Geothermal Play Fairway Analysis -- Appalachian Basin

Project Officer: Holly Thomas

Total Project Funding: $453,228

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Teresa Jordan

Cornell University

Play Fairway Analysis

Relevance/Impact of Research

Objective: Reduce risk for low-temperature projects in NE USA

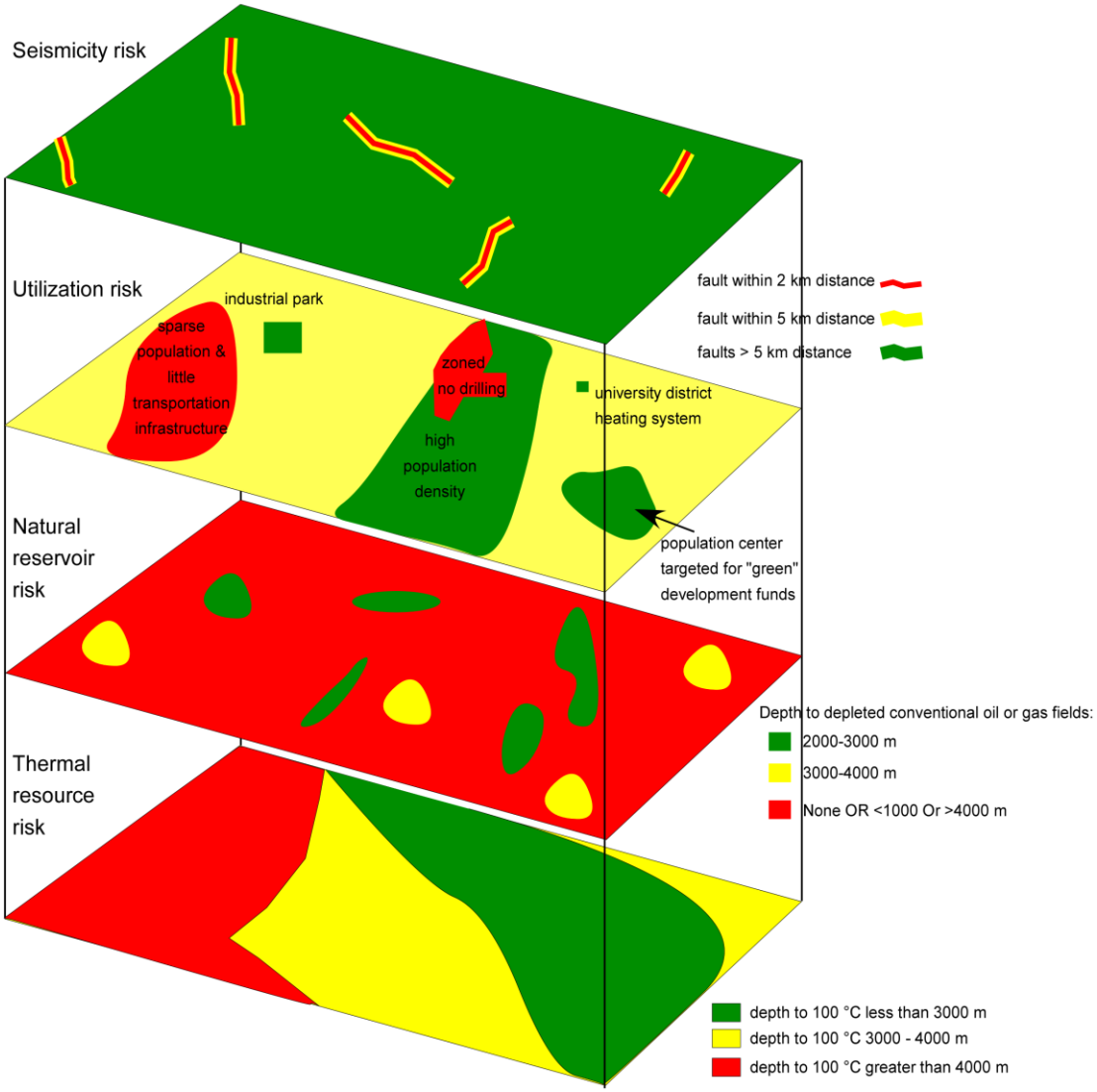
- Broadly viewed, the Appalachian sedimentary basin *may* offer 80–120 ^{o}C water at 3–4 km depth where there is a large demand for heat
- Potential users want to know whether their location coincides with geologically favorable factors
- Risks facing investors poorly known
- Play Fairway Analysis illuminates co-location of heat resource, rocks suitable to circulate water, and consumers; plus major faults to avoid
- Levelized cost of heat calculated for case studies informs decisions
- Project adapts extensive data collected for fossil fuel activity to basin-scale analysis of geothermal resources and risks
- Lowers risks and costs of exploration

- *Only* considers natural porosity-permeability of sedimentary rocks

Scientific/Technical Approach

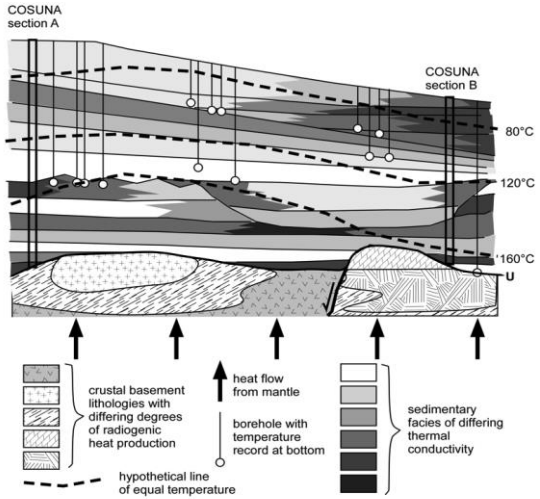
Spatial variations map 4 Risk Factors

- Heat resource quality
- Reservoir rock 3D distribution and quality
- Locate to avoid major faults oriented favorably for slip if fluid pressure changes
- Heat utilization demand



Scientific/Technical Approach

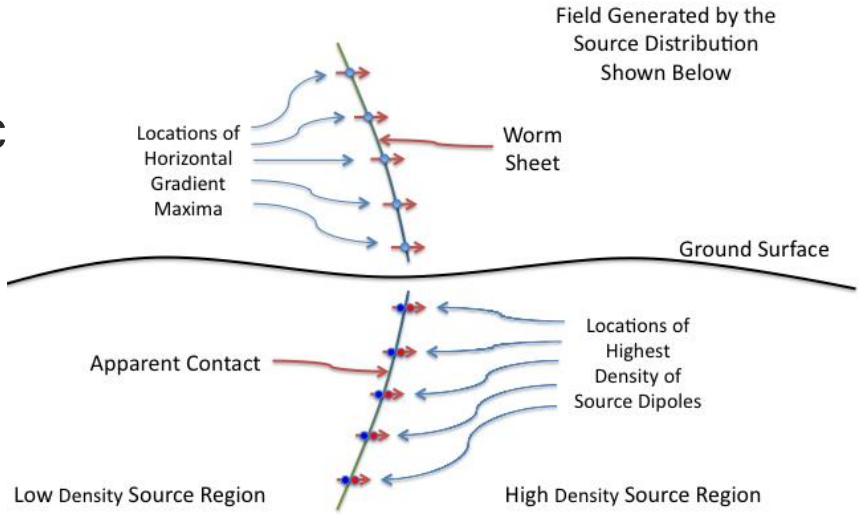
- **Risk Factor #1: Heat resource**
  - >13,000 borehole temperatures for depths 1000 to >6000 m
  - Develop corrections for non-equilibrium borehole temperature data
  - Develop and code new 1D thermal model to determine temperatures-at-depths of interest
  - Utilize COSUNA stratigraphic columns as conductivity stratigraphy for all wells
  - Create spatially complete heat resource maps by interpolation between wells



  - Test sensitivity of temperature-at-depth predictions to uncertain input parameters using locally-derived conductivity stratigraphy for 50–100 wells and Monte Carlo simulation

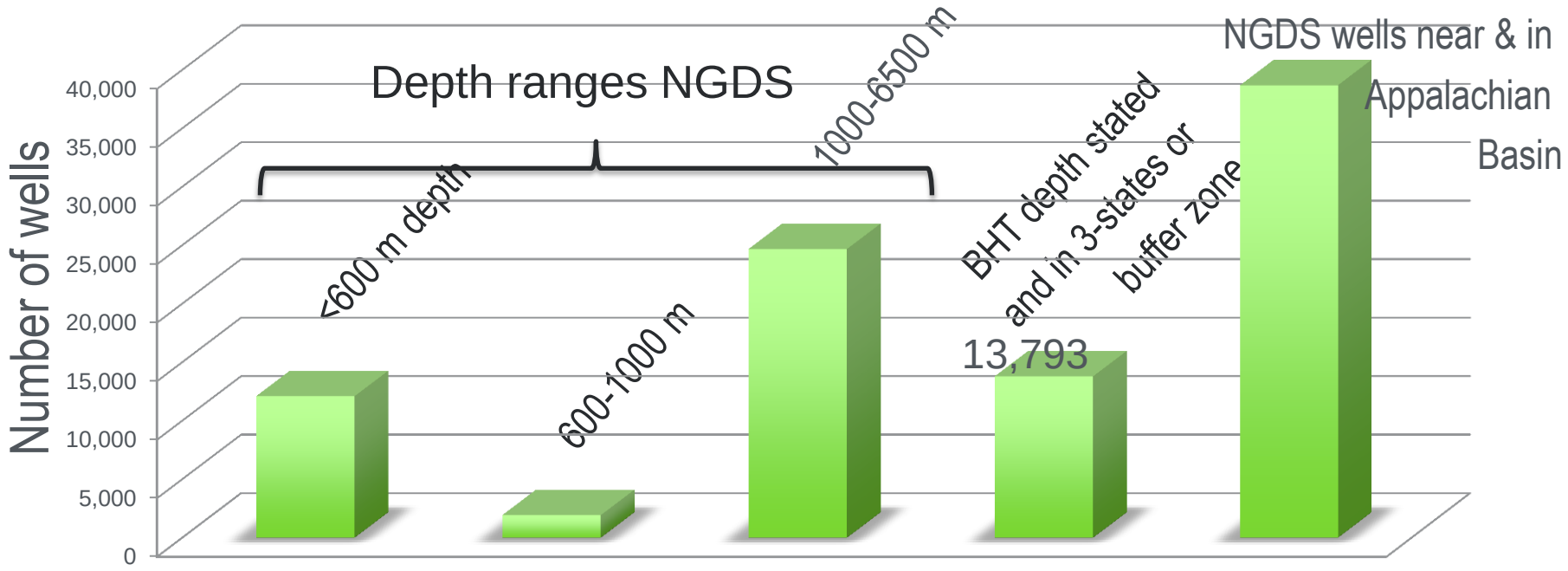
- **Risk Factor #2: Reservoir rock quality**
  - "Reservoir" defined by volume of rock through which fluids can be circulated, irrespective of temperature
  - Reservoir characterized by parameters controlling natural fluid circulation and management: porosity, permeability, pressure
  - Data collected and analyzed by state geological survey experts
  - Map vertical and horizontal extents of proven oil and gas fields and porous rocks inventoried for carbon sequestration assessment
  - Incorporate permeability, porosity and pressure to rank reservoir intrinsic quality

- **Risk Factor #3: Faults of size and orientation prone to induced seismicity**
  - Analyze gravity and magnetic data to detect boundaries between rocks of differing properties



  - Compile historical earthquakes and microseismicity (M>2.1) from Earthscope Transportable Array
  - Compare potential field boundaries, seismic epicenters, and mapped faults to identify faults with likely surface areas large enough to cause a felt earthquake if slipping occurs
  - Categorize risks associated with these faults based on degree of seismicity and spatial orientation relative to stress field

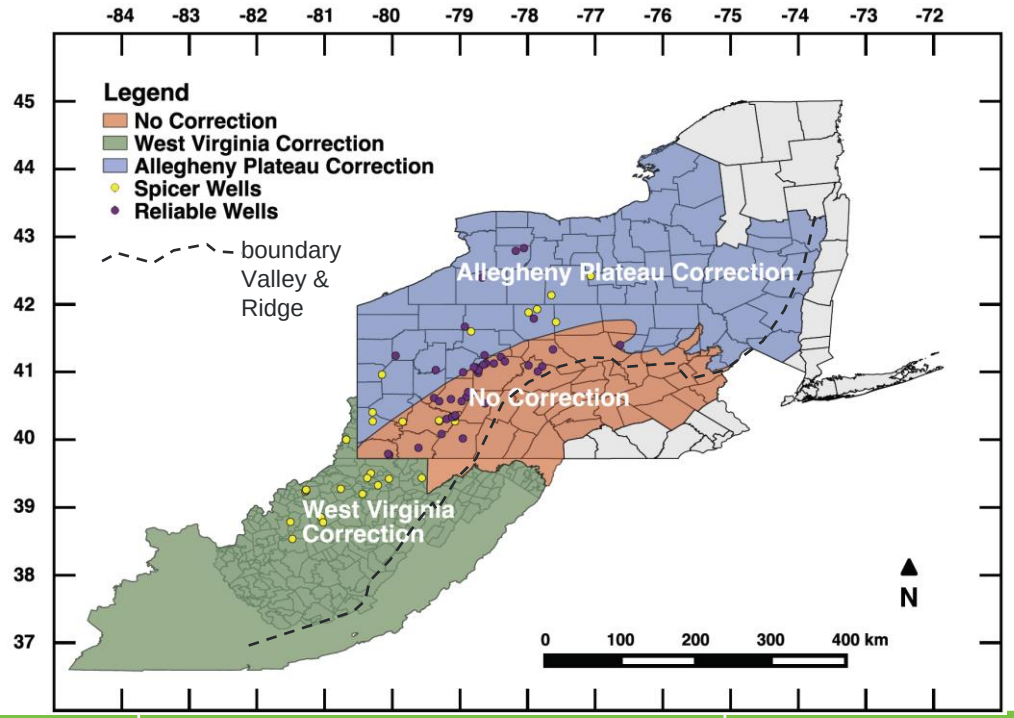
>>200,000 oil & gas boreholes drilled in Appalachian Basin, subset used



Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Milestone 1.3 80% of data sets are accessible for use in project	same	January 30, 2015

Heat resource:

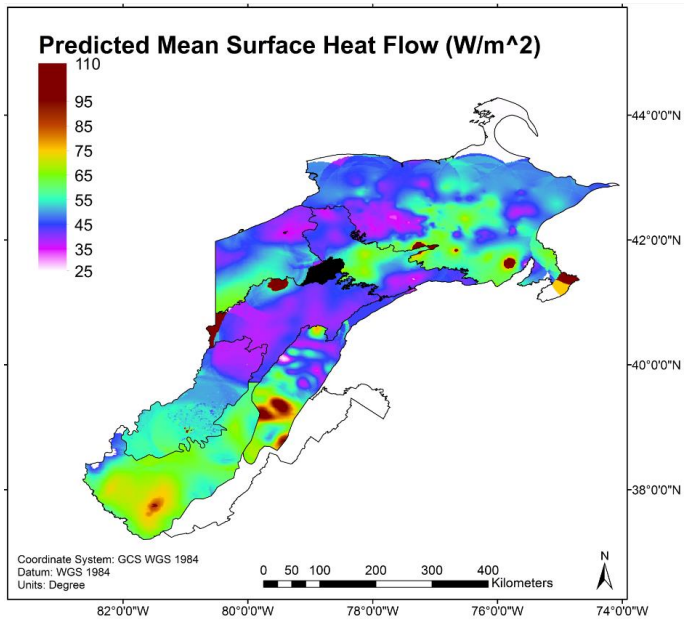
Based on few equilibrium temperature wells and sparse thermal logs collected after known post-drilling time lag, develop corrections for bulk of BHTs.

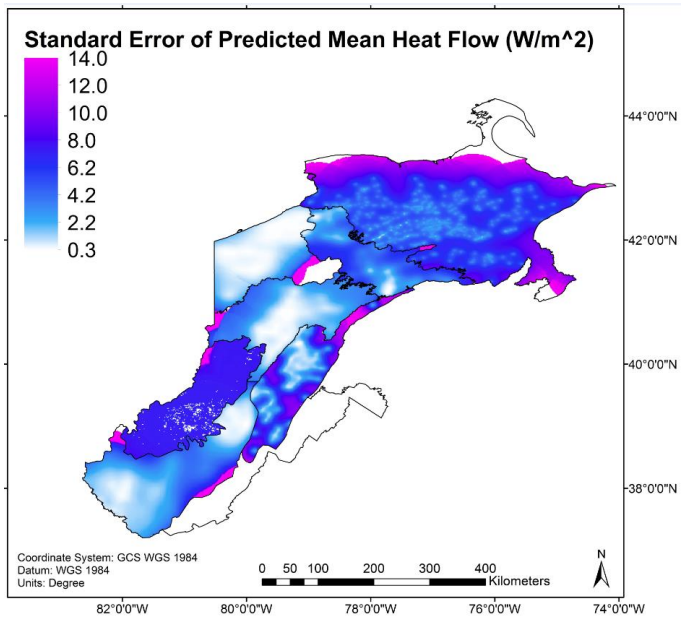


Original Planned Milestone	Actual Milestone	Date Completed
M. 1.4. Thermal Reservoir Modeling and Analysis: Complete validation/alteration of baseline thermal maps and data.	same	March 30, 2015

Heat resource:

Baseline mean surface heat flow and its variations





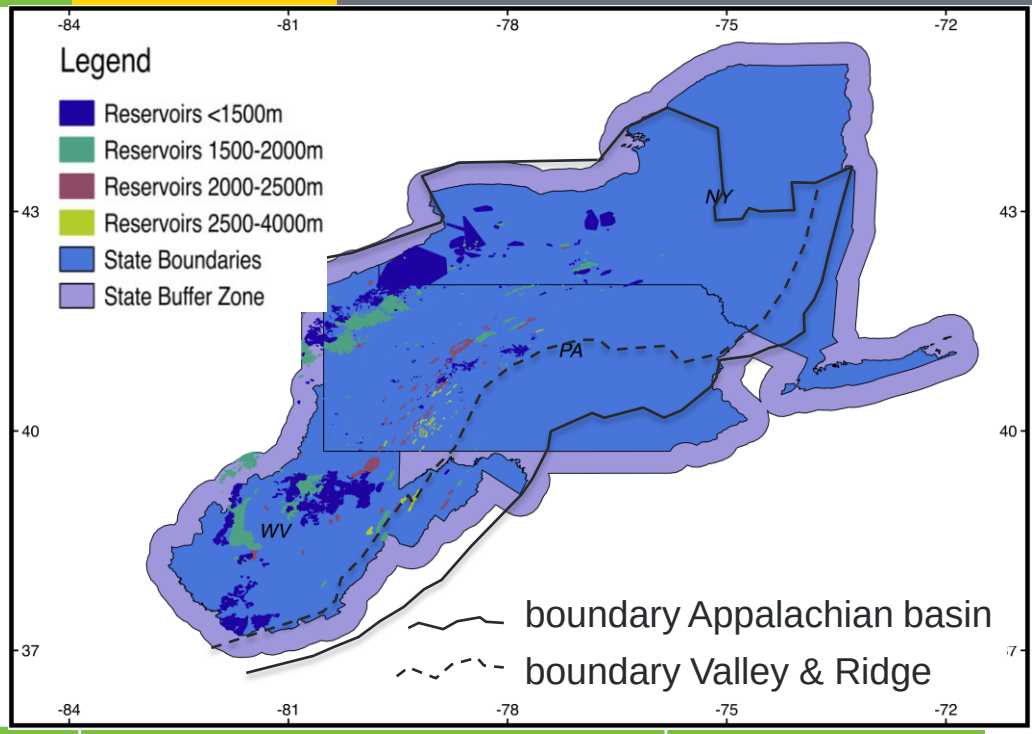
Original Planned Milestone	Actual Milestone	Date Completed
M. 1.4. Thermal Reservoir Modeling and Analysis: Complete validation/alteration of baseline thermal maps and data.	same	March 30, 2015

Reservoirs:

Perspective of oil, gas, or CO_2-sequestration utility.

Hydrocarbon occurrence dictates data and knowledge.

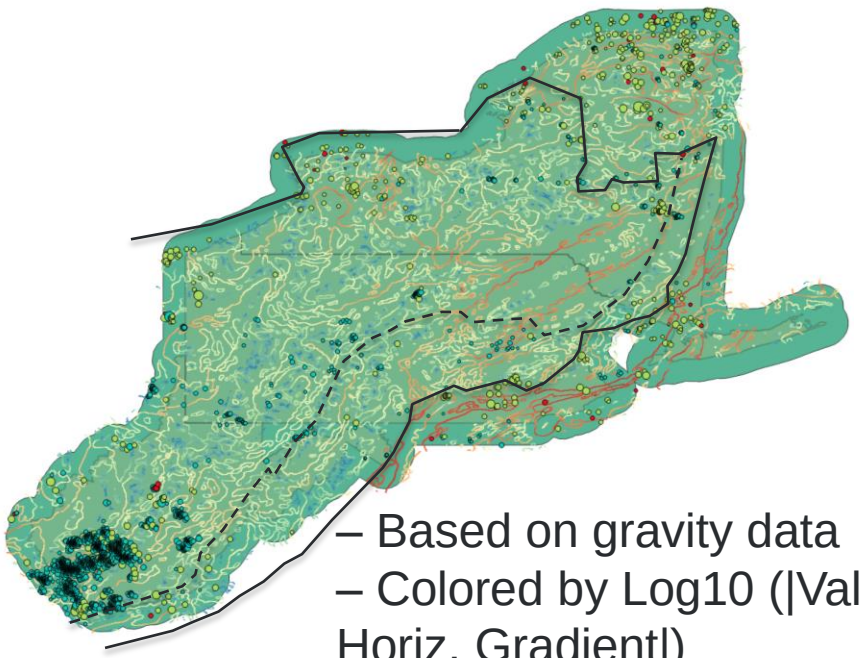
Geothermal reservoirs share need for fluid circulation, but do not need source, trap, maturation, migration, etc.



Original Planned Milestone	Actual Milestone	Date Completed
M. 2.2. Complete analysis of natural reservoir quality and complete draft maps with reservoir ranking and supporting data.	same	on target for April 30, 2015

Basement geology that likely controls faults locations and orientations:

Edges between rock bodies of contrasting density at 3-4 km depth (~top of basement)



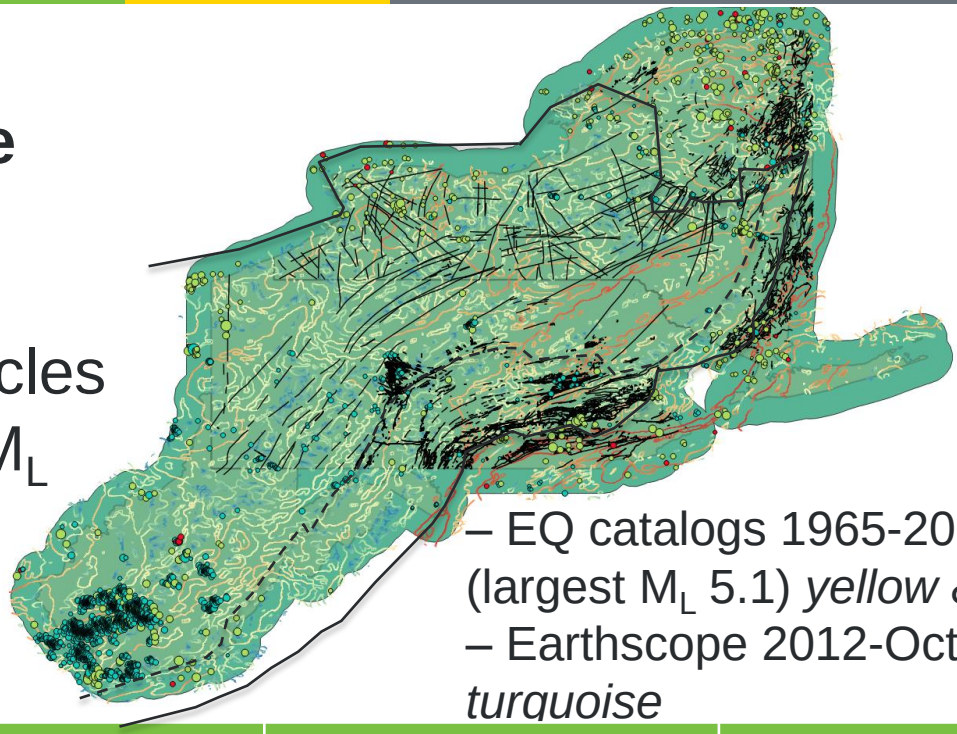
– Based on gravity data
– Colored by Log10 (|Value Horiz. Gradient|)

Original Planned Milestone	Actual Milestone	Date Completed
M. 3.2. Potential field analysis of fault locations complete.	same	March 30, 2015

Basement geology more uniformly mapped than are earthquakes and faults:

Note earthquake location circles
–Radius proportional to M_L

Compiled faults and lineaments

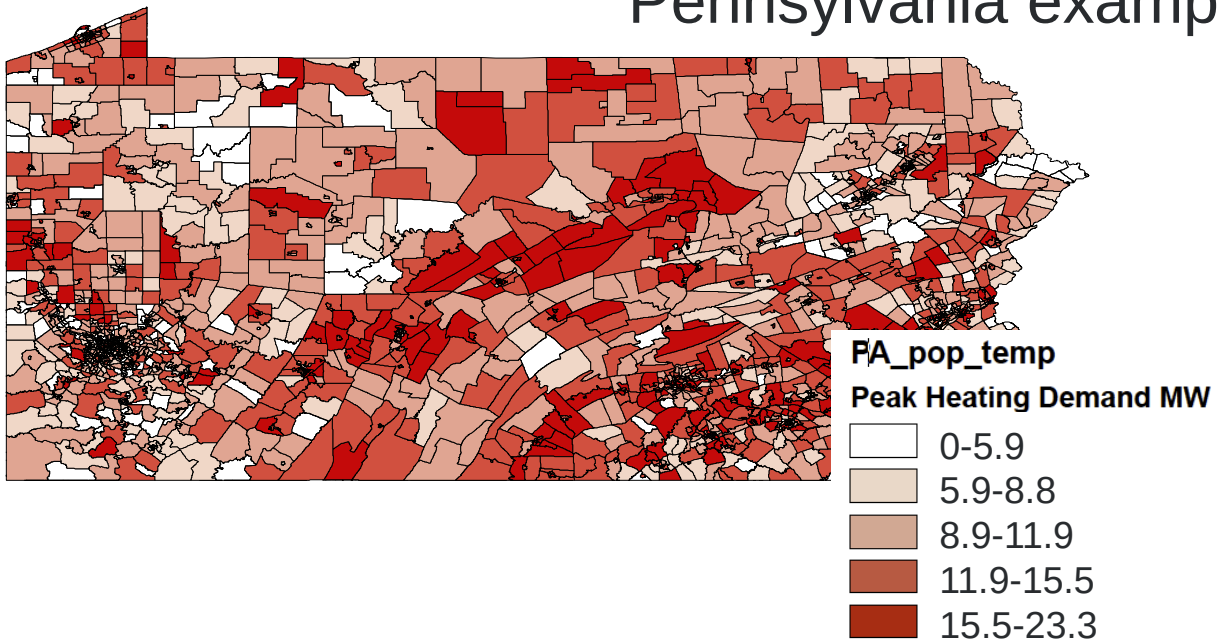


– EQ catalogs 1965-2014 (largest M_L 5.1) *yellow & red*
– Earthscope 2012-Oct. ’14 *turquoise*

Original Planned Milestone	Actual Milestone	Date Completed
M. 3.4. Seismicity data available through the fifth project month and older earthquake catalogs will have been compiled and reviewed, and fault maps 50% complete.	same	March 30, 2015

Utilization:
Residential and Commercial demand for space and water heating

Pennsylvania example



Original Planned Milestone	Actual Milestone	Date Completed
M. 4.1 Compile data and complete maps evaluating potential to utilize low temperature geothermal resources	same	March 30, 2015

Future Directions

- Individual risk factor maps are near completion, allowing focus to shift to
  - Overall risk assessment
  - Identifying multiple favorable sub-regions in each state
  - Illustrating for a few key regions levelized cost of heat and uncertainties

Milestone or Go/No-Go	Status & Expected Completion Date
M 1.5 Complete ranking map of heat resource levels (Green/Yellow/Red) for the most favorable counties	early stage; 6/30/15
M 2.3 Complete ranking map of natural resource quality	in progress; 6/30/15
M 3.5 Complete risk ranking map of potential for induced seismicity	assembling; 6/30/15
M 4.2 Complete analysis for Levelized Cost of Heat (LCOH) for two communities in each state	not yet begun; 6/30/15
M 5.1-5.3 Initial definition of weighting factors for risk levels; assignment of risk to RFs 1-4; produce Common Risk Segment (CRS) maps	identifications of risk criteria begun; 3/31/15; 6/30/15; 9/30/15

Summary

- Accuracy and understanding of uncertainty are both improving significantly, reducing risk for future projects.
- Co-location of favorable temperatures and documented natural reservoirs narrows focus greatly.
- This project's results are restricted to use of natural permeability. If stimulation is added, picture will change.
- Methods developed for Appalachian Basin transferable to other sedimentary basins.