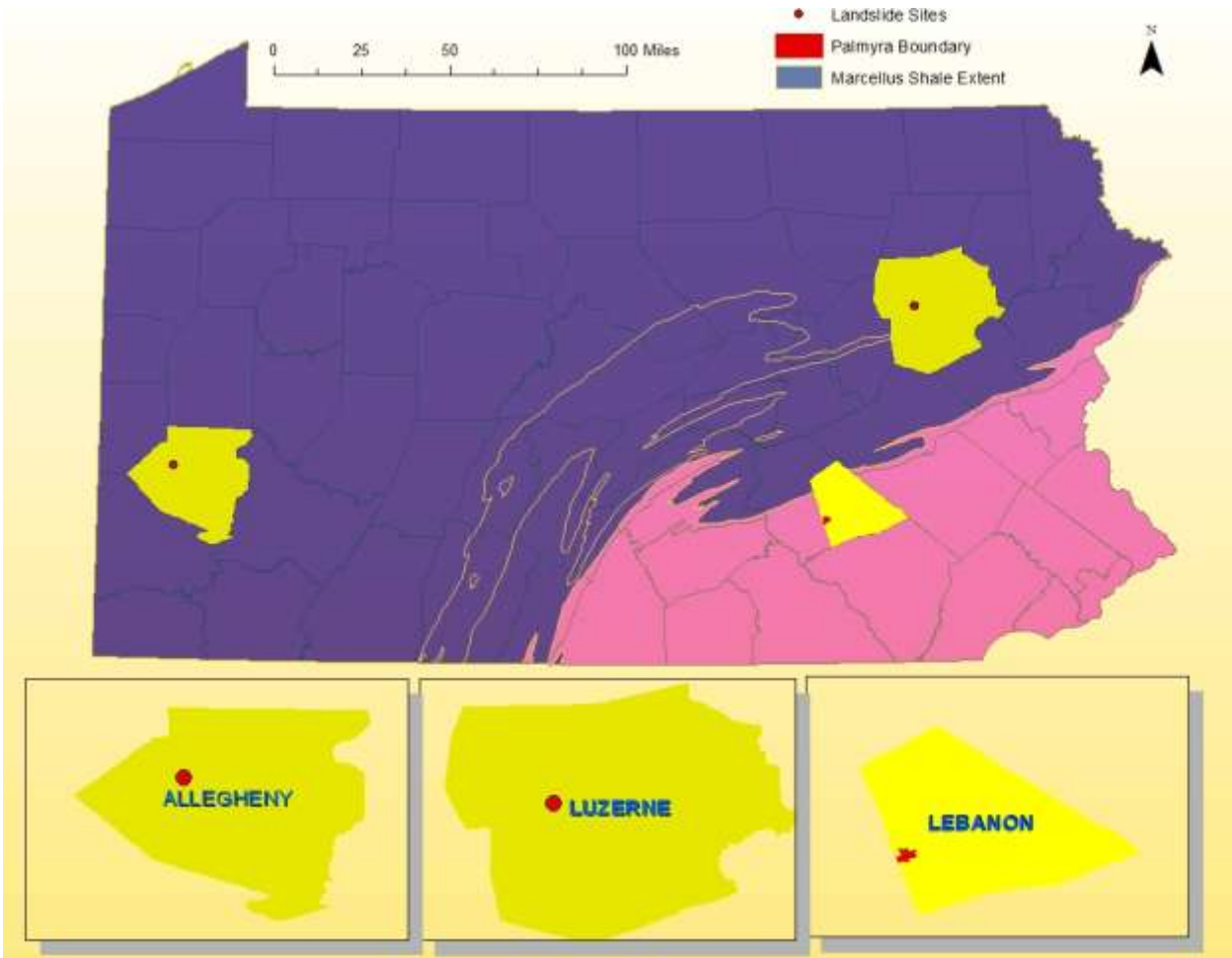


# Pennsylvania Geology

## Sinkholes, Landslides and Natural Gas



GIS 161 Remote Sensing  
HACC Spring 2011  
Prof. Ernst  
Chuck Hamilton

## Pennsylvania Geology

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## Overview

Geology is the scientific study of the origin, history and structure of the earth. The geology of Pennsylvania is complex and represents a wide mix of strata, resources and physical characteristics. The geologic history of Pennsylvania can be put in context by an understanding of the forces and processes which shaped those features. Some of those forces and processes include tectonic drift, atmospheric and water erosion, volcanic activity, and the deposit, fossilization and transformation of plants into sedimentary rock.

Pennsylvania geology can also be understood by using maps to examine the physiographic characteristics, the bedrock geology and the topographic characteristics. To illustrate these aspects of Pennsylvania geology two kinds of hazards are explored- landslides and sinkholes, and an examination of the Marcellus shale natural gas play is undertaken. The geologic characteristic which underlies all three of these areas is shale rock. Shale is a flat, brittle sedimentary rock and is a prominent part of the geology in most areas of the state. It is found at varying levels, depths and concentrations. The physical characteristics like its vulnerability to dissolution in weak acidic fluids, its brittle nature and its composition of carboniferous materials that contain petroleum products are expressed as causes of sinkholes and landslides and as deposits of oil and gas, respectively.

Supporting and expanding on the documentation of the case studies are three literature reviews that deal with a technological application that are used in remote sensing and GIS. The literature reviews enumerate aspects with landslides, sinkholes (or karst features) and oil and gas exploration and resourcing

This report concludes with some implications and trends of these three geological aspects for the citizens of Pennsylvania.

## Physiographic Provinces

Physiography refers to the geography that deals with the exterior physical features and changes of the earth. Physiography are physical features of the land that are easily recognizable, visually distinct from each other at both micro- and macro scales and are composed of homogenous compositions of sedimentary, metamorphic and igneous rock at various stages of mixing, formation and decomposition based on geologic forces (tectonic drift, fracturing, volcanoes, earthquakes etc.) and erosive (water and air) forces over time (millions of years).

Pennsylvania is comprised of six distinct physiographic provinces, each of which has various sections which are comprised of a variety of areas. The provinces are distinguished by the shape of the land as well as the composition of the underlying rock. Figure 1 below gives a view of the physiographic provinces in Pennsylvania. Notice the flatter topography in the Appalachian Plateau Province in the northwest area of the state, and the mountainous Ridge and Valley

Province. These are dramatic contrasting examples of the results of geologic and erosive forces forming surface topography.

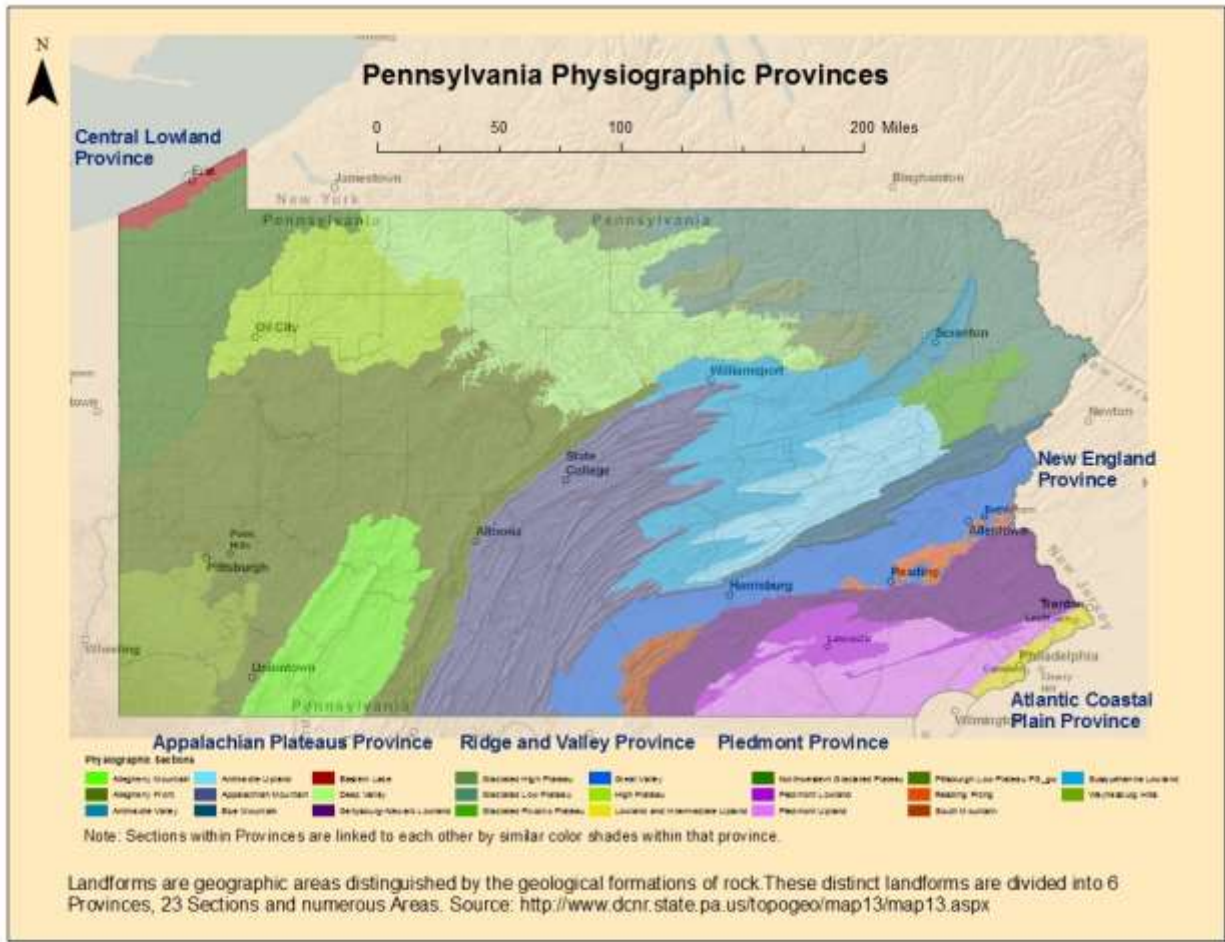


Figure 1 Physiographic Provinces of Pennsylvania

So, in terms of sinkholes, landslides and gas and oil resource development, certain provinces are more likely to have them than others. Causative factors in geo-hazards include soil and rock composition, slope, elevation, and hydration- each of which are determinants of suitability for a variety of human use. Valleys, for instance, especially along river tracts, may accumulate loose shale and colluvial soils over the course of eons. The slope of hillsides and ridges has a lot to do with the likelihood of landslides. Elevation, hydration and soil composition has direct impact on the plant species which are adapted to that ecological niche and thus the root structure holding soils in place. Development of oil and gas resources can change surface and sub-surface conditions as well and either mitigate or enhance other geo-hazards.

### Bedrock Geology

Bedrock Geology are sections of unbroken solid rock, overlaid in most places by soil or rock fragments. Also called subsurface geology, the study of bedrock geology is important

for mineral, metal and oil and gas deposits. Virtually all surface materials ultimately are derived from bedrock (meteorites are an exception). Fossils are often found in bedrock. Stratigraphy, or the branch of geology which focuses on the layers dividing rock in the earth, is an important approach to establishing the age, scale and evolution of bedrock formations. In Pennsylvania there are several distinct bedrock formations. Figure 2 below shows the bedrock geological formations in Pennsylvania.

**Brief History of Geological Eras of Pennsylvania**

- 1 billion years ago – Precambrian Grenville Orogeny
- 575 million years ago – late Precambrian rift event
- 525-450 million years ago – Cambrian-Ordovician passive margin stage
- 450 million years ago – u. Ordovician Taconic Orogeny
- 435-405 million years ago – Silurian passive margin
- 405-360 million years ago – Devonian Acadian-Caledonian Orogeny
- **360-285 million years ago – Carboniferous passive margin (Pennsylvania Period)**
- 285-245 million years ago – Permian Alleghenian Orogeny (Mass Extinction)
- 245-210 million years ago – Pangea
- 210 million years ago – m. Jurassic rifting event begins
- 150-0 million years ago – Cretaceous to present passive margin

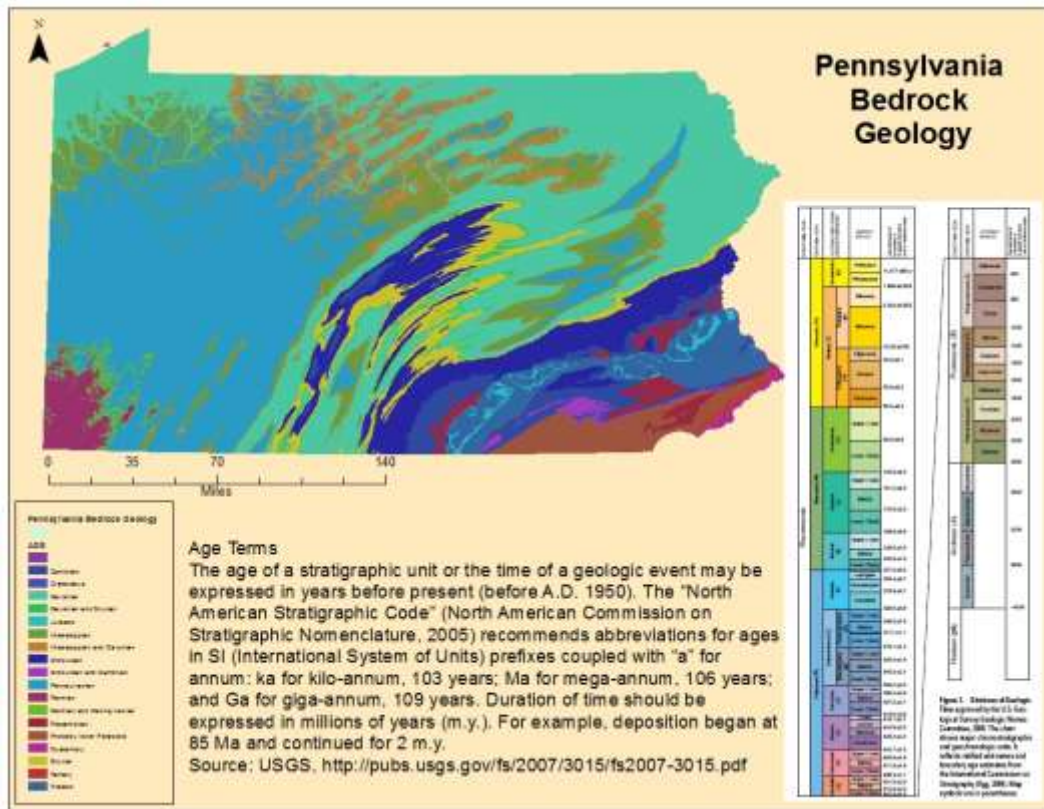


Figure 2 Bedrock Geology

## Topography of Pennsylvania

Topography refers to the detailed charting of the features of an area, district, or locality. Topography is relevant to the understanding of the form, structure and most efficient use of the lands in Pennsylvania. City and town planning and zoning are areas in which topography is a necessity. Roads and highways, and other transportation related projects depend upon up to date and accurate surveys. Boundary lines, whether political, governmental, or municipal, all use topographic sources to provide visual reference and contribute to best use of resources.

Below are topographic maps which illustrate a variety of aspects of Pennsylvania. Figure 3 shows the county outlines and underlying landscape features such as mountains and valleys. Notice how the landforms of Pennsylvania help determine the boundary shapes of the counties. If you compare the county boundary lines in Pennsylvania, for instance, with those in Iowa or many other Midwestern and western states, you will see a stark contrast: the Western states are often rectangular and laid out in a grid pattern. Those are examples of a mapping initiative by President Thomas Jefferson in the early 19<sup>th</sup> century.

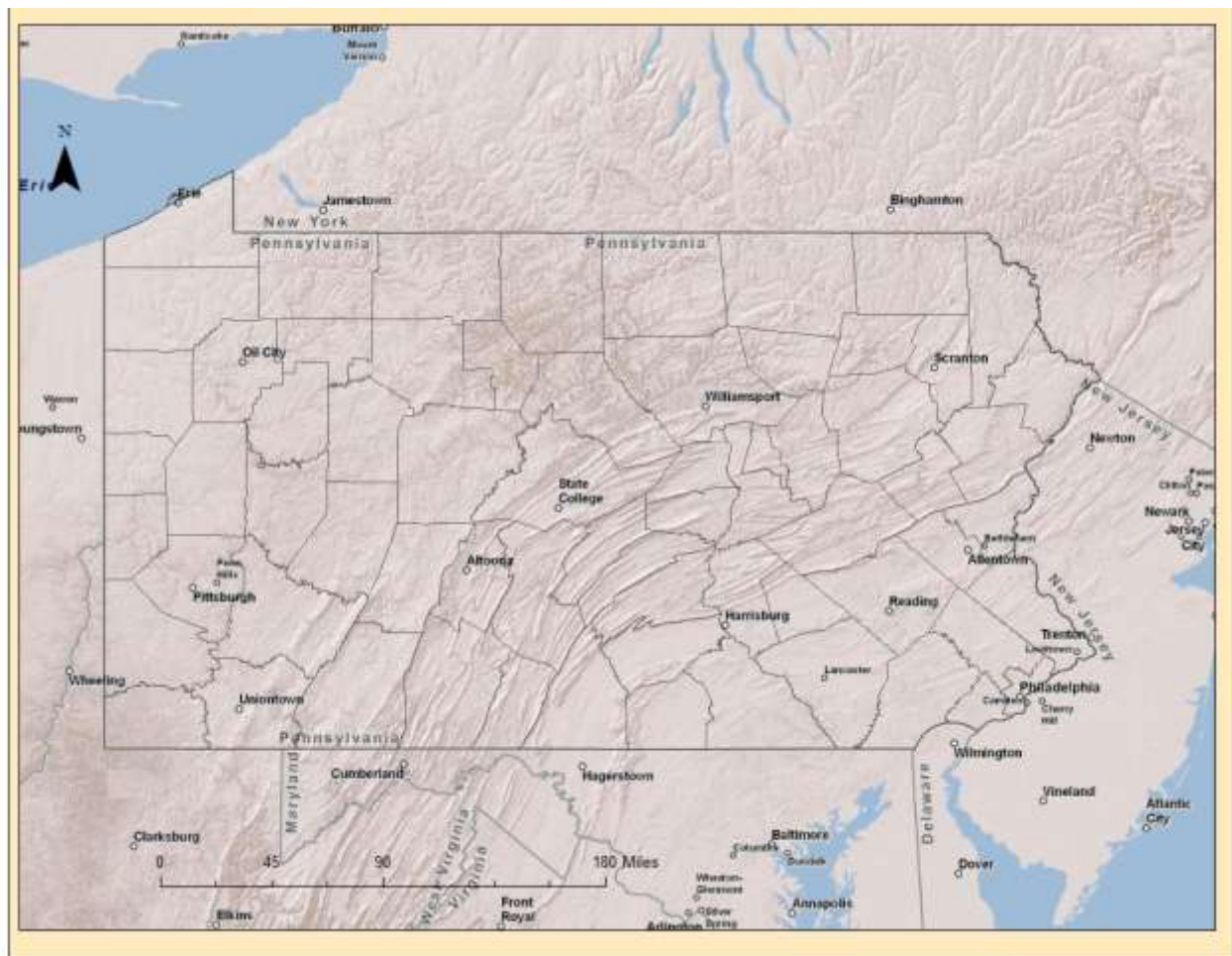


Figure 3 Shows the topography, or 3Dimensional representation, of the surface features of Pennsylvania.

The next Figure, Figure 4, focuses on the major roadways in Pennsylvania. Notice how the landforms- the Allegheny Mountains, glaciated plains and the Piedmont Province each affect the direction and uniformity of the roads. For example, if the most direct route between Altoona and Williamsport were the only criteria Highway 99 would not curve along the ridges of the Appalachians.



Figure 4 Shows roadways in Pennsylvania and their construction along topographic lines. This is reflective of best use of resources and materials and not the most direct route between locations.

## Geological Hazards

Geologic Hazards include sinkholes, landslides, floods and earthquakes. This is an important area of consideration to planners, environmentalists, developers and communities.

### Sinkholes

One example of geological hazards is karsts features. Karst features are areas in which the subsurface rock is eroded away over time and eventually collapses, leaving what in the common lexicon are called sinkholes. Note that all of the sinkholes are located in the central,

south central and southeast parts of the state. This is understandable when considering the geologic composition of the underlying strata. Sinkhole prone areas in Pennsylvania are primarily composed of limestone, which water erodes more quickly than the surrounding bedrock, thus creating collapsible pockets. Figure 5 below shows the distribution of sinkholes across Pennsylvania.

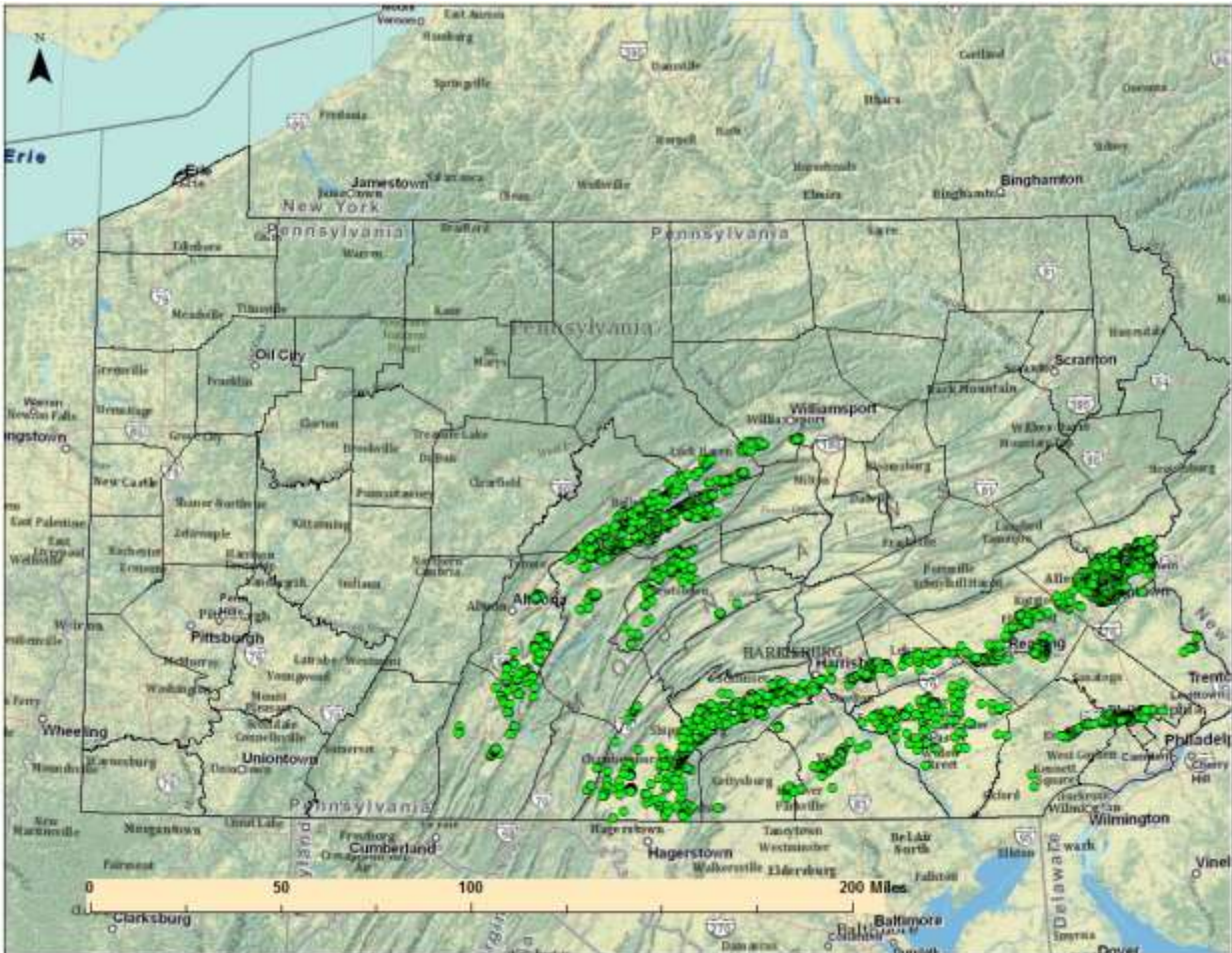


Figure 5 Distributions of Sinkholes across Pennsylvania

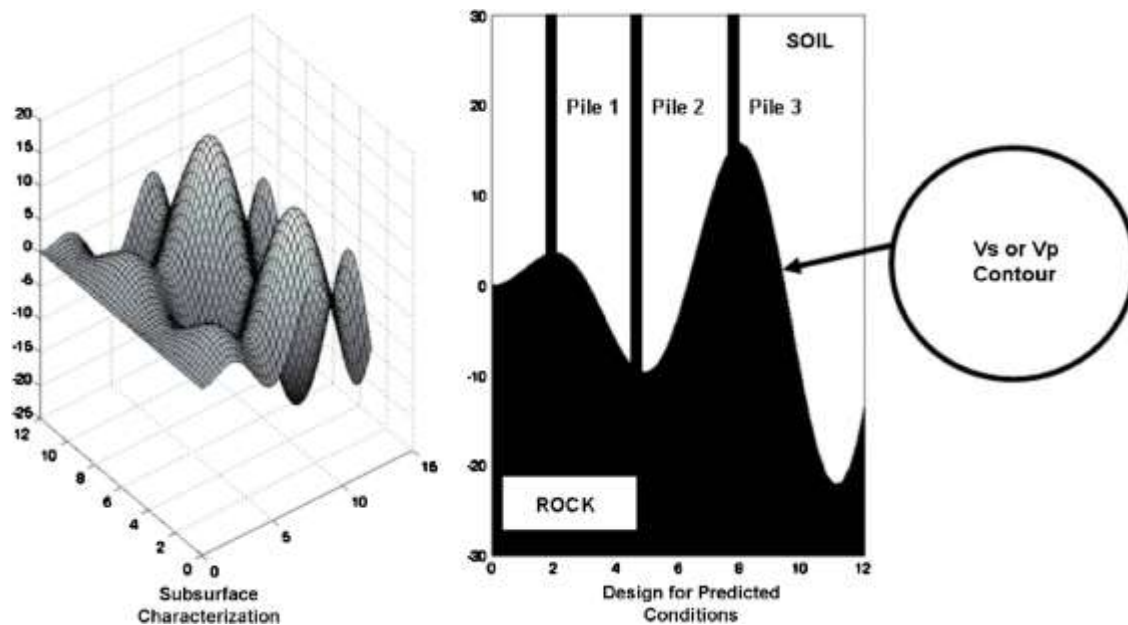
## Literature Review of Sinkhole Technology

### Application of Seismic Refraction Tomography in Karst Terrain

One new technology being increasingly employed to determine location and severity of karst features is Seismic Refraction Tomography or SRT. It is a useful tool because it is cost effective and simple to conduct studies. Essentially, Seismic Refraction utilizes vibrations which propagate through subsurface rock to build models of the area- both three dimensional and two dimensional. Used in conjunction with other technologies such as ground truth (visually inspecting a site), electromagnetic induction, techniques like aerial photography, LIDAR (Light Detection And Ranging) and satellite imaging and boring (Hiltunen and Cramer 938). SRT can

provide supportive data useful in planning building projects. This article explores the efficacy of SRT in a high karsts area in central Pennsylvania for the purposes of planning placement of bridge pilings.

The actual method employed in SRT is to place geophones along a survey line, usually at 2 foot intervals for 120 feet. A sledge hammer or explosive charge is then deployed which generates the seismic wave. Travel time of the wave through the subsurface material is gathered by the geophones and collected by a computer and run through specialized software to build the models. Different density of subsurface features provides variation in travel time of the seismic waves, with a positive correlation between density and velocity of travel time (Hiltunen and Cramer 940). Diagram 1 below is a schematic of future design practice.



**Diagram 1** Idealized schematic of future design practice based upon predicted subsurface conditions

As a control on SRT, synthetic models were built and input into the software prior to field test data. The two primary reasons for this were to assess the ability of SRT and the Seislmager software to “delineate subsurface features that are routinely present in karst terrane” and to develop an analysis protocol that is believable (Hiltunen and Cramer 940). Several tests of SRT have been conducted since 1989 which support its efficacy on wide areas: Venkatanarayana and Rao 1989 in Southwestern India, Benson and Yuhr 1993 in Wisconsin, and Carpenter et al. 2003 in Illinois and Kentucky (Hiltunen and Cramer 941).

This current study was much narrower in area, shallower and more specific as to detailed site characterization necessary to determine bridge piling placement. Three examples of SRT were cited in the paper. They all were along the Interstate I-99 corridor between Bald Eagle and State College, Pa. and named sites 317, 318 and 319. This literature review will summarize sites 317 and 318.

Site 317 is an area where a culvert box will be placed for Buffalo Run under I99. The results of the test indicated silty sand to sandy clay with dolomite fragments to a dolomite rock formation

along the 25 meters of the refraction line. This result confirmed a geotechnical boring along the same line. The authors state that “It is interesting to note that the top of bedrock at both stations lies along nearly the same  $P$ -wave velocity contour, which is a velocity in the range of 1.0–1.2 km/ s 1,000–1,200 m/ s. This is a strong indication that seismic waveltomograms can accurately characterize the soil/rock interface.” (Hiltunen and Cramer 942).

The second example at site 318 was an abutment structure that would become a two lane bridge of I-99 over Rt. 322. Fifteen steel H-pilings were driven laterally across the abutment. The outer pilings near the geotechnical borings were consistent with the soil-rock interface. However, the inner pilings- 9 of the 15- were significantly different in needed depth, showing a variation of 25% to the outer pilings. Diagram 2 is of pilings done during construction phase and demonstrates variation in depth:

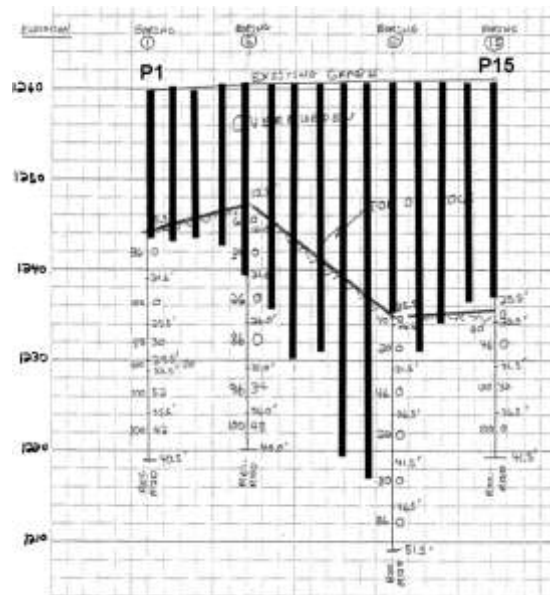


Diagram 2 schematic elevation views of exploratory boring logs and pile locations for Structure 318, Abutment 1

Even though SRT also missed demonstrating composition of softer material near the center of the piling line the variation was only 10% as opposed to the 25% error rate of the borings. This is a significant improvement in accuracy (Hiltunen and Cramer 945).

Overall, design and construction engineers related to the authors several real world anecdotes in which they were surprised by karst features that were not apparent during the design phase. These included both situations in which foundations designed for shallow rock and foundations designed for deep soil. The authors state “It can be concluded from these site comparisons that geophysical techniques such as seismic refraction tomography can provide important additional information to site characterization for bridge foundations in karst terrain. However, these techniques should not be viewed as a replacement, but should be conducted during design stage site investigation to aid selection of borehole locations and other testing needs.” (Hiltunen and Cramer 946).

When water moves into the subsurface features of an area the geologic composite erodes and this creates subsidence, or sinking, on the surface. In Pennsylvania sinkholes most commonly

occur in areas where limestone and dolomite are found because they are vulnerable to erosion from acidic fluids. The underlying rock base is eroded, opening up pockets where soil and residual stone suddenly sink into lower levels of the earth. They can vary in size from a few feet to many yards in diameter.

Diagram 4 below is a side view diagram of a typical limestone formation which has eroded, creating a sinkhole. Diagram 5 is a 2D view of a sinkhole system. Note how the refuse from the surface accumulates in the spaces between the collapsed limestone walls.

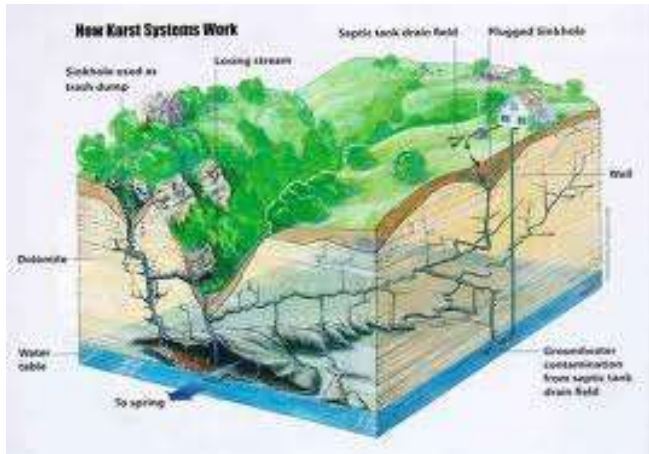


Diagram 3 is a 3D cutaway showing a karst system with surface features

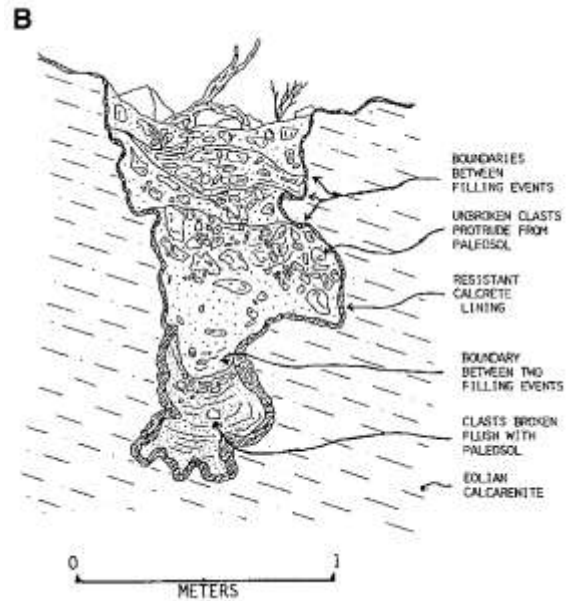


Diagram 4 Typical 2D view of a sinkhole system

### Case Study: Sinkholes in Palmyra

There are four types of karsts- sinkholes, surface depressions, surface mines and caves (DCNR). This case study focuses on sinkholes, and in particular sinkholes in Palmyra, PA just outside of Harrisburg, the state capitol. There are 144,225 karst features in Pennsylvania, of which 3619 are sinkholes, 191 are caves, 1916 are surface mines and 138,519 are surface depressions as listed by the Pennsylvania Geological Survey.

Palmyra, Pennsylvania, located to the northeast of the state capitol Harrisburg is an excellent example of land with karst features. Sinkholes in which there is a natural collapse of surface material into the karst area creates a hazard to humans. Figure 6 below shows the city of Palmyra in a topographic view with the approximately 60 sinkholes in green and approximately 170 surface depressions in yellow. These estimates are approximate due to the continual creation and repair of sinkholes and depressions. According to an article in the Patriot News Newspaper "This is the 15th time the sinkhole (on Rt. 422) has been repaired since January 2009. The cost tops \$220,000." (Patriot News April 21<sup>st</sup>, 2011). Figure 7 below shows sinkholes only in Palmyra.

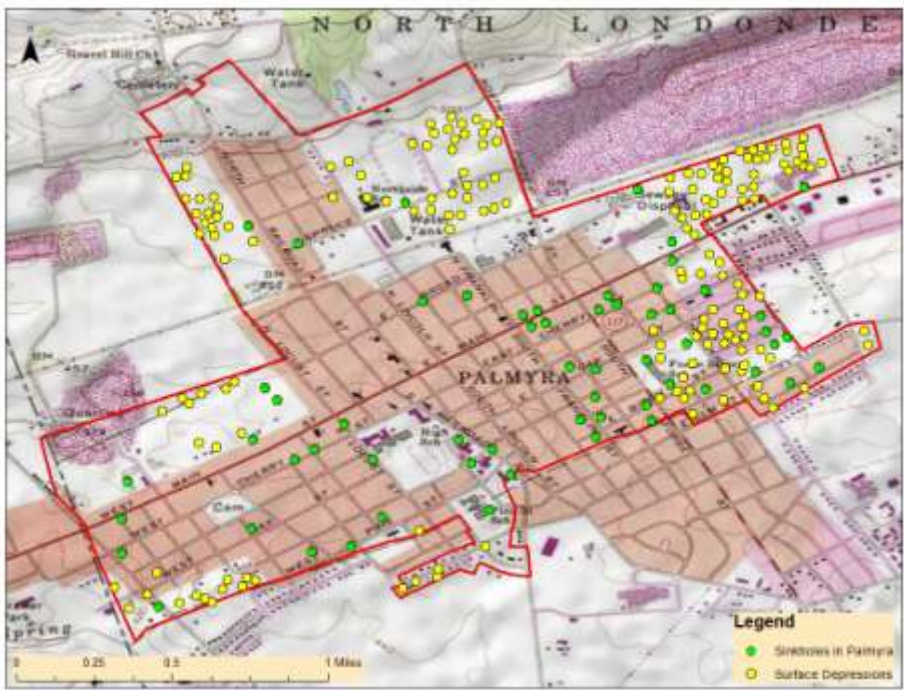


Figure 6 shows the location of the 230 sinkholes and surface depressions in Palmyra PA

Sinkholes are hazards with varying levels of threat to people depending upon where they occur, what structures are near, their size and timing and frequency of occurrence and recurrence.

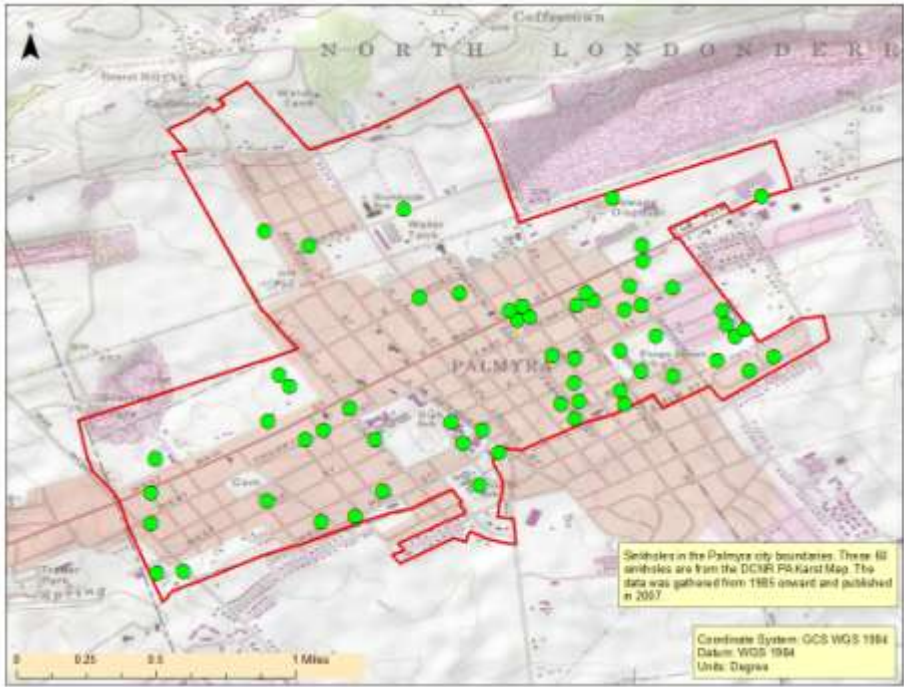


Figure 7 shows only the sinkholes within the Palmyra city boundaries

Physiographically, Palmyra is part of the Great Valley Section in the Ridge and Valley Province. This section's geology is comprised of carbonate bedrock- shale and siltstones to the north and limestone and dolomite to the south. Since limestone as a sedimentary rock it is subject to erosion from groundwater, which causes unpredictable collapses (Kochanov pg.6). Figure 8 shows an overlay of southeast Pennsylvania's Great Valley Section geology and the sinkholes in the area. Figure 9 is a closer view of the Palmyra area geology and sinkholes.

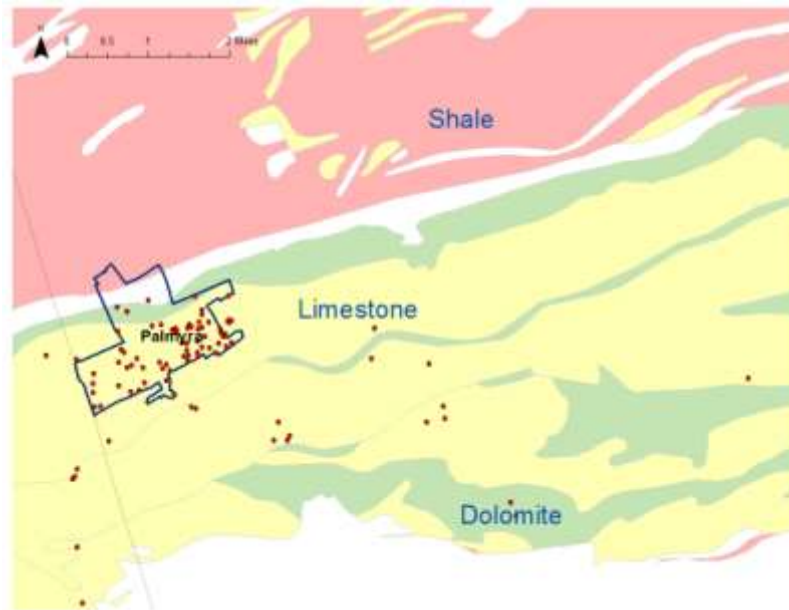


Figure 8 shows a county level view of sinkhole placement over the geology. Note sinkholes are all in limestone or silty limestone areas

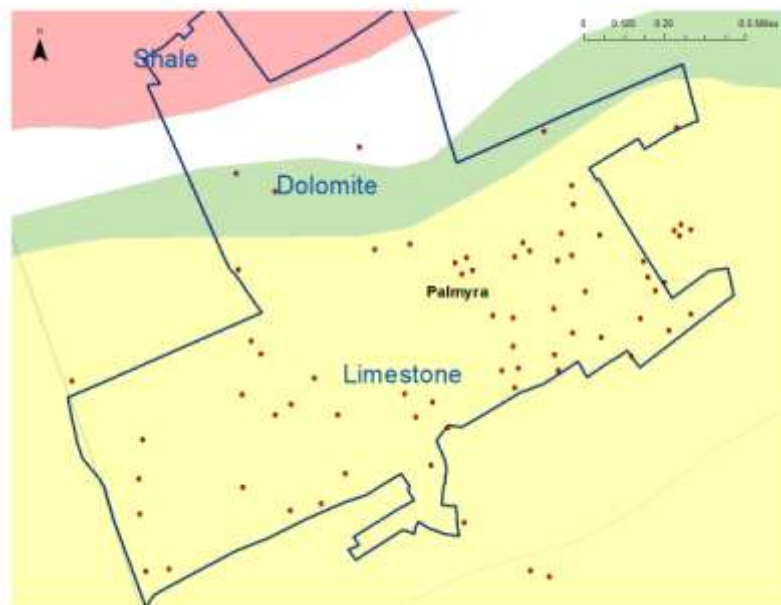


Figure 9 A closer view of the city of Palmyra and sinkholes over underlying limestone

In Figure 10 a closer view of a section of Palmyra centered on E. Main St. and Forge Road illustrates that sinkholes and surface depressions present different problems for differently zoned areas. For instance, the Forge Street Elementary school at bottom right of Figure 6 has two sinkholes adjacent to the school building itself, which potentially presents a hazard to the students, staff and teachers in the building. Alternatively, in the upper portion of the Figure the intersection of Duke Street and Cherry Street has a sinkhole. This presents a hazard to motorists on those streets. Since sinkholes open up unexpectedly and since there is no 'easy fix' for them (the most common being filling them in and covering them over) sinkholes present an ongoing challenge for residents in Palmyra.

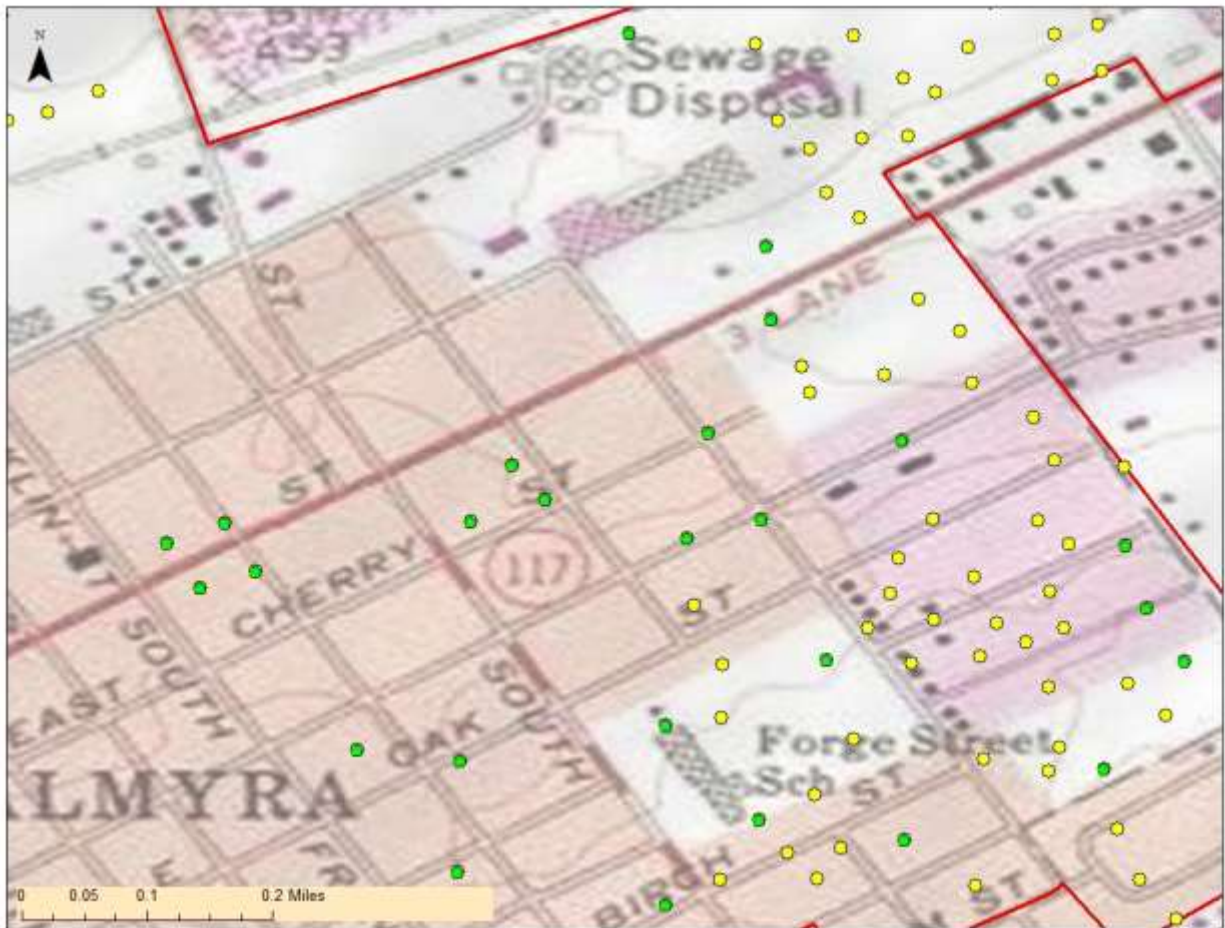


Figure 10 close up of sinkholes centered on Forge Road and East Main

The next map gives a clearer picture of the actual structures overlying these karst features from an oblique Bing Map base. Figure 11 details the same area in the previous map in an aerial view from 4000 feet. It is clear that sinkholes are a continuing challenge to the general populace and municipal planners in Palmyra. Notice the sinkholes both on streets and on the baseball fields.



Figure 11 shows an aerial view of the southeast corner of Palmyra with sinkhole locations

Next, in Figure 12 using PAMAP high resolution orthoimages as background the sinkholes in Palmyra are clearly presenting a hazard as many lie along roadways.



Figure 12 shows the sinkholes overlaying PAFigure high resolution orthoimages

NAIP (National Agricultural Imagery Program) would provide yet another perspective on sinkholes if there were farmland in Palmyra. However, all of Palmyra is zoned as urbanized area with a few fields. A historical perspective is often useful in determining frequency and severity of

sinkholes. The following three Photos 2, 3 and 4 from the Penn Pilot program show aerial views of Palmyra from 1937, 1956 and 1970.

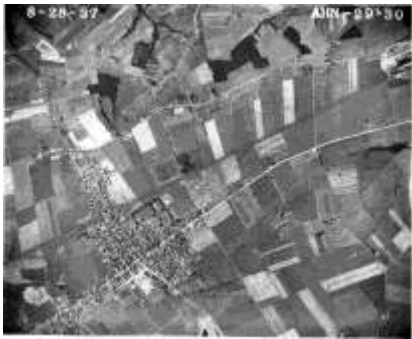


Photo 2 1937 Penn Pilot Aerial



Photo 3 1956 Penn Pilot Aerial



Photo 4 1970 Penn Pilot Aerial

The population of Palmyra was 7096 in 2000 (Census). The following Figure 13 shows population density in conjunction with the sinkholes.

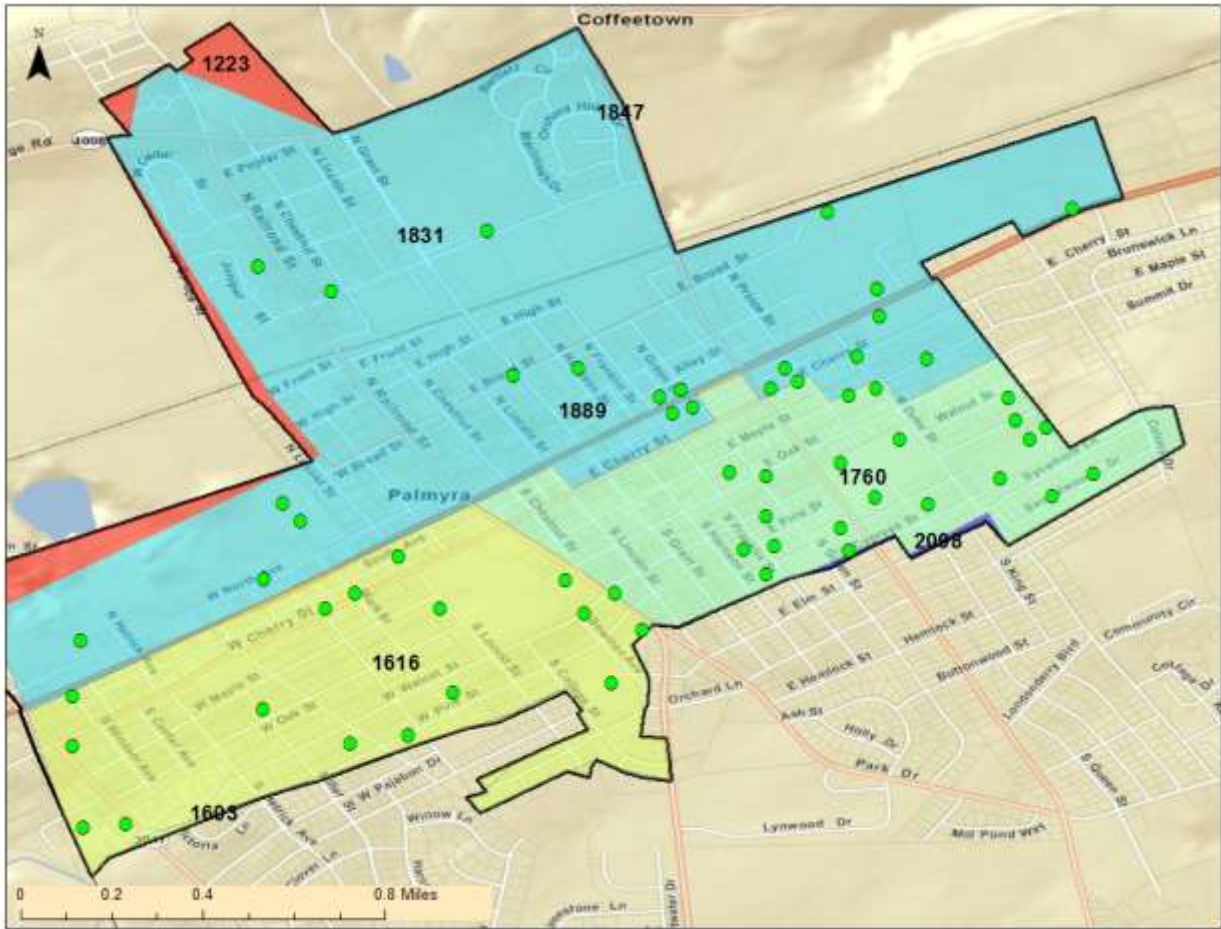


Figure 13 Population distributions in Palmyra. Notice higher density of sinkholes in reverse correlation relative to population

The following Figure 14 demonstrates land use and zoning within Palmyra. Note that the majority of sinkholes fall within multi- and single- family residential zones.

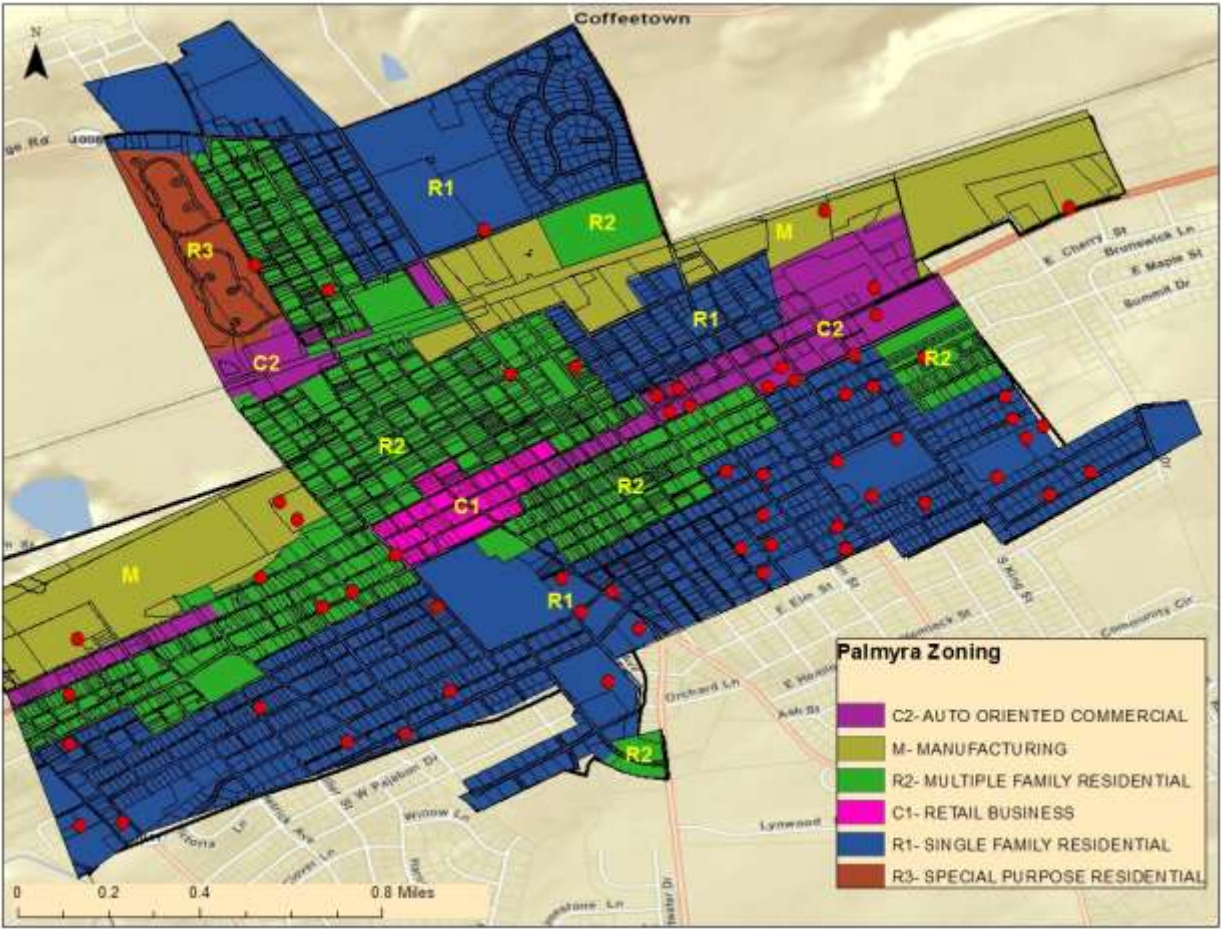


Figure 14 overlays sinkholes on zones. Note that the majority of sinkholes occur in single family residential areas

These are pictures of recent sinkholes in Central PA and Palmyra. Photo 5 is a sinkhole that has opened up 15 times since January 2009. It is directly under the main street of Palmyra. Photo 6 is a good illustration of the suddenness and unpredictability of sinkhole events. While located in Mechanicsburg on private property, west of Harrisburg, it is a good example of the hazard presented to the public.



Photo 5 Shows a current (Spring 2011) on East Main St. (Rt. 422) in Palmyra



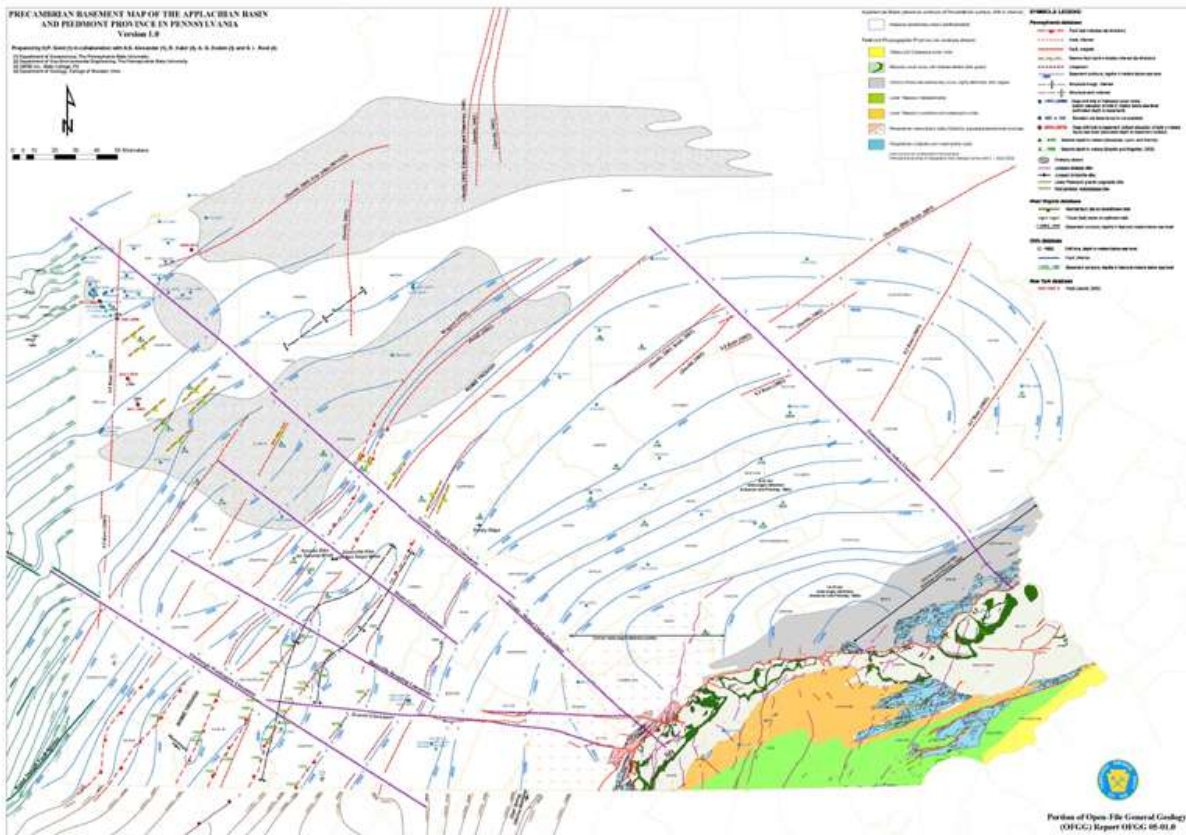


Figure 15 Basement Geological Figure of Pennsylvania

## Landslides

Landslides are another geological hazard found in Pennsylvania. Unlike sinkholes, landslides occur on the surface of the earth and are caused by combinations of loose land cover, rain, flooding and land use, which often occur in tandem and magnify each other's effects (PA Geological Survey).

## Literature Review of Landslide Technology

### Landslides: Towards an early-warning system for global landslides triggered by rainfall and earthquake

This paper discussed the proposal of building an early-warning system for landslides. There were three components for the framework of the proposal- a landslide susceptibility database, a real-time precipitation estimation system, and a ground shaking prediction system following earthquakes. The challenge of building a real-time prediction system based on the two primary triggers for landslides (earthquakes and heavy rains) by integration with geospatial datasets is

“tremendous” (Hong and Adler 3713). However, the authors also contend that the need is great and justifies exploration of this proposed system.

In this system the landslide susceptibility database derives from analysis of the geospatial information gathered by satellite technology- remote sensing. This will be used to establish the ‘where’ landslides could occur. The second function- the ‘when’ of landslides- is based on the two primary triggers of landslide vulnerable areas- rainfall and earthquakes. By overlaying data in real time when an earthquake or heavy rainfall occurs on vulnerable areas it is expected enough warning can go out to help mitigate the effects.

Currently data is available for elevation from the NASA Shuttle Radar Topography Mission (SRTM), for soil composition from Digital Soil of the World (<http://www.fao.org/AG/aql/aql/dsmw.htm>), and geographical distribution of land cover types from MODIS (Moderate Resolution Imaging Spectroradiometer). Scale used in these datasets is at 30 meters.

The illustration below, Diagram 6, represents the process involved in a real time system. Note that several pieces of an effective system do not currently exist in an integrated database, in particular the underlying geological makeup of the landslide areas.

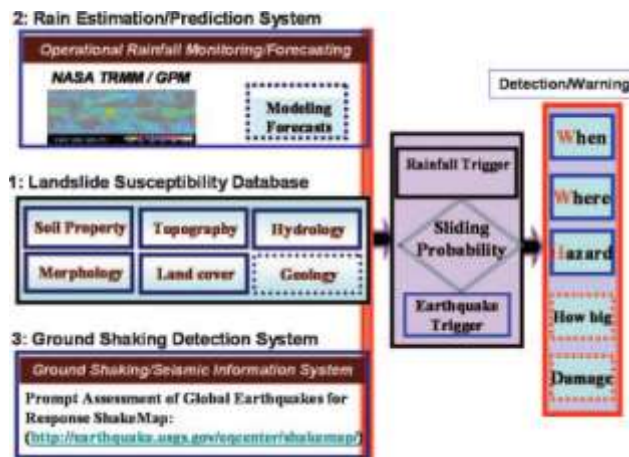


Diagram 6 Conceptual framework of real-time monitoring/warning system for landslides triggered by rainfall and earthquake. Note that dash-line boxes are important components but are not covered in this study.

NASA has several projects which measure and report precipitation including the Tropical Rainfall Measuring Mission, Multi-satellite Precipitation Analysis, and the Global Precipitation Measurement mission. The authors claim that that the “TMPA is successful at reproducing the surface-observation-based histogram of precipitation at fine scale” (Hong and Adler 3715). Currently there is no single global standard for a rainfall intensity-duration threshold. The TRMM may not be a completely accurate predictor “due to its independence of local climatic and geomorphological characteristics” (Hong and Adler 3715). Earlier results were not useful in predicting landslides for short duration high intensity rainfalls.

There is a near real time earthquake information system that has been developed by the USGS. A warning system has been developed from this called PAGER (Prompt Assessment of Global Earthquakes for Response). This system then generates a ShakeFigure which is posted online at <http://earthquake.usgs.gov/eqcenter/shakeFigure/> that provides data in several forms

useful for disaster response teams, communities and researchers. Diagram 7 below illustrates the recent 8.0 earthquake in New Zealand.

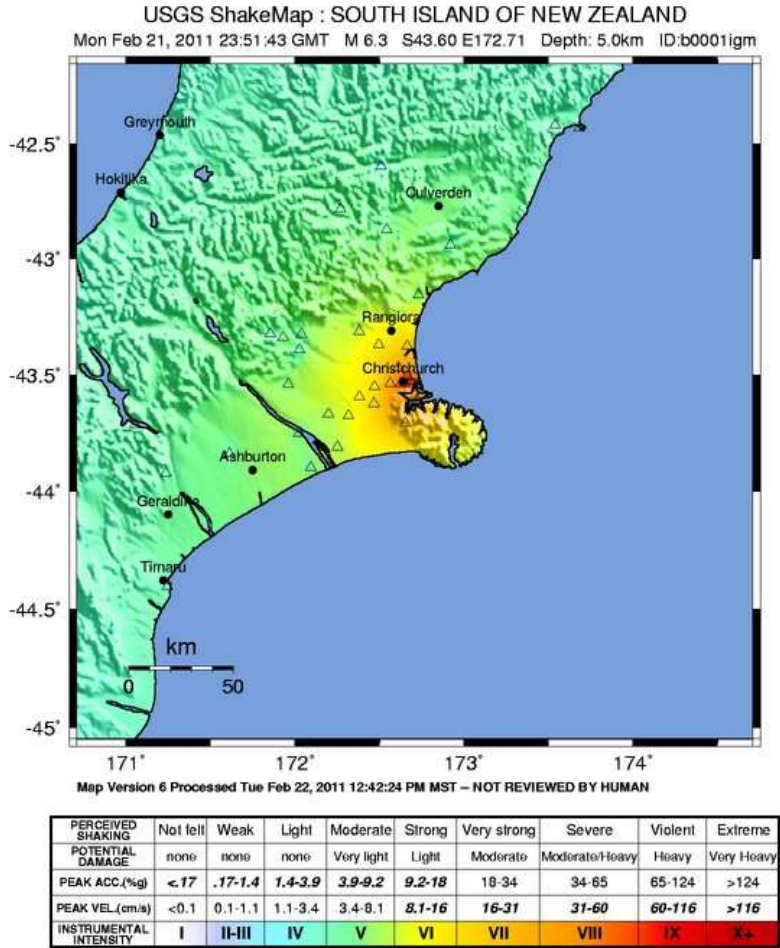


Diagram 7 ShakeFigure from the New Zealand earthquake

The lead time of this proposed system will require multi-agency and interdisciplinary cooperation on a global basis. Also, landslide lead time will be enhanced by using rain forecasts from 1-10 days from numerical weather models. Forecasting seismic waves is still several years in the future (Hong and Adler 3717).

### Case Study: Landslides in Allegheny and Luzerne Counties

What conditions lead to landslides? Landslides are geological hazards “involving the movement of earth materials down a slope” (Delano pg1). Landslides can cause significant damage to utilities, buildings, roads, businesses and communities when they occur. Conditions which lead to landslides include slope stability which is based on the surface and subsurface composition of the landslide area. If there is a large amount of unconsolidated material such as loose or uncovered soil, loose rock, or the surface is highly permeable to water the chances for a

landslide rise. Also, steepness of the slope or fractures in the underlying bedrock can cause landslides.

Landslides occur in Pennsylvania in particular due to the topographic composition of the state. Figure 16 below shows that the mountainous and hilly regions in the Southwestern and Northeastern parts of the state. Both areas have similar landcover characteristics of steep slopes, loose surface composition and sufficient annual water to create landslide conditions.

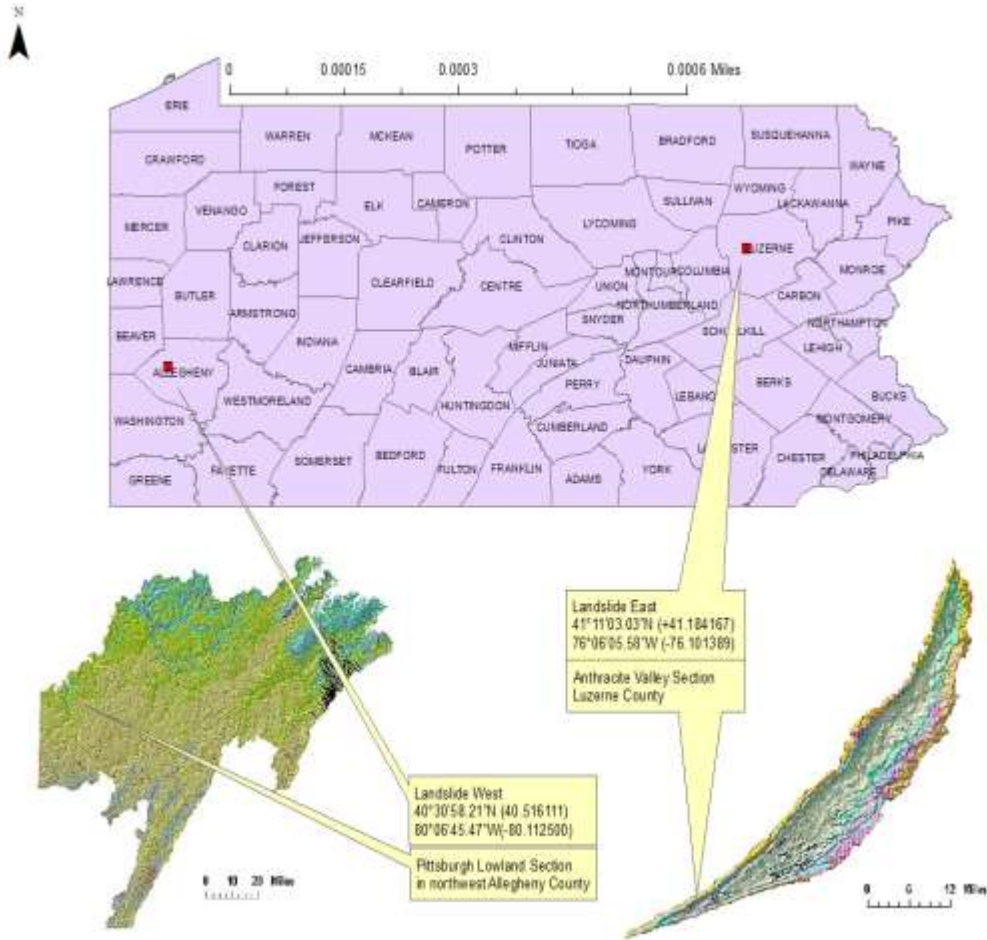


Figure 16 Location of two landslides in Pennsylvania referenced to the physiographic provinces

**Allegheny Landslide**

The western landslide case study is located in the northwestern part of Allegheny County just north of Pittsburgh along the banks of the Ohio River, in the southwestern portion of the Pittsburgh Low Plateau Section of the Appalachian Plateaus Province. According to DCNR, this section is characterized by the facts that “The uplands are developed on rocks containing the bulk of the significant bituminous coal in Pennsylvania. The landscape reflects this by the presence of some operating surface mines, many old stripping areas, and many reclaimed stripping areas” (DCNR2). DCNR goes on by stating “Some of the land surface in the southwestern part of the Section is very susceptible to landslides” (DCNR2).

Figures 17 shows a hillshade view of the landslide area. The landslide is located in the upper left of the Figure and is about .5 miles in length. Figure 18 adds a hillshade view overlaying an

aerial view to show placement of land use. Note the industrial zone on Neville Island and if a large mudslide were to occur it could wipe out sections of Highway 65.

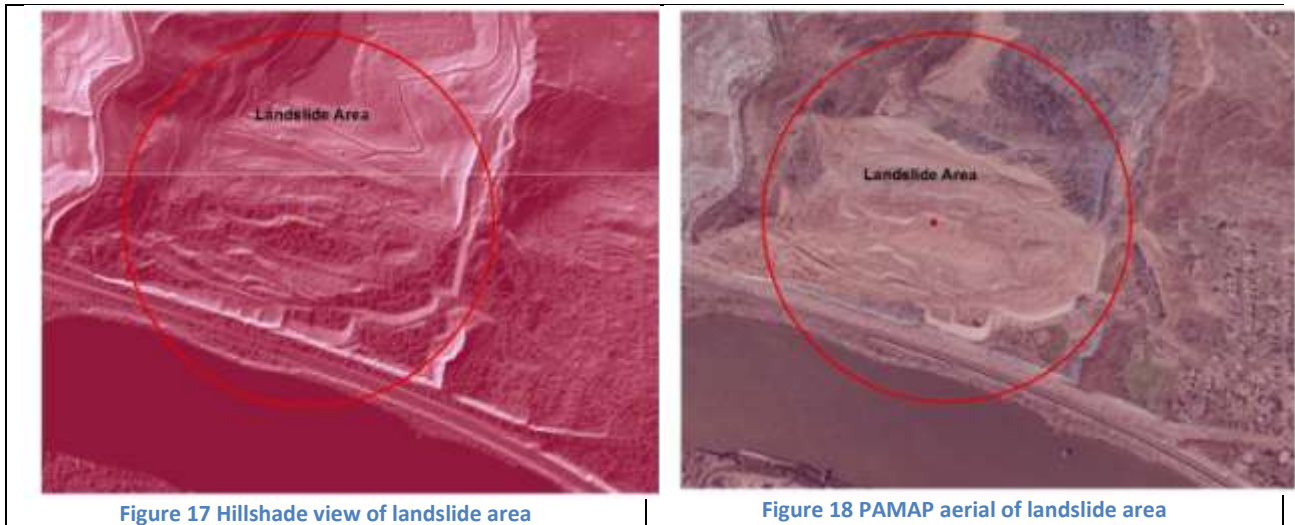


Figure 17 Hillshade view of landslide area

Figure 18 PAMAP aerial of landslide area

This DEM (Digital Elevation Model) dataset was created by the PAMAP Program from PASDA for the DCNR. It has a horizontal ground resolution of 3.2 feet. Using LIDAR elevation points the maps represent 10,000 feet by 10,000 feet on the ground. The coordinate systems are NAD83 State Plane North and State Plane South (PASDA). Figure 19 is a 3D rendering of the landslide area from the south. Figure 20 is a 3D aerial drapery over a DEM. Note the lack of vegetative or artificial land cover over the landslide site.

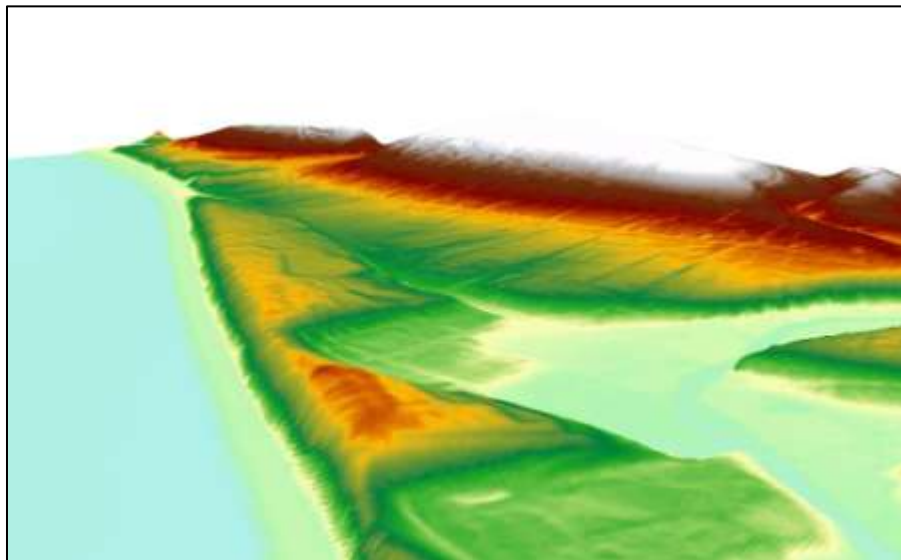


Figure 19 3D rendering of the Allegheny landslide area. The flow of the landslide is to the south



Figure 20 is a 3D aerial view rendering showing the elevation of the landslide area. Notice the lack of land cover like vegetation

**Luzerne Landslide**

A similar situation is found in the eastern landslide case study located in the central part of Luzerne County along the banks of the Susquehanna River. Geologically, the Anthracite Valley Section is characterized as “rocks are composed of sandstone, siltstone, conglomerate, and anthracite coal” (DCNR3).

Figures 21 shows a hillshade view of the landslide area. The landslide is located in the upper left of the Figure and is about .5 miles in length. Figure 22 shows an aerial view to illustrate land use. Note the housing development across the river at the bottom right. Figure 23 is a 3D rendering of the Luzerne landslide area and more clearly outlines the extent and slope. The view is from the southwest and the landslide is in the top center of the picture.

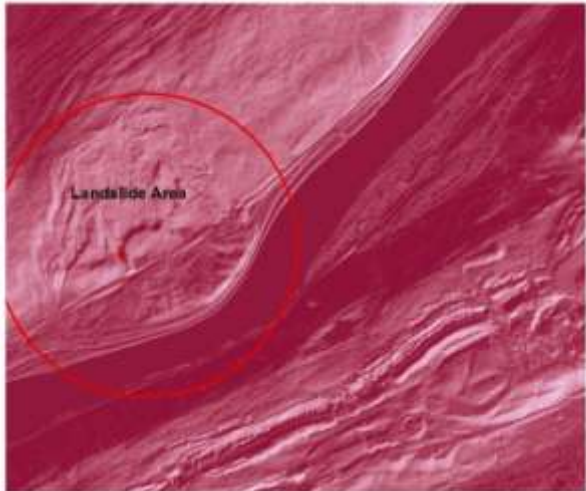


Figure 21 Hillshade view of landslide area



Figure 22 PAMAP aerial view of landslide area

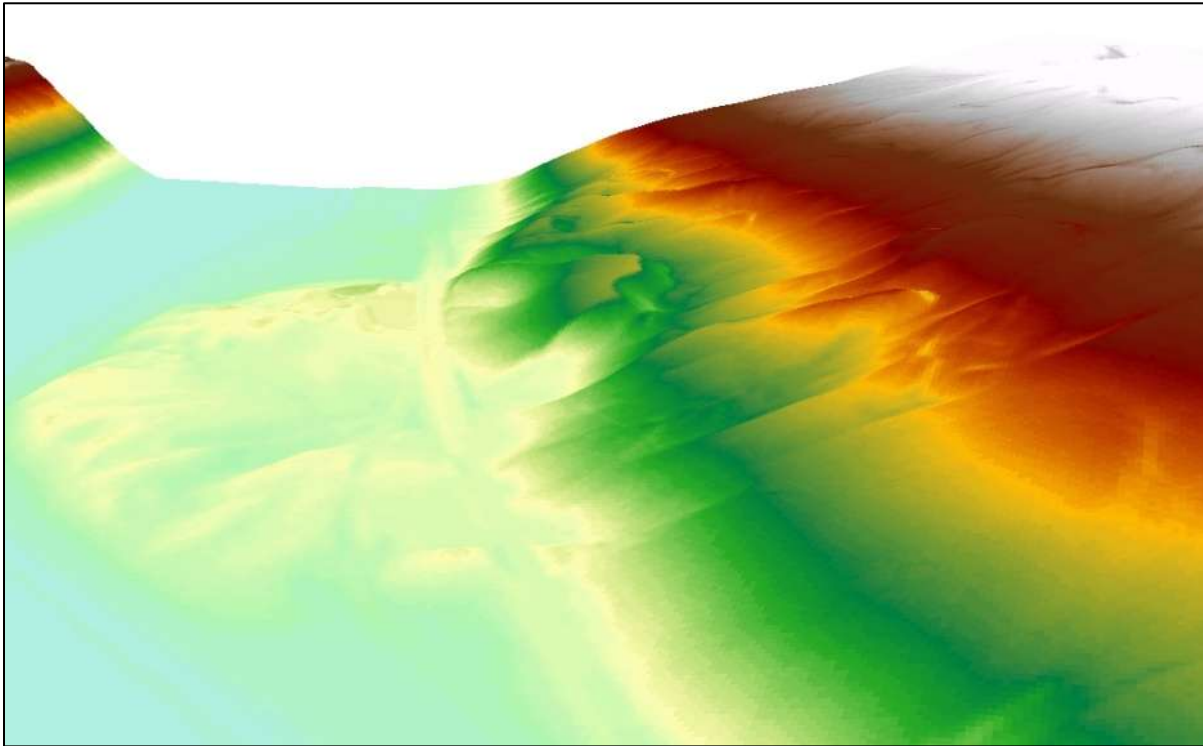


Figure 23 3D view of Luzerne landslide area. Note extent of landslide into the river



Figure 24 3D aerial view of Luzerne landslide area. This gives a clearer perspective of the sloped hills and land cover

So, the geological conditions that create landslide susceptible areas are the surface materials such as soil composition, type of rock, and water content. These materials are broken out in the following Table 1 (Delano pg 7), as well as the type of landslide they are prone to create:

<b>Table 1. Types of Landslides in Pennsylvania</b>			
<b>Type of Movement</b>		<b>Type of Material</b>	
Fall		Bedrock	Engineering Soil
			Coarse Grained
Fall		Rock Fall	
Slide	Translational	Rock Slide	Debris Slide
	Rotational	Rock Slump	Slump
Flow	Rapid	Rock Creep	Debris Avalanche Mudflow
	Slow		Debris Flow Earthflow
			Talus Creep Soil Creep

Table 1 Describes the materials in landslides and the types of resultant landslides

The relevance of landslides as geological hazards is related to the population in the area. For instance, if a section of a dirt mountain road in a national forest is temporarily wiped out by a mudslide it is of much less immediate concern than if it happens to a two or four lane highway in a densely populated area. The latter will cause direct economic impact, danger and inconvenience while the former can be repaired over time with lesser impact to humans.

The following Figures 25 and 26 overlay population density and land use data in the east and west landslide areas in Allegheny and Luzerne counties. The population in Allegheny County is 1,223,488 and in Luzerne County is 320,918, according to the 2010 Census.

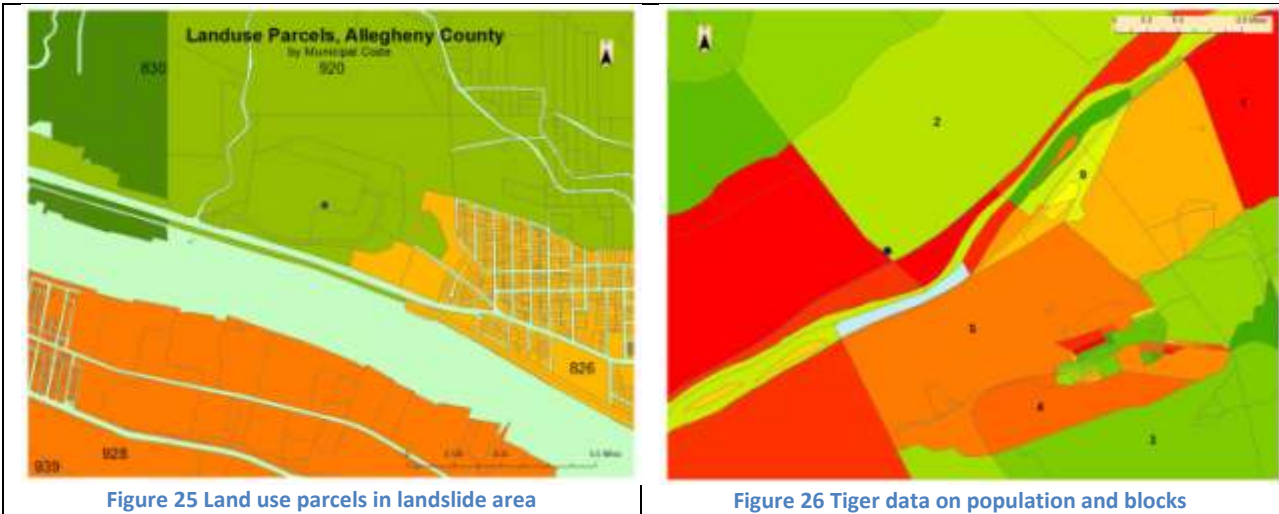
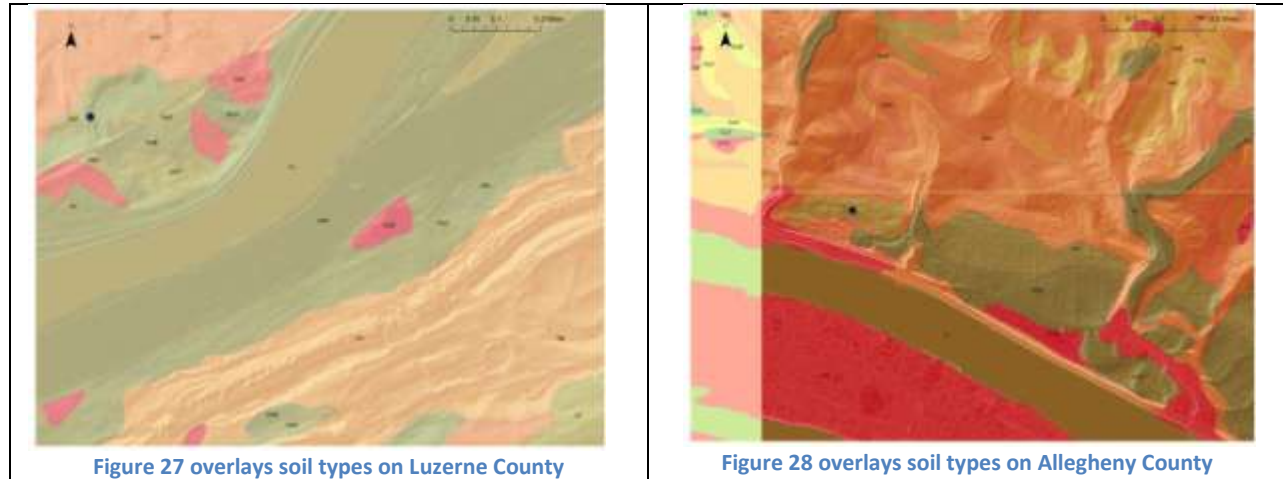


Figure 25 Land use parcels in landslide area

Figure 26 Tiger data on population and blocks

Figure 27 and 28 shows soil composition in the landslide areas. Soils which are prevalent in these two areas are loosely composed, high moisture retention and are subject to facilitating landslides.



## Geologic Resources

### Introduction

These resources include gas and oil deposits, minerals and aquifers. This report will explore natural gas and oil deposits in Pennsylvania. Pennsylvania is also rich in coal deposits which can present environmental threats to water sources, and when surface mined lead to hazards such as landslides, or subsurface mined create subsidence issues such as sinkholes.

### Oil and Gas: An Emerging Giant: Prospects and Economic Impacts of Developing the Marcellus Shale Natural Gas Play

The natural gas play in the Marcellus Shale formation in Pennsylvania holds promise as an energy and monetary boon for the U.S. There are, however, several considerations including environmental, technological, and financial and taxation issues to be addressed as the play develops. The scale of natural gas which could be extracted is perhaps the largest reservoir in the world. Estimates are that almost 500 trillion cubic feet of gas are recoverable (Considine, Watson and Entler ii). Natural gas has an environmental advantage over oil in that as it burns 1/3 less greenhouse gases are released into the atmosphere. On the other hand, fracking or hydraulic fracturing used to release the deposits may present a significant challenge for exploitation of the play. The report recommends against a severance tax at this time on extraction by undermining the competitive advantage of lower taxes in Pennsylvania vs. other plays in other states.

One of the key challenges is building the infrastructure of pipelines, roads and transportation of the gas from the wells to the consumers. Processing facilities will need to be built to refine the natural gas and separate out heavier gases such as propane, ethane and butane (Considine,

Watson and Entler 6). Diagram 8 is a comparison of the extent of Marcellus shale with Barnett Shale.

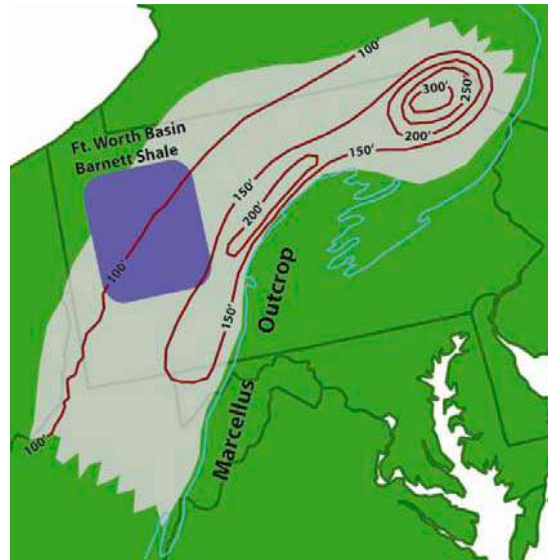


Diagram 8 Extent of Marcellus Compared with Barnett Shale Formation

The report next turns to the strategic significance of Marcellus shale. Local, national and international market forces set the cost/price of natural gas which makes the price volatile. This affects the pace and scale of development. However, given the projected rising costs of oil, its environmental impacts, and global climate change fears, natural gas extraction and usage should continue to rise in scale and benefit.

Use of natural gas is largely in electrical power plant generation. Increasingly coal fired plants are using natural gas as an agent in conjunction with coal, with an added environmental benefit because it burns cleaner. (Considine, Watson and Entler 8) Competition with Marcellus shale for power generation include wind power, and other sources of natural gas- in particular in Wyoming, Texas, Arkansas and Illinois. Diagram 9 shows domestic competition with Marcellus.

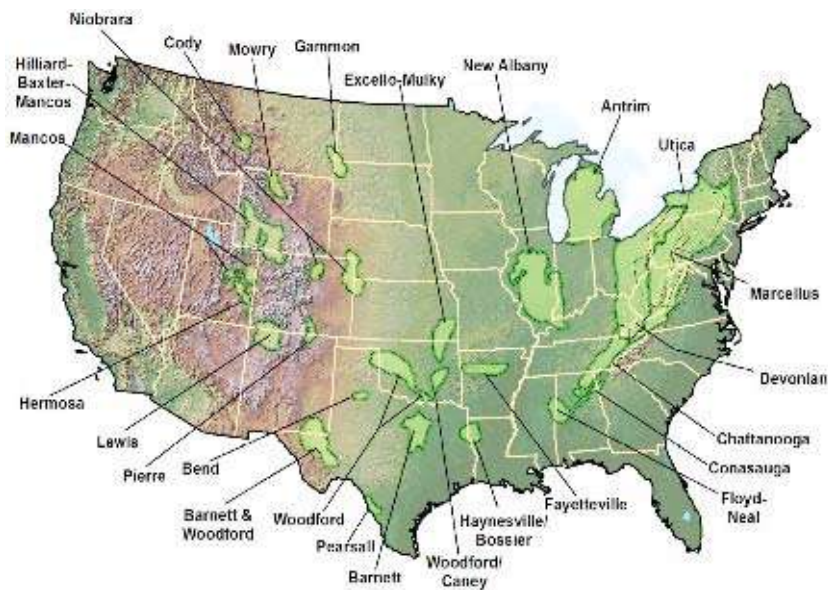


Diagram 9 Domestic Natural Gas Deposits in competition with the Marcellus Play

The geographic location of Marcellus shale is an advantage because it is within 200 miles of large natural gas markets with potential demand of almost 20 billion cubic feet per day. In addition, the switch over by large fleets of vehicles to natural gas could provide a growing market.

A closer look at development includes the processes of leasing, exploration and drilling and well completion. Leasing involves a producer buying the rights to extract the gas underneath a landowner's property. Typically, a set fee is paid up front and royalties are then paid over time to the landowners based on volume of gas extracted. Exploration uses seismic surveys to build 3D models of the fractured shale lines up to 2 miles beneath the surface. Drilling and well completion involve placing steel pipes down to the gas permeated shale, then branching out horizontally for up to a mile along fault lines to gather the gas. An important part of this process involves using water and propanants to shatter the shale and allow the gas to flow in quantity up the pipes (Considine, Watson and Entler 14).

The last step in the process is the transportation, processing and sales of the gas. This involves pipelines, removal of water vapor, other petro compounds and selling to the consumers.

Some of the benefits for local economies are included in Photo 1 below:



Photo 1 Natural Gas Development Activities and Local Beneficiaries

According to the authors “The total economic impacts are the sum of the direct, indirect, and induced spending, set off from the expenditures by Marcellus producers.” The total spent by producers that added to Pennsylvania’s economy as of 2008 was almost 3 billion dollars. This amount is expected to increase manifold as the play develops. Also, the authors determined

that “for every \$1 that the Marcellus industry spends in the state, \$1.94 of total economic output is generated” (Considine, Watson and Entler 23).

The authors estimate growth in drilling Marcellus shale as increasing to 1000 wells in 2010 up to as many as 2800 in 2020. Chart 1 below displays the millions of cubic feet potentially extracted by day from 2008 to 2020.

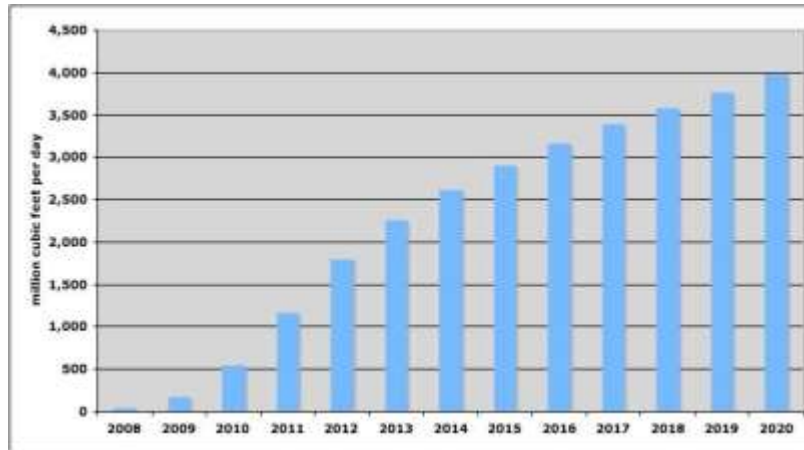


Chart 1 Forecast for Marcellus Natural Gas Production 2009-2020

In conclusion, this report was strongly in favor of development of Marcellus shale with little or no severance tax for the drillers and justifies that conclusion by stating that any tax revenue lost would be more than made up in employment and economic growth for the state.

## Case Study of Pennsylvania’s Oil and Gas Resources: Marcellus

### Introduction

The history of geological economic resources in Pennsylvania is as long as the settlement of the commonwealth in the early 17<sup>th</sup> century. The exploitation of these natural resources has always reflected the technology of the day. In the earliest history of Pennsylvania colonists mined coal and limestone in particular. Coal was useful as a medium for heating and as a fuel for iron work. Limestone is a necessary ingredient in a variety of construction, transportation, industrial and agricultural sectors including aggregate for roads and foundations, purifying glass, a soil conditioner for acidic soils and many others (Minerals).

Other geological resources include oil. In fact, the first oil well drilled in America was in 1859 in Titusville Pa. According to Penn State Professor Brian Black “Oil was known to be seeping out of the ground in western Pennsylvania in the mid 1700s. When the first oil well was drilled in Titusville in 1859, oil “became the prime mover in American society,” he said” (Black1).

Diagram 10 below demonstrates the wealth of variety and distribution of geological resources in Pennsylvania.



Diagram 10 Locations and types of geological resources found in Pennsylvania

Indeed “by the late 1600’s, Quaker settlers were using local shale and clays to make bricks to build their homes. During the 1700’s, the mining of iron, lead, copper, and other metal ores met the needs of a burgeoning colonial society” (DCNR4).

The wide varieties of geological resources in Pennsylvania that have been used for centuries are still being harvested today.

## Marcellus Shale Natural Gas Extraction in Pennsylvania

GIS and Remote Sensing are being used to study Marcellus Shale by locating promising pockets with higher concentrations of natural gas, easier drilling spots to reach those pockets, locating and harnessing local and regional water sources to help fracture the rock containing the gas and determining transport routes and pipeline placement. Beyond location, GIS technologies also are useful in real time tracking of environmental impacts (or helping to mitigate them), changes in traffic and population patterns in booming areas and a host of other infrastructural needs that grow when economic and social changes occur in drilling areas. Figure 29 shows the distribution of Marcellus shale across the western, northern and northeastern parts of Pennsylvania.

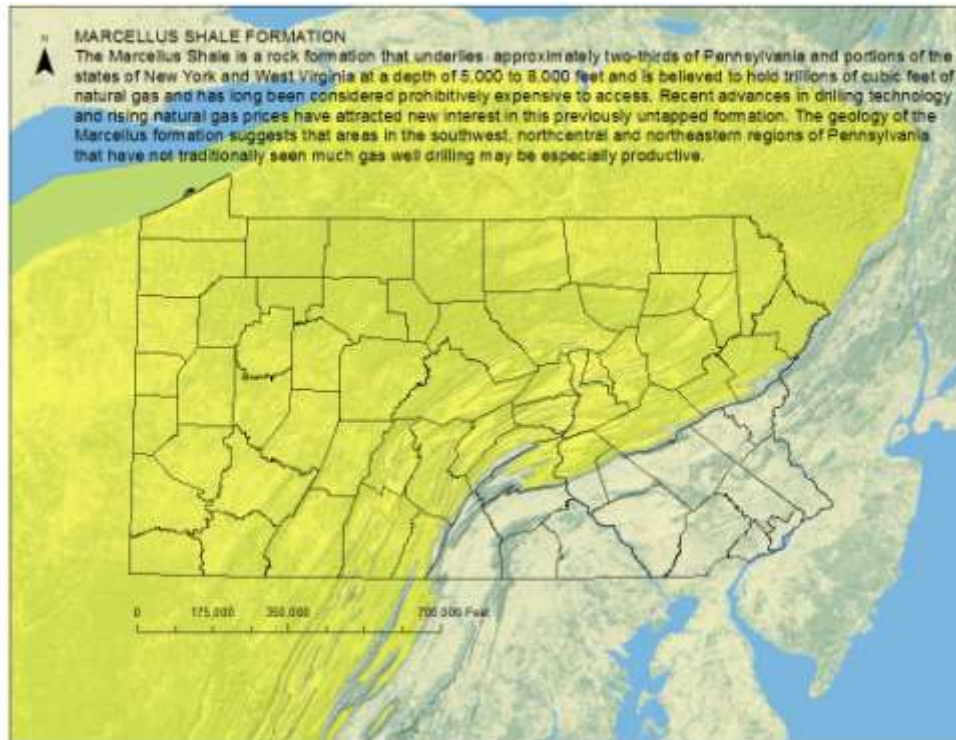


Figure 29 illustrates the extent of Marcellus shale in Pennsylvania and Northeastern U.S.

Methodology for extracting natural gas from Marcellus shell is by a process called hydrofracturing, or fracking for short. Essentially, a conventional drilling rig sinks a well to the substrate containing the shale and then bends horizontally for up to a mile. Once this is complete high pressure water, gels and sands are injected into the well from the surface which then fractures the shale and releases the gas. The gas is then gathered up through the well and brought to the surface where it is processed and transported to market. Diagram 11 below gives a graphical view of how horizontal drilling works.

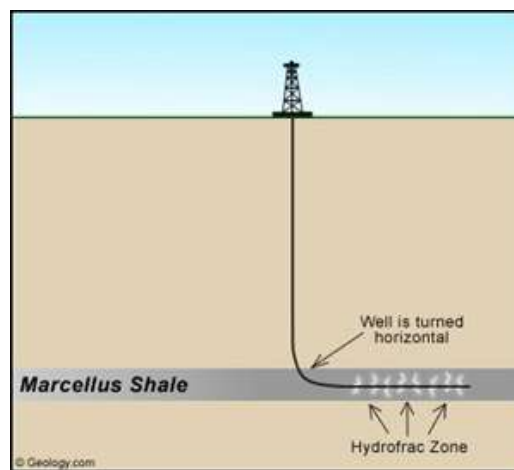


Diagram 11 is a representation of horizontal drilling

## Methodology of extraction

The Marcellus Shale is a rock formation that underlies approximately two-thirds of Pennsylvania and portions of the states of New York and West Virginia at a depth of 5,000 to 8,000 feet and is believed to hold trillions of cubic feet of natural gas and has long been considered prohibitively expensive to access. Recent advances in drilling technology and rising natural gas prices have attracted new interest in this previously untapped formation. The geology of the Marcellus formation suggests that areas in the southwest, northern and northeastern regions of Pennsylvania that have not traditionally seen much gas well drilling may be especially productive. According to Geology.com “Marcellus Shale, also referred to as the Marcellus Formation, is a [Middle Devonian](#)-age black, low density, carbonaceous (organic rich) shale that occurs in the subsurface” (Geology1). The Middle Devonian shale (deposited from 395 to 345 million years ago) is located from the surface to more than a mile underground.

## Results

The first use of fracking for Marcellus gas was done by Range Resources - Appalachia, LLC in 2003. The success of the well opened up the play for natural gas in Pennsylvania and the process has accelerated since 2005. By 2010 over 2300 wells had been drilled. Table 2 below shows the acceleration in drilling over the past several years.

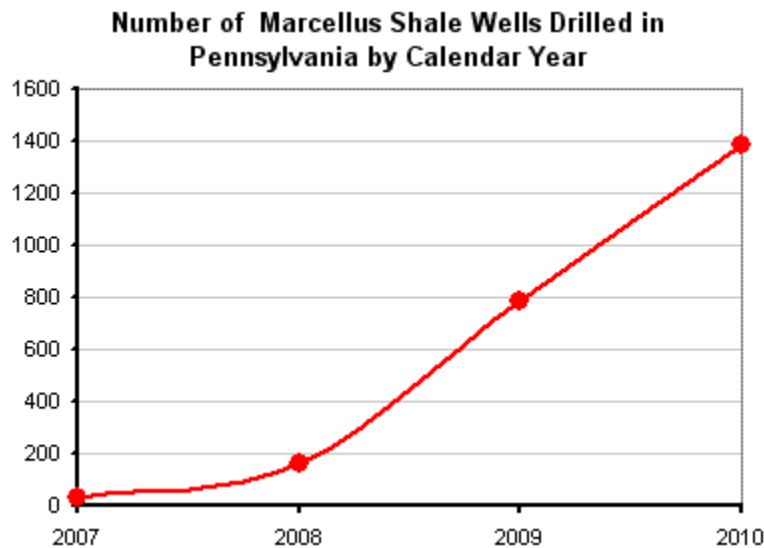


Table 2 Drilled wells by year

Marcellus shale drilling using fracking is a controversial and new technology. There is a growing chorus of voices in the public sphere questioning the environmental impacts of fracking, natural gas leakage, and transportation and infrastructure necessary to bring Marcellus gas to market. In fact, over 260 different chemicals are used in fracking, many of them with potentially unhealthy effects if they come in contact with humans or other forms of life in the watersheds and aquifers surrounding the wells, according to Scientific American (Scientific1). One area of contention currently being debated in Pennsylvania is the leasing of state forests and game

lands for gas extraction. Another is the question of taxing the companies bringing this resource to market and if so by how much and in what way. The current governor of Pennsylvania, Tom Corbett, favors little or no taxes on the corporations while numerous activist, environmental groups, citizen advocates, legislators, special interests and other stakeholders are presenting a variety of options in terms of taxation as the debate develops.

### **Conclusions**

These three case studies on sinkholes in Palmyra, landslides in Allegheny and Luzerne Counties, and Marcellus shale natural gas drilling across northern and western Pennsylvania all share the common factor of potential hazard to humans. From the very local (Palmyra), to wider area (Allegheny and Luzerne) to statewide (Marcellus) these potentially hazardous phenomena also clearly mark the challenges which mother nature presents, and mankind's need to understand and wisely harness resources to build a sustainable environment in which to live and prosper.

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## **Figures**

Figure 1 below gives a view of the physiographic provinces in Pennsylvania

Figure 2 Bedrock geological formations in Pennsylvania

Figure 3 Topography of the surface features of Pennsylvania

Figure 4 Roadways in Pennsylvania and their construction along topographic lines

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Figure 12 High resolution PAFigure color orthoimages aerial photo under the sinkholes

Figure13 Population distribution in Palmyra

Figure 14 Precambrian Basement Figure of the Appalachian Basin and Piedmont Province, D.P. Gold (1) in collaboration with S.S. Alexander (1), R. Cakir (2), A. G. Doden (3) and S. I. Root (4)

Figure 15 Sinkholes in Palmyra over parcel zones

Figure 16 Location of two landslides in Pennsylvania referenced to the physiographic provinces

Figure 17 Hillshade view of the Allegheny Landslide from a DEM

Figure 18 PAMAP aerial photo draped over a DEM of the landslide area in Allegheny County

Figure 19 3D hillshade rendering of the Allegheny landslide area from the south

Figure 20 3D aerial rendering of the Allegheny landslide area

Figure 21 Hillshade view of the Luzerne Landslide from a DEM

Figure 22 PAMAP aerial photo draped over a DEM of the landslide in Luzerne County

Figure 23 3D hillshade rendering of the Luzerne landslide area from the southwest

Figure 24 3D aerial rendering of the Luzerne landslide area

Figure 25 overlays population and land use in Allegheny County

Figures 26 overlays population and land use in Luzerne County

Figure 27 shows soil composition in the landslide area in Allegheny County

Figure 28 shows soil composition in the landslide area in Luzerne County

Figure 29 illustrates the extent of Marcellus shale in Pennsylvania

## Tables

Table 1 A table showing the materials comprising landslide prone areas with the type of landslide most likely, Delano Pg 7

Table 2 Marcellus shale wells drilled from 2007-2010

### Charts

Chart 1 Forecast for Marcellus Natural Gas Production 2009-2020

Chart 2 is a Bar Chart of volume of estimated recoverable natural gas by Sector or County

### Diagrams

Diagram 1 Schematic of future piling placement design practice

Diagram 2 Schematic elevation view of exploratory boring logs and pile locations for Structure 318, Abutment 1

Diagram 3 Side view of a typical limestone formation which has eroded, creating a sinkhole

Diagram 4 Two dimensional view of a sinkhole system

Diagram 5 Conceptual framework of real-time monitoring/warning system for landslides

Diagram 6 ShakeFigure from the New Zealand earthquake

Diagram 7 Extent of Marcellus Compared with Barnett Shale Formation

Diagram 8 Domestic competition with Marcellus

Diagram 9 Shows a cutout from the PGS Basement Figure of Lebanon and Palmyra

Diagram 10 Locations and types of geological resources found in Pennsylvania Source: <http://www.dcnr.state.pa.us/topogeo/econresource/index.aspx>

Diagram 11 is a representation horizontal drilling  
Source: <http://www.dec.ny.gov/energy/46288.html>

### Photos

Photo 1 Natural Gas Development Activities and Local Beneficiaries

Photo 2 Penn Pilot 1937 Aerial of Palmyra. Source <http://www.pennpilot.psu.edu>

Photo 3 Penn Pilot 1956 Aerial of Palmyra. Source <http://www.pennpilot.psu.edu>

Photo 4 Penn Pilot 1970 Aerial of Palmyra. Source <http://www.pennpilot.psu.edu>

Photo 5 Shows a current (Spring 2011) on East Main St. (Rt. 422) in Palmyra . Source:  
<http://www.abc27.com/story/14352077/sinkhole-near-palmyra-filled-again-route-422-reopened?redirected=true>

Photo 6 Sinkhole opens in Lower Allen Township, Mechanicsburg PA. Source:  
[http://www.pennlive.com/midstate/index.ssf/2011/04/sinkhole\\_opens\\_in\\_lower\\_allen.htm](http://www.pennlive.com/midstate/index.ssf/2011/04/sinkhole_opens_in_lower_allen.htm)  
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