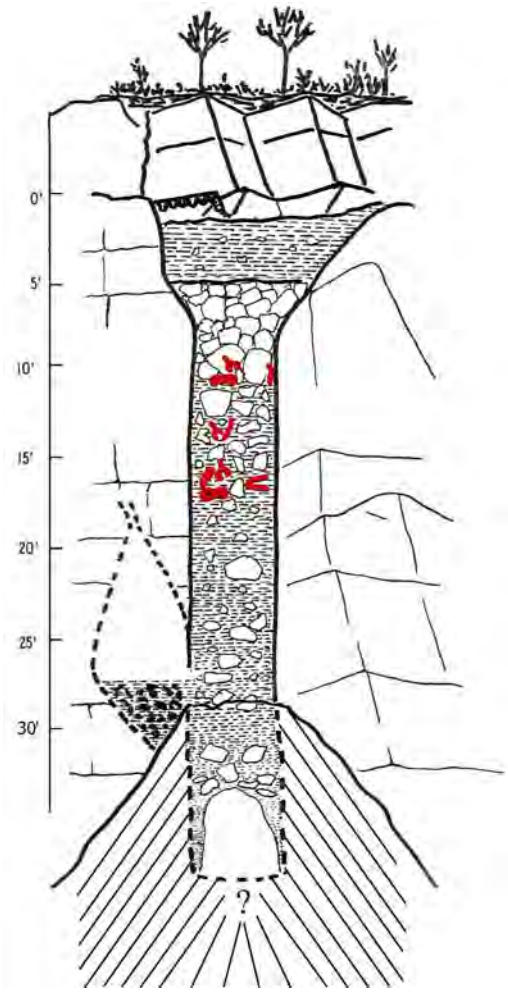

Figure 5. Diagram of the Hollidaysburg fissure showing distribution of Mastodon bones (in red) and the adjacent small cave with bone deposit (in black).

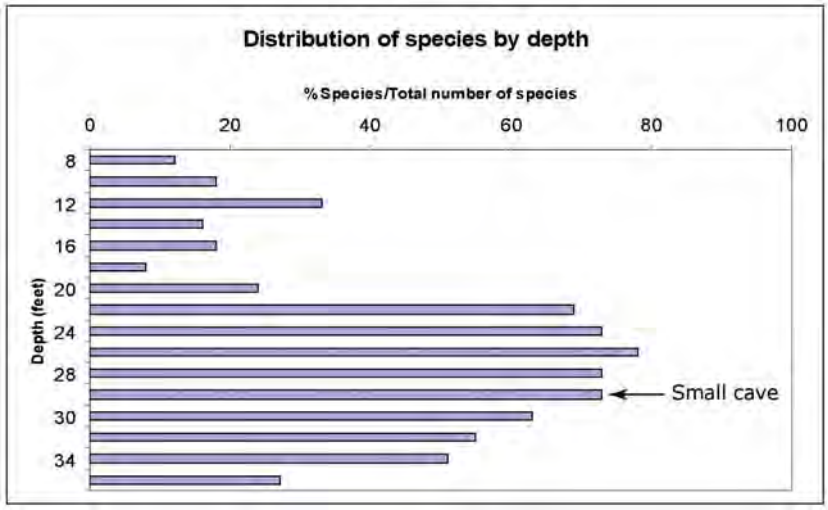

Figure 6. Distribution of species by depth in the Hollidaysburg fissure deposit.

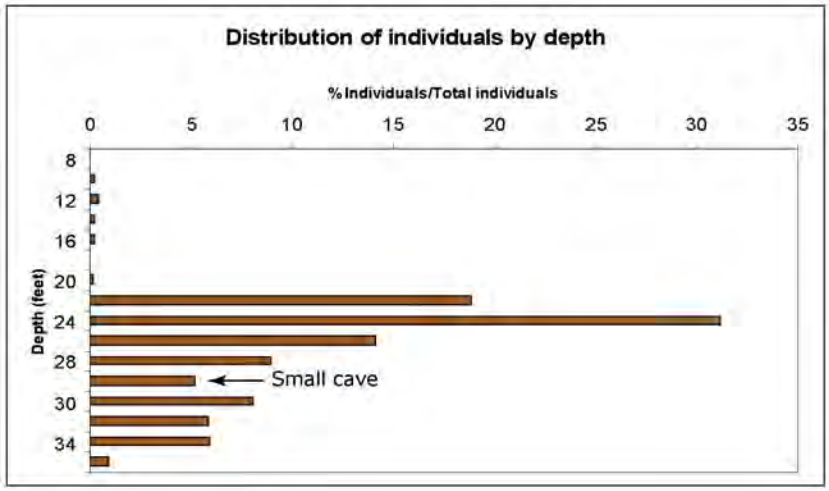

Figure 7. Distribution of individuals by depth in the Hollidaysburg fissure deposit.

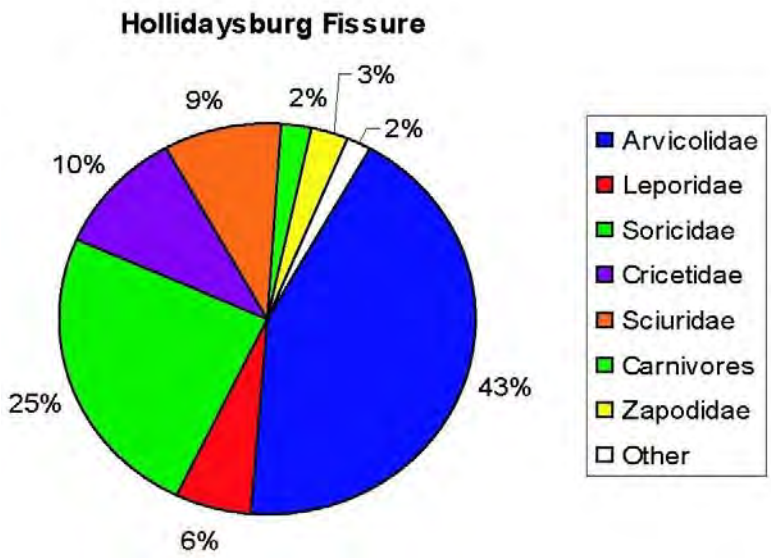

Figure 8. Percentages of major mammal groups in the Hollidaysburg fissure.

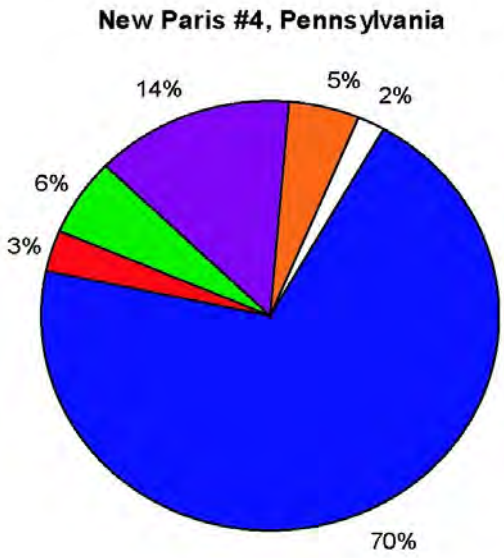

Figure 9. Percentages of major mammal groups in the New Paris, No. 4 site. For color coded legend see Figure 8.

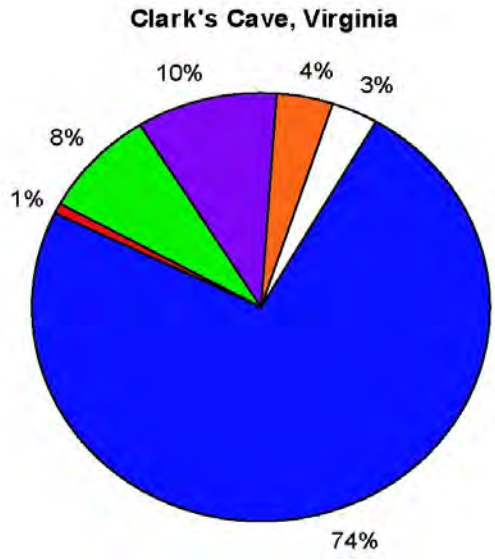

Figure 10. Percentages of major mammal groups in the Clarks Cave site. For color coded legend see Figure 8.

TABLE 2. Mammalian Fauna. Minimum numbers of individuals according to depth in the fissure

MAMMALIAN FAUNA	DEPTH IN FEET																
	7 to 9	*9 to 11*	*11 to 13*	*13 to 15*	*15 to 17*	*17 to 19*	*19 to 21*	*21 to 23*	*23 to 25*	*25 to 27*	*27 to 29*	*small cave*	*29 to 31*	*31 to 33*	*33 to 35*	*35 to 37*	*Total*
Hairy-tailed Mole			1	1				4	8	3	5		8	6	7		43
Star-nosed Mole		1						5	14	6	3	1	2	1			33
Short-tailed Shrew	1	5	2	2	1		1	186	394	137	195	84	248	156	194		1606
Smokey Shrew			2	1	2		1	65	80	31	12	4	8	3	5		209
Masked Shrew								92	154	52	40	10	25	9	22		409
Pygmy Shrew								26	26	13	8	2	3		3		81
Big Brown Bat			1		2			1	1	1	2	2	1		1		12
Little Brown Bat								7	13	10	1	3	4	2	1		41
Woodchuck			2			1	1	17	47	28	21	20	14	9	3	1	164
13-lined Ground Squirrel			2		1		2	14	27	6	6	2	4	3			67
Eastern Chipmunk	1		3		1			22	68	21	47	18	84	85	56	9	415
Flying Squirrel								2	3	3	3		4	2			17
Red Squirrel								40	78	35	11	12	12	2	5		195
Beaver								2	2	1	1	1	1				8
Giant Beaver										1							1
Deer Mouse		1	1	2	2		1	89	135	63	43	22	78	54	77	15	583
Eastern Woodrat		1					1	46	92	45	49	43	37	24	15	10	363
Spruce Vole								3	8	5	1				1	1	19
Lemming *(sp?)*									*2*	*3*	*5*						*10*
Southern Bog Lemming	1		1					29	56	27	14	6	24	28	19	6	211
Collard Lemming *(Dicrostonyx hudsonius)*									29								29
Northern Bog Lemming								35	34	19	11		1	1		1	102
Red-backed Vole		1	1					102	126	49	43	6	17	16	3	4	368
Meadow Vole	1		4	4			1	67	106	55	24	9	13	19	3	4	310
Meadow Vole/Rock Vole	1	5	4	2	2			350	615	314	91	53	14	21	17	13	1502
Rock Vole			1				1	350	415	79	33	10	27	18	20		1054
Rock Vole (Sp?)								*24*	*53*	*23*	*2*						*102*
Yellow-cheeked Vole							3	3	2				1	1			10
Pine Vole	1	1	3	1	1			40	69	34	45	9	28	33	7	7	279
Muskrat				1				2	7	3	2	2		1	1		19
Meadow Jumping Mouse		1	1					8	17	6	10	4	8	1	2	2	60
Woodland Jumping Mouse		1	1		2			39	40	27	23	14	19	14	18	7	205
Porcupine						1	1		4	2	3	7	4				22
New England Rabbit/Hare	1	3	4	2	2	1	2	40	119	74	59	94	49	22	63		535
Pine Martin										2	2		1				5
Least Weasel								15	28	3	1	3	1		1		53
Weasel								7	15	5	3	4		2			36
Mink							1	3	5	1	2	2	2		1		17
Striped Skunk			2			1		14	17	14	7	17	5	7	3		87
Black Bear								1				2					3
Coyote										3							3
Dire Wolf										1							1
Gray Wolf								1				1					2
Gray Fox										1	1	2				1	5
Bobcat												1					1
Long-nosed Peccary										1	1	2		1		1	6
American Elk												1					1
White-tailed Deer								1	2	2		2		1	1		9
Caribou									1			1					2
Stag-Moose												1					1
Musk Ox									1								1
Vero Tapir													1				1
Horse											1						1
Mastodon		x	x	x	x	x											1
# species in each layer	6	9	17	8	9	4	12	35	37	40	37	37	32	28	26	14	51
# individuals in each layer	7	20	36	17	17	4	16	1752	2913	1309	831	477	748	542	549	82	9320
% species/total # species	12	18	33	16	18	8	24	69	73	78	73	73	63	55	51	27	
Depths (median value)	8	10	12	14	16	18	20	22	24	26	28	29	30	32	34	36	
% individuals/total individuals	0.08	0.22	0.39	0.18	0.18	0.04	0.17	18.86	31.14	14.09	8.94	5.13	8.05	5.83	5.91	0.88	100.09

Table 2. Mammalian fauna of the Hollidaysburg fissure deposit.

charcoal continued to a depth of 39 feet where we stopped the excavation because there had been no fossils found in the previous foot of matrix. The excavation had cleared the floor of the fissure except for a small area of approximately 1½ feet in diameter which was beneath a precariously balanced boulder.

At the 28-foot level, a number of bones and teeth of large mammals were uncovered along with abundant rabbit bones. This fossiliferous layer extended into an adjacent small cave which reached upward to 19 feet and extended down to 31 feet. Here a great abundance of animal bones were closely packed with very little clay in between. Many skulls and jaws were present - some were still articulated. These bones were probably washed into this small cave and were protected from crushing rock falls that often occurred in the main fissure.

Many of the large mammal bones found here were from juveniles which might have carelessly fallen into the fissure or they were brought there by predators. The opening might have been too small for an adult to enter. The isolated teeth of large mammals were probably brought there by the scavenges of woodrats which may have inhabited the fissure. Other animals which might have inhabited the fissure include other small rodents and bats as well as birds, snakes, frogs, turtles, toads, and salamanders and insects. Many remains of these animals were found throughout the column as shown in Table 3.

Non-mammalian Fauna	Depth in feet from top of fissure											
	11-13	13-15	15-17	17-19	19-21	21-23	23-25	25-27	27-29	29-31	31-33	33-35	35-37
Snail							X	X	X	X	X		
Insect						X	X	X	X	X	X	X	X
Fish					X	X	X	X	X	X	X	X	X
Salamander/Frog	—					X	X	X	X	X	X	X	
Snake				X	X	X	X	X	X	X	X	X	X
Bird					X	X	X	X	X	X	X		

Table 3. Presence of non-mammalian fauna according to depth in the fissure.

At 31 feet, we encountered a 3-inch snake bone layer which yielded not only huge quantities of vertebrae and ribs but numerous delicate jaws, some skulls, and a few rattlesnake fangs. The sediment contained up to 75% snake bone at this level. It is common for a number of snake species to hibernate together and such a hibernaculum might have been buried by sediment or water.

Throughout the column, 9391 individual mammals were collected. This minimum number of individuals was based on the highest replication of skulls, jaws, and teeth and may not be the actual number in the deposit because huge amounts of post cranial bones were also collected.

The largest group of mammals collected was the Arvicolidae (voles), which totaled 43% of the total individual mammals (Figure 8). The Soricidae (shrews), comprised 25% of the total individuals. The large number of small mammals might reflect inadvertent trapping of unwary animals tumbling into the sinkhole, being buried in their habitat, or becoming prey of other animals. The relatively small number of carnivores present might have been a benefit of their greater alertness and agility. The exception to this trend are the skunks, whose larger occurrence might be explained by their myopic sight. No opossums have been found in any Pleistocene deposit in any Valley and Ridge site, although they are common there today (Guilday *e. al.*, 1978, pp. 63-64). We were always on the lookout for signs of human presence because Paleo-Indians lived in the area at that time, but none were found. The charcoal and fire-reddened rocks found could have been from naturally occurring fires, rather than campfires.

A comparison was made between the fossil mammalian fauna of the Hollidaysburg Fissure and that of two other mid-Appalachian late-Pleistocene deposits - New Paris No. 4, Pennsylvania, and Clarks Cave, Virginia. These three deposits are in the same physiographic area and were filled at about the same time interval. In the New Paris No. 4 site, the mammals were trapped by falling down a narrow, vertical fissure 10 meters deep and filled with surface debris. At Clarks Cave, most of the mammals found were from raptors' digestive remains which had been deposited on the floor in a sheltered cave entrance. In both of these faunas, the greatest percentage of animals found were small mammals, as shown in Figures 9 and 10. Excluding the number of bats, the small rodents comprised at least 98% of the fauna although in differing proportions of the various families. There were more voles and fewer rabbits, squirrels, and shrews than at the Hollidaysburg Fissure.

Measurements comparing the fossil species from the Hollidaysburg Fissure with their recent counterparts have yet to be made, although an increase in size was noted in the skulls of woodchucks, beavers, and porcupines of late Pleistocene Age. This adaptation, known as "Bergmann's Rule", produces a smaller surface-to-mass ratio and therefore conserves body heat in colder environments. However, some of the mammalian fauna from New Paris No. 4 (*Lepus americanus*, *Mustela ermina*, and many burrowing mammals) had a negative Bergman response (Guilday *et al.*, 1964, p. 179).

BIOTIC DESCRIPTIONS

Mollusca

Gastropoda

Three species of land snails were recovered and all three are found in the area today. *Triodopsis albolabris* is the most common snail found.

Arthropoda

Insecta

Chitinous wing cases of insects were found throughout much of the column but it was not possible to determine the species from which they came.

Pisces

Fish scales were found throughout much of the column and probably were brought there by predators. A nearby river could have been the fish habitat.

Amphibia

Many frog, toad, and salamander bones were recovered but their species have not yet been determined.

Reptilia

Chelonia

One complete jaw and a number of plastron plates of a turtle were recovered.

Squamata

Many vertebrae, ribs, skulls, and jaws of snakes were collected. All of the determinations were based on the vertebrae. A few rattlesnake fangs were found. A few articulated skeletons were carefully removed. Since the species could be identified by the vertebrae, we tried to recover any frontals or jaws in the vicinity so an identification key could be made for these bones in the future.

Aves

Two coracoid bones of a duck such as a Teal and a cranium of a Merganser were identified. An owl, such as the Great Horned Owl, was represented by a tarsus metatarsus bone. The cranium of a woodpecker, such as the Hairy Woodpecker, was also identified and many post-cranial bones were found throughout the column. Of these, only the owl might have inhabited the fissure. Others probably were brought into the fissure as prey. If a bird accidentally fell into the fissure, it might have been trapped in a vertical passage.

Insectivora

Microsorex hoyi (Pygmy Shrew) has rarely been found in Recent collections and there has been only one recorded from Pennsylvania. It was probably common during the late Pleistocene since it has been found in a number of those sites. *Blarina brevicauda* (Short-tailed Shrew) was the most abundant shrew recorded throughout the column and Recent forms range throughout the eastern half of the United States and Canada.

Chiroptera

Species other than *Eptesicus fuscus* (Big Brown Bat) and *Myotis sp.* (Little Brown Bat) may be present in this site. There has not been an adequate key made for bat skulls and jaws but I am in the process of acquiring cranial parts of various Recent species in order to identify the less common ones.

Rodentia

A nearly complete skull of a *Citellus tridecemlineatus* (13-lined Ground Squirrel) was found and John Guilday wrote that it was the best one ever found as a fossil in the Appalachians (correspondence, 19 April l978). This has not been commonly found in late Pleistocene deposits. *Tamiasciurus hudsonicus* (Red Squirrel) was the most abundant squirrel found in the fissure and it was more abundant in the middle section while *Tamias striatus* (Eastern Chipmunk) was the abundant squirrel in the lower section of the cave.

An upper incisor and a molar were found of *Castoroides ohioensis* (Giant Beaver). The incisor was fluted and much larger than that of *Castor canadensis* (Beaver). The Giant Beaver was nearly as large as a young black bear.

Dicrostonyx hudsonius (Collared Lemming) were found only at one interval. This could be a case of Lemming emigration since it is known to occur in North America, but on a smaller scale than in Scandinavia. The population builds up for 3-4 years and then, when the food supply is entirely gone, they "crash" and the population is nearly wiped out.

Huge amounts of complete skulls and jaws, as well as hundreds of single teeth, were collected for the voles and mice. There were a number of teeth for which I was unable to find descriptions in my reference material. With more research, I hope to be able to completely identify this group.

Lagomorpha

Leporidae

It was not possible to distinguish between *Lepus americanus* (Snowshoe Hare) and *Sylvilagus transitionalis* (New England Cottontail) unless the skull was fairly complete. Several skulls provided enough evidence to determine that both species were present in the fissure.

Carnivora

Mustelidae

There is a lot of variation in the size of the mustelids. Female skulls are smaller than male skulls and there is a continuum in size among *Mustela rixosa* (Least Weasel), *Mustela frenata* (Weasel), and *Mustela vison* (Mink). More study needs to be done with this group to properly identify the different species.

Ursidae

Many separate teeth of *Ursus americanus* (Black Bear) were found as well as a shoulder blade and a number of leg bones.

Canidae

Variation in size is also a problem with identifying the canids. Fox, coyote, and wolf teeth are very similar in structure and only differ in size. There seemed to be somewhat of a continuum of size from a fox to a wolf.

A left mandible with 3 teeth was found which belonged to *Canis dirus* (Dire Wolf). This is now an extinct animal that was much larger than Recent wolves.

A *Lynx sp.* (Bobcat) was identified by a right mandible with a number of teeth. It was a young animal with the molars still unerupted in the jaw.

Artiodactyla

A partial skull and jaw of a *Mylohyus nasutus* (Long-nosed Peccary) was found. A number of teeth were present. Many other single teeth, as well as an ulna, were found of other peccaries.

Separate teeth of *Cervus elaphus* (American Elk), *Odocoileus virginianus* (White-tailed Deer), *Rangifer tarandus* (Caribou), *Cervalces sp.* (Stag-Moose), and *Bootherium bombifrons* (Wood Musk Ox) were found. Leg bones of elk and caribou, and an atlas of caribou were also identified.

Perissodactyla

Well preserved jaws and the dental portions of a skull of *Tapirus cf. Veroensis* (Vero Tapir) were recovered. This was a juvenile due to the number of unerupted adult teeth within the bone.

Two molars of *Equus sp.* (Horse) were found. This may be the latest record of a horse which became extinct at the end of the Pleistocene.

Proboscidea

Many bones of a young *Mammut americanum* (Mastodon) were recovered. The jaws were complete with several unerupted teeth. A fragmentary skeleton of the animal was found in the upper section of the fissure, scattered throughout the column in a 6-foot layer. The mastodon was dated 10,000-12,000 years B.P. by amino acid racemezation by J. Bada of the Scripps Institute of Oceanography.

_____ Samples of the clay were taken at every 2-foot interval and processed to determine the palynology of the area at that time period. These samples have yet to be studied but since the site is in proximity of the New Paris No. 4, one would expect to find both spruce and pine pollen here too.

ECOLOGICAL IMPLICATIONS

Fifty-two species of mammals were identified from the Hollidaysburg Fissure. Those species still in existence today consist of an intermesh of ones occupying quite diverse ecological habitats. This mixture of forms inhabit northern, western, and deciduous eastern areas. Over 50% of all those present day species have extended their range northward to a cooler, more moist environment. While many of these species still inhabit the higher elevations of the Appalachian Mountains of Pennsylvania, six are now only found inhabiting areas to the north and west. These are the northern bog lemming, collared lemming, yellow-cheeked vole, gray wolf, and caribou. The 13-lined ground squirrel now inhabits only the central plains of the United States and Canada. Elk have been reintroduced recently into Pennsylvania and the coyote has expanded its range far into the eastern United States.

It is difficult to imagine an environment which would encompass this wide range of habitats as suggested by the fissure fauna and one really can not explain such a group in terms of each species' individual requirements in the present time. Such a unique fauna does not exist today and would have experienced different interspecific and ecological pressures than those affecting the population today. The fossil fauna and the pollen analysis of deposits similar in age to the Hollidaysburg Fissure have provided an insight into the environment of this area during the last part of the Pleistocene. New Paris, No. 4,

Pennsylvania and Clark's Cave, Virginia have bone deposits dated 11,000 yB.P. - nearly identical to the age of the Hollidaysburg Fissure. New Paris, No. 4 and Hollidaysburg Fissure were filled by animals trapped in vertical fissures while Clark's Cave held remains of animals preyed upon by raptors and buried in the talus at the cave entrance. There were only minor differences in the composition of the fauna from the three sites. All were dominated by small rodents and insectivores (Figures 8, 9 and 10) and the greater percent of the mammal species were from a boreal woodland and meadow habitat. This suggests a cooler and more moist environment, such as is found today in Alaska and southern Canada. Different habitats would exist within this environment with nearby streams, meadows, and ponds providing many ecological niches and topographic diversity ranging from mountain top to valley floor.

Pollen analysis shows that the area immediately south of the glacial moraine was an open, treeless tundra dominated by grasses and sedges. Further south, in the area of the three bone deposits, Spruce and Pine were the dominant species. All three deposits occur within the Valley and Ridge Province with long parallel NE/SW trending ridges and intermontane valleys formed from folded Paleozoic rock. These valleys extended from the glacial margin southward, providing a migratory route for the northern late Pleistocene fauna. As the glacier retreated, this area became more temperate and deciduous forests gradually replaced the area of spruce and pine trees.

This transition from a boreal coniferous to a temperate deciduous forest in this region occurred at 12,700 to 10,000y B.P. (Guilday *et al.*, 1978). This change proceeded rapidly as reflected in the changing makeup of the mammalian fauna. Most mammals which had inhabited the area during boreal time either migrated northward, acclimated, or become extinct (Guilday *et al.*, 1977). More temperate species (such as chipmunks, southern bog lemmings, pine voles, and meadow voles) would be able to migrate into this area.

Noting the occurrence of the species in Table 2, the greatest number of individuals among the boreal species were located between depths of 21 and 25 feet. Their numbers declined at greater depths where species which would suggest a warmer climate were the more abundant mammals.

Perhaps this was a short-term oscillation in temperature, similar to that which Guilday *et al.* (1978) found in the Baker Bluff Cave Deposit. They suggested that this temperature oscillation could have produced fairly large-scale biotic adjustments.

These deepest fossils must still be dated to determine when they were deposited. Also very interesting are the few species found in the upper levels. This was almost entirely a more temperate fauna signifying a change again to a warmer environment.

ACKNOWLEDGMENTS

I am indebted to many people who helped me with this project. My family, relatives, friends, and some Pennsylvania State University students helped with the excavation. The neighborhood children spent many hours picking out the bones from the washed matrix. John Guilday of the Carnegie Museum provided invaluable help with bone identification, even setting up a small reference collection for my use. Roger J. Cuffey of Pennsylvania State University gave me encouragement throughout the project. Storrs Olson of the Smithsonian Institution provided bird identification and J. Allan Holman of Michigan State University helped with the snake identification. Very special thanks go to my husband, Tom, who spent many hours in all phases of the project. I also gratefully thank David "Duff" Gold and Arnold Doden of Pennsylvania State University for their support and editorial assistance. And finally, thanks to Julia Goodman of Harrisburg for giving permission to work on this site.

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FIELD TRIP # 1 THURSDAY AFTERNOON

FRANKSTOWN QUARRY (Fossiliferous Pleistocene Cave)

Leader: Shirley Fonda

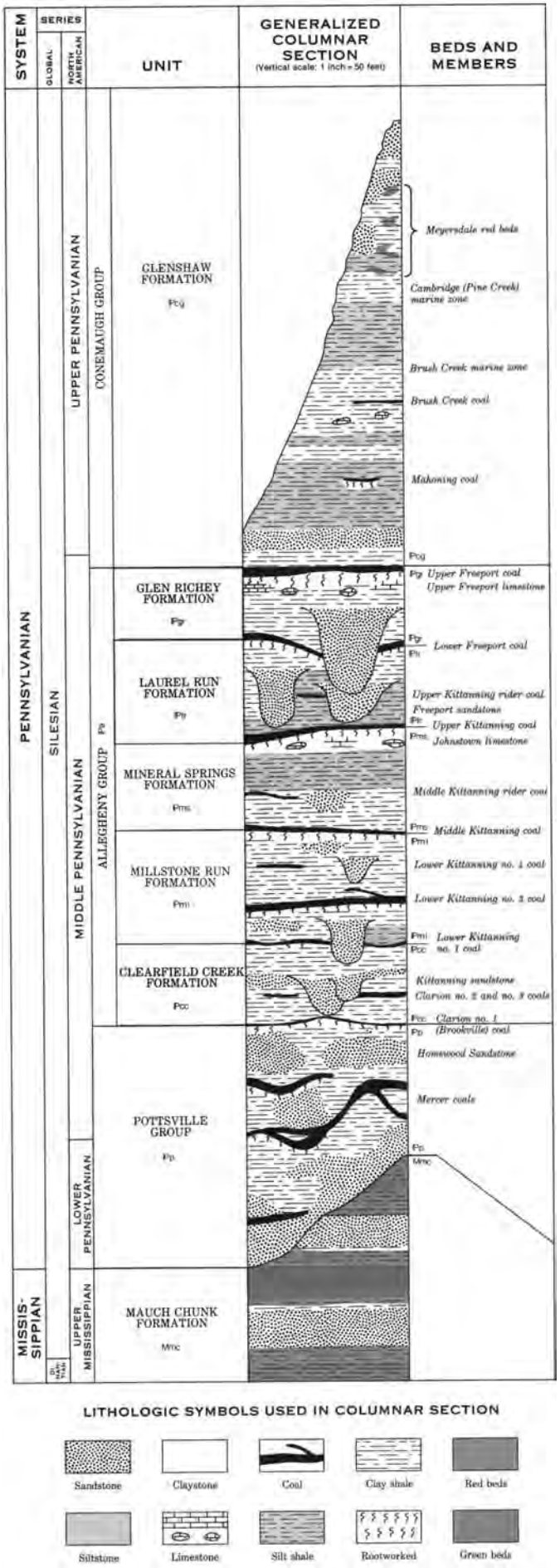
ITINERARY

		Assemble in parking lot of Ramada Inn.
0.1	0.1	Turn left from parking lot and right onto Plank Road (Rte 220 S).
1.6	1.7	Junction with N. Juniata Road.
0.8	2.5	Left on Rte 22.
1.5	4.0	Junction with Rte 36 in Hollidaysburg. Continue east on Rte 22.
2.15	6.15	Turn left into country store and gas station parking lot in Frankstown.
		Walk approximately 600 yards uphill on path to abandoned quarry.

Spend approximately 2 hours at the fissure and on the debris mounds of cave sediments.

Return via same path to the parking lot, and drive back along Rte 22 to Hollidaysburg.

2.15	8.3	Turn right at junction in Hollidaysburg onto Rte 36 N
0.1	8.4	Walnut Street intersection, Hollidaysburg.
3.3	11.7	Left at intersection in Altoona, onto Plank Road south.
1.3	13.0	Exit right to Ramada Inn.
0.1	13.1	Ramada Inn parking lot



Modified from Plate 2 of the Pennsylvania Geological Survey Atlas 86, *Geology and mineral resources of the Blandburg, Tipton, Altoona, and Bellwood quadrangles, Blair, Cambria, Clearfield, and Centre Counties, Pennsylvania*