PENNSYLVANIA GEOLOGY

PENNSYLVANIA GEOLOGICAL SURVEY

VOL. 21/2

COMMONWEALTH OF PENNSYLVANIA
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TOPOGRAPHIC AND GEOLOGIC SURVEY
Donald M. Hoskins, Director

CONTENTS

ON THE COVER: Crenulations (microfolds) in the Marburg Schist of York County as viewed under a microscope (cross-polarized light). The axial planes of the crenulations are parallel to the second regional (S2) schistosity, which is discussed in relationship to schist of the Wissahickon Formation in the article on pages 3–9. The dark bands are coincident with the axial planes. This photomicrograph has been rotated 90 degrees clockwise from the true orientation, making the right edge of the photograph the true top. The horizontal field of view is 4 mm. Photograph by David W. Valentino.

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VOL. 21, NO. 2 **APRIL 1990**

Earth Day Certainties

Earth Day, 1990, commemorates the first Earth Day on April 22, 1970. New goals focus on building a safe, just, and sustainable planet; the "sustainable common future" of the World Commission on Environment and Development (the Brundtland report). The authors of this report also recognize the need for use of the earth's resources, including its mineral and energy resources.

Geologists are well suited to participate in the decisions of the decades ahead regarding a "sustainable common future," and participate we must. Our perspective of geologic time and earth events allows us to state some certainties of which all must be aware:

1. The earth is not fragile as some would believe—it is only life that is fragile. The earth existed for many millions of years without any atmosphere and hydrosphere; only the lithosphere was there. The lithosphere will persist without air and water.
2. The dynamism of our celestial system and cycles within the earth will produce natural change far greater than any man-induced change. That these natural changes may produce catastrophes far greater than any previously experienced by man does not make them any less natural.
3. Even knowing these certainties, geologists and other scientists also know that there are immense uncertainties associated with understanding the interrelationships of the lithosphere, hydrosphere, and atmosphere. Predicting the behavior of the systems is not yet possible.
4. The oft-stated aphorism "If it doesn't grow it must be mined" is true now and will be in the future. Although resource recovery disrupts the earth's surface, it can and is being done in an environmentally benign manner. Stating this does not imply that unrestrained growth is possible or desirable, only that maintenance of current human-engineered structures requires mineral resources.

A certainty of the 1990 Earth Day, as it is of every day of our earth, was stated by Van Loon in his 1932 book *Geography*: "We are all of us fellow passengers on the same planet and we are all of us equally responsible for the happiness and well-being of the world in which we happen to live."

Donald M. Hoskins

Donald M. Hoskins
State Geologist

IN MEMORIAM

Harry F. Ferguson (1921–1989)

Harry F. Ferguson passed away on November 4, 1989, after a long illness. He was an outstanding practitioner in the field of engineering geology, a professional who consistently emphasized the fundamentals in developing a geologic framework and relating it to the engineering requirements of the project. Through his many contributions, both with the U.S. Army Corps of Engineers and in private practice, he had a major influence on the practice of engineering geology in the upper Ohio River basin.

When Harry graduated from the University of Pittsburgh in 1949 with a B.S. degree in Geology, he joined the Groundwater Branch of the U.S. Geological Survey in Baltimore and conducted groundwater investigations throughout Maryland. In 1955 he transferred to the Military Geology Branch in Washington, D. C., where he was part of a team that developed terrain intelligence reports on strategic foreign areas.

Harry's career shifted to engineering geology in 1956 when he returned to Pittsburgh to work at the Pittsburgh District office of the U.S. Army Corps of Engineers. For the next decade he worked closely with District Geologist Shailer Philbrick, handling all geological and geotechnical aspects for the subsurface investigation, design, and construction of numerous flood-control dams, navigation locks, and flood-protection projects. Geological observations made by Harry during the excavation of numerous rock foundations for civil engineering projects throughout the Allegheny Plateau led to his pioneering work on valley stress relief, published in 1967. Harry succeeded Dr. Philbrick as District Geologist in 1966, and was named Chief of the Foundations and Materials Branch (later Geotechnical Branch) of the Pittsburgh District in 1972, one of the first two geologists to serve in that capacity. Following his retirement from the Corps in 1980, Harry practiced full time as a geotechnical consultant on a wide range of projects until the time of his death.

Harry was also a great influence for many young geologists and colleagues through his discussions at technical meetings and on field trips. He was an active participant in many professional and community organizations, and served as chairman of the Engineering Geology Division of the Geological Society of America in 1982.

Harry will be deeply missed by his many friends and colleagues within the geologic community. He is survived by his wife Vivian, his son Michael, and three daughters, Sandra, Jill, and Andrea.

by Richard E. Gray

A Linear Segment of the Martic Line: an Example of Dextral Transposition in the Piedmont Province of Pennsylvania

by David W. Valentino
Pennsylvania Geological Survey

Introduction

After an absence of nearly two and a half decades, the Pennsylvania Geological Survey has returned to the Piedmont province! This most complex of Pennsylvania's geologic terrains was the focus of much government-funded research in the first half of this century. Through the efforts of Florence Bascom, Eleanora Bliss Knopf, Anna Jonas, and George Stose, nearly all of the Piedmont was geologically mapped at a scale of 1:62,500. The new paradigm of plate tectonics and a quantum leap in our understanding of structural and metamorphic processes make revision of this old mapping necessary. Although the early workers recognized metamorphic minerals and rock structures, these geologic elements were not interpreted in the context of multiple orogeny, lithotectonic units, and crystal plastic flow. To remedy this situation, the Pennsylvania Survey has focused a major new mapping initiative in the Piedmont, the first phase of which is a detailed study of the metamorphic rocks exposed on the east side of the Susquehanna River gorge between Columbia, Lancaster County, and the Maryland line (Figure 1). This recent reconnaissance work has resulted in some exciting and thought-provoking findings (Faill and Valentino, 1989; Valentino, 1989).

Recognition and interpretation of microstructures in schist of the Wissahickon Formation exposed in the lower Susquehanna gorge provide evidence for horizontal compression and strike-parallel ductile faulting, which were not previously recognized. The "fault zone," or ductile shear zone, incorporates part of the enigmatic Martic Line, the contact between the Cambro-Ordovician Conestoga Formation and the Precambrian-Lower Paleozoic(?) Wissahickon Formation. Wissahickon phyllonite in the Turkey Hill area south of the Martic Line (Figure 2) contains subvertical crenulations and cubic pyrite crystals (5 to10 mm across) with attached quartz pressure fringes. Crenulations are the result of horizontal compression, and asymmetric dis-

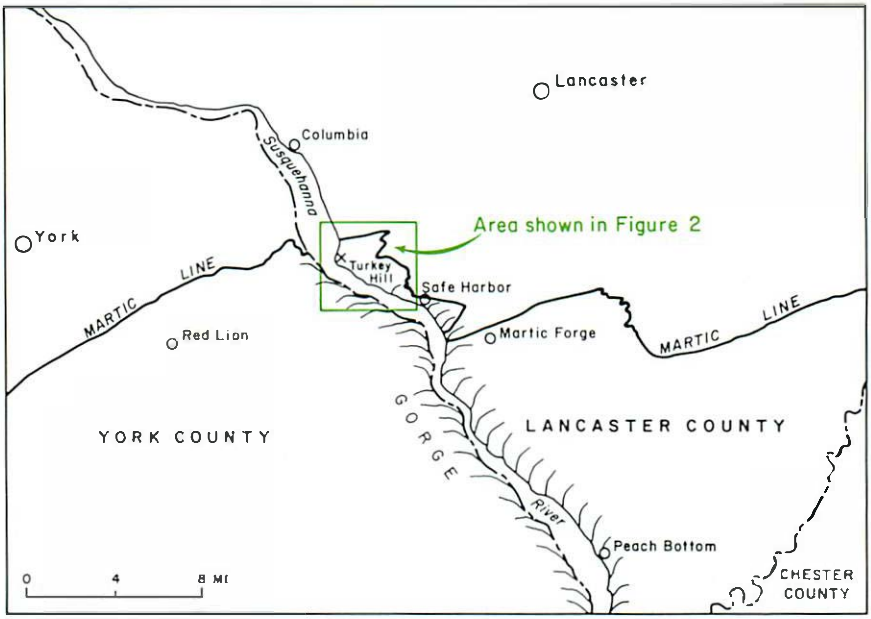

Figure 1. Map of Lancaster and York Counties showing the Susquehanna River gorge.

tribution of the quartz pressure fringes indicates dextral (right-lateral) ductile shearing.

Schistosity Relationships

The Wissahickon schists and phyllites bear interesting schistosity relationships in the area between Safe Harbor and Turkey Hill. At Safe Harbor, schistosity in Wissahickon schist is defined by parallel alignment of coarse chlorite, muscovite, biotite, and planar aggregates of plagioclase feldspar and quartz (S1). This S1 schistosity strikes 245° to 260° and dips moderately 40° to 50°NW. North of Safe Harbor, the S1 schistosity gradually steepens. As Turkey Hill is approached from the south, the schistosity (S1) progressively shows signs of weak to intense upright crenulation (small-scale folding having wavelengths up to a few millimeters). At Turkey Hill, crenulation of the S1 schistosity (Figure 3) was so intense that a new subvertical schistosity (S2) striking 070° developed and practically obliterated the S1 schistosity (Figure 4). This new (S2) schistosity is now defined by parallel alignment of very fine (submillimeter) musco-

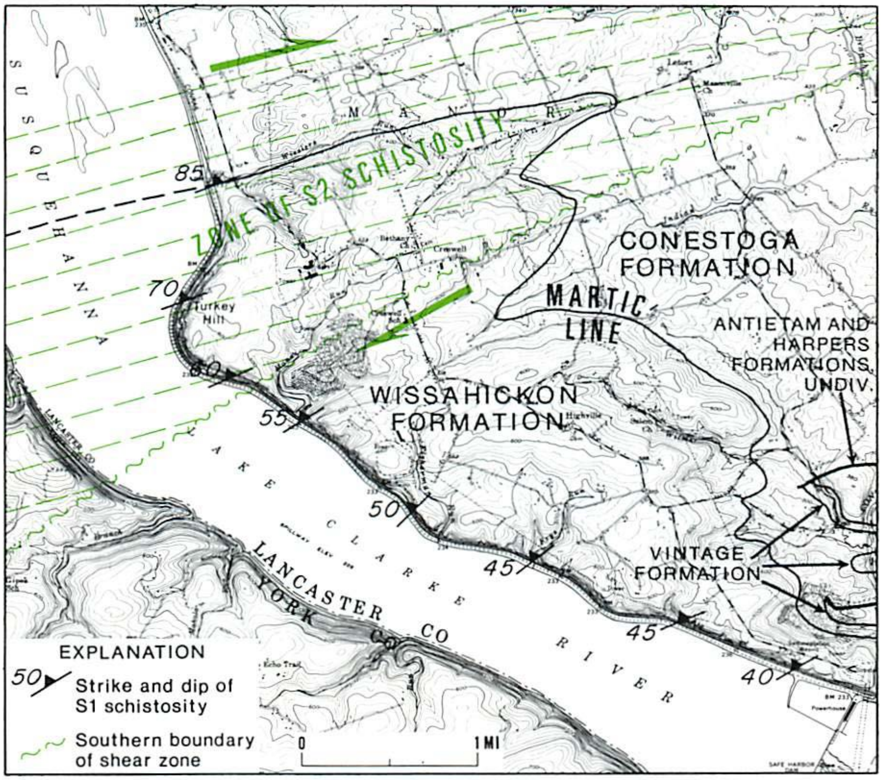

Figure 2. Bedrock and structure map of the Turkey Hill area, Lancaster County, Pennsylvania. The northern boundary of the zone of S2 schistosity is beyond the upper limit of this map.

vite and chlorite crystals and recrystallized planar quartz aggregates. Diamond-shaped profiles of intersection lineations (S2 x S1) clearly show the relative timing between the two schistosities.

Pyrite Crystals with Quartz Pressure Fringes

Oriented rock samples cut from the schist at Turkey Hill show pyrite crystals that have asymmetric quartz pressure fringes. The profiles of these microstructures are best observed on surfaces cut perpendicular to new (S2) schistosity and roughly parallel to the earth surface (horizontal). Pyrite crystals range in size from 5 to 10 mm, and the quartz pressure fringes are commonly twice the length of the host pyrite crystal (Figure 5).

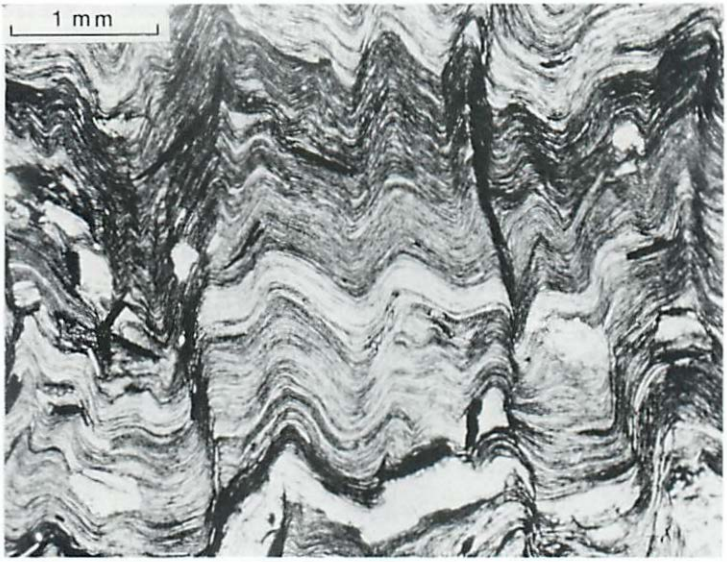

Figure 3. Photomicrograph of crenulations and weak second (S2) schistosity developed on the first (S1) schistosity. The view is looking 260 degrees at a nearly vertical surface.

How do these structures develop? At the onset of ductile shearing the rock begins to flow, allowing for growth of quartz in the direction of maximum extension (Ramsay, 1967) adjacent to the rigid pyrite crystal (Figure 6A). Continued shearing is accompanied by further quartz growth (Figure 6B). The final result is a pyrite crystal that has quartz pressure fringes distributed asymmetrically about the crystal;

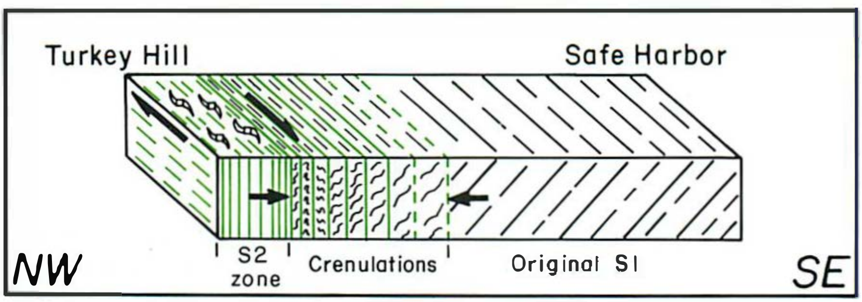

Figure 4. Schematic block diagram showing the development of the second (S2) schistosity; the first (S1) schistosity is shown as a reference structure.

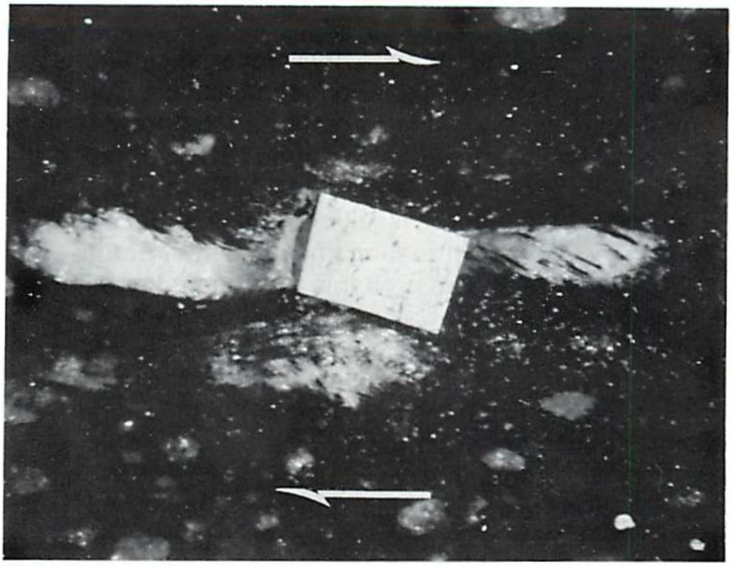

Figure 5. Pyrite crystal (6 mm across) having quartz pressure fringes associated with the second (S2) schistosity.

the pressure fringes point in the direction of structural offset (Figure 6C). The implications of asymmetric distribution are that (1) the rock has undergone simple shear; and (2) the shear sense can be determined (Ramsay, 1967; Ramsay and Huber, 1983; Simpson and Schmid, 1983; Etchecopar and Malavieille, 1987).

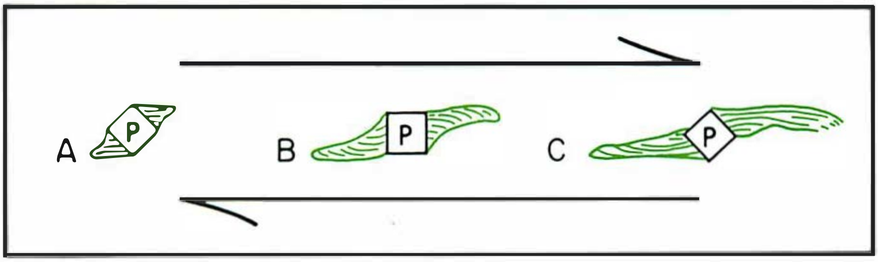

Figure 6. Schematic diagram showing the development of quartz pressure fringes. A. Ductile shear allows for quartz growth in the direction of maximum extension. B. Continuous ductile shear allows for further growth of the pressure fringe. C. The final quartz pressure fringes are distributed asymmetrically about the host pyrite crystal.

Regional Implications

The zone of second (S2) schistosity is located along the northernmost contact of the Wissahickon Formation and the Conestoga (marble) Formation (Figure 2). This formational contact is a linear segment of the Martic Line previously inferred to be a thrust fault (Knopf and Jonas, 1929; Stose and Stose, 1944; Wise, 1970). Although the original juxtaposition of the Wissahickon against the Conestoga Formation may have been by thrusting, the present structure at this contact is not a thrust fault. It is probable that evidence for much earlier structures, if they existed, was obliterated during the development of the first (S1) and second (S2) schistosities.

The crenulations defined by microfolding of the initial (S1) schistosity are associated with the development of the second (S2) schistosity. Crenulations are evidence for rock compression oriented perpendicular to the crenulation axial plane. Because the axial planes of the crenulations are subvertical, the compressive stress was horizontally oriented. The pyrite crystals with quartz pressure fringes that were recognized during this investigation have an asymmetry (upper right and lower left), when viewed looking into the earth, that indicates transcurrent dextral shearing. Microstructural analysis in this second (S2) schistosity zone revealed consistent dextral offset. An unusual linear prong of Wissahickon schist extends eastward into the Conestoga Formation along strike of the second (S2) schistosity zone at Turkey Hill. The overlap of the linear prong of Wissahickon schist with the zone of second (S2) schistosity suggests that the Wissahickon-Conestoga contact (the Martic Line) has been locally transposed dextrally. The combination of crenulations and microscopic shear structures associated with the second (S2) schistosity suggests a model of dextral strike-slip ductile faulting having a strong component of horizontal compression.

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Announcing the

1990 Field Conference of Pennsylvania Geologists

The 55th Annual Field Conference of Pennsylvania Geologists will be held in Lancaster, Pennsylvania, October 4-6, 1990. Special features of the 1990 Conference are as follows:

- The first day will be spent in the Piedmont of southern Lancaster County, where the main topic of discussion will be the metamorphism and structural development of the Tucquan antiform.
- The second day will be spent examining Cambrian limestones between Lancaster and York, with emphasis on problems of correlation in time-transgressive sequences and differences in intensity of deformation.
- Metabasalt, potholes, and landscape evolution are added attractions.

Registration information will be sent in early August. If you are not on the current Field Conference mailing list and wish to attend the 1990 Conference, please write to the Field Conference of Pennsylvania Geologists, P. O. Box 1124, Harrisburg, PA 17108-1124 (*please note new address*).

J. P. Lesley and the Great Anticline Debate

by John A. Harper
Pennsylvania Geological Survey

One of the principal tools used by the petroleum industry in locating potential new oil and natural gas reserves is the so-called "anticlinal theory." This theory was first developed prior to the drilling of Drake's well and was first published in definitive form in 1861. A simplified statement of the theory is as follows: because oil and natural gas are lighter and more buoyant, they will migrate within reservoir rocks to the highest point of an anticline or dome, and water will occupy the lowest points (Figure 1). Therefore, by drilling into the highest point on an anticline, the driller will obtain oil and/or gas rather than water.

Because many anticlines can be mapped at the surface without any knowledge of subsurface geology, especially in areas of gentle structure (Figure 1A), the "theory" worked well in the search for oil and gas in the early years. Therefore, it has been readily accepted by petroleum geologists for over 100 years. But it was not always so well thought of. In fact, from the mid-1860's until well into the 1880's, the anticlinal theory was considered controversial and unsupportable, largely because of the efforts of J. Peter Lesley, Director of the Second Geological Survey of Pennsylvania. Owen (1975, p. 78) claimed that Lesley "probably knew more than any other man about the geology of Pennsylvania" at that time. As chief geologist in the world's leading oil-producing state, Lesley was a force to be reckoned with concerning the geology of petroleum. Although he expressed some early support for the theory in 1863, his opposition to it was firmly set by 1865 and later became something of an obsession.

It is plain why Lesley felt that the theory had no validity in Pennsylvania. His consulting work in the oil fields in the early 1860's taught him that Pennsylvania's oil reservoirs were controlled by stratigraphy rather than by structure. This was later reiterated and clarified by geologists of the Second Survey. The depositional origin of the reser-

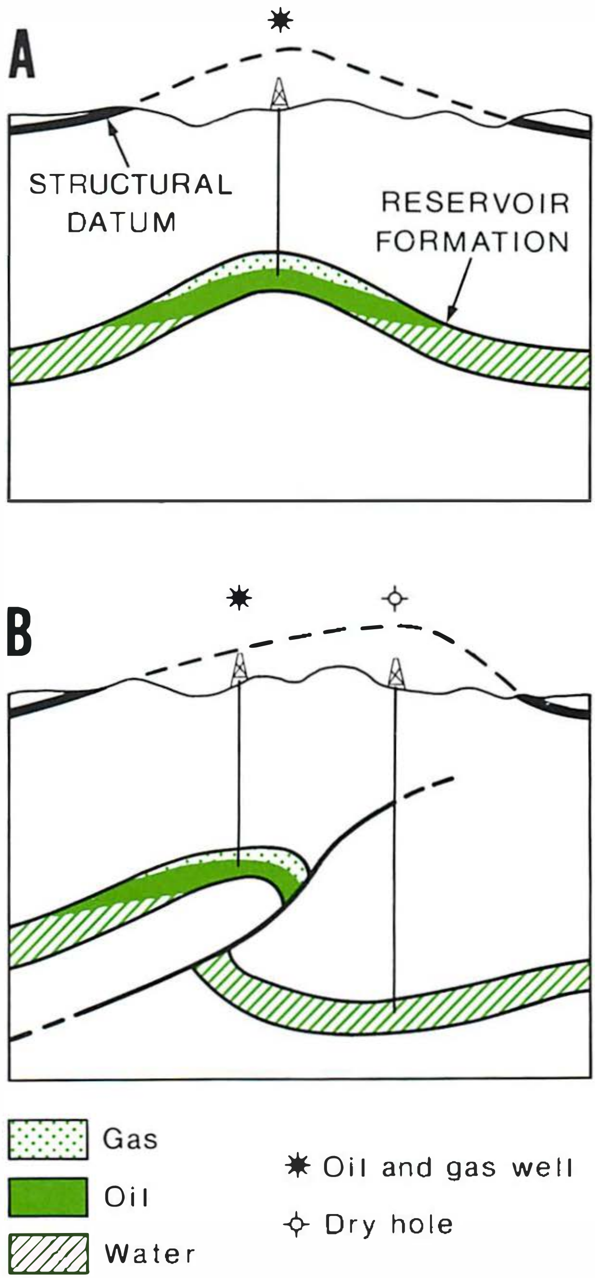

Figure 1. Graphic depictions of the anticlinal theory. According to the theory, oil and gas will be found in the reservoir rocks at the highest point of an anticline. Hydrocarbons can be found easily by using surface structure to delineate subsurface structure in areas of gentle to moderate folding (A). However, in areas where the structure is more intense, surface structure could be misleading, especially when used to the exclusion of all other exploratory methods (B).

voir rock, its geometry, and its composition and grain size were clearly more important to production than structural disturbance. In northwestern Pennsylvania, structure in the oil fields consists almost exclusively of a very low angle regional dip toward the southwest (Figures 2 and 3). In contrast, in central Pennsylvania, where anticlines form an impressive part of the geology, there were no known oil and gas reserves. Still, there is no clear reason why Lesley was so adamant in his opposition to the concept in general, particularly in light of his earlier support. He was so convinced that oil accumulations had nothing to do with geologic structure that he wrote (in Carll, 1880, p. xvi):

> The supposed connection of petroleum with anticlinal and synclinal axes, faults, crevices, cleavage planes, etc. is now a deservedly forgotten superstition. Geologists well acquainted with the oil regions never had the slightest faith in it, and it maintained its standing in the popular fancy only by being fostered by self-assuming experts who were not experienced geologists.

Lesley's convictions were well supported during the work of the Second Survey, mainly by John Carll, the Survey's expert on the oil industry (see, for example, Carll, 1875 and 1880). Carll is often considered by historians, such as Owen (1975) and Galey (1985), to have espoused the anticlinal theory, in direct contradiction to the philosophy of his superior. It this is so, there is no clear indication from his writings to substantiate it, aside from the last sentence of the following quotation (Carll, 1886, p. 73–74):

> . . . the anticlinals and synclinals now seen on the surface should not be taken as guides in searching for the oil-sands. These undulations were produced by movements in the earth-crust long after the oil-sands were deposited—as is shown by the fact that the coal measures are equally affected by the same waves—consequently they could have had no agency whatever in controlling and directing the currents which had already laid down the oil-sands thousands of years before. In so far as these anticlinals and synclinals affect the productiveness of the oil-sands, by affording an opportunity for gas to collect at the crowns of the arches and salt water to settle in the depressions between them, just so far ought they to have an influence in the selection of a location for an oil well, and no farther.

In fact, Carll's published reports indicate that he had very little faith in the idea. Having worked extensively in the oil fields of northwestern Pennsylvania for many years prior to joining the Survey, he, like

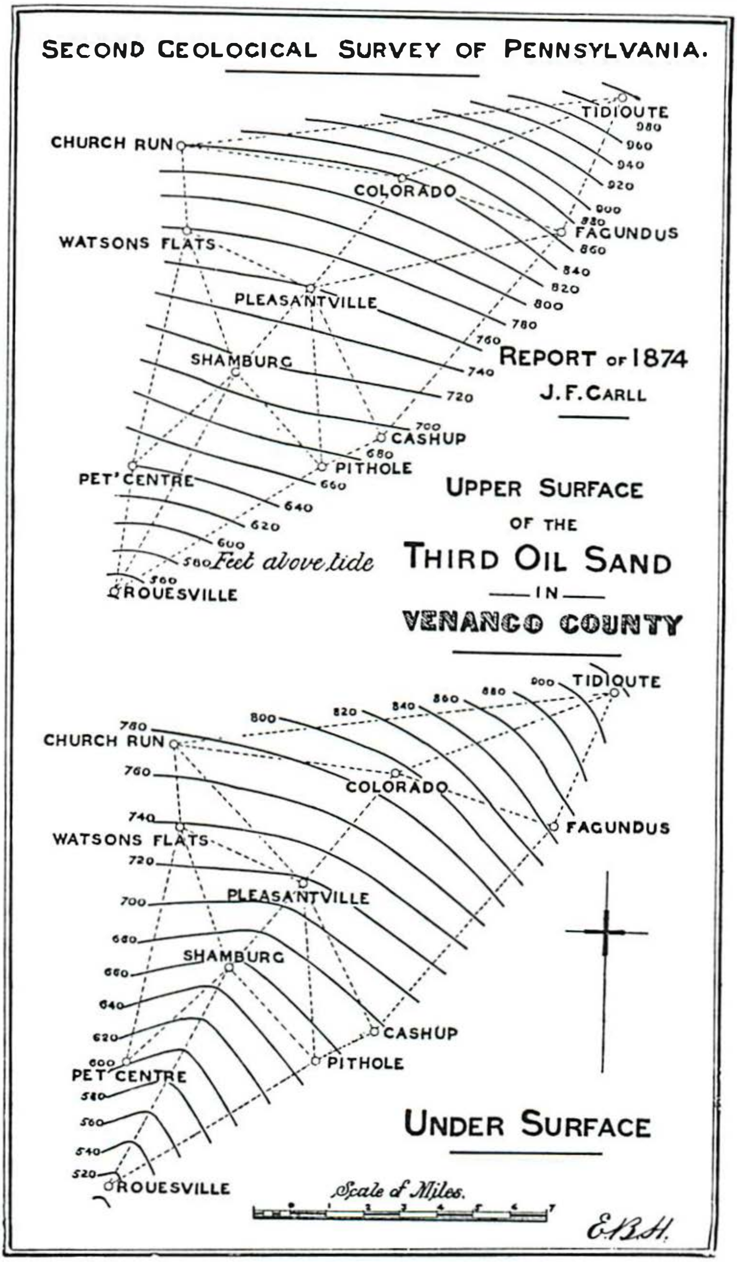

Figure 2. The first published subsurface structure maps, by John F. Carll (1875, p. 19), show that the reservoir rocks in northwestern Pennsylvania dip gently to the southwest.

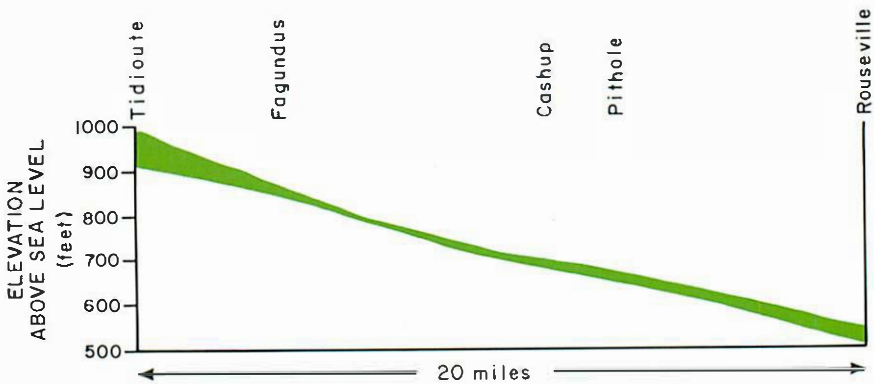

Figure 3. Structural cross section from Tidioute, Warren County, to Rouseville, Venango County, based on Carll's (1875) structure maps of the top and bottom of the Venango Third sand (Figure 2). Variations in sandstone composition and thickness are much more important than structure for controlling reservoir characteristics in this area.

Lesley, was all too aware that the oil pools owed their existence to depositional conditions, not to regional postdepositional disturbances. He stated (Carll, 1886, p. 75) that "the place to look for the guides and indices that will aid us most in an intelligent tracing of the oil-bearing sands is in the rocks themselves, and not . . . in the structure or position of the superimposed strata."

Lesley's determination to repudiate the concept had much influence within the Survey. J. J. Stevenson, the prestigious geology professor who was in charge of the bituminous coal studies of southwestern Pennsylvania, apparently accepted the anticlinal theory but with some reservation. Stevenson lived and worked in West Virginia, and so was very familiar with the successful drilling on the Burning Springs anticline in the northwestern part of that state. But during his tenure with the Second Survey he never expressed a strong opinion of whether or not the theory worked in Pennsylvania. Others, such as H. M. Chance and Charles Ashburner, both of whom had worked in the oil fields of northwestern Pennsylvania, gave only grudging lip service to the theory in reports or letters published outside the Survey. They strongly reiterated Carll's contentions that stratigraphic controls were far more important than structure in governing the emplacement of petroleum.

The one very notable exception to Survey staff indifference or antagonism to the theory was Stevenson's protégé, I. C. White. White was something of a maverick, as adamantly in favor of the concept as Lesley was against it. In fact, White published his own version of the theory in 1885, and actually laid claim to the concept. Most petroleum geologists credit White with giving the theory the impetus and acceptance it deserved, and with bringing the concept into the twentieth century.

Lesley continued to fight the anticlinal theory until his health broke in 1894 (Galey, 1985). Despite his profound influence, however, the concept prevailed. It worked, after all, and to the oil man spending money looking for elusive hydrocarbons, what could be more convincing? In fact, one of the major criticisms by the oil industry at that time was that the Second Survey could only tell them what they already knew, rather than give them a simple and straightforward exploratory tool for finding oil and gas. As stated by DeGolyer (1961, p. 24), "The anticlinal theory had the decided advantage that, in addition to being practically and theoretically as sound as the stratigraphic-trap theory, it afforded useful clues to the prospector in his search for new pools, a value not possessed by the stratigraphic-trap type of pool."

Fortunately for J. P. Lesley, he is remembered well for all of his contributions to geology in general and to the geology of Pennsylvania in particular. It would be a monumental mistake to denigrate a man of such historical and scientific importance simply for the sake of one misjudgment.

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Association of Engineering Geologists to Meet in Pittsburgh

Pennsylvania Geological Survey to Be Co-Sponsor of Teachers' Workshop

The Allegheny-Ohio Section of the Association of Engineering Geologists (AEG) will host the 33rd Annual Meeting of AEG from October 1 to 5, 1990, at the Hilton and Towers in Pittsburgh. The theme of this national meeting is "Engineering Geology for the 90's." The diverse program includes technical sessions, symposia, and short courses.

Technical sessions will focus on applied environmental and geological issues related to mine subsidence, hazardous-waste investigation and remediation, environmental geology, groundwater, slope stability, dams, karst, and erosion.

Two symposia are scheduled. One symposium will include 32 papers on the state-of-the-art prediction and control of mine subsidence. The other symposium will include 30 papers addressing the history of, need for, and current status of professional registration for geologists.

Four half-day short courses are scheduled concurrent with the Annual Meeting. They are "Environmental Applications of Engineering Geophysics," Sunday, September 30; "Applications of Microcomputers to Rock Slope Stability Analysis," Monday, October 1; "An Introduction to Geosynthetics: Selection, Design, and Applications to Waste Facilities," Monday, October 1; and "Site Characterization for Nuclear Waste Disposal," Thursday, October 4.

On Tuesday, October 2, the Pennsylvania Geological Survey, the University of Pittsburgh Department of Geology and Planetary Science, the Pittsburgh Geological Society, and the Allegheny-Ohio Section of AEG will sponsor a one-day Teachers' Workshop in conjunction with the annual meeting. Junior high and high school teachers will have the opportunity to broaden their understanding of geology, and will have hands-on experience in utilizing practical geological applications to compliment their environmental science curriculum. Teachers will also have the opportunity to receive Continuing Education Units through their participation in the workshop and meeting. Although teachers will be required to register for the workshop, they will not be charged a registration fee due to the generous financial sponsorship of the workshop by industry companies and organizations.

There will also be an Exhibit Program, which will be situated in an area centrally located to all meeting and function rooms. To receive a brochure and information for registration and exhibits, please contact AEG, MEMS, P. O. Box 270, Greensburg PA 15601, telephone 412-836-6813 (800-441-1674 in Pennsylvania; 800-343-5129 outside Pennsylvania).

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412-645-7057

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Joseph E. Kunz, *Clerk Typist*
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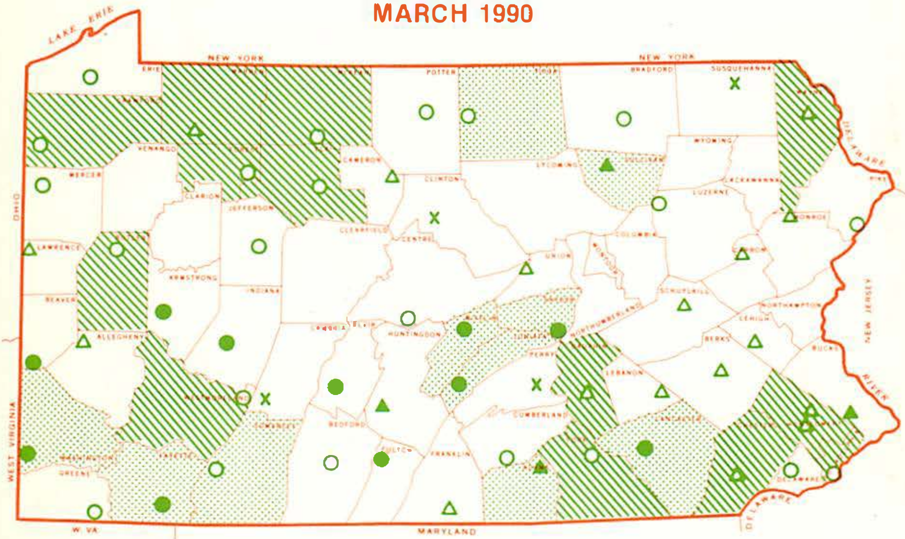
Antonette K. Markowski, *Geologist (Harrisburg Office)*
John Petro, *Cartographic Draftsman*

IN COOPERATION WITH THE U.S. GEOLOGICAL SURVEY

TOPOGRAPHIC MAPPING
GROUNDWATER-RESOURCE MAPPING

GROUNDWATER LEVELS FOR MARCH 1990



EXPLANATION

Above last year	Below last year	Above last year	Below last year				
Observation well		Observation well equipped with data-collection platform		No data	High	Normal range	Low

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Bureau of Topographic and Geologic Survey
Department of Environmental Resources
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