About Thermal Quality Analysis Maps and Structured Data

Abstract These files are part of a larger dataset uploaded in support of **Low Temperature Geothermal Play Fairway Analysis for the Appalachian Basin** (**GPFA-AB**, DOE Project **DE-EE0006726**). Phase 1 of the GPFA-AB project identified potential Geothermal Play Fairways within the Appalachian basin of **Pennsylvania**, **West Virginia** and **New York**. This was accomplished through analysis of 4 key criteria or 'risks': thermal quality, natural reservoir productivity, risk of seismicity, and heat utilization. Each of these analyses represent a distinct project task, with the fifth task encompassing combination of the 4 risks factors. Supporting data for all five tasks has been uploaded into the Geothermal Data Repository node of the National Geothermal Data System (NGDS).

This file is a portion of the data for **Thermal Quality Analysis** (project task 1). The Thermal Quality Analysis Maps and Structured Data includes all of the necessary shapefiles, rasters, datasets, code, and references to code repositories that were used to create the thermal resource and risk factor maps as part of the GPFA-AB project. The identified Geothermal Play Fairways are also provided with the larger dataset. Figures (.png) are provided as examples of the shapefiles and rasters. The regional standardized 1 km^2 grid used in the project is also provided as points (cell centers), polygons, and as a raster. Two ArcGIS toolboxes are available: 1) RegionalGridModels.tbx for creating resource and risk factor maps on the standardized grid, and 2) ThermalRiskFactorModels.tbx for use in making the thermal resource maps and cross sections. These toolboxes contain "item description" documentation for each model within the toolbox, and for the toolbox itself. This submission also contains three R scripts: 1) AddNewSeisFields.R to add seismic risk data to attribute tables of seismic risk, 2) StratifiedKrigingInterpolation.R for the interpolations used in the thermal resource analysis, and 3) LeaveOneOutCrossValidation.R for the cross validations used in the thermal interpolations.

This document describes the full **Thermal Quality Analysis** data that was submitted, with the files retrieved in this download highlighted. Please note hyperlinks have been inserted to the relevant sub-section of **Methods of Calculations and Assumptions** appearing later in this document.

Key Words Appalachian Basin, West Virginia, New York, Pennsylvania, district heating, low-temperature geothermal, thermal conductivity, heat flow, geotherms, resource assessment.

Citation When referencing this data, please use the following:

Title: Thermal Quality Analysis in Low-Temperature Geothermal Play Fairway Analysis for the Appalachian Basin (GPFA-AB)

Author(s): Jared D. Smith, Calvin A. Whealton, Franklin G. Horowitz, Teresa E. Jordan, and Jery R. Stedinger

Date: October 2015

Contents of Submission

1. Regional Grid for Risk Factor Rasters and Thermal Resource Rasters

Please note the Methods of Calculations and Assumptions for this section as well.

a) Regional Grid Shapefiles and Raster

Polygon, Point, and Raster grid, respectively, made using ArcGIS Create Fishnet tool

Fishnet2.shp	154 MB
Fishnet2_label.shp	78 MB
GridNAD.tif	1025 kB

_b) ArcGISToolbox_RegionalGridModels_

ArcGIS Toolbox: RegionalGridModels.tbx 855 kB

Thermal Models

FullRegionGrid (formerly ThermalFiles_Final. This tool is more general.)

Reservoir Models

ReservoirConversionVectorToRaster (formerly ReservoirConversion_FINAL)

Utilization Models

PolygonToRaster_wPolygons

Seismic Models

SeismicEQ_ToRaster

AddDistanceToEarthquakeToGrid (formerly New_EQJoin)

AddSeisStressAngleToGrid (formerly SeisStressMagGrav)

R Script for Seismic Files

AddNewSeisFieldsFunctions.R 7 kB

2. Thermal Model Data Files

a) State Well Temperature Databases

Please note the Methods of Calculations and Assumptions for this section as well.

All_States_BHT_HeatFlow_Raw_Combined.xlsm	39 MB
AASG_Combined.xlsx	9.8 MB
AASG_Processed.xlsx	5.1 MB
AASG_Thermed.xlsx	8.4 MB
AASG_Thermed_AllThicksAndConds.xlsx	162 MB

b) COSUNA Columns and Sections

Please note the [Methods of Calculations and Assumptions for this section]() as well.

AllCOSUNASections_final.shp	597 kB
COSUNA_Columns_NY-PA-WV-VA-OH-KY-MD.xlsm	994 kB
Carter Conductivities.xlsx	10 kB
Conductivity.xlsx	11 kB
NY_Conductivity_final.xlsx	322 kB
PA_Conductivity_final.xlsx	47 kB
WV_Conductivity_final.xlsx	30 kB

c) Sediment Thickness

Please note the [Methods of Calculations and Assumptions for this section]() as well.

dem30mallwgs	(Binary Grid)	4.27 GB
tbrsedthickm	(Binary Grid)	519 kB

3. BHT Correction Sections

Please note the [Methods of Calculations and Assumptions for this section]() as well.

BHT_Corr_Sections.shp		299 kB
Rome Trough final.shp		2.19 kB
WhealtonDrillingFluid.csv		791 kB
DrillingFluidMatches.csv		140 kB
DrillingFluidQuery	(SQL Query)	214 B

4. Worm Based Interpolation Regions

Please note the [Methods of Calculations and Assumptions for this section]() as well.

a) Worm Data

GravWorms_18+.shp	73.1 MB
MagWorms_18+.shp	251 MB

b) Model Used To Create Boundaries in ArcGIS Toolbox ThermalRiskFactorModels 2.4 MB

BoundaryCreationUsingWorms (ArcGIS Model)

c) ***UnBuffered Interpolation Regions***

WormBasedInterpolationRegions.png	1056 kB
WormBasedInterpolationRegions.shp	128 kB
CNY.shp	3 kB
CT.shp	5 kB
CWV.shp	9 kB
ENY.shp	6 kB
ENYPA.shp	23 kB
MT.shp	14 kB
NWPANY.shp	6 kB
SWPA.shp	9 kB
VR.shp	45 kB
WPA.shp	7 kB

d) ***50 km Buffered Interpolation Regions – Exterior Buffer Only***

WormBasedInterpolationRegions_BufferedArea.shp	67 kB
WormBasedInterpolationRegions_OuterBuffer.shp	67 kB
BoundedCNY.shp	21.1 kB
BoundedCT.shp	26.9 kB
BoundedCWV.shp	23.2 kB
BoundedENY.shp	27.4 kB
BoundedENYPA.shp	48.1 kB
BoundedMT.shp	36.7 kB
BoundedNWPANY.shp	29.1 kB
BoundedSWPA.shp	25.6 kB
BoundedVR.shp	73.6 kB
BoundedWPA.shp	25.5 kB

e) ***1 km Gridded Regions - buffered by 50 km on the exterior of the section***

grdcny3	(Binary Grid)	2.93 kB
grdct3	(Binary Grid)	2.98 kB
grdcwv3	(Binary Grid)	4.32 kB
grdeny3	(Binary Grid)	3.83 kB
grdenypa3	(Binary Grid)	4.44 kB
grdmt3	(Binary Grid)	3.83 kB
grdnwpany3	(Binary Grid)	3.91 kB
grdswpa3	(Binary Grid)	4.20 kB
grdvr3	(Binary Grid)	7.29 kB
grdwpa3	(Binary Grid)	3.95 kB

5. Well Data - Outliers Removed

Please note the Methods of Calculations and Assumptions for this section as well.

a) ***R Scripts Used for Sorting Data and Removing Outliers***

SortingWells.R

DataArrangementAndRunOutlierAnalysis.R

b) ***Surface Heat Flow***

DeepestWells_NotOutliers_32km_Qs.shp 29.3 MB

c) ***Temperature at 1.5 km***

DeepestWells_NotOutliers_32km_T15.shp 81.9 MB

d) ***Temperature at 2.5 km***

DeepestWells_NotOutliers_32km_T25.shp 82.1 MB

e) ***Temperature at 3.5 km***

DeepestWells_NotOutliers_32km_T35.shp 81.9 MB

f) ***Depth to 80 °C***

DeepestWells_NotOutliers_32km_D80C.shp 28.9 MB

g) ***Depth to 100 °C***

DeepestWells_NotOutliers_32km_D100C.shp 81.0 MB

6. Thermal Resource Interpolation Results

Please note the Methods of Calculations and Assumptions for this section as well.

a) ArcGIS toolbox: ThermalRiskFactorModels		***2.55 MB***
WellClipsToWormSections	(ArcGIS Model)	
BufferedRasterToClippedRaster	(ArcGIS Model)	
MergeCrossValidationResults	(ArcGIS Model)	
ExtractThermalPropertiesToCrossSection	(ArcGIS Model)	
AddExtraInfoToCrossSection	(ArcGIS Model)	
CrossSectionExtraction	(ArcGIS Model)	

b) *R Scripts for Interpolation*

StratifiedKrigingInterpolation.R	172 kB
LeaveOneOutCrossValidation.R	9 kB

c) *Results Data Files*

Surface Heat Flow		
heatflowpred	(Binary Grid)	2.0 MB
heatflowerr	(Binary Grid)	2.0 MB
HeatFlow_pred.png		509 kB
HeatFlow_error.png		562 kB
Temperature at 1.5 km		
t1p5kmpred	(Binary Grid)	2.0 MB
t1p5kmerr	(Binary Grid)	2.0 MB
Temp1p5km_pred_resource.png		408 kB
Temp1p5km_error.png		517 kB
Temperature at 2.5 km		
t2p5kmpred	(Binary Grid)	2.0 MB
t2p5kmerr	(Binary Grid)	2.0 MB
Temp2p5km_pred_resource.png		486 kB
Temp2p5km_error.png		583 kB
Temperature at 3.5 km		
t3p5kmpred	(Binary Grid)	2.0 MB
t3p5kmerr	(Binary Grid)	2.0 MB

Temp3p5km_pred_resource.png		446 kB
Temp3p5km_error.png		570 kB
Depth to 80 °C		
d80Cpred	(Binary Grid)	2.0 MB
d80Cerr	(Binary Grid)	2.0 MB
Depth80C_pred_resource.png		523 kB
Depth80C_error.png		573 kB
Depth to 100 °C		
d100Cpred	(Binary Grid)	2.0 MB
d100Cerr	(Binary Grid)	2.0 MB
Depth100C_pred_resource.png		548 kB
Depth100C_error.png		611 kB
Cross Validation Results		
kcv_Merged_HF.shp		1.76 MB
kcv_Merged_t1p5km.shp		1.79 MB
kcv_Merged_t2p5km.shp		1.77 MB
kcv_Merged_t3p5km.shp		1.77 MB
kcv_Merged_d80C.shp		1.74 MB
kcv_Merged_d100C.shp		1.75 MB

7. Favorable Counties Results

Predicted Mean and Standard Error of Predicted Mean for Depth to 80 °C and the Thermal Risk Factor Play Fairway Metric on a 0 to 5 point scale.

Please note the Methods of Calculations and Assumptions for this section as well.

a) ***ArcGIS toolbox: ThermalRiskFactorModels for clipping data to the counties of interest CountyMapMaking***

b) ***Images of Results from CountyMapMaking model***

MapOfBestCounties.png	336 kB
ChauErie_Thermal_d80Cp.png	617 kB
ChauErie_Thermal_d80Ce.png	866 kB
ChauErie_ThermalPFM_5_0_5.png	750 kB
ChauErie_ThermalPFM_sd5.png	884 kB

FayettePreston_Thermal_d80Cp.png	628 kB
FayettePreston_Thermal_d80Ce.png	661 kB
FayettePreston_ThermalPFM_5_0_5.png	600 kB
FayettePreston_ThermalPFM_sd5.png	654 kB
FingerLakes_Thermal_d80Cp.png	751 kB
FingerLakes_Thermal_d80Ce.png	826 kB
FingerLakes_ThermalPFM_5_0_5.png	633 kB
FingerLakes_ThermalPFM_sd5.png	725 kB
Gilmer_Thermal_d80Cp.png	578 kB
Gilmer _Thermal_d80Ce.png	691 kB
Gilmer _ThermalPFM_5_0_5.png	582 kB
Gilmer _ThermalPFM_sd5.png	697 kB
KnawLinc_Thermal_d80Cp.png	647 kB
KnawLinc_Thermal_d80Ce.png	698 kB
KnawLinc_ThermalPFM_5_0_5.png	614 kB
KnawLinc_ThermalPFM_sd5.png	695 kB

c) ***Cross Sections – points and lines shapefiles, and plots of results for Depth to 80 °C and the thermal play fairway metric on a 0 to 5 point scale.***

CrossSections.shp	2 kB
CrossSectionPtsC_FINAL.shp	78 kB
CrossSectionC-C'_D80C.png	23 kB
CrossSectionC-C'_PFM5.png	20 kB
CrossSectionPtsD_FINAL.shp	42 kB
CrossSectionD-D'_D80C.png	20 kB
CrossSectionD-D'_PFM5.png	21 kB
CrossSectionPtsE_FINAL.shp	54 kB
CrossSectionE-E'_D80C.png	18 kB
CrossSectionE-E'_PFM5.png	19 kB
CrossSectionPtsF_FINAL.shp	25 kB
CrossSectionF-F'_D80C.png	22 kB

CrossSectionF-F'_PFM5.png	21 kB
CrossSectionPtsG_FINAL.shp	111 kB
CrossSectionG-G'_D80C.png	25 kB
CrossSectionG-G'_PFM5.png	26 kB

Cross Validation Results for Depth to 80 °C

ChauErie_Thermal_d80Cp_cv.png	1.25 MB
ChauErie_Thermal_d80Cp_cv_crosssection.png	1.26 MB
FayettePreston_Thermal_d80Cp_cv.png	681 kB
FayettePreston_Thermal_d80Cp_cv_crosssection.png	690 kB
FingerLakes_Thermal_d80Cp_cv.png	1 MB
FingerLakes_Thermal_d80Cp_cv_crosssection.png	1 MB
Gilmer_Thermal_d80Cp_cv.png	855 kB
Gilmer_Thermal_d80Cp_cv_crosssection.png	870 kB
KnawLinc_Thermal_d80Cp_cv.png	774 kB
KnawLinc_Thermal_d80Cp_cv_crosssection.png	786 kB

8. Play Fairways

Please note the Methods of Calculations and Assumptions for this section as well.

fairwaysOuter.shp	2.12 kB
fairwaysInner.shp	2.06 kB
HighPriority.lyr	7.00 kB
MediumPriority.lyr	7.00 kB

Sources Primary sources of information referenced in preparation of this submission include:

American Association of Petroleum Geologists (AAPG). (1985a). Northern Appalachian Region correlation chart. D.G. Patchen, K.L. Avary, and R.B. Erwin, regional coordinators.

American Association of Petroleum Geologists (AAPG). (1985b). Southern Appalachian Region correlation chart. D.G. Patchen, K.L. Avary, and R.B. Erwin, regional coordinators.

Frone, Zachary. "Anadarko Basin Thermal Conductivity Measurements" in *Low Temperature Geothermal Play Fairway Analysis for the Appalachian Basin: Final Phase 1 Research Report*, U.S. Dept. of Energy Award No. DE-EE0006726. Principal Investigator Teresa Jordan. Submitted Oct. 16, 2015.

Jordan, T.E.. *Low Temperature Geothermal Play Fairway Analysis for the Appalachian Basin: Final Phase 1 Research Report*, U.S. Dept. of Energy Award No. DE-EE0006726. Principal Investigator Teresa Jordan. Submitted Oct. 16, 2015.

Smith, J.D.. "9_GPFA-AB_InterpolationThermalFieldEstimation" in *Low Temperature Geothermal Play Fairway Analysis for the Appalachian Basin: Final Phase 1 Research Report*, U.S. Dept. of Energy Award No. DE-EE0006726. Principal Investigator Teresa Jordan. Submitted Oct. 16, 2015.

Smith, J.D.. "10_GPFA-AB_SelectBestThermalResourcesCounties" in *Low Temperature Geothermal Play Fairway Analysis for the Appalachian Basin: Final Phase 1 Research Report*, U.S. Dept. of Energy Award No. DE-EE0006726. Principal Investigator Teresa Jordan. Submitted Oct. 16, 2015.

Smith, J.D. and F.G. Horowitz. "8_GPFA-AB_ThermalModelMethods" in *Low Temperature Geothermal Play Fairway Analysis for the Appalachian Basin: Final Phase 1 Research Report*, U.S. Dept. of Energy Award No. DE-EE0006726. Principal Investigator Teresa Jordan. Submitted Oct. 16, 2015.

Smith, J.D. and F.G. Horowitz. "14_GPFA-AB_SeismicRiskMapCreationMethods" in *Low Temperature Geothermal Play Fairway Analysis for the Appalachian Basin: Final Phase 1 Research Report*, U.S. Dept. of Energy Award No. DE-EE0006726. Principal Investigator Teresa Jordan. Submitted Oct. 16, 2015.

Smith, J.D., F.G. Horowitz, and C.A. Whealton (2015). One dimensional conductive geothermal Python code. Online Git Repository. https://bitbucket.org/geothermalcode/jaredthermalconductivity (posted 2015-10-15 20:01:56)

Smith, J.D., T.E. Jordan, and Z.S. Frone. "4_GPFA-AB_ThermalConductivityStratigraphyCOSUNA" in *Low Temperature Geothermal Play Fairway Analysis for the Appalachian Basin: Final Phase 1 Research Report*, U.S. Dept. of Energy Award No. DE-EE0006726. Principal Investigator Teresa Jordan. Submitted Oct. 16, 2015.

USGS. (2014). *National Map*. Available online http://viewer.nationalmap.gov/viewer/nhd.html?p=nhd

West Virginia Geological and Economic Survey (WVGES). (2006). PCMB_Contours.zip [Data file]. Trenton Black River Project. Data available online http://www.wvgs.wvnet.edu/www/tbr/resources.asp

Whealton, C.A. (2015). Statistical Correction of Temperature Data for New York and Pennsylvania Wells. Master's Thesis, Cornell University, Environmental and Water Resources Systems Engineering.

Whealton, C.A. and J.D. Smith (2015). [geothermal_pfa] code repository. Available Online https://github.com/calvinwhealton/geothermal_pfa

Whealton, C.A., and J.R. Stedinger. "6_GPFA-AB_ThermalOutlierAssessment" in *Low Temperature Geothermal Play Fairway Analysis for the Appalachian Basin: Final Phase 1 Research Report*, U.S. Dept. of Energy Award No. DE-EE0006726. Principal Investigator Teresa Jordan. Submitted Oct. 16, 2015.

Whealton, C.A., J.R. Stedinger, and F.G. Horowitz. "2_GPFA-AB_BHTCorrections" in *Low Temperature Geothermal Play Fairway Analysis for the Appalachian Basin: Final Phase*

1 Research Report, U.S. Dept. of Energy Award No. DE-EE0006726. Principal Investigator Teresa Jordan. Submitted Oct. 16, 2015.

Whealton, C.A., J.R. Stedinger, F.G. Horowitz, and J.D. Smith. "16_GPFA-AB_RiskAnalysisAndRiskFactorDescriptions" in *Low Temperature Geothermal Play Fairway Analysis for the Appalachian Basin: Final Phase 1 Research Report*, U.S. Dept. of Energy Award No. DE-EE0006726. Principal Investigator Teresa Jordan. Submitted Oct. 16, 2015.

Special Use Considerations

ArcGIS 10.1 or later is needed to use the models in the ArcGIS toolboxes; however this limitation is only a result of the generalized file saving format provided by versions 10.1 and later. If desired, one could modify the default saving location of the scratch geodatabase (%scratchGDB%) in the intermediate files of each model to use the models in earlier versions of ArcGIS.

Python 2.7 is needed to run the 1-D thermal model. The code repository is Smith, Horowitz, and Whealton (2015).

Postgres, or another SQL application is needed to run the DrillingFluidQuery.

Methods of Calculations and Assumptions

1. Regional Grid for All Risk Factor Maps

The shapefiles, ArcGIS toolbox, and R script contained within this folder were used to convert vector and raster files to the standardized 1 km^2 grid used in this project. The code is general enough to be used in other studies that may need to work on a standard grid. ArcGIS 10.1 or later is needed to use the models in the toolbox.

Details regarding methods for seismic risk factor conversion may be found in the memo entitled 14_GPFA-AB_SeismicRiskMapCreationMethods.pdf (Smith and Horowitz, 2015). The R script AddNewSeisFieldsFunctions.R implements some of the methods described in the memo.

Details about all of the ArcGIS toolbox models may be found in the memo entitled 16_GPFA-AB_RiskAnalysisAndRiskFactorDescriptions.pdf (Whealton, et al., 2015). Some models have been given different names since the memo was written. These models have the former names listed next to the current model name in the list above.

2. Thermal Model Data Files

a) *State Well Temperature Databases*

These databases are from the American Association of State Geologists (AASG), in association with the National Geothermal Data System (NGDS). A unique identifier called StateID is common in all of these databases, and it may be used to join the databases together, and also back to the original data (the Raw file). Processing details, and file and field name definitions for these databases may be found in 8_GPFA-AB_ThermalModelMethods.pdf (Smith and Horowitz, 2015). The only difference between the database entitled AASG_Thermed.xlsx and AASG_Thermed_AllThicksAndConds.xlsx has columns for the formation thicknesses (Layer) and thermal conductivities (Cond) corresponding to each thickness for each well. There are also columns for the temperature at 10 m (T0) to 5000 m (T499) in 10 m increments.

Note that some records in AASG_Thermed.xlsx and AASG_Thermed_AllThicksAndConds.xlsx have -9999 in the Depth50C, Depth80C, and Depth100C. This is because the maximum depth for these fields was 20000 m, and for these records one would have to go deeper than 20000 m to reach 50 °C, 80 °C, or 100 °C.

The calculation of the geotherm and surface heat flow for these wells was done using the code repository developed by Smith, Horowitz, and Whealton (2015) and described in 8_GPFA-AB_ThermalModelMethods.pdf (Smith and Horowitz, 2015).

b) ***COSUNA Column Sections***

This folder contains shapefiles and spreadsheets of data that were made from the AAPG (1985a; 1985b) COSUNA columns. Details about the processing of the data can be found in 4_GPFA-AB_ThermalConductivityStratigraphyCOSUNA (Smith, Jordan, and Frone, 2015) and 3_GPFA-AB_AnadarkoBasinThermalConductivity (Frone, 2015).

All_COSUNA_Sections.shp contains polygons of the COSUNA sections within the Appalachian Basin. Field descriptions are contained within Smith, Jordan, and Frone (2015).

DOE_NY_PA_WV_KY_OH_MD_VA_v6_Q3.xlsx contains the stratigraphic information for all of the COSUNA columns within the region of interest in the Appalachian Basin. Please consult Smith, Jordan, and Frone (2015) for field header descriptions.

Carter Conductivities.xlsx is the excel file of thermal conductivities used for general lithologies. Both Smith, Jordan, and Frone (2015), and Frone (2015) explain the selection of this data.

The three files called NY_Conductivity_Final.xlsx, PA_Conductivity_Final.xlsx, and WV_Conductivity_Final.xlsx contain the results of the Monte Carlo Analysis of each formation to determine the mean and standard error of the thermal conductivity. The Monte Carlo Analysis methods are described in Smith, Jordan, and Frone (2015). The file Conductivities.xlsx is simply a linked data table used in this analysis.

c) ***Sediment Thickness***

The sediment thickness shapefile was made using contours of the Precambrian Basement from the Trenton Black River Project (WVGES, 2006). To obtain depth to basement, the elevation had to be added on to the depth to basement from sea level. The digital elevation model (DEM) used in this project is 30 m resolution from the USGS (2014). Latitudes from 37° N to 41° N, and longitudes from 79° W to 85° W were used and mosaicked together using ArcGIS mosaic tool. Further details about the processing steps are provided in the file entitled 8_GPFA-AB_ThermalModelMethods.pdf (Smith and Horowitz, 2015).

3. BHT Correction Sections

The BHT correction sections were defined based on structural features within the Appalachian Basin, and geographic boundaries. The Rome Trough (e.g. Repetski et al. [2008]) defines the boundary between the Allegheny Plateau Correction section and the Zero Correction section. The Zero Correction section is for everywhere southeast of the Rome Trough in Pennsylvania, and is also used for Maryland because the well cluster in Maryland appears to be consistent with the well cluster across the border in Pennsylvania. The Allegheny Plateau is used for all wells located northwest of the Rome Trough. West Virginia, Virginia, and Kentucky all have a separate correction section defined based on wells in West Virginia. Further details about the use of BHT correction sections are provided in the file entitled 2_GPFA-AB_BHTCorrections.pdf (Whealton, Stedinger, and Horowitz, 2015). An image of the Rome Trough is provided in Repetski et al. (2008). This was georeferenced in ArcGIS based on county boundaries, and digitized using the Editor toolbar into Rome Trough final.shp

BHT_Corr_Sections.shp is the shapefile of the BHT correction sections. The attribute table contains a number from 0 to 3, indicating the region. This is the “reg” field in the BHT correction code in the Whealton (2015) code repository.

WhealtonDrillingFluid.csv contains wells with drilling fluid as found by Whealton (2015). DrillingFluidMatches.csv are the wells that matched using the DrillingFluidQuery in Postgres Admin III. Further details about these processing steps are provided in entitled 8_GPFA-AB_ThermalModelMethods.pdf (Smith and Horowitz, 2015).

4. Worm Based Interpolation Boundaries

This folder contains the files used and the products of the worm-based delineation of interpolation boundaries using ArcGIS. The gravity and pseudogravity (magnetic) worms are contained in two SQLite databases that are part of a separate data submission, “Risk of Seismicity in Low-Temperature Geothermal Play Fairway Analysis for the Appalachian Basin (GPFA-AB)”. These databases were loaded into QGIS and queried for only those worm levels (worm_level) that were greater than 18, which is essentially deeper than 18 km. These were converted into a shapefile for display purposes (GravWorms_18+.shp and MagWorms_18+.shp). Digitization of the interpolation boundaries was done in ArcGIS using the Editor toolbar, and was based primarily on the gravity worms. Only one region, SWPA, required information from the magnetic worms because of a strong magnetic contrast that defines this section. Names of the boundaries were made according to geographic location within the Appalachian Basin. For example, the so-called Valley and Ridge boundary roughly follows the Valley and Ridge physiographic province. Further details, including full names of the sections, are provided within the file called 9_GPFA-AB_InterpolationThermalFieldEstimation.pdf. Note that section MT and section WWV are used interchangeably to refer to the same section.

5. Well Data – Outliers Removed

This file contains the well data sorted for outliers, and the R scripts used to process the data. Before running the outlier identification, wells in AASG_Thermed.xlsx were checked for the same spatial location. Only the deepest well in a given location is used for quality purposes. The R script SortingWells.R contains two functions that were developed to sort the data according to these specifications. Further details about the data processing are provided in 9_GPFA-AB_InterpolationThermalFieldEstimation.pdf (Smith, 2015). Outlier identification is done using the local identification function in Whealton and Smith (2015) with a 32 km searching radius for points. The nearest 25 points are used to check for outliers. Details about the algorithm are provided in 6_GPFA-AB_ThermalOutlierAssessment.pdf (Whealton and Stedinger, 2015).

For ease in setting up the data for outlier identification, a function was written in R script DataArrangementAndRunOutlierAnalysis.R. This function sets up the data and runs the outlier identification function.

6. Thermal Resource Interpolation Results

This folder contains the results of the thermal resource interpolation as binary grid (raster) files. Images of the rasters are also provided. Raster files ending in "pred" are the predicted mean for that resource, and files ending in "err" are the standard error of the predicted mean for that resource. Leave one out cross validation results are provided for each thermal resource.

Several models were built in order to process the well database with outliers removed. ArcGIS toolbox ThermalRiskFactorModels contains the ArcGIS processing tools used. First, the WellClipsToWormSections model was used to clip the wells to the worm sections (interpolation regions). Then, the 1 km^2 gridded regions (see Worm Based Interpolation Boundaries folder above) along with the wells in those regions were loaded into R using the rgdal package. Then, a stratified kriging algorithm implemented in the R gstat package was used to create rasters of the predicted mean and the standard error of the predicted mean. The code used to make these rasters is called StratifiedKrigingInterpolation.R Details about the interpolation, and exploratory data analysis on the well data is provided in 9_GPFA-AB_InterpolationThermalFieldEstimation.pdf (Smith, 2015).

The output rasters from R are brought into ArcGIS for further spatial processing. First, the BufferedRasterToClippedRaster tool is used to clip the interpolations back to the Worm Sections. Then, the Mosaic tool in ArcGIS is used to merge all predicted mean rasters into a single raster, and all error rasters into a single raster for each thermal resource.

A leave one out cross validation was performed on each of the thermal resources. The code used to implement the cross validation is provided in the R script LeaveOneOutCrossValidation.R The results of the cross validation are given for each thermal resource.

Other tools provided in this toolbox are useful for creating cross sections of the thermal resource. ExtractThermalPropertiesToCrossSection model extracts the predicted mean and the standard error of predicted mean to the attribute table of a line of cross section. The AddExtraInfoToCrossSection model is then used to add any other desired information, such as state and county boundaries, to the cross section attribute table. These two functions can be combined as a single function, as provided by the CrossSectionExtraction model.

7. Favorable Counties

This folder contains raster for thermal resource predicted mean, standard error of predicted mean, and cross validation results on the county level for the 5 county maps made in the GPFA-AB project. Thermal resource cross sections made using the models in ThermalRiskFactorModels toolbox are also provided. Cross validation results are only shown for the Depth to 80 °C variable, but other variables can be made using the provided functions and cross validation data.

Details about the selected of the favorable counties are provided in 10_GPFA-AB_SelectBestThermalResourcesCounties.pdf (Smith, 2015).

The favorable counties referenced here were selected on the basis of the thermal quality analysis portion of the project. Four counties were selected from each of the three states in the study area (New York, Pennsylvania and West Virginia), for a total of twelve. Because some counties are adjacent, there are 5 county level maps. The image MapOfBestCounties.png within the collection of images shows all twelve highlighted on one map.

- ChauErie refers to Erie County, PA and Chautauqua County, NY.
- FayettePreston refers to Fayette County, PA and Preston county, WV
- Gilmer refers to Gilmer County, WV
- KnawLinc refers to Kanawha County, WV and Lincoln County, WV
- FingerLakes refers to Stuben, Tomkins, and Chemung Counties of NY and Potter and Tiaga Counties of PA

8. Play Fairways

This folder contains the Geothermal Play Fairways as identified by the GPFA-AB Team. Details about how these play fairways were selected are provided in Jordan et al. (2015). The inner (high priority) and outer (medium priority) fairways are provided, along with ArcGIS symbology layers.

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