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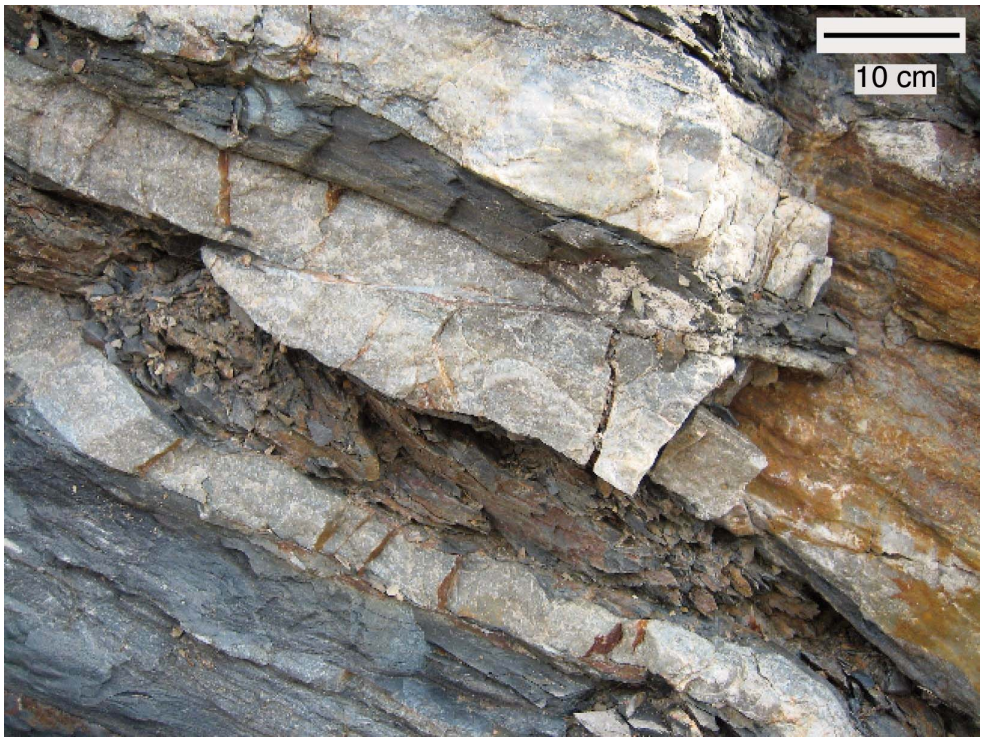

Folded wedge fault in the Tuscarora quartzite west of Macedonia, Pa. The wedge fault accommodated bed-parallel shortening when the beds were subhorizontal; it was then rotated during later folding (see article on page 4).

—Photograph by Zeshan Ismat

EDITORIAL

Spring Is Here!

Gale C. Blackmer, State Geologist
Pennsylvania Geological Survey

Spring is here! At least that's what the calendar and the abundance of blossoms say. I'm confident the weather will catch up soon. And in spring, the thoughts of geologists young and old turn toward our first love—going outside to look at rocks! For the professionals among us, field season is in full swing. The corner of our Middletown building that houses the Mapping Division is more often than not dark and empty these days, its denizens out mapping in McKean County and Wayne County, measuring the bathymetry of state park lakes, or pursuing other ventures closer to home, such as observing and recording the newly opened rock cuts along U.S. Route 11/15 across the Susquehanna River.

For the geologic tourist (I count myself as one of these now), Pennsylvania offers any number of ways to pursue your happiness—trails lined with points of geologic interest, hikes and drives to scenic vistas, waterfalls, rock cities, boulder fields, and other geologic wonders. If you are looking for a new favorite place to visit, we have resources to help you find it. These days, even an outdoor trek starts on the internet, so here are some websites to help you plan your trip: view maps, photos, and information about outstanding geologic features at www.gis.dcnr.state.pa.us/maps/index.html; peruse the story maps of the Department of Conservation and Natural Resources at http://maps.dcnr.pa.gov/StoryMaps/ to see a selection of the top waterfalls, outstanding geologic features, and National Natural Landmarks; take a hike along the Northern Extension of the York County Heritage Rail Trail using our hot-off-the-presses geologic trail guide, Open-File Report OFMI 16–03.0; or take a geologic paddling trip using our geology guide to the Yellow Breeches Creek from Messiah College to McCormick Road, OFMI 15–21.0. The latter two guides are currently downloadable from our "Publications by Series" page (www.dcnr.state.pa.us/topogeo/publications/pgspub/index.htm) under Open-File Reports. Other nontechnical guides, including descriptions of geologic features in 22 of Pennsylvania's state parks, can be downloaded from the Park Guide series page. By the end of summer,

Pennsylvania
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the two Open-File reports and the Park Guides will be moved into a new series called Trail of Geology, which will be accessible through that same web page.

Spring is also a time to launch new ventures. On the groundwater front, the Pennsylvania Groundwater Information System (PaGWIS) has a newly redesigned search tool, found at www.dcnr.state.pa.us/topogeo/groundwater/pagwis/index.htm. If you are familiar with the old system, you should find this one much more user friendly. Give it a try. Also, we have a whole new crop of interns, both here in Middletown and in Pittsburgh. Over the course of the summer, they will be entering backlog water-well data into PaGWIS; working in the core library; preparing geologic samples for bulk mineralogy analysis; scanning, digitizing, and processing geophysical logs for inclusion in the Exploration and Development Well Information Network (EDWIN); assisting with data entry relative to enhanced oil recovery opportunities in southwestern Pennsylvania; and mapping geologic units that serve as potential geologic carbon sequestration reservoir targets. And finally, in March, a couple of weeks short of the start of Spring, we welcomed Arianne Proctor to the Bureau as the new manager of the Mapping Division. You will meet her in a profile on page 17.

Happy Spring!

Gale C. Blackmer

Gale C. Blackmer
State Geologist

Deformation History Expressed Within the Juniata Culmination, Central Pennsylvania

Zeshan Ismat[1] and Justin Herbert[2]
Franklin and Marshall College

Introduction

Mountain belts (fold-thrust belts) are commonly curvilinear and vary in width along their length (Sussman and Weil, 2004). The number and size of the curves and degree of curvature may provide clues to the overall development of fold-thrust belts. Many of the current methods and terminology used today by geologists to understand the formation of mountains come from studies conducted in the Appalachian Mountains (e.g., Dana, 1866; Rodgers, 1963; Faill, 1973, 1999).

The Appalachian Mountains (Figure 1) extend from Newfoundland to central Alabama. Two of the chief distinguishing features of all fold belts, including the Appalachians, are (1) the prominent curves, termed salients, concave toward the foreland, that make up the entire mountain range, and (2) the patterns defined by thrusts and plunging folds. Our state is home to a distinctive salient—the Pennsylvania, or central, salient, within which are conspicuous plunging anticlines and synclines. These occur within the Ridge and Valley physiographic province.

The structural history of the Pennsylvania salient has been studied for more than 150 years (Dana, 1866; Rodgers, 1963; Gray and Stamatakos, 1997; Thomas, 1977, 2006; Faill, 1999; Wise, 2004; Ong and others, 2007; Sak and others, 2014) and still remains controversial. In map view, the Pennsylvania salient has a broad arcuate pattern with a central northwest-trending topographic high and structural culmination, the Juniata culmination. (A culmination is the highest part of a structural feature.) The "limbs" of the salient are composed of folds that plunge to the northeast and southwest on either side of the culmination (Faill, 1973) (Figure 1). The folds and thrusts within the salient formed during the Permian Alleghanian orogeny as the Laurentian and African cratons collided (Faill, 1999).

Currently, *two-azimuth* and *one-azimuth* models are used to explain the formation of the culmination and the adjacent plunging folds (Figure 2). Both models assume that the North American craton margin had a preexisting continental embayment, a ridge-transform corner, during the breakup of Rodinia and the opening of the Iapetus Ocean (Thomas, 2006), which guided and shaped the present geometry of the Pennsylvania salient during Alleghanian deformation. The limbs of the salient are defined by the Reading Prong and Blue Ridge. They are parallel to the flanks of the culmination. In both models, the Juniata culmination formed at the Eocambrian (latest Precambrian) reentrant's corner (Figure 1). Each model, however, predicts a different set of structures within the culmination.

The two-azimuth model suggests that the salient formed by two separate shortening directions, one directed approximately perpendicular to the Reading Prong and the other approximately perpendicular to Blue Ridge, and thus approximately perpendicular to the salient's limbs. Hence, the Juniata culmination formed as a result of the convergence of these two shortening directions (Figure 2) (Wise, 2004). The one-azimuth model, however, proposes a unidirectional northwest-directed transport toward the center of the salient (Gray and Stamatakos, 1997; Sak and others, 2014). In this case, the culmination formed

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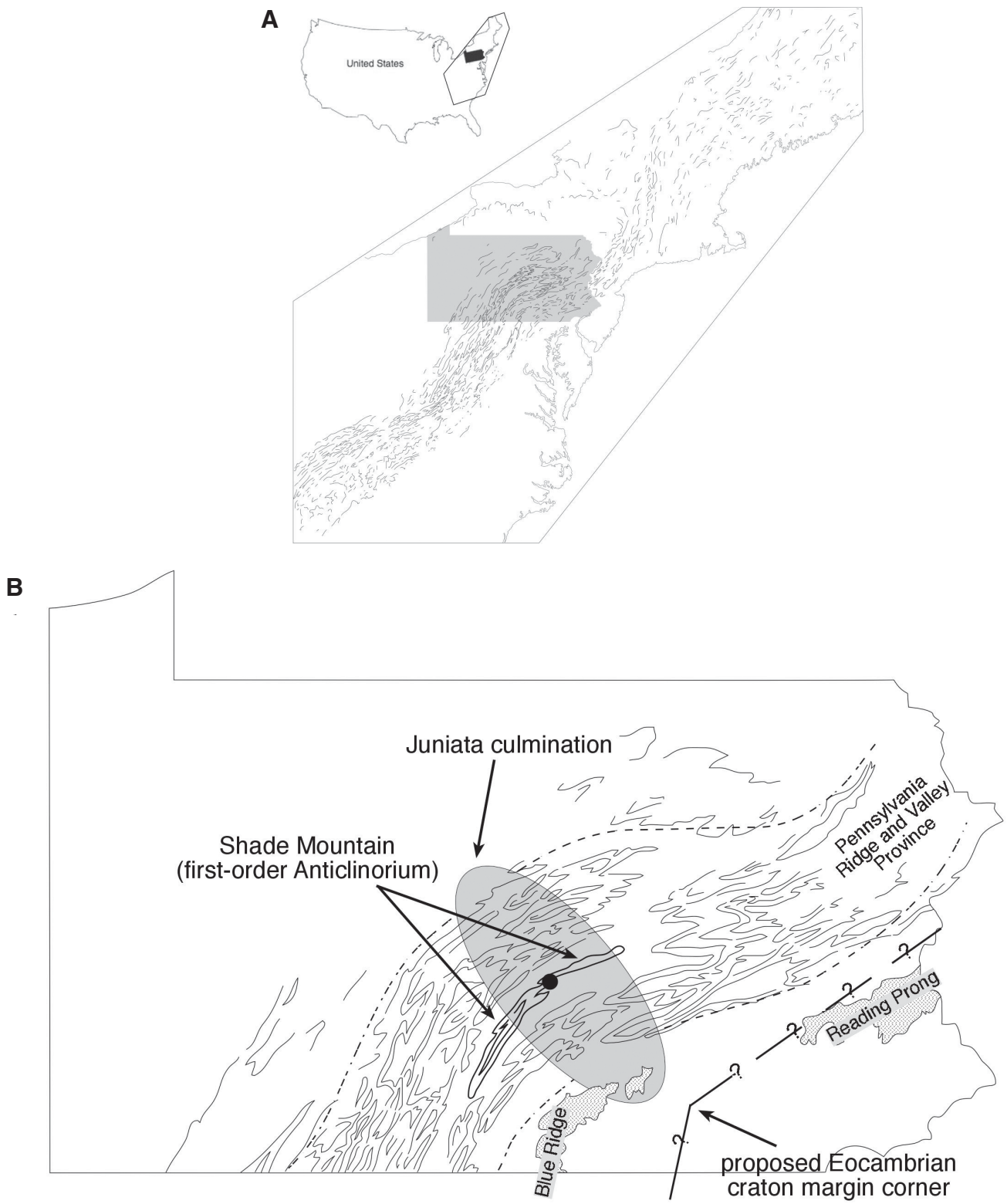


Figure 1. A, Generalized map of the northern and central Appalachian Mountains showing major folds and topographic highs. B, Map of Pennsylvania showing folds in the Ridge and Valley physiographic province, the general area of the Juniata culmination, the proposed location of the Eocambrian craton's edge (dashed line and question marks), and the Blue Ridge and Reading Prong basement uplifts. The corner of the craton (also called the continental embayment or the reentrant's corner) is also indicated. The black dot marks the location of the field area.

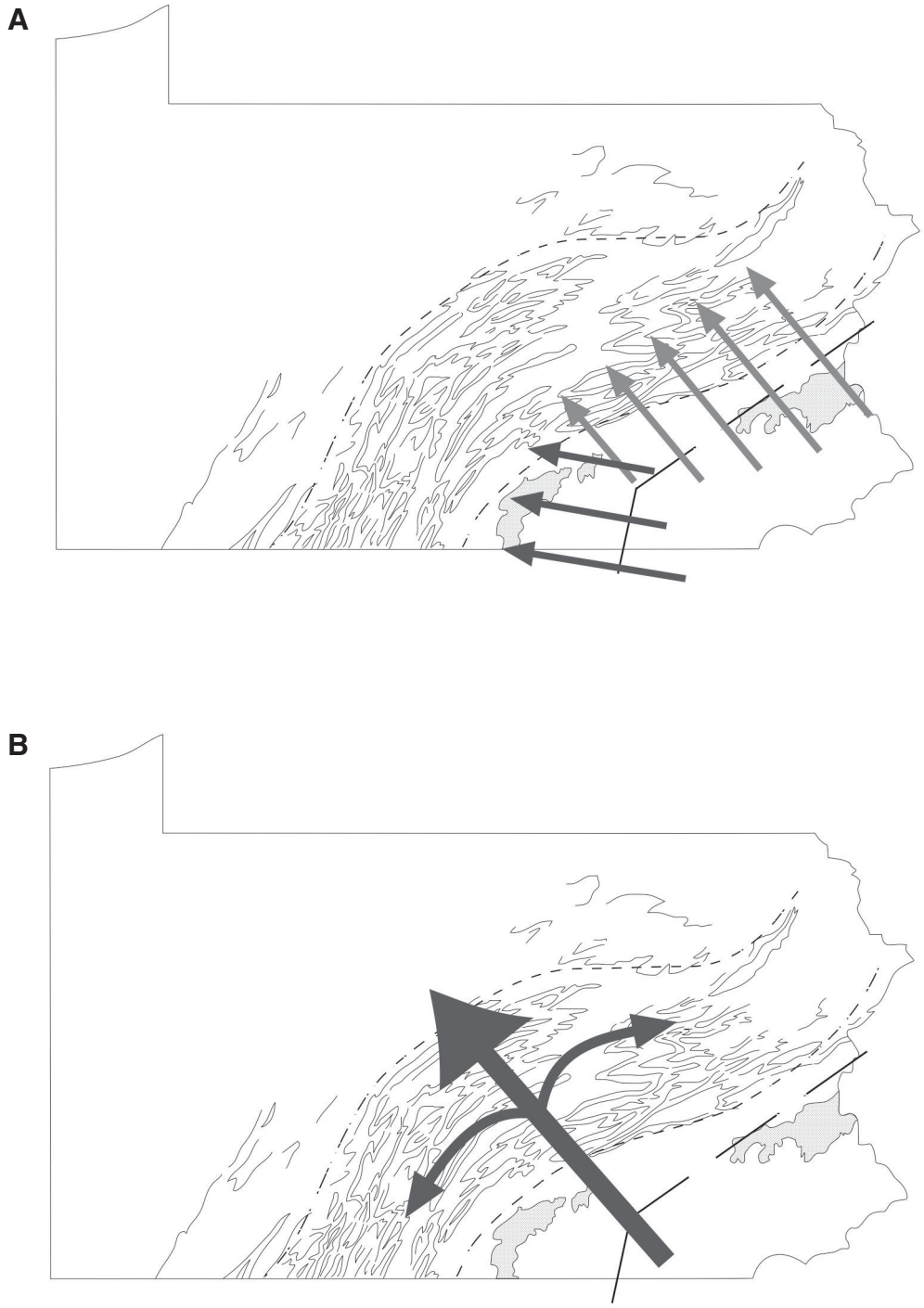


Figure 2. Generalized maps of the Ridge and Valley physiographic province showing the transport directions (arrows) in the two-azimuth (A) and one-azimuth (B) tectonic models. In A, the arrows lie at a high angle to the basement-cored uplifts (shaded).

as a result of concentrated shortening in a region where the sedimentary package was the thickest, specifically along the Eocambrian corner (Figure 2). Thus, the sediment "wedge" moved forward, forming the culmination, and flow occurred laterally, producing the plunging folds in the limbs—akin to an advancing angled snowplow.

One might expect that two overprinting sets of shortening directions should have been preserved in the culmination if the salient had been formed by the two-azimuth model. Alternatively, if the Pennsylvania salient formed according to the one-azimuth model, a single shortening direction, overall parallel to the Juniata culmination, should have been preserved.

Construction for the newly expanded U.S. Route 22/322 approximately 4 miles east of Lewistown has exposed a transect through the Juniata culmination. In our study, we examined structures preserved along this transect and analyzed the shortening directions defined by several generations of structures that are present. The intent was to determine the overall shortening history within the Juniata culmination. We examined the salient's two limbs in order to determine which model, if either, is appropriate. The new exposures provide a resolution to the choice of models.

Solving this puzzle may help us understand the role of preexisting sedimentary packages and the shape of the preexisting craton to mountain-belt formation. Also, culminations are commonly regions for natural resource exploration; therefore, understanding the formation of this one may provide clues for potential exploration locations. Finally, this area may provide another model for mountain-belt formation.

Location of Study Area and General Structure

The transect is located in the central region of the Juniata culmination, along the newly expanded U.S. Route 22/322 (Mannino, 2010), west of Macedonia, Pa. (Figure 3). The new roadcut trends northwest-southeast and exposes a cross section approximately perpendicular to the first-order fold hinges, providing a view of a profile plane for study. Therefore, the geometry of the structures is not distorted.

The transect lies within the first-order Shade Mountain anticlinorium (Figures 3, 4, and 5). The Shade Mountain anticlinorium is composed of two second-order anticlines, Shade Mountain and Blue Mountain, which form an en echelon fold pair (Figures 3 and 4). The transect is on the northwest limb of Blue Mountain and consists of three third-order asymmetric folds and smaller higher order folds throughout (Figures 4 and 5).

Stratigraphy

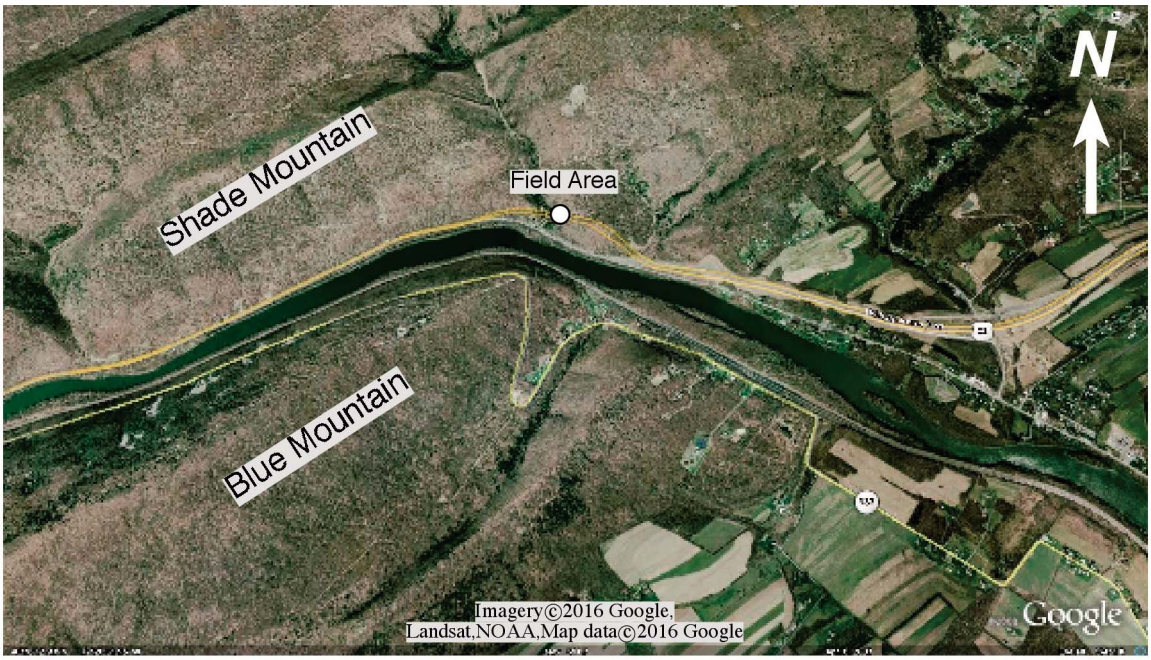
The contact between the Silurian Tuscarora quartzite and the Silurian Rose Hill shale is exposed in the study area (Figures 5 and 6). The Tuscarora beds on the northwest side of the outcrop are massive (1 to 14 meters thick), composed of about 80 percent quartzite and thinner interbedded shale layers. The southeast end of the cross section is thin bedded (a few centimeters to a few meters thick) and has repeated layers of equal amounts of shale and quartzite.

The geometry of the folds reflects the lateral bed-thickness changes along the transect (Figures 5 and 7). At the northwest end, where the quartzite beds are significantly thicker, the folds are more open and have rounded hinges. At the southeast end, the folds are much tighter and form kink folds.

Fold Data

The first- and second-order folds are upright, and their hinges are oriented approximately 55°/235° (that is, they plunge 55° toward 235°). The two main third-order folds plunge 4°/238°, with a hinge surface dipping 75° toward 333° (Figure 8). The fourth-order fold plunges 7°/231° and its hinge surface dips 64° towards 317°(Figure 8). These fold orientations indicate an average shortening directed toward the northwest (325°), perpendicular to the fold hinges and parallel to the trend of the Juniata culmination. The data support a one-azimuth model.

A



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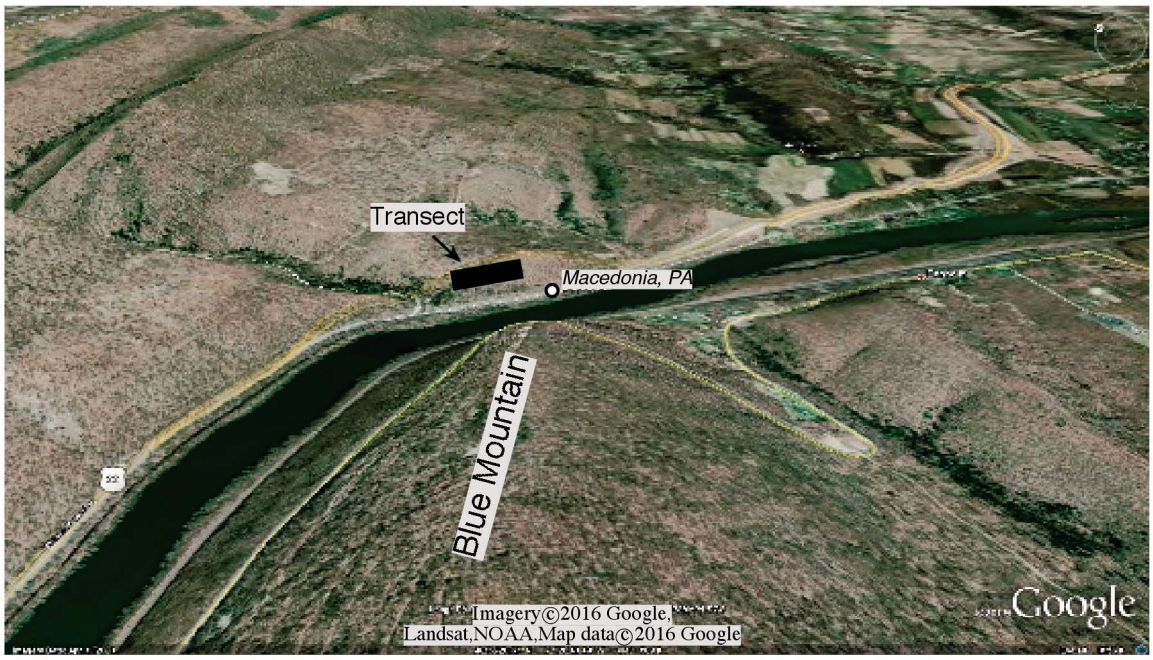


Figure 3. High-angle (A) and oblique (B) views of the field area (from Google Maps). The black box in B marks the location of the transect.

Deformation History

In order to more clearly track the deformation history, detailed outcrop-scale (mesoscale) data were collected across the third- and fourth-order folds. The deformation features were then separated into three generations, based on cross-cutting relationships.

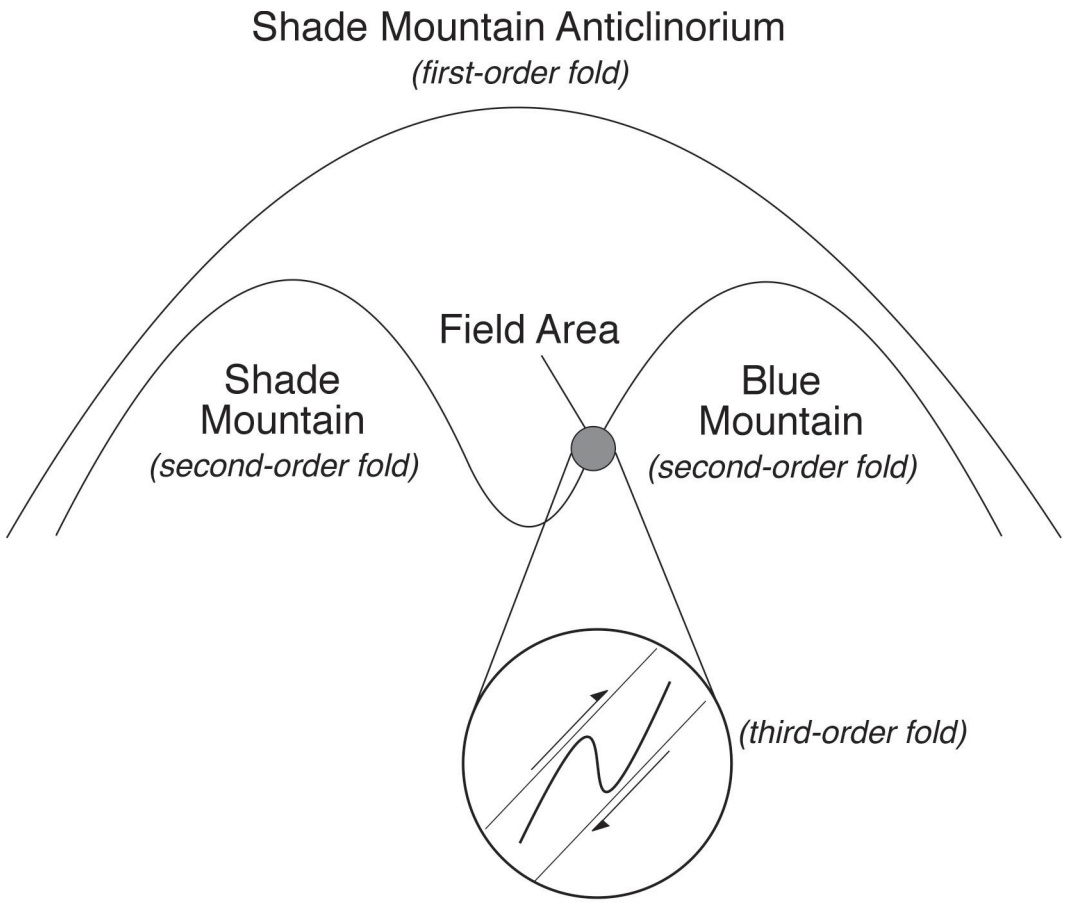
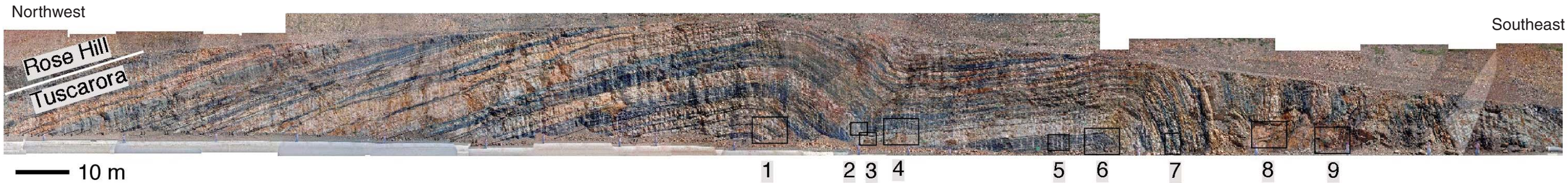


Figure 4. Schematic cross section of various fold orders in the region near the field area.

First Stage. The first stage of deformation is preserved as layer-parallel shortening structures, specifically low-angle wedge faults in the quartzite layers (see cover photograph) and a cleavage set oriented perpendicular to bedding in the subhorizontal shale layers (Figures 7A and 7B). Near the hinge regions of the third-order folds, the wedge faults are folded, and on the steep limbs (>60° dip), the wedge faults are passively rotated (Figures 7A, 7B, 7C, and 7D). Both relationships indicate that wedge faulting took place when the beds were subhorizontal and were deformed by later folding. Assuming that the shortening direction is parallel to the dip direction of the faults and perpendicular to the cleavage surfaces, these first-stage structures suggest a single shortening direction toward the northwest.

Second Stage. Extensional faults formed in the hinge regions to accomodate outer-arc lengthening (Figures 7E and 7F) during the second, or folding, stage of deformation. In the shale layers, two cleavage sets (S_1 and S_2) are preserved in the steeper dipping (>30°) beds (Figure 7G). The gently dipping cleavage surfaces (S_1) are cross cut by the younger second set of steeply dipping cleavages (S_2). We interpret the older set (S_1) as having been rotated during flexural slip folding. The younger, steeper set (S_2) then formed as the folds became tighter. Both cleavage sets dip toward the southeast, which indicates a shortening direction in plan view toward the northwest (Figure 7G). Distorted primary sedimentary structures suggest layer-parallel slip during folding (Figure 7H).



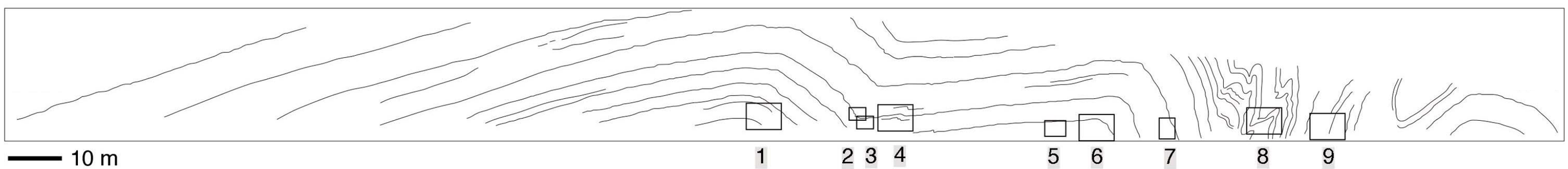


Figure 5. Photomosaic and sketch of transect. Areas in boxes are enlarged in the photographs in Figure 7.

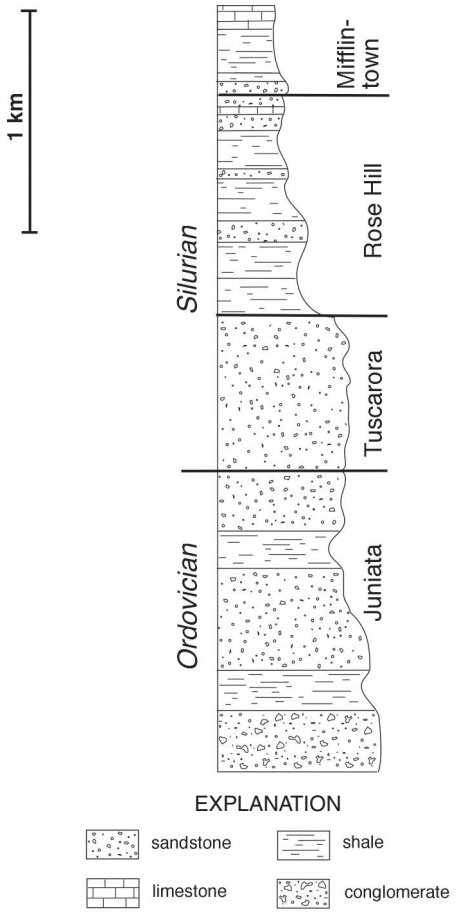


Figure 6. Stratigraphic column showing the two formations exposed in the transect (Tuscarora and Rose Hill), as well as one formation above and one below.

Third Stage. The third and final stage of deformation took place after the folds became tighter (limb dips >60°). Low-angle (conjugate) thrust faults cut across steep limbs of the third-order folds (Figures 7B and 7D). These faults are approximately perpendicular to the third- and fourth-order fold hinges, which suggests a shortening direction toward the northwest.

Subvertical faults that strike approximately parallel to the transect (325°) also are preserved (Figure 7C). These faults formed during the entire deformation history, and their orientations indicate displacements toward the northwest. Two examples are relevant. One such fault preserves almost horizontal slickenlines ("a lineation on a fault surface, defined by grooves, ridges, and/or striations" [Nueuendorf and others, 2005]); it is crosscut by stage 3 low-angle faults, indicating that it formed between stage 2 folding and stage 3 faulting. Another subvertical fault displays folded slickenlines, suggesting that the fault formed prior to stage 2 folding (Figure 7I).

Conclusions

The stages of deformation preserved throughout the Pennsylvania Ridge and Valley province, specifically layer-parallel shortening, main folding (Faill, 1973), and fold modification including low-

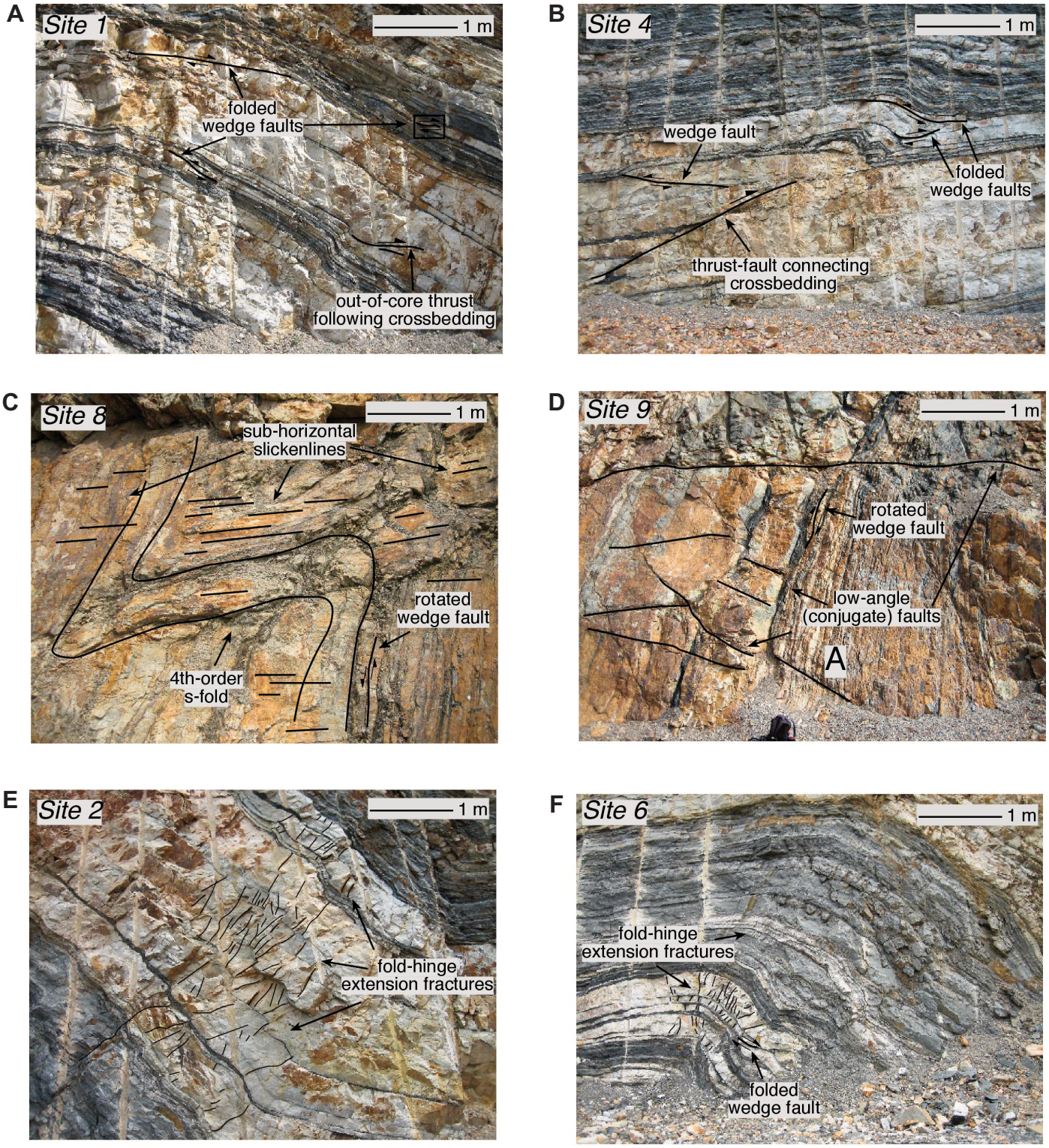
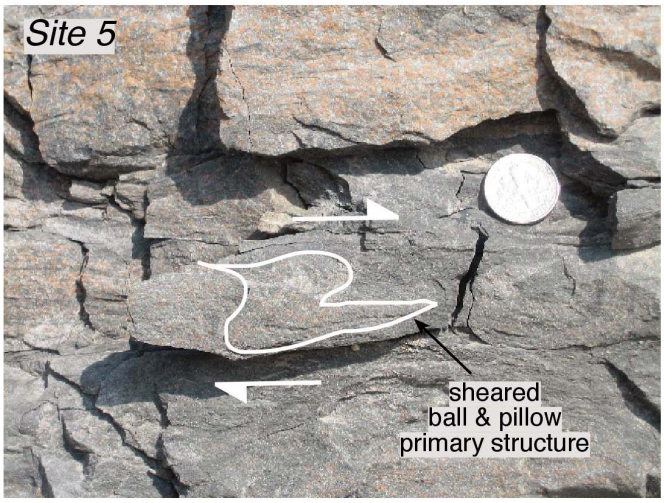


Figure 7. Photographs showing highlighted secondary features. All photographs are toward the northeast and are referred to in the text along with explanations. See Figure 5 for site locations.

G

H



I

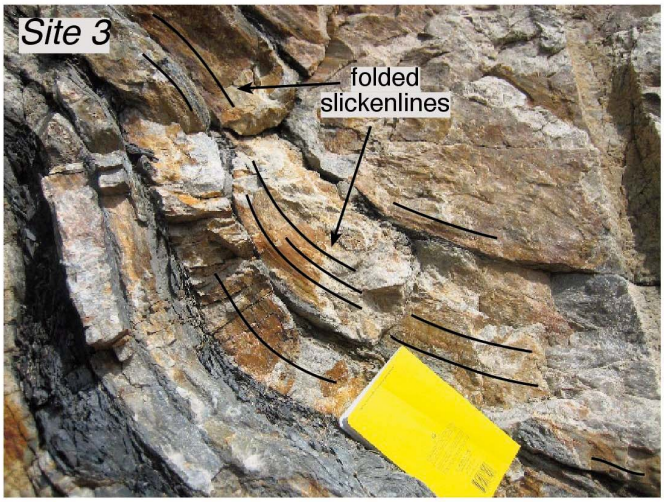


Figure 7. (Continued).

angle thrust faulting (Nickelsen, 1979), are preserved as well in the Juniata culmination. The various stages of deformation preserved throughout the transect define a consistent shortening direction toward the northwest (320°–330°). Structural data suggest that a single transport direction, parallel to the proposed Eocambrian cratonic corner (Thomas, 1977), assisted in the development of the Juniata culmination (Figures 1 and 2). The Pennsylvania salient fits the one-azimuth model (Gray and Stamatakos, 1997; Sak and others, 2014).

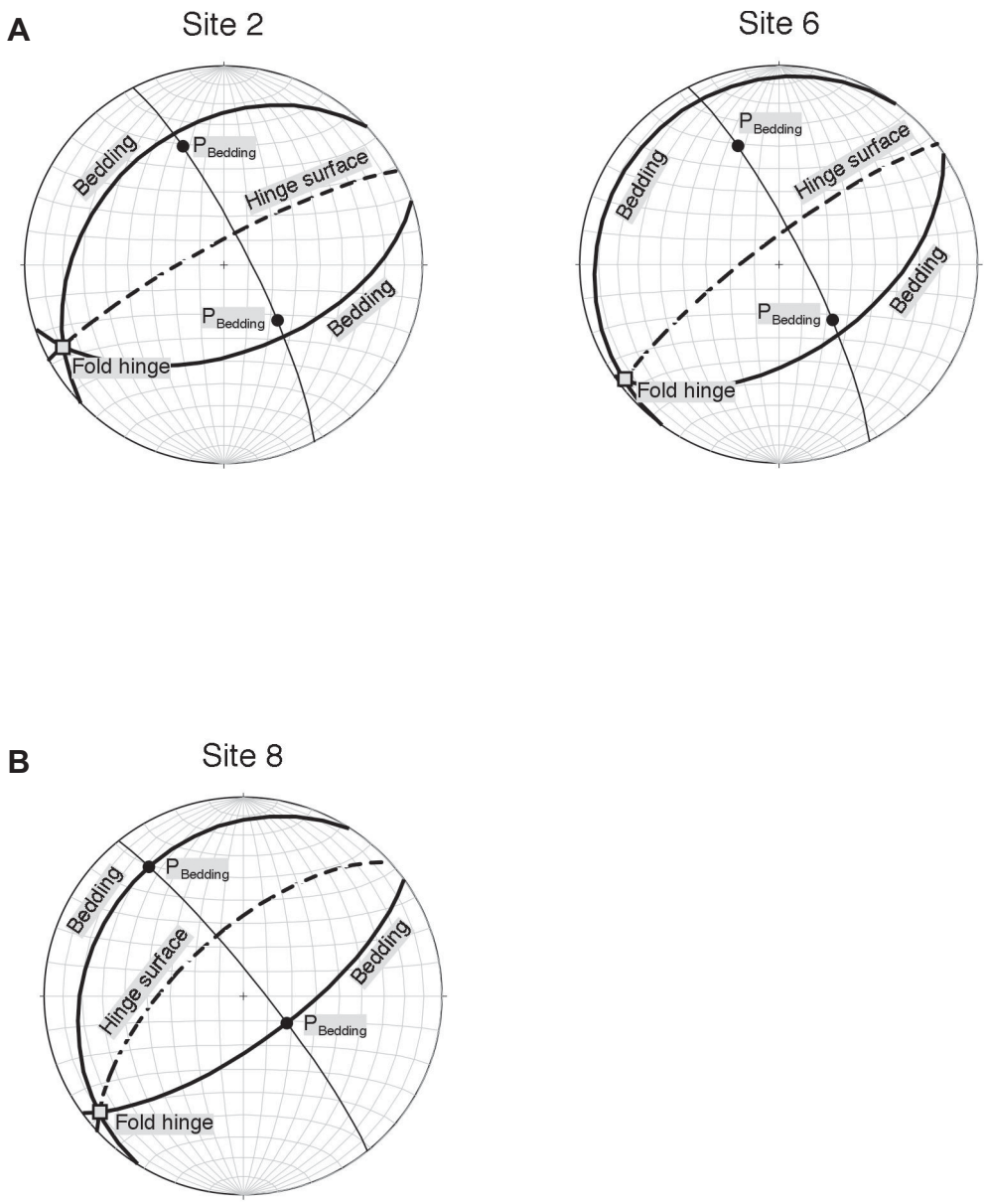


Figure 8. A, The orientations of the fold hinges from third-order folds exposed at sites 2 and 6. B, The orientation of the fold hinge from a fourth-order fold exposed at site 8. See Figure 5 for site locations.

Acknowledgments

We thank the Committee on Grants at Franklin and Marshall College for funding this research. We also thank Noel Potter, Peter Sak, and Robert Walter for helpful comments on Justin Herbert's senior thesis, on which this paper is based. We also thank two anonymous reviewers for their helpful comments, and Anne Lutz for her patience and thoughtful suggestions.

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ANNOUNCEMENT

The 81st Annual Field Conference of Pennsylvania Geologists, October 6–8, 2016

Energy and Environments: Geology in the "Nether World" of Indiana County, Pennsylvania

The Pennsylvania Geological Survey and the Department of Geoscience at Indiana University of Pennsylvania are proud to announce the **81st Annual Field Conference of Pennsylvania Geologists,** to be headquartered in Indiana, Pa., in 2016. The conference will highlight Indiana County and adjacent areas, which have been rich in both energy resources and nonfuel mineral resources for more than 100 years. We will look at both past and present environments. The first Geological Survey of Pennsylvania passed to the right and left of Indiana County, leaving it a veritable "nether world of geology." Since then, the geology of this area has been fleshed out, and we will do our best to cover as much of it as we can during this conference. Some of the stops and preconference trips this year include the Johnstown 1889 flood site, the Mississippian-Pennsylvanian unconformity, flint clay localities, several fossil sites, the Loyalhanna Limestone, the Saltsburg Sandstone, and kayaking and caving preconference trips.

Registration for this Field Conference will open on August 1, 2016. More information about this and previous conferences can be obtained at http://fcopg.org/, or you can ask to be added to our mailing list by emailing Stephen Shank at stshank@pa.gov.

Contacts: Katherine Schmid, Chair, 412–442–4232, kschmid@pa.gov; Kristen Hand, Vice Chair, 717–702–2046, khand@pa.gov; Stephen Shank, Secretary, 717–702–2021, stshank@pa.gov; and Connie Cross, Treasurer, 717–702–2054, ccross@pa.gov.

The Mississippian-Pennsylvanian unconformity along Pa. Route 56 in Indiana County, Pa.

BUREAU NEWS

New Geologist Manager at the Bureau

Arianne M. Proctor joined the Pennsylvania Geological Survey in March 2016 and currently serves as the manager of the bureau's Geologic Mapping Division. Arianne is assuming the functions of StateMap coordinator from Gale Blackmer as Gale takes on all the duties of State Geologist. Arianne will be responsible for managing all services, investigations, and data collection in the Mapping Division. She will work with other bureau management to develop policies and standards for publications, data collection, and data archiving.

Previously, Arianne was the chief of the oil and gas program in the Pennsylvania Bureau of Forestry's Minerals Division, where she managed natural gas development on State Forest lands, including negotiating and executing leases, approving the locations of gas infrastructure, and lease royalty accounting and auditing. Prior to joining the Department of Conservation and Natural Resources in 2010, she was employed by the Department of Environmental Protection, where she developed public water supply source-water protection plans and inventoried potential sources of contamination. She also researched the occurrence of pharmaceuticals, hormones, and organic wastewater compounds in Pennsylvania waters and the available water-treatment technologies capable of removing the compounds. Before joining the commonwealth in 2003, Arianne worked for an environmental consulting firm on assignments that included modeling groundwater flow in area landfills, environmental cleanup projects, and designing aquifer test monitoring. Arianne earned an M.S. degree in geology with a concentration in hydrogeology from Florida Atlantic University.

Arianne is from and currently lives in Harrisburg with her husband and two children. In her spare time, she enjoys being with her family on the farm or out hiking and fishing, watching their kids play soccer, squeezing in an occasional round of golf, maintaining the gardens, and canning the fruits of their labor.

BUREAU NEWS

Science Fair Judging

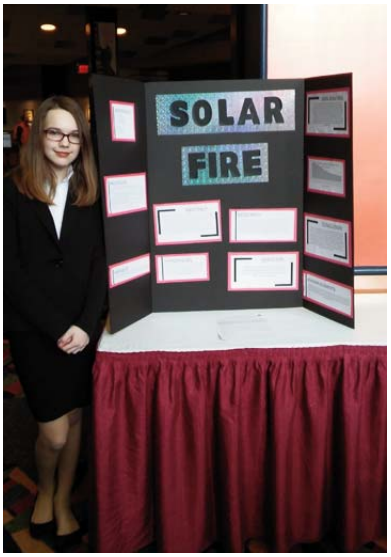
Staff geologist Toni Markowski had the pleasure of category judging Energy and Transportation projects at the 59th Capital Area Science and Engineering Fair (CASEF). The fair was held at the Whitaker Center for Science and the Arts in Harrisburg on February 25, 2016. Eight junior and senior students had an opportunity to showcase their creativity and problem-solving abilities through project definition, design and methodology, construction and testing, written reporting, and interviews. Junior project "Solar Fire" and senior project "VAWT vs. HAWT—A Wind Turbine Face Off" were nominated for Grand Champion.

This year's CASEF was especially exciting for students and judges because two new awards were offered. The first award, the **Dr. George Hayward Love, Sr., Judges' Award,** is presented to students whose projects exhibit excellence in display presentation, exceptional communication skills, positive reception to judges' critique, and an overall pleasant judging experience. Dr. Love served as a local science fair judge for more than 40 years, taught biology and chemistry at John Harris High School, served as Harrisburg School District director of personnel and director of the special projects division, and served as assistant commissioner for basic education with the Pennsylvania Department of Education. Toni recommended two senior Energy and and Transportation projects, "Which Source of Biomass Produces the Most Energy?" and "Electromagnetic Acceleration Launch Simulation," for this award.

The second is actually a group of awards, the **regional awards** as listed below, which are available to a limited number of students whose projects meet specific category criteria. Four projects were nominated for various regional awards. Grand Champion nominees are also eligible for the Dr. George Hayward Love, Sr., Judges' Award and regional awards.

Regional awards were provided by the following organizations:

- Air Force
- American Meteorological Society
- American Psychological Association
- Arizona State University Walton Sustainability Solutions Initiatives
- Association for Women Geoscientists
- GENIUS Olympiad
- Intel Excellence in Computer Science
- Mu Alpha Theta
- NASA EARTH
- National Oceanic and Atmospheric Administration
- Ricoh Americas Corporation
- Society for In Vitro Biology
- Stockholm Junior Water Prize
- U.S. Metric Association
- Yale Science and Engineering Association



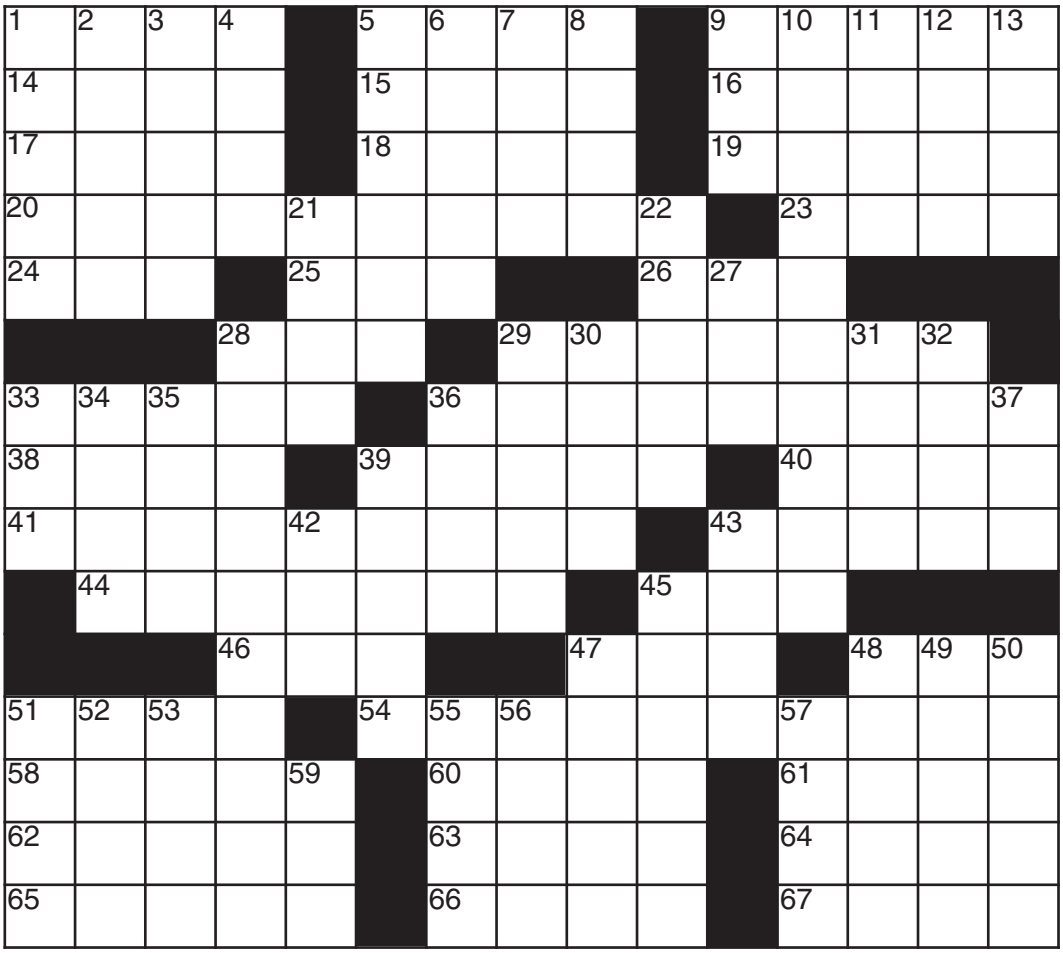
Anyone interested in judging for the 60th CASEF in 2017 should contact Valerie Knowles (CASEF Director) at 717–724–3892 or casef@whitakercenter.org. For further information about CASEF, see www.casef.org/.

GEOPUZZLE

Geopuzzle Number 1

(Solution on page 22)

William Kochanov
Pennsylvania Geological Survey



ACROSS

1. Noncoms (abbr.)
5. College collection area
9. Deposit of sediment
14. Dismounted
15. Do ____ others
16. East African tribe
17. Melody pattern (Hind.)
18. Malayan roofing material
19. Shipping container
20. Anhydrous minerals
23. #86 and #38 (per. table)
24. New Year festival
25. Summertime for 58 across

ACROSS *(Continued)*

26. German self
28. Common headwear at the Blue Parrot
29. Paul Harvey's source of information
33. Feudal area
36. Attractive mineral
38. Asian river
39. Goods
40. Crazy about
41. Countdowns
43. One high schooler
44. Painters
45. Malted beverage
46. Erode
47. Sault ____ Marie
48. Damage
51. Icelandic calcite
54. Take it for "granite," with 5 down on the side
58. A "capital seducer"
60. Pan's nemesis
61. Gaelic
62. A variety of 5 down
63. Southerner's delight
64. Continental "bedding"
65. Metric measure
66. Was observed
67. Utters

DOWN

1. 200 mg
2. A shaper, a surface, or a flier
3. Not dark
4. Remain
5. Four of these in a gallon?
6. Loosen
7. Rat-____
8. Thread lubricant
9. Former regulatory agency (abbr.)
10. Not as attractive as 36 acress
11. Horse color
12. Bits for Fido
13. ____ do well
21. ____ slayer (Cooper)
22. Stop, Curve, Falling rocks
27. Number three in a common trio
28. White or yellow, often a metamorphosed fellow
29. Roles
30. Relative of 37 down (pl.)
31. Angels afield
32. Suffix (fem.)
33. Traveler's need
34. Conan a.k.a.
35. Sudanese people
36. Agora
37. A long, long, long, long, long time ago
39. Compared
42. Aunt (sp.)
43. Guinness
45. Lower Pennsylvanian stage
47. Strand
48. Santa ____
49. To rate
50. Angler's needs
51. Tasty canned treat
52. Aid to Hill residents
53. I smell ____
55. Flower (Ger.)
56. Puff on the hooka
57. Not much
59. In a line (abbr.)

GEOPOETRY

This poem was written by former Bureau Director and State Geologist Donald Hoskins in response to a question about the reason for the name of the Ridge and Valley physiographic province.

Ridge First and Valley Second

In the alphabet
Ridge is first
To start a simple verse

In the Ridge and Valley
more importantly,
valleys would not exist
without the ridge

Valleys without a ridge
are flat, quiescent
awaiting erosion
and farmer's plows

It is the rising
of the ridges
muscular flexing,
earth's energy exposed

Therefore Ridge is first
the active term
Valley is second
I affirm.

—Donald M. Hoskins

RECENT PUBLICATION

Open-File Miscellaneous Investigation **[May 2016]**

- A guide for the geologic tourist to the northern extension of the York County Heritage Rail Trail

Solution to Geopuzzle Number 1

C	P	L	S		Q	U	A	D		A	P	R	O	N
A	L	I	T		U	N	T	O		N	Y	O	R	E
R	A	G	A		A	T	A	P		C	R	A	T	E
A	N	H	Y	D	R	I	T	E	S		R	N	S	R
T	E	T		E	T	E			I	C	H			
			F	E	Z		P	A	G	E	O	N	E	
M	A	N	O	R		M	A	G	N	E	T	I	T	E
A	M	U	R		W	A	R	E	S		I	N	T	O
P	R	E	S	T	A	R	T	S		A	T	E	E	N
	A	R	T	I	S	T	S		A	L	E			
			E	A	T			S	T	E		M	A	R
S	P	A	R		O	R	T	H	O	C	L	A	S	E
P	A	R	I	S		H	O	O	K		E	R	S	E
A	G	A	T	E		O	K	R	A		S	I	A	L
M	E	T	E	R		S	E	E	N		S	A	Y	S

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Feature Articles: All feature articles should be timely, lively, interesting, and well illustrated. The length of a feature article is ideally 5 to 7 pages, including illustrations. Line drawings should be submitted as CorelDraw (v. 9 or above) or Adobe Illustrator (v. 8 or above) files.

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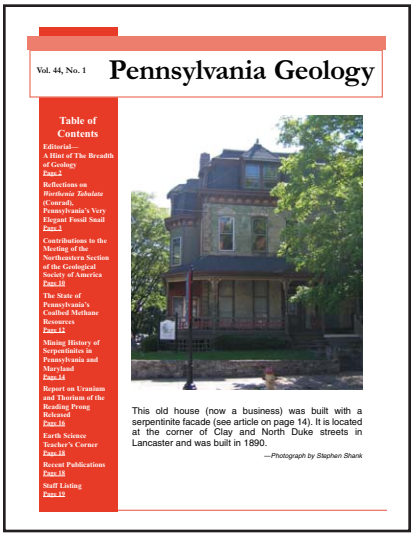
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This old house (now a business) was built with a serpentinite facade (see article on page 14). It is located at the corner of Clay and North Duke streets in Lancaster and was built in 1890.

—Photograph by Stephen Shank

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