ON THE COVER: Ringing Rocks County Park, 1 mile west of Upper Black Eddy, Bucks County. A diabase boulder field (largest in the East) where it is possible to play a tune (Rock of Ages) by striking boulders with a hammer.

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FROM THE DESK OF THE STATE GEOLOGIST . . .

SO WHAT'S THE WORTH OF A GEOLOGIC REPORT?

Recently a highly dedicated watchdog of space and dollars suggested we dispose of our stock of published geologic reports because many of them are more than two years old. People who publish are supposed to know that it's all over for a book after a year and a half. I tried to explain that while Pennsylvania has undergone numerous geological upheavals over the millions of years, our geological reports would still be valid and useful after several decades. Our efficiency expert didn't give up. How come, said he, most of the geologic reports we have issued only sell 20 to 50 copies a year — how important can they be?

Good question: How important is a geologic report? How much is the report worth if it enables the highway department to pick a route that saves millions of dollars in construction costs? What's the value if the report identifies the location of mineral deposits needed to provide lime for the farmers, clay for the brickmakers, or coal for the steel industry? To justify its existence, how many copies of a geologic map must be sold which shows the location of geologic faults hazardous to nuclear power plants, and the location of sinkholes hazardous to schools and dams? How do you assess the value of a geologic report which identifies the location of groundwater needed to locate a new glass factory employing hundreds, or a sprawling, new multimillion dollar bottling operation? If our reports lead to natural gas occurrences that heat our homes, and dam sites that keep them from being flooded, must we sell as many copies as Gone With the Wind to justify their existence? Among those who tunneled the Turnpike, designed routes 80 and 81, engineered the renewal of Philadelphia, developed water wells for thirsty Lehigh, Bucks, and Chester Counties, rehabilitated the stripped lands of Western Pennsylvania, none of those eager users of our geologic reports were less thankful because the reports were done 10 years ago and the sale of the publications did not make the Times' best seller list.

To those who concern themselves over cost benefit ratios, turnover, and timeliness, we who issue geologic reports say: rest easy. Be assured the value of the report is not measured by its $4.75 price (plus tax); nor does its 1962 date relegate it to the uselessness of a vintage phone book, nor does its annual sale of 47 copies measure real need. Whether they provide mineral raw materials for our industries, locate the waters needed for our survival, identify the geologic hazards that can ruin us, or assist the road-builders, farmers, and recreation planners, our geologic reports measure up well to the test of time and value.

Arthur A. Scoblow
The "Eastern Overthrust Belt": An Explanation of Oil and Gas Activities in Central and Eastern Pennsylvania

by John A. Harper and Christopher D. Laughrey
Pa. Geological Survey

Within the last year or two there has been a flurry of activity in the central and eastern parts of Pennsylvania as large oil companies, seismic surveying crews and land speculators moved into these areas. Industry has invested millions of dollars and hundreds of man-years of work in an area that has traditionally been considered non-productive or uneconomical as far as oil and natural gas are concerned. With so much interest being spurred throughout Pennsylvania, we receive numerous questions from the general public, news media, consumer groups, and companies outside the Appalachian area as to what this activity means. What is the reason for this sudden interest in previously undrilled, unexplored, and unleased land in Pennsylvania, we are asked, and what will it mean to the citizens and industry of the Commonwealth? The interest is not restricted to Pennsylvania; the oil industry has targeted the entire Appalachian Mountain system, from Alabama to New England, for this exploratory and leasing activity, all because of what has become known in recent years as the "Eastern Overthrust Belt". The "Eastern Overthrust Belt", a term basically synonymous with the Appalachian Mountains, consists of a large assortment of folds and normal, strike-slip, and high-angle reverse faults as well as abundant low-angle thrusts of various dimensions.

The areal extent of the "Eastern Overthrust Belt" is a matter of argument. Many geologists, especially those associated with oil companies which search for oil and gas in "exotic" places, consider it restricted to the Valley and Ridge and the Great Valley provinces of the Appalachian chain, those areas associated with intense folding and faulting in Lower and Middle Paleozoic rock. Some investigators suggest that the major overthrusts extend from the Valley and Ridge eastward to the present continental margin, involving the Blue Ridge, Piedmont and Coastal Plain. Others, particularly geolo-
gists with the U.S. Geological Survey, consider the "Eastern Overthrust Belt" to include all these and other areas of the Appalachian Mountain system, including the structurally complex portions of the Allegheny Plateau (Figure 1). The latter view is reflected by the so-called overthrust test wells being drilled in the plateau areas of southeastern New York and northcentral Pennsylvania. Some companies have even leased land and are planning to drill in the greatly deformed crystalline rocks of western Vermont. Under the circumstances, Pennsylvania citizens should not be too surprised by offers to lease their land.

The "Eastern Overthrust Belt" concept is, generally speaking, not new. It has as its basis what is known as "thin-skinned tectonics", an idea originated by structural geologists working in the southern part of the Appalachians during the early part of this century. Thin-skinned tectonics, a term coined by Appalachian geologist John Rogers in the late 1940's, refers to the idea that deformation in the mountain system affected only the sedimentary rocks lying on top of the crystalline basement. Huge, low-angle thrusts faults with miles of displacement separate the deformed sedimentary strata from essentially undeformed basement rocks. This concept opposed the old idea, termed "thick-skinned tectonics" by Rogers, that folding and faulting occurred in the basement rocks and that

Figure 1. Location and extent of the "Eastern Overthrust Belt" (Appalachian Mountains.
the overlying sedimentary rocks are only secondarily folded and faulted in imitation of the basement. Many well-known Pennsylvania geologists of the first half of the 1900's, including George H. Ashley and Richard E. Sherrill, were adherents of the thick-skinned concept. Both maintained that the sediments in the fold belt are too weak to support their own weight; therefore, the basement must be involved. Thick-skinned tectonics is illustrated in Figure 2A.

Thin-skinned tectonics (Figure 2B) became a working hypothesis when geologists needed a model to explain what appeared to be shortening of sedimentary rock packages across vast distances. The Valley and Ridge and Blue Ridge provinces in the southern Appalachians are approximately 150 kilometers wide at present, but according to geologists working in that part of the country the area was originally about 450 kilometers wide when the rocks were deposited. Was a block of rock 300 kilometers wide simply removed? If so, where did it go? According to the thin-skinned tectonics concept, the rock layers farther to the east shoved over the western rocks, pushing them into the subsurface as pressures were applied by the colliding North American and African plates. Dozens of sub-horizontal and low-angle thrust faults, many of which extend to the surface, carried eastern rocks over western rocks in a series of imbricated sheets, similar to shuffling a deck of cards. This is especially apparent in the southern Appalachian Mountains where surficial geologic structure is dominated by thrust faults. In the central Appalachian Mountains, especially in Pennsylvania, the thrusts faults remain deeply buried for the most part and folding dominates

Figure 2. Generalized cross sections across southern Pennsylvania, illustrating the evolution of a concept. Not to scale.
A. Thick-skinned tectonics, in which the crystalline basement rocks (Precambrian) are folded and faulted, and the “weak” Paleozoic sedimentary rocks drape over these structures in imitation of them.
B. Older thin-skinned tectonics concept, in which the folding and faulting occurs in the sedimentary rocks and the basement is generally not involved; the Blue Ridge (South Mountain) and Piedmont are rooted in the basement and the major detachment fault rode up over them without affecting the crystalline rocks.
C. Newer thin-skinned tectonics concept, the “Eastern Overthrust Belt” idea, in which the structural styles are similar to the older concept (B), but the Piedmont and Blue Ridge are also involved; these crystalline rocks are shown thrust up over Cambrian sedimentary rocks.
the surface structure. Because of this, thin-skinned tectonics had a more difficult time being accepted in the north.

The thin-skinned concept, although embraced by a wide range of geologists, was nevertheless speculative in nature until limited drilling began in the Valley and Ridge Province in the 1950's. This drilling provided essential evidence to strengthen the general thin-skinned hypothesis, inasmuch as some wells were deep enough to penetrate multiple layers of rocks separated by faults. However, the concept remained relatively unconfirmed until the development and improvement of seismic exploration techniques. Seismic profiles across the Appalachian fold belt in all of its segments have given much credence to the thin-skinned model, and it is safe to say that there is general agreement among geologists to its validity throughout much of the Appalachians. However, the limits of the affected area have yet to be established.

The current excitement over the not-so-new concept of the “Eastern Overthrust Belt” comes as a result of three recent developments. Probably the most important of these was passage of the Natural Gas Policy Act (NGPA) of 1978 which encourages escalated exploration of high cost natural gas by gradual deregulation of gas prices. The recent acquisition and published evaluation of high-resolution seismic reflection data in the eastern portion of the southern Appalachian region is a second major development. The third is the discovery of large amounts of oil and natural gas in the “Western Overthrust Belt”, an area of the Rocky Mountains structurally similar to the “Eastern Overthrust Belt”.

Geophysical information, acquired from seismic surveys especially, locally confirms and regionally refines some aspects of the thin-skinned tectonics hypothesis. Innovative interpretations of these data have opened up whole new ideas on the origin and developmental history of the Appalachians. Recent surveys in Tennessee, Georgia and Virginia indicate reflective horizons beneath the Piedmont and Blue Ridge which have been interpreted as subhorizontal sedimentary rock layers. These interpretations indicate overthrusting has also affected the crystalline rocks in the eastern Appalachian provinces of the Southern Appalachians; there they have become detached from basement and thrust over more westerly Early Paleozoic rocks (Figure 2C). This would make it feasible for companies to drill through the crystalline rocks east of the Valley and Ridge and still encounter sediments, and perhaps petroleum deposits as well, at depth. In such a case the depth would probably be 30,000 to 40,000 feet. We have had the opportunity to examine seismic data in the Appalachians, and especially in Pennsylvania, which seems to indicate the presence of this detachment structure
in the subsurface at least as far north as the southern most portion of Pennsylvania. The extent of the Blue Ridge detachment is not nearly so great this far north as in Georgia, but it appears to exist to some degree. Presence of seismic reflections east of this detachment probably represents fault zones rooted in the Precambrian basement. Many of the oil and gas companies have had information of this kind for at least 10 years. This accounts for some of the leasing and subsequent seismic surveying activity in the southeastern counties of Pennsylvania.

The age and structural complexity of the eastern Valley and Ridge, Great Valley, Blue Ridge, and Piedmont require a consideration of the thermal history of that portion of the "Eastern Overthrust Belt". Assuming that the Piedmont actually has been thrust tens or hundreds of kilometers westward, Paleozoic sedimentary rocks beneath it probably reached temperatures and pressures high enough to initiate at least low-grade metamorphism. Under such conditions most hydrocarbons in the rocks at the time would have reached the gaseous phase (e.g. methane) and been driven off into the atmosphere, or possibly into reservoirs in the cooler adjacent areas. Many geologists believe the heat and pressure to which those rocks were subjected probably removed any hydrocarbons which once might have been there. In other words, structurally the Eastern Overthrust Belt may exist, but may be barren of oil or gas.

However high the stakes may be, the petroleum industry appears prepared to wager huge sums of money to drill deep wells in the "Eastern Overthrust Belt". Any such venture is a gamble, however, and in gambling terms industry has to study its cards carefully before upping the ante. So it is that residents in central and eastern Pennsylvania, as well as from other "non-productive" areas, should expect more and more to receive requests for leasing and permits for seismic work as the next few years unfold. But only time and a lot of money will tell if the gamble was worth the risk. There may be oil or gas down there, or there may be none.
On April 12 and May 12, 1982, the greater Philadelphia region experienced two more earthquakes. Since this is the second sequence of earthquakes in almost two years, the lower Delaware River Valley has been one of the most seismically active regions on the east coast during the last decade. The April 12, 1982 event occurred at 5:14 PM Eastern Standard Time and had a Nuttli magnitude of 2.9. This earthquake apparently occurred between the towns of Cornwells Heights, Pa. and Burlington, N.J. along the Delaware River (Figure 1). Thus the epicenter of the April 12 earthquake was very near the felt areas of the Sept. 10, 1877 and Dec. 27, 1961 earthquakes that affected the regions surrounding the towns of Bristol, Pa. and Burlington, N.J. (Abdypoor and Bischke, 1982). The May 12th event occurred at 12:01 Eastern Standard Time, was smaller than the April 12 earthquake, and was apparently centered near the town of Penndel, Pa., about 6 miles to the northwest of the April 12 earthquake.

Two years prior to these events the city of Philadelphia and its northern suburbs experienced 5 earthquakes, of which 3 were felt. The two largest of these earthquakes occurred on March 5 and 11, 1980 and had revised Nuttli magnitudes of 3.0 and 3.2, respectively. They were most strongly felt in the Abington, Glenside, Jenkintown, and Huntingdon Valley areas of Pennsylvania (Bischke, 1980). This is significant because the Huntingdon Valley fault, a very old but major tectonic dislocation (Tearpock and Bischke, 1980), runs through these cities. Penndel, Pa., the apparent center of the small May 12, 1982 event, is located on the Huntingdon Valley fault about 10 miles to the east of the epicenters of the March 5 and 11, 1980 earthquakes.

Immediately after the April 12 event a number of local and regional newspapers published an earthquake felt report questionnaire to test people's reactions to the earthquake. Of these questionnaires
222 and 139 were returned from the Pennsylvania and New Jersey areas, respectively. These data were analyzed at Temple University and a modified Mercalli intensity map was constructed for the April 12 event (Figure 1).

People living within the felt area both heard and felt the earthquake, and most people reported a trembling motion lasting from between 5 to 10 seconds. People’s reactions to the earthquake varied, although most descriptions of what occurred at the time of the earthquake were remarkably similar. Many people described the earthquake as a distant explosion or boom; while others thought that their furnace or oil heater blew up, that a truck hit a pothole or a building, or that furniture was being dragged across the floor. In two other cases a vase overturned, and dishes moved slightly. In general, however, most people agreed that the 1982 event was not as intense as the 1980 events; that the earthquake shook the buildings in which they were located and that the windows often rattled. These descriptions place the April 12 event between intensity III to IV on the Mercalli scale, although intensity V was felt locally.

An examination of the isoseismal map (Figure 1) shows that the earthquake was felt from the Mt. Airy-City Line region in western Philadelphia to Pemberton, N.J. in the east, and from the Newtown-Yardely, Pa. areas in the north to the Medford Lakes, N.J. region in the south. This area corresponds to a region of 485 sq. miles. As a comparison, the magnitude 3.2 March 11, 1980 earthquake was felt over a 350 sq. mile area (See Bischke, 1980). How can the smaller magnitude 2.9 April 12, 1982 event be felt over a larger area than the magnitude 3.2 1980 event?

Two factors could contribute to the differences in the size of the felt areas. First, the 1982 earthquake may have occurred at a shallower depth than the 1980 earthquake, although many people also reported hearing the 1980 events. This suggests that all of these earthquakes were shallow earthquakes. Second, an examination of the Isoseismal map of the Aug. 22, 1938 Central New Jersey earthquake (Neumann, 1940) reveals that the isoseismals over the unconsolidated or soft coastal plain sediments, which exist to the south of the Delaware River, are deflected far to the east or southeast and towards the New Jersey shore. To the north of the Delaware River the rocks are crystalline or hard, being composed of Wissahickon schist and Precambrian gneisses. Here the isoseismals of the 1938 earthquake trend east northeast and are most compact and closer together. Thus it appears that the unconsolidated coastal plain sediments of New Jersey are more capable of transmitting high amplitude waves over larger areas than are the crystalline rocks to the north of the Delaware River. As the epicenter of the April 12 earth-
quake was near the Pennsylvania-New Jersey border, and as the earthquake was felt over a larger area of New Jersey than of Pennsylvania, the isoseismal map (Figure 1) seems to confirm the above conclusion. This can best be seen by first placing a sheet of paper along the Fall Line on figure 1 and covering the state of New Jersey,
and then repeating this process by covering the state of Pennsylvania.

Since the Greater Philadelphia region has had a history of twin or multiple earthquakes, twin earthquakes occurring in this region on March 17 and Nov. 29, 1800, Nov. 11 and 14, 1840, and on March 5 and 11, 1980 (Conrad and Geyer, 1971; Abdypoor and Bischke, 1982); The Delaware Valley earthquake research team, in conjunction with Penn State University, installed a portable microearthquake seismograph (MEQ 800) at the Johnsville Naval Air Development Center (see Figure 1). This instrument recorded a small event on May 12, 1980 at 12:01 PM which occurred 8 miles away from the Naval Air Development Center. At precisely this time Police stations and a local newspaper located near the towns of Bristol, Levittown, Newtown, Trevose and Penndel, Pa. reported receiving numerous telephone calls complaining about an explosion and earth tremors. This area is outlined by the dashed line region on Figure 1. As Penndel, Pa. is located 8 miles from the Naval Air Development Center, and as this town is located in the center of the felt area of the May 12 event, Penndel is the likely center for this probable earthquake. A more accurate location for this event is not possible as it was apparently too small to be recorded at more distant seismic stations.

It appears possible that the Huntingdon Valley fault was responsible for the May 12 event. Residents within the felt area reported hearing an explosion and/or feeling their houses shake. Thus the May 12 event was on the order of Mercalli intensity III.

Therefore the Greater Philadelphia region appears to have two active fault lines: the Huntingdon Valley fault to the north of the city and the Fall Line fault beneath the Delaware River. The Feb. 28, 1973 (M = 3.8) Wilmington, Delaware, and Dec. 27, 1961 Pennsylvania-New Jersey earthquakes support this conclusion. The Wilmington, Delaware earthquake was located adjacent to the city of Wilmington and directly beneath the Delaware River (Sbar, et al., 1975). Thus the Fall Line lineament, which runs from northern Virginia to New York City, seems to have been responsible for the April 12, 1982 earthquake.

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REFERENCES


Dr. Edgar T. Wherry

Pennsylvania has lost a distinguished scientist and major contributor to geological knowledge in the death of Edgar T. Wherry on May 19, 1982. With an undergraduate degree in chemistry and his doctorate in mineralogy (from Penn), Professor Wherry went on to become a distinguished botanist at Penn, an outstanding mineralogist at the U.S. National Museum and U.S. Department of Agriculture, and an enthusiastic field geologist, with frequent contributions to the geologic data that was being assembled at the Pennsylvania Geologic Survey. Dr. Wherry was a prolific author, active in each of his fields of interest, and so very capable of bringing together the diverse sciences as a true naturalist. Almost to his passing at age 96, we continued to receive notes from him on his latest geologic thoughts and concepts.

The Pennsylvania Survey is privileged to have known Dr. Wherry as a friend and co-worker.
Kutztown State College has a quarry!

by William Kreiger
Kutztown State College

Although the quarry was purchased with a large tract of land in 1970, much of the campus population is not aware that it is part of the Kutztown State College campus. The five acre quarry is located on the southern limits of the campus behind Keystone Gymnasium and South Dining Hall. It is not in commercial operation, but it is being utilized by students of geology. Kutztown State College is fortu-

Figure 1. The southeast wall of the quarry bench showing fault zone, solution cavities, and bedding among other sedimentary features.
nate to have this extraordinary facility for the quarry has a multitude of uses in geology, environmental science and biological science.

It is a "hands on" learning tool and several quarry related laboratory exercises have been developed by the geology instructors. Some features of sedimentary rocks to note in the quarry are bedding, jointing, mudcracks, fossils, and solution cavities. Structural features include fault zones and folds (Figure 1). The ground-water table level and the water table fluctuation can also be observed here.

The exposed rock is Ordovician limestone of the Beekmantown Group, the Epler Formation. It formed from limy sediments deposited in a warm water marine environment about 450 million years ago. Limestone blocks construct the foundation of Old Main (Figure 2) and other buildings on the campus. These blocks of limestone building stone could have come from this quarry.

An instructional tool realized by few educational institutions, the quarry can be very important and useful in achieving educational goals at Kutztown State College. It appears that the quarry is only beginning to be realized for its potential educational value. Credit must be given to the foresight of the President, Board of Directors, administrative staff, and faculty for an applied learning opportunity.

Figure 2. The Keystone Normal School limestone cornerstone dated 1892 at the entrance to Old Main.
MOODS OF THE SUSQUEHANNA

by John P. Wilshusen
Pa. Geological Survey

We well remember the devastation of Hurricane Agnes ten years ago but we tend to forget the changing moods of the Susquehanna River as it flows by our doors.

Sometimes the flow of the river is so low that it seems to have stopped altogether as might be imagined from this photo (Figure 1) near Wrightsville, October, 1980. At other times the channel is filled to overflowing as is shown in Figure 2 taken in Harrisburg, September, 1975. Most interesting perhaps is part of the river turning solid with thick slabs of ice buckling into ice ridges reminiscent of the Great Ice Age which left Pennsylvania only about 12 to 13,000 years ago (Figure 3). The catastrophism that the pictured geologist is thinking about is an idea that sudden, violent, short-lived events have greatly modified the Earth's crust.

Figure 1. The Susquehanna River at Wrightsville during a period of low flow, October, 1980.
Figure 2. The Susquehanna River at Harrisburg during a period of high flow associated with tropical storm Eloise, 1975.

Figure 3. Prominent Pleistocene geologist (W. D. Sevon) contemplates catastrophism while seated in River Front Park, Harrisburg, January, 1982. Photo by J. P. Wilshusen.
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