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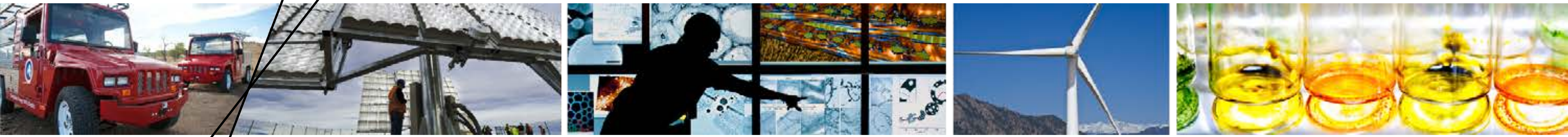
Estimate of the Geothermal Energy Resource in the Major Sedimentary Basins in the United States



GRC 36th Annual Meeting

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Introduction

Photo by Warren Gretz, NREL/PIX 00450

Geothermal energy from sedimentary basins utilize ‘hot’ geothermal fluids (>100^{o}C) produced from sedimentary basins throughout the United States to generate electricity.

Advantages:

- Reservoirs are porous, permeable, and well characterized from oil and gas exploration.
- Temperature gradients are known and proven from oil and gas well records.
- Drilling and reservoir fracturing techniques are proven in sedimentary conditions.

Disadvantages:

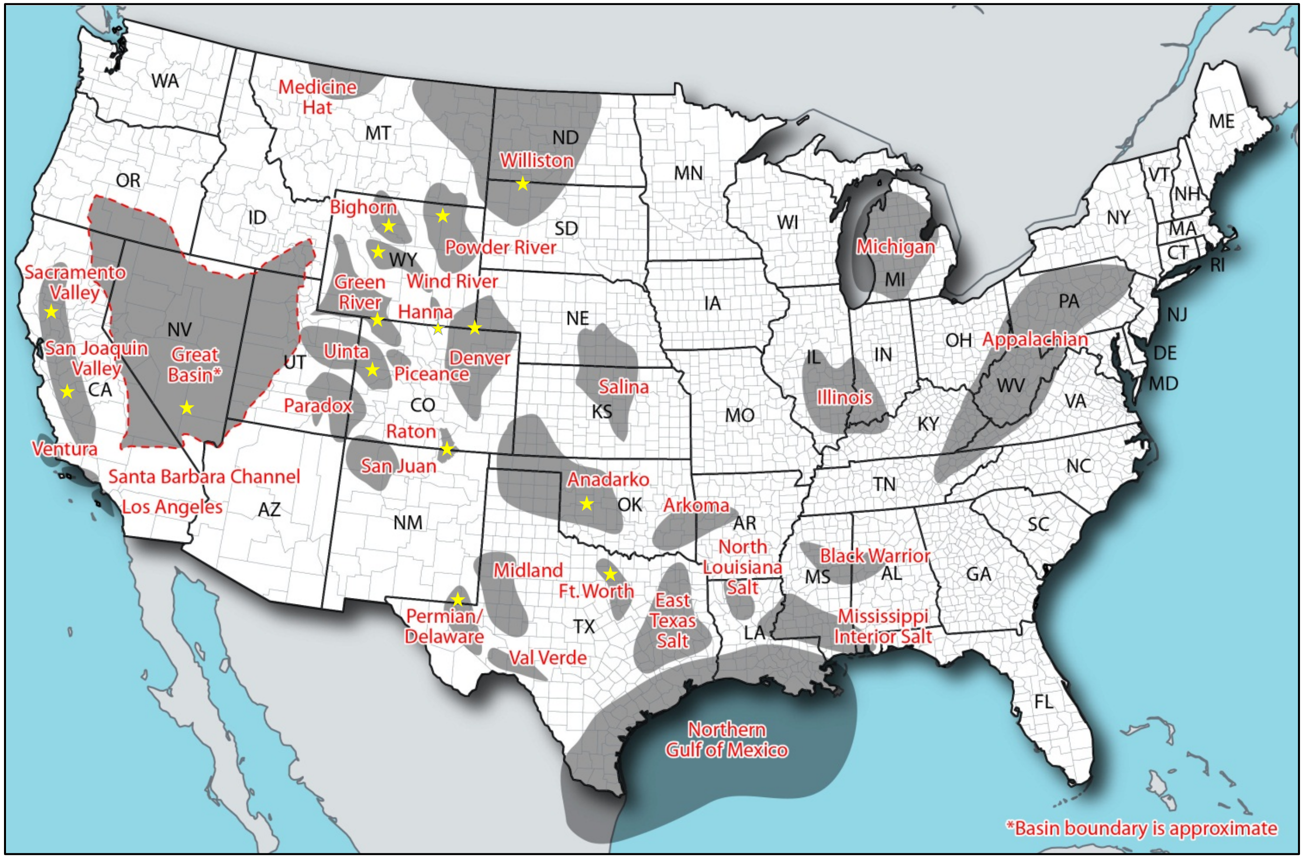
- Significant depths are required to encounter high temperatures.
- It is an emerging industry.

Goals and Methodology

Goal: Provide an initial estimate of the total thermal energy available in U.S. sedimentary basins.

1. **Review sedimentary basins throughout the United States and eliminate basins with lowest potential**
   - Top 15 basins were identified
2. **Delineate and map areal extent and depth contours of each basin identified for spatial analysis purposes**
3. **Estimate temperature profile for each basin using available data**
4. **Calculate basin volume as a function of temperature**
5. **Determine heat in-place using reservoir volume as a function of temperature.**

U.S. Sedimentary Basins



Basins included in analysis

1	Anadarko
2	Bighorn
3	Denver
4	Ft. Worth
5	Great Basin
6	Green River
7	Hanna
8	Permian/Delaware
9	Powder River
10	Raton
11	Sacramento
12	San Joaquin
13	Uinta
14	Williston
15	Wind River

Basins included in the analysis were chosen based on:

1. High measured temperatures
2. Basin depth
3. Rock type (i.e., sandstone or highly fractured shale).

Approach

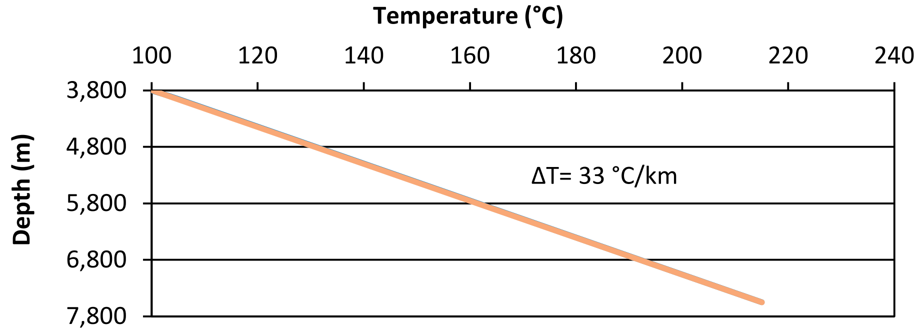
1. **Performed literature search for all known deep sedimentary basins**
2. **Applied Kehle temperature correction to downhole temperatures (Kehle et al. 1970) up to 3,900 meters then applied a linear temperature correction (Blackwell et al. 2010)**
3. **Estimated thermal resource in-place using reservoir volume, assuming constant rock density and heat capacity using Muffler method (1979)**
4. **Developed qualitative thermal recovery factor for each basin.**

	Data Category	**Main Data Sources**
1	Basin lithology—stratigraphic column	Published literature as well as oil and gas logs
2	Structural cross-sections	USGS, AAPG
3	Depth to basement maps	AAPG, USGS, and journal articles
4	Temperature logs, thermal profiles, and BHTs from the basin's deepest wells	State geological survey database; Oil and Gas Commission records
5	Production rates and reservoir properties	Published literature; oil and gas logs
6	Hydrologic potentiometric maps	USGS – Water Resources Division reports
7	Hottest documented downhole temperature in each basin	State geological surveys; AAPG
8	Previous geothermal resource assessments.	State geological surveys; DOE Technical Reports.

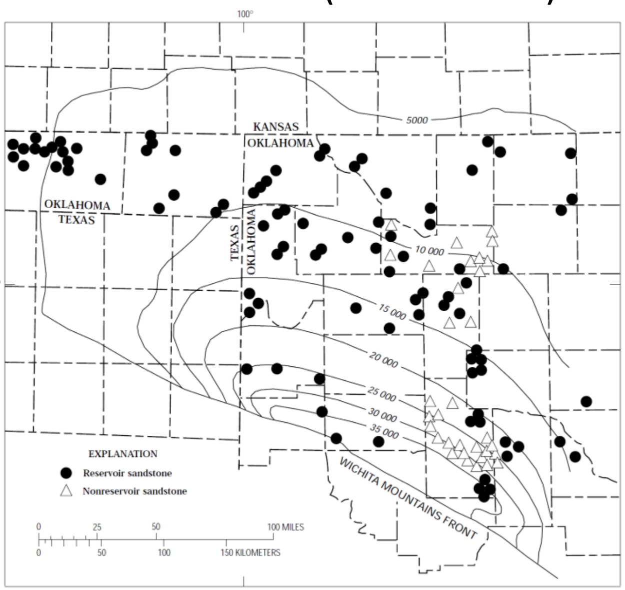
Basin Spatial Analysis: Anadarko Basin

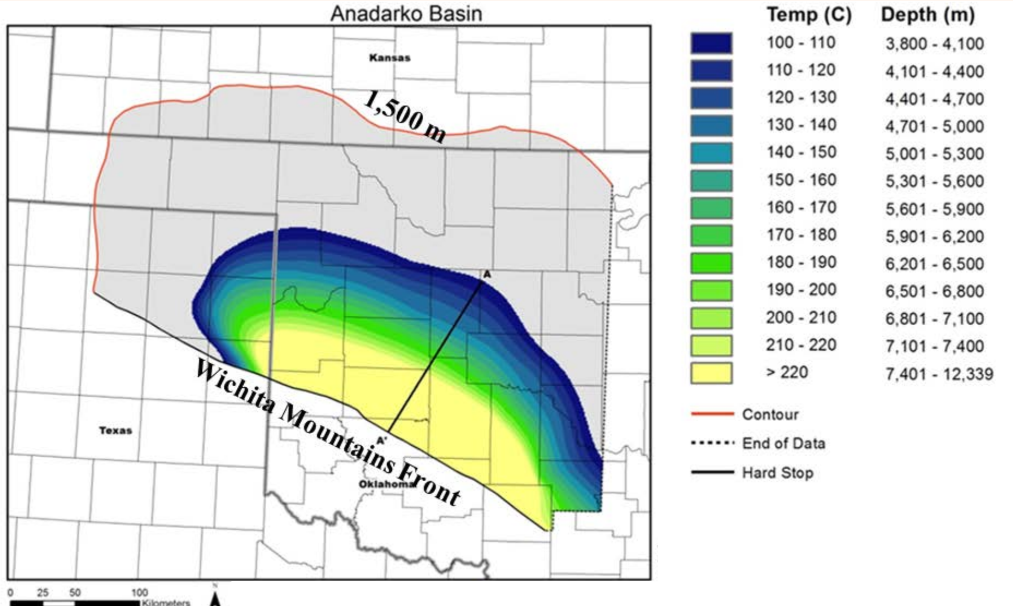
1. Digitize available basin thickness and depth data
2. Determine a single temperature gradient for each basin
3. Calculate volume of rock for each 10°C temperature interval for areas with T>100° C.

2. Temperature gradient (AAPG Data Rom)



1. Thickness data (Hester 1997)

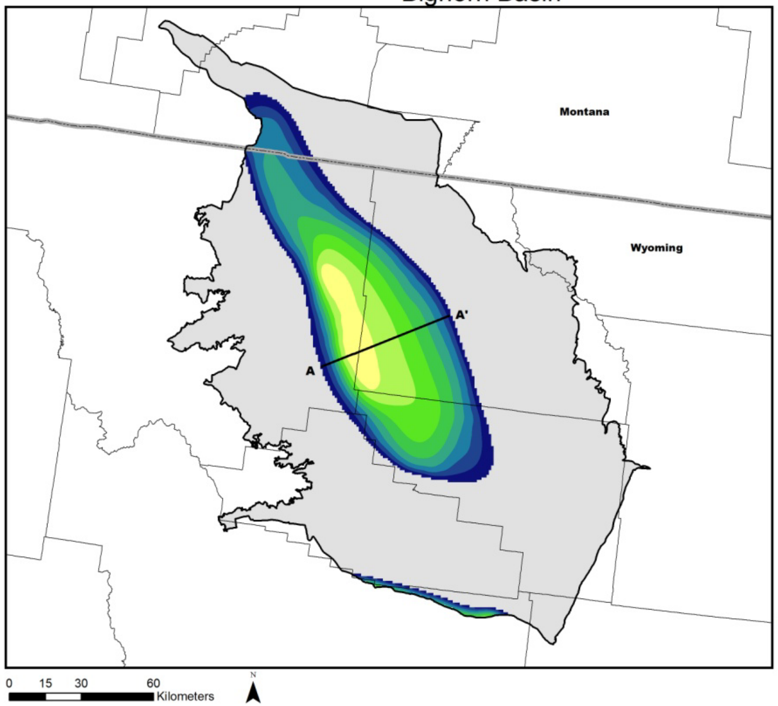




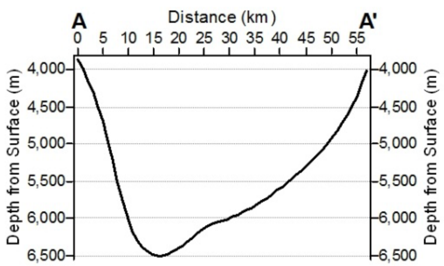
3. Calculated volume and temperature

Basin Analysis Examples: Bighorn and Williston Basins

Bighorn Basin

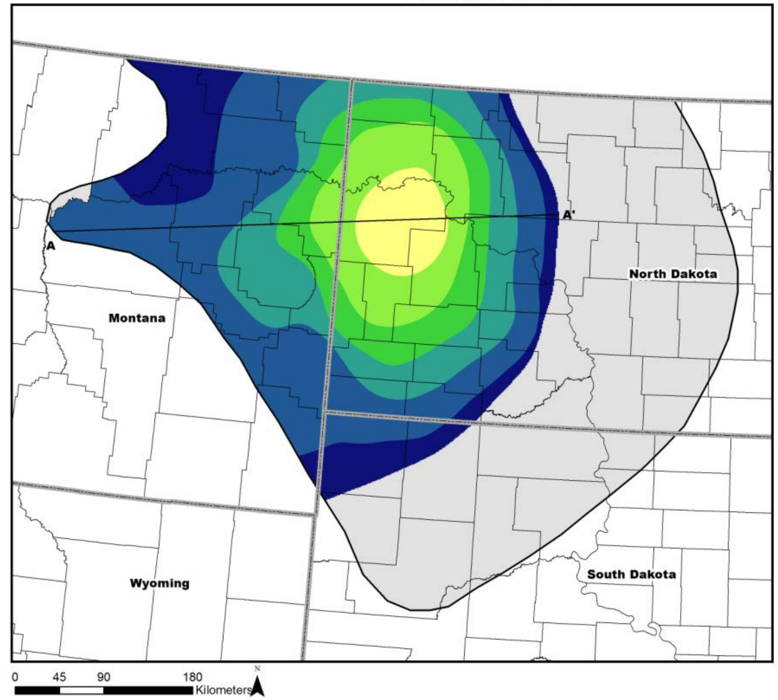


	Temp (C)	Depth (m)
	100 - 110	3,800 - 4,145
	110 - 120	4,146 - 4,490
	120 - 130	4,491 - 4,835
	130 - 140	4,836 - 5,180
	140 - 150	5,181 - 5,525
	150 - 160	5,526 - 5,870
	160 - 170	5,871 - 6,215
	170 - 180	6,216 - 6,512



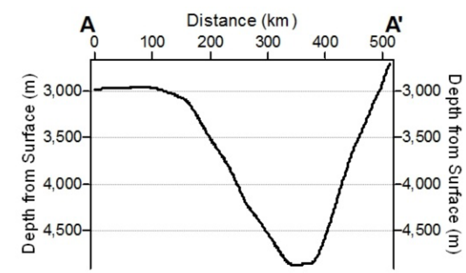
Hard Stop

Williston Basin

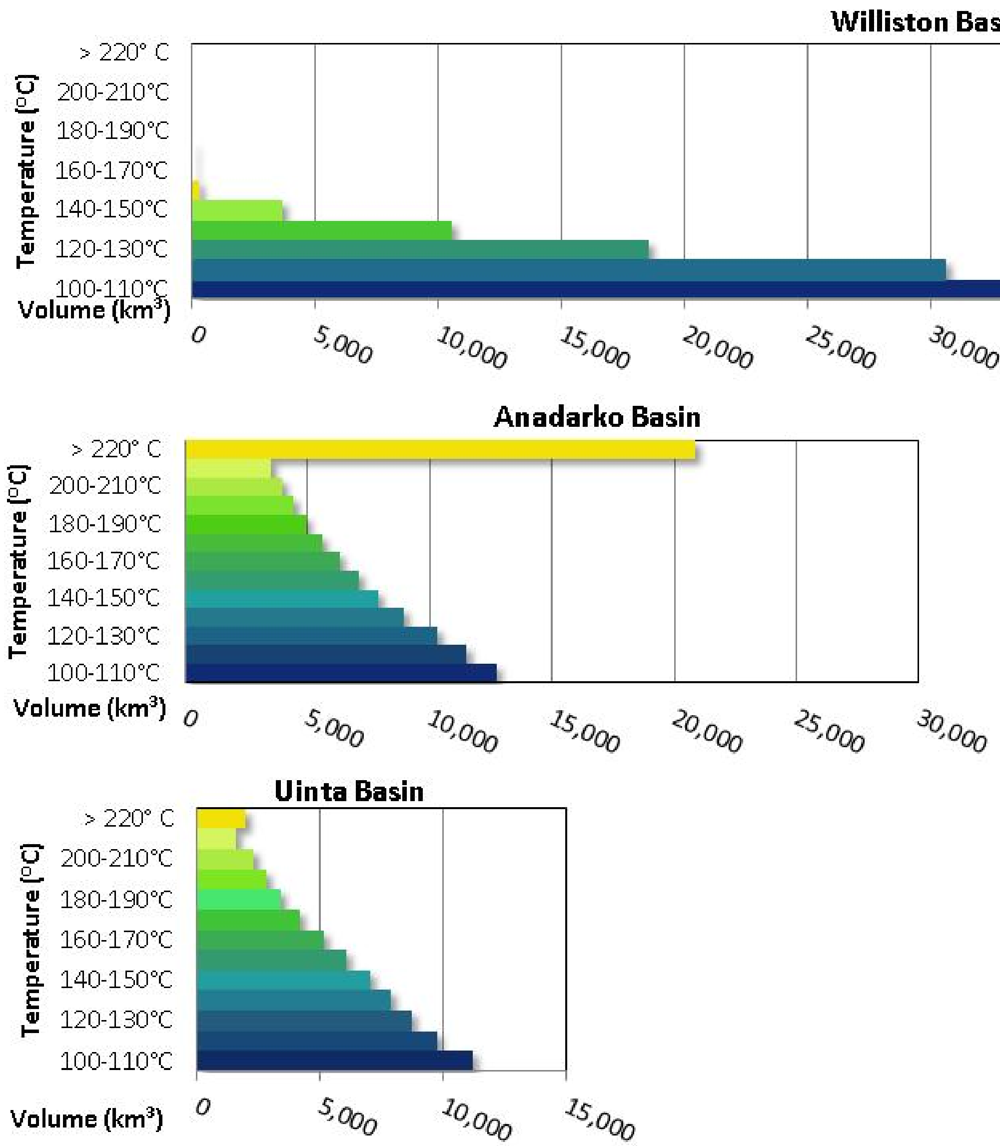


	Temp (C)	Depth (m)
	100 - 110	2,700 - 2,919
	110 - 120	2,920 - 3,336
	120 - 130	3,337 - 3,753
	130 - 140	3,754 - 4,170
	140 - 150	4,171 - 4,587
	150 - 160	4,588 - 5,004

Hard Stop



Sedimentary Basin Volume vs. Temperature



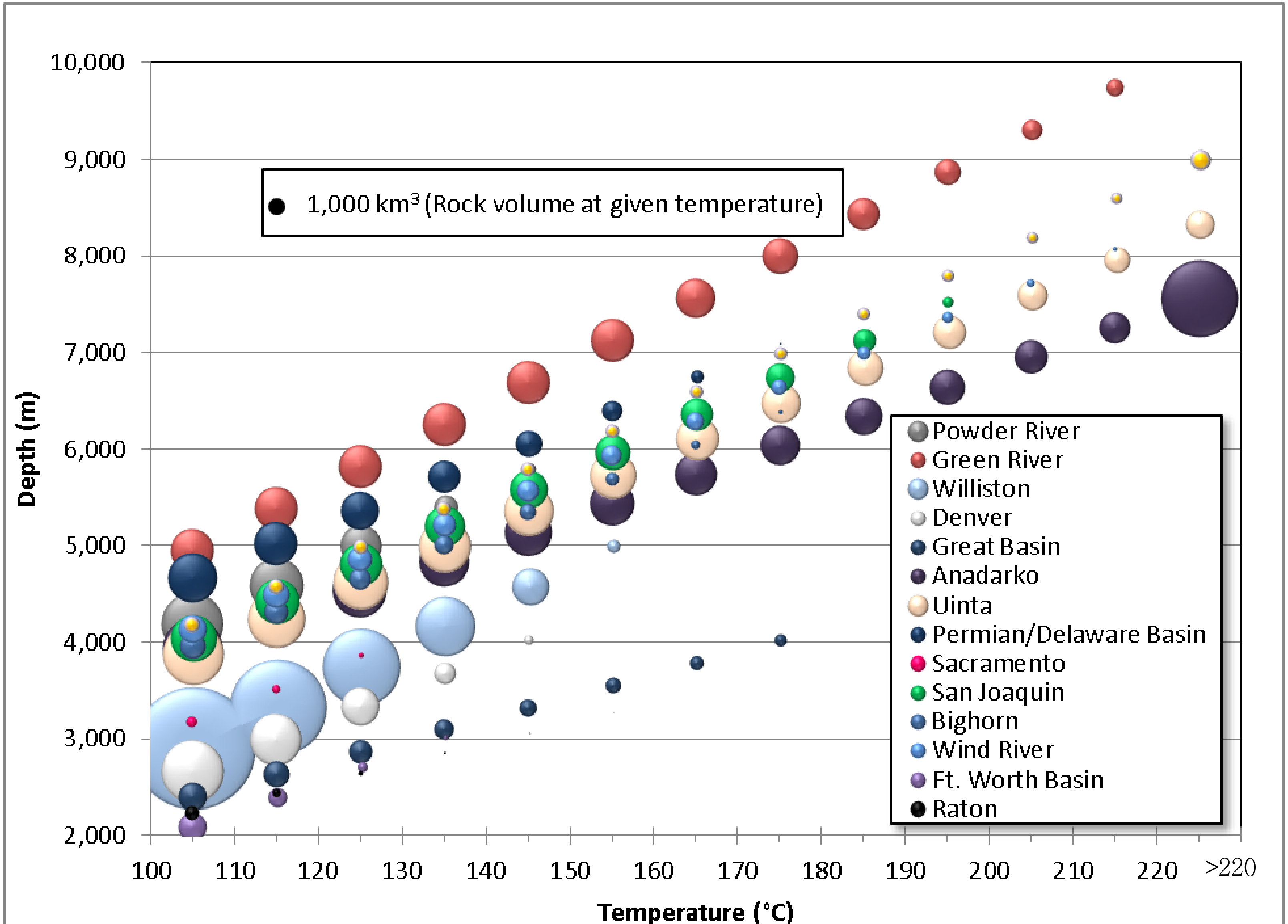
Figures show sedimentary basin volumes by temperature interval

- Roughly match basin profiles
- Figures have identical scale so that comparisons of relative volume of basins can be made

Significant variability among basins

- Thermal energy in-place is a function of both temperature and volume
- Williston is a large, but relatively cool basin compared with Anadarko, which is smaller but at significantly higher temperatures.

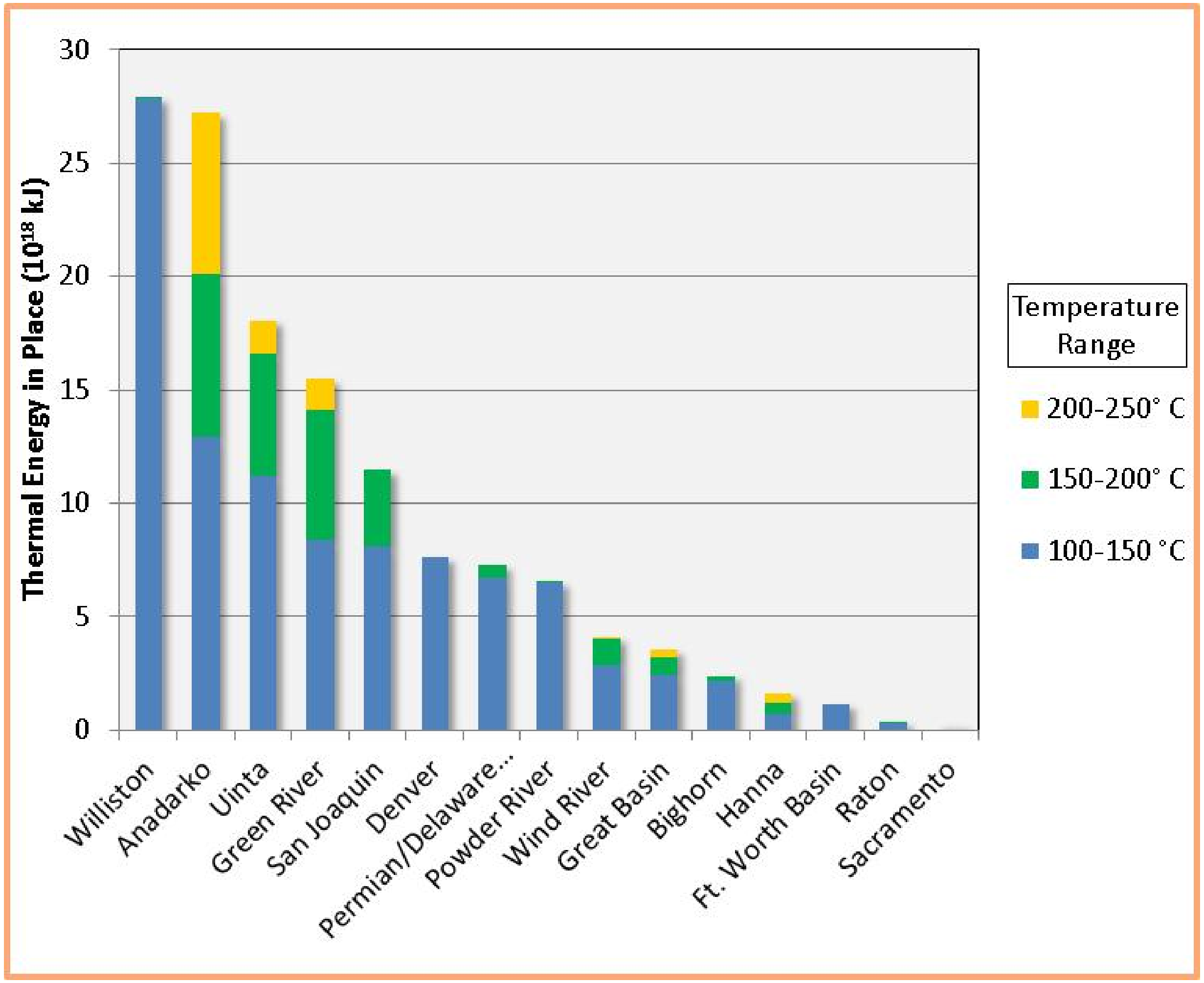
Sedimentary Basin Volume vs. Temperature and Depth



Thermal Energy In-Place (kJ) by Basin

Calculated using methodology described by Muffler (1979) using the following assumptions:

Assumptions	Value
Porosity	20%
Reference Temperature	15°C
Rock Density	2.55 x 10^{12} kg/km^3
Rock Heat Capacity	1 kJ/kg°C
Water Density	1. 00 x 10^{12} kg/km^3
Water Heat Capacity	4.18 kJ/kg°C



Majority of thermal energy in sedimentary basins is at relatively low temperatures (100-150°C).

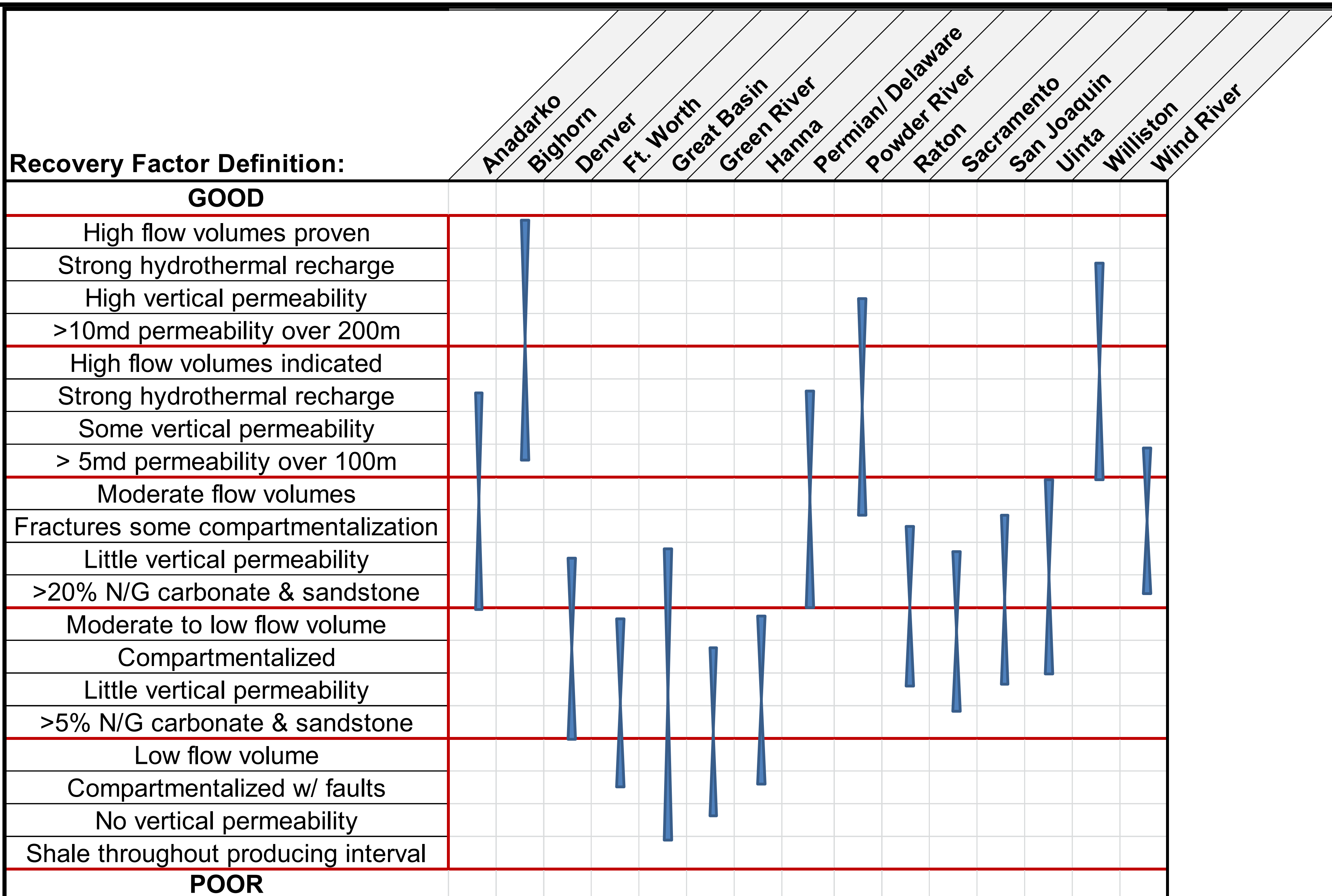
Reservoir Productivity Analysis

- **Converting the thermal energy in-place to electricity generation potential requires knowing the thermal recovery factor (amount of thermal energy that can be produced)**
  – Recovery factors for geothermal rarely published
  – Little previous work or data on recovering geothermal fluids (brine) from sedimentary basins
  – Reservoir stimulation or fracturing techniques could significantly increase the amount of fluid that can be recovered from a reservoir compared to its "natural" reservoir productivity
- **Instead, reservoir productivity was assessed by creating a qualitative matrix that correlated reservoir productivity to measurable geologic conditions.**

Qualitative Reservoir Productivity Matrix

Flow Volume	Hydrothermal Recharge	Vertical Permeability	Horizontal Permeability
Good Reservoir Productivity			
High flow volumes proven	Strong hydrothermal recharge	High vertical permeability	>10md permeability over 200m interval
High flow volumes indicated	Strong hydrothermal recharge	Some vertical permeability	> 5md permeability over 100m interval
Moderate flow volumes	Fractures, some compartmentalization	Low vertical permeability	>20% net/gross interval carbonate and sandstones
Moderate to low flow volume	Reservoir compartmentalized	Low vertical permeability	>5% net/gross interval carbonate and sandstones
Low flow volume	Reservoir compartmentalized with sealing faults	No vertical permeability	Shale throughout producing interval with low permeability
Poor Reservoir Productivity			

Qualitative Reservoir Productivity by Basin



Results and Conclusions

Fifteen sedimentary basins were studied to estimate the magnitude of this resource

- Completed spatial analysis of sedimentary basins
- Estimated thermal energy in-place for each basin
- Developed a 'first look' at resource estimate
  - Basin properties were averaged across large areas and more detailed studies are needed to refine estimates.

Overall resource potential is large

- Thermal energy in place in sedimentary basins is substantial: **1.35×10^{20} kJ**
- Majority of thermal energy is at relatively low temperatures (100-150^{o}C), but high temperature regions have been identified.

Electricity generation potential depends on thermal recovery factor

- Currently, little data exists on thermal recovery for sedimentary basins
- Qualitatively assessed reservoir productivity for each basin
- Reservoir productivity varies significantly across basins, and could vary within the basin based on continuity
- Thermal recovery factor should be correlated with reservoir productivity, but reservoir stimulation/fracturing techniques could significantly increase the amount of geothermal fluid that could be recovered
- Additional work could include reservoir modeling and a demonstration project.

THANK YOU!

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