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DIGITAL MAPPING TECHNIQUES 2024

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The contents of this document are provisional

See Presentations and Proceedings

from the DMT Meetings (1997-2024)

http://ngmdb.usgs.gov/info/dmt/

Modeling bedrock elevation of Pennsylvania using an adaptive GIS methodology: The first steps towards a 3D geologic model of Pennsylvania

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Brave New 3D World

The Pennsylvania Geological Survey (PaGS) has embarked on a new endeavor to create a 3D geologic model of Pennsylvania in support of the U.S. GeoFramework Initiative. PaGS is creating digital elevation models of major geologic bounding surfaces. As a first step, PaGS developed a digital surface that represents the bedrock elevation beneath unconsolidated sediments. Over the years, geologists have used subsurface data from water wells, geotechnical borings, and seismic surveys to map the bedrock elevation. The historical process of generating a bedrock elevation map, which involves contouring the data by hand, is a laborious process and subject to radical changes in interpretation whenever new data are collected. Using digital mapping techniques, geostatistical analysis, and GIS workflow models, the newly developed method to generate a bedrock elevation surface has shifted away from time-consuming manual efforts and towards automated computer processing, which allows for the rapid update of this surface as new data are collected.

Geoframework Initiative

Geologic mapping forms the bedrock of geological understanding, offering insights into the complex interplay of Earth's processes and features. The current effort by PaGS to establish a 3D geologic model of Pennsylvania underscores the contemporary fusion of geoscience and geospatial technology. As a pivotal starting point, this article delves into the innovative methodology adopted for modeling bedrock elevation beneath unconsolidated sediments, showcasing the efficacy of adaptive GIS techniques and computational automation.

At the heart of this endeavor is the U.S. Geoframework Initiative, which aims to integrate detailed national- and continental-resolution 2D and 3D geologic information produced by federal and state partners. The first step towards this goal is to create a 3D surface representing the top of bedrock beneath the unconsolidated sediments of Pennsylvania.

Traditionally, bedrock elevation and drift thickness maps were hand contoured by geologists using subsurface data obtained from water wells, geotechnical borings, and seismic surveys (Figure 1). This manual process was not only labor-intensive but also susceptible to significant reinterpretation whenever new data emerged. In contrast, the advanced approach developed by PaGS leverages contemporary tools, such as digital mapping techniques, geostatistical analysis, and an iterative GIS workflow model. This departure from traditional methodologies has provoked a paradigm shift, transitioning from time-intensive manual processes to automated computational processing. As a result, this methodology allows efficient real-time updating of the bedrock elevation model, rendering it adaptable and responsive to the dynamic acquisition of new data.

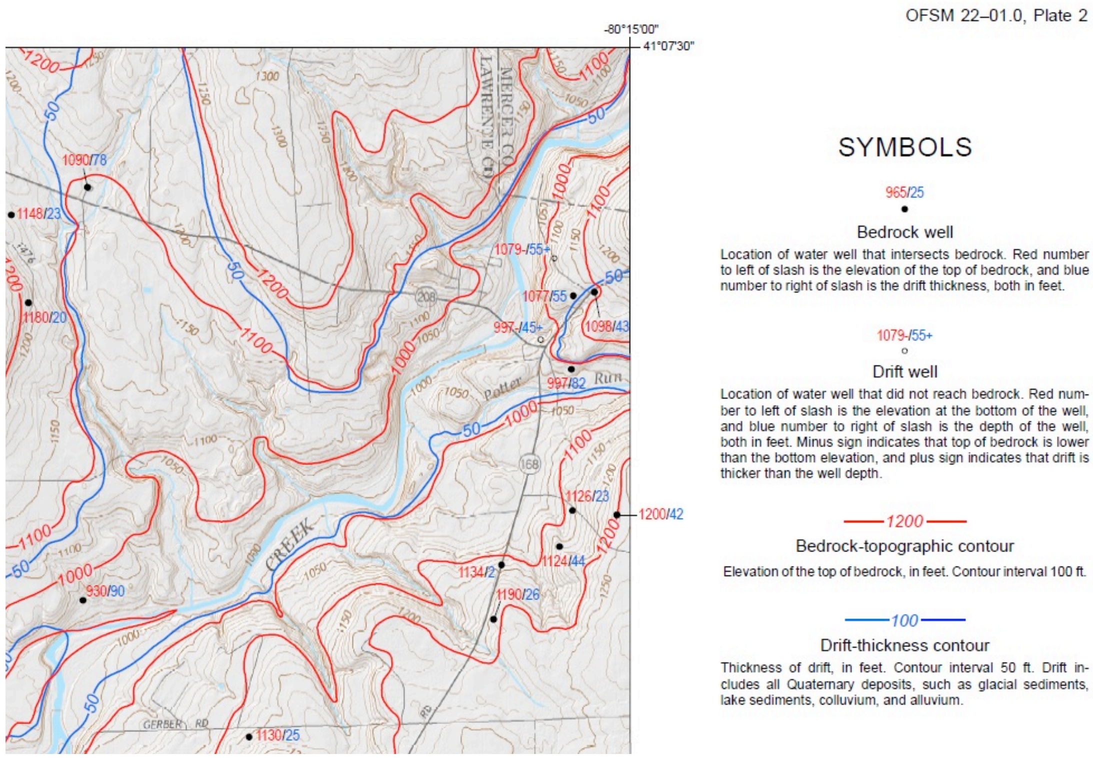

Figure 1. The northeastern portion of Bedrock-topography and drift-thickness map of the New Castle North 7.5-minute quadrangle, Lawrence, and Mercer Counties, Pennsylvania (Open-File Surficial Geologic Map 22–01.0).

Water Well Data

PaGS assembled over 214,000 relevant water-well records from Pennsylvania GroundWater Information System (PaGWIS) and borehole data used in the pilot project covering the glaciated portion of northwestern Pennsylvania (Figure 2). Although the density of water wells varies across the state, data coverage extends across all physiographic sections and major topographic landforms found within Pennsylvania. Each well record used in the analysis contains a measurement of the depth to bedrock (in feet) or a notation indicating that bedrock was not encountered during well drilling. For the purpose of determining the thickness of unconsolidated sediments, the well records are separated into two datasets—bedrock wells (wells that penetrate bedrock) and drift wells (wells that did not encounter bedrock). Using this data, PaGS interpolated a sediment thickness model of the state. The initial results were inconsistent, subject to variations in spatial data density. An approach was needed to help fill in the gaps.

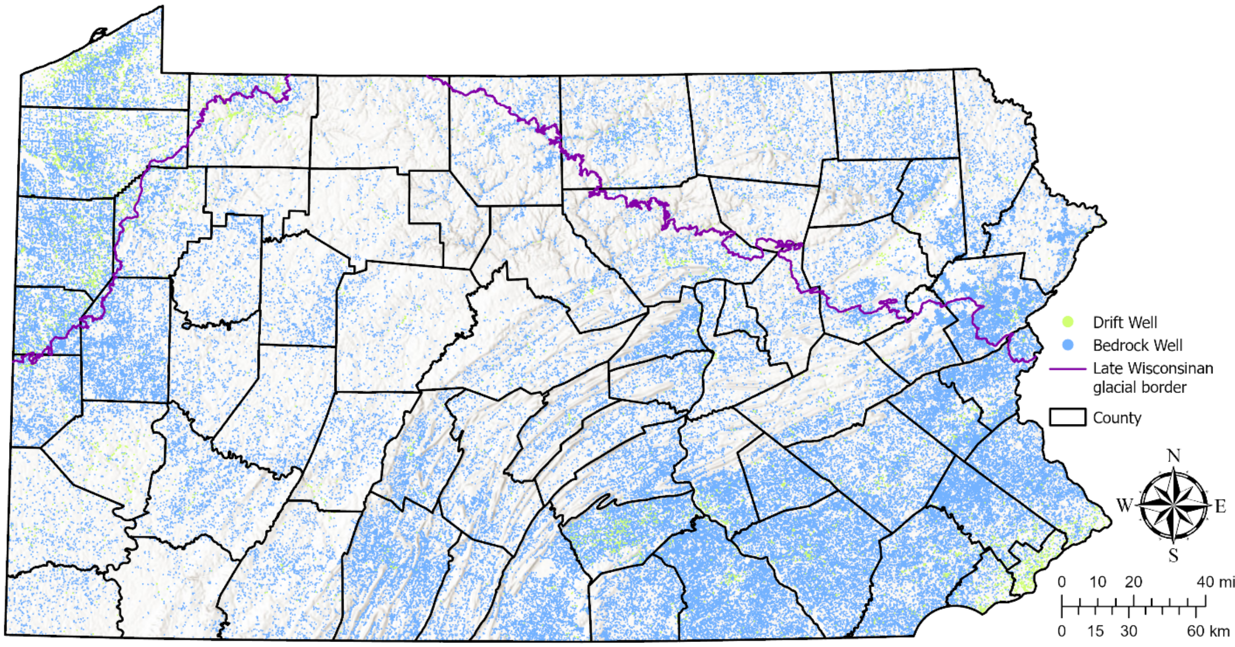

Figure 2. Geographic distribution of water well data points used in the analysis.

Topographic Position Index

The project team used physiographic section and topographic position index to identify the landform type in which each well resides. Topographic Position Index (TPI) is a quantitative landform analysis that uses land surface elevation data to determine landforms such as ridge, upper slope, middle slope/flats, lower slope, and valley. While the concept of classifying landforms based on contour maps has been widely applied through various techniques, a modern GIS application of TPI was presented at an Esri International User Conference by Weiss (2001). A variation of the Weiss method was used to generate a composite TPI raster of Pennsylvania for the purposes of this project (Figure 3).

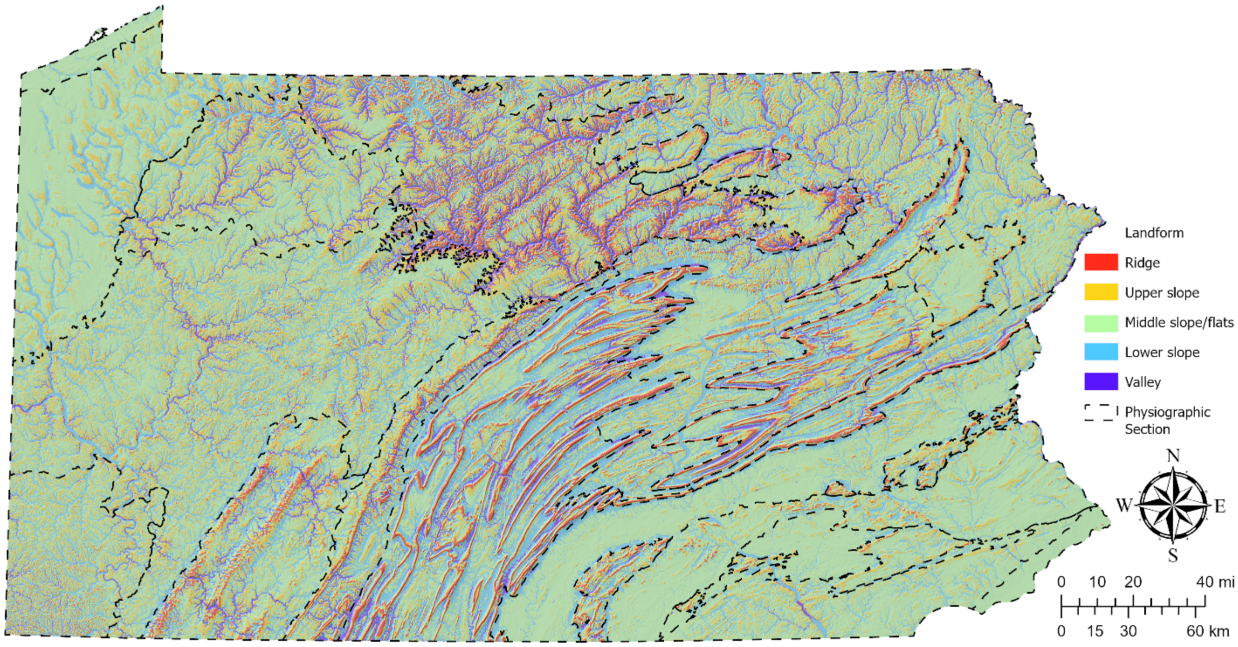

Figure 3. Classification of landforms by Topographic Position Index (TPI)

Statistical Relationship Establishment

The heart of the methodology resides in the statistical relationship between TPI and the sediment thickness specific to individual physiographic sections (Figure 4). This relationship, supported by geostatistical principles, produced a surrogate model. Here, "surrogate model" refers to a set of predictive data; specifically, projected sediment thicknesses in regions characterized by sparse empirical data.

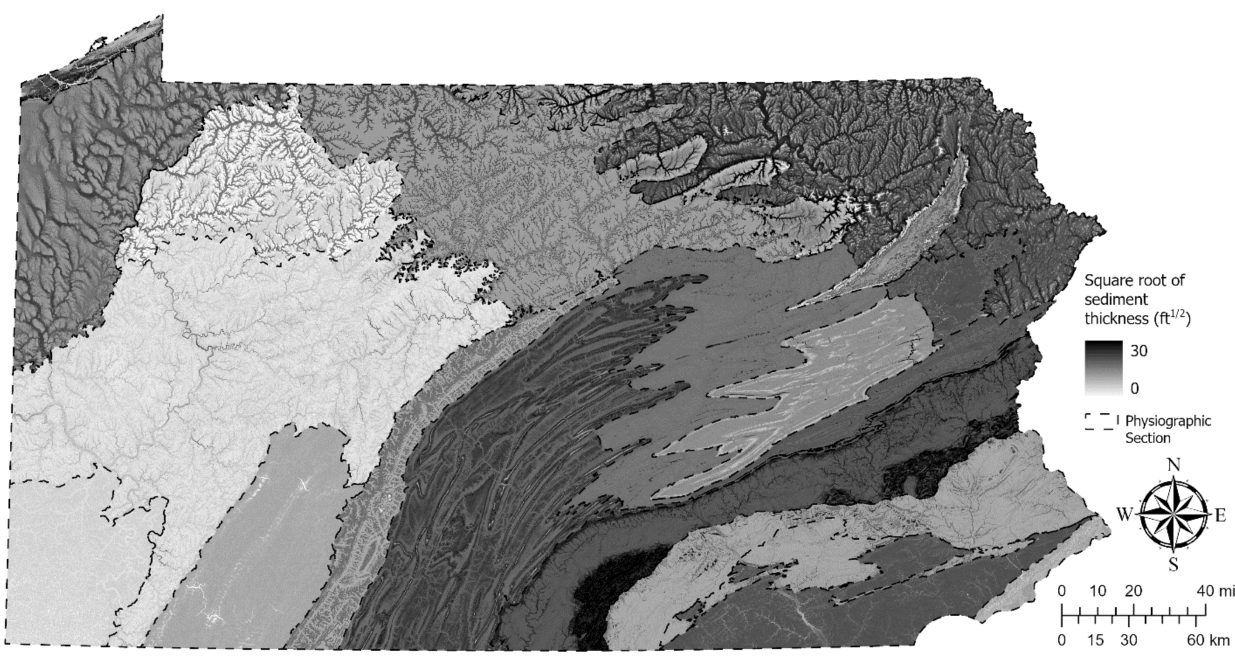

Figure 4. The statistical relationship between bedrock depth and TPI for each Physiographic Section yields a surrogate model of sediment thickness.

Iterative Refinement

The surrogate model was created by using landform-based statistics to generate “synthetic” data points in order to fill in gaps in empirical data coverage. An iterative refinement process, through assimilation of empirical well data and synthetic points derived from the surrogate model, produced an adaptable sediment thickness model that bridges empirical observations and predictive analytics. An interpolated sediment thickness model was generated based on over 400,000 data points — bedrock wells, drift wells, and synthetic points (Figure 5).

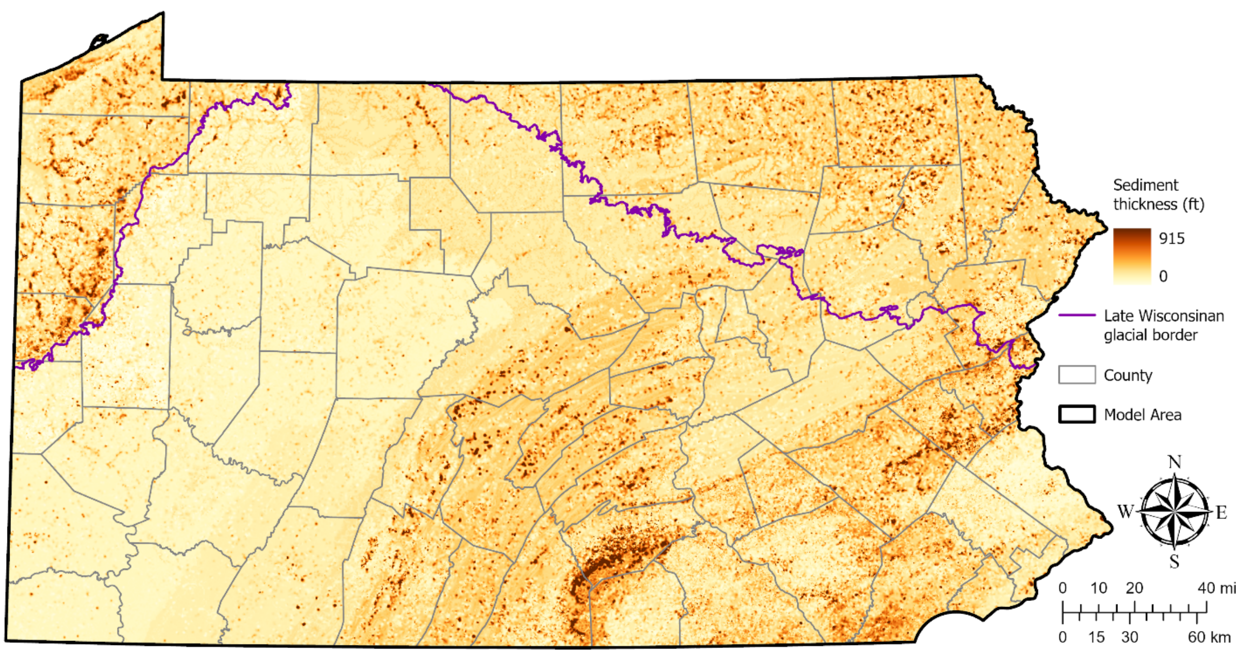

Figure 5. Interpolated sediment thickness based on well data and the surrogate model.

Conditional Smoothing Techniques

The sediment thickness model was resampled to conform to a similar resolution surface topography digital elevation raster. Through this process of raster resampling, the sediment thickness raster adopts the same projected coordinate system, cell size, and cell position as the surface elevation raster. As discussed in Soller and Garrity (2018), the surface elevation raster needs to be smoothed to remove detail before subtracting the sediment thickness to create a bedrock elevation raster. The degree of smoothing was applied proportionally to the magnitude of sediment thickness. A 100-meter grid bedrock elevation raster was calculated by subtracting the resultant sediment thickness raster from the conditionally smoothed surface elevation raster.

Digital Elevation Model of Bedrock Topography

The first generation of this bedrock model is accessible through the Pennsylvania Spatial Data Access (PASDA) and PaGEODE. Bedrock elevations represented by raster values are relative to the North

American Vertical Datum of 1988 (NAVD88) in feet (Figure 6). Since the bedrock elevation model is derived from statistical computations, the resultant prediction should be presented as a range of values rather than a single, definitive surface. A 90% confidence interval has been generated based on comparison of the model prediction and empirical data. The elevation data is presented as a 3-band raster in feet above mean sea level. Each cell contains three values: a predicted bedrock elevation and the upper and lower bounds of the prediction.

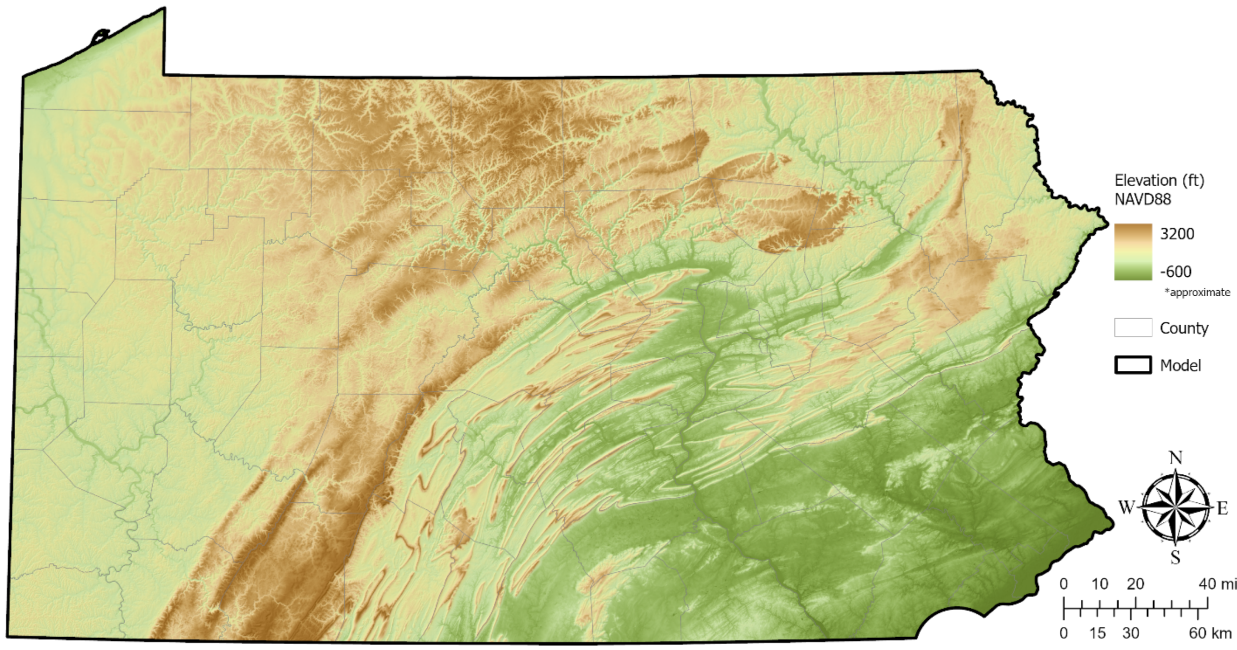

Figure 6. Digital elevation model of bedrock topography beneath unconsolidated sediments of Pennsylvania (Data Release DR 23-01.0).

Unlike previous drift thickness and bedrock elevation mapping efforts that relied on hand-contouring techniques, the methodology developed through the course of this project is designed to be replicated with minimal manual input. The process can be re-run and a new model can be generated as new data is collected. Thus, the bedrock elevation model can be refined and improved on a periodic basis to reflect the continually expanding well borehole dataset. In essence, PaGS' innovative GIS methodology marks a significant stride towards a comprehensive 3D geologic framework for Pennsylvania. This achievement not only exemplifies the power of modern geospatial techniques but also underscores the Survey's commitment to refining and expanding its geological insights over time.

Acknowledgments

Funding for this project was provided in part from a 2021 Great Lakes Geologic Mapping Coalition grant, administered through the U.S. Geological Survey. The Pennsylvania Geological Survey (PaGS) acknowledges the diligent efforts of its team members in executing this pioneering methodology and producing the bedrock elevation model. The project team extends their gratitude to CivicMapper LLC for their invaluable contributions to the project.

References

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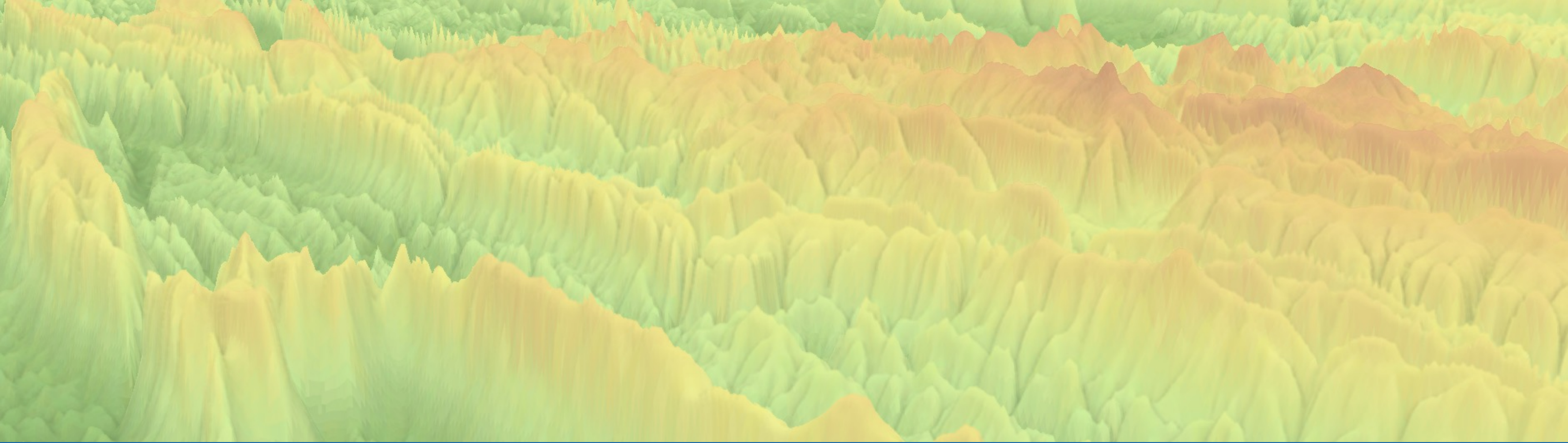

Modeling Bedrock Elevation of Pennsylvania

Using an Adaptive GIS Methodology

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Craig Ebersole, PG | Senior Geoscientist
Geologic & Geographic Information Services

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AND NATURAL RESOURCES

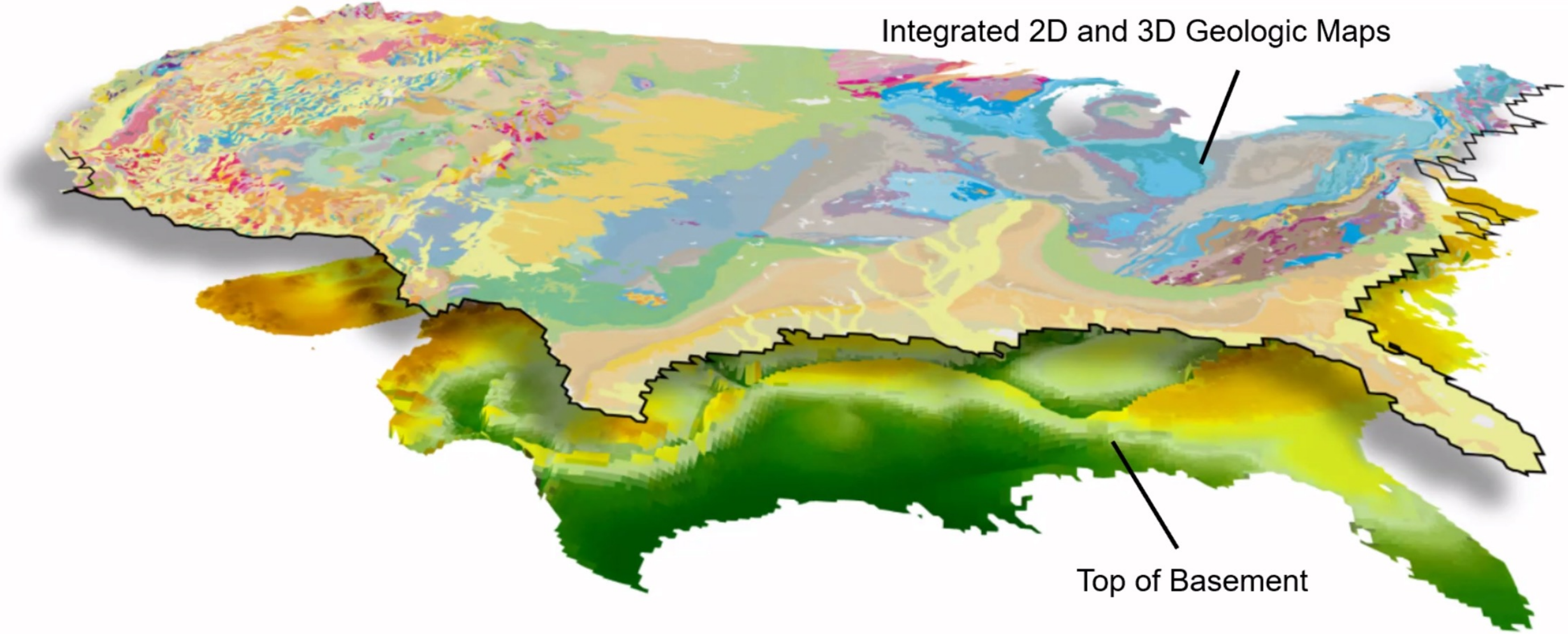
PENNSYLVANIA GEOLOGICAL SURVEY
EST. 1836

Bedrock Digital Elevation Model of Pennsylvania

- **Background**
  - US GeoFramework Initiative (USGI)
  - Great Lakes Geologic Mapping Coalition (GLGMC)
  - Northwestern Pennsylvania pilot project
- **GIS Methodology**
  - Pennsylvania Ground Water Information System (PaGWIS)
  - Topographic Position Index (TPI)
  - Regression analysis based on landforms
  - Depth-to-bedrock surrogate model
  - Conditional smoothing
- **Data Delivery**
  - 100-meter digital rasters
  - Confidence interval
  - Pennsylvania GEOlogic Data Exploration (PaGEODE)
  - Periodic updates

The US GeoFramework Initiative Promise

Congress has directed NCGMP to "bring together *detailed national and continental*-resolution **2D** and **3D** information produced throughout the Survey and by federal and state partners."



US GeoFramework Initiative

USGS Grant-funded Projects in Pennsylvania

- **2020 STATEMAP**

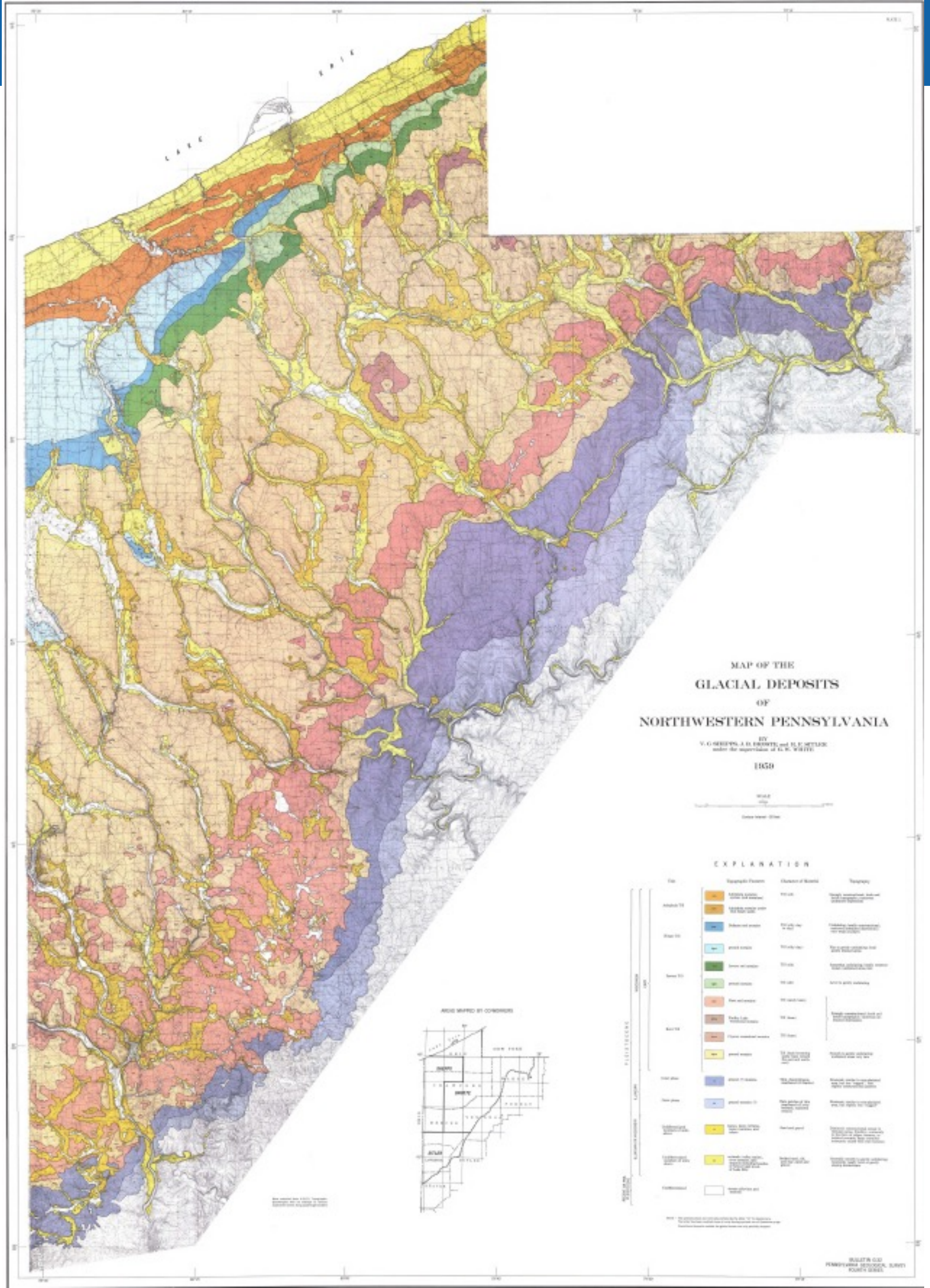
  3D bedrock derivative mapping of the Broad Top coalfield, Huntingdon, Bedford, and Fulton Counties

- **2020 Great Lakes Geologic Mapping Coalition**

  Prepare a Digital Elevation Model of Bedrock Topography of the Glaciated Portion of Northwestern Pennsylvania

- **2021 Great Lakes Geologic Mapping Coalition *special project***

  Complete a statewide digital elevation model (DEM) in raster format of the bedrock topography beneath all Quaternary sediments of Pennsylvania



DIGITAL ELEVATION MODEL OF BEDROCK TOPOGRAPHY OF THE GLACIATED PORTION OF NORTHWESTERN PENNSYLVANIA

- PaGS, in partnership with Allegheny College, assembled a variety of borehole data within the glaciated eight-county area to develop a raster of bedrock elevation

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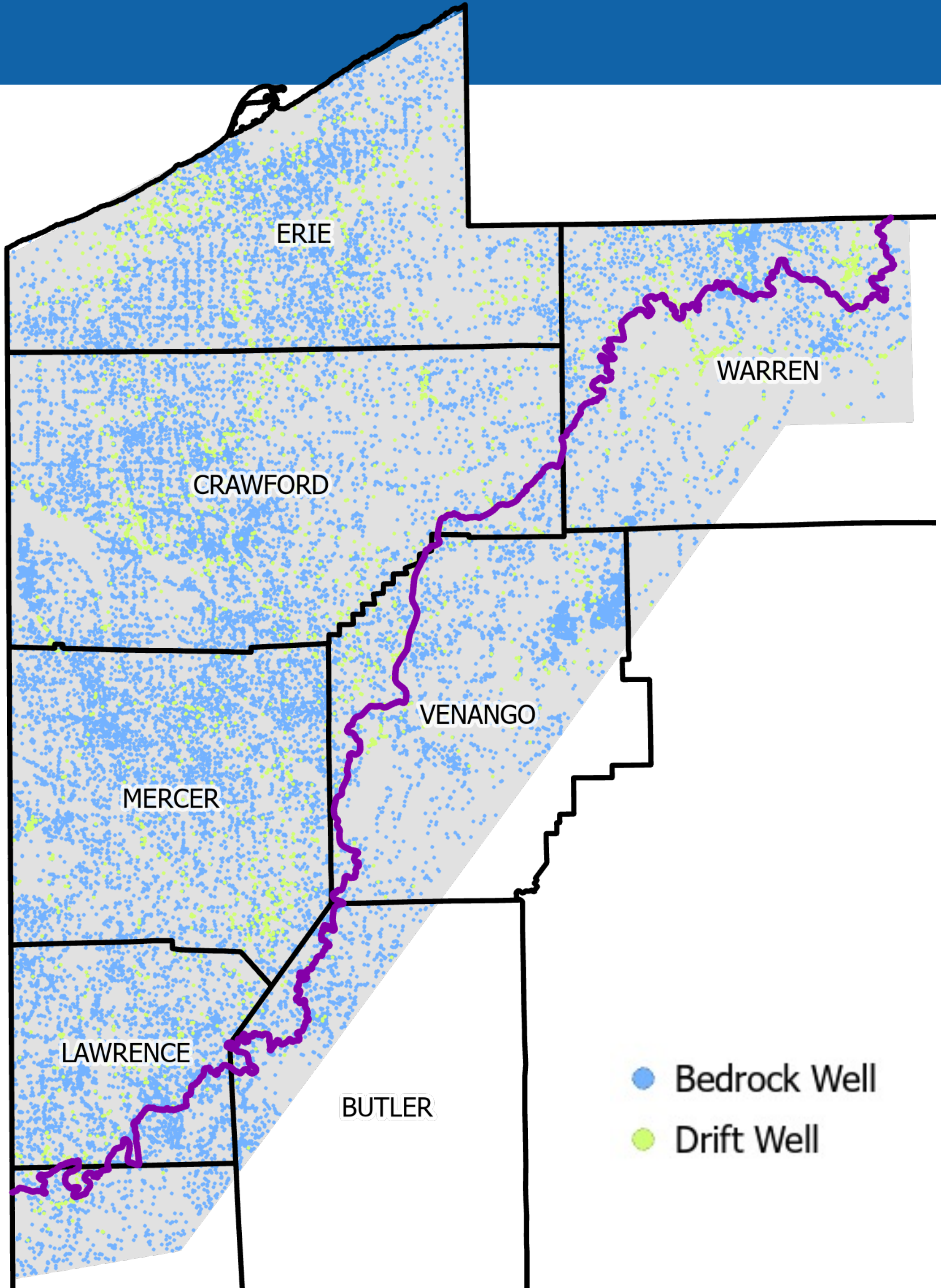

DIGITAL ELEVATION MODEL OF BEDROCK TOPOGRAPHY OF THE GLACIATED PORTION OF NORTHWESTERN PENNSYLVANIA

- Pennsylvania Groundwater Information System (PaGWIS)
  - >25,000 water-well records
- Exploration and Development Well Information Network (EDWIN)
  - Oil and gas well completion reports
- Pennsylvania Department of Transportation (PennDOT)
  - Geotech borings

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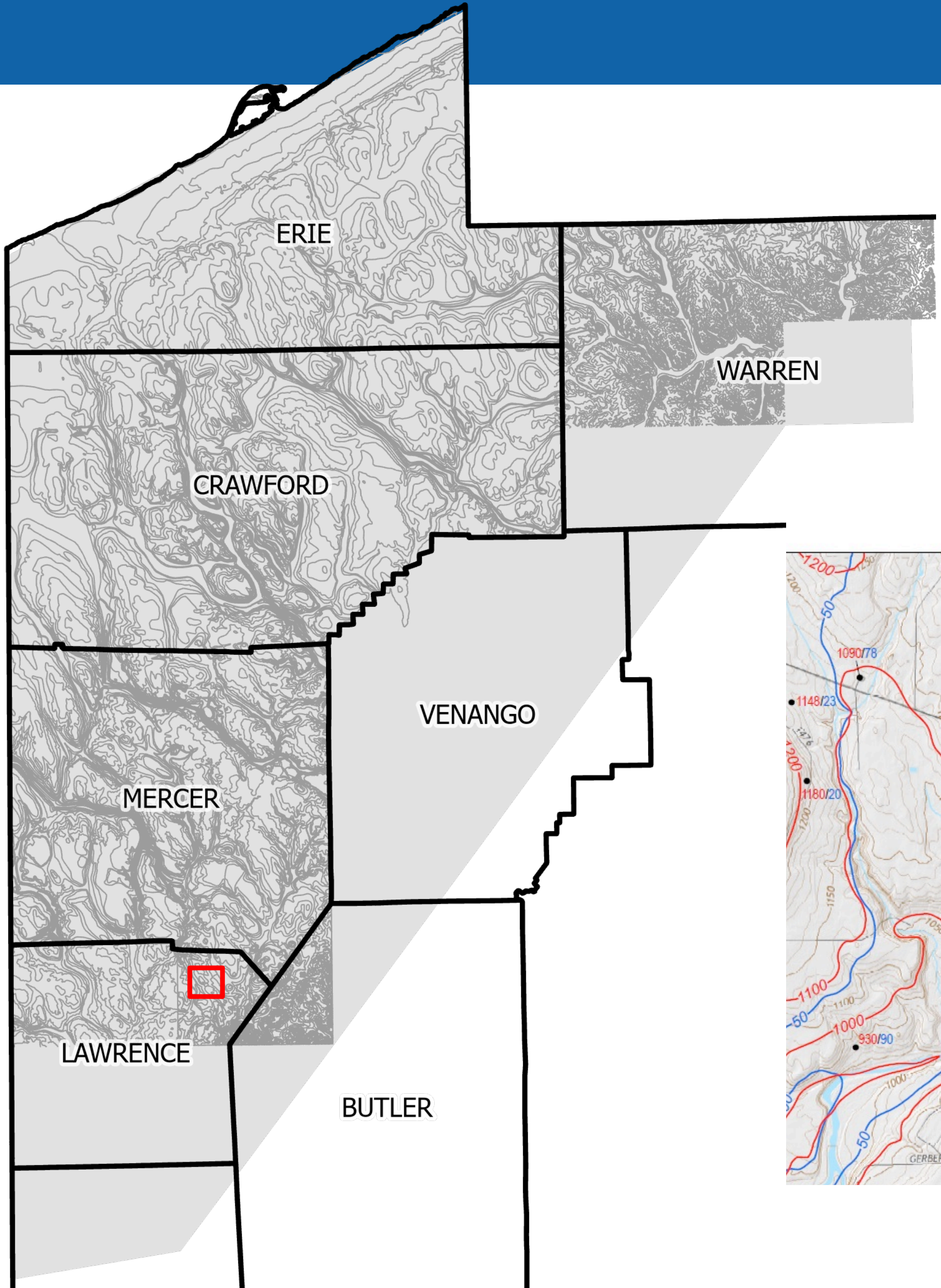
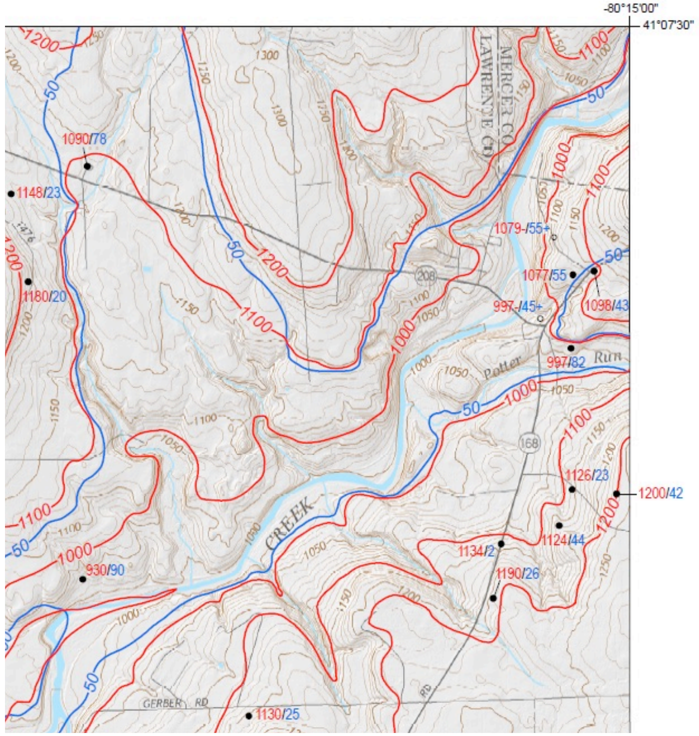


OFSM 22–01.0, Plate 2



SYMBOLS

965/25

Bedrock well

Location of water well that intersects bedrock. Red number to left of slash is the elevation of the top of bedrock, and blue number to right of slash is the drift thickness, both in feet.

1079-/55+

Drift well

Location of water well that did not reach bedrock. Red number to left of slash is the elevation at the bottom of the well, and blue number to right of slash is the depth of the well, both in feet. Minus sign indicates that top of bedrock is lower than the bottom elevation, and plus sign indicates that drift is thicker than the well depth.

1200

Bedrock-topographic contour

Elevation of the top of bedrock, in feet. Contour interval 100 ft.

100

Drift-thickness contour

Thickness of drift, in feet. Contour interval 50 ft. Drift includes all Quaternary deposits, such as glacial sediments, lake sediments, colluvium, and alluvium.

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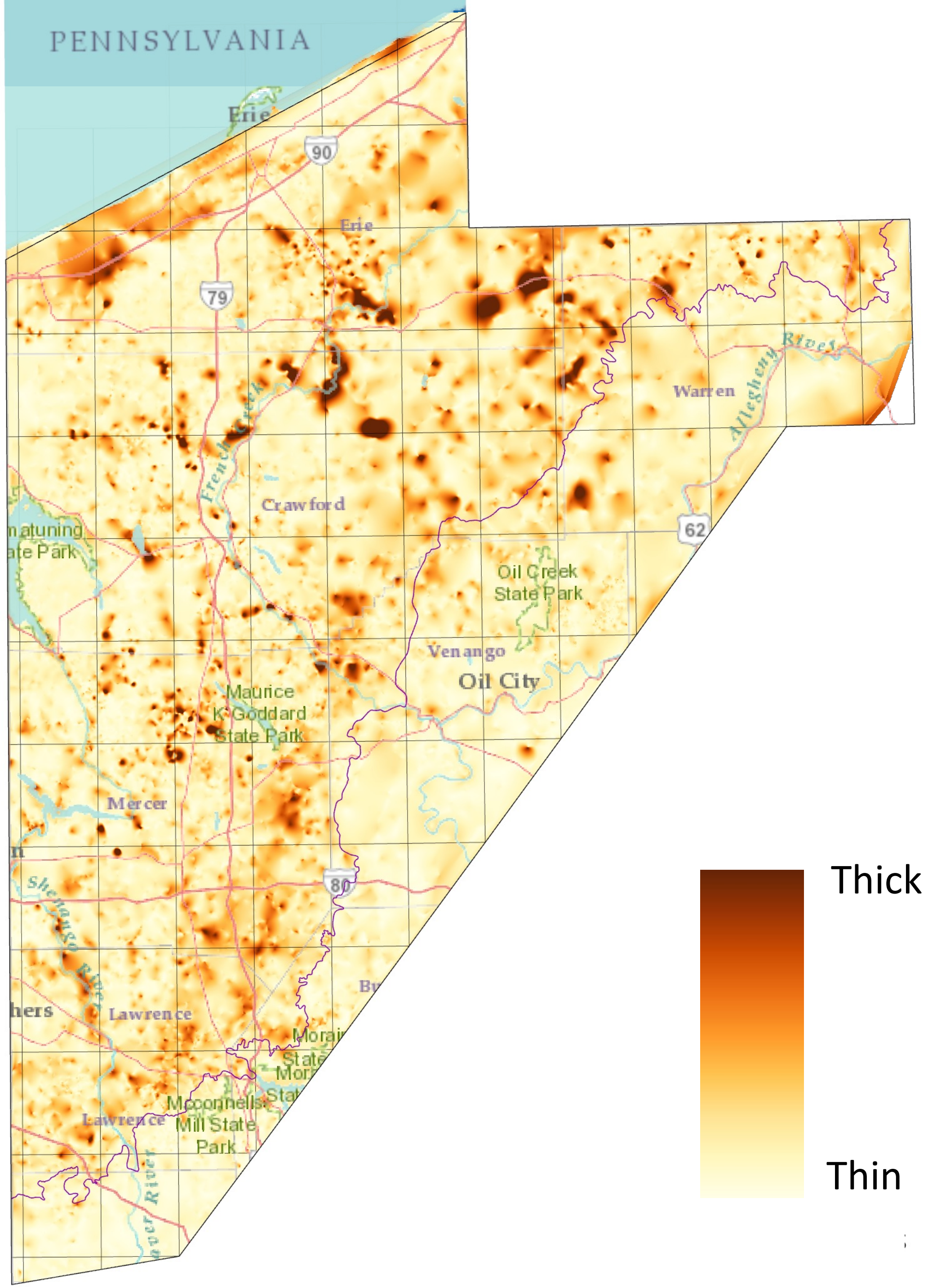

- Drift thickness model based on borehole data

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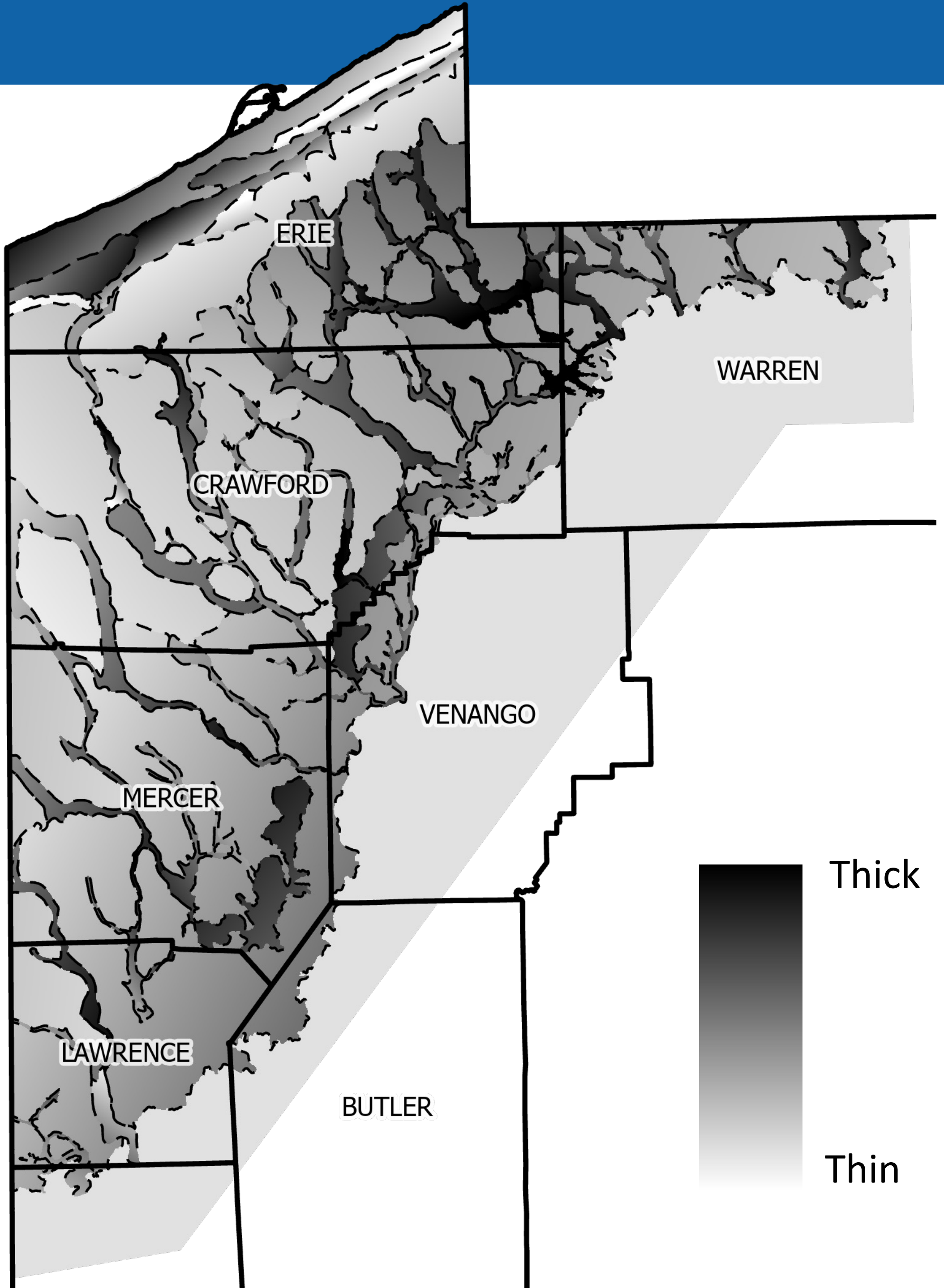
DIGITAL ELEVATION MODEL OF BEDROCK TOPOGRAPHY OF THE GLACIATED PORTION OF NORTHWESTERN PENNSYLVANIA



- Geostatistical trend of drift thickness for each landform

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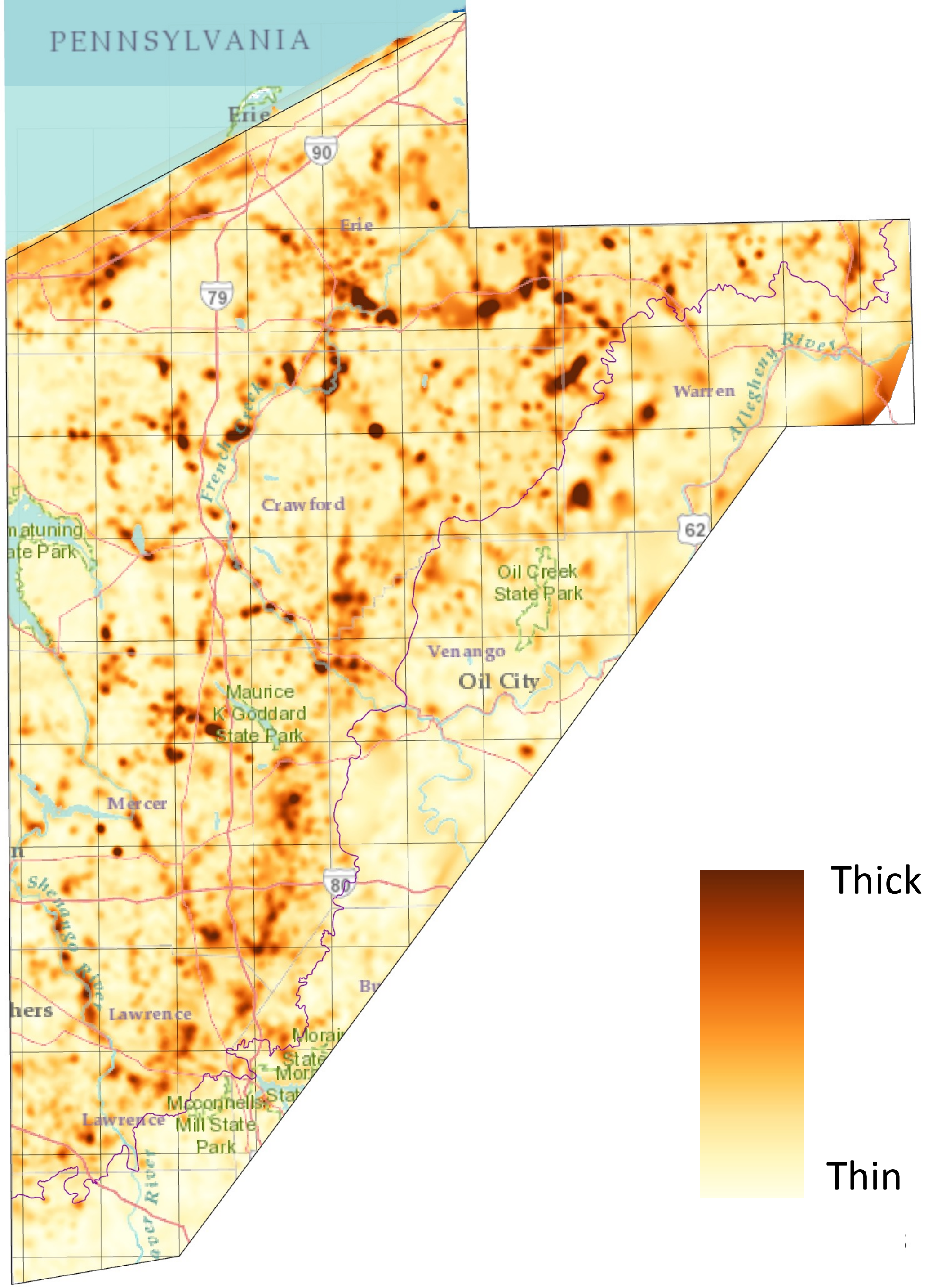
DIGITAL ELEVATION MODEL OF BEDROCK TOPOGRAPHY OF THE GLACIATED PORTION OF NORTHWESTERN PENNSYLVANIA



- Smoothing techniques were applied to the resultant bedrock elevation model to filter data “noise” and local detail while maintaining regional trends

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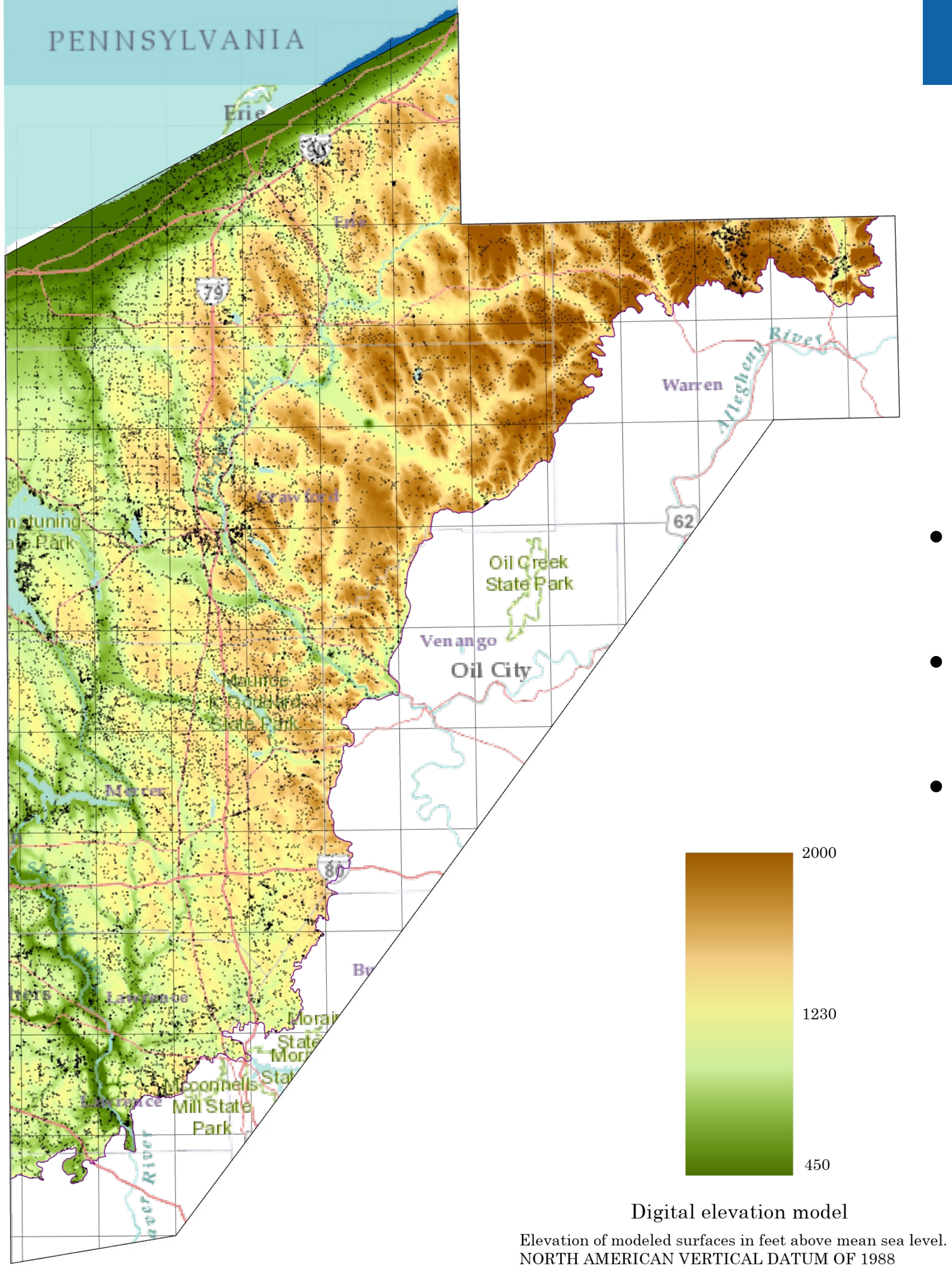
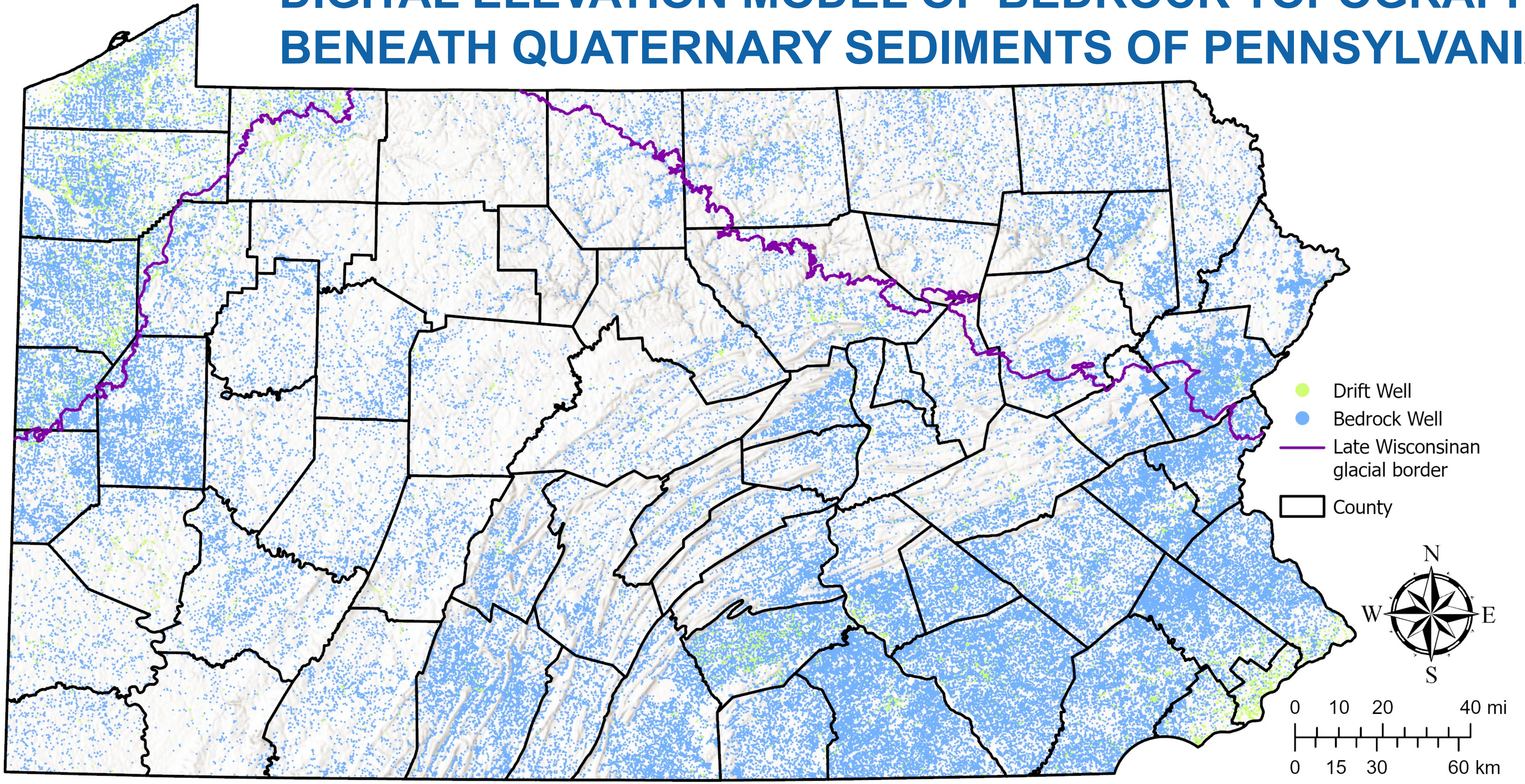


DIGITAL ELEVATION MODEL OF BEDROCK TOPOGRAPHY OF THE GLACIATED PORTION OF NORTHWESTERN PENNSYLVANIA

- Replicated with minimal manual input.
- A new model can be generated as new data is collected.
- Updated on a periodic basis.

DIGITAL ELEVATION MODEL OF BEDROCK TOPOGRAPHY BENEATH QUATERNARY SEDIMENTS OF PENNSYLVANIA



Over 214,000 water well records

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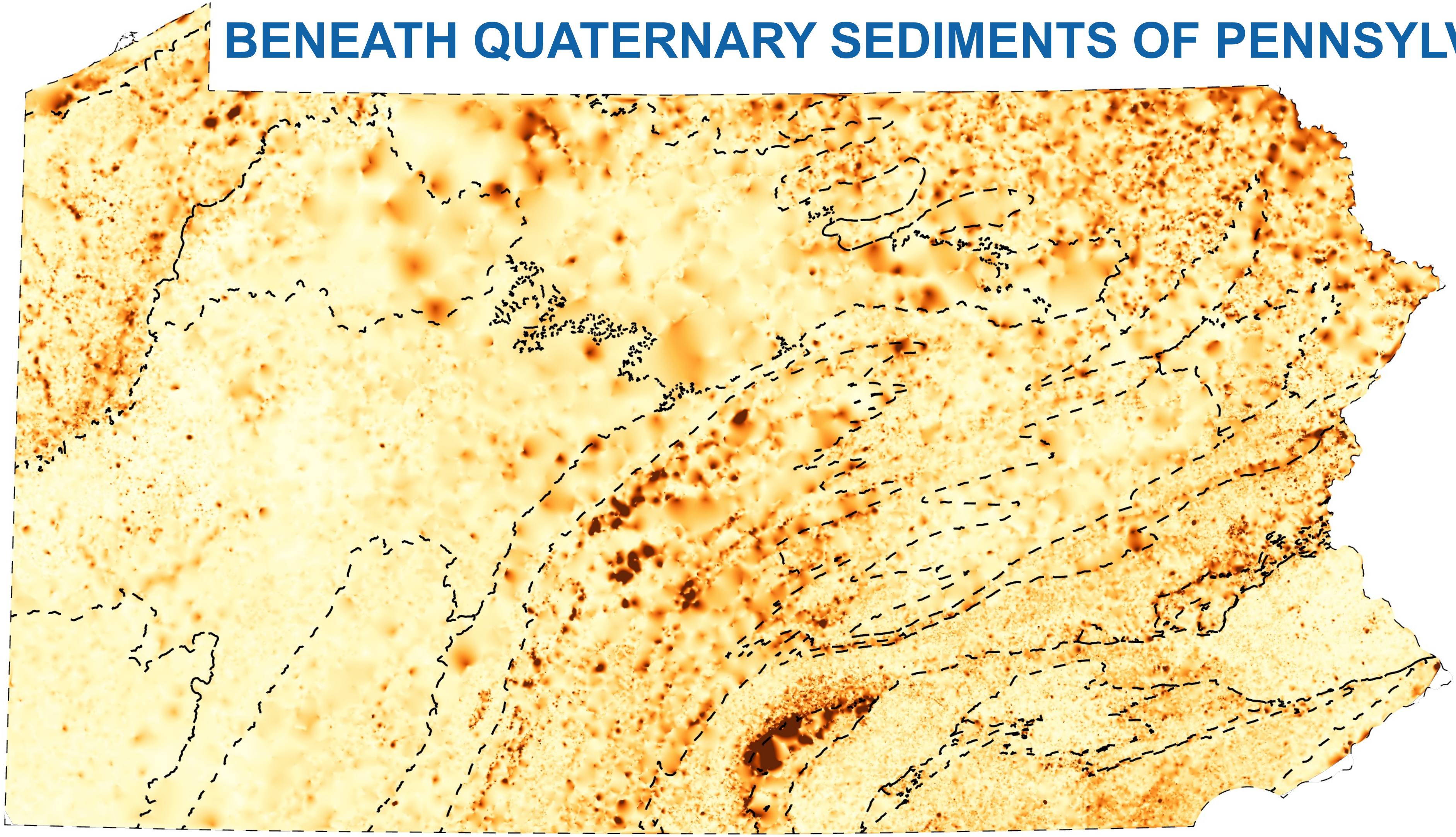

Unconsolidated deposit thickness model based on borehole data

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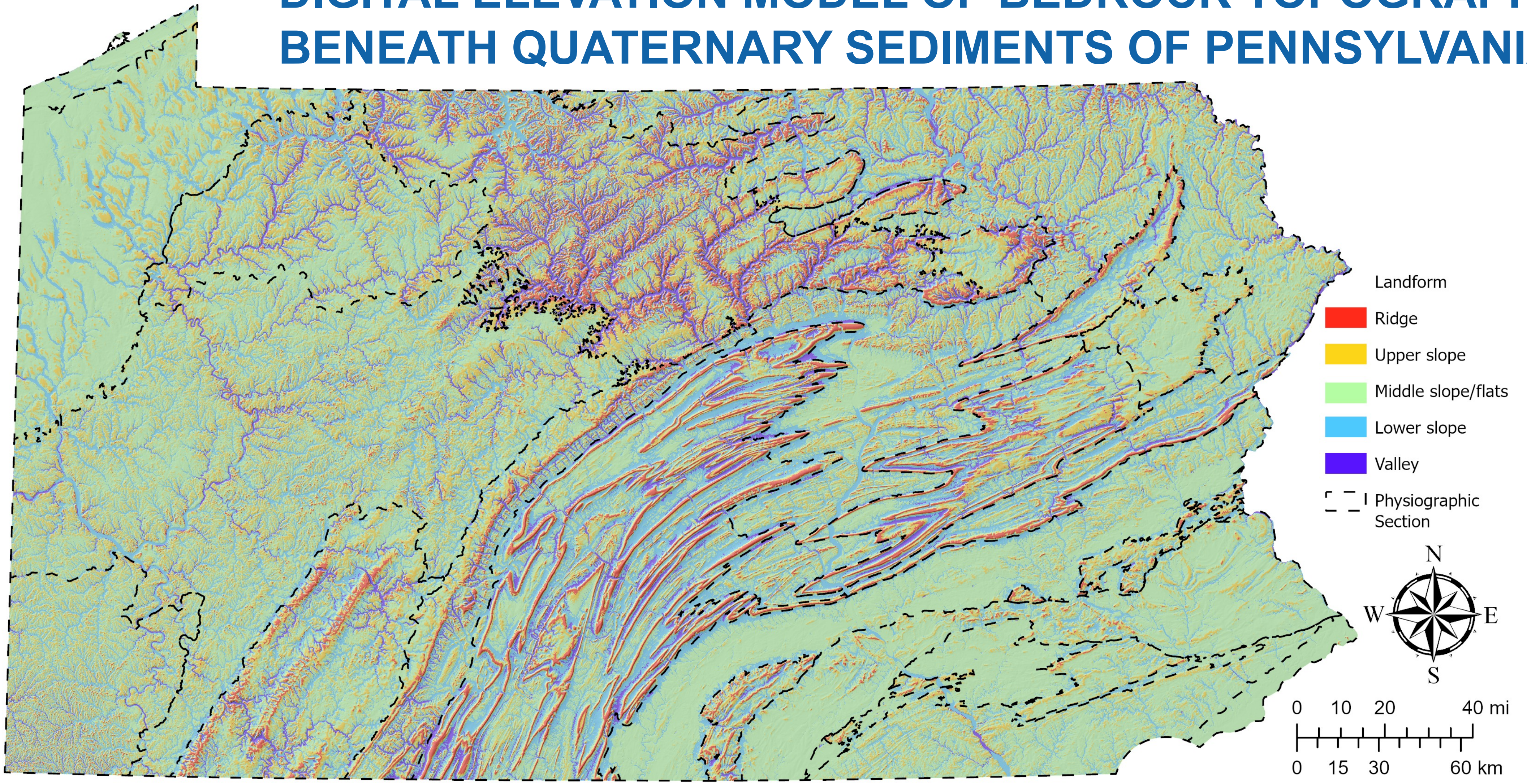
DIGITAL ELEVATION MODEL OF BEDROCK TOPOGRAPHY BENEATH QUATERNARY SEDIMENTS OF PENNSYLVANIA



Topographic Position Index (TPI) to classify landforms

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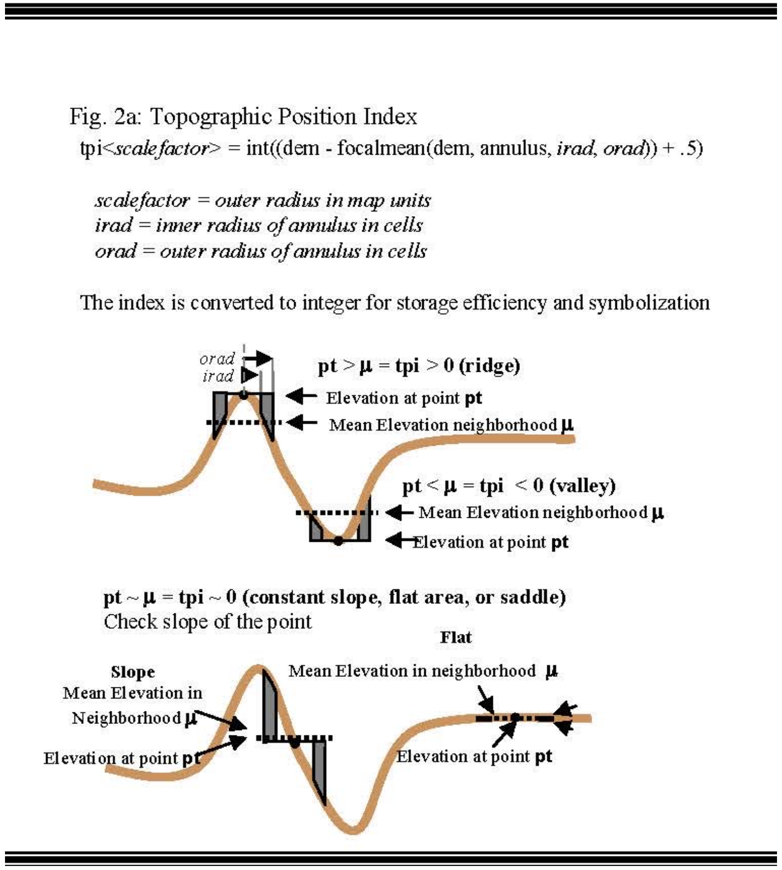
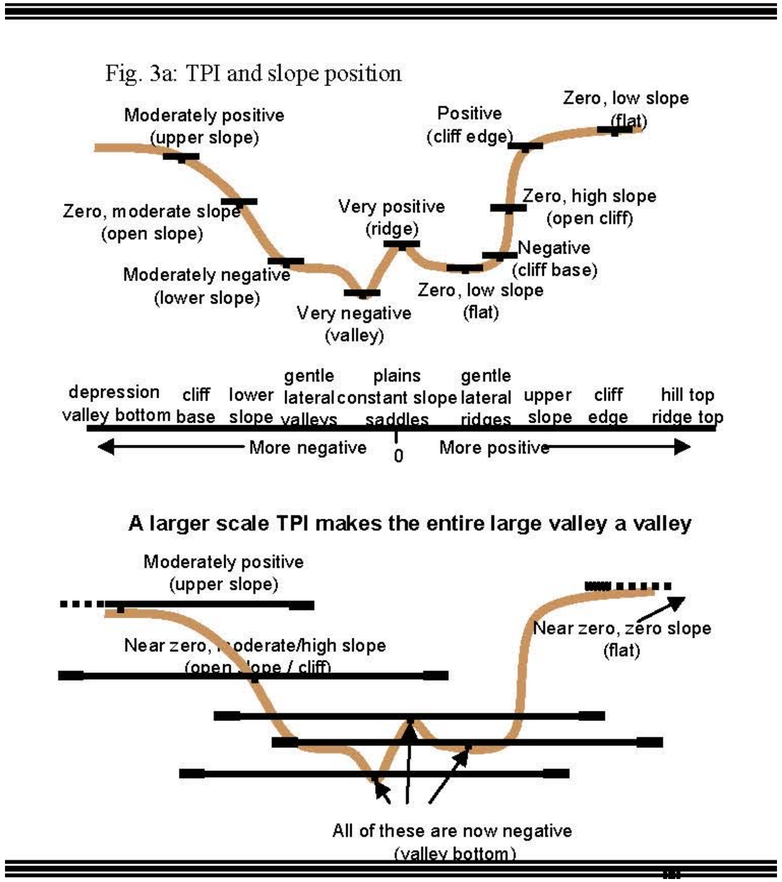
Topographic Position Index (TPI)

Andrew Weiss, 2001

The Nature Conservancy
SAVING THE LAST GREAT PLACES ON EARTH





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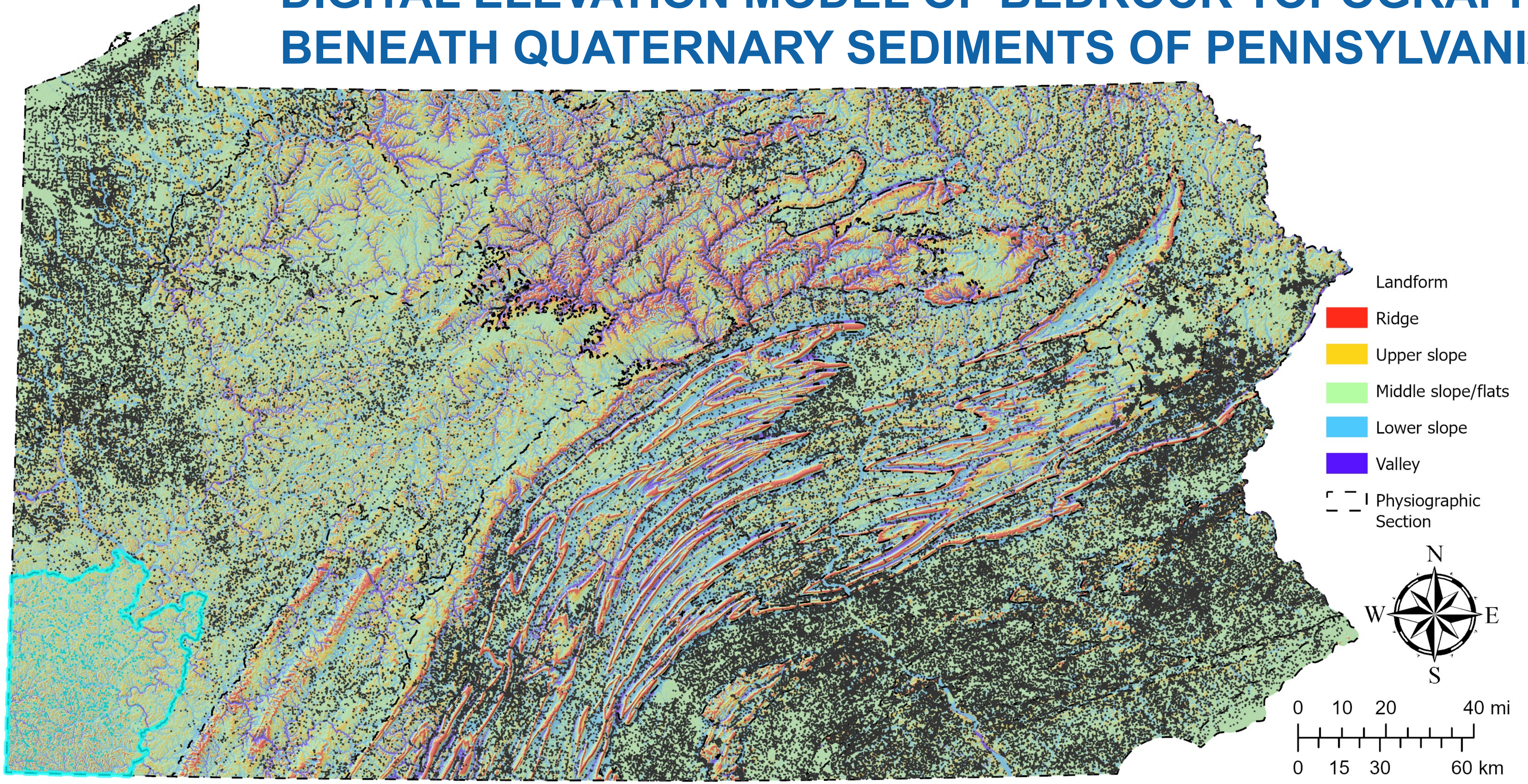

Compare well data points to corresponding TPI value

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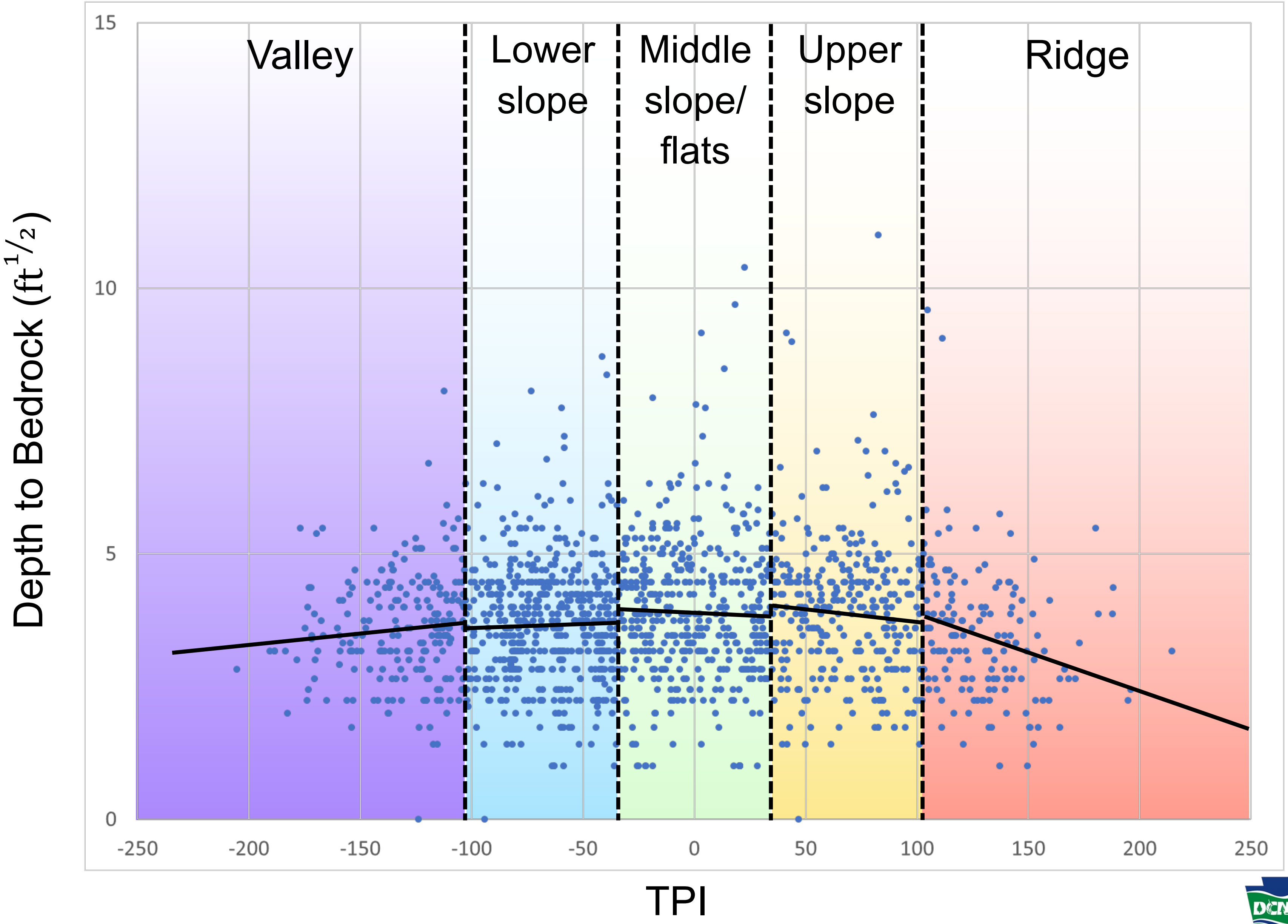
Regression model



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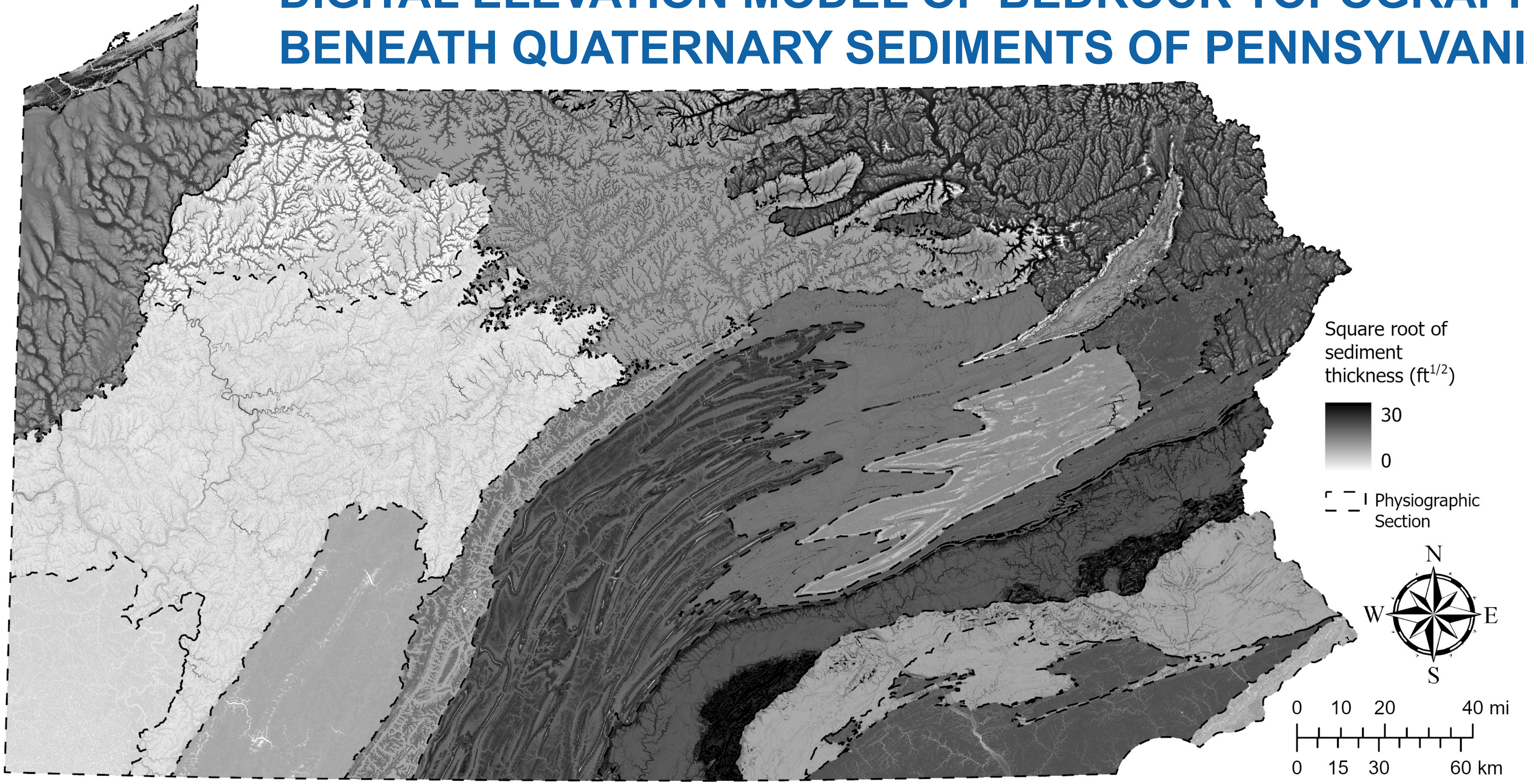

Relationship between sediment thickness and TPI for each Physiographic Section

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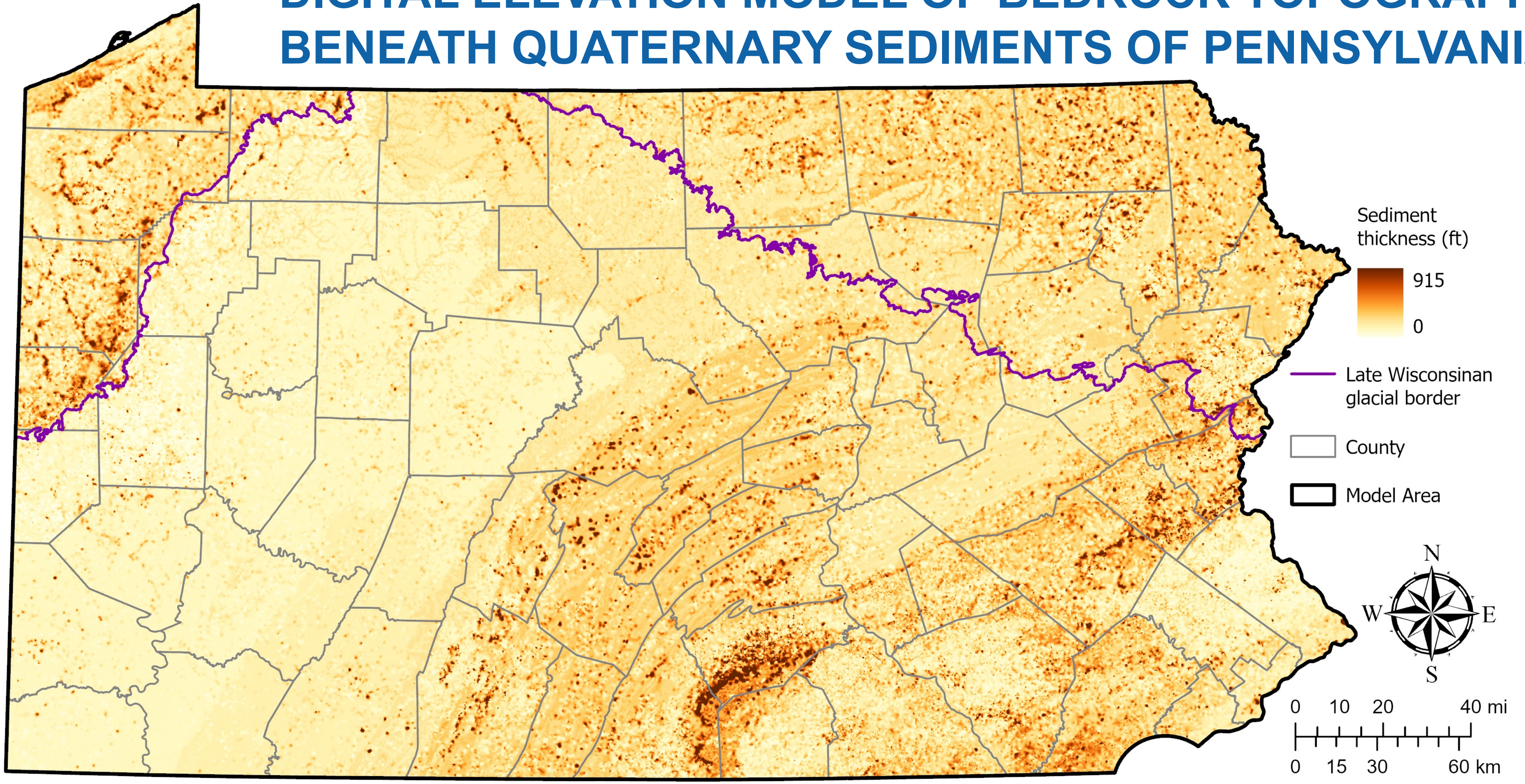
DIGITAL ELEVATION MODEL OF BEDROCK TOPOGRAPHY BENEATH QUATERNARY SEDIMENTS OF PENNSYLVANIA



Interpolated sediment thickness based on over 400,000 data points – bedrock wells, drift wells, and synthetic points

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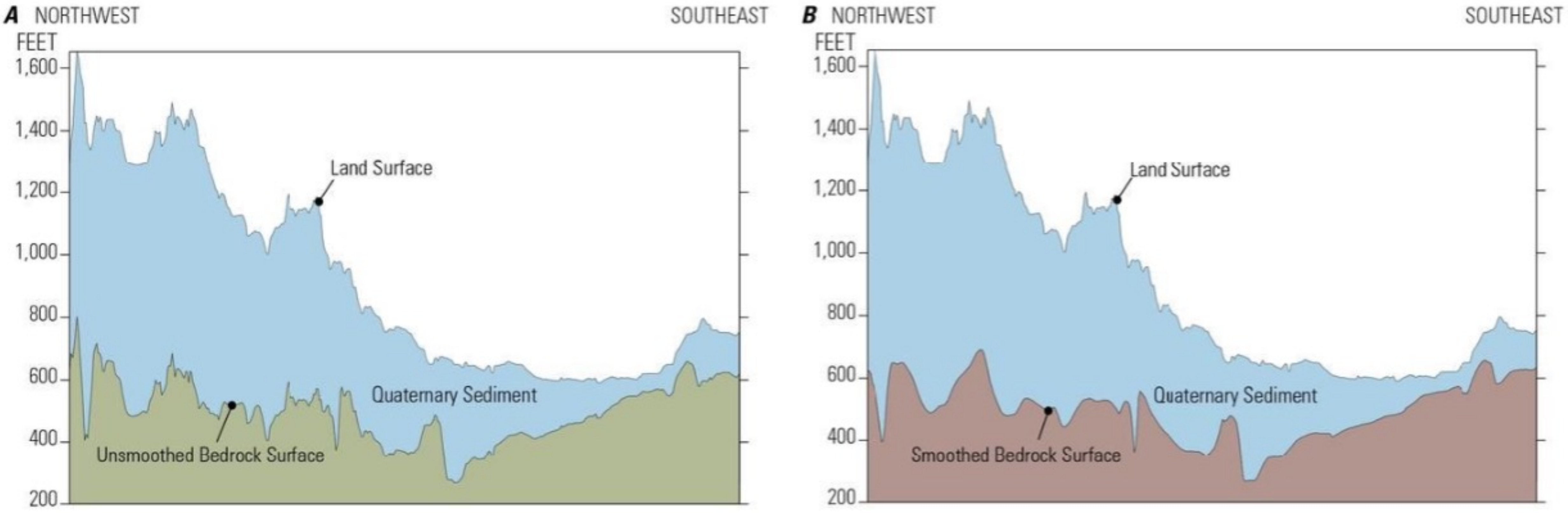
Conditional smoothing



Soller and Garrity, 2018

Quaternary sediment thickness and bedrock topography of the glaciated United States east of the Rocky Mountains

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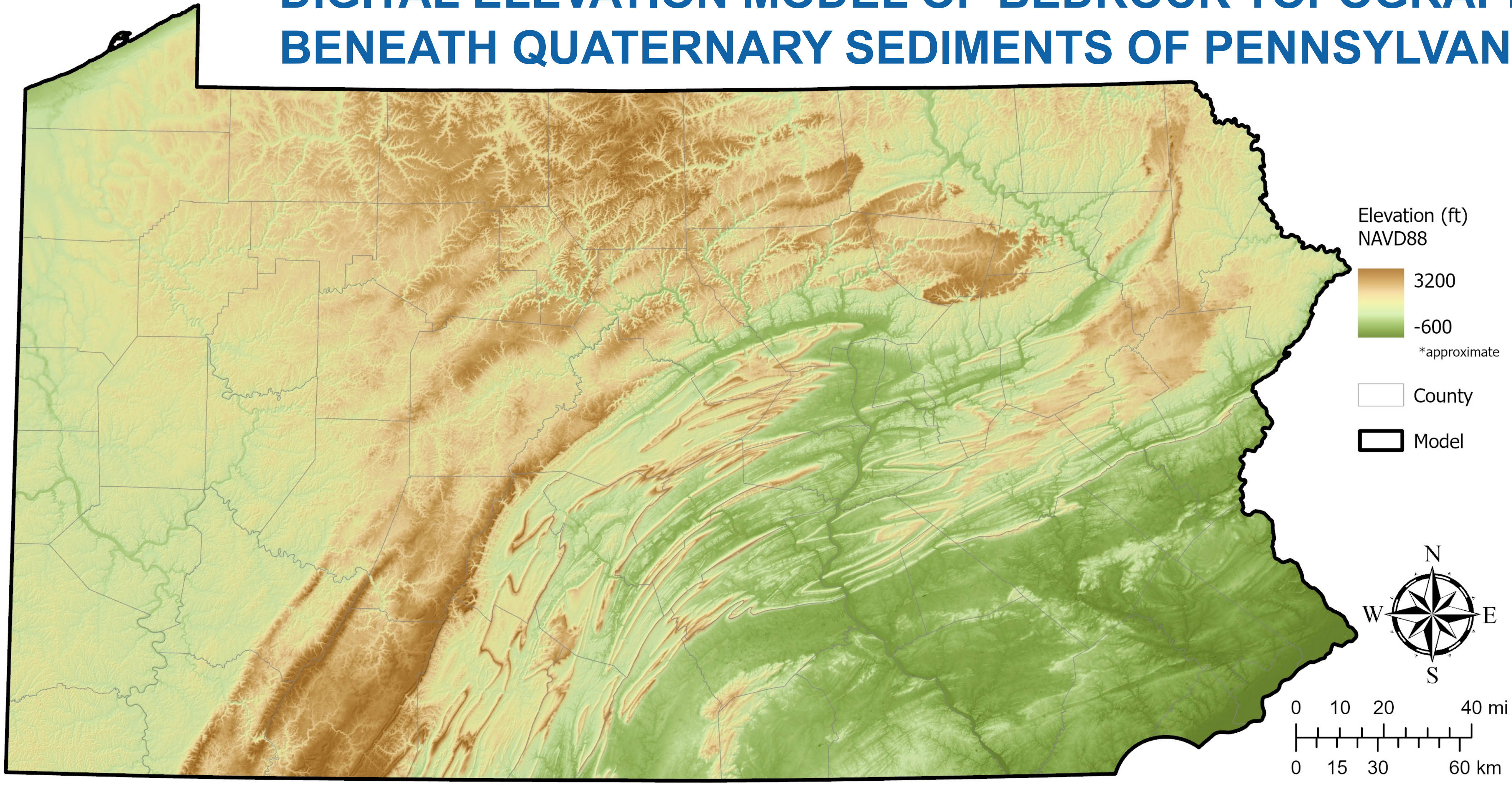

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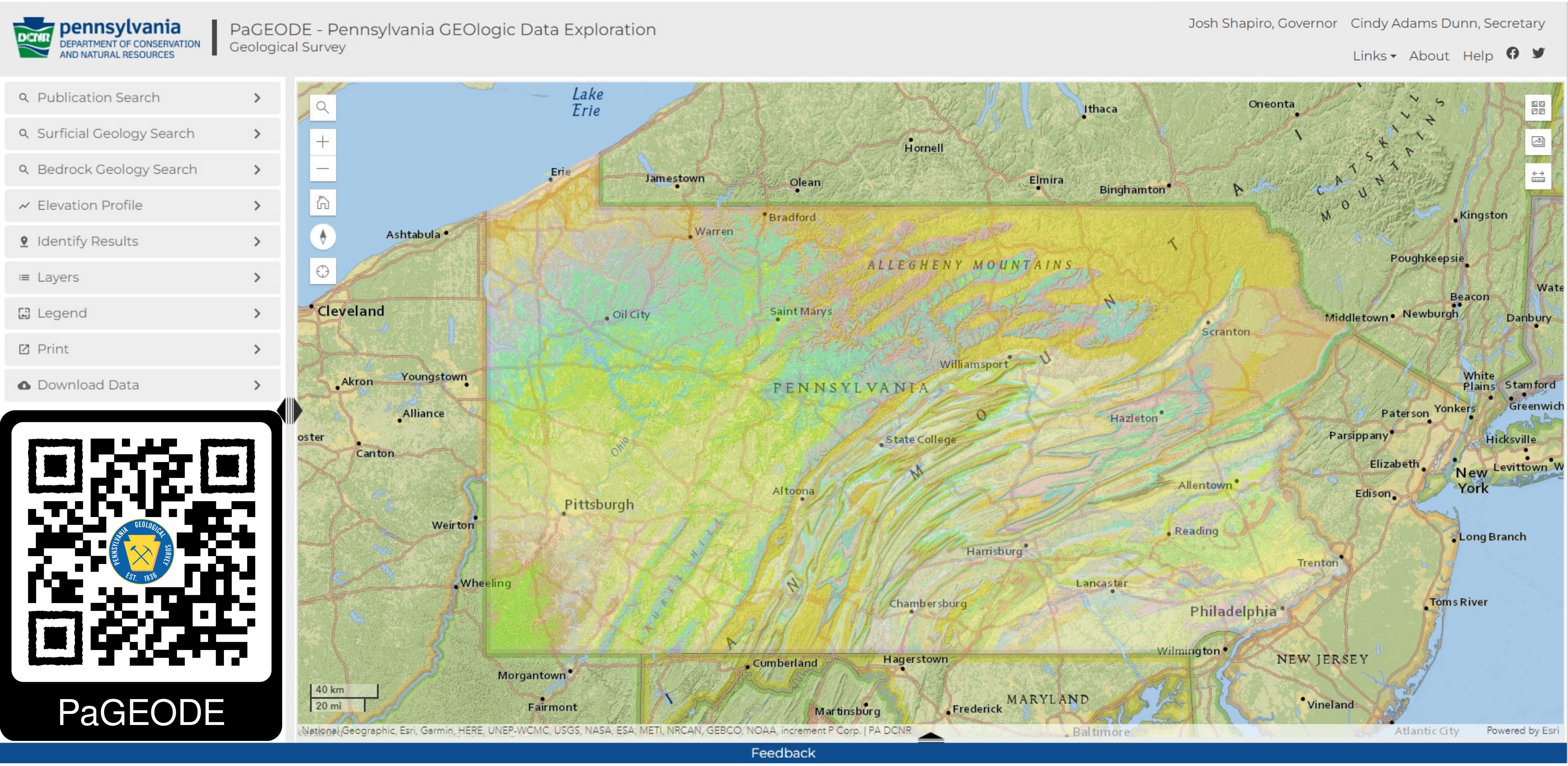
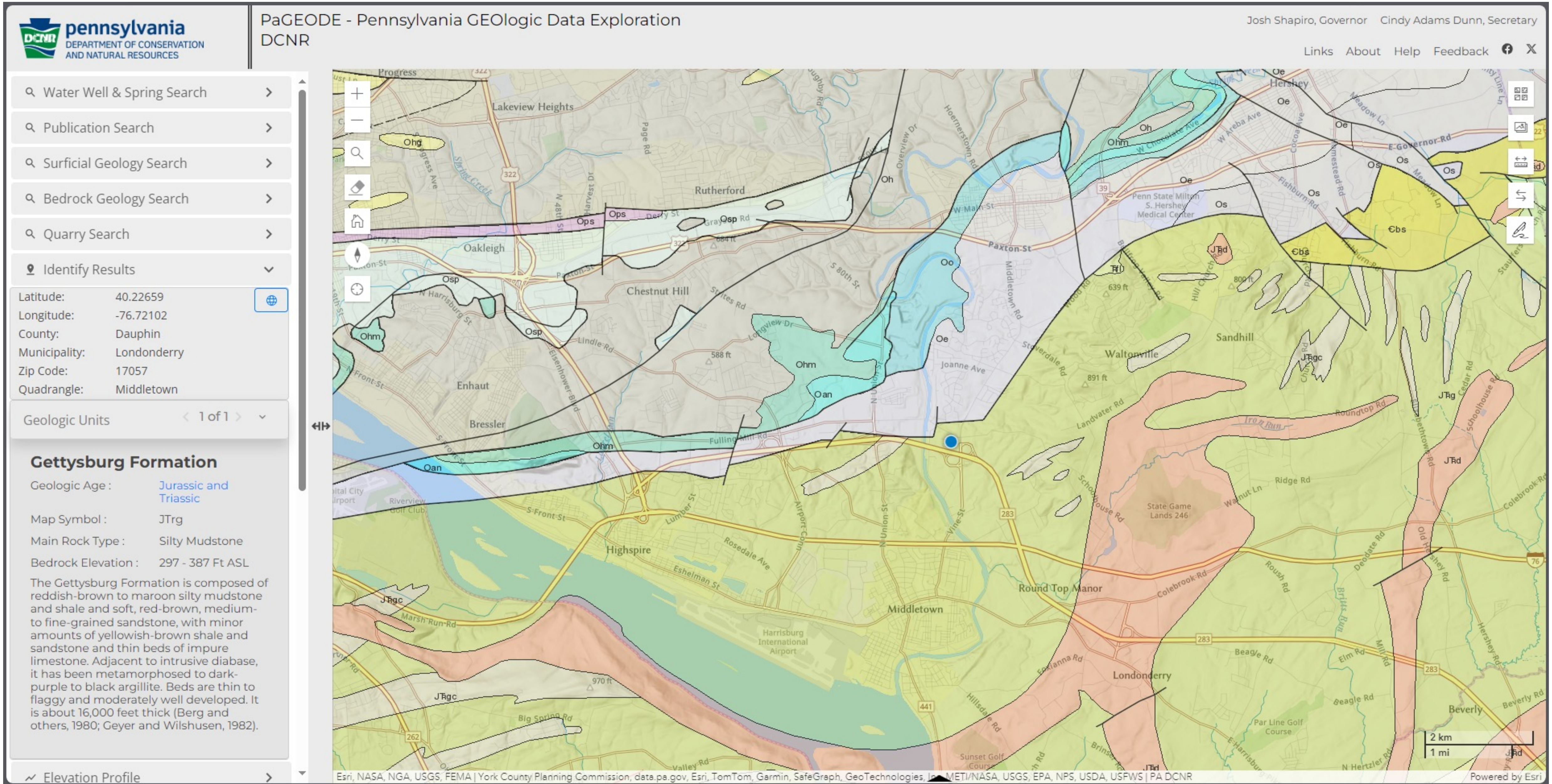
PaGEODE – Pennsylvania GEOlogic Data Exploration





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PaGEODE - Pennsylvania GEOlogic Data Exploration
DCNR
Josh Shapiro, Governor
Cindy Adams Dunn, Secretary
Links
About
Help
Feedback
Water Well & Spring Search
Publication Search
Surficial Geology Search
Bedrock Geology Search
Quarry Search
Identify Results
Latitude: 40.22659
Longitude: -76.72102
County: Dauphin
Municipality: Londonderry
Zip Code: 17057
Quadrangle: Middletown
Geologic Units
1 of 1
Gettysburg Formation
Geologic Age : Jurassic and Triassic
Map Symbol : JTrg
Main Rock Type : Silty Mudstone
Bedrock Elevation : 297 - 387 Ft ASL
The Gettysburg Formation is composed of reddish-brown to maroon silty mudstone and shale and soft, red-brown, medium- to fine-grained sandstone, with minor amounts of yellowish-brown shale and sandstone and thin beds of impure limestone. Adjacent to intrusive diabase, it has been metamorphosed to dark-purple to black argillite. Beds are thin to flaggy and moderately well developed. It is about 16,000 feet thick (Berg and others, 1980; Geyer and Wilshusen, 1982).
Elevation Profile
Lakeview Heights
Rutherford
Oakleigh
Chestnut Hill
Enhaut
Bressler
Highspire
Middletown
Round Top Manor
Londonderry
Hershey
Sandhill
Waltonville
Beverly
Harrisburg International Airport
2 km
1 mi
Esri, NASA, NGA, USGS, FEMA | York County Planning Commission, data.pa.gov, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS | PA DCNR
Powered by Esri

Bedrock Digital Elevation Model of Pennsylvania

- **Background**
  - US GeoFramework Initiative (USGI)
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  - Northwestern Pennsylvania pilot project

- **GIS Methodology**
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  - Depth-to-bedrock surrogate model
  - Conditional smoothing

- **Data Delivery**
  - 100-meter digital rasters
  - Confidence interval
  - Pennsylvania GEOlogic Data Exploration (PaGEODE)
  - Periodic updates

PaGEODE

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PaGEODE

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