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Pennsylvania GEOLOGY

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ON THE COVER

Side-looking airborne radar (SLAR) image of the Everett 15-minute quadrangle, Bedford County, Pa. (see article on page 2). Note the accentuation of topography and the textural and tonal differences among imagery pixels. North is oriented parallel to the length of the image and toward the top of the cover. The scale is 1:250,000.

PENNSYLVANIA GEOLOGY

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VOL. 30, NO. 3/4 **FALL/WINTER 1999**

STATE GEOLOGIST'S EDITORIAL

Groundwater and Land-Use Planning

With this issue, we announce a new edition of our Educational Series 3, *The Geology of Pennsylvania's Groundwater.* ES 3 provides readers with a modern, clear description of the most important renewable resource of our Commonwealth—water. Written in easy-to-read, nontechnical language, as well as amply and colorfully illustrated, ES 3 is designed to educate all readers about the source of much of the water that we use daily. To provide for wide usage of this educational report, the publication is free of charge, as are all of the other ten reports in this series! Public and private partners financially supported the printing of the new groundwater booklet.

The release of ES 3 is timely because it arrives just prior to the spring 2000 publication of the Governor's Center for Local Government reports about land use. In 1999, the Center conducted 53 forums throughout Pennsylvania on land use in our Commonwealth. According to the reports, "protecting our natural resources, particularly the quality and quantity of water resources, was one of the topics most frequently discussed during the forums." Concern about Pennsylvania's water resources was the sixth most frequently discussed topic of the forums.

At nearly half of the forums, representatives of the Pennsylvania Council of Professional Geologists stressed the need to incorporate the hydrologic cycle into a water-resources management program and the need to plan on a watershed basis, because "water resources do not respond to political boundaries."

Acting on the results of the forums, the Governor's Sound Land Use Advisory Committee developed four principal categories of recommendations, one of which was Education and Training. The Center will develop a Sound Land Use Education Program to implement this recommendation. In support of the program, *The Geology of Pennsylvania's Groundwater* provides easily understood descriptions and information about Pennsylvania's groundwater. ES 3 will aid all concerned people to work within their communities to develop and implement sound land-use plans that include supportable management and protection of our most valuable and necessary natural resource—groundwater.

Donald M. Hoskins
State Geologist

Geologic Mapping Using Radar Imagery in the Ridge and Valley Province

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INTRODUCTION. Side-looking airborne radar (SLAR) imagery proved to be a useful tool for mapping certain lithologic units and geologic structures in Connecticut. It has even greater value for mapping geology in the Ridge and Valley terrane of Pennsylvania, as demonstrated by recent work in the Everett 15-minute quadrangle in Bedford County.

Geologic Setting. The Everett area lies entirely within the Ridge and Valley province of the central Appalachians (Figure 1), a region in which strongly folded sedimentary rocks ranging in age from Cambrian to Pennsylvanian (approximately 570 to 290 million years old) are exposed. In Pennsylvania, the Ridge and Valley province is subdivided into the Appalachian Mountain section in the west and the Great Valley section in the east. The province is bounded on the east by metamorphosed Precambrian and Cambrian sedimentary and igneous rocks of the Blue Ridge and New England provinces, as well as nonmetamorphosed Triassic and Jurassic sedimentary and igneous rocks of the Gettysburg-Newark Lowland section of the Piedmont province. The Appalachian Plateaus province lies to the west of the Ridge and Valley. It is comprised of middle to upper Paleozoic strata, which, unlike the strata of the Ridge and Valley, are only very gently folded.

The cover rocks in the Ridge and Valley province are allochthonous, having been transported from their original location along regional décollements (“thin-skinned” tectonics of Rodgers, 1949). These rocks consist of two layers: a ductile layer and an underlying stiff layer. Sandstones, siltstones, and shales compose the ductile layer, whereas the stiff layer is comprised largely of carbonate units. Most anticlines

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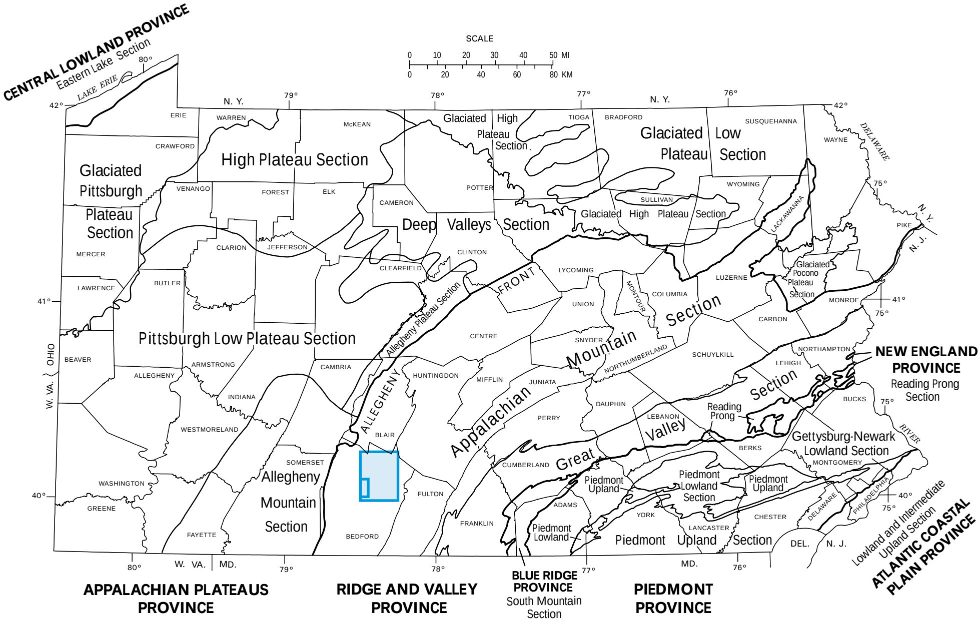

Figure 1. Physiographic map of Pennsylvania showing the location of the Everett 15-minute quadrangle within the Ridge and Valley province. Smaller rectangle indicates the area shown in Figure 3.

resulted from the imbricate stacking of carbonate units by ramping thrust faults, and synclines formed in the intervening regions. As a result of the thin-skinned tectonics and erosion, the surface expression of fold limbs and noses is well defined by resistant sandstone, orthoquartzite, and cherty carbonate rock ridges and intervening shale and carbonate valleys (front cover). The regional strike of structures and topography in the study area is north-northeast.

Background. The author's first experience with geologic interpretation of remotely sensed data (i.e., data obtained from sensors on aircraft or spacecraft) came when he was working on his master's thesis in structural geology and geophysics (Altamura, 1983). As part of the thesis, he analyzed U.S. Geological Survey (USGS) aeromagnetic data and supplemental ground-magnetic data using geophysical modeling techniques.

Later, the author was employed by the Connecticut Geological and Natural History Survey where one of his first tasks was to evaluate the new SLAR imagery for southern New England. Applying the techniques he used for his master's thesis, it was apparent to the author that there was a geologic component in the imagery, and a

Glossary of Technical Terms

aeromagnetic: describes data acquired from an airborne magnetometer.

allochthonous: refers to a mass of rocks, such as a thrust sheet, that has been moved from its original site by tectonic forces.

anticlinorium: a composite anticlinal structure of regional extent comprised of lesser folds.

coquinite: a compact, well-indurated, and firmly cemented detrital limestone composed chiefly of mechanically sorted fossil debris that experienced transport and abrasion before deposition.

décollement: a shallow-dipping to subhorizontal detachment surface in strata, resulting in independent styles of deformation in the rocks above and below.

drumlinoid: an oval hill or ridge of glacial till whose shape resembles that of a drumlin but is less regular and symmetrical.

fracture trace: a mappable simple or composite linear feature of the earth's surface whose parts are aligned in a straight or gently curved relationship and presumably reflect a subsurface phenomenon. Fracture traces are commonly expressed topographically as depressions or lines of depressions that range in length from approximately 100 m (300 ft) to 1.6 km (1 mi).

lineament: a mappable simple or composite linear feature of the earth's surface whose parts are aligned in a straight or gently curved relationship and presumably reflect a subsurface phenomenon. Like fracture traces, lineaments are commonly depressions or lines of depressions, but they are larger in size, ranging from longer than 1.6 km (1 mi) up to approximately 500 km (300 mi). Lineaments are prominent on relief models, high-altitude aerial photographs and imagery, satellite imagery, and mosaics of Landsat imagery.

lithology: the description of rocks, or the physical character of a rock.

marl: earthy mixture of clay and calcium carbonate.

morphotectonics: the tectonic interpretation of the morphology (shape) of present topographic features of the earth's surface.

orthoquartzite: a clastic sedimentary rock that is made up almost exclusively of quartz sand.

ramping: thrust faulting such that the fault surface is steeply inclined, at least near the surface.

geological investigation of Connecticut using the SLAR imagery was conducted. The Connecticut investigation, which is summarized in this article, laid the foundation for similar work in the Pennsylvania Ridge and Valley.

METHODOLOGY. SLAR data is acquired by transmitting a radar beam perpendicular to the ground track of an aircraft. When represented on photographic film, this data gives an illuminated view of the land that enhances subtle surface features and facilitates geological interpretation. A resolution of up to 10 m (33 ft) is possible (John Gardner, written communication, 1992). 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, SLAR systems can be used to prepare image base maps of cloud-covered areas.

Geologic mapping of the Everett area involved the interpretation of SLAR imagery viewed both stereoscopically and monoscopically. The SLAR stereo strips and mosaic base map used for this study were prepared by Motorola Airborne Remote Sensing (MARS) from X-band synthetic aperture radar data for the USGS.

The author interpreted geomorphic features, geologic structures (e.g., faults and lineaments), and lithologies on the 1:250,000-scale SLAR strip images, which he viewed stereoscopically. The lithologic contacts and geologic structures were drafted on a transparent overlay registered to the SLAR strips, and this information was transferred to a second clear overlay atop the 1:62,500-scale SLAR mosaic base map of the study area. Selected interpretations were field checked for accuracy.

GEOLOGICAL INVESTIGATION OF CONNECTICUT.

SLAR Lineament Mapping. The predominantly crystalline terranes of Connecticut made geologic mapping using SLAR imagery somewhat difficult. Metamorphosed sedimentary and igneous rocks make up approximately two thirds of the exposed bedrock in Connecticut. At 1:250,000 scale, most metamorphosed silicate rock units lack distinguishable attributes of textural, tonal, or topographic expression on SLAR imagery. Stratigraphic mapping was possible only in some areas of the essentially nonmetamorphosed Newark terrane, which is dominantly comprised of interbedded sedimentary and volcanic rocks. Consequently, in the Connecticut investigation, the author concentrated on mapping faults and presumed fracture zones (i.e., fracture traces and lineaments). His work resulted in the publication of a 1:125,000-scale lineament map of Connecticut (Altamura, 1985). The expression of subtle fracture traces and lineaments on SLAR imagery was found to be unmatched by other remotely sensed imagery.

The value of the lineament map was underscored by (1) the identification of previously unrecognized regional fracture zones, including the 31-mile-long Snake Meadow Brook fault (Altamura, 1987), and (2) an improved discrimination between local faults and other linear features, such as ridges and drumlinoids (Altamura and Quarrier, 1986).

SLAR Groundwater Application. While at the Connecticut Survey, the author used the SLAR lineament map and the Survey's large water-well database to test the hypothesis that bedrock wells in close proximity to SLAR lineaments would exhibit higher specific capacities (yields per foot of drawdown per foot of well depth) than more distant wells. Use of lineaments and fracture traces as groundwater prospecting tools had been proposed by Lattman and Parizek (1964). The extensive water-well database of the state government allowed for an unusual opportunity to statistically investigate this now classic method, which is utilized by most groundwater consulting firms in the world. The study was conducted on the core of a gneiss dome along the Bronson Hill anticlinorium, an area underlain by a single crystalline bedrock lithology. The water-well database included well location, well depth, well yield, static water level, drawdown, and lithologic information.

The study showed that the wells with the highest specific capacities occurred near the center of the SLAR lineaments (as hypothesized), but it also showed that some wells characterized by low specific capacities occurred in these same areas (Figure 2). A possible explanation for these findings is that the lineaments represent zones of fractures of variable spacing and openness that affect local groundwater transmissivities.

GEOLOGICAL INVESTIGATION IN THE PENNSYLVANIA RIDGE AND VALLEY. Geologic mapping using SLAR imagery in Pennsylvania began in the Everett 15-minute quadrangle. The geologic setting of the Ridge and Valley is ideal for using remote-sensing techniques to map stratigraphy and structure. The strong shadow enhancement on SLAR images (depression angle of approximately 20 degrees) made SLAR a useful tool for detecting lithological differences that are manifest by changes in slope due to weathering and erosion, as well as for detecting subtle linear valleys associated with faults, lineaments, and fracture traces. Studying textural, tonal, and topographic expressions portrayed in the imagery, the author prepared an overlay map at 1:62,500 scale for the Everett quadrangle on which geologic units were interpreted (Figure 3). In general, depending on vegetation and land use, ridges and other topographic highs were interpreted as coarse-grained clastic facies (e.g., conglomerates and sandstones), slopes as shales, and valley bottoms as carbonates (limestones or dolostones). In addition, relatively flat, open stream valleys having gentle slopes on either side were interpreted to be alluvial deposits. The distribution of each unit was traced throughout the quadrangle and integrated with the other units.

The attitudes of particular formations and fractures were deduced using classic morphotectonic inferences of “V” patterns (formed by geologic contacts crossed by streams) and of trellis drainage patterns.

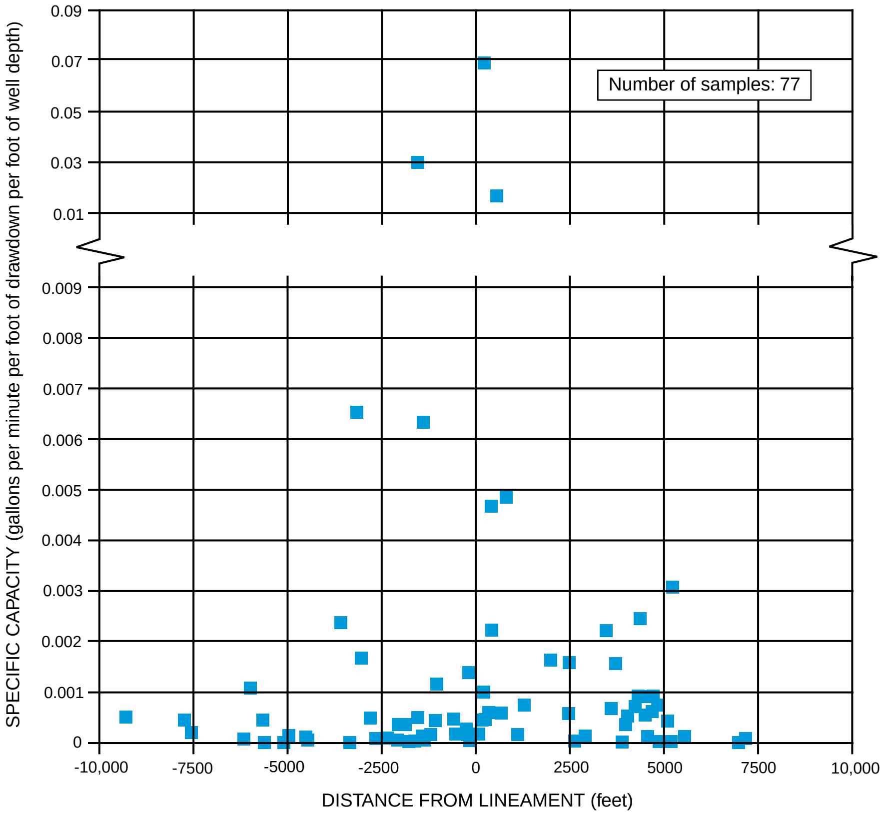

Figure 2. Specific capacities of water wells versus their distances from a mapped SLAR lineament, the Candlewood Hill Brook lineament near Killingworth, Conn. The highest specific capacities are found in wells closest to the lineament, a presumed fracture zone. Note the change in scale along the y-axis.

Structures were then inferred from the attitudes of the stratigraphic units. Mirror-image repetition of the same bed across strike implied folds, whereas lateral offsets of geologic units across linear valleys implied faults.

The *Geologic Map of Pennsylvania* (Berg and others, 1980) and the *Stratigraphic Correlation Chart of Pennsylvania* (Berg and others, 1986) were used as references for the stratigraphy of the Everett area. However, all geologic contacts and structures shown on the map produced for this study reflect the author's interpretation of their position on the SLAR stereo strips and mosaic image.

In the southwestern part of the study area, four units (Dm, Dmh_1, Dmh_2, and Dmh_3) were identified as subdivisions of what had been

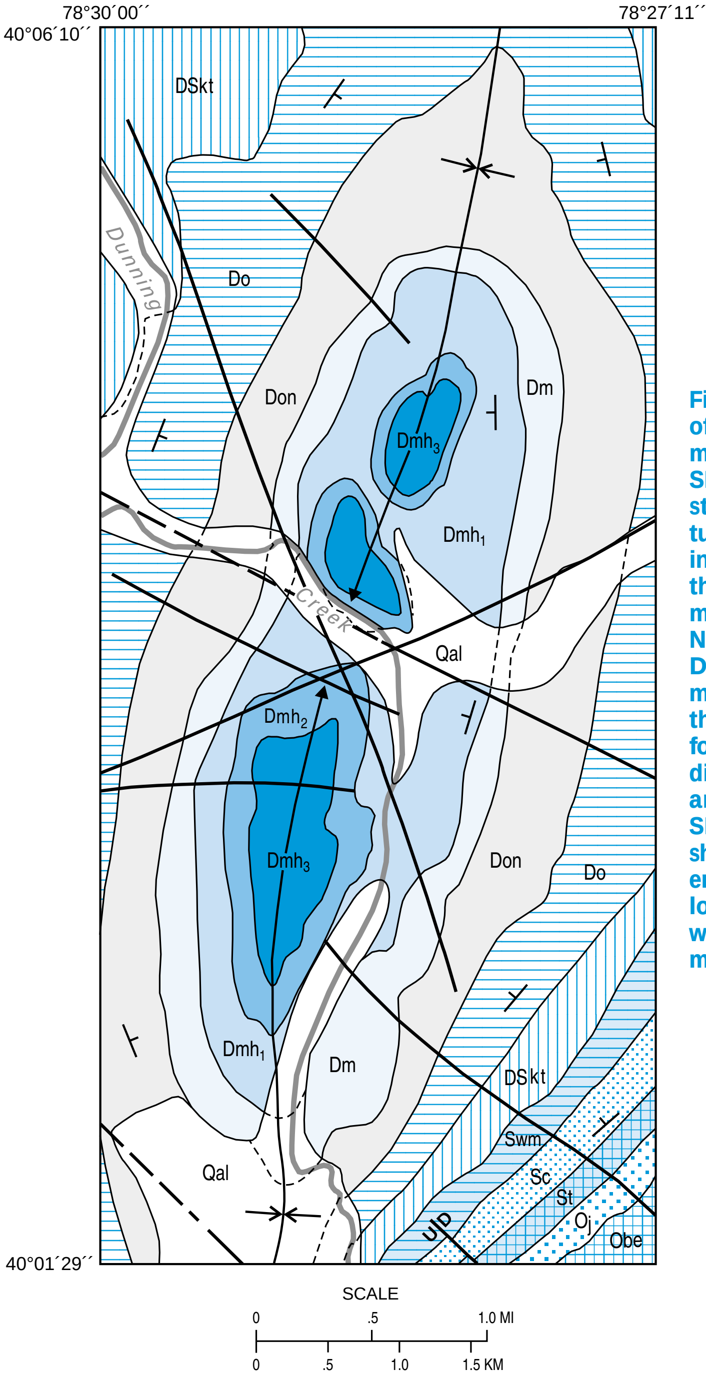

Figure 3. Enlargement of part of the geologic map derived from SLAR imagery of the study area. The structural basin shown is in the western half of the Everett West 7.5-minute quadrangle. Note the units Dmh_3, Dmh_2, Dmh_1, and Dm mapped in the core of the basin. These units form ridges and slopes discussed in the text and visible on the SLAR mosaic image shown on the front cover. See Figure 1 for the location of this area within the Everett 15-minute quadrangle.

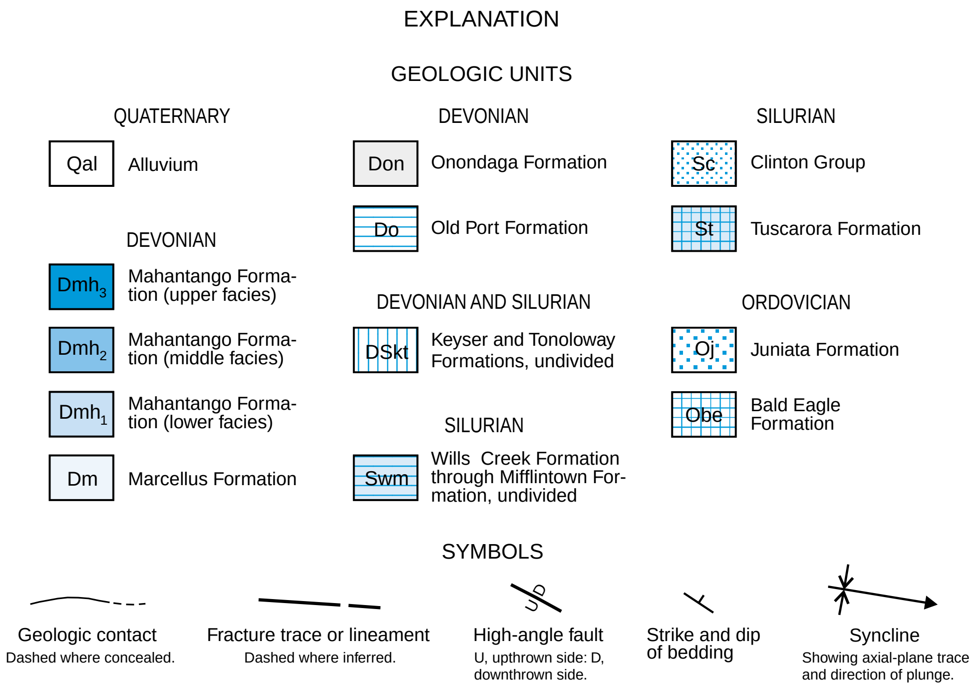

Figure 3. *Continued.*

shown by Berg and others (1980) as Devonian Hamilton Group (Figure 3; Altamura and Gold, 1992). Field checking revealed that these units represent two repeating coarsening-upward marine cycles. The coarsening-upward cycles are defined by shales (Dm and Dmh_2) overlain by siltstones, fine-grained sandstones, and minor fossiliferous coquinites and structureless marls (Dmh_1 and Dmh_3). Dm and Dmh_2 form slopes, and Dmh_1 and Dmh_3 form ridges. Because the physical characteristics of Dm are consistent with the Middle Devonian Marcellus Formation, it has been identified as such on the map. Dmh_1 through Dmh_3 correspond to depositional cycles recognized in the Middle Devonian Mahantango Formation (Dennison and Hasson, 1976; Duke and others, 1991).

Stratigraphically below the Marcellus Formation is the Middle to Lower Devonian Onondaga Formation, which in turn is underlain by the Lower Devonian Old Port Formation. These two formations are part of the outer edge of the basin shown in Figure 3. The Onondaga Formation underlies a valley between slopes of the Marcellus Formation and ridges formed by the Ridgeley Member of the Old Port Formation. The floor of a rare borrow pit in this valley reveals abundant shale fragments that probably represent the Needmore Shale, a member of the Onondaga.

The most prominent ridges seen on the SLAR image of the study area (front cover) are formed by the resistant orthoquartzite of the Lower Silurian Tuscarora Formation. One of these ridges wraps around the eastern side of the basin (Figure 3) and trends north-northeast north of the basin. Another Tuscarora ridge trends north-northeast across the center of the study area, and in the northern part of the area, it turns and forms the elongated nose of a southward-plunging anticline. Between and adjacent to these two ridges are slopes and dissected hills that are underlain by Ordovician Juniata Formation and Bald Eagle Formation sandstones and Reedsville Shale. Older Cambrian and Ordovician limestones, dolostones, and sandstones occur across the intervening wide valley. In the valley, most of the land underlain by carbonates is farmed, and most of the land underlain by sandstones is wooded. The associated land-use patterns were helpful in distinguishing these units on the SLAR image.

To the east of the central Tuscarora ridge, the rocks get progressively younger. In the southeastern part of the study area, the resistant sandstone of the Mississippian Pocono Formation forms a V-shaped ridge around the southern edge of the Broad Top coal basin, which includes sequences of Pennsylvanian sandstones, siltstones, shales, and coals.

In the eastern part of the study area, between the Broad Top basin and the central Tuscarora ridge, the author mapped belts of north-northeast-trending ridges and valleys. From west to east these represent rocks from the Middle Silurian through the Upper Devonian. Once again, what had been shown as Hamilton Group by Berg and others (1980) was subdivided into four distinct units. The author also distinguished ridge- and slope-forming units within the Catskill Formation. Field checks showed the ridge-forming unit to be dominantly sandstone and the slope-forming unit to be dominantly shale red beds.

Faults were interpreted where the radar expression of units shows clear offset of stratigraphy. Lineaments and fracture traces are also shown on the geologic map. Of particular note is the Everett-Bedford lineament (Gold and Parizek, 1976; Abriel, 1978; Gold and others, 1978), which has approximately 20 km (12 mi) of its approximately 100 km (62 mi) length in the Everett 15-minute-quadrangle area. This lineament trends N82°W across the southernmost part of the quadrangle and is represented on the SLAR image (front cover) by the two noticeable water gaps through the Tuscarora ridges and several straight stream segments. The abrupt termination of the Broad Top syncline in the southeastern part of the study area may also be related to the lineament. Kowalik and Gold (1976) suggested that lineaments defined by the alignment of abruptly plunging ends of long, continuous folds in the Ridge and Valley terrane are due to structures within the cover rocks. Southworth (1986), on the other hand, identified the Everett-Bedford lineament as a cross-strike structural discontinuity having its origin in the basement.

Any of the lineaments (and fracture traces) in the study area are potential targets for groundwater supplies (e.g., Lattman and Parizek, 1964). At locations where two or more lineaments intersect, such as in the central part of the basin shown in Figure 3, there is an added likelihood for groundwater resources. The use of lineaments has also been advanced for gas exploration in Devonian shales (Wheeler, 1980; Southworth, 1986) in the central Appalachians. Potential targets for gas exploration are located in the southern part of the Everett quadrangle where the Everett-Bedford lineament transgresses Devonian shales. Both groundwater prospecting and gas exploration rely on the assumption that lineaments represent fracture zones, and high fracture permeability is expected.

CONCLUSIONS. SLAR imagery is a useful tool for detecting lithologies and structures that are manifest by changes in slope during erosion. Earlier work by the author using SLAR imagery in Connecticut allowed him to recognize new structures and to provide new interpretations of the geology. His work in the Everett 15-minute quadrangle in the Ridge and Valley province resulted in some refinement of the local geology based on new interpretations and field checking. In the Everett West 7.5-minute quadrangle, the Marcellus Formation and three lithologic facies within the Mahantango Formation were delineated within an area that was previously mapped as Hamilton Group. Lineaments and fractures traces evident on the SLAR imagery for the study area are potential targets for groundwater resources and, where they transgress Devonian shales, may be targets for natural gas.

The author’s geologic map that was derived from SLAR imagery of the Everett 15-minute quadrangle is currently in review (Altamura, in preparation). The overall success of using SLAR imagery for geologic mapping in the study area has encouraged further mapping in the Ridge and Valley terrane. The author is currently mapping in the Hollidaysburg and Bedford 15-minute quadrangles in south-central Pennsylvania.

ACKNOWLEDGMENTS. The use of SLAR imagery to produce a geologic map for the Everett 15-minute-quadrangle area was possible due to the assistance and support of the Connecticut Geological and Natural History Survey, J. V. Gardner of Motorola Airborne Remote Sensing, and the Pennsylvania Geological Survey. D. P. Gold, a geology professor at Pennsylvania State University, took a particular interest in the project and provided suggestions and encouragement. The author thanks D. M. Hoskins, State Geologist of the Pennsylvania Geological Survey, and Survey geologist J. D. Inners for their reviews of this manuscript. An early draft benefited from the comments of A. G. Doden of Susquehanna University. The author is particularly grateful to J. V. Gardner for introducing him to the technique of geologic mapping using SLAR imagery and for sharing his affection for the geology of the Everett area.

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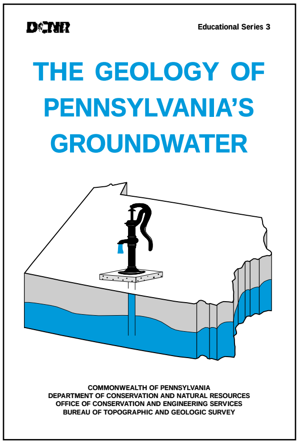
NEW RELEASES

New Edition of Educational Series 3



About half of Pennsylvania's 12 million residents rely on groundwater for drinking water, making the understanding of groundwater extremely important to the environment, health, and economy of the state. To help the public understand this very important natural resource, the Bureau of Topographic and Geologic Survey has published the third edition of **Educational Series 3, The Geology of Pennsylvania's Groundwater,** by staff hydrogeologist Gary M. Fleeger. This 34-page booklet is well-illustrated and written in nontechnical language. In contrast to previous editions, the new edition has a much greater emphasis on the geology of groundwater in Pennsylvania and less emphasis on demographics and legal issues.

The booklet contains information on the origin of groundwater, uses of groundwater in Pennsylvania, groundwater storage and flow, and groundwater chemistry. Several common misconceptions about groundwater flow, such as the popularly reported existence of an "underground river" beneath downtown Pittsburgh, are addressed. Through Pennsylvania examples, the author clearly illustrates how atmospheric water, surface water, and groundwater are part of the same system. The reader will learn how differences in natural groundwater chemistry can result from differences in rock types and topography, and how the chemistry of Pennsylvania's groundwater can be degraded without introducing any contaminants into the system.

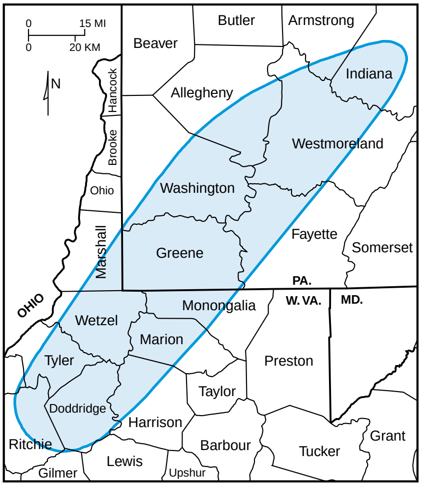
The American Institute of Professional Geologists, Pennsylvania Section, the Pennsylvania Association of Conservation Districts, the Pennsylvania Association of Township Supervisors, and the Philadelphia Suburban Water Company all provided financial support for the publication of this report.

Copies of Educational Series 3 are available free upon request from the Bureau of Topographic and Geologic Survey, P. O. Box 8453, Harrisburg, PA 17105–8453, telephone 717–787–2169. The booklet may also be viewed on the Bureau's web site at www.dcnr.state.pa.us/topogeo/pub/pub.htm.

Partnership Yields Open-File Report on Coal-Bed Methane in Pennsylvania and West Virginia

The Bureau of Topographic and Geologic Survey announces the availability of **Open-File Report 98–13, Geological Aspects of Coalbed Methane in the Northern Appalachian Coal Basin, Southwestern Pennsylvania and North-Central West Virginia.** This 72-page publication is based on geological investigations conducted in seven counties in southwestern Pennsylvania and eight counties in West Virginia between 1991 and 1993 by staff of the Pennsylvania and West Virginia Geological Surveys. It is a reprint of Topical Report GRI–95/0221, which was published by the Gas Research Institute of Chicago, Ill., in 1995.

Northern Westmoreland County and southern Indiana County have been identified in this report as prime areas for targeting development of coal-bed meth-

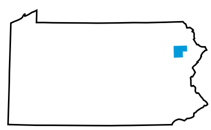


Location of study area.

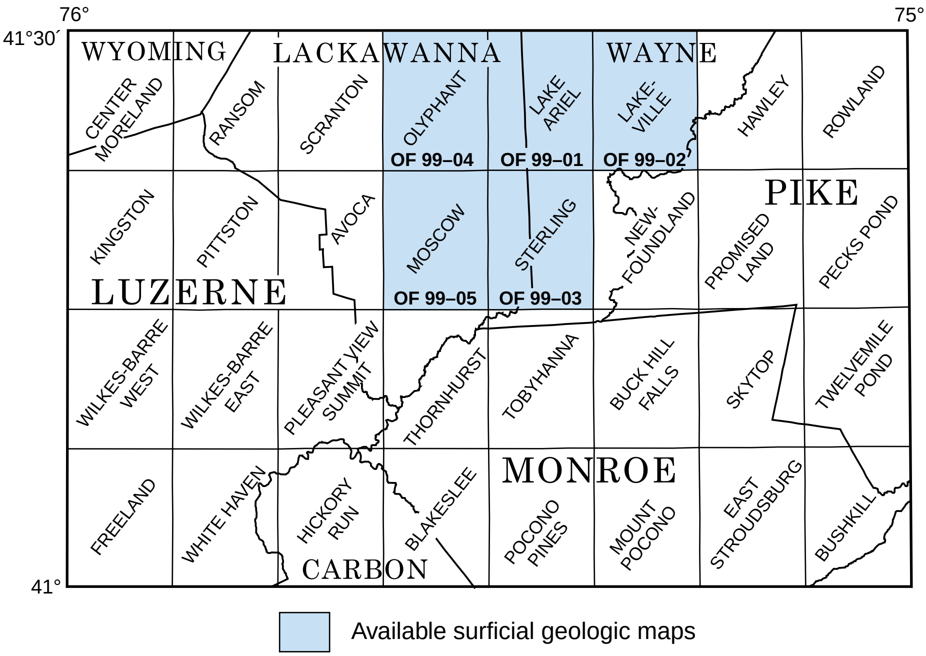
ane in Pennsylvania. Antonette K. Markowski and John A. Harper, staff geologists, found that, compared with other Pennsylvania bituminous coals, bituminous coals in the Allegheny Formation have the greatest potential for producing methane because of their higher coal rank. The report features 31 maps, 11 cross sections, and other diagrams illustrating the distributions and thicknesses of coals and associated sandstones. Areas where repeated intervals of coal and intervening sandstone layers are "stacked" are the best target areas for exploratory drilling and production because the coals in these areas have higher coal ranks and higher methane-gas content than the coals in other areas.

Open-File Report 98–13 may be purchased for **$3.00 plus $0.18 sales tax** for Pennsylvania residents. Prepayment is required; please make checks payable to *Commonwealth of Pennsylvania.* Additional ordering information is given at the end of the following announcement.

Surficial Geology of the Scranton Area



The first of a series of new open-file reports consisting of surficial geologic and isopach maps of the Scranton area has been published by the Bureau of Topographic and Geologic Survey. Five reports covering five 7.5-minute quadrangles—Lake Ariel, Lakeville, Sterling, Olyphant, and Moscow—in the north-central part of the Scranton 30- x 60-minute map sheet are now available (see figure on next page). The scale of the individual maps is 1:24,000 (1 inch equals 2,000 feet). The mapping was done by Duane D. Braun of Bloomsburg University, Bloomsburg, Pa., under a coop-



erative STATEMAP agreement between the Bureau and the U.S. Geological Survey.

All of the reports consist of uncolored photocopies of surficial geologic units hand drawn on a topographic quadrangle base map and of corresponding thicknesses of surficial deposits shown on a blank base. The maps are accompanied by a short text containing detailed descriptions of the surficial geologic units and a brief discussion on mapping methodology, previous work, and geologic history. Each report also includes a table showing the relationship between mapped units and county soil series.

Open File Reports 99–01—99–05 may be purchased for **$2.50 each, plus $0.15 sales tax** for Pennsylvania residents. Prepayment is required; please make checks payable to *Commonwealth of Pennsylvania.*

Orders for open-file reports should be sent to Open-File Sales, Bureau of Topographic and Geologic Survey, P. O. Box 8453, Harrisburg, PA 17105–8453. The reports may be examined in the Bureau library located on the second floor of the Evangelical Press Building, 1500 North Third Street, Harrisburg, telephone 717–783–8077, and in the Pittsburgh office of the Bureau at 500 Waterfront Drive, Washington's Landing, telephone 412–442–4235.

For further information on open-file reports, please contact Jon Inners, Chief, Geologic Mapping Division, telephone 717–783–7262.

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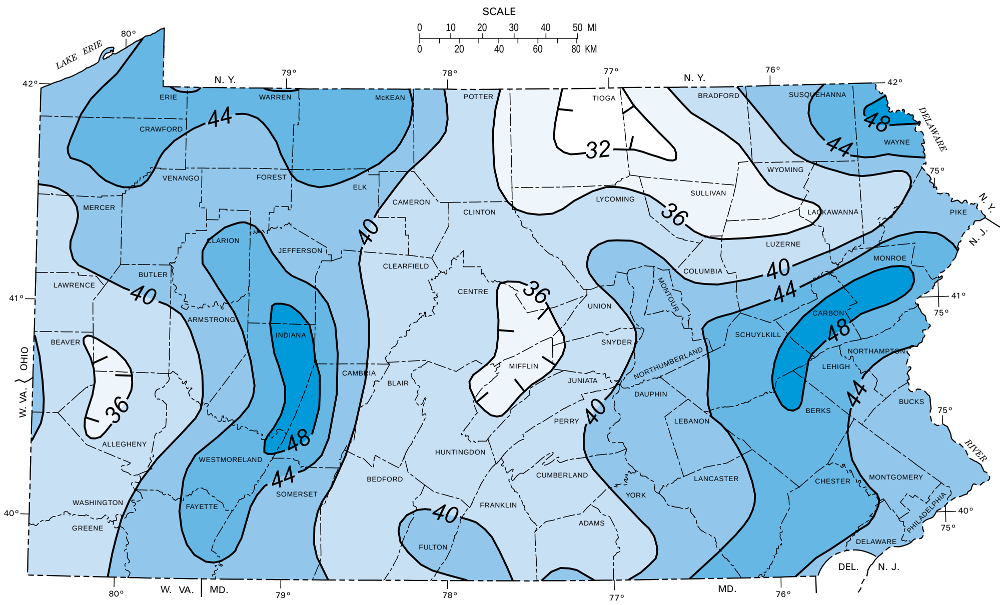

Precipitation values are in inches.

Bureau of Topographic and Geologic Survey
Department of Conservation and Natural Resources
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Harrisburg, PA 17105–8453

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