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Geothermal Play Fairway Analysis (GPFA): A Texas/Gulf Coast Case Study

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ABSTRACT

Geothermal Play Fairway Analysis (GPFA) is an exploration process adopted to geothermal, that integrates data of critical risk elements inherent to that specific geothermal play type. The key function of GPFA is to reduce risk and increase focus for improving exploration success rates. GPFA begins at the regional/basin scale, and progressively focuses in on the play scale. It then examines the critical risk element data to highlight which play areas have the highest likelihood of success (prospects).

The outputs from the GPFA process are Common Risk Segment (CRS) & Composite Common Risk Segment (CCRS) Maps. CRS maps define areas that contain the same general Probability of Success (PoS) for each individual risk element based on the input data. Operator analyzed/ determined cutoff values or classes are then applied to each map with color assignments indicating high (red), medium (yellow) and low (green) risk areas for each element under consideration. Each individual CRS map is then composited into a single CCRS map.

Publicly available data on hundreds of thousands of boreholes in Texas and the Gulf Coast demonstrate excellent potential for geothermal electricity generation from either current or abandoned oil and gas wells. Near-surface geothermal resources, at depths of 3 km (9,842 ft) or less, are generally less than 150°C (302°F) in Texas. Economically feasible electricity generation is possible with available subsurface temperature conditions within reasonable depths—generally greater than 120°C (248°F) within 4 km (13,123 ft) – given the prolific oil and gas well drilling. Extensive data exists to depths as much as 8 km (26,246 ft), indicating temperatures in excess of 300°C (572°F).

1. INTRODUCTION – GEOTHERMAL SYSTEMS

Geothermal fields are found throughout the world in a range of geological settings and are increasingly being developed as a significant long-term energy resource. Geothermal systems have distinct characteristics which are reflected in the chemistry of the geothermal fluids and their potential applications. However, they all have in common a heat source which drives water present in the upper sections of the Earth's crust into convection. Many geothermal resources can be used for space heating applications (e.g., urban district heating schemes, greenhouse heating, etc...) while higher temperature systems (>150°C) are used to generate electricity through the production of steam. Before moving into the application of GPFA, it is important to understand the defining characteristics of a "geothermal system".

If you are involved with the geothermal world, you have likely heard the terms "hydrothermal" and "Geothermal Heat Pump", which are correlated with conventional geothermal systems. Additionally, terms like "Enhanced Geothermal Systems (EGS)" and "Advanced Geothermal Systems" which are linked to unconventional geothermal systems. While these are one way to "define" a geothermal system, we are not discussing that here. In this context, we are looking at the general characteristics that are associated with geothermal systems; liquid vs. vapor dominated, low or high temperature, sedimentary or volcanic, etc.

Geothermal systems are commonly classified by a series of descriptive terms:

Reservoir equilibrium state: This is the fundamental division between geothermal systems and is based on the circulation of the reservoir fluid and the mechanism of heat transfer. Systems in dynamic equilibrium are continually recharged by water entering the reservoir. The water is heated and then discharged out of the reservoir, either to the surface or to underground permeable horizons. Heat is transferred through the system by convection and circulation of the fluid. Systems in static equilibrium have minor to no recharge in the reservoir and heat is transferred only by conduction.

Fluid type: The reservoir fluid can be composed mainly of liquid water (liquid-dominated) or steam (vapor-dominated). In the majority of reservoirs, both steam and liquid water exist in varying proportions as two-phase. Liquid-dominated systems are most common, some which contain a steam cap which can expand or develop on exploitation as happened at Wairakei, New Zealand. Systems which discharge only steam are rare - the best known are Larderello, Italy and The Geysers, USA. Note that liquid-dominated systems are sometimes called water-dominated; this is not a good term since all hydrothermal fields are composed of water in either the liquid or vapor phase. Vapor-dominated systems are also referred to as steam fields.

Reservoir temperature: The temperature (or enthalpy) of geothermal reservoirs is an important parameter in terms of fluid chemistry and potential resource usage. Systems are commonly described as low-temperature (<180°C) or high-temperature (>150°C). Low-temperature systems are used for "direct-use" applications (e.g., heating), while high-temperature systems can be used for electricity generation as well as direct-use applications.

Host rock: The rocks which contain the geothermal reservoir (the "host rocks") react with the geothermal fluid. As fluid-rock interactions determine the final composition of the geothermal waters and gases, a knowledge of the host rocks is important for application of geothermometers and understanding potential scaling problems if the field is developed. Volcanic, clastic-sedimentary, and carbonate-sedimentary rocks (and the metamorphic equivalents of these lithologies) all yield geothermal fluids with contrasting and distinct chemistries. If the subsurface geology is poorly understood, it may be possible to predict the lithologies from the water chemistry.

Heat source: The heat source for the system is a function of the geological or tectonic setting. If the heat flow is provided by a magma, then such systems are termed volcanogenic and are invariably high-temperature systems. Heat is not always supplied by magma, and a geothermal system can be generated in areas of tectonic activity. For example, heat may be supplied by the tectonic uplift of hot basement rocks, or water can be heated by unusually deep circulation created by movement of a permeable horizon or faulting. These are termed non-volcanogenic systems and include examples of both high and low-temperature reservoirs.

2. GEOTHERMAL PLAY FAIRWAY ANALYSIS (GPFA)

GPFA, an exploration process developed by the oil and gas industry and now adopted to Geothermal, integrates data of critical risk elements inherent to that specific geothermal play type (Nielson et al., 2015). The key function of GPFA is to reduce risk and increase focus for improving exploration success rates.

GPFA was first applied to petroleum systems and is now being developed for understanding geothermal systems. The elements required for a conventional petroleum play or “petroleum system” are a source rock, reservoir rock, migration pathway, and seal (Figure 1). To be considered a prospect (high PoS), the play must also contain structural or stratigraphic traps, and have a source rock sufficiently heated to generate hydrocarbons at a time – the critical moment – when all the other required elements (e.g., reservoirs, pathways, seals, traps) were in place.

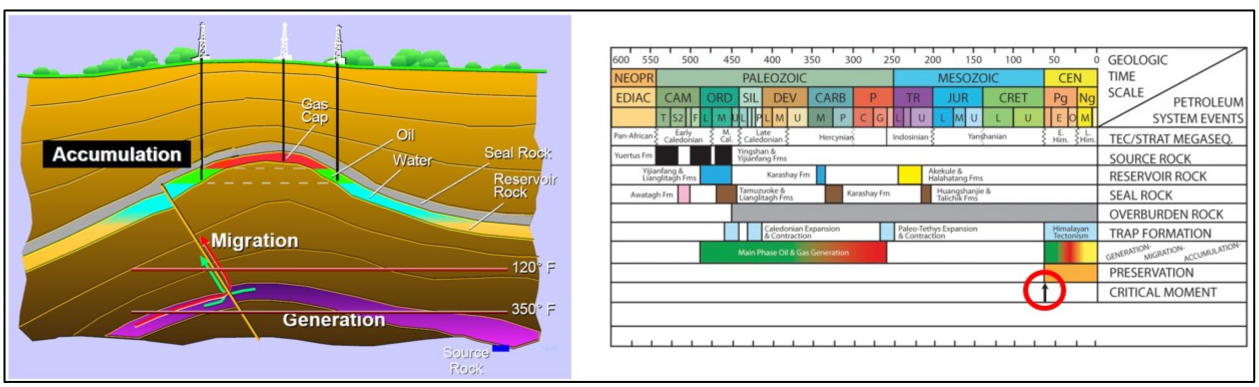


Figure 1: Elements required for a conventional petroleum play or “petroleum system”; source rock, reservoir rock, migration pathway, and seal.

The elements required for an unconventional petroleum play or “petroleum system” are inherently different from a conventional system as the source rock is also the reservoir (Figure 2). The low permeability organic rich shale reaches required thermal maturity to produce hydrocarbons which are then produced through hydraulic fracturing (artificial permeability network).

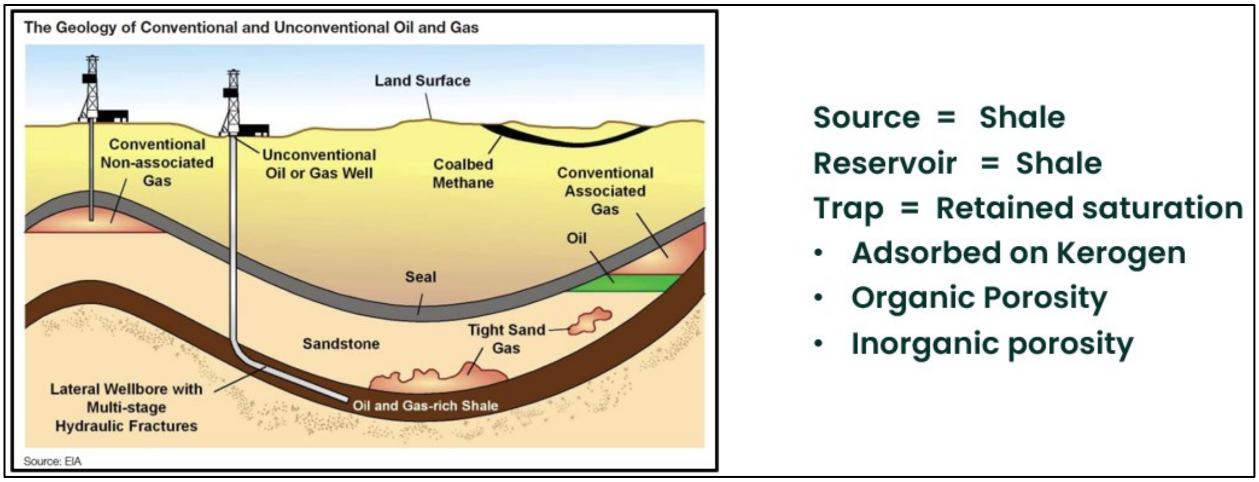


Figure 2: Elements required for an unconventional petroleum play or "petroleum system" are inherently different from a conventional system as the source rock is also the reservoir.

GPFA begins at the regional/basin scale, and progressively focuses in on the play scale (Figure 3). It then examines the critical risk element data to highlight which play areas have the highest likelihood of success (prospects).

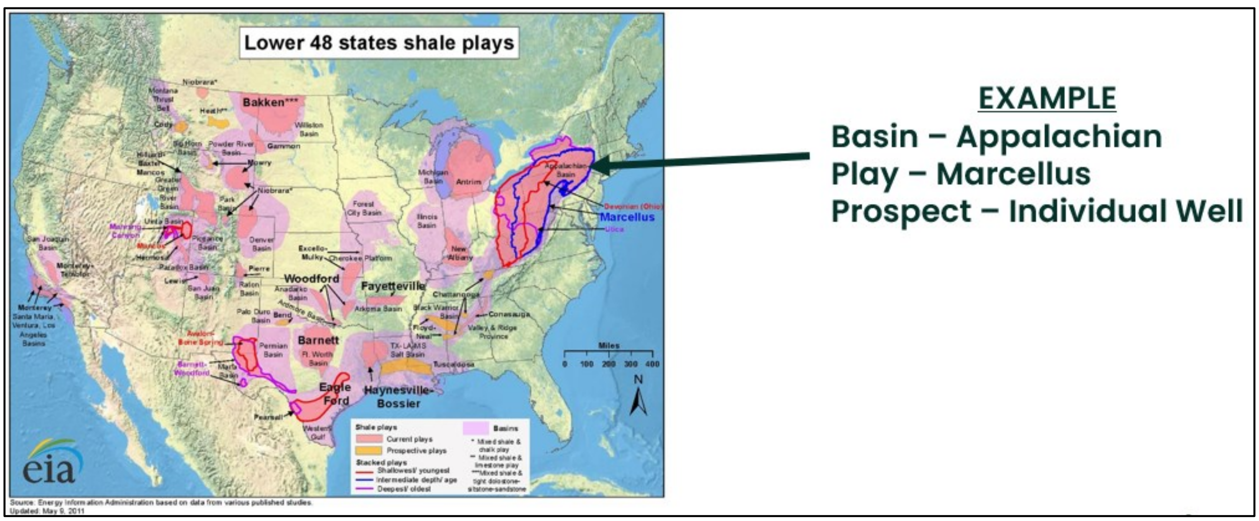


Figure 3: GPFA begins at the regional/basin scale, and progressively focuses in on the play scale (Jordan, Teresa et al., 2016).

3. COMMON RISK SEGMENT (CRS) & COMPOSITE COMMON RISK SEGMENT (CCRS) MAPS

The outputs from the GPFA process are Common Risk Segment (CRS) & Composite Common Risk Segment (CCRS) Maps (Figure 4). CRS maps define areas that contain the same general Probability of Success (PoS) for each individual risk element based on the input data (Faulds, James E., et al., 2021). Operator analyzed/determined cutoff values or classes are then applied to each map with color assignments indicating high (red), medium (yellow) and low (green) risk areas for each element under consideration. Each individual CRS map is then composited into a single CCRS map. In conventional petroleum exploration, the risk elements are the reservoir, source, charge, and trap.

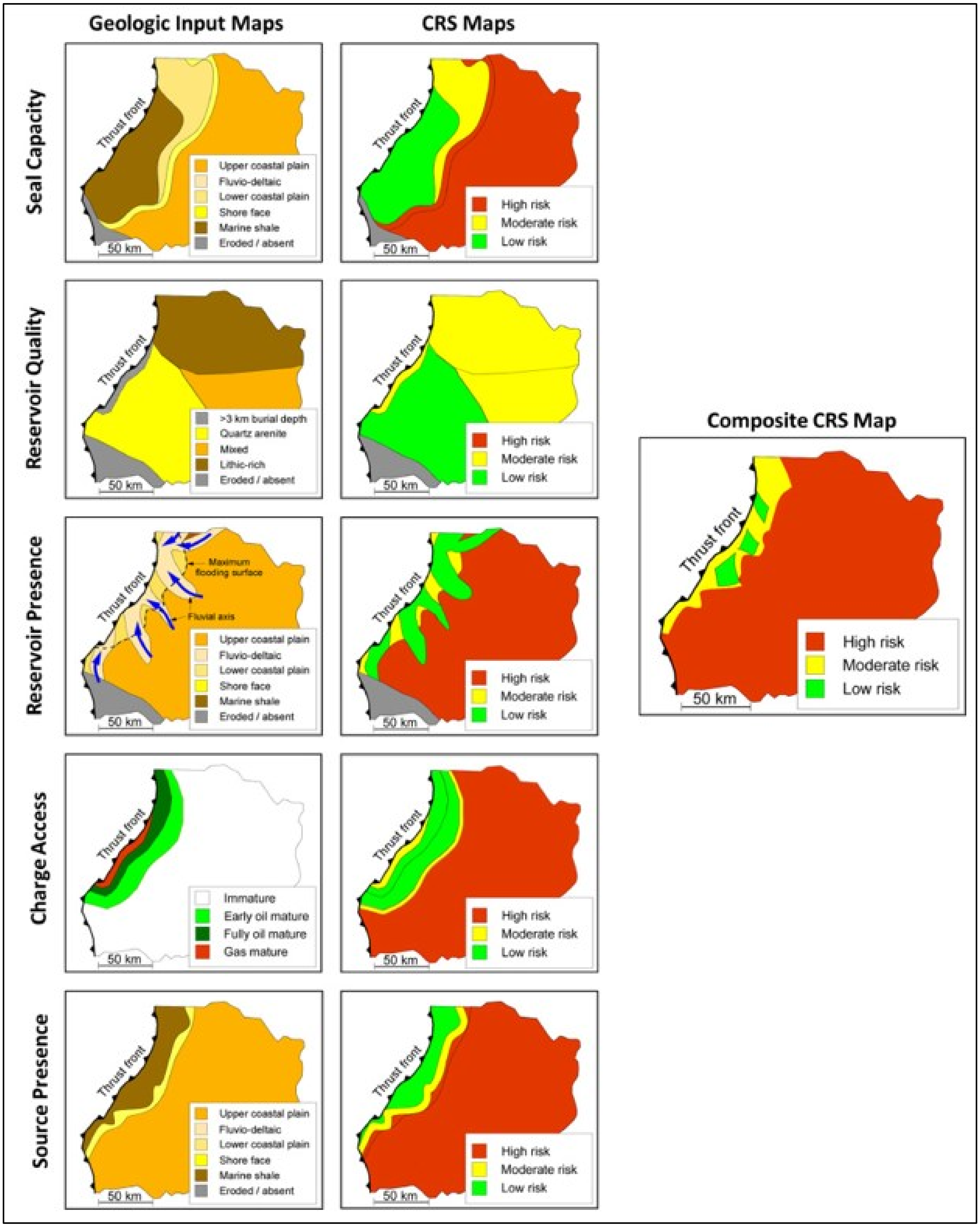


Figure 4: Common Risk Segment (CRS) & Composite Common Risk Segment (CCRS) Maps. CRS maps define areas that contain the same general Probability of Success (PoS) for each individual risk element. Source: Bump, 2021. Common risk segment mapping: Streamlining exploration for carbon storage sites, with application to coastal Texas and Louisiana.

For an unconventional petroleum system, here are some examples of the critical risk elements and their associated risk cutoff values (Figure 5). Note the asterisk for EGS next to the % clay critical risk parameter. In an unconventional petroleum system that requires fracturing, if the % clay gets too high, the rock is too ductile, and the fractures will not remain open. The same would apply to EGS, which requires the generation of a fracture network.

% Initial TOC

<2%	2-4%	>4%

Thermal Maturity (%Ro)

Oil	<0.7, >1.2	0.7 – 0.85, 1.1 – 1.2	0.85 – 1.1
Wet Gas	<0.9, >1.6	0.9 – 1.1, 1.5 – 1.6	1.1 – 1.4
Gas	>3.0, <0.9	0.9 – 1.1, 2.8 – 3.0	1.1 – 2.8

Risk

Low
Moderate
High

% Clay

>45%	35-45%	<35%	**(*EGS)**

Figure 5: Critical risk elements and their associated risk cutoff values.

The CRS/CCRS workflow using heat flow (mW/m^2) as an example (Figure 6):

1. Gather risk element data
2. QC data
3. Import data into GIS system
4. Conduct interpolation (IDW, TIN) to create continuous surface
5. Apply cutoff value colors (green, yellow, red)
6. Single layer risk CRS created
7. Integrate/stack individual CRS layers to create CCRS

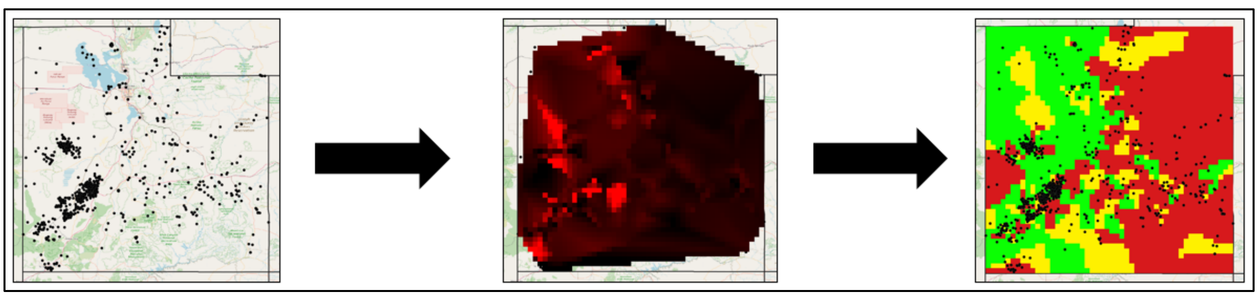


Figure 6: CRS/CCRS workflow using heat flow data (mW/m2) as an example. Heat flow data points (mW/m2) imported into GIS, followed by an IDW/TIN interpolation continuous surface and final risk value colors applied to form a single CRS layer.

4. GEOTHERMAL CRS ELEMENTS

In a geothermal play or system, the main exploration risk elements for this study are (a) heat resource, (b) permeability, (c) recharge and (d) seal.

a: Heat: While trivial that a high-level heat source is the principal requirement for an effective and economic geothermal system, accessibility depth for drilling and evaluation purposes, as well as interval complexity are important factors.

b: Permeability: Geothermal reservoirs are reliant on natural fracture permeability, associated with fracturing related to tectonic and magmatic processes, or through stimulated fractures if feasible.

c: Temperature recharge capacity of the migration of fluids within the geothermal system is critical to maintaining a long-lived resource with economic heatflow dynamics.

d: A seal keeps fluid from escaping or mixing with colder shallower aquifers. It also acts as a thermal insulator to the geothermal reservoir.

In the following GPFA example conducted in the Tularosa Basin (Bennett, Carlon R. et al., 2015), we see the individual CRS elements combined into a final CCRS map (Figure 7):

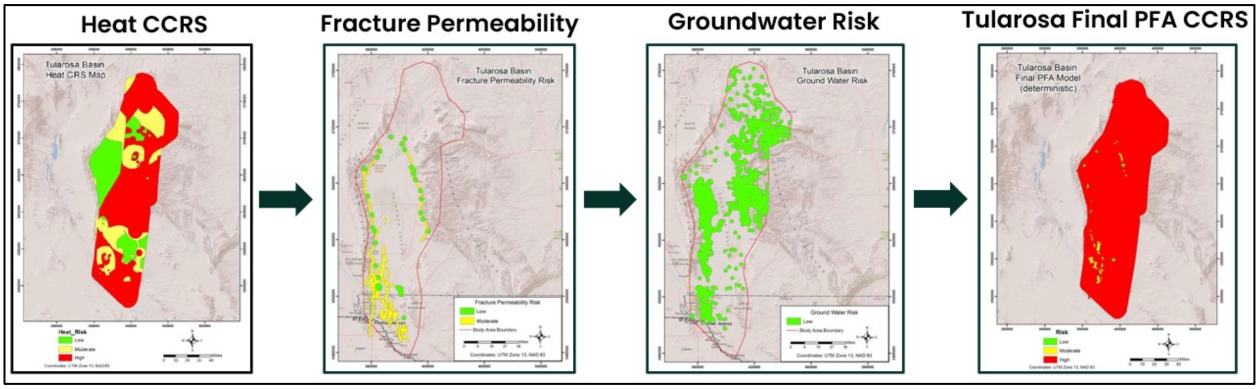


Figure 7: GPFA example from the Tularosa Basin. Source: Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), Geothermal Technologies Office DE-EE0006730; Innovative Play Fairway Modelling Applied to the Tularosa Basin.

Through the application of GPFA and screening for critical risk elements inherent to a functional geothermal system (heat, groundwater, and fracture permeability), this study was able to reduce an exploration area of approximately 6500 km2 into 8 specific high graded potential plays/target sites (Figure 8). These prospects represent areas where all the critical risk elements coincide with a low-risk determination.

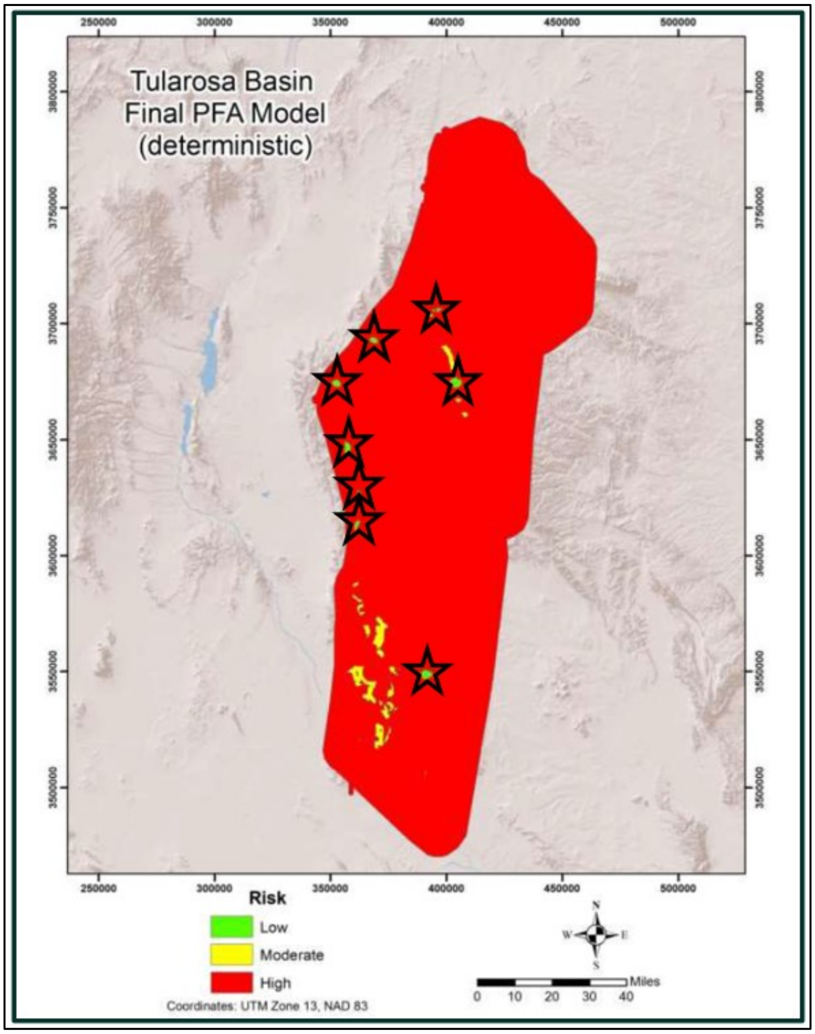


Figure 8: GPFA CCRS final map from the Tularosa Basin. Source: Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), Geothermal Technologies Office DE-EE0006730; Innovative Play Fairway Modelling Applied to the Tularosa Basin.

Here we present some example heat geothermal risk elements and their associated risk cutoff values:

1. Temp. Gradient °C/km
   - 0 °C/km – 60 °C/km = High Risk (Red)
   - 60 °C/km – 80 °C/km = Moderate Risk (Yellow)
   - >80 °C/km = Low Risk (Green)
2. Quartz Geothermometer °C
   - 0 °C/km – 60 °C/km = High Risk (Red)
   - 60 °C/km – 80 °C/km = Moderate Risk (Yellow)
   - >80 °C/km = Low Risk (Green)
3. Heat Flow mW/m2
   - 55 – 70 mW/m2 = High Risk (Red)
   - 70 – 85 mW/m2 = Moderate Risk (Yellow)
   - >85 mW/m2 = Low Risk (Green)

The most important risk element for geothermal is heat; you can think of this as the equivalent to the source rock in petroleum systems. Without a source rock, there simply isn't a petroleum system to be investigated. Similarly, if you don't have the necessary heat resource, there is no functional geothermal system.

5. HI-FI ADVANCEMENTS

After understanding the basics of GPFA, we recommend advancing to more sophisticated and automated analysis with a high-fidelity solution. Again, leveraging the knowledge base of the petroleum industry, the results below (Figure 9) were produced using the Power Risk Optimizer from the Priemere Power Tools for ArcGIS (Help@Priemere.com). With the same data & parameters as above, the same eight Prospects (Hot/Go Spots) were identified.

However, the final hi-fi results can be classified at any desired level of detail, and there is greater resolution to consider with the six colors utilized. And as a further diagnostic aid, the polygon labels indicate the critical risk factor (CRF) as the element with the greatest impact within each area. These automated features facilitate rapid iteration on various models and parameters to achieve a more thorough and accurate understanding of the GPFA system.

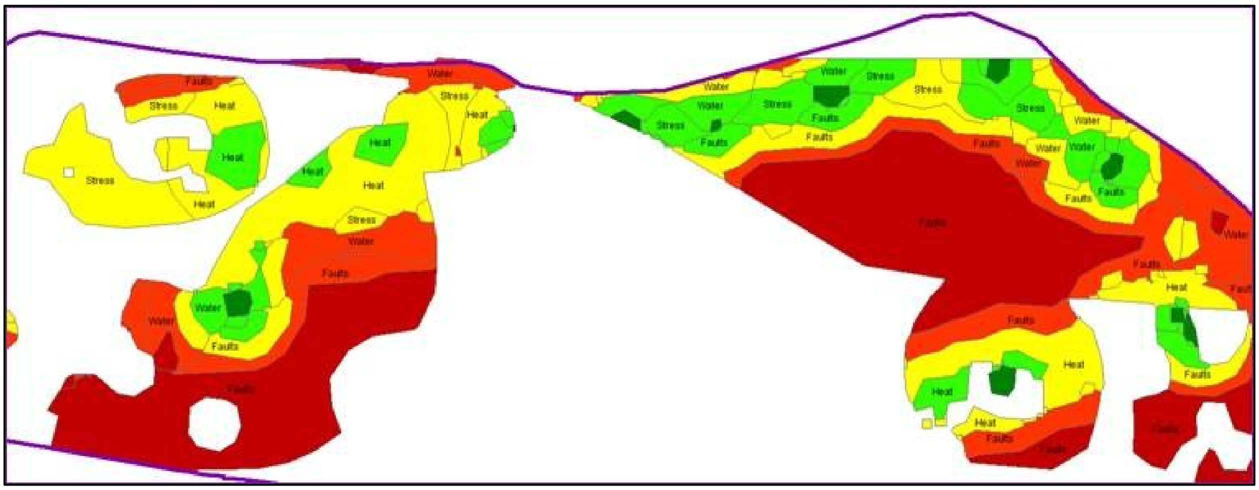


Figure 9: Hi-Fi GPFA example for the Tularosa Basin from the Priemere Power Risk Optimizer.

6. INITIAL GPFA SCREENING

When initiating an investigation into a new geothermal exploration area, a "high-level first pass" should be conducted for the heat resource before initiating the full GPFA process or detailed feasibility assessment. This is an important first step prior to conducting a detailed study so that you can determine if there is even a heat resource to be explored before wasting time on a more extensive study.

The initial step is to investigate for any geothermal gradient data that may be available within the exploration area. This will usually be in the form of borehole temperature logs from previously drilled oil and gas wells. In the United States, you can generally find this data across most geothermal exploration areas. An example resource for this is the Southern Methodist University (SMU) National Geothermal Data System.

This detailed database has provided the means to create some key geothermal maps in the United States, such as the Geothermal Map of North America (Figure 10), Heat Flow Map of the Continental U.S. (Figure 11) and the NREL Favorability of Deep Enhanced Geothermal Systems (Figure 12):

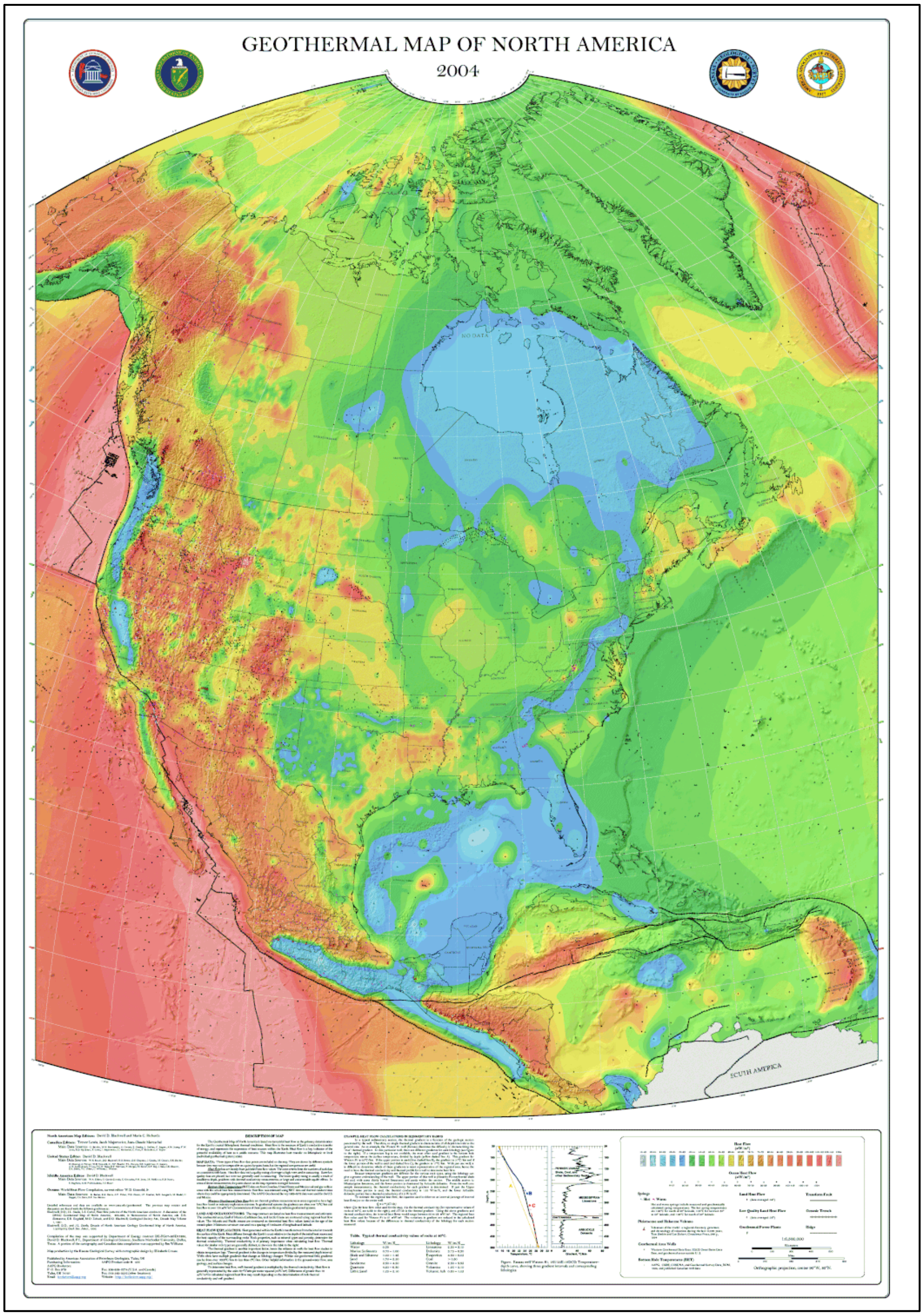


Figure 10: Geothermal Map of North America. Source: Blackwell, D.D., and M. Richards, Geothermal Map of North America, AAPG Map, scale 1:6,500,000, Product Code 423, 2004.

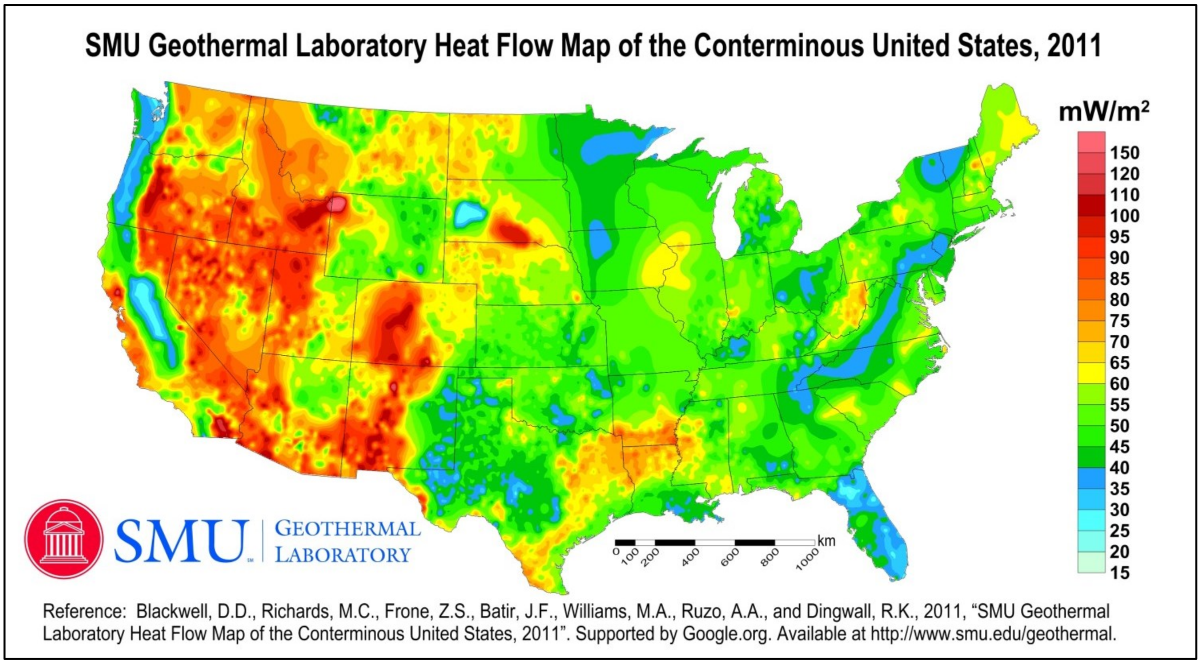


Figure 11: Heat Flow Map of the Continental U.S. Source: Blackwell, David, M. Richards, Z. Frone, J. Batir, A. Ruzo, R. Dingwall, and M. Williams 2011, Temperature at depth maps for the conterminous US and geothermal resource estimates, GRC Transactions, 35 (GRC1029452).

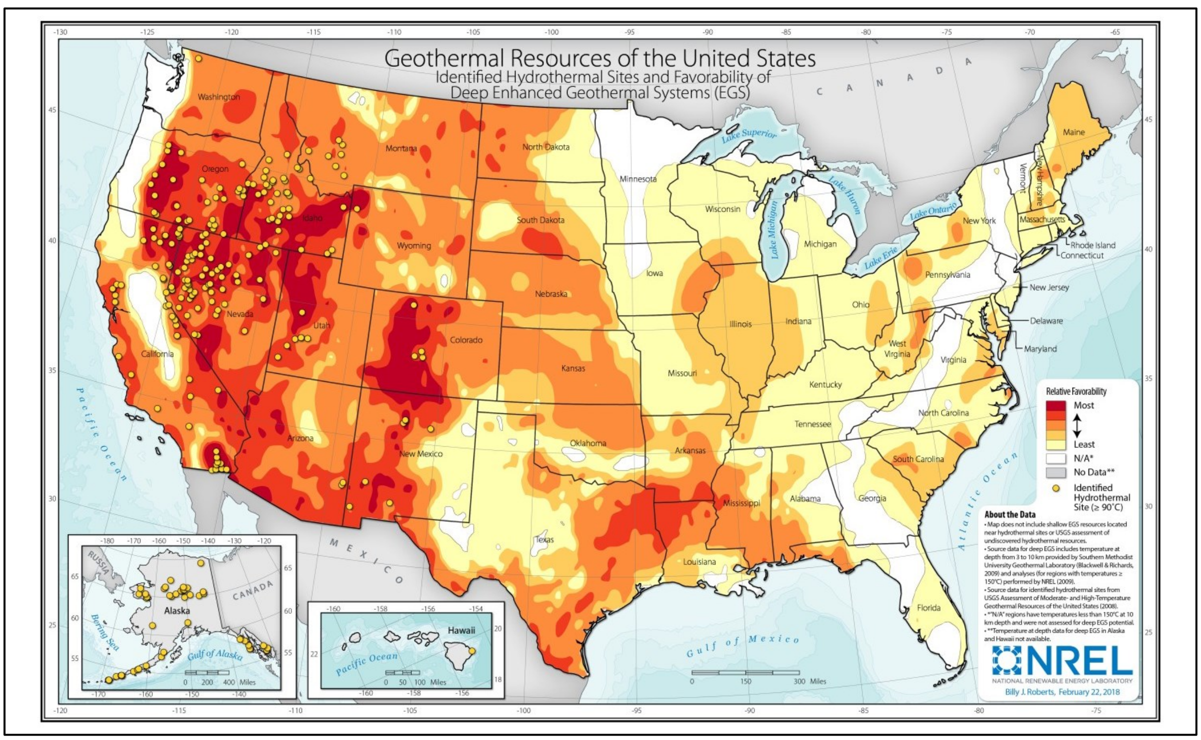


Figure 12: NREL Favorability of Deep Enhanced Geothermal Systems. Source: [NREL Geothermal Resources of the United States—Identified Hydrothermal Sites and Favorability of Deep Enhanced Geothermal Systems]

The main reason we want to look at geothermal gradients from these borehole temperature logs first is to determine if the exploration area is even suitable to geothermal development and economically feasible (Shervais, John W., et al., 2021). The previously described risk cutoffs generally applied to geothermal gradients are as follows:

Temp. Gradient °C/km

- 0 °C/km – 60 °C/km = High Risk (Red)
- 60 °C/km – 80 °C/km = Moderate Risk (Yellow)
- >80 °C/km = Low Risk (Green)

Below 60 °C/km, down to about 40 °C/km, a geothermal resource could still be possible but will likely require an Organic Rankine Cycle (ORC), which includes additional costs. Once you get down to gradients such as ~25 °C/km, you start to enter regions that are simply not favorable to geothermal development. This is due to two reasons; a) an appreciable heat resource is not present and b) you have to drill too deep to reach the required temperatures and therefore it becomes economically unfeasible especially since the largest cost associated with geothermal projects is the drilling. If you have to drill to 8-10 km just to reach 150 °C (which is the base temperature generally required for closed-loop systems and even higher temperatures for EGS), the drilling cost is too much. Notice in the NREL favorability map above, they didn't even consider areas where 150 °C were not reached by 10 km exactly for this reason.

For example, in a recent study a client was looking to investigate geothermal resource development in Louisiana (LA) for closed-loop applications. Prior to initiating a full GPFA study, a first high-level pass for the heat resource was conducted. The parish areas they were initially evaluating are shown in Figure 13.

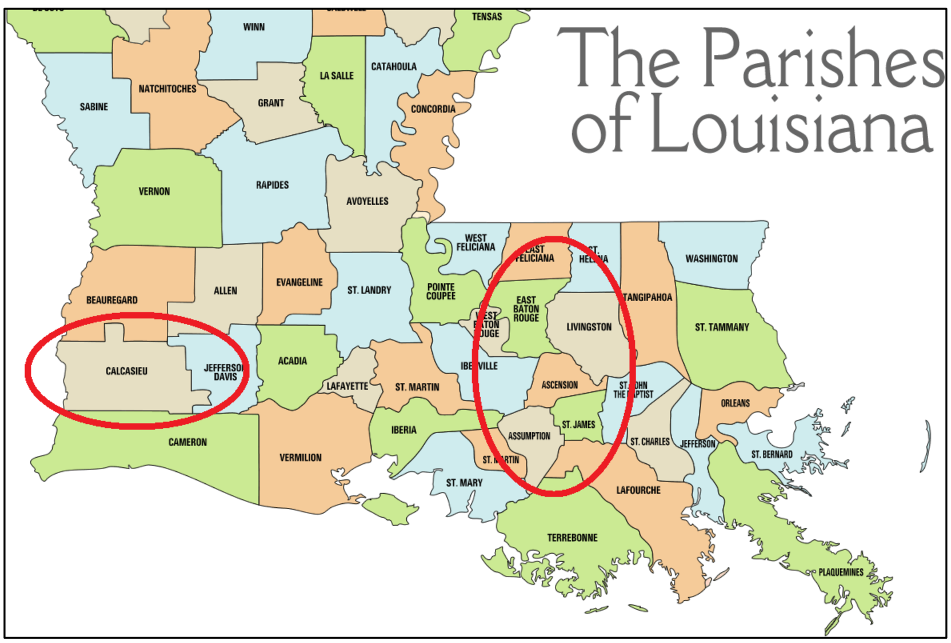


Figure 13: Louisiana Parish Map. The exploration areas of interest are circled in red.

For the first pass, these parishes were evaluated from a temperature/geothermal gradient perspective (Figure 14 and 15):

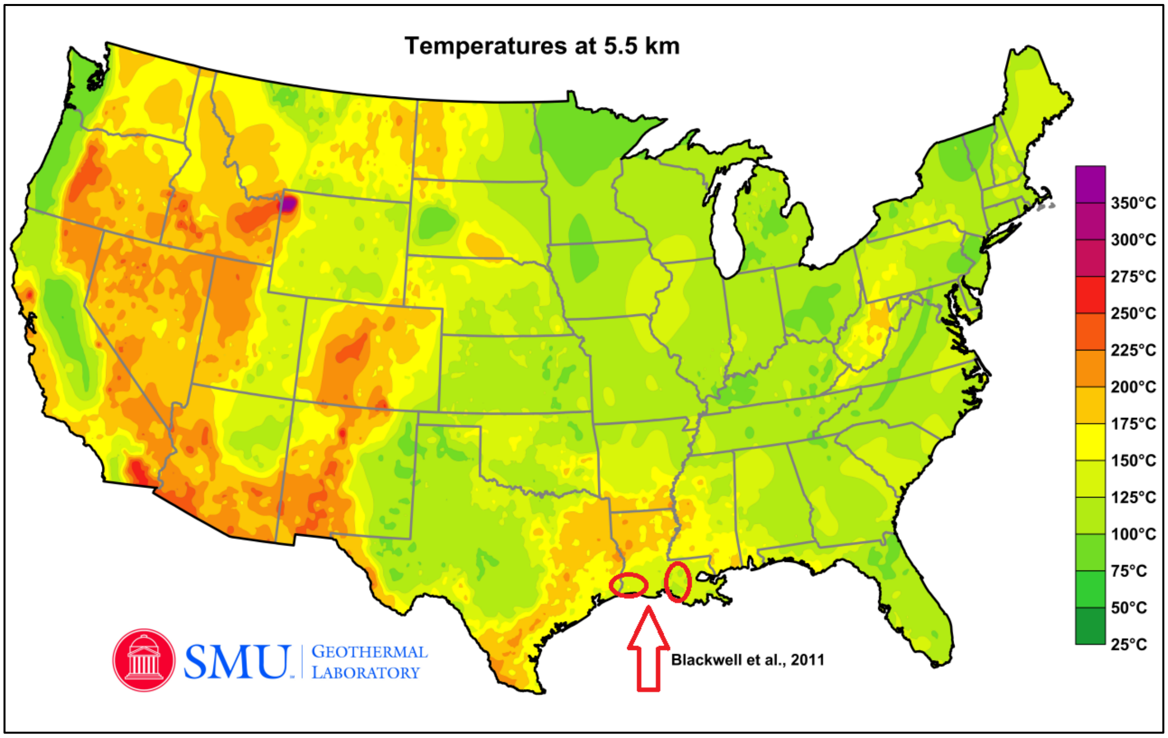


Figure 14: Temperatures at 5.5 km depth with identified counties in red. Source: Blackwell, D., Richards, M., Frone, Z., Ruzo, A., Dingwall, R., & Williams, M. (2011). Temperature-At-Depth Maps For the Conterminous US and Geothermal Resource Estimates. ***GRC Transactions,*** **35(GRC1029452).**

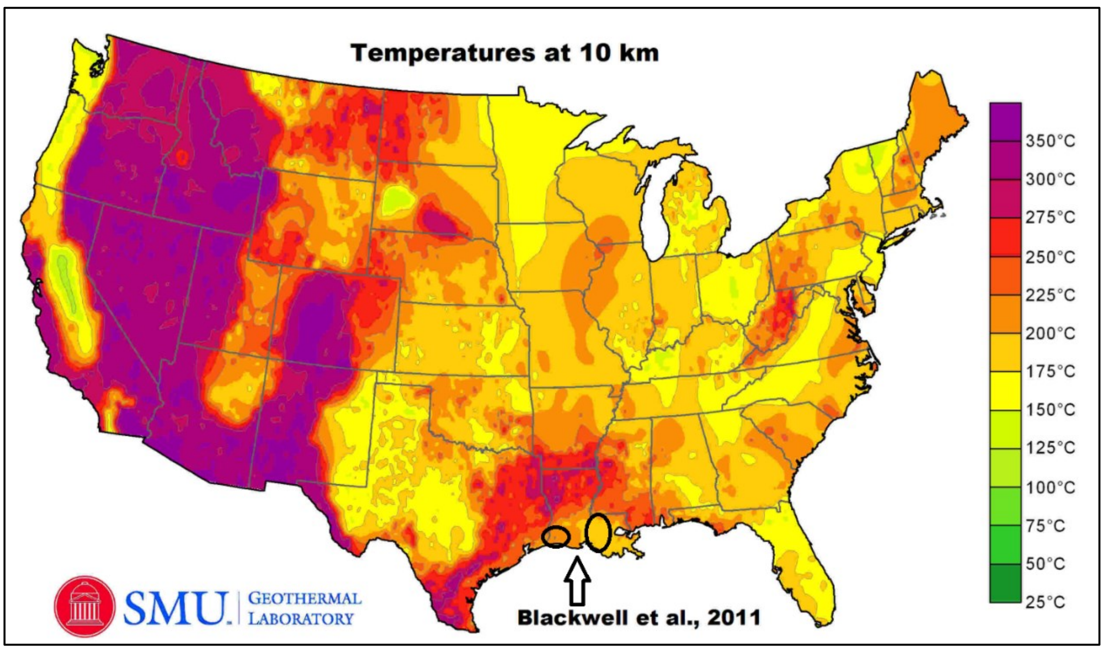


Figure 15: Temperatures at 10 km depth with identified counties in red. Source: Blackwell, D., Richards, M., Frone, Z., Ruzo, A., Dingwall, R., & Williams, M. (2011). Temperature-At-Depth Maps For the Conterminous US and Geothermal Resource Estimates. ***GRC Transactions,*** **35(GRC1029452).**

As can be seen, the client would have to drill to ~10 km to even reach temperatures above 150 °C, base temperatures generally required for optimal closed-loop geothermal systems. This would require significant drilling costs that would make a geothermal project in the area economically unfeasible. This first-pass heat resource assessment provided the client key information that saved them significant time and money.

In this case, the client had interests across the state of LA, and as can be seen in the pictures above, the geothermal gradients in the northern part of the state are amenable to geothermal development.

The geothermal regimes between Northern & Southern LA are completely different from each other due to the Sabine and Monroe Uplifts in the north. These resulted in igneous intrusions that have higher radiogenic heat production (RHP) that provide higher heat flow and also have higher thermal conductivities, creating higher present day geothermal gradients in northern LA. These are absent to the south, where geothermal gradients are significantly lower. Additionally, there are large salt domes present in northern LA and not present in southern LA. Salt domes act as "thermal wicks" and are very efficient at wicking heat from its deeper base up to the top of the salt dome, resulting in locally higher temps at shallower depths.

7. GPFA SCREENING APPLIED TO THE TEXAS/GULF COAST REGION

Texas produces more oil and natural gas than any other state and to date remains the largest producer of these natural resources, with approximately 4 million barrels per day (MMbbl/d) of oil and more than 20 billion cubic feet per day (Bcf/d) of gas. There is no other state or region worldwide which has been as extensively explored or drilled for oil and natural gas as Texas. Currently, there are ~187,401 active oil wells and 98,709 active gas wells producing oil and natural gas in the state, according to the Railroad Commission of Texas. Additionally, over 7000 of these wells have been abandoned and require significant financial expenses to properly plug and decommission. The assessment supports the imperative need for these wells to be analyzed and assessed for their significant geothermal energy resource potential as an extension of the well life and return on investment of deployed capital, as well as benefiting corporate and societal carbon neutrality goals.

As previously stated, the most critical GPFA element is the heat resource, which is intimately tied to the existing geothermal gradient. In Texas and the Gulf Coast Region, areas with the highest geothermal gradients are found in Southwest Texas (Eagle Ford) and East Texas/Northwest Louisiana (Haynesville), as depicted in the regional geothermal gradient (°C/km) CRS map (Figure 16). The cutoffs applied in this CRS map are as follows: 0-35 °C/km (red) = no geothermal potential, 35-50 °C/km (yellow) = potential for low enthalpy/direct use applications, 50-100 °C/km (green) = electricity/power generation potential.

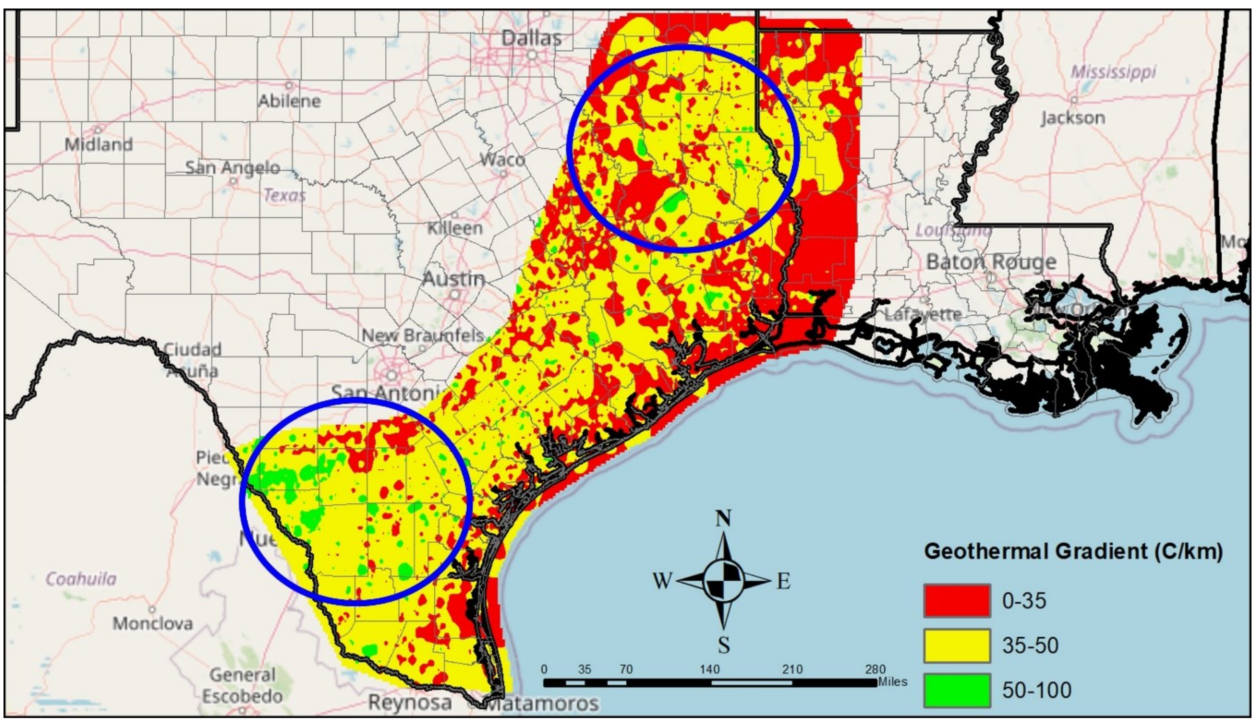


Figure 16: Regional TX/LA Geothermal Gradient CRS Mapping.

The mechanisms behind these two elevated geothermal gradient regions are different. In the Northeast, as can be viewed below (Figure 17), the Haynesville region heat flow values are in excess of 60 – 85 mW/m^2, which is anomalously high compared to the surrounding region. This higher heat flow is attributed to greater radiogenic heat production (RHP) in the igneous basement rocks and the presence of salt domes/diapirs, which have a thermal conductivity 2 to 4 times greater than any other sedimentary rocks (Gray and Nunn, 2010).

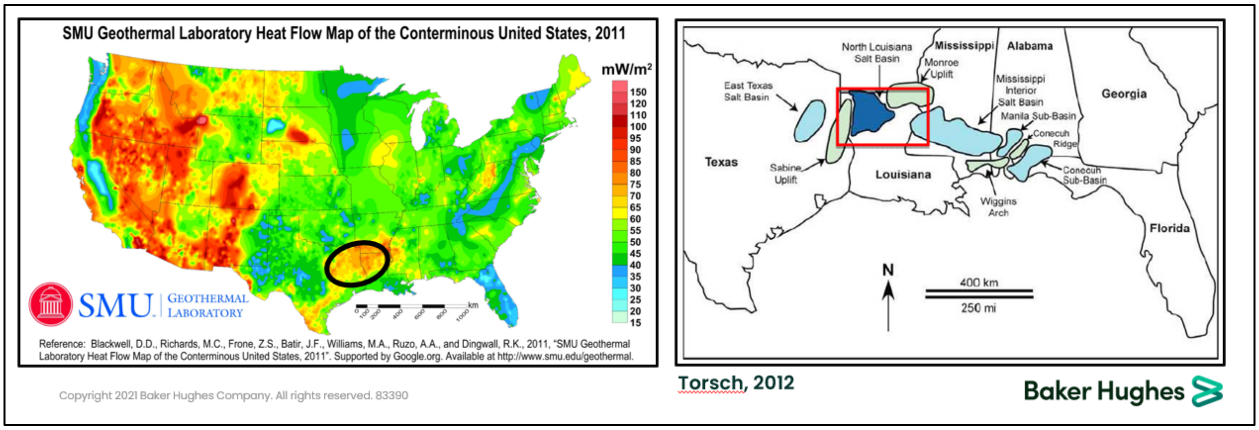


Figure 17: Haynesville Geothermal Potential.

The salt diapirs are of particular interest in geothermal development and exist across the Haynesville region, as shown in the map cross section A-A´ (Figure 18).

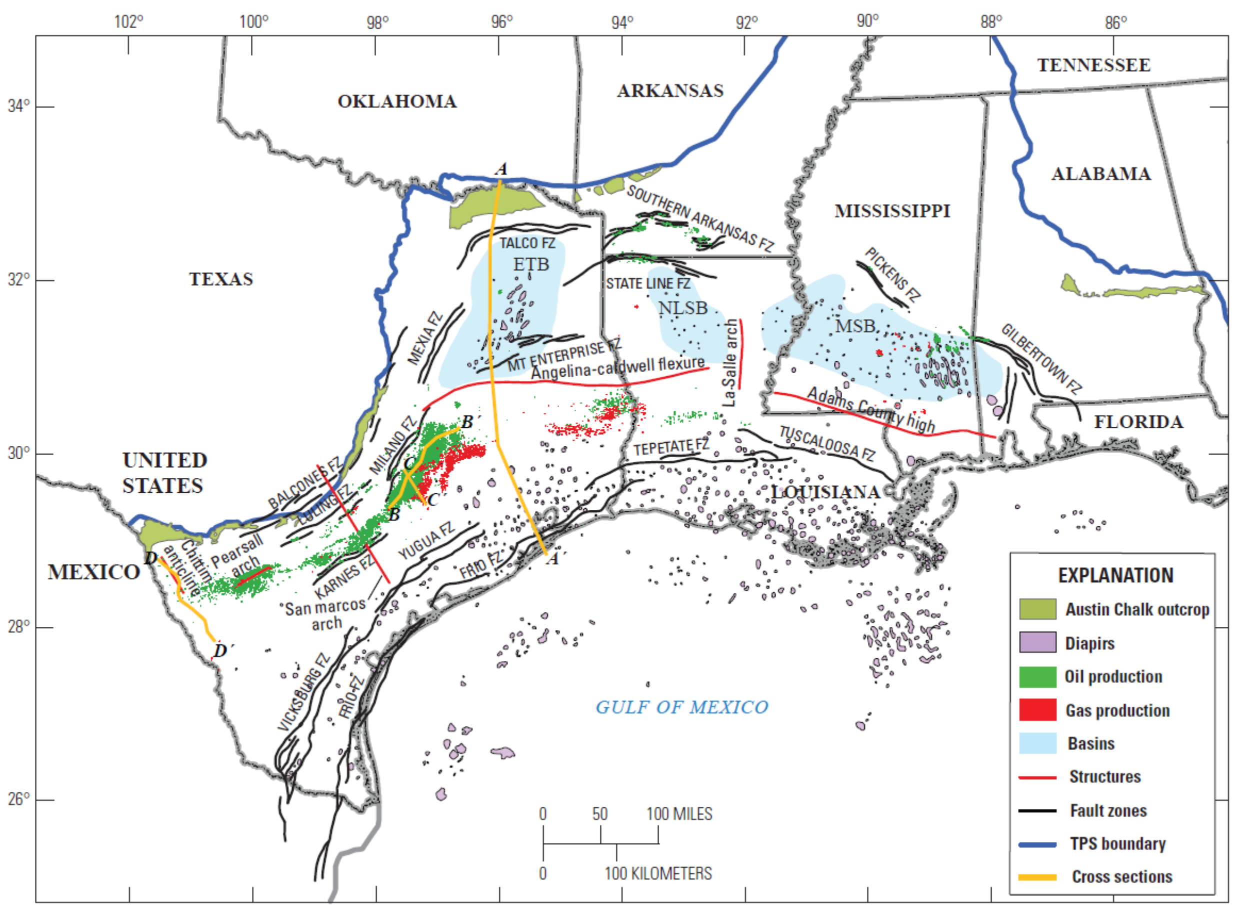


Figure 18: Map cross section A-A´ showing the location of salt diapirs from OK to the TX Gulf Coast (Pearson, 2012).

When viewing the cross section A-A´, it can be seen these salt diapirs are large vertical columnar structures that can extend to depths nearing 10 km and upwards to the near surface (Figure 19). These high thermal conductivity diapirs can act as "thermal wicks", where they capture or "wick" much higher temperatures near their base to the top of the diapir. There will be some heat loss along the upward flow of the diapir but due to their high thermal conductivity/heat transfer capability, much higher temperatures can be "wicked" up to the top of the diapir, creating a localized elevated geothermal gradient that can be significantly higher than the surrounding area. In viewing individual well data, areas near these diapirs can often have geothermal gradients between 60-90 °C/km, whereas ambient background for the region is ~ 35 – 40 °C/km. While drilling into a diapir would need to be avoided due to their ductile/plastic nature, higher geothermal gradients could be exploited around them for geothermal energy. The elevated geothermal gradients would reduce drilling costs to attain required functional temperatures and provide greater energy production, although more research must be applied in understanding the extent of this localized diapir effect.

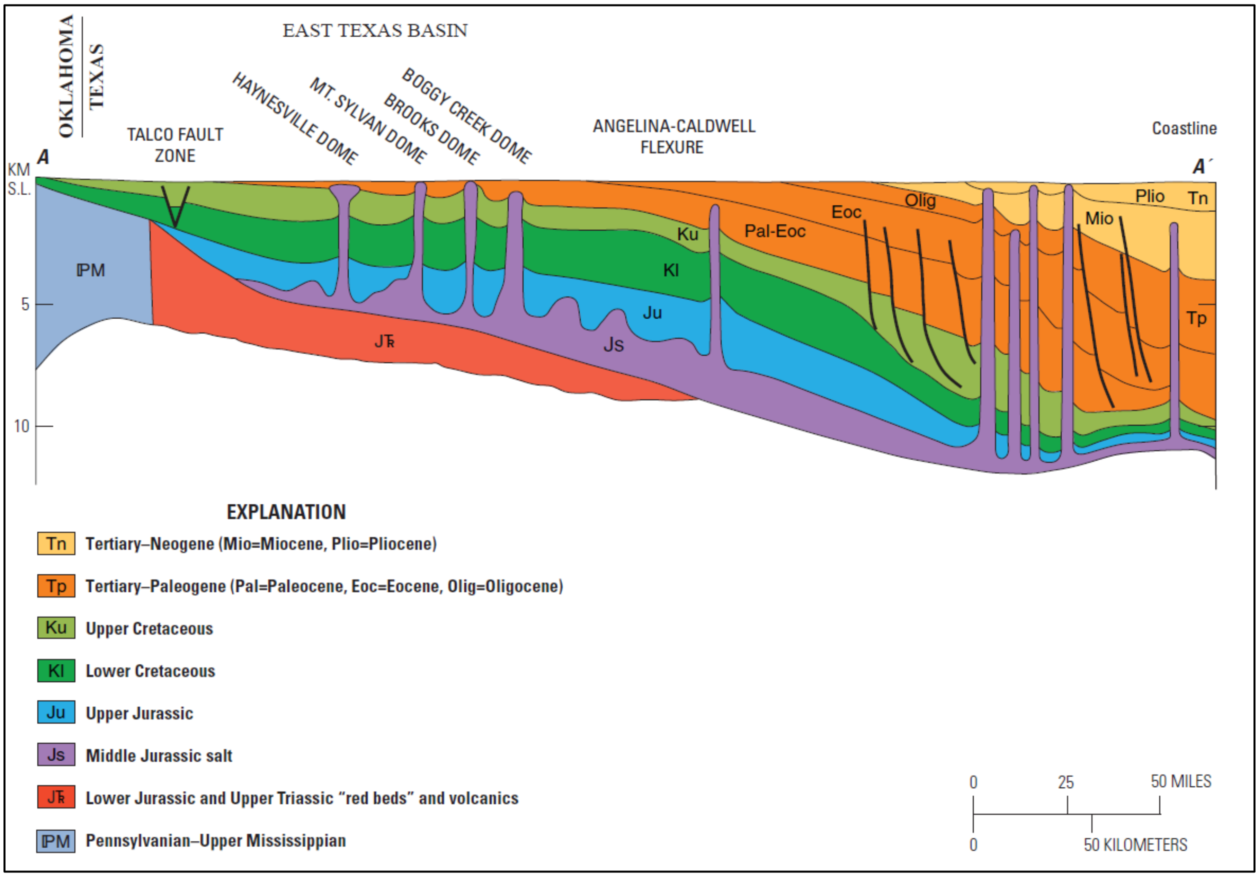
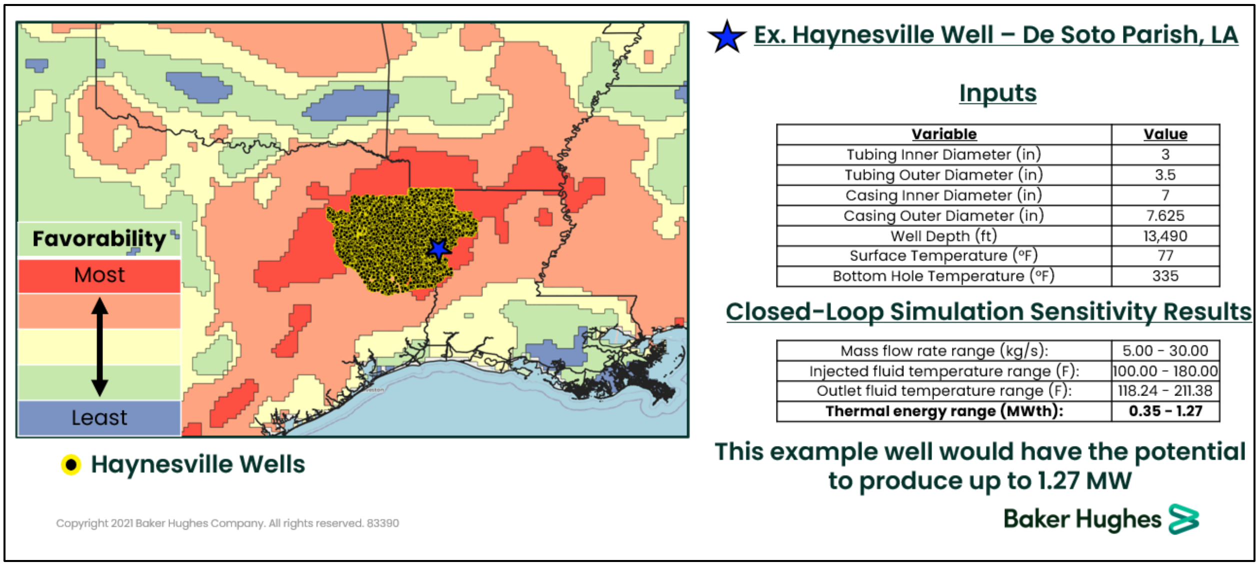


Figure 19: Cross section A-A´ with salt diapir structures from OK to the TX Gulf Coast (Pearson, 2012).

As demonstrated in the NREL Geothermal Favorability Map, the vast majority of Haynesville oil and gas wells depicted below (Figure 20) lie within a high geothermal favorability area, with bottom hole temperatures that are amenable to closed-loop applications and excellent candidates for repurposing.



Variable	Value
Tubing Inner Diameter (in)	3
Tubing Outer Diameter (in)	3.5
Casing Inner Diameter (in)	7
Casing Outer Diameter (in)	7.625
Well Depth (ft)	13,490
Surface Temperature (°F)	77
Bottom Hole Temperature (°F)	335

Mass flow rate range (kg/s):	5.00 - 30.00
Injected fluid temperature range (F):	100.00 - 180.00
Outlet fluid temperature range (F):	118.24 - 211.38
Thermal energy range (MWth):	**0.35 - 1.27**

Figure 20: Haynesville Geothermal Potential – Closed-Loop Applications

The example well shows potential to produce up to 1.27 MWth and with thousands of wells like it within the Haynesville region, the potential for large scale power generation is significant.

The mechanism for the higher geothermal gradients in Southwest Texas (Eagle Ford) is likely tied to geopressured zones that are known to exist along the Texas Gulf Coast/Gulf of Mexico region. When reaching overpressure levels (>.70 psi/ft) due to rapid deposition and compaction, hot fluids can be driven upward along fault planes, resulting in elevated geothermal gradients. This was shown in the following two figures (Figure 21 & 22), where a study clearly demonstrated the correlation between depth to overpressure and geothermal gradients. Where the depth to top of overpressure was shallower, the depth to 300 °F was also less, resulting in elevated geothermal gradients.

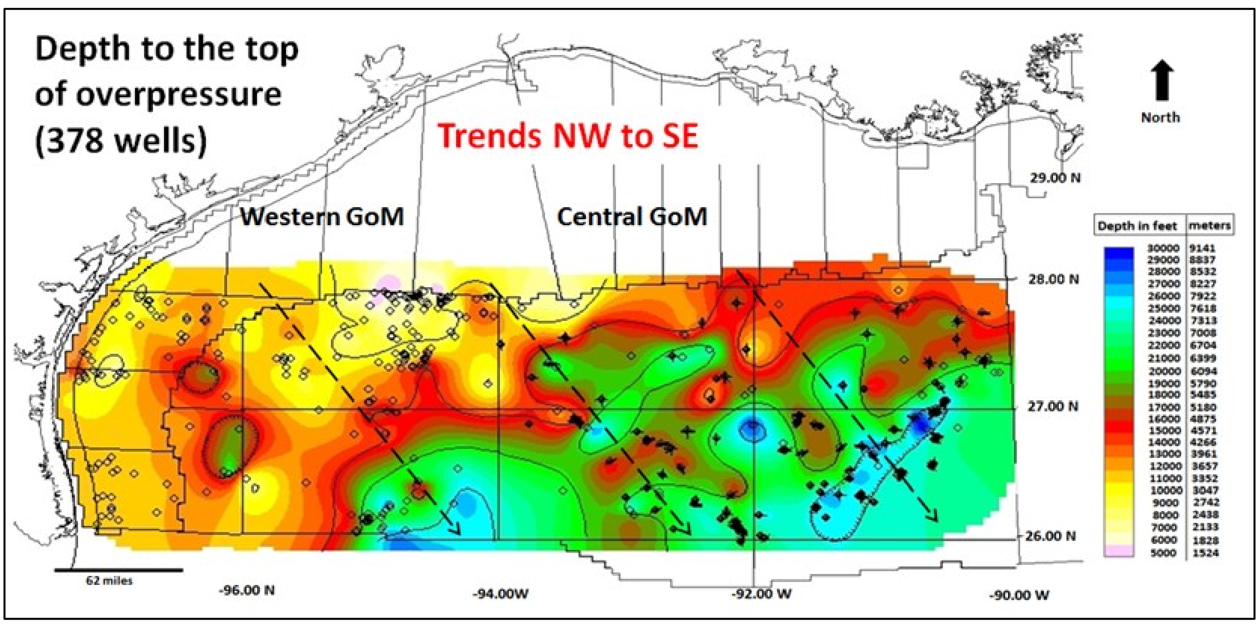


Figure 21: Depth to the top of overpressure (in ft and m) from geopressure gradients computed from 378 wells located in both the western and central GoM (Cornelius, 2020).

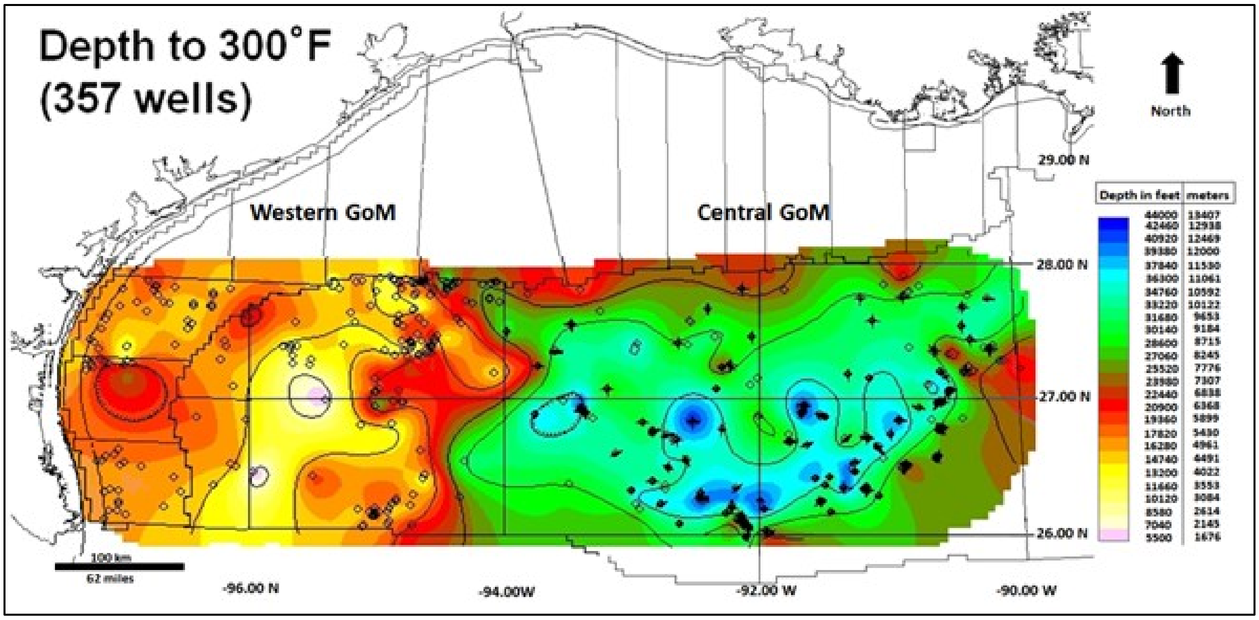


Figure 22: Depth to 300° F (in ft and m) from geothermal gradients computed from 357 wells located in both the WGOM and CGOM (Cornelius, 2020).

Additionally, applying the NREL Geothermal Favorability Map to the Southwest Texas Eagle Ford Region (Figure 18) and some example well data from the Enverus DrillingInfo Database, it can be seen that many existing wells are in high geothermal favorability areas that are also amenable to repurposing from oil and gas into geothermal wells.

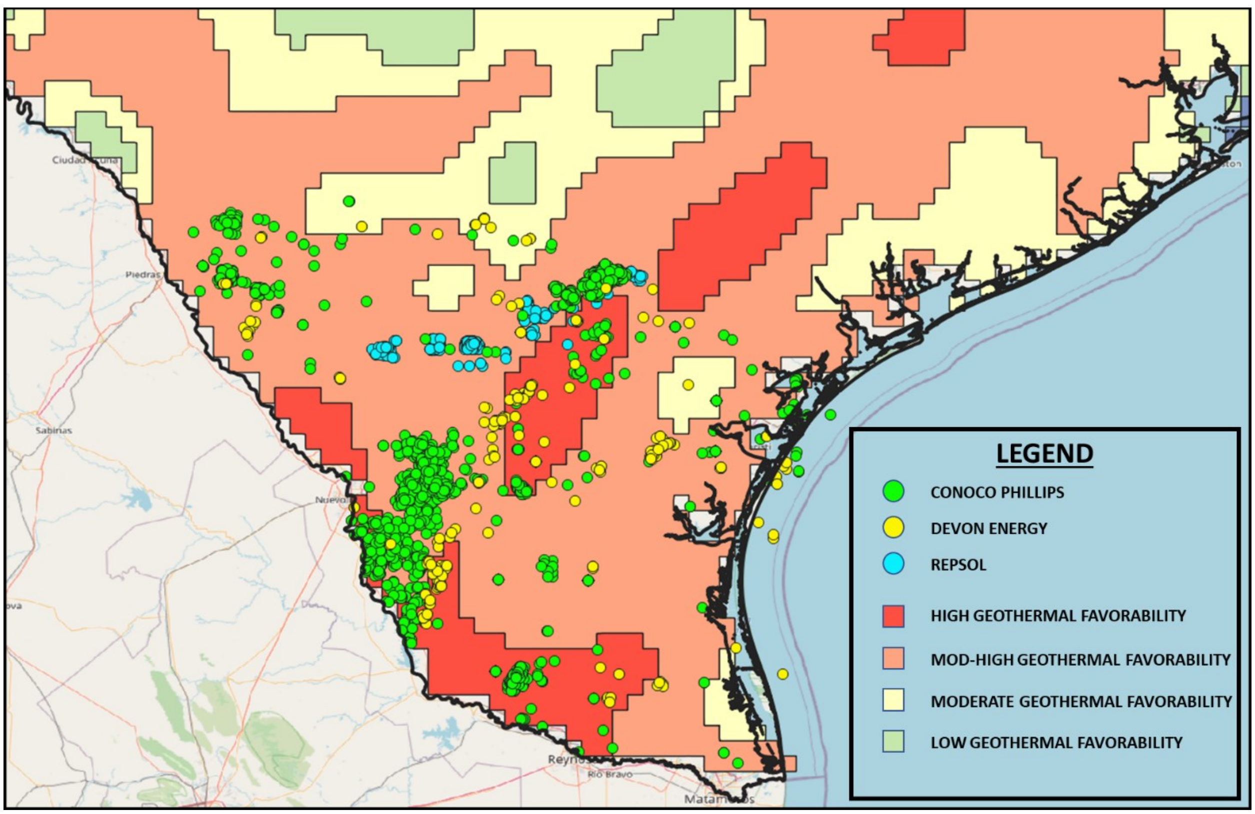


Figure 18: Southwest Texas (Eagle Ford) Geothermal Potential – Repurposing and Closed-Loop Applications

This clearly demonstrates an exploitable geothermal heat resource CRS element, which would then be combined with CRS maps for permeability, recharge, and seal to create a composite CCRS map identifying locations within these regions with functional geothermal systems that have potential for large scale power generation.

8. CONCLUSIONS

Geothermal resources have been recognized for some time as a possible significant source of energy but to date have seen marginal increases in their development and application. Much of this is attributed to the substantial upfront costs associated with geothermal projects coupled with a lack of reservoir characterization. While the resource potential is recognized, investors have been hesitant to proceed with these high risk, long return on investment (ROI) scenarios.

GPFA will provide significant value in geothermal exploration by:

- Reducing Exploration Risk
- Increasing % Probability of Success (PoS)
- Increasing the Return on Investment (ROI)

Though many cost reducing technologies are being developed in the geothermal industry right now, continued refinement and development of GPFA workflows and their associated risk reduction will continue to increase investor confidence and support the full-scale growth of geothermal in the coming energy transition.

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