Sedimentary Geothermal Play Types of the Texas Gulf Coast: Applications to Electrical Power Generation

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Ph.D. Candidate – May 2024

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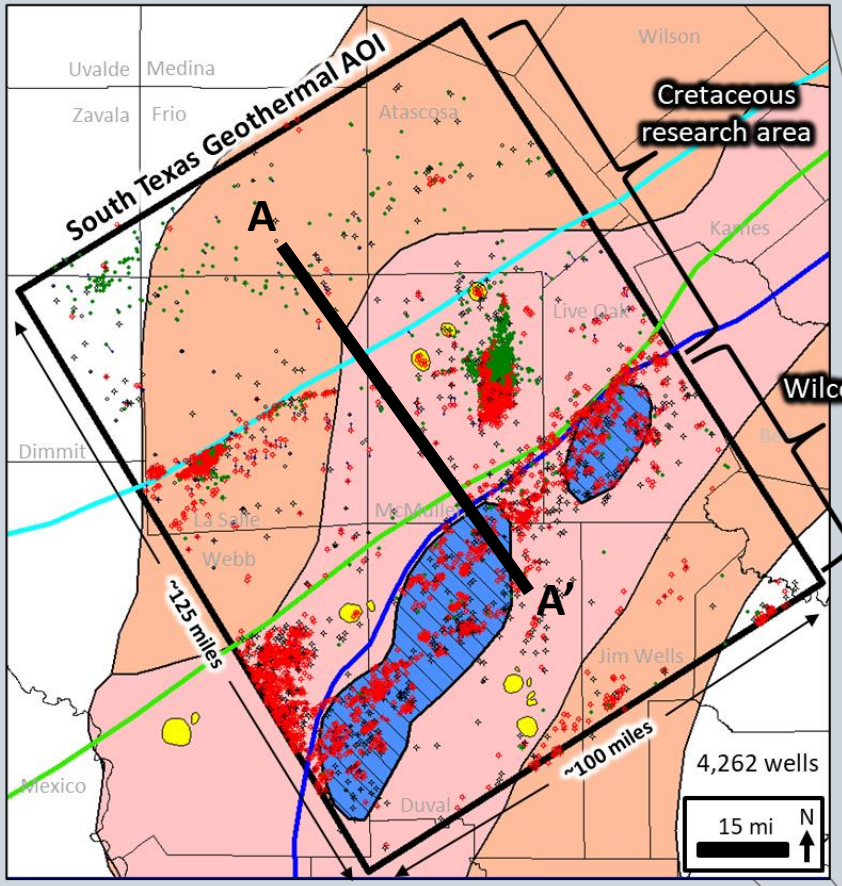
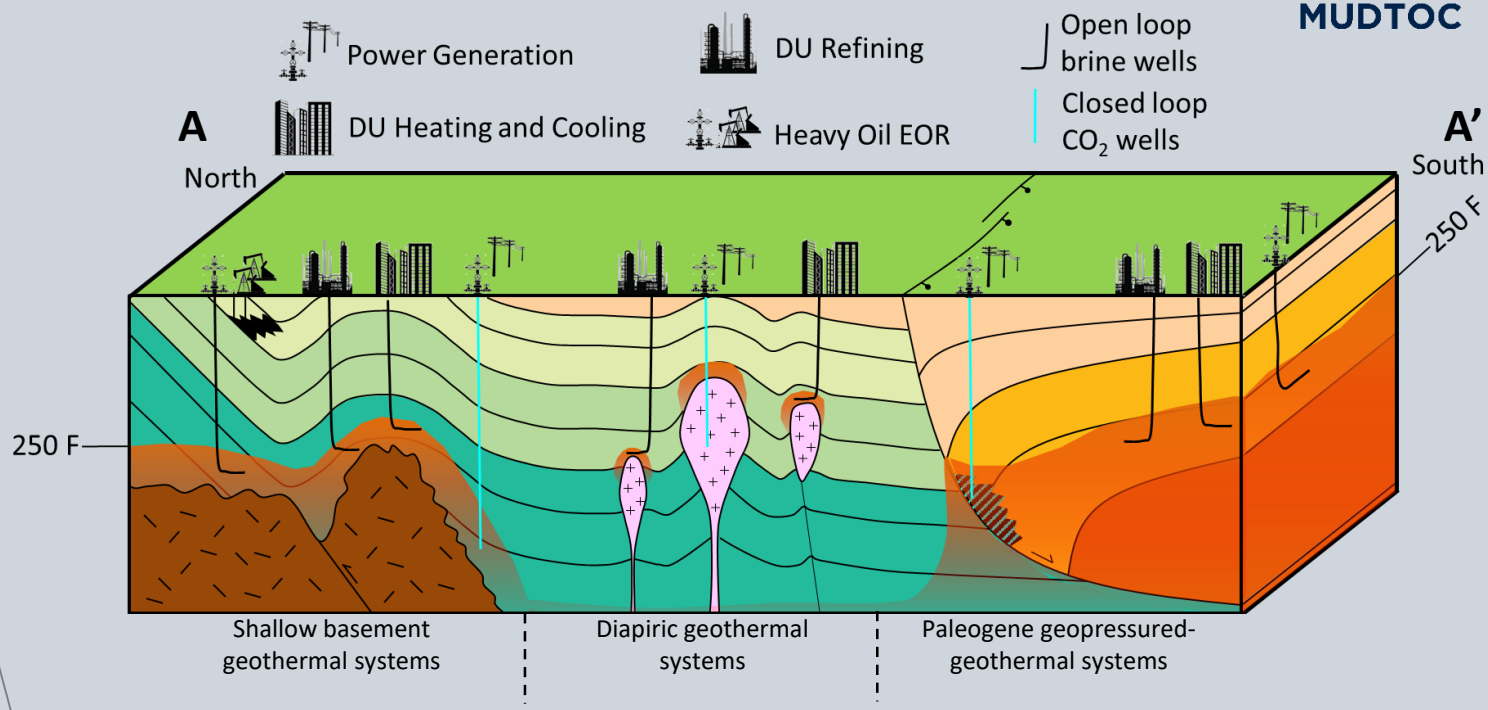
South Texas Geothermal Research Area





250° F at 9,000 ft

250° F at 10,000 ft

Wilcox Geopressured-Geothermal Fairways

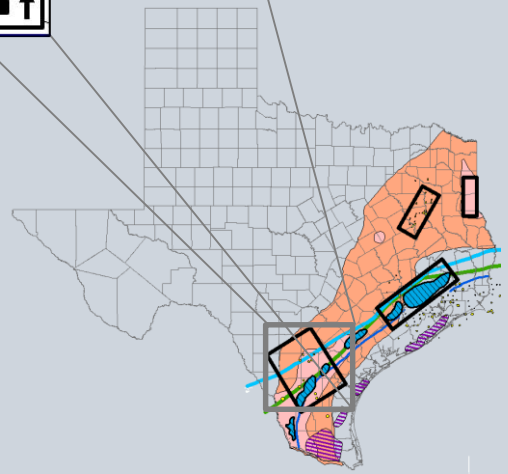
Geothermal Area of Interest

Albian Shelf Margin (Edwards)

Aptian Shelf Margin (Stuart City – Sligo)

Wilcox Fault Zone

Salt Diapirs



Map elements from Blackwell et al., 2010; Bebout et al., 1982; Condon and Dyman, 2006; and Ewing, 1991.

Requirements for Geothermal Plays

For open loop well designs:

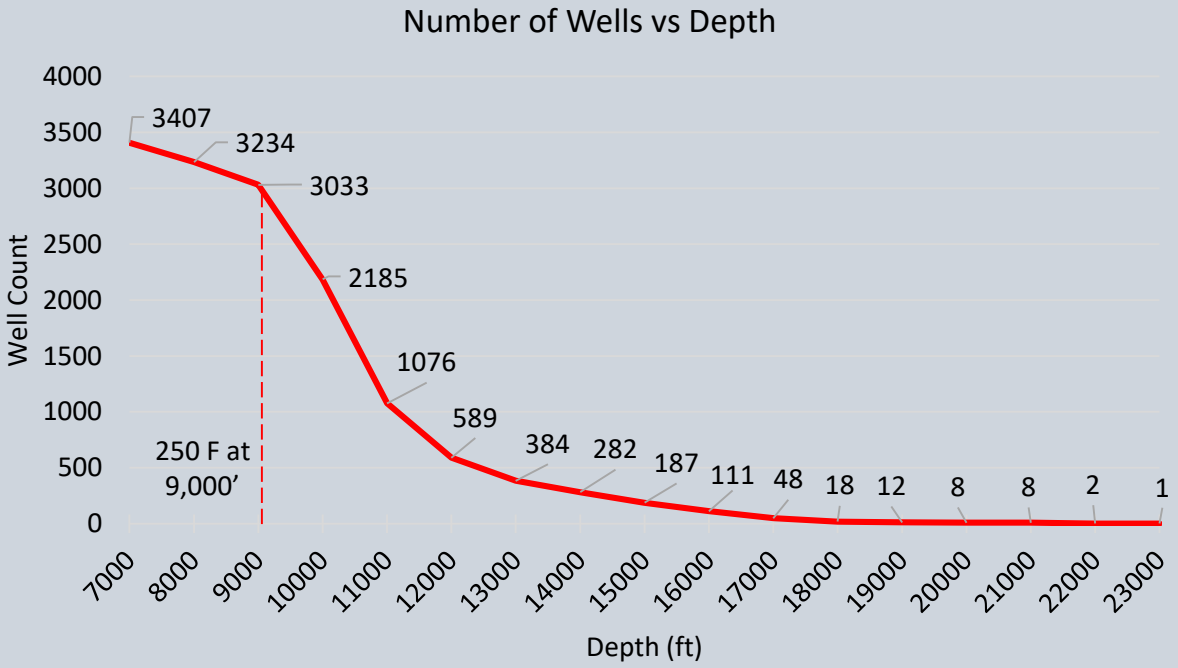
1. Reservoir temperatures >250° F
2. Porosity >15%
3. Permeability >10 mD
4. Pressure >0.75 psi/ft

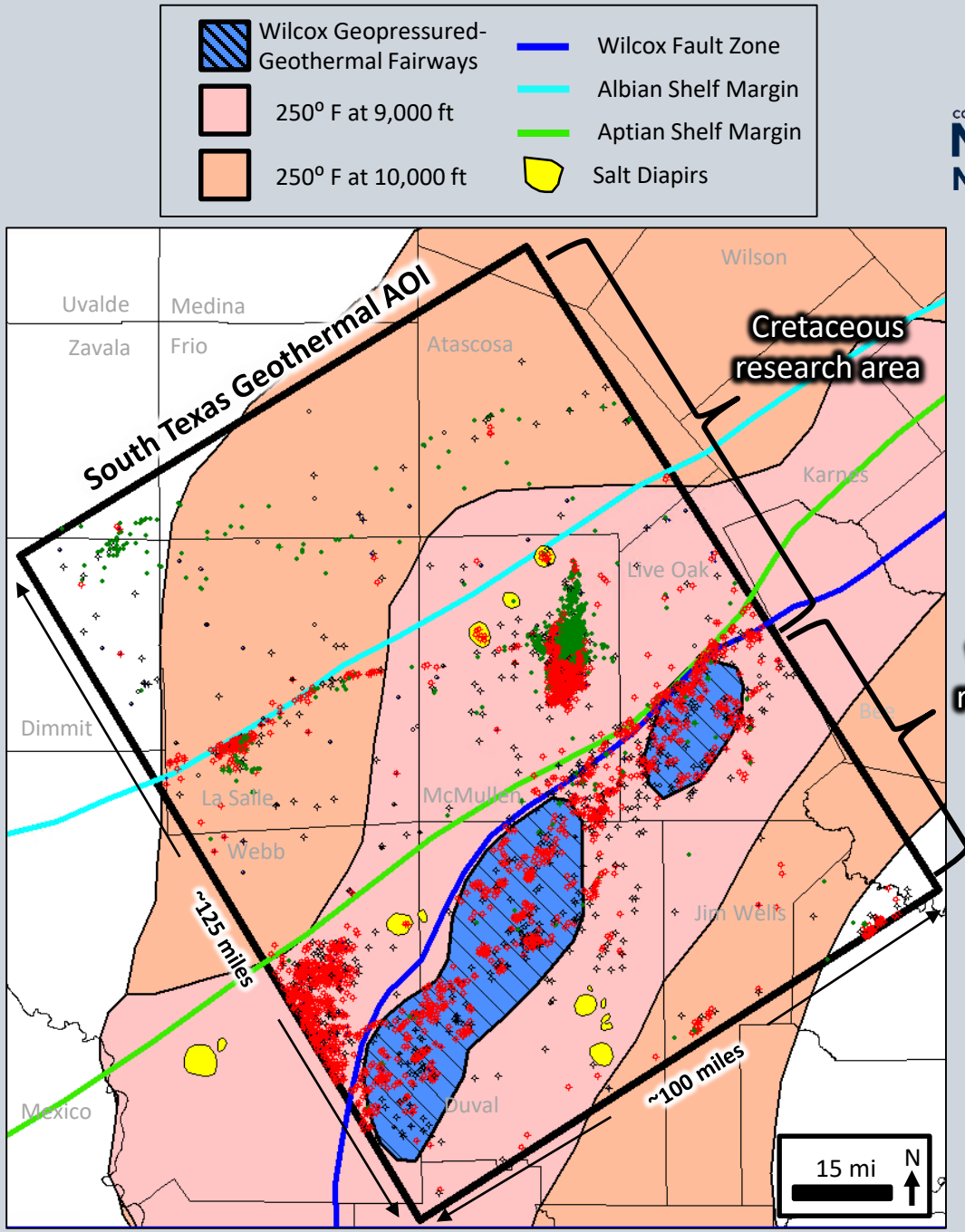
For closed loop well designs:

1. Reservoir temperatures >250° F
2. Drilling efficiency

Digital Log Data

- 3,407 vertical wells with digital logs greater than 7,000 ft TVD provided by TGS
- Great spatial distribution of well data across entire AOI
- Deepest well: 24,220 ft TVD
- Total wells within AOI: 93,595

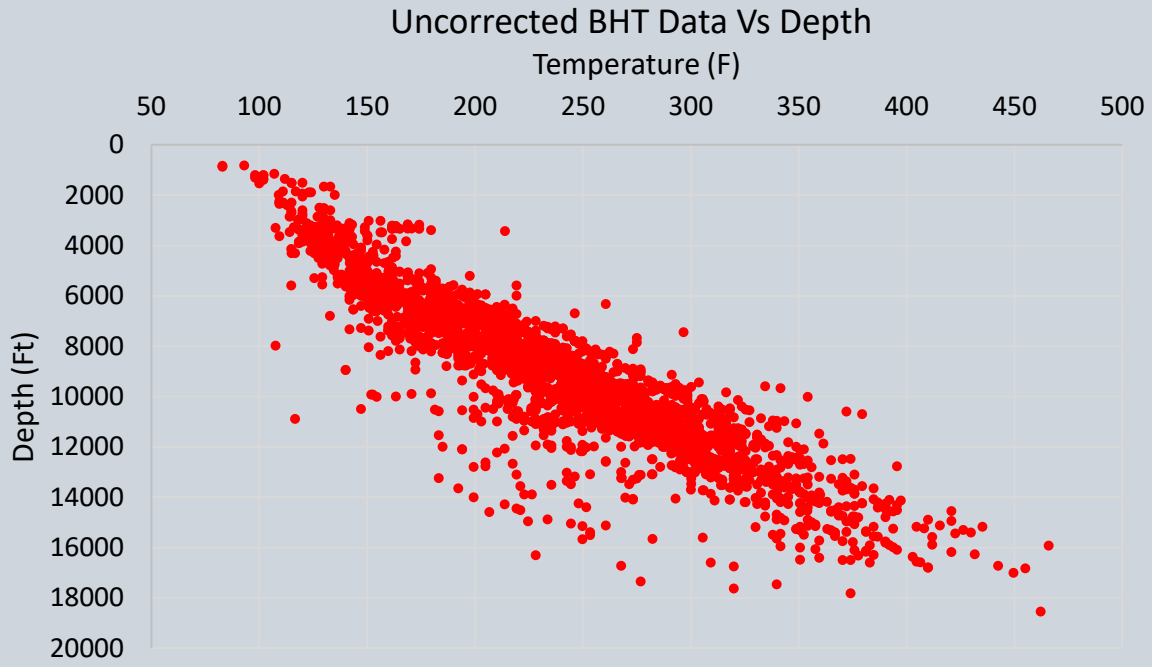


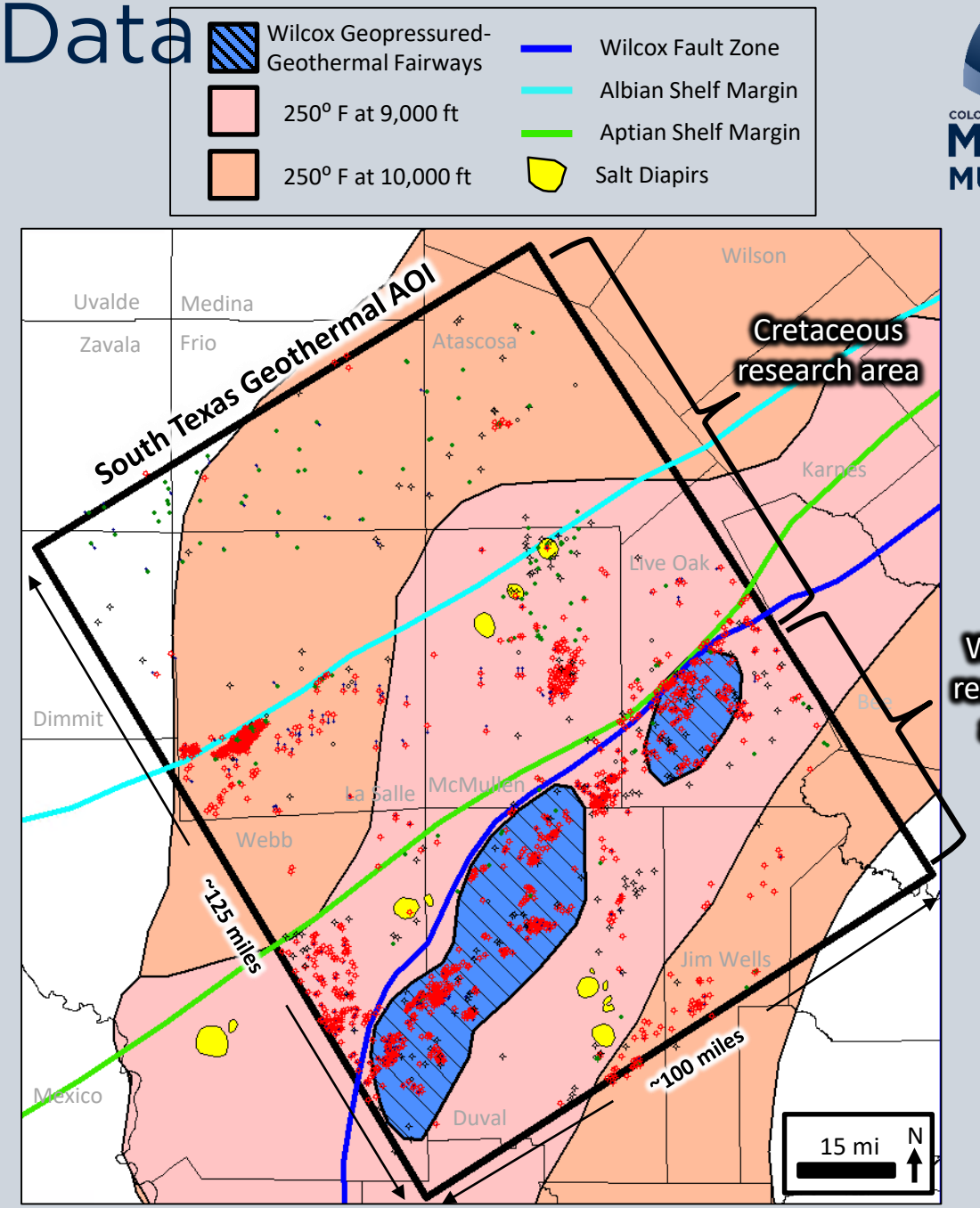


Map elements from Blackwell et al., 2010; Bebout et al., 1982; Condon and Dyman, 2006; and Ewing, 1991.

Bottom Hole Temperature Data

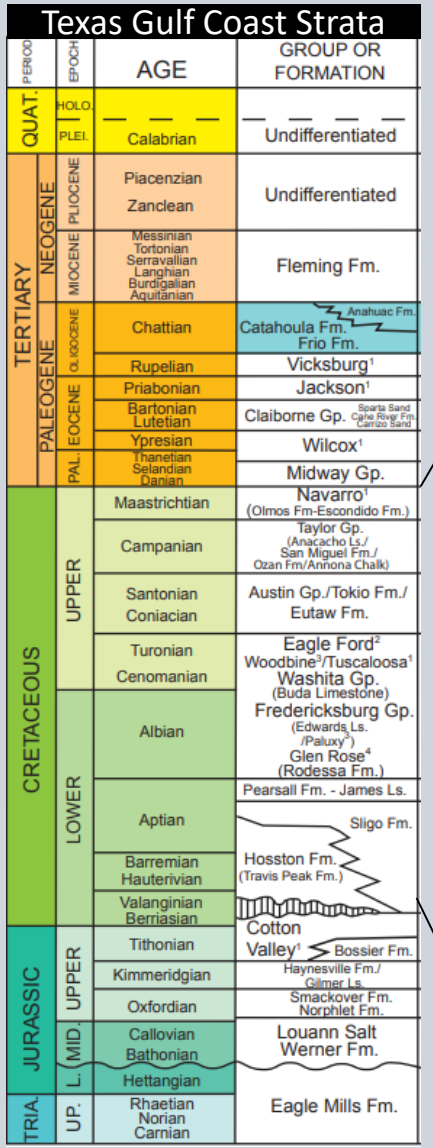
- 1,590 wells with one or multiple BHT measurement from SMU database
- Good spatial distribution of data across entire research area
- Highest recorded BHT: 466 F at 15,925 ft
- Deepest recorded BHT: 18,550 ft (462 F)





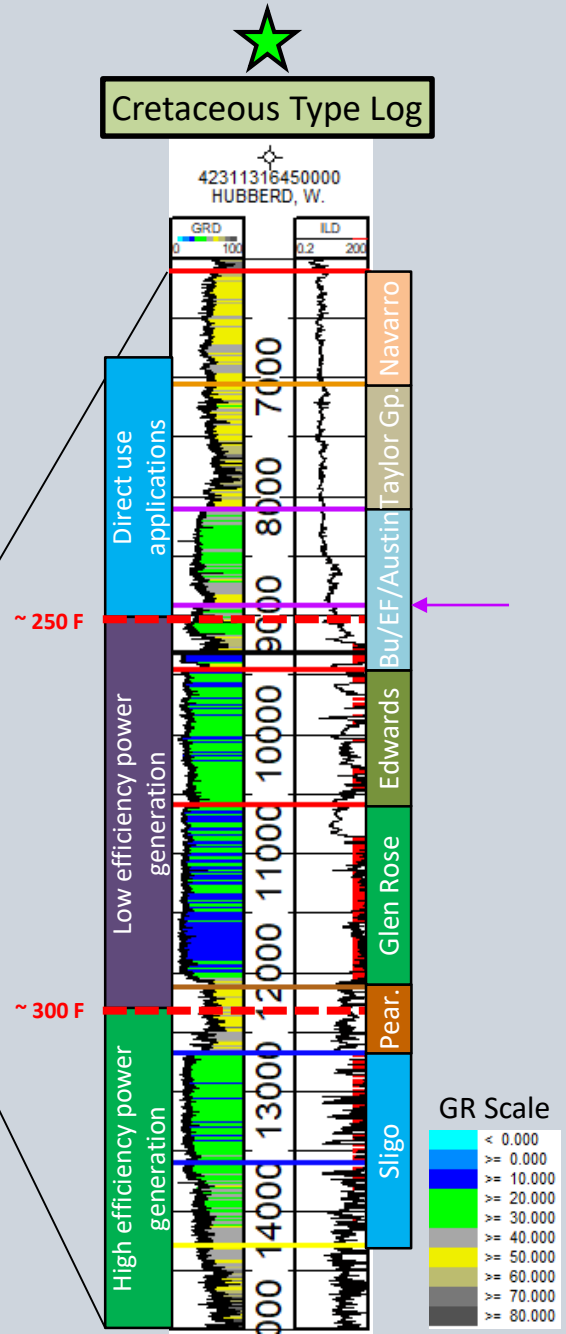
Map elements from Blackwell et al., 2010; Bebout et al., 1982; Condon and Dyman, 2006; and Ewing, 1991.

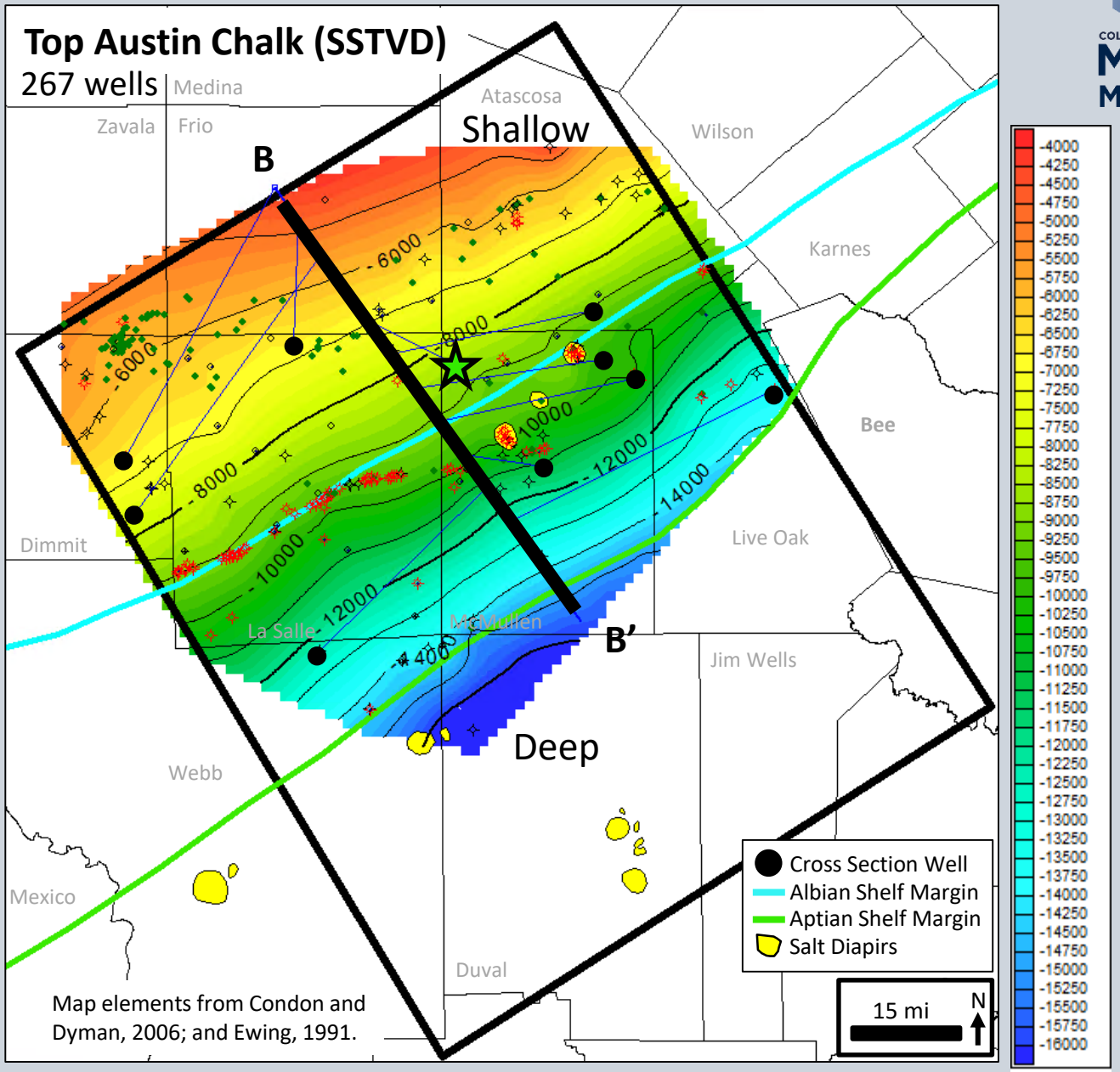
Cretaceous Type Log, Strata, and Regional Structure



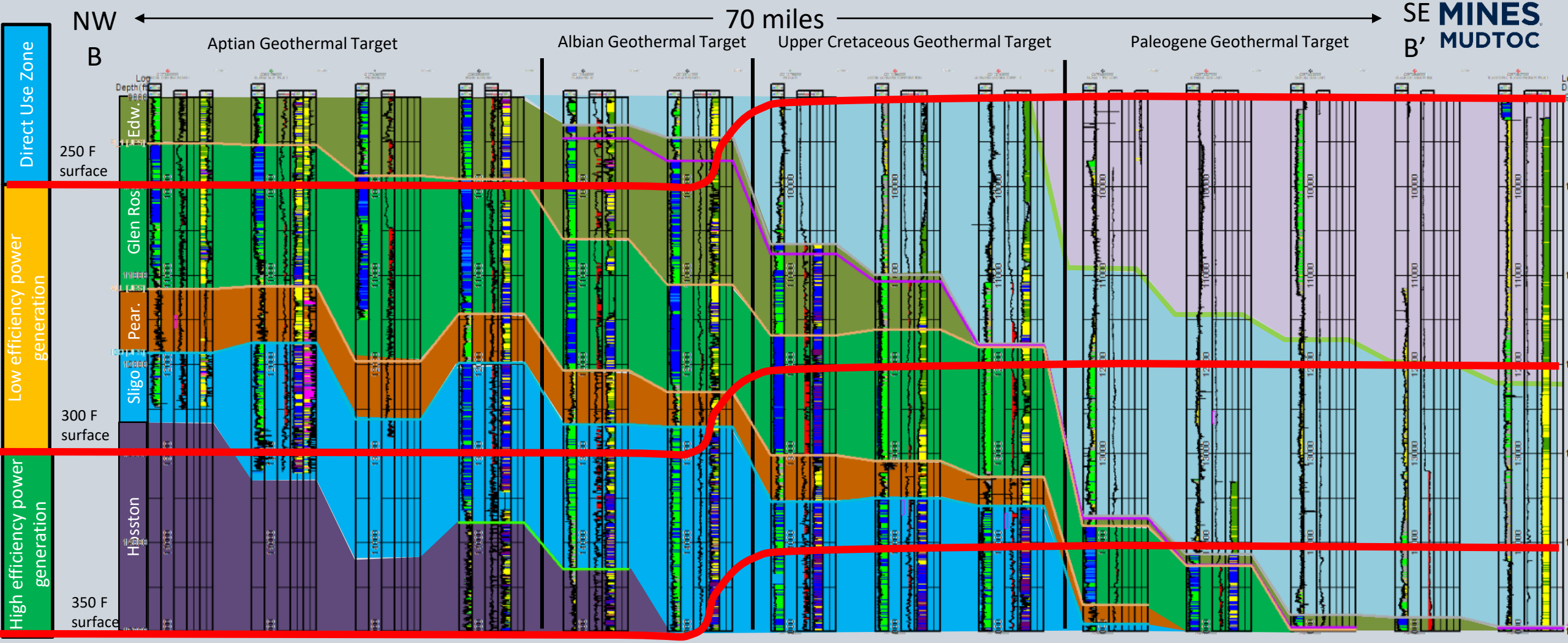
Modified From Swanson et al., 2013

Cretaceous Type Log

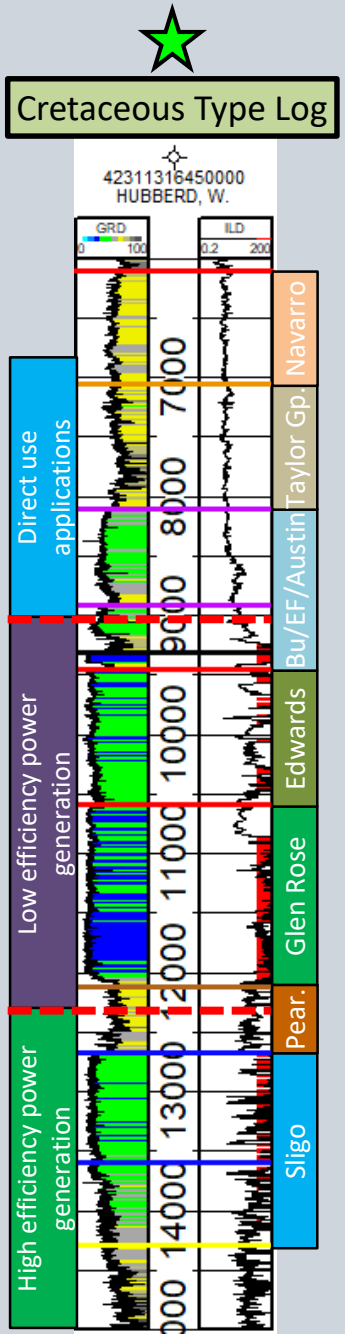


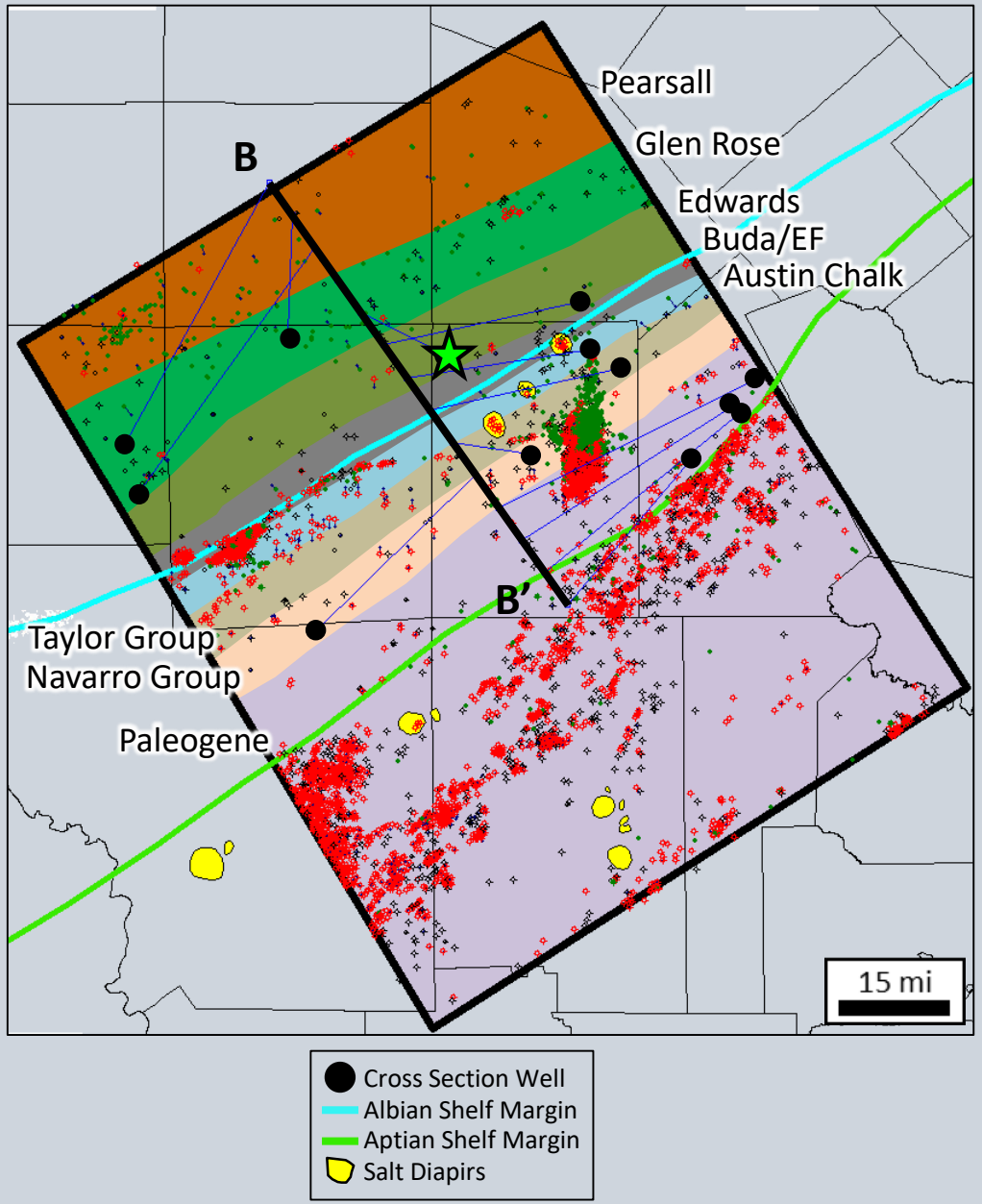


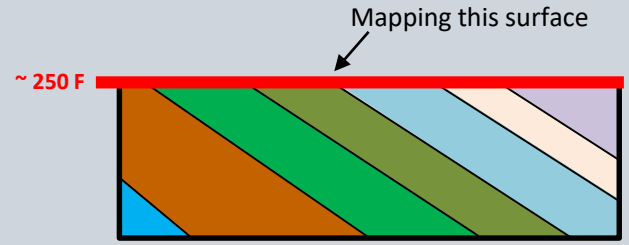
Geothermal Play Fairways – Dip Section



Preliminary 250º F Geothermal Play Fairway Map



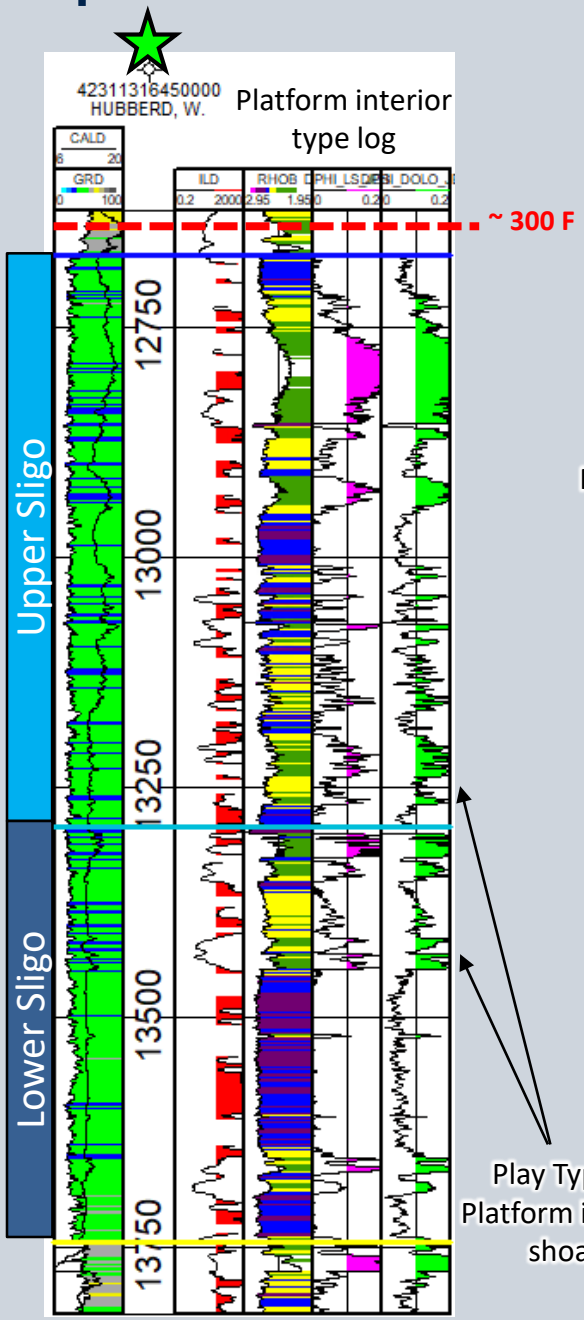




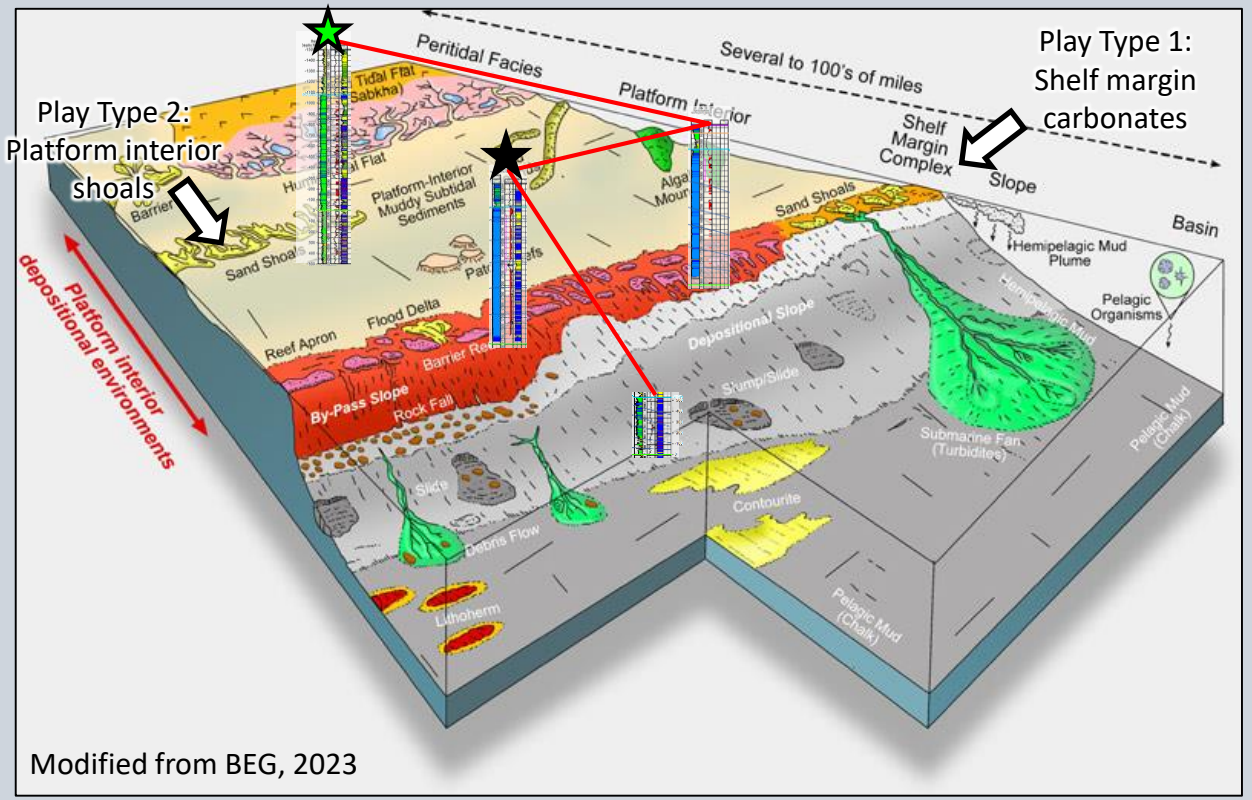
South Texas Geothermal Play Types

1. Aptian and Albian shelf margin reefs and shoals
2. Aptian and Albian platform interior shoals
3. Maastrichtian fluvial and deltaic systems
4. Paleogene geopressured-geothermal systems
5. Salt diapirs and adjacent reservoirs
6. Repurposing existing oil and gas fields

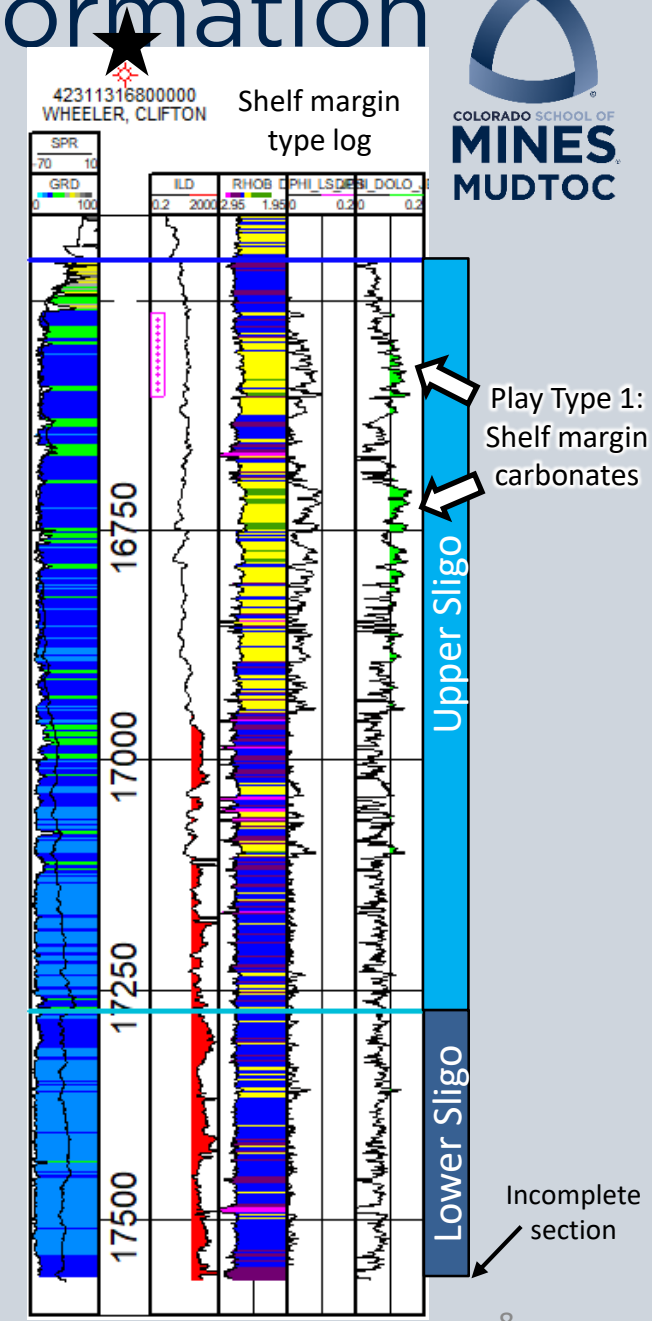
Aptian Geothermal Play Types – Sligo Formation



Play Type 2: Platform interior shoals



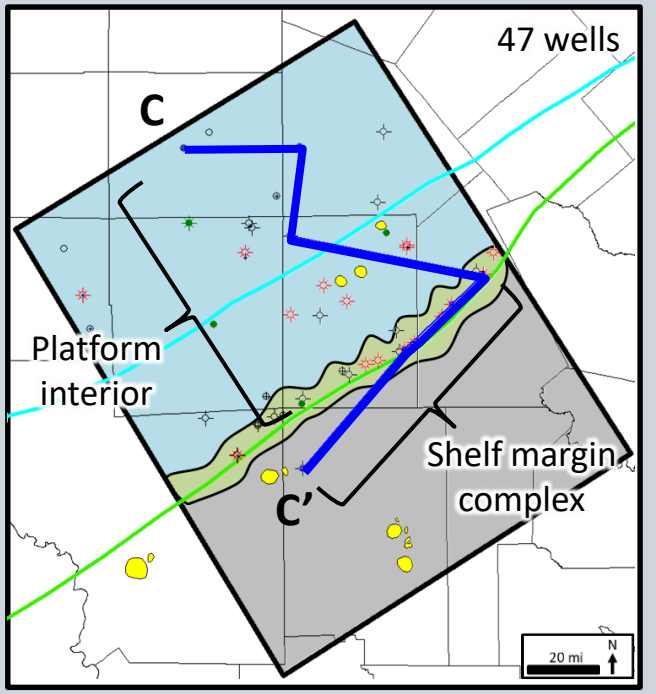
Modified from BEG, 2023

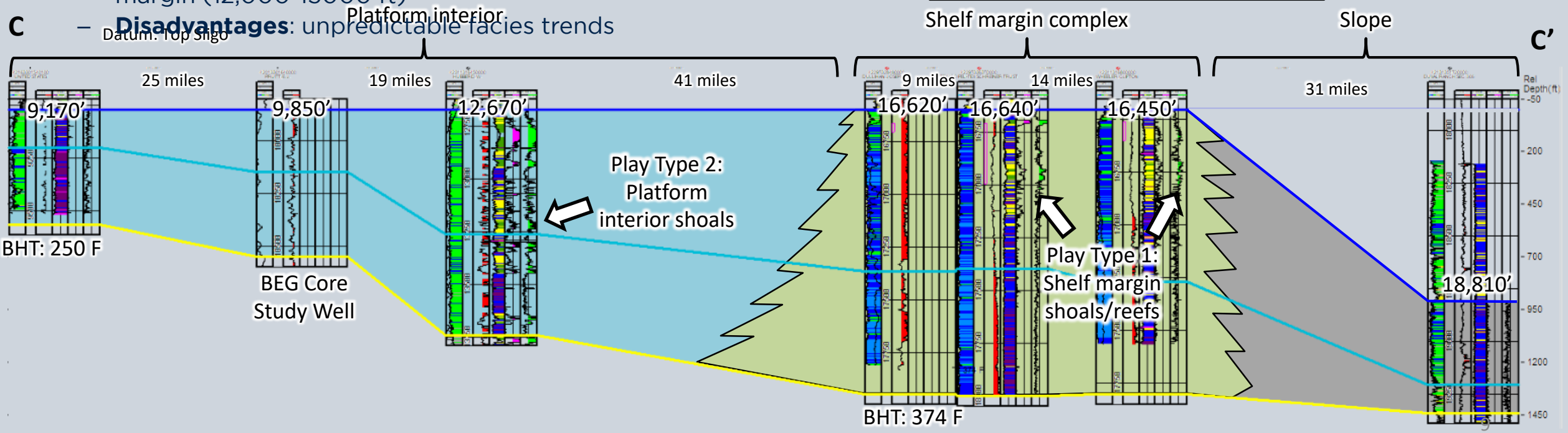


Adjacent well BHT: 374 F

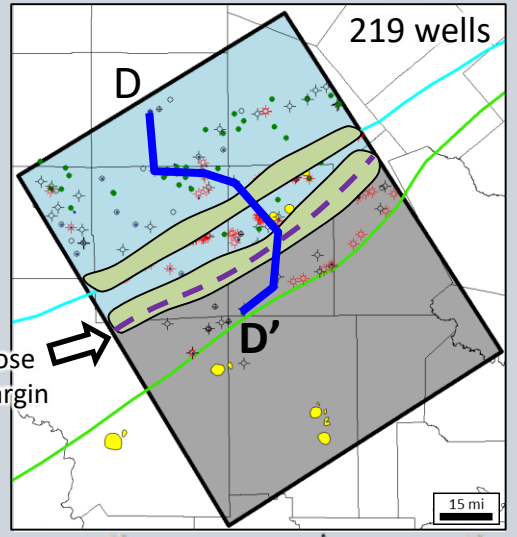
Aptian Geothermal Play Types – Sligo Formation

- Play Type 1: Shelf margin complex
  - **Advantages**: linear trend, potential for high permeability in shelf margin facies, high temperatures (300-350 F) across shelf margin trend
  - **Disadvantages**: unpredictable porosity/permeability trends, depth to shelf margin facies (>16,000 ft)
- Play Type 2: Platform interior shoals
  - **Advantages**: potential for high permeability facies, high temperatures (300-350 F) across shelf margin trend, shallower depths than shelf margin (12,000-15000 ft)
  - **Disadvantages**: unpredictable facies trends





Albian Geothermal Play Types – Edwards and Glen Rose Formations



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- Albian Shelf Margin
- Aptian Shelf Margin
- Salt Diapirs
- Platform interior
- Shelf margin complex
- Slope/basin

D

16 miles | 13 miles | 8 miles | 18 miles | 14 miles | 11 miles

D'

Datum: Top Buda

5,920′ | 8,050′ | 8,780′ | 9,500′ | 11,790′ | 14,780′ | 16,120′

Edwards

Glen Rose

Pear.

Sligo

Platform interior

Edwards Shelf Margin

~ 250 F

Slope

Play Type 1: Shelf margin shoals/reefs

Glen Rose Shelf Margin

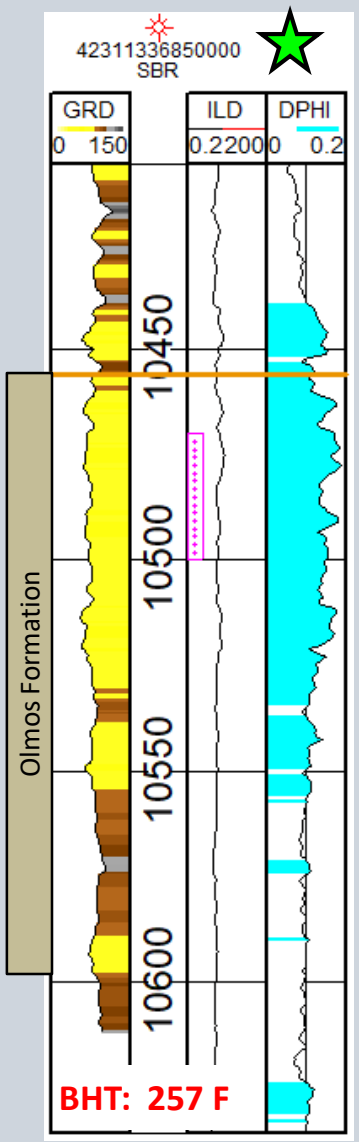
Play Type 2: Platform interior shoals

Slope

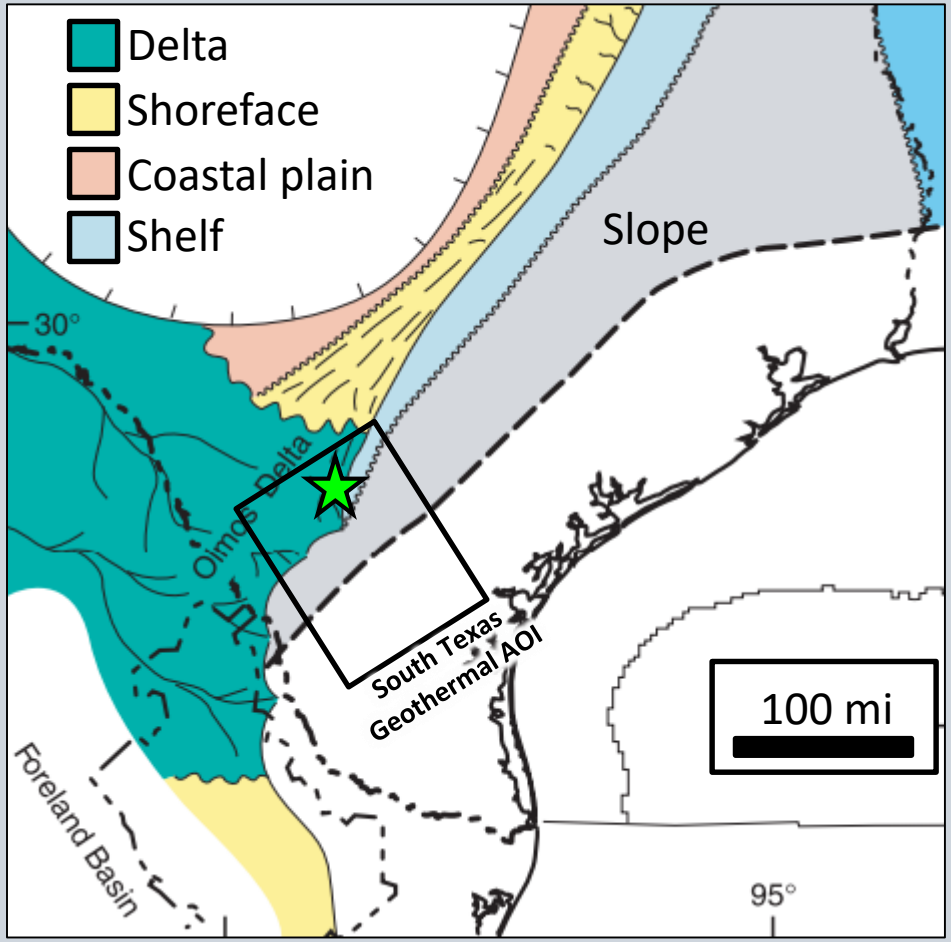
Platform interior

Sligo Shelf Margin

Maastrichtian Geothermal Play Types – Olmos Formation



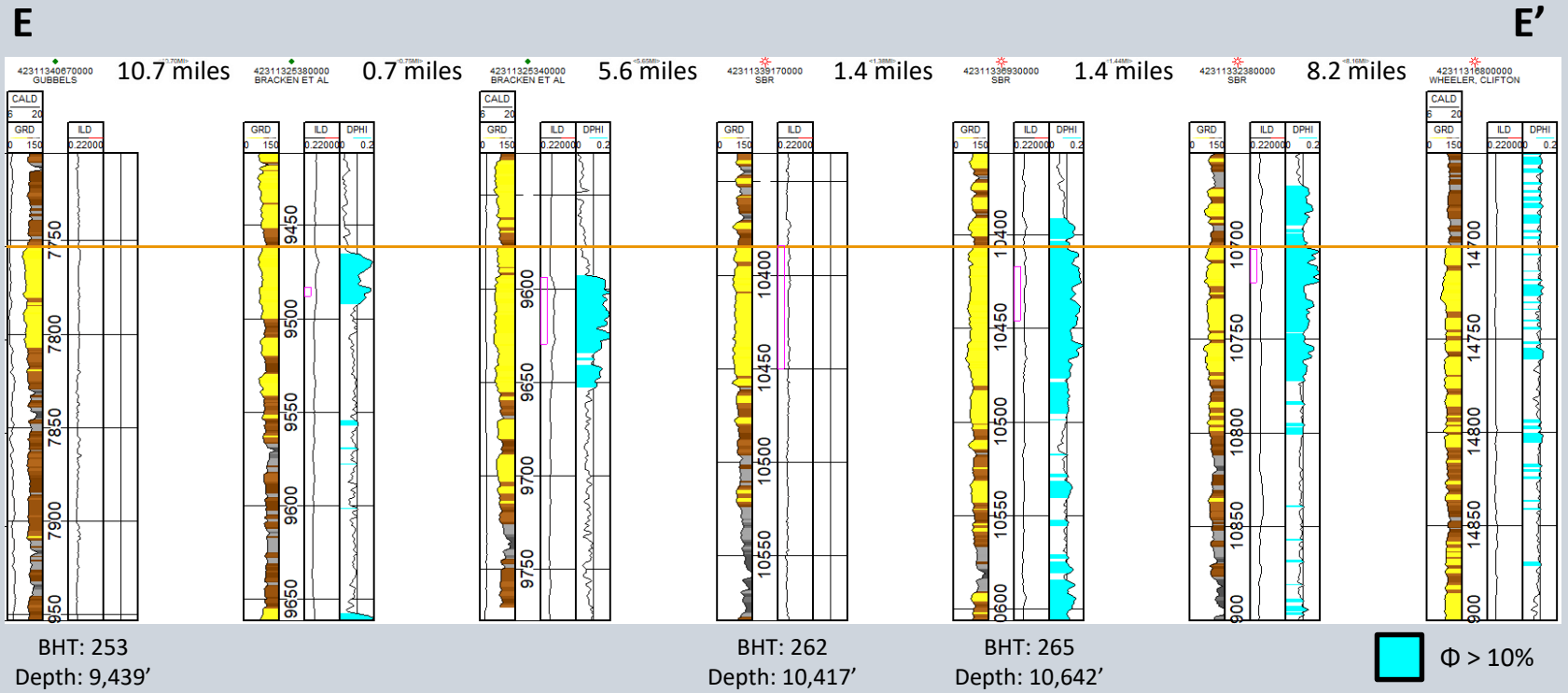
Maastrichtian paleogeography

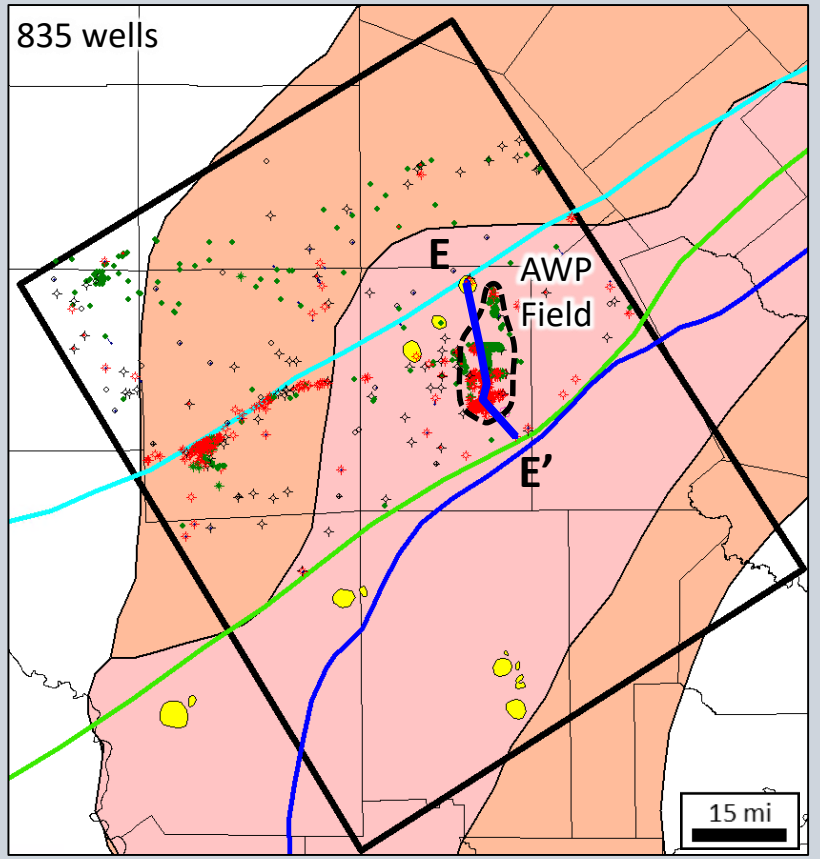


From Galloway, 2008

- Deltaic sands of the Olmos Formation
- BHTs just above 250 F across part of the research area
- Two potential play types
  - Target porous wet sands with open loop wells along trend
  - Repurposing existing oil and gas wells in AWP Field

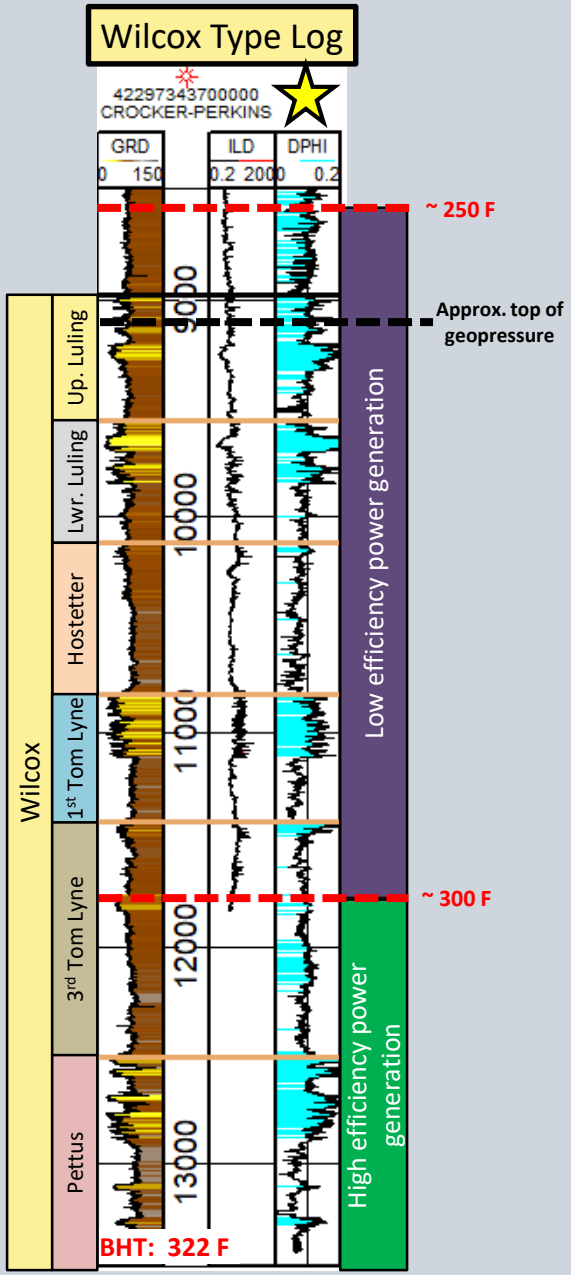
Maastrichtian Geothermal Play Types – Repurposing AWP Field for Geothermal





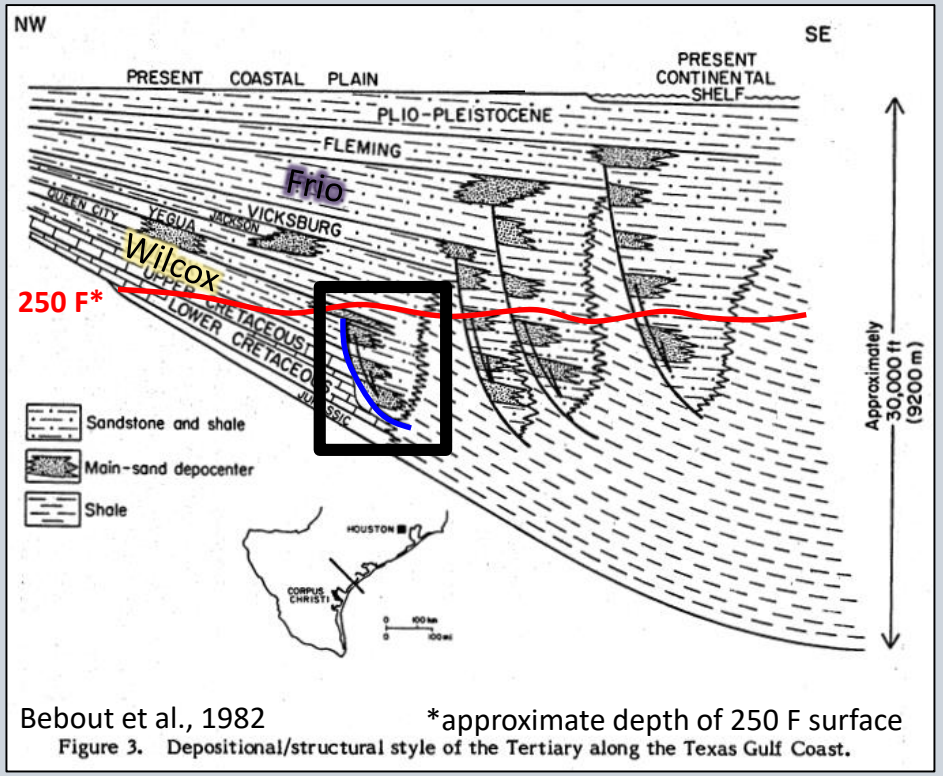
- 1,000+ vertical wells nearing end of production
- BHTs > 250 F across most of the field
- Repurposing vertical wells for closed-loop geothermal
- Use co-produced water from oil and gas production to generate electricity
- Extend wells to deeper formations

Paleogene Geopressured-Geothermal Systems



- Two Wilcox geopressured fairways in the research area
- Wilcox BHTs are > 250 F south of the main Wilcox fault zone
- Multiple over-pressured sands

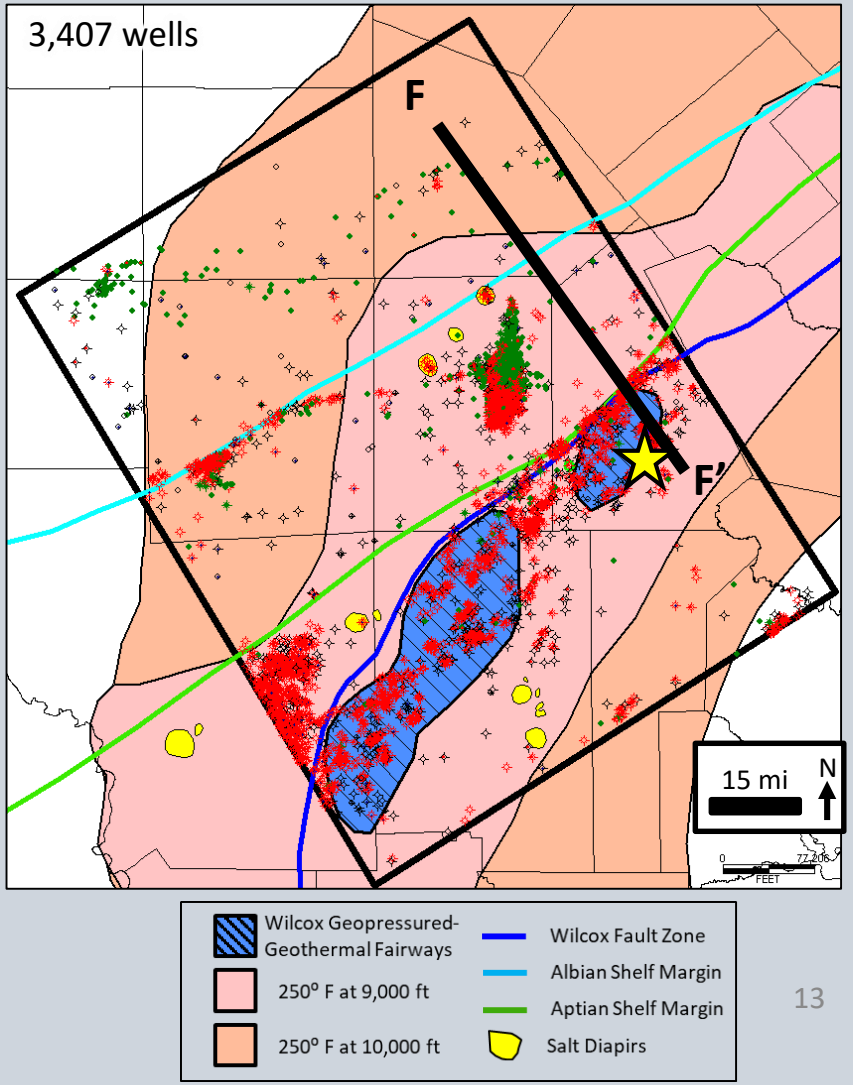
F F’



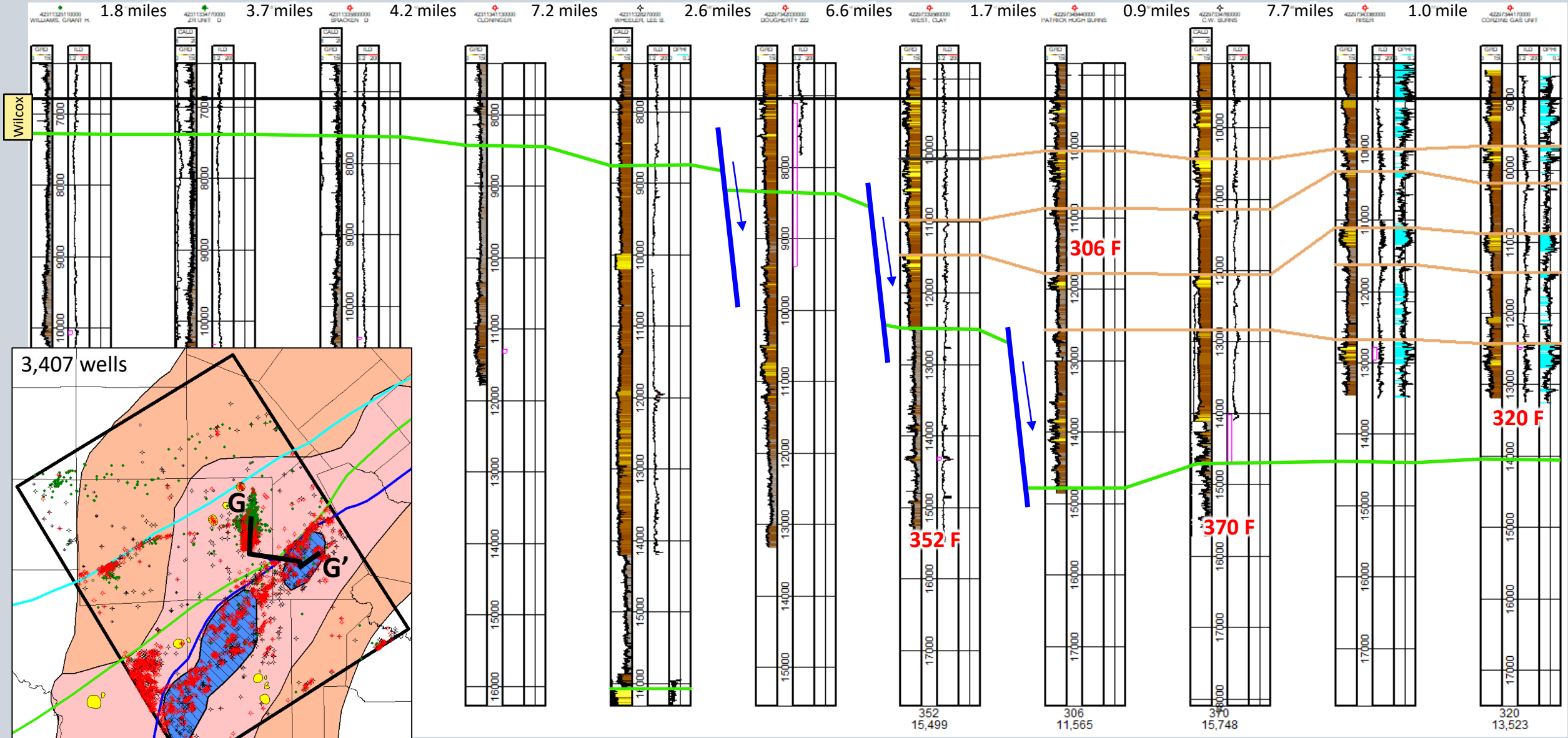
Bebout et al., 1982

*approximate depth of 250 F surface

Figure 3. Depositional/structural style of the Tertiary along the Texas Gulf Coast.

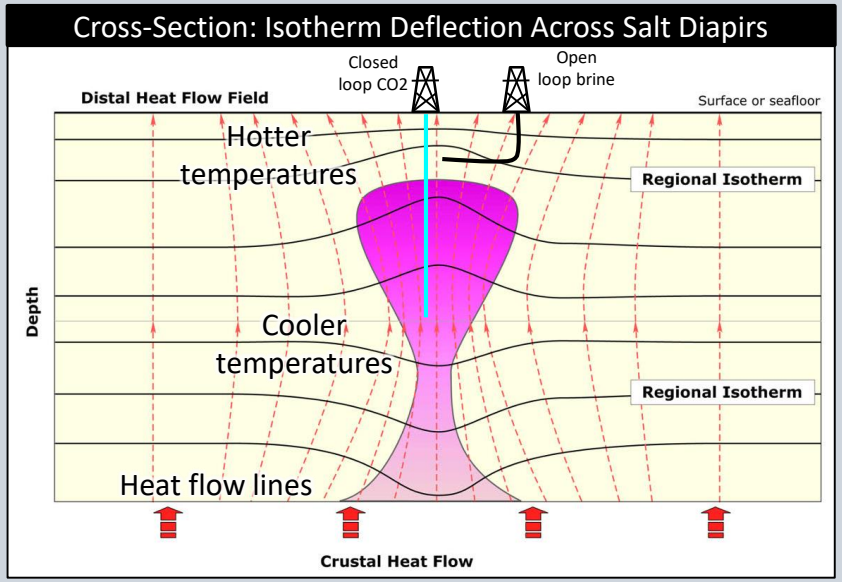


Wilcox Cross-Section

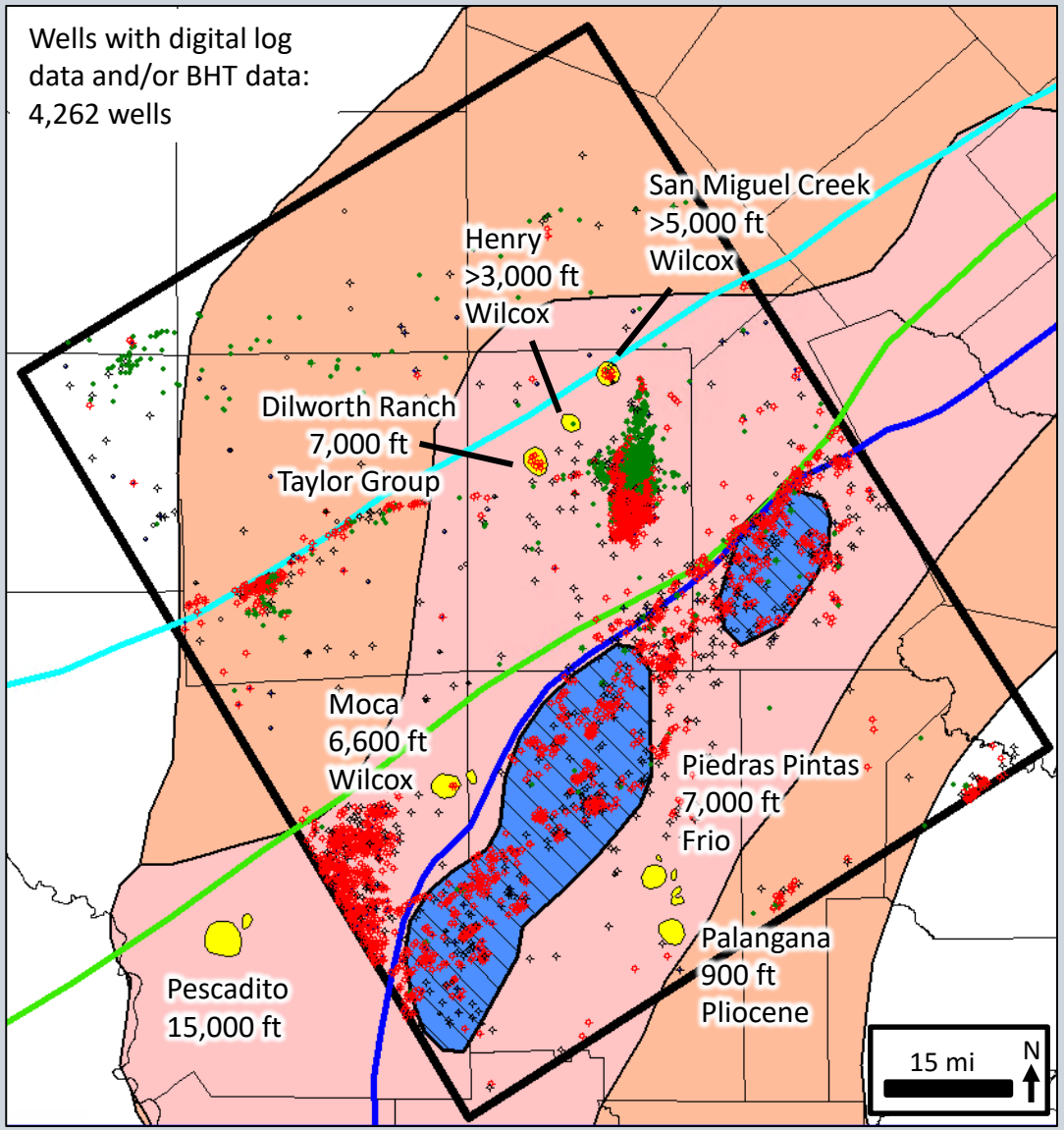


Diapiric Geothermal Systems

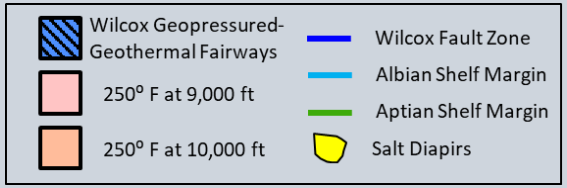
- Six salt diapirs within AOI and one outside
- Oil and gas fields on top and adjacent to each diapir
- High thermal conductivity of salt sets up two play types
  - Targeting abnormally hot reservoirs above the diapir – open loop wells
  - Targeting the diapir itself for the heat contained within – closed loop wells (coaxial or u-loop)



Courtesy of C. Rivera from Mark Rowan, personal communication



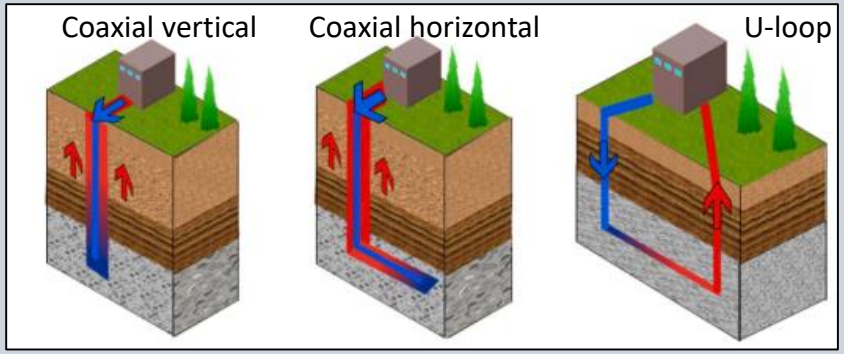
Salt dome name
Approximate depth to crest of salt
Formation above dome



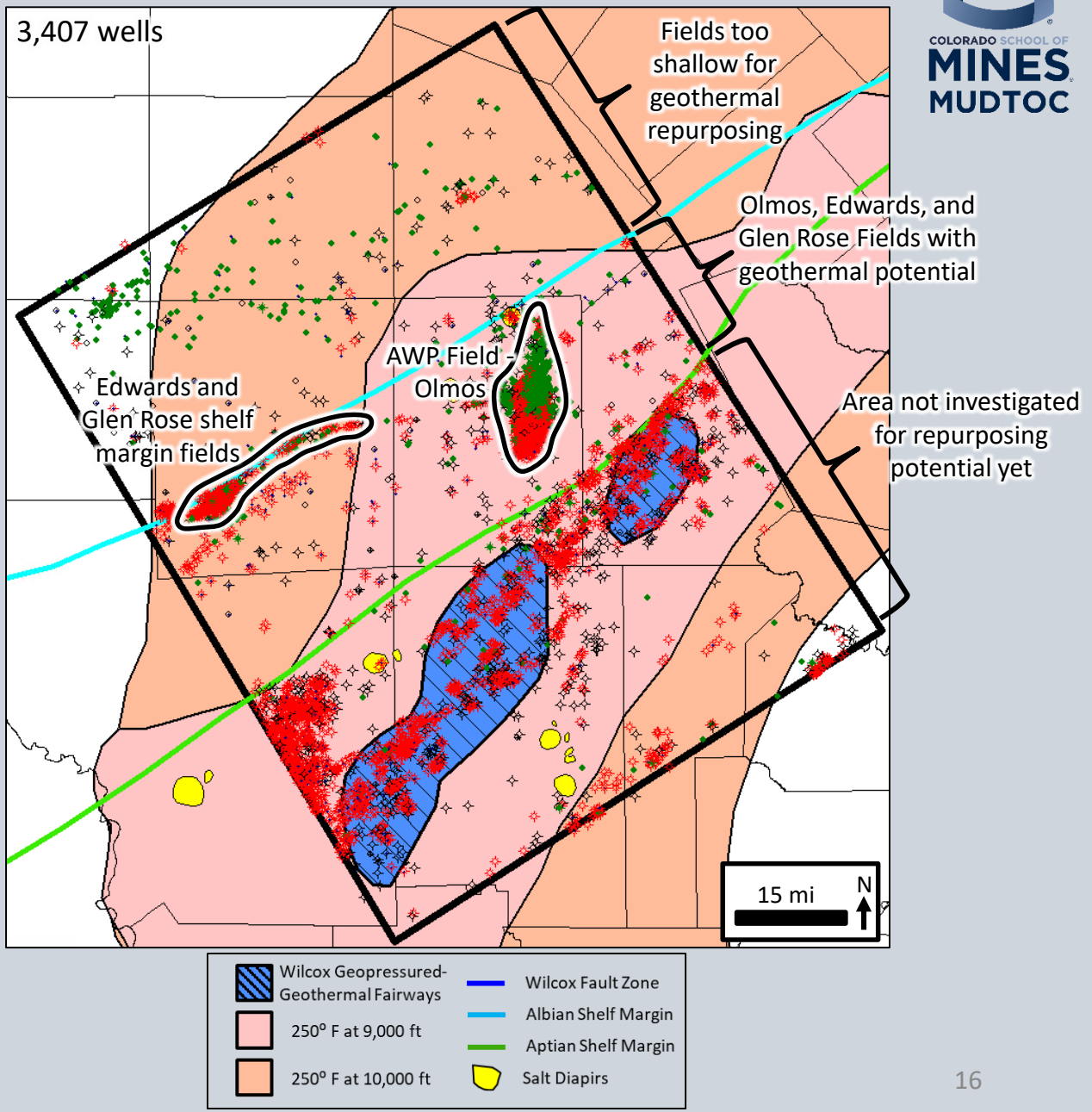
Repurposing Existing Oil and Gas Fields

- Edwards Formation shelf margin fields
  - Vertical wells in porous carbonate reservoirs with BHTs > 250 F
  - 300+ wells in this trend
- Olmos Formation AWP Field
  - Vertical wells in porous sandstone reservoirs with BHTs > 250 F
  - 1,000+ wells in this field
- Repurposing methods
  - Use produced water from oil and gas production to generate electricity or for a direct use application
  - Repurpose aging vertical wells for closed loop geothermal
  - Extend vertical wells into deeper formations

Closed Loop Well Designs

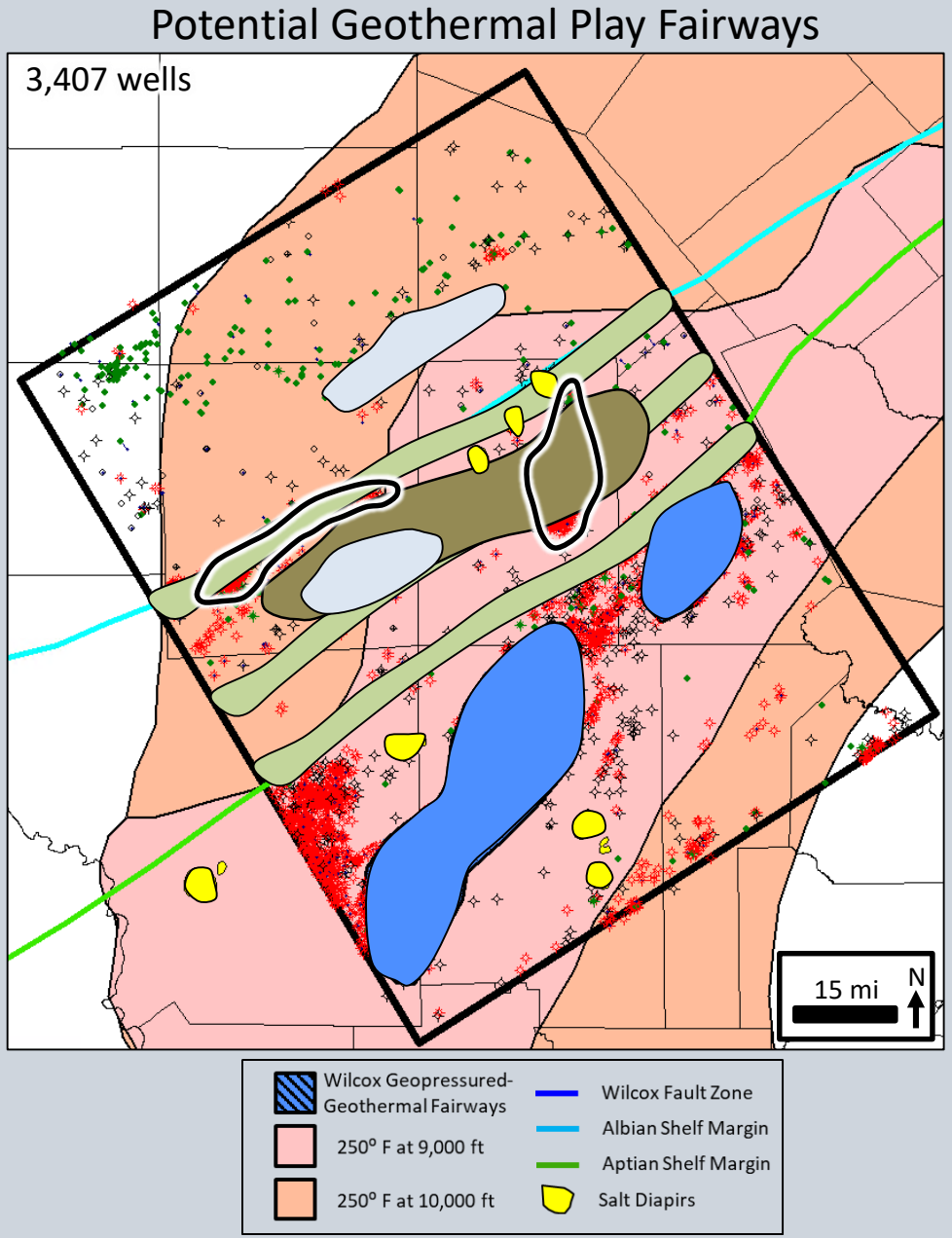


From Beckers, et al., 2022



Conclusions

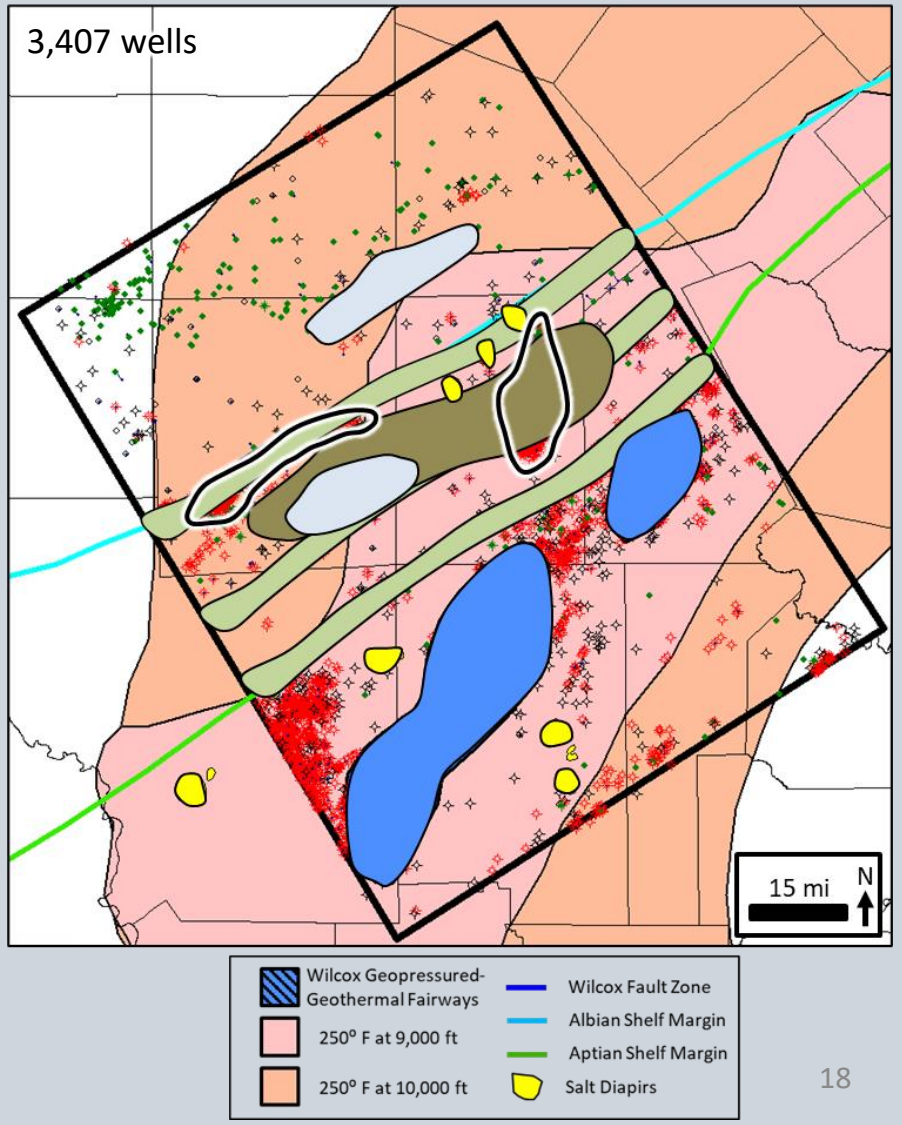
- Six different geothermal play types within the research area
- Aptian and Albian shelf margin carbonates, Sligo is very hot (>300 F) but are buried very deep
- Aptian and Albian platform interior shoals are in a good temperature and depth window for geothermal exploration
- Maastrichtian deltaic sandstones have exploration potential along trend from producing oil/gas fields
- Geopressured-geothermal zones in the Wilcox are perspective targets for open loop geothermal
- More investigation need to understand geothermal potential of salt diapirs
- Both Lower Cretaceous and Upper Cretaceous oil and gas fields have repurposing potential (still need to investigate Paleogene fields)



Future Work and Deliverables

	Data Requirements	Well log data	Seismic data	Core data	Corrected BHTs	Produced fluid	Water chemistry	Cost estimates for DCE
Project Deliverables	Regional correlations, stratigraphic framework	■		■				
	BHT correction, temperature mapping, play type identification	■	■	■	■			
	Petrophysics/reservoir characterization of each play type	■	■	■	■	■	■	
	Reservoir modeling, flow rate, thermal depletion/recharge	■		■	■	■		
	Resource estimate calculations, subsurface risk assessment	■	■		■	■	■	
	Techno-economic evaluation and recommendation	■			■	■	■	■

Potential Geothermal Play Fairways



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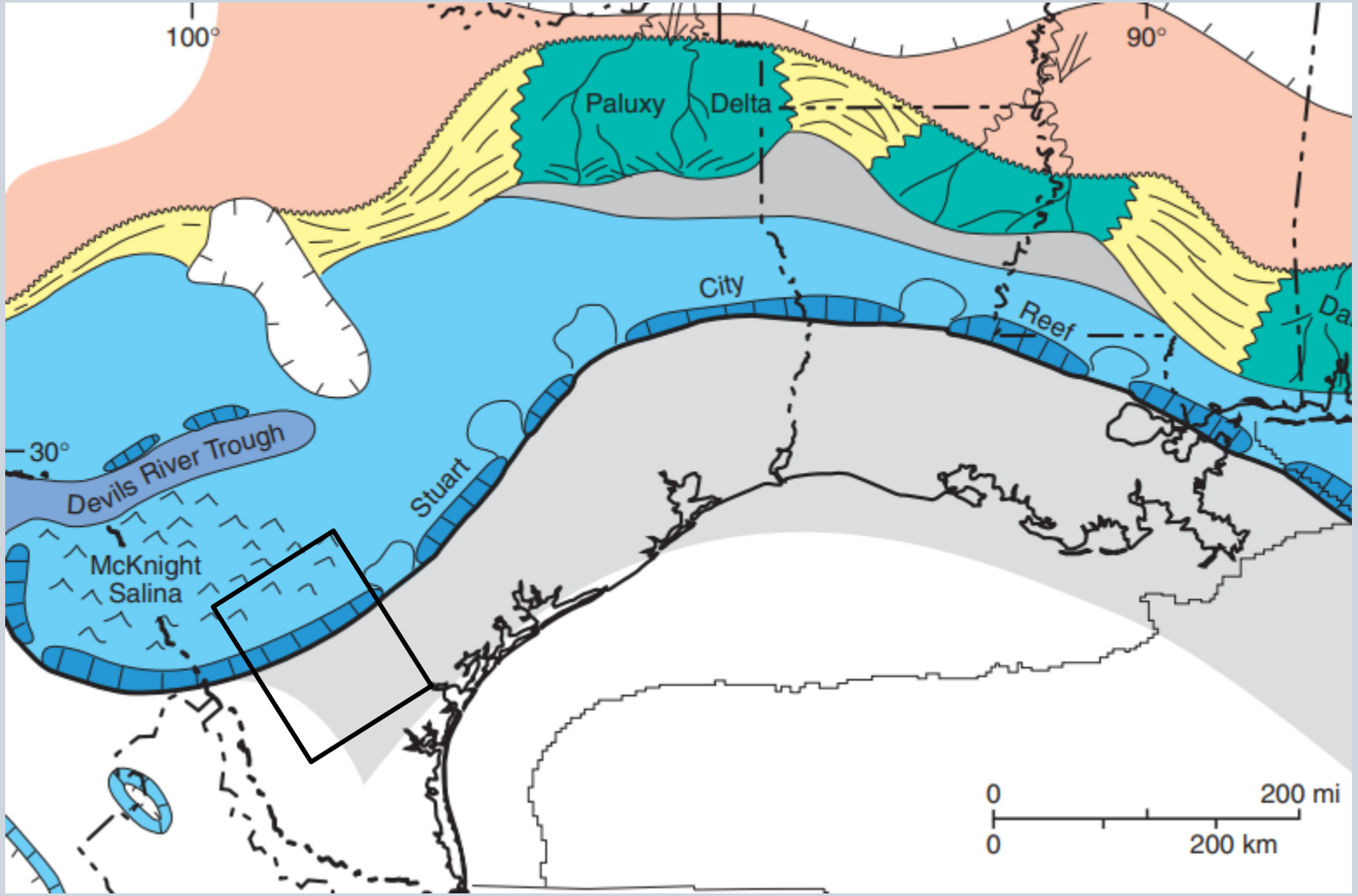
Texas Gulf Coast Strata

PERIOD	EPOCH	AGE	GROUP OR FORMATION	Geothermal
QUAT.	HOLO. / PLEI.	Calabrian	Undifferentiated	
TERTIARY – NEOGENE	PLIOCENE	Piacenzian Zanclean	Undifferentiated	
TERTIARY – NEOGENE	MIOCENE	Messinian Tortonian Serravallian Langhian Burdigalian Aquitanian	Fleming Fm.	
TERTIARY – PALEOGENE	OLIGOCENE	Chattian	Anahuac Fm. Catahoula Fm. Frio Fm.	⚡
TERTIARY – PALEOGENE	EOCENE	Rupelian	Vicksburg[1]	
		Priabonian	Jackson[1]	
		Bartonian Lutetian	Claiborne Gp. (Sparta Sand; Cane River Fm.; Carrizo Sand)	
		Ypresian	Wilcox[1]	
	PAL.	Thanetian Selandian Danian	Midway Gp.	
CRETACEOUS	UPPER	Maastrichtian	Navarro[1] (Olmos Fm-Escondido Fm.)	
		Campanian	Taylor Gp. (Anacacho Ls./ San Miguel Fm./ Ozan Fm/Annona Chalk)	
		Santonian Coniacian	Austin Gp./Tokio Fm./ Eutaw Fm.	
		Turonian Cenomanian	Eagle Ford[2] Woodbine[3]/Tuscaloosa[4] Washita Gp. (Buda Limestone) Fredericksburg Gp. (Edwards Ls. /Paluxy[4]) Glen Rose[4] (Rodessa Fm.)	⚡
	LOWER	Albian		
		Aptian	Pearsall Fm. - James Ls.	
		Barremian Hauterivian	Sligo Fm. Hosston Fm. (Travis Peak Fm.)	⚡
		Valanginian Berriasian		
JURASSIC	UPPER	Tithonian	Cotton Valley[1] / Bossier Fm.	⚡
		Kimmeridgian	Haynesville Fm./ Gilmer Ls.	
		Oxfordian	Smackover Fm. Norphlet Fm.	
	MID	Callovian Bathonian	Louann Salt Werner Fm.	⚡
	L.	Hettangian		
TRIA.	UP.	Rhaetian Norian Carnian	Eagle Mills Fm.	

Modified From Swanson et al., 2013

⚡ Proven

⚡ Unproven



Tertiary Geopressured-Geothermal Systems

PERIOD	EPOCH	AGE	GROUP OR FORMATION	GAS	OIL	SOURCE ROCK Shale	SOURCE ROCK Coal	Geothermal
QUAT.	HOLO. / PLEI.	Calabrian	Undifferentiated	▲	●			
TERTIARY / NEOGENE	PLIOCENE	Piacenzian / Zanclean	Undifferentiated	▲	●			
TERTIARY / NEOGENE	MIOCENE	Messinian / Tortonian / Serravallian / Langhian / Burdigalian / Aquitanian	Fleming Fm.	▲	●			
TERTIARY / PALEOGENE	OLIGOCENE	Chattian	Anahuac Fm. / Catahoula Fm. / Frio Fm.	▲	●			↯
TERTIARY / PALEOGENE	OLIGOCENE	Rupelian	Vicksburg[1]	▲	●	■	★	
TERTIARY / PALEOGENE	EOCENE	Priabonian	Jackson[1]	▲	●	■	★	↯
TERTIARY / PALEOGENE	EOCENE	Bartonian / Lutetian	Claiborne Gp. (Sparta Sand / Cane River Fm / Carrizo Sand)	▲	●	■	★	
TERTIARY / PALEOGENE	EOCENE	Ypresian	Wilcox[1]	▲	●	■	★	↯
TERTIARY / PALEOGENE	PAL.	Thanetian / Selandian / Danian	Midway Gp.	▲	●	■		

Modified From Swanson et al., 2013

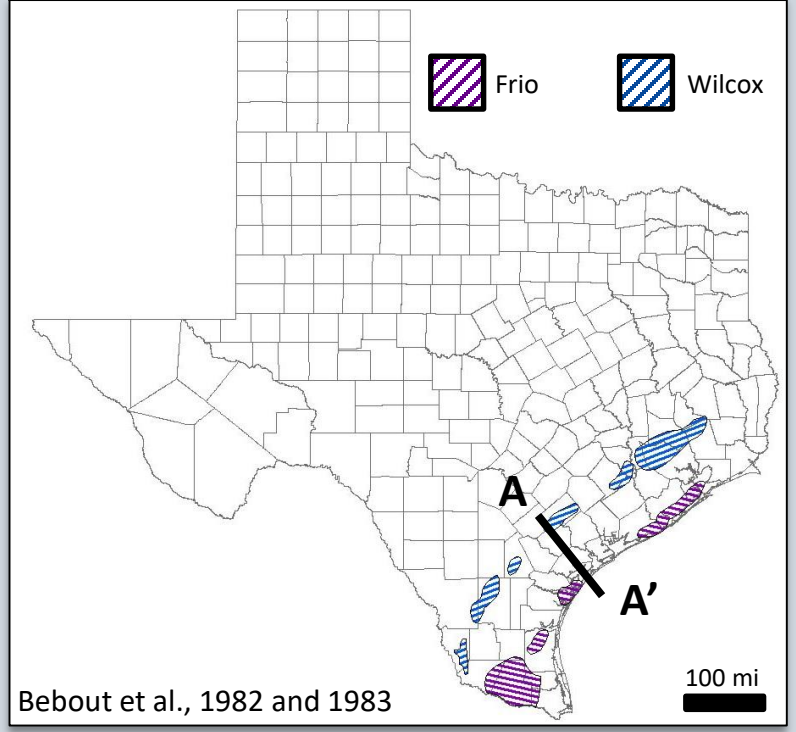
EXPLANATION
- Gas reservoir rock
- Oil reservoir rock
- Shale source rock
- Coal source rock

Fm. = Formation
Gp. = Group
Ls. = Limestone

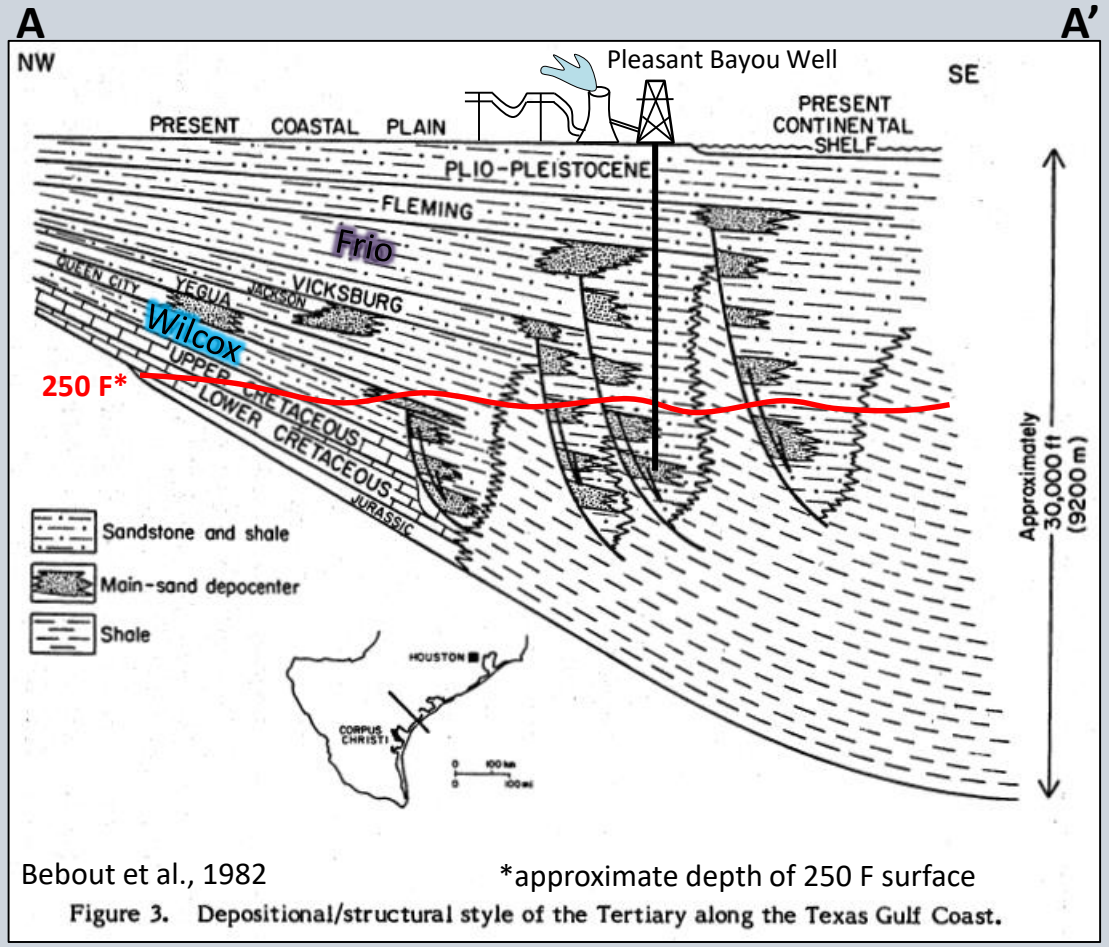
Formations with geopressured zones

↯ Proven
↯ Unproven

Wilcox and Frio Geopressured-Geothermal Fairways



Bebout et al., 1982 and 1983



Bebout et al., 1982

*approximate depth of 250 F surface

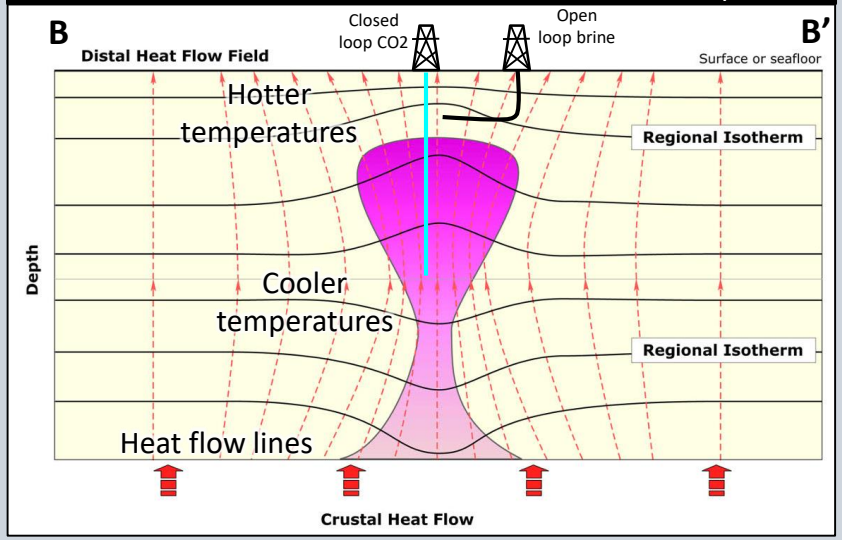
Figure 3. Depositional/structural style of the Tertiary along the Texas Gulf Coast.

Geothermal Energy Potential of Salt Diapirs

- Salt diapirs were first discussed as a source of geothermal energy in 1975
- High thermal conductivity of salt diapirs sets up two possible geothermal plays types
  1. Utilizing the salt diapir itself with closed loop well design
  2. Reservoirs above the salt diapir with elevated temperatures
- Anomalous temperature field extends a lateral distance of about 3 diapir radii from the center (Jensen, 1989)
- Internal diapir temperatures can range from 330 F at 10,000 ft to 580 F at 20,000 ft (Jacoby and Paul, 1975)
- Targeting hot reservoirs above diapirs could reduce drilling costs by ~30% when targeting similar temperatures at deeper depths (Jensen, 1989)

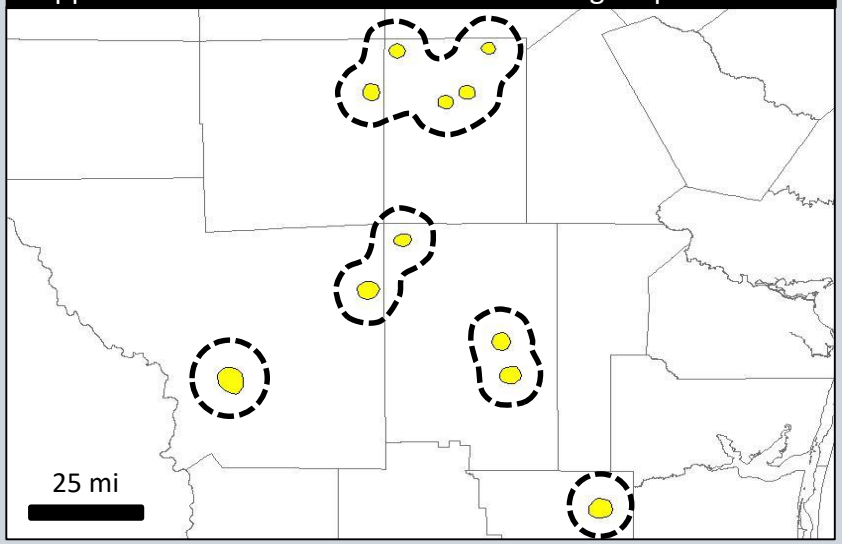
How do we characterize and test the energy potential in these diapirs?

Cross-Section: Isotherm Deflection Across Salt Diapirs

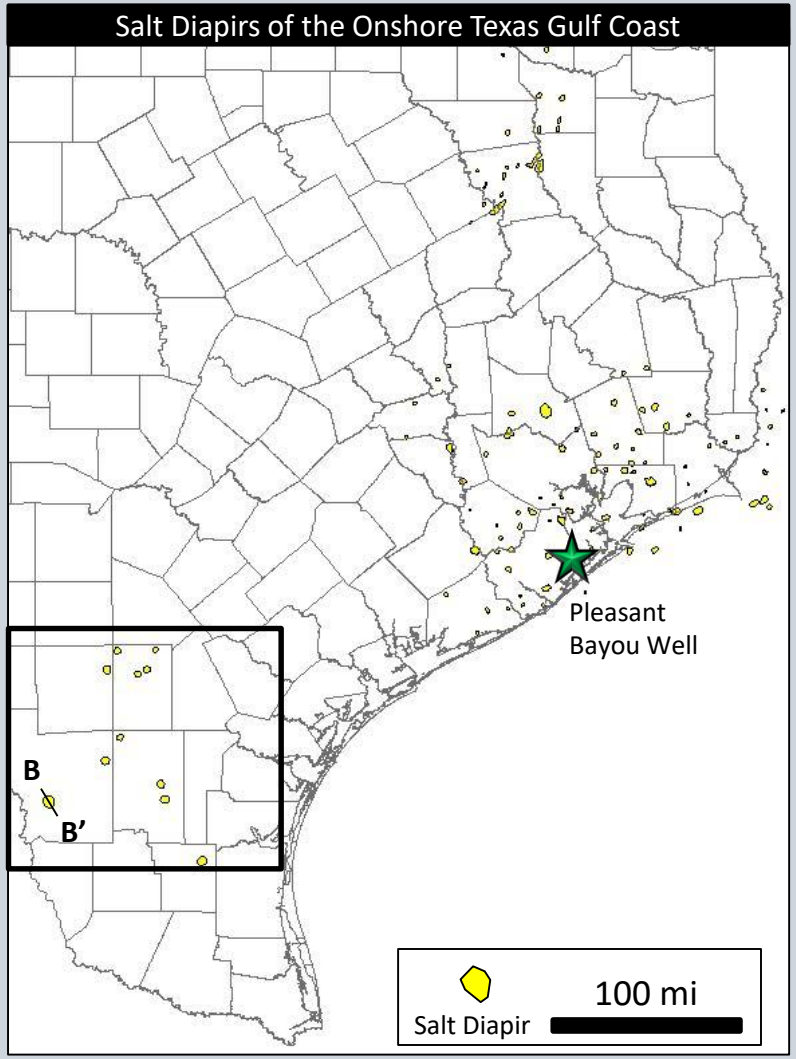


Courtesy of C. Rivera from Mark Rowan, personal communication

Approximate Heat Flow Extend Surrounding Diapirs in S. Tx.



Salt Diapirs of the Onshore Texas Gulf Coast

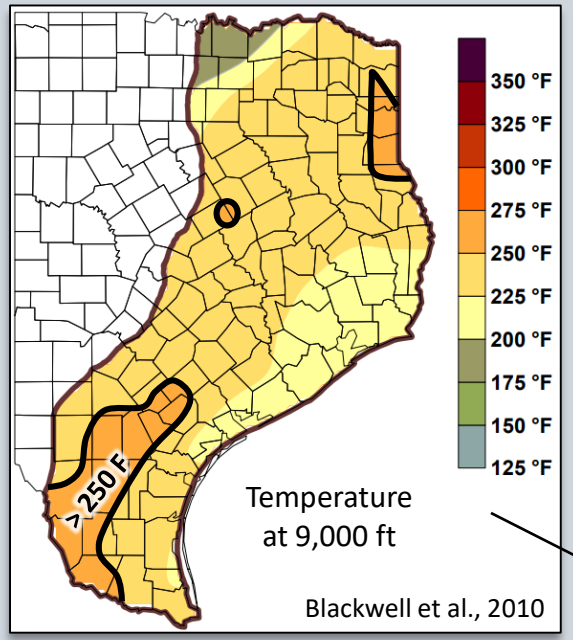


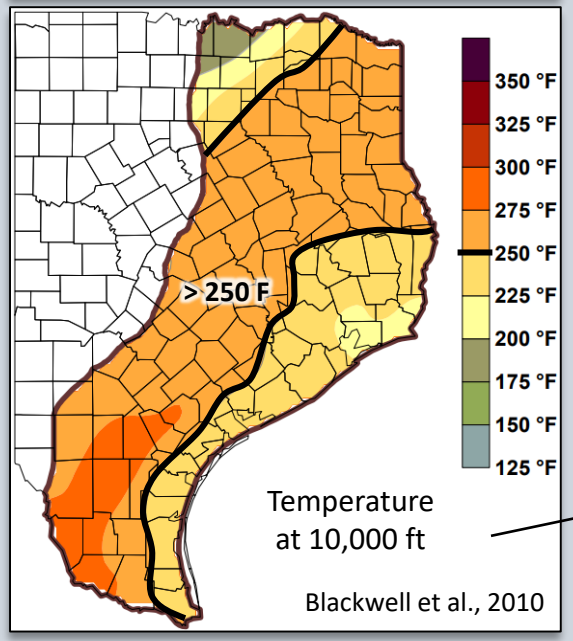
Diapir locations from Condon and Dyman, 2006

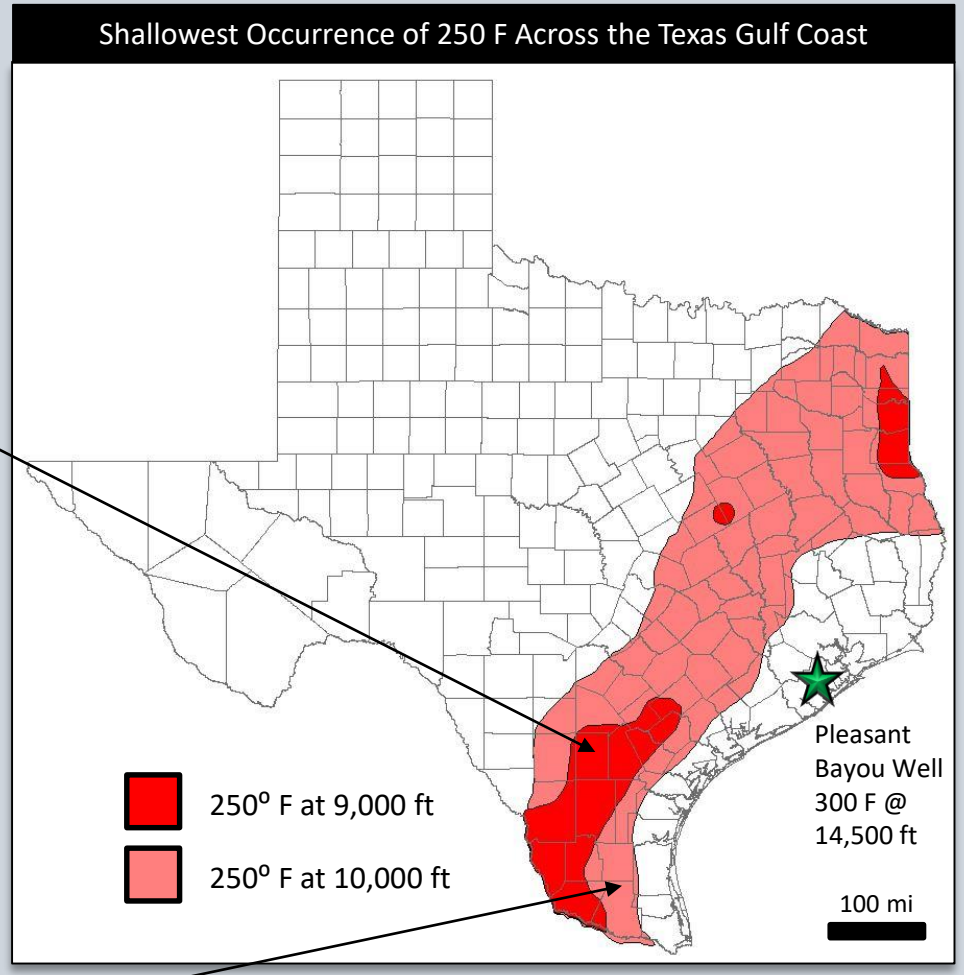
Temperature at Depth Mapping (SMU Geothermal Lab)

- Maps made from 9,500+ wells with corrected BHT measurements using the SMU-Harrison temperature correction equation
- Temperature depth maps made every 1,000 ft between 8,000 ft and 14,000 ft
- 250^{o} F is approximately the minimum temperature suitable for electrical power generation

Key question: What formations are at these depths across Texas?



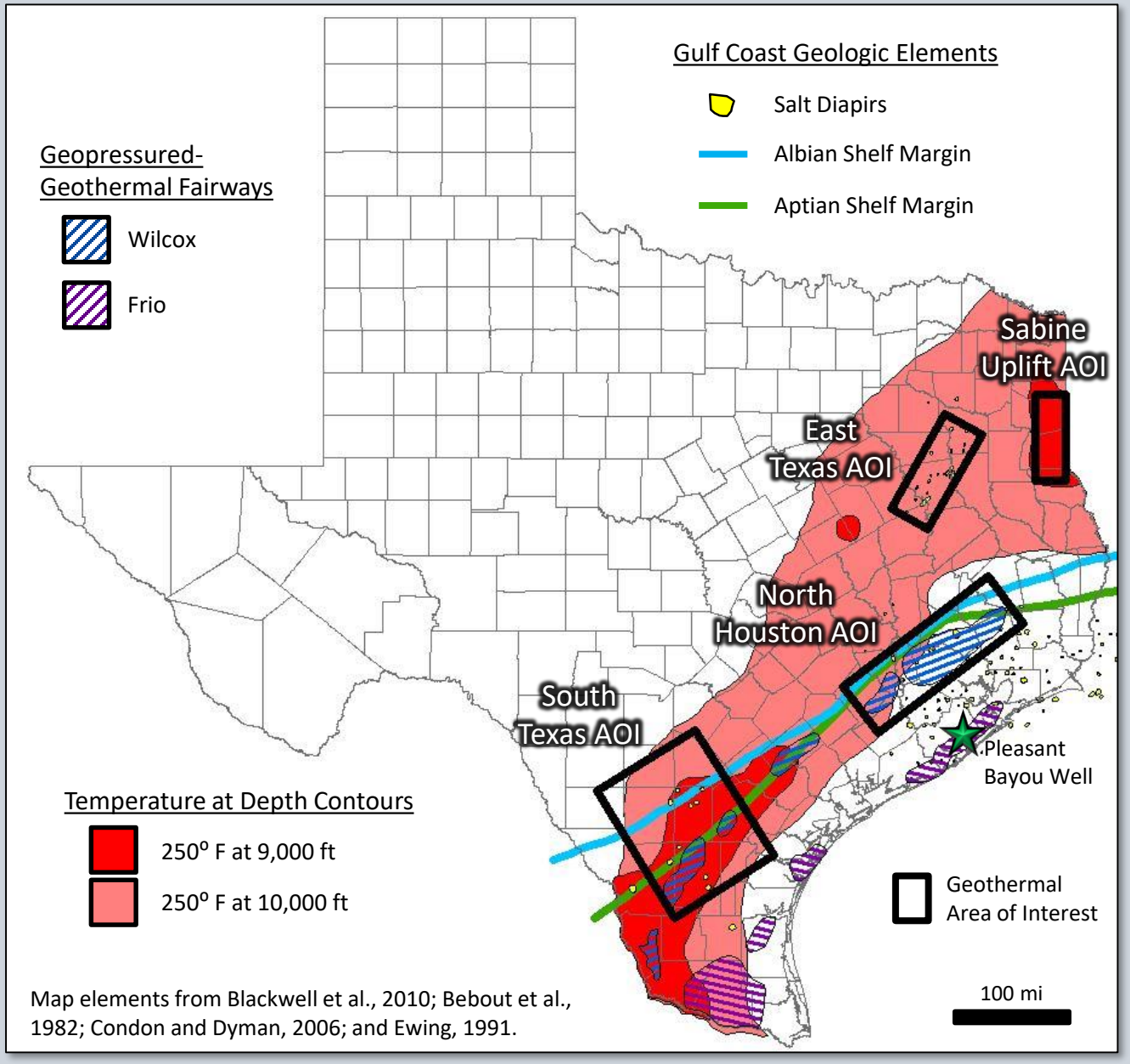


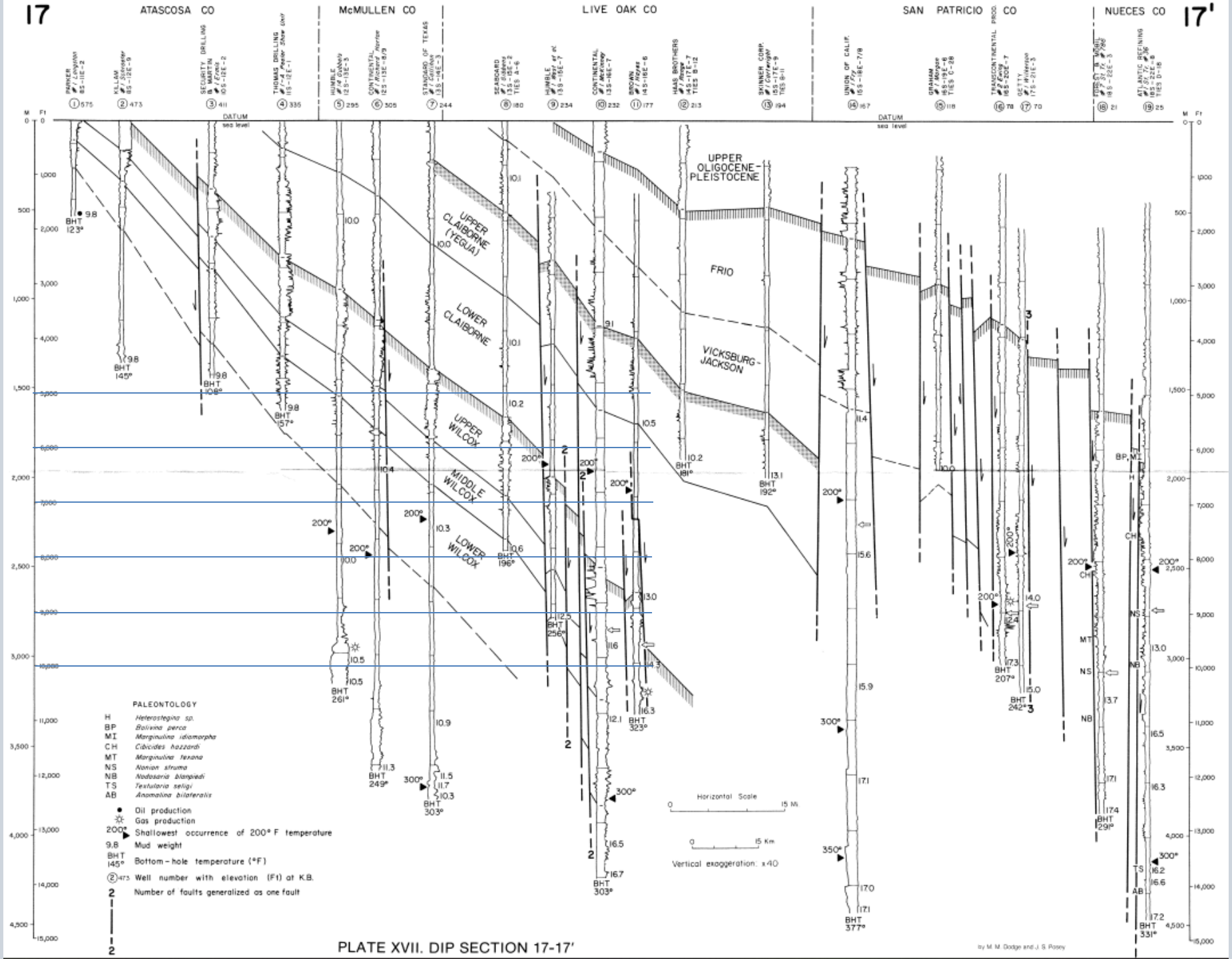


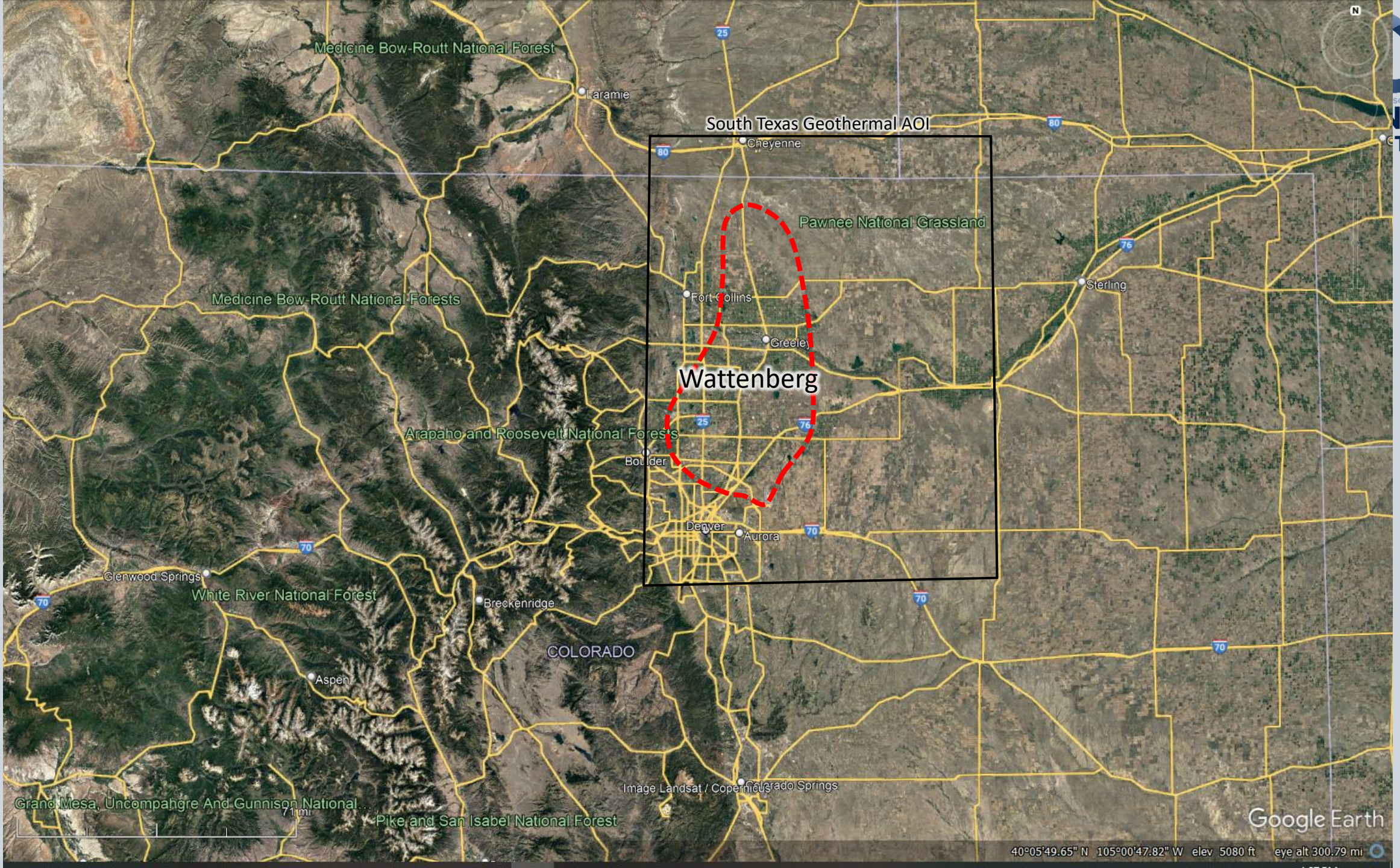
Texas Gulf Coast Sedimentary Geothermal Areas of Interest

- Four areas identified for potential sedimentary geothermal research project
- South Texas contains the most elements for a research project
- North Houston has a large Wilcox fairway directly under a major metropolitan area
- East Texas has highest concentration of salt domes
- Sabine Uplift has heat anomalies in Jurassic formations which are likely too deep to study in South Texas

Key Project Characteristics	South Texas	North Houston	East Texas	Sabine Uplift
250 F @ 9,000’	✓	✗	✗	✓
Geopressure	✓	✓	✗	✗
K/Jr Formations	✓	✗	✓	✓
Salt Diapirs	✓	✓	✓	✗




17
ATASCOSA CO
McMULLEN CO
LIVE OAK CO
SAN PATRICIO CO
NUECES CO
17'
DATUM
sea level
UPPER CLAIBORNE (TEGUA)
LOWER CLAIBORNE
UPPER WILCOX
MIDDLE WILCOX
LOWER WILCOX
UPPER OLIGOCENE-PLEISTOCENE
FRIO
VICKSBURG-JACKSON
PALEONTOLOGY
H Heterostegina sp.
BP Bolivina perca
MI Marginulina idiomorpha
CH Cibicides hazzardi
MT Marginulina texana
NS Nonion struma
NB Nodosaria blanpiedi
TS Textularia seligi
AB Anomalina bilateralis
Oil production
Gas production
200° Shallowest occurrence of 200° F temperature
9.8 Mud weight
BHT 145° Bottom-hole temperature (°F)
Well number with elevation (Ft) at K.B.
Number of faults generalized as one fault
Horizontal Scale
Vertical exaggeration: x40
PLATE XVII. DIP SECTION 17-17'


South Texas Geothermal AOI
Wattenberg
Medicine Bow-Routt National Forest
Laramie
Cheyenne
Pawnee National Grassland
Medicine Bow-Routt National Forests
Fort Collins
Greeley
Sterling
Arapaho and Roosevelt National Forests
Boulder
Denver
Aurora
Glenwood Springs
White River National Forest
Breckenridge
COLORADO
Aspen
Colorado Springs
Grand Mesa, Uncompahgre And Gunnison National ...
Pike and San Isabel National Forest
Image Landsat / Copernicus
Google Earth
40°05'49.65" N 105°00'47.82" W elev 5080 ft eye alt 300.79 mi