# Geothermal Potential of Deep Sedimentary Basins in the United States*

**Tom Anderson**[1]

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## Abstract

Geothermal energy development has a promising future as part of a broad energy supply mix to meet growing demand in the United States and globally. Currently developed hydrothermal systems are a significant energy source, but these systems have limited geographic extent. Research is underway, including ongoing pilot projects, to evaluate the potential for EGS, or Engineered Geothermal Systems, to drill into hot crystalline rock, and create fractured reservoirs suitable for water injection and production cycles. However, a challenge to the economics of these systems is the drilling and fracturing cost. Co-production of geothermal energy associated with oil operations has been demonstrated successfully at Teapot Dome, where produced water is of sufficient quantity and adequate temperature to generate electricity with binary/hybrid systems. However, this approach has yet to be embraced by the oil industry. A potential new path toward expanded geothermal energy production is to use known porous and permeable reservoir rocks in appropriate sedimentary basins, where those packages of rocks have sufficient temperature, thickness, porosity, and permeability, existing at depths that are not so great that drilling costs make the potential system uneconomic. This presentation describes a DOE-funded project to identify, screen, and model these potential systems, incorporating geology, engineering, and economic modeling disciplines. From a geologic perspective, 17 basins in the western U.S. have been examined. Stratigraphic columns were compiled, including unit depths and thicknesses, along with thermal profiles. Target reservoir sections at appropriate depths and temperatures have been evaluated with respect to porosity and permeability, primarily from available core data, supplemented with wire-line log analysis. For screening purposes, thresholds of < 4 km depth and > 125 °C temperatures were applied to meet economic targets. Results indicate that many of those basins should be excluded, for example, the Bighorn Basin of Wyoming has favorable porous and permeable reservoir rocks and good temperatures for geothermal energy production, but these occur at nearly 6 km, too deep for economic drilling costs. The temperature at the 4 km threshold is only 100-110 °C, in the marginal range for binary geothermal power systems. Based on this work, basins meeting the criteria are the Williston, Denver, Great Basin, Fort Worth, Sacramento, Gulf Coast, and Imperial Valley.

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EGI Energy & Geoscience Institute
AT THE UNIVERSITY OF UTAH

# Geothermal Potential of Deep Sedimentary Basins in the United States

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# Introduction

- Currently developed **hydrothermal** systems are a significant energy source, but these systems have limited geographic extent.
- Research is underway to evaluate the potential for **EGS** to drill into hot crystalline rock and create fractured reservoirs suitable for water injection and production cycles. However, a challenge to the economics of these systems is the drilling and fracturing cost.
- "**Co-production**" of geothermal energy associated with oil operations has been demonstrated successfully at Teapot Dome*. However, this approach has yet to be embraced by the oil industry.

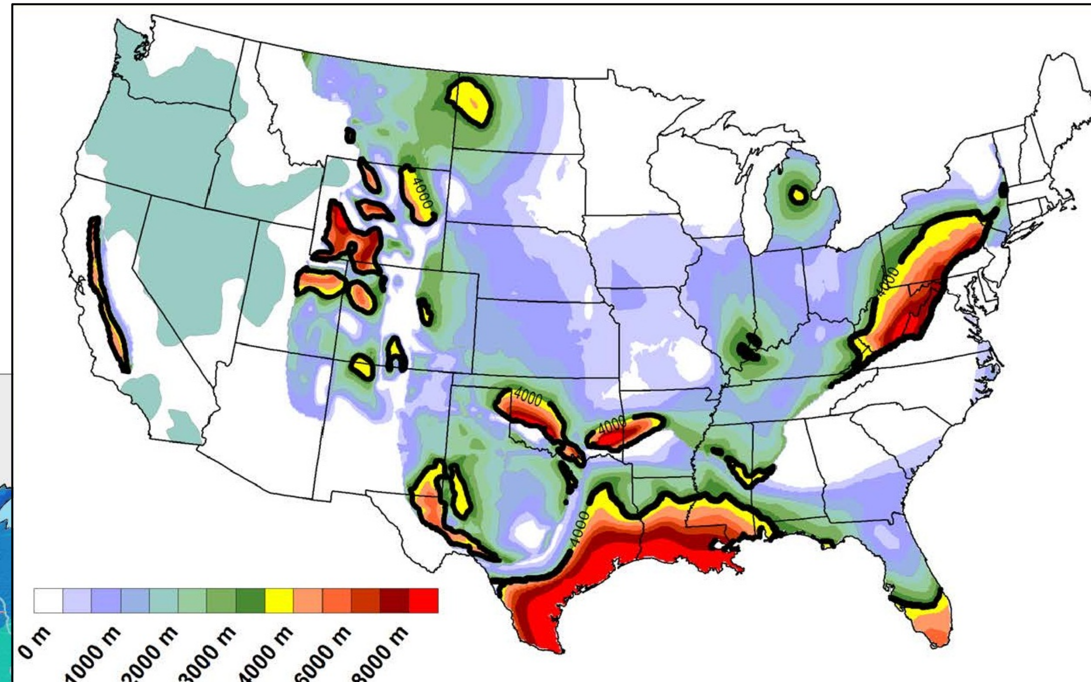
***A potential new path toward expanded geothermal energy production is to use known porous and permeable reservoir rocks in appropriate sedimentary basins, where those packages of rocks have sufficient temperature, thickness, porosity, and permeability, existing at depths that are not so great that drilling costs make the potential system uneconomic.***

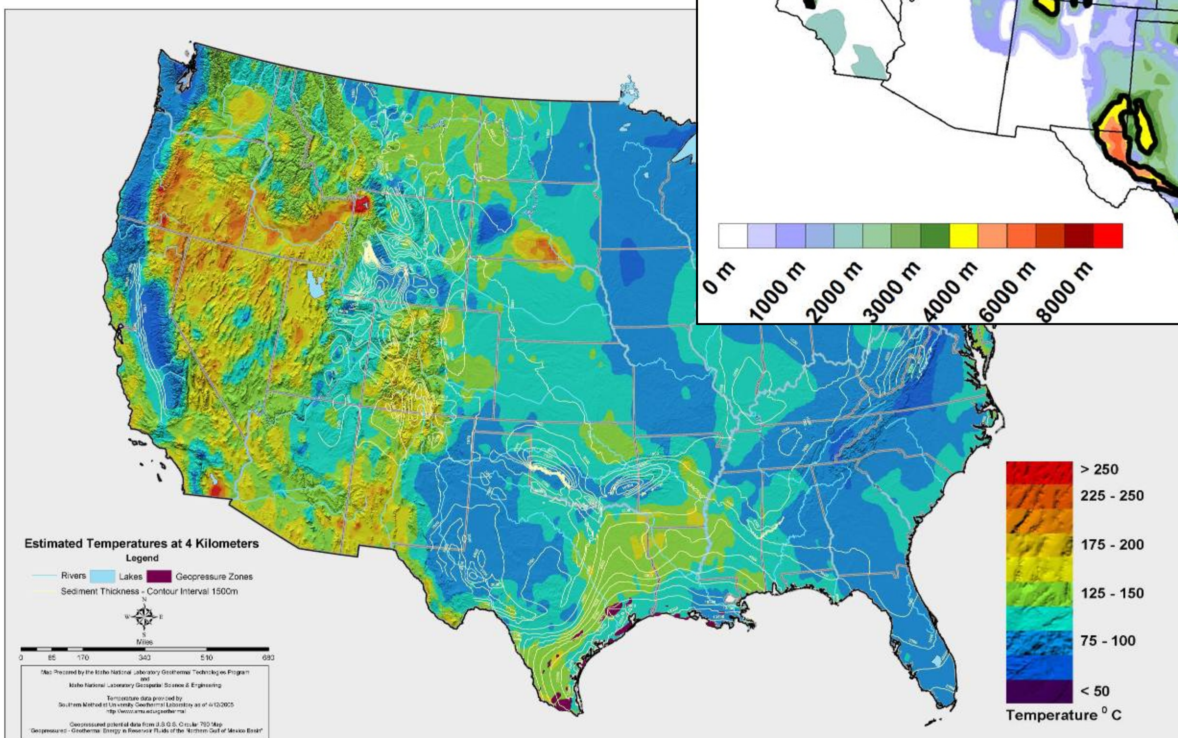
*Anderson, T.C., L.A. Johnson, and E.D. Walker, 2009, **Oil Production Waste Stream: A Source of Electrical Power**: Renewable Energy World North America, November 2009

# Sediment Thickness in the Continental U.S. and Temperature at 4 km Depth

***Where to start – previous maps on sedimentary basins***

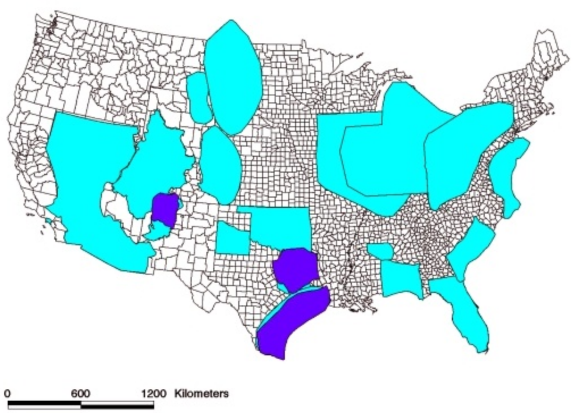
Tester, Jefferson W., et al, 2006, **The Future of Geothermal Energy**, MIT Report; http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf



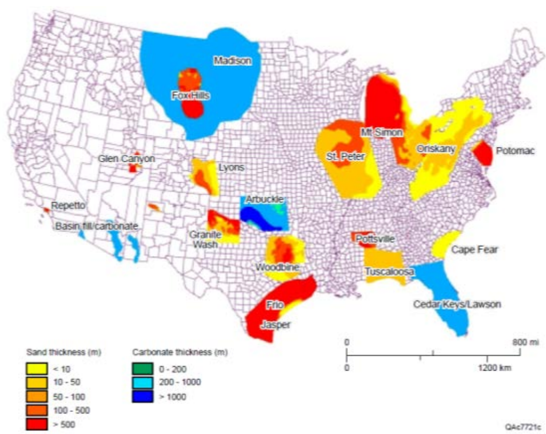




Idaho National Laboratory, 2005, **Map of Estimated Temperatures at 4 Kilometers**, Temperature data provided by Southern Methodist University Geothermal Laboratory; http://www.smu.edu/geothermal

# An Interesting Parallel: $CO_2$ Sequestration Screening Study




Basins




Formations

| Formations common to this study and mine: |
|---|
| Arbuckle Group, OK |
| Basin and Range sandstone and carbonates |
| Frio Formation, TX |
| Lyons Sandstone , DJ Basin |
| Madison Group, Williston |
| Tuscaloosa Group, Gulf Coast |
| Woodbine Formation, TX |

*Objective: identify "optimal geological environments for carbon dioxide disposal in brine-bearing formations in the United States". Many $CO_2$ geologic sequestration targets have similarities to deep sedimentary basin geothermal flow units:* ***porosity, areal extent, thickness, volume, depth, continuity, and permeability*** *to flow. Other common parameters include* ***drilling cost effects on economics*** *and reservoir isolation from potable aquifers.*

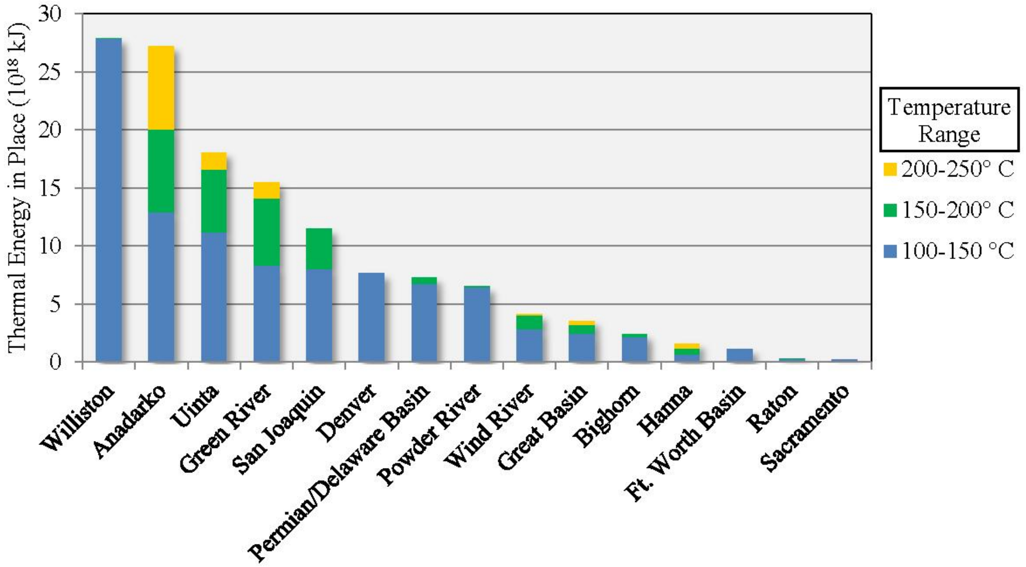

Hovorka, S. D., Romero, M. L., Treviño, R. H., Warne, A. G., Ambrose, W. A., Knox, P. R., and Tremblay, T. A., 2000, **Technical summary: optimal geological environments for carbon dioxide disposal in brine-bearing formations (aquifers) in the United States**: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for U.S. Department of Energy, National Energy Technology Laboratory, under contract no. DE-AC26-98FT40417, 232 p. GCCC Digital Publication Series #00-01.

# Basins Studied

- Anadarko
- Bighorn
- Delaware/Permian
- Denver (Denver-Julesburg)
- Fort Worth
- Great Basin
- Green River
- Gulf Coast
- Hanna (including Laramie and Shirley)
- Imperial Valley (or Salton Trough)
- Powder River
- Raton
- Sacramento
- San Joaquin
- Uinta/Piceance
- Williston
- Wind River

***Eastern basins don't have the heat***

# Total Heat in Place for Basins Studied (from Porro, et al 2012)



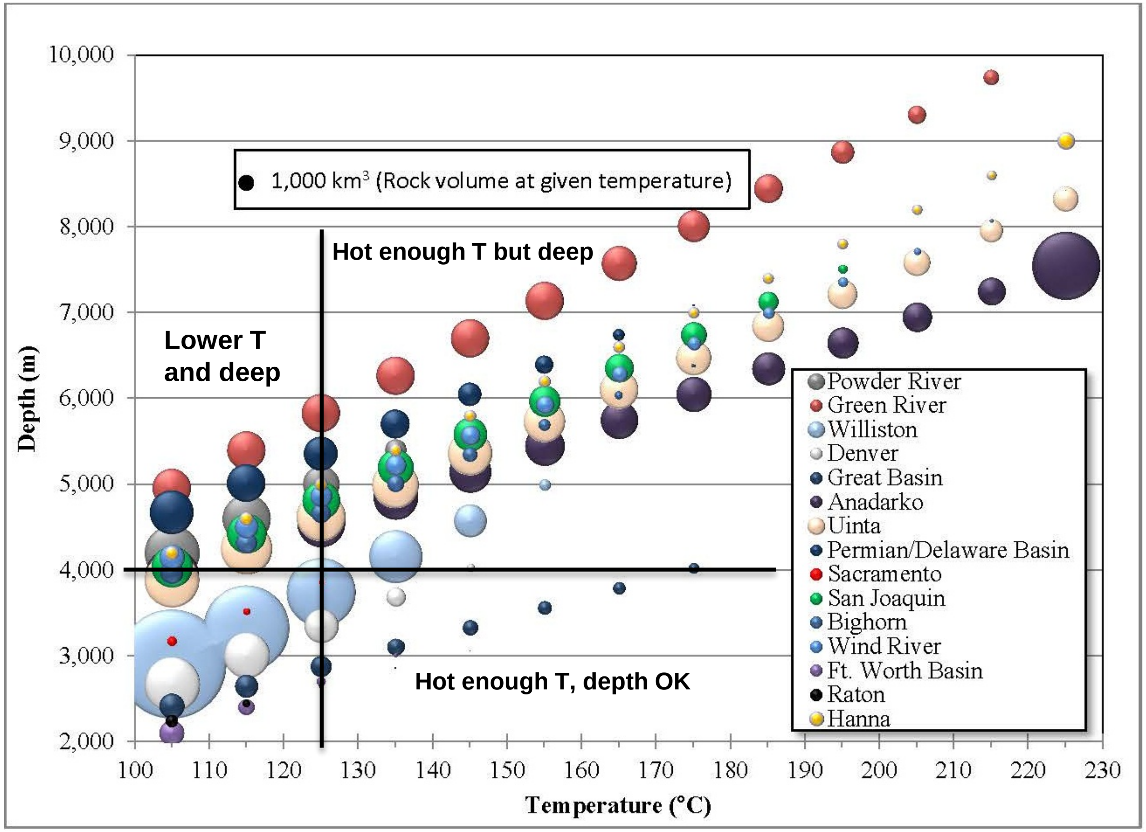

A recent project completed by National Renewable Energy Laboratory (NREL) staff has contributed significantly to the effort to evaluate and screen deep sedimentary basins for geothermal potential. Their study consisted of 15 of the 17 basins I studied (they did not include the Gulf Coast region and the Imperial Valley).

However:

- Their areal extent for the Great Basin covered Nevada only and it apparently focused on basin fill sediments rather than Paleozoic reservoirs
- They didn't consider quantitative porosity and permeability or specific potential target reservoirs – ***so I added these characteristics***

Porro, Colleen, A. Esposito, C. Augustine, and B. Roberts, 2012, **An Estimate of the Geothermal Energy Resource in the Major Sedimentary Basins in the United States;** Geothermal Resources Council Transactions, Vol. 36.

# Sedimentary Basin Volume vs. Temperature and Depth for Basins Studied



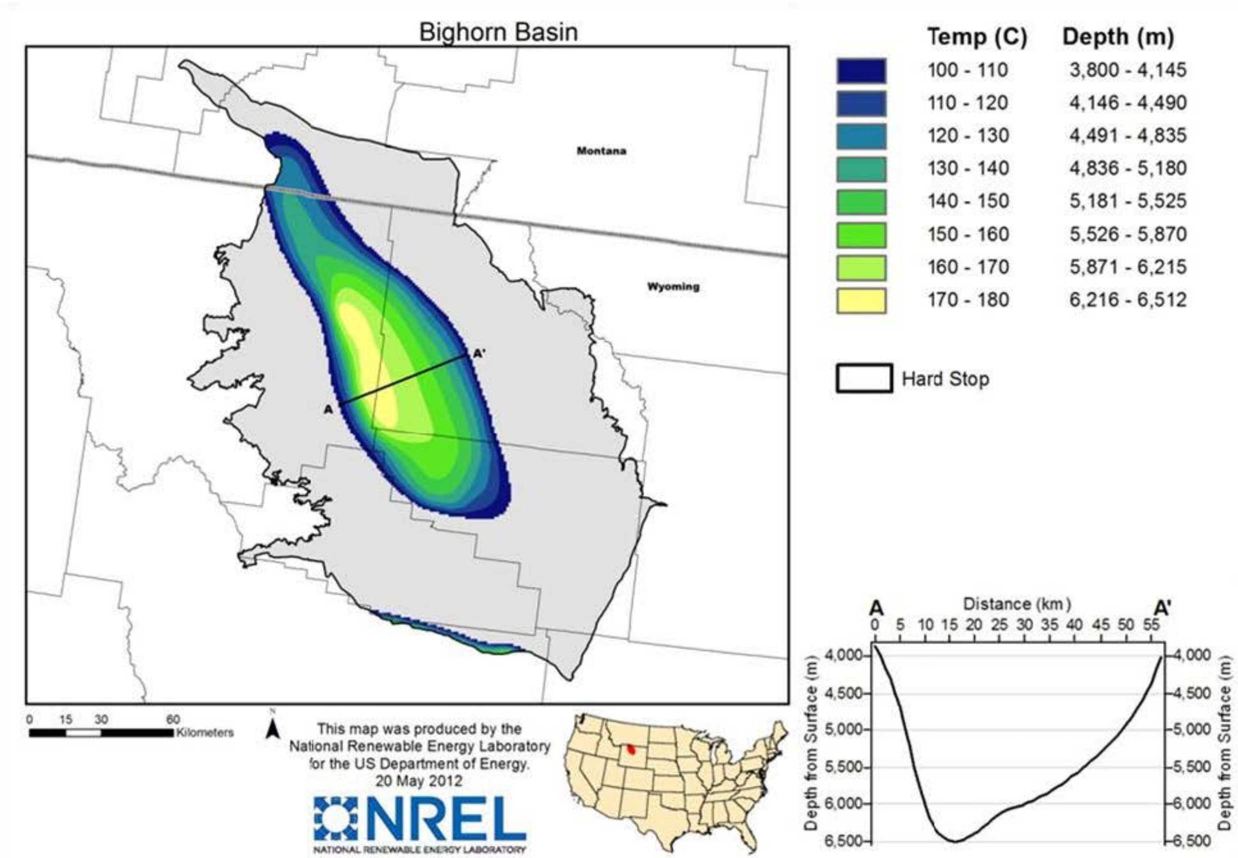

*Threshold lines and annotation overlaid on graphic by present author*

The extended abstract (Porro et al, 2012) from their GRC presentation shows an innovative method for illustrating sedimentary volume, depth, and temperatures for all basins they studied.

*For current study screening purposes, thresholds of < 4 km depth and > 125 °C temperatures were applied to meet economic targets, and these lines and annotation are overlaid on the Porro et al diagram.*


Porro, Colleen, A. Esposito, C. Augustine, and B. Roberts, 2012, **An Estimate of the Geothermal Energy Resource in the Major Sedimentary Basins in the United States;** Geothermal Resources Council Transactions, Vol. 36.

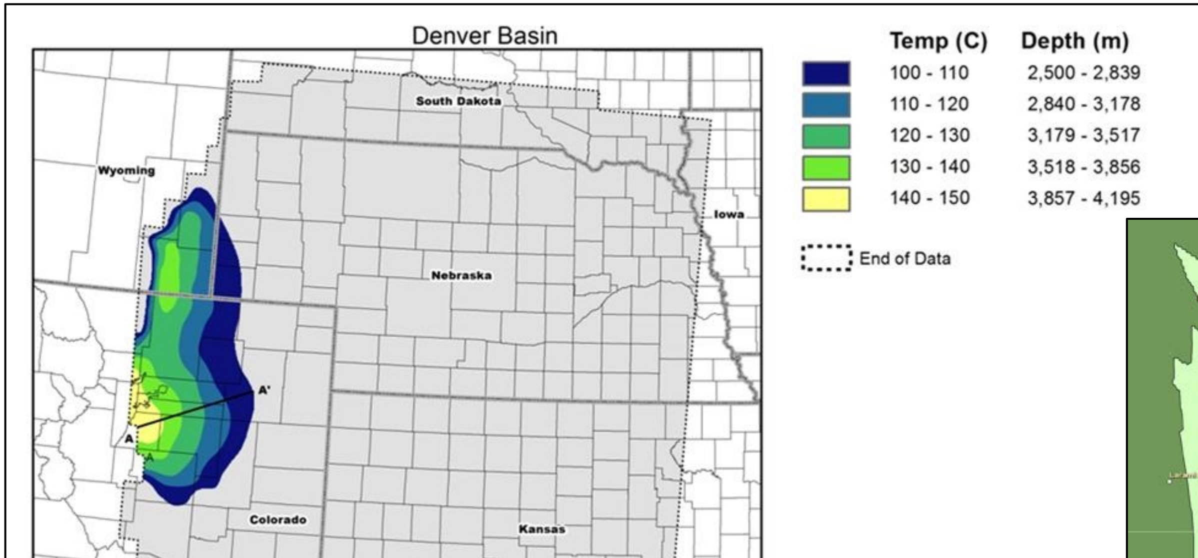
# Doesn't Make the Grade: Bighorn Basin Structure and Temperatures



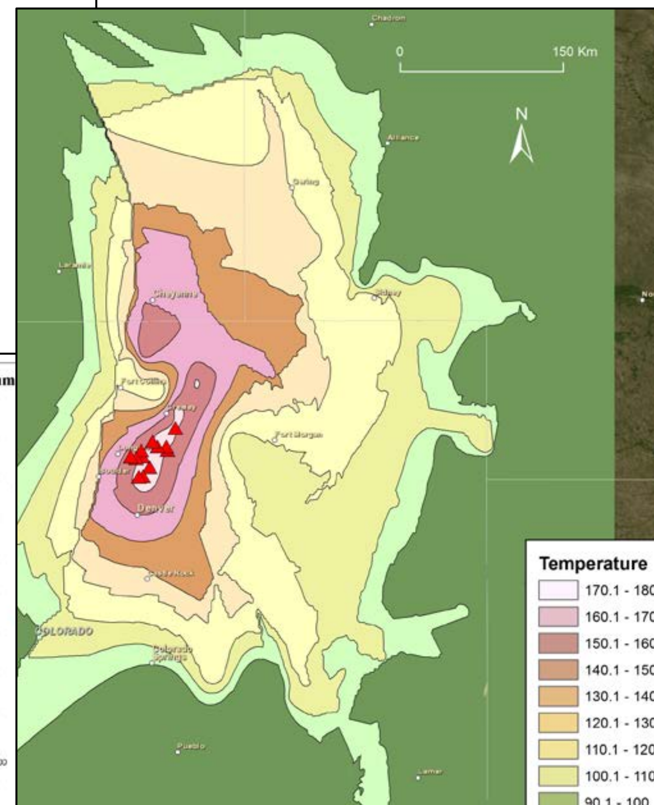

*Results from the Porro et al study indicate that many of the basins should be excluded, for example, the Bighorn Basin has good temperatures for geothermal energy production, but these occur at over 5 km, assumed too deep for economic drilling costs. The temperature at the 4 km threshold is only 100-110 °C, in the barely marginal range for binary power systems.*

Porro, Colleen, A. Esposito, C. Augustine, and B. Roberts, 2012, **An Estimate of the Geothermal Energy Resource in the Major Sedimentary Basins in the United States;** Geothermal Resources Council Transactions, Vol. 36.

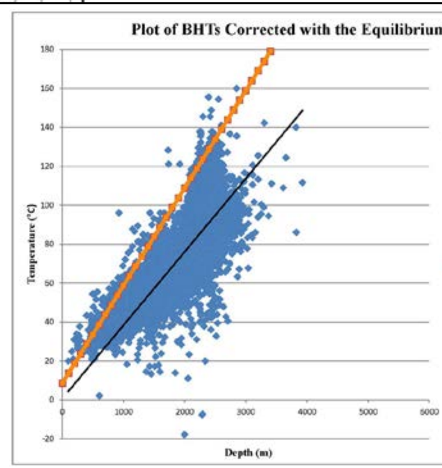
# Denver Basin Structure Map with Temperatures




Porro, Colleen, A. Esposito, C. Augustine, and B. Roberts, 2012, **An Estimate of the Geothermal Energy Resource in the Major Sedimentary Basins in the United States;** Geothermal Resources Council Transactions, Vol. 36.



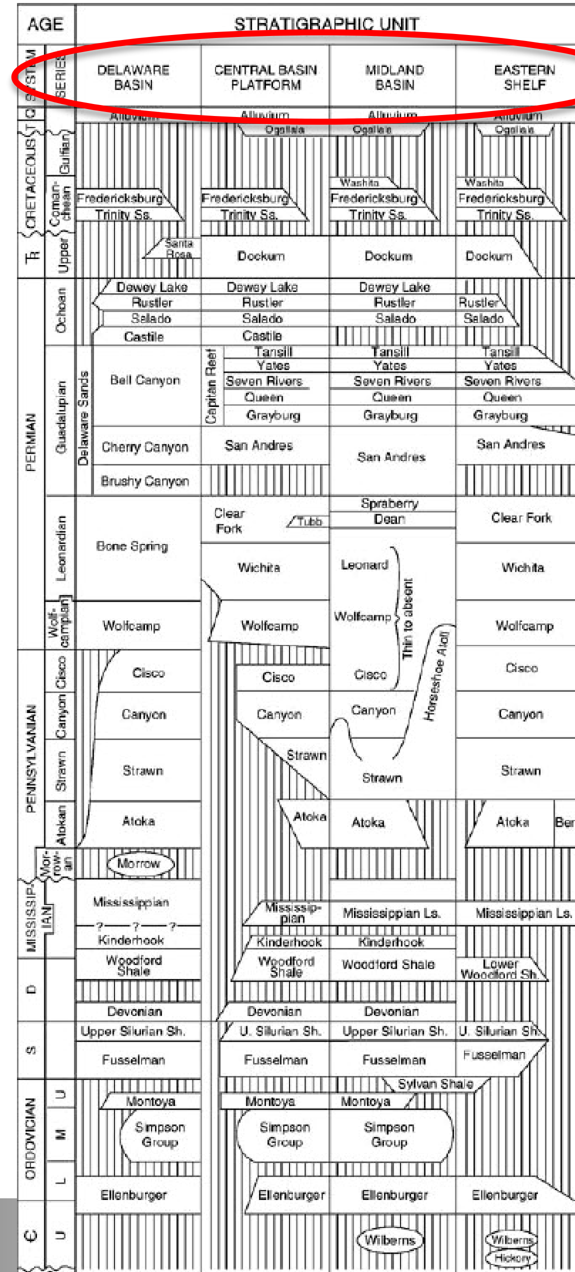

**The Denver Basin has mid-range potential and should be further evaluated. Recent bottom-hole temperature (BHT) corrected data analysis by Crowell et al (2012) indicates the Denver Basin Dakota Group has better temperatures than previously thought (Porro et al).**




Crowell, Anna M., Aaron T. Ochsner, and Will Gosnold., 2012, **Correcting bottomhole temperatures in the Denver Basin: Colorado and Nebraska**, GRC Trans., 36, 201-206.

# Stratigraphic Columns – Sources

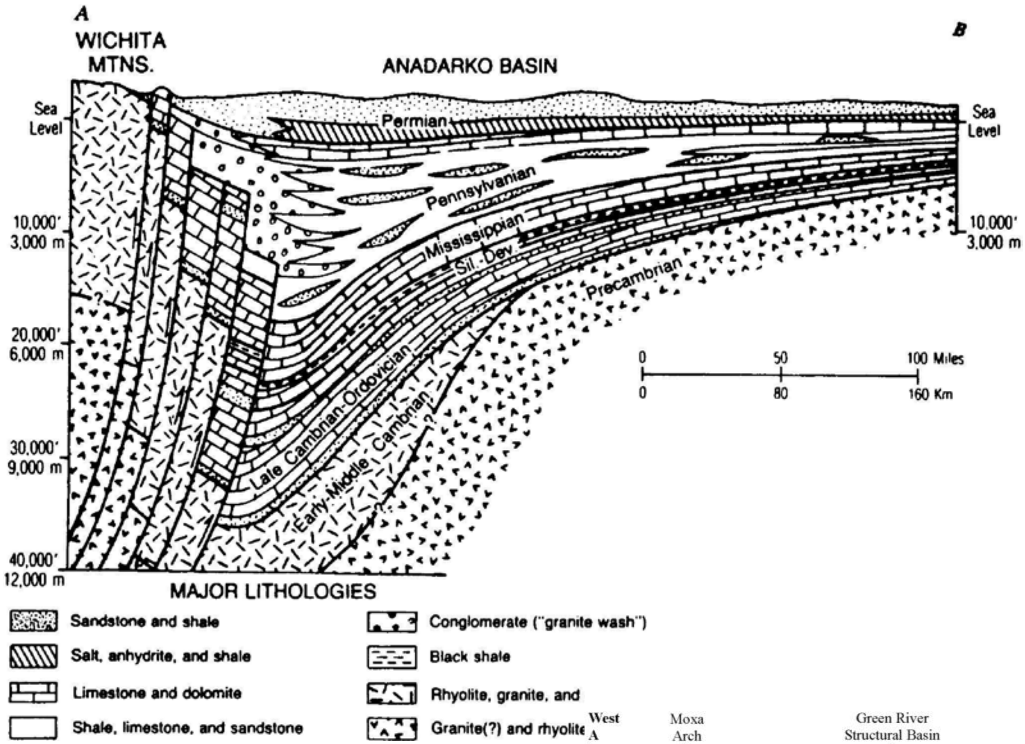
| Era | Period | Epoch | Formation: Northwest Shelf | Formation: Delaware Basin | General Lithology | Approximate Thickness (ft) |
|---|---|---|---|---|---|---|
| Paleozoic | Permian | Ochoan | Dewey Lake | | Redbeds / Anhydrite | 200–400 |
| | | | Rustler | | Halite | 100 |
| | | | Salado | Castile Anhydrite | Halite / Anhydrite | 1000 |
| | | Guadalupian | Artesia Group: Tansill; Capitan | Delaware Mountain Group: Bell Canyon | Anhydrite / Dolo. | 200 |
| | | | Yates; Capitan | Bell Canyon | Ss Sh / Anhydrite | 200 |
| | | | Seven Rivers; Capitan | Bell Canyon | Dolomite / Anhydrite | 500 |
| | | | Queen; Goat Seep | Bell Canyon / Cherry Canyon | Sandy Dolomite / Anhydrite / Shale | 200–500 |
| | | | Grayburg | Cherry Canyon | Dolomite / Anhy. / Shale / Sandstone | 300 |
| | | | *San Andres* | Cherry Canyon / Brushy Canyon | Dolomite / Anhydrite | 1500 |
| | | Leonardian | Glorieta | Brushy Canyon | Sandy Dolomite | 100 |
| | | | Yeso | Victoria Peak; Bone Spring | Dolo. / Anh. / Ss. | 1500 |
| | | | Abo | Bone Spring | Dolo. / Anh. / Sh. | 1000 |
| | | Wolfcampian | Wolfcamp | | Limestone / Dolo. | 0–1500 |
| | Pennsylvanian | Virgilian | Cisco | | Limestone / Ss. | 0–1250 |
| | | Missourian | Canyon | | Limestone / Sh. | |
| | | Des Moinesian | Strawn | | Limestone / Ss. | 0–750 |
| | | Atokan | Bend | | Lime / Ss. / Sh. | 0–1250 |
| | | Morrowan | Morrow | | Lime / Ss. / Sh. | |
| | Mississippian | | | | Limestone / Sh. | 0–800 |
| | Devonian | | | | Dolomite / Chert | 0–1200 |
| | Silurian | | Fusselman | | Dolomite / Chert | |
| | Ordovician | Upper | Montoya | | Dolomite / Chert | 0–400 |
| | | Middle | Simpson | | Lime / Ss. / Sh. | 0–200 |
| | | Lower | Ellenburger | | Dolomite | 0–400 |
| | Cambrian | | | | Sandstone | |






Hills J.M., 1984. "Sedimentation, tectonism, and hydrocarbon generation in Delaware basin, west Texas and southeastern New Mexico."American Association of Petroleum Geologists Bulletin, v. 68(3), p. 250-267; U. S. Geological Survey Digital Data Series DDS-36; 1996

# Example Geologic Cross Sections

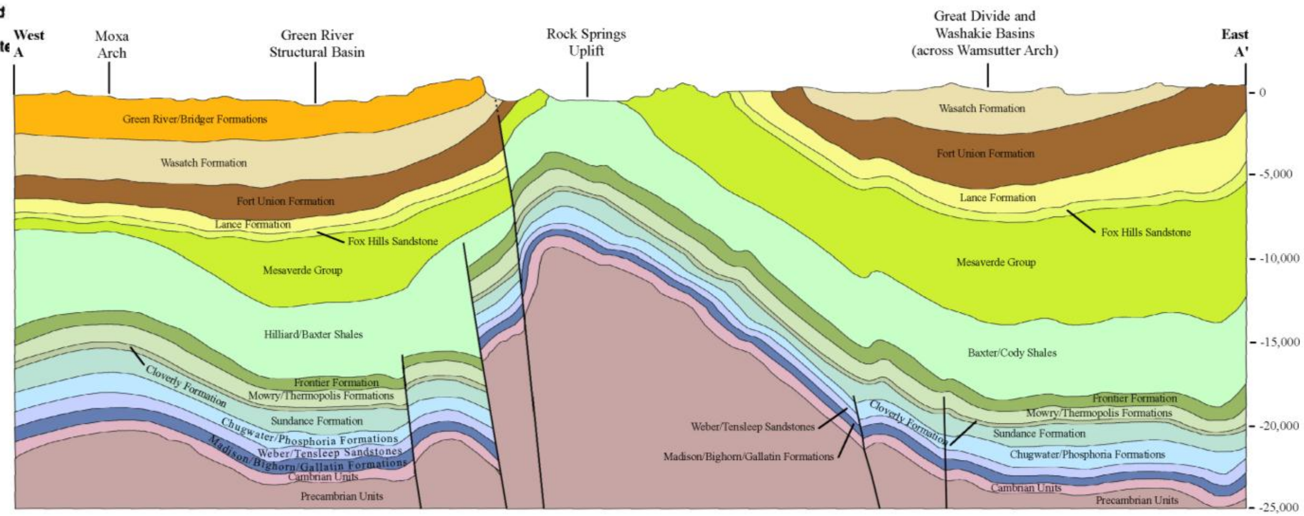



## Anadarko Basin

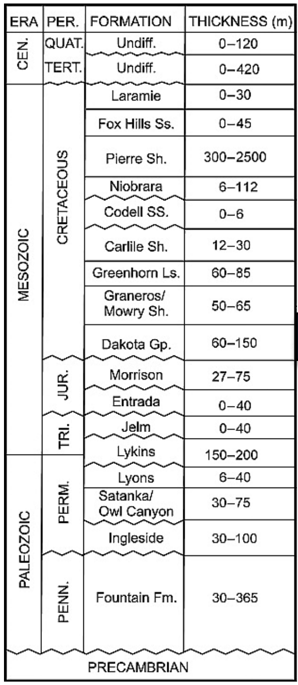
Johnson, K. S., 1989, **Geological evolution of the Anadarko basin**, *in* K. S. Johnson, ed., Anadarko basin symposium, 1988: Oklahoma Geological Survey Circular 90, p. 3–12.

Fred McLaughlin and Yuriy Ganshin, Wyoming State Geological Survey, *in* Clarey, Keith E., T. Bartos, D. Copeland, L. L. Hallberg, M. L. Clark, and M. L. Thompson, 2010, **Green River Basin Water Plan II – Groundwater study**: Wyoming Water Development Commission and Wyoming State Geological Survey.

## Greater Green River Basin



# Denver Basin Stratigraphic Column




| Period | Formation (Group) | Lithology | Thickness (ft) | Depth (ft) | Porosity % | Perm. md | Temp. °C | HC Zones |
|---|---|---|---|---|---|---|---|---|
| Tertiary | Castle Rock | Conglomerate | 400 | - | | | | |
| Cretaceous | Dawson | SS, Sh | 1,200 | - | | | | |
| | Denver | SS, Sh | 1,000 | 1,200 | | | | CBM |
| | Arapahoe | SS | 600 | 2,200 | | | | |
| | Laramie | SS | 150 | 2,800 | | | | CBM |
| | Fox Hills | SS | 200 | 2,950 | | | | |
| | Pierre | Sh, SS | 6,000 | 3,150 | | | 100-110 | Oil/Gas |
| | Niobrara | Sh, LS | 350 | 9,150 | | | 110-120 | Oil |
| | Codell | SS | 20 | 9,500 | | | 120-130 | Oil/Gas |
| | Carlile | Sh | 100 | 9,520 | | | 120-130 | |
| | Greenhorn | LS | 300 | 9,620 | | | 120-130 | |
| | Graneros/ "D" SS | Sh | 200 | 9,920 | | | 120-130 | Oil/Gas |
| | Mowry | Sh | 200 | 10,120 | | | 120-130 | |
| | Muddy "J" SS | SS | 500 | 10,320 | | | 120-130 | Oil/Gas |
| | Skull Creek | Sh | 200 | 10,820 | | | 130-140 | |
| | Plainview/Dakota | SS | 200 | 11,020 | | | 130-140 | Oil/Gas |
| | Lytle/Lakota | SS | 100 | 11,220 | | | 130-140 | Oil/Gas |
| Jurassic | Morrison | Sh, SS, LS | 250 | 11,320 | | | 130-140 | |
| | Ralston Creek | Sh, LS, SS | 100 | 11,570 | | | 130-140 | |
| | Entrada | Sh, SS | 150 | 11,670 | | | 130-140 | |
| Triassic | Jelm | SS | 150 | 11,820 | | | 140-150 | |
| Permian | Lykins | SS | 650 | 11,970 | | | 140-150 | |
| | **Lyons** | **SS** | **130** | **12,620** | **15** | **45** | **140-150** | Oil/Gas |
| | **Ingleside** | **Dol** | **330** | **12,750** | **19** | **100** | **140-150** | |
| Pennsylvanian | Fountain | SS | 1,200 | 13,080 | | | 140-150 | |
| Mississippian | Guernsey | | | 14,280 | | | | |
| Cambrian | Flathead | SS | | 14,280 | | | | |

# Sedimentary Basin Stratigraphic Columns

## Anadarko

| Period | Formation/Group | Lithology | Thickness | Depth (ft) | Porosity % | Perm. md | Temp °C |
|---|---|---|---|---|---|---|---|
| Tertiary | Ogalla | | 30 | 30 | | | |
| Cretaceous | Dakota | SS | 50 | 80 | | | |
| Permian | Elk City | SS | 170 | 250 | | | |
| | Cloud Chief | Gypsum | 300 | 550 | | | |
| | Whitehorse | SS, Sh | 390 | 940 | | | |
| | El Reno | SS, Sh | 600 | 1,540 | | | |
| | Hennessey | SS, Sh, Evaporites | 400 | 1,940 | | | |
| | Chase | LS | 150 | 2,090 | | | |
| | Council Grove | Sh, LS | 325 | 2,415 | | | |
| | Admire | Sh | 225 | 2,640 | | | |
| Pennsylvanian | Wabaunsee | Sh | 500 | 3,140 | | | |
| | Shawnee | LS | 350 | 3,490 | | | |
| | Douglas | LS | 1,000 | 4,490 | | | |
| | Lansing | LS, Sh | 3,200 | 7,690 | | | |
| | Kansas City | LS, Sh | 300 | 7,990 | | | |
| | Marmaton | LS | 3,000 | 10,990 | | | |
| | Cherokee | Sh, SS | 3,800 | 14,790 | | | |
| | Atoka | Sh | 4,300 | 19,090 | | | |
| | **Morrow** | **Sh, SS** | **3,750** | **22,840** | 15 | 100 | |
| Mississippian | Springer | Sh, SS | 1,700 | 24,540 | | | |
| | Chester | Sh, LS, Dol | 300 | 24,840 | | | |
| | Meramac | LS | 1,000 | 25,840 | | | |
| | Osage | LS | 300 | 26,140 | | | |
| Devonian | Woodford | Sh | 750 | 26,890 | | | |
| Silurian | Hunton | LS, Dol | 1,000 | 27,890 | | | |
| Ordovician | Sylvan | Sh | 2,000 | 29,890 | | | |
| | Viola | LS | 600 | 30,490 | | | |
| | Simpson | SS, Dol, Sh | 1,350 | 31,840 | | | |
| | Arbuckle | Dol & inter-bedded LS | 7,600 | 39,440 | | | 320-380 |
| Cambrian | Reagan | SS | | 39,440 | | | 380-400 |

## Bighorn

| Period | Formation/Group | Lithology | Thickness | Depth (ft) | Porosity % |
|---|---|---|---|---|---|
| Tertiary | Willwood | SS, Sh, Carbonates | 2,000 | - | |
| | Ft. Union | SS | 6,000 | 2,000 | |
| Cretaceous | Lance | SS, Sh | 1,000 | 8,000 | |
| | Meeteetse | Coal | 1,000 | 9,000 | |
| | Mesaverde | SS, Sh | 1,100 | 10,000 | |
| | Cody | Sh | 2,000 | 11,100 | |
| | Frontier | SS, Sh, Bentonite | 600 | 13,100 | |
| | Mowry | Sh | 365 | 13,700 | |
| | Muddy | SS | 300 | 14,065 | |
| | Thermopolis | Sh | 560 | 14,365 | |
| | Cloverly | SS | 350 | 14,925 | |
| Jurassic | Morrison | LS, SS, Sh | 200 | 15,275 | |
| | Sundance | Sh, SS | 365 | 15,475 | |
| | Gypsum Spring | Evap | 200 | 15,840 | |
| Triassic | Chugwater | Sh, LS | 1,000 | 16,040 | |
| Permian | Park City (Phospho | Carbonates | 150 | 17,040 | |
| Pennsylvanian | **Tensleep** | **SS** | **200** | **17,190** | **16.6** |
| | Amsden | Inter-bedded LS, Sh, SS | 280 | 17,390 | |
| Mississppian | Madison | LS | 750 | 17,670 | |
| Devonian | Three Forks | Sh, Dol | 200 | 18,420 | |
| Ordovician | Bighorn | Dol | 365 | 18,620 | |
| Cambrian | Gallatin | LS | 400 | 18,985 | |
| | Gros Ventre | Inter-bedded LS, Sh, SS | 700 | 19,385 | |
| | Flathead | SS | 150 | 20,085 | |

## Delaware/Permian

| Period | Formation/Group | Lithology | Thickness | Depth (ft) | Porosity % | Perm. md | Temp. °C | HC Zones |
|---|---|---|---|---|---|---|---|---|
| Cretaceous | Fredericksburg | LS | 0-90 | 90 | | | | |
| | Trinity | SS | 30 | 120 | | | | |
| Triassic | Santa Rosa | SS | 250 | 370 | | | | |
| Permian | Dewey Lake | Redbeds, Anhydrite | 400 | 770 | | | | |
| | Rustler | Halite | 100 | 870 | | | | |
| | Salado | Halite, Anhydrite | 1000 | 1870 | | | | |
| | Castile | | | 1870 | | | | |
| | **Bell Canyon** | **Anhydrite, SS, Sh, Dol** | **1400** | **3270** | **24** | **40** | | x |
| | Cherry Canyon (San Andres) | Dol, Sh, SS, Anhydrite | 1800 | 5070 | | | | x |
| | Brushy Canyon (San Andres) | Dol-Sandy | 100 | 5170 | | | | x |
| | Bone Spring | Dol, SS, Sh, Anhydrite | 2500 | 7670 | | | | x |
| | Wolfcamp | LS, Dol | 1500 | 9170 | | | | x |
| Pennsylvanian | Cisco | LS, SS | 1250 | 10420 | | | | |
| | Canyon | LS, Sh | | 10420 | | | | |
| | Strawn | LS, SS | 750 | 11170 | | | | |
| | Bend | LS, SS, Sh | 1250 | 12420 | | | | |
| | Morrow | LS, SS, Sh | 1100 | 13520 | | | | x |
| Mississippian | | LS, Sh | 800 | 14320 | | | 100-110 | |
| Devonian | Woodford | Sh | 700 | 15020 | | | 100-110 | x |
| | | Dol, Chert | 1200 | 16220 | | | 110-120 | |
| Silurian | Fusselman | Dol, Chert | 15 | 16235 | | | 110-120 | |
| Ordovician | Montoya | Dol, Chert | 400 | 16635 | | | 110-120 | |
| | Simpson | LS, SS, Sh | 200 | 16835 | | | 110-120 | |
| | **Ellenburger** | **Dol** | **400** | **17235** | **15** | **50** | **120-130** | **x** |
| Cambrian | | | | 17235 | | | 120-130 | |

## Denver

| Period | Formation (Group) | Lithology | Thickness (ft) | Depth (ft) | Porosity | Perm. | Temp. | HC Zones |
|---|---|---|---|---|---|---|---|---|
| Tertiary | Castle Rock | Conglomerate | 400 | - | | | | |
| Cretaceous | Dawson | SS, Sh | 1,200 | - | | | | |
| | Denver | SS, Sh | 1,000 | 1,200 | | | | |
| | Arapahoe | SS | 600 | 2,200 | | | | |
| | Laramie | SS | 150 | 2,800 | | | | |
| | Fox Hills | SS | 200 | 2,950 | | | | |
| | Pierre | Sh, SS | 6,000 | 3,150 | | | | |
| | Niobrara | Sh, LS | 350 | 9,150 | | | | |
| | Codell | SS | 20 | 9,500 | | | | |
| | Carlile | Sh | 100 | 9,520 | | | | |
| | Greenhorn | LS | 300 | 9,620 | | | | |
| | Graneros/"D" SS | Sh | 200 | 9,920 | | | | |
| | Mowry | Sh | 200 | 10,120 | | | | |
| | Muddy "J" SS | SS | 500 | 10,320 | | | | |
| | Skull Creek | Sh | 200 | 10,820 | | | | |
| | Plainview/Dakota | SS | 200 | 11,020 | | | | |
| | Lytle/Lakota | SS | 100 | 11,220 | | | | |
| Jurassic | Morrison | Sh, SS, LS | 250 | 11,320 | | | 130-140 | |
| | Ralston Creek | Sh, LS, SS | 100 | 11,570 | | | 130-140 | |
| | Entrada | Sh, SS | 150 | 11,670 | | | 130-140 | |
| Triassic | Jelm | SS | 150 | 11,820 | | | 140-150 | |
| Permian | Lykins | SS | 650 | 11,970 | | | 140-150 | |
| | **Lyons** | **SS** | **130** | **12,620** | **15** | **45** | **140-150** | **Oil/Gas** |
| | **Ingleside** | **Dol** | **330** | **12,750** | | | | |
| Pennsylvanian | Fountain | SS | 1,200 | 13,080 | | | | |
| Mississippian | Guernsey | | | 14,280 | | | | |
| Cambrian | Flathead | SS | | 14,280 | | | | |

## Fort Worth

| Period | Formation/Group | Lithology | Thickness | Depth (ft) | Porosity % | Perm. md | Temp. °C | HC Zones |
|---|---|---|---|---|---|---|---|---|
| Cretaceous | Fredericksburg | LS | 400 | 0 | | | | |
| | Trinity | SS | 300 | 400 | | | | |
| Permian | Wichita | Dol | 600 | 700 | | | | |
| Pennsylvanian | Cisco | LS, SS | 800 | 1300 | | | | Gas/Oil |
| | Canyon | LS, Sh | 1000 | 2100 | | | | Oil |
| | Strawn | LS, SS | 1600 | 3100 | | | | Oil/Gas |
| | Bend | LS, SS, Sh | 2000 | 4700 | | | | Gas/Oil |
| | Marble Falls | LS | 350 | 6700 | | | 100-110 | Oil |
| Mississippian | Barnett (includes Forestburg & Chappel LS) | Sh, LS | 700 | 7050 | | | 110-120 | Gas/Oil |
| Ordovician | Viola | LS | 120 | 7750 | | | 120-130 | Oil |
| | Simpson | LS, SS, Sh | 100 | 7870 | | | 120-130 | |
| | **Ellenburger** | **Dol** | **1500** | **7970** | **15** | **50** | **130-140** | **Oil** |
| Cambrian | Wilberns | LS, Dol | 400 | 9470 | | | 140-150 | |
| | Riley | Ss, Ls | 300 | 9870 | | | 140-150 | |
| | Hickory | SS | 200 | 10170 | | | 140-150 | |

## Powder River

| Period | Formation/Group | Lithology | Thickness | Depth (ft) | Porosity % | Perm. md | Temp. °C | HC Zones |
|---|---|---|---|---|---|---|---|---|
| Tertiary | White River | SS, LS | 300 | - | | | | |
| | Wasatch | SS, Sh | 2,300 | 300 | | | | |
| | Fort Union | SS, Sh | 1,100 | 2,600 | | | | Coal/CBM |
| Cretaceous | Lance | SS, Sh | 1,000 | 3,700 | | | | Oil |
| | Fox Hills | SS | 500 | 4,700 | | | | |
| | Lewis | Sh | 2,200 | 5,200 | | | | |
| | Mesaverde | SS | 2,000 | 7,400 | | | | Oil |
| | Cody/Steele/ Pierre, Shannon | Sh, SS | 2,500 | 9,400 | 14 | 20 | | Oil |
| | Niobrara | LS, Sh | 500 | 11,900 | | | | Oil |
| | Carlile | Sh | 300 | 12,400 | | | | |
| | Frontier | SS, Sh | 700 | 12,700 | | | 100-110 | Oil, Gas |
| | Mowry | Sh | 350 | 13,400 | | | 100-110 | Oil |
| | Muddy | SS | 50 | 13,750 | 24 | 10 | 100-110 | Oil |
| | Thermopolis | Sh | 100 | 13,800 | | | 100-110 | |
| | Dakota Group | Sh, SS | 225 | 13,900 | 11 | 25 | 100-110 | Oil, Gas |
| | Morrison | Sh, SS | 200 | 14,125 | | | 110-120 | |
| Jurassic | Sundance | SS, Sh, LS | 330 | 14,325 | | | 110-120 | Oil |
| | Gypsum Spring | Evap, Sh | 150 | 14,655 | | | 110-120 | |
| Triassic | Chugwater | SS, Sh | 675 | 14,805 | | | 110-120 | |
| Permian | Goose Egg | Sh, LS | 380 | 15,480 | | | 120-130 | Oil |
| **Pennsylvanian** | **Tensleep/Leo/ Minnelusa** | **SS, Dol** | **500** | **15,860** | **11** | **20** | **120-130** | **Oil** |
| | Amsden | Sh, SS, LS | 200 | 16,360 | | | 120-130 | |
| Mississippian | Madison | LS | 600 | 16,560 | 17.5 | 30 | 130-140 | |
| Devonian | Jefferson | Sh, SS, Dol | 100 | 17,160 | | | 130-140 | |
| Ordovician | Bighorn | Dol | 300 | 17,260 | | | 130-140 | |
| Cambrian | Gallatin | LS | 160 | 17,560 | | | 130-140 | |
| | Gros Ventre | SS, Sh, LS | 690 | 17,720 | | | 140-150 | |
| | Flathead | SS | 450 | 18,410 | | | 140-150 | |

## Hanna

| Period | Formation/Group | Lithology | Thickness | Depth (ft) | Porosity % | Perm. md |
|---|---|---|---|---|---|---|
| Tertiary | Hanna | SS, Sh | 18,000 | - | | |
| | Ferris | SS, Sh | 2,000 | 18,000 | | |
| Cretaceous | Medicine Bow | SS, Sh | 6,000 | 20,000 | | |
| | Fox Hills | SS | 200 | 26,000 | | |
| | Lewis | Sh | 2,100 | 26,200 | | |
| | Mesaverde | SS, Sh | 2,600 | 28,300 | | |
| | Steele | SS, Sh | 2,000 | 30,900 | | |
| | Niobrara | Sh | 400 | 32,900 | | |
| | Frontier | Sh | 300 | 33,300 | | |
| | Mowry | Sh | 300 | 33,600 | | |
| | Muddy | SS | 100 | 33,800 | | |
| | Thermopolis | Sh, Bentonite | 150 | 33,900 | | |
| | Cloverly | SS | 100 | 34,050 | | |
| Jurassic | Morrison | SS, Sh | 150 | 34,150 | | |
| | Sundance | SS, Sh, LS | 150 | 34,300 | | |
| Triassic | Chugwater | SS, Sh | 400 | 34,450 | | |
| Permian | Goose Egg | Sh, LS, gypsum | 200 | 34,850 | | |
| Pennsylvanian | Tensleep | SS | 300 | 35,050 | 11 | 20 |
| | Amsden | Sh, SS,LS | 200 | 35,350 | | |
| Mississippian | Madison | LS, Dol | 500 | 35,550 | | |
| Cambrian | Flathead | SS | 150 | 36,050 | | |

## Great Basin

| Period | Formation/Group | Lithology | Thickness | Depth (ft) | Porosity % |
|---|---|---|---|---|---|
| | Basalts (various) | volcanic | 300 | 300 | |
| Tertiary | Basin Fill | Cong, SS, Sh | 6000 | 6300 | |
| | Volcanics (various) | volcanic | 500 | 6800 | |
| Cretaceous | North Horn | Cong, LS | 1500 | 8300 | |
| Jurassic | Entrada | SS | 500 | 8800 | |
| | Arapien | Sh | 500 | 9300 | |
| | Twin Creek | LS | 200 | 9500 | |
| | Navajo | SS | 1500 | 11000 | |
| Triassic | Chinle | Sh | 200 | 11200 | |
| | Moenkopi | SS, Sh | 1000 | 12200 | |
| Permian | Arcturus Group | LS | 880 | 13080 | |
| Pennsylvanian | Ely Ls | LS | 1000 | 14080 | |
| Mississippian | Chainman Sh | Sh | 1000 | 15080 | |
| | Joana LS | LS | 200 | 15280 | |
| Devonian | Pilot Sh | Sh | 300 | 15580 | |
| | Guilmette | LS | 750 | 16330 | |
| | Simonson | Dol | 550 | 16880 | 10 |
| | Sevy | Dol | 710 | 17590 | 10 |
| Silurian | Laketown | Dol | 250 | 17840 | 10 |

## Green River

| Period | Formation/Group | Lithology | Thickness | Depth (ft) | Porosity % |
|---|---|---|---|---|---|
| Tertiary | Bridger | SS | 2,300 | - | |
| | Green River | SS, Sh | 4,000 | 2,300 | |
| | Wasatch | SS, Sh | 3,200 | 6,300 | |
| | Fort Union | SS, Sh | 3,000 | 9,500 | |
| | Lance | SS, Sh | 1,000 | 12,500 | |
| | Fox Hills | SS | 500 | 13,500 | |
| Cretaceous | Mesaverde | SS, Sh | 7,000 | 14,000 | |
| | Baxter (Hilliard) | Sh | 4,100 | 21,000 | |
| | Frontier | Sh, SS, Bent | 1,600 | 25,100 | |
| | Mowry | Sh | 500 | 26,700 | |
| | Muddy | SS | 50 | 27,200 | |
| | Thermopolis | Sh | 200 | 27,250 | |
| | **Dakota** | **SS** | **200** | **27,450** | **14** |
| | Cloverly | SS | 100 | 27,650 | |
| Jurassic | Morrison | LS, SS, Sh | 325 | 27,750 | |
| | Sundance | SS, LS | 3,000 | 28,075 | |
| | Gypsum Spring | Evap | 600 | 31,075 | |
| | Nugget | SS | 500 | 31,675 | |
| Triassic | Chugwater | SS, Sh | 2,800 | 32,175 | |
| | Dinwoody | SS | 120 | 34,975 | |
| Permian | Phosphoria | Carbonates | 300 | 35,095 | |
| Pennsylvanian | Tensleep (Weber) | SS | 400 | 35,395 | 15 |
| | | Inter-bedde | 250 | 35,795 | |
| | | SS | 70 | 36,045 | |
| | | LS | 1,000 | 36,115 | |
| | | SS | 380 | 37,115 | |
| | | Dol | 300 | 37,495 | |
| | | LS | 300 | 37,795 | |
| | ntre | Inter-bedde | 700 | 38,095 | |
| | | SS | 200 | 38,795 | |

## Gulf Coast

| Period | Formation/Group | Lithology | Thickness | Depth (ft) | Porosity % | Perm. md | Temp. °C | HC Zones |
|---|---|---|---|---|---|---|---|---|
| Tertiary | Goliad/Willis | SS | 2,000 | - | | | | |
| | Lagarto/Fleming | Clay | 1,500 | 2,000 | | | | |
| | **Frio** | **SS** | **1,500** | **3,500** | **25** | **400** | | Ga |
| | Vicksburg | LS | 500 | 5,000 | 19.5 | 2.5 | | Ga |
| | **Jackson** | **Clays, SS** | **1,200** | **5,500** | **31** | **600** | | Oil |
| | Yegua | | 1,000 | 6,700 | | | | Ga |
| | Claiborne Group | Ss, Clay, Quartzite | 2,000 | 7,700 | | | 100-120 | Ga |
| | **Wilcox** | **SS, Sh** | **4,000** | **9,700** | **28.5** | **100** | **120-140** | Ga |
| | Midway | LS, Sh | 1,500 | 13,700 | | | 140-180 | |
| Cretaceous | Navarro, Olmos, Escondido | SS, Sh | 2,200 | 15,200 | | | 180-200 | Ga |
| | Taylor/San Miguel | Clays | 2,000 | 17,400 | | | 200-220 | Ga |
| | Austin | Chalk | 1,300 | 19,400 | | | 220-240 | Ga |
| | Eagle Ford | Sh | 500 | 20,700 | | | 240-260 | Ga |
| | Woodbine, Tuscaloosa | SS | 400 | 21,200 | 28 | 100 | 240-260 | Ga |
| | Buda | LS | 100 | 21,600 | | | 260-280 | Ga |
| | Del Rio | Clays | 100 | 21,700 | | | 260-280 | |
| | Georgetown | LS | 100 | 21,800 | | | 260-280 | Gas/Oil |
| | **Edwards, Fredericksburg** | **LS** | **800** | **21,900** | **25** | **180** | **260-280** | **Gas/Oil** |
| | Glen Rose | LS | 500 | 22,700 | | | 260-280 | Gas/Oil |
| | Pearsall | LS, SS | 100 | 23,200 | | | 280-300 | Gas/Oil |
| | Sligo | LS | 2,000 | 23,300 | | | 280-300 | Gas/Oil |
| | Hosston/Travis Peak | SS | 1,550 | 25,300 | 12 | 9 | | |
| Jurassic | Cotton Valley | Sh, LS | 1,400 | 26,850 | 12.5 | 25 | | |
| | Buckner | Evap | 1,500 | 28,250 | | | | |
| | Smackover | LS | 850 | 29,750 | | | | |
| | Louann Salt | Evap | | 30,600 | | | | |
| Triassic | Eagle Mills | SS, Slt, Intrusive | | | | | | |
| Paleozoic | Ouachita | | | | | | | |

## Raton

| Period | Formation/Group | Lithology | Thickness | Depth (ft) | Porosity % | Perm. md | Temp. °C | HC Zones |
|---|---|---|---|---|---|---|---|---|
| Recent | | Alluvium, basalt | 30 | - | | | | |
| Miocene | Devils Hole* | Congl | 25 | 30 | | | | |
| Oligocene | Farisita* | Congl, SS | - | 55 | | | | |
| Eocene | Huerfano* | Sh, Clyst | - | 55 | | | | |
| | Cuchara* | SS, Clyst | - | 55 | | | | |
| Paleocene | Poison Canyon | Congl, SS, Sltst, Sh | 1,000 | 55 | | | | Gas |
| Paleocene/ Cretaceous | Raton | SS, Sltst, Sh, coal, Congl | 1,500 | 1,055 | | | | Oil, Gas, coal, CBM |
| Upper Cretaceous | Vermejo | Sh, Sltst, SS, coal | 360 | 2,555 | | | | Oil, Gas, coal, CBM |
| | Trinidad | SS | 255 | 2,915 | 7 | 0.01 | | Oil, Gas |
| | Pierre | Sh, Sltst | 1,500 | 3,170 | | | | Oil, Gas |
| | Niobrara | Sh, LS | 560 | 4,670 | 8 | | | Oil |
| | Benton | SS, Sh, LS | 380 | 5,230 | | | | Gas |
| Lower Cretaceous | Dakota | SS, Congl, SS, Sh | 100 | 5,610 | 15 | 20 | | Oil |
| | Purgatoire | SS, Congl SS,Sh | 100 | 5,710 | 8 | | | |
| Jurassic | Morrison | Sh, LS, Sltst, gypsum, SS | 150 | 5,810 | 7.5 | | | |
| | Ralston Creek | Sh, LS, Sltst, gypsum, SS | 30 | 5,960 | | | | |
| | Entrada | Sh, LS, Sltst, gypsum, SS | 40 | 5,990 | 16 | 2 | | |
| Triassic | Dockum (Chinle) | SS, Shs, LS | 1,000 | 6,030 | 6 | | | |
| Permian | Bernal | Sltst, Sh | 150 | 7,030 | | | | |
| | San Andreas | LS | 150 | 7,180 | | | | |
| | Glorieta | Tight SS | 275 | 7,330 | 3.3 | | | |
| | Yeso | Sltst, Sh, SS, Dol, gypsum | 500 | 7,605 | | | | |
| Permian/Pennsylvanian | Sangre de Cristo Formation | LS, arkose, Congl | 6,500 | 8,105 | 5.2 | | 130-140 | Gas |
| Pennsylvanian | Madera | Arkose, LS | 700 | 14,605 | | | 140-160 | |
| *Absent in the Northern Raton Basin. | | | | 15,305 | *from log data (Table 3)* | | | |

## Sacramento

| Period | Formation/Group | Lithology | Thickness | Depth (ft) | Porosity % | Perm. md | Temp. °C | HC Zones |
|---|---|---|---|---|---|---|---|---|
| Tertiary | Mehrten | SS, Sh | 1,000 | - | | | | |
| | Valley Springs | SS, Sh | 1,000 | 1,000 | | | | |
| | Markley | SS, Sh | 600 | 2,000 | | | | |
| | Nortonville | Sh | 400 | 2,600 | | | | |
| | Domengine | SS | 400 | 3,000 | | | | |
| | Capay | Sh | 400 | 3,400 | | | | |
| | Mokelumne River | SS | 1,800 | 3,800 | | | | |
| Cretaceous | H&T | Sh | 250 | 5,600 | | | | |
| | Starkey | SS, Sh | 1,000 | 5,850 | | | | |
| | Winters | SS | 3,000 | 6,850 | | | | |
| | Sacramento | Sh | 700 | 9,850 | | | | |
| | Forbes/Kione | SS, Sh | 1,050 | 10,550 | | | | |
| | Dobbins | Sh | 375 | 11,600 | | | | |
| | Guinda | SS | 200 | 11,975 | | | | |
| | Funks | Sh | 300 | 12,175 | | | | |
| | Sites | SS | 300 | 12,475 | | | | |
| | Yolo | Sh | 300 | 12,775 | | | | |
| | Venado | SS | 300 | 13,075 | | | | |

## San Joaquin

| Period | Formation/Group | Lithology | Thickness | Depth (ft) | Porosity % | Perm. md |
|---|---|---|---|---|---|---|
| Tertiary | Tulare | SS | 2,900 | - | 35 | 700 |
| | San Joaquin | Sh | 2,300 | 2,900 | | |
| | Etchegoin | Sh | 5,000 | 5,200 | | |
| | Monterey (Reef Ridge, McClure, Santa Margarita SS) | Sh | 2,700 | 10,200 | 32 | 800 |
| | Temblor/Zilch | SS | 1,600 | 12,900 | | |
| | Vaqueros | SS | 700 | 14,500 | 14.5 | 30 |
| | Leda | SS | 260 | 15,200 | | |
| | Tumey | Sh | 1,200 | 15,460 | | |
| | Kreyenhagen | Sh | 1,200 | 16,660 | | |
| | Domengine | SS | 950 | 17,860 | | |
| | Lodo | Sh, SS | 1,500 | 18,810 | | |
| Cretaceous | Moreno | Sh | 700 | 20,310 | | |
| | Panoche | Sh | 3,000 | 21,010 | | |

## Uinta/Piceance

| Period | Formation/Group | Lithology | Thickness | Depth (ft) | Porosity % | Perm. md | Temp. °C | HC Zones |
|---|---|---|---|---|---|---|---|---|
| Tertiary | Alluvium | SS, Sh | 200 | - | | | | |
| | Duchesne River | SS | 3,000 | 200 | | | | |
| | Uinta | Sh | 5,000 | 3,200 | | | | |
| | Green River | Sh, LS | 6,000 | 8,200 | | | 100-120 | Gas/Oil |
| | Colton/ Wasatch | SS, Sh | 1,500 | 14,200 | 10 | 1 | 120-140 | Gas/Oil |
| | Flagstaff/ Fort Union | Sh, LS | 2,000 | 15,700 | | | 140-150 | Gas |
| | North Horn | SS, Sh | 2,500 | 17,700 | | | 150-160 | |
| Cretaceous | **Price River/ Mesaverde** | **SS** | **3,200** | **20,200** | **18** | **75** | **160-200** | **Gas/Oil** |
| | Mancos (including Castlegate, Black-hawk, Emery, and Ferron SS) | Sh | 5,000 | 23,400 | | | 200-220 | Gas |
| | Frontier-Mowry | SS, Sh | 350 | 28,400 | | | >220 | Oil |
| | Dakota-Cedar Mtn | SS, Sh | 300 | 28,750 | | | >220 | Gas/O |
| Jurassic | Morrison | SS, Sh | 1,100 | 29,050 | | | >220 | Gas/O |
| | Stump/ Curtis | Sh, LS | 200 | 30,150 | | | >220 | Oil |
| | Entrada | SS | 500 | 30,350 | | | >220 | Oil/Ga |
| | Twin Creek/ Carmel | LS, Sh | 650 | 30,850 | | | >220 | |
| | Nugget | SS | 700 | 31,500 | | | >220 | |
| Triassic | Chinle/ Shinarump | Sh, SS | 400 | 32,200 | | | >220 | Oil |
| | Thaynes/ Moenkopi | Sh, LS | 1,400 | 32,600 | | | >220 | |
| Permian | Weber & Park City | LS, SS | 1,500 | 34,000 | | | >220 | Oil |
| Pennsylvanian | Lower Weber | SS | 1,200 | 35,500 | 12.5 | 10 | >220 | Oil |
| | Morgan/Minturn | LS | 250 | 36,700 | | | >220 | |
| | RoundValley | LS | 300 | 36,950 | | | >220 | |
| Mississippian | Manning Canyon | Sh | 100 | 37,250 | | | >220 | |
| | Doughnut/ Humbug | Sh | 200 | 37,350 | | | >220 | |
| | Deseret | LS | 650 | 37,550 | | | >220 | |
| | Madison/ Leadville | LS | 250 | 38,200 | | | >220 | |
| | Maxfield | LS | 300 | 38,450 | | | >220 | |
| Cambrian | Ophir/Dotsero | Sh | 50 | 38,750 | | | >220 | |
| | Lodore-Tintic/ Sawatch | SS, Qtzite | 500 | 38,800 | | | >220 | |

## Imperial Valley

| Period | Formation/Group | Lithology | Thickness | Depth (ft) | Porosity % | Perm. md | Temp. °C |
|---|---|---|---|---|---|---|---|
| Pleistocene | Alluvium | SS, Sh, Slt | 1,000 | - | | | |
| | Brawley/Ocotillo | SS, Sh, Slt, Conglo-merate | 1,500 | 1,000 | | | |
| Pliocene | Borrego | Slt | 5,600 | 2,500 | 15 | 100 | 100-130 |
| | Palm Springs | SS | 6,000 | 8,100 | 25 | 250 | 130-200 |
| Miocene | Imperial | SS, Slt | 3,900 | 14,100 | | | 200-280 |
| | Split Mountain | SS, Evap | 2,700 | 18,000 | | | 280-320 |
| | Anza | SS | 1,200 | 20,700 | | | 320-340 |
| | Alverson | Volcanics | 700 | 21,900 | | | >340 |

## Wind River

| Period | Formation/Group | Lithology | Thickness | Depth (ft) | Porosity % | Perm. md | Temp. °C | HC Zones |
|---|---|---|---|---|---|---|---|---|
| Tertiary | Wind River | Claystone | 5,000 | - | | | | |
| | Indian Meadows | Congl. | 5,000 | 5,000 | | | | |
| | Ft Union | Sh | 4,500 | 10,000 | | | | |
| Cretaceous | Lance | SS, Sh | 3,000 | 14,500 | | | 110-130 | |
| | Meeteetse | Coal | 2,000 | 17,500 | | | 130-150 | |
| | Mesaverde | SS, Sh | 300 | 19,500 | | | 150-170 | |
| | Cody | Sh | 3,000 | 19,800 | | | 170-190 | |
| | Frontier | Sh, SS | 700 | 22,800 | | | 190-200 | |
| | Mowry | Sh | 700 | 23,500 | | | 200-210 | |
| | Muddy | SS | 50 | 24,200 | 17.5 | 0.5 | 210-220 | |
| | Thermopolis | Sh | 160 | 24,250 | | | 210-220 | |
| | Cloverly | Sh, SS | 125 | 24,410 | | | 210-220 | |
| Jurassic | Morrison | LS, SS, Sh | 210 | 24,535 | | | 210-220 | |
| | Sundance | Sh, SS | 400 | 24,745 | | | 210-220 | |
| | Gypsum Spring | Evap, Sh | 150 | 25,145 | | | 210-220 | |
| Triassic | Nugget | SS | 50 | 25,295 | | | >220 | Gas/Oil |
| | Chugwater | Sh, LS, SS | 1,200 | 25,345 | | | >220 | Gas/Oil |
| | Dinwoody | SS | 100 | 26,545 | | | >220 | |
| Permian | Phosphoria | Carbonates | 200 | 26,645 | | | >220 | Oil/Gas |
| Pennsylvanian | Tensleep | SS | 250 | 26,845 | 15 | 70 | >220 | Oil/Gas |
| | Amsden | LS, Sh, SS | 200 | 27,095 | | | >220 | Gas/Oil |
| Mississippian | Madison | LS | 500 | 27,295 | | | >220 | Oil/Gas |
| Ordovician | Big Horn | Dol | 50 | 27,795 | | | >220 | |
| Cambrian | Gallatin | LS | 300 | 27,845 | | | >220 | |
| | Gros Ventre | Sh | 500 | 28,145 | | | >220 | |
| | Flathead | SS | 350 | 28,645 | | | >220 | |

# Sources, Ages, and Locations of Porosity-Permeability Data Sets

| No. | Authors and Date | Geologic Age | Formation Name | Location | Basin / Province | Field |
|---|---|---|---|---|---|---|
| | | | | | | |
| 1 | Aase and others, 1996 | Jurassic | unnamed formation | North Sea | Central Graben | Ula and Gyda fields |
| 2 | Amthor and Okkerman, 1998 | Permian | Slochteren Formation | Netherlands | Permian Basin, North Sea | various and unnamed |
| 3 | Atkinson and others, 1990 | Permian-Triassic | Ivishak Formation | Alaska | North Slope of Alaska | Prudhoe Bay Field |
| 4 | Bloch and others, 1990 | Mississippian | Kekiktuk Conglomerate | Alaska | North Slope of Alaska | Endicott Field |
| 5 | Bloch, 1991 | Oligocene-Miocene | unnamed formation | South China Sea | unnamed | Yacheng Field |
| 6 | Bloch and others, 2002 | Jurassic | Ile Formation, Fangst Group | North Sea | North Sea | Block 6406 |
| 7 | Bourbie and Zinszner, 1985 | Oligocene | Fontainebleau Sand | France | Paris Basin, France | none |
| 8 | Bowker and Jackson, 1989 | Permian-Pennsylvanian | Weber Sandstone | Colorado | Piceance Basin | Rangely Field |
| 9 | Cant and Ethier, 1984 | Early Cretaceous | Falher Member of Spirit River Formation | Alberta, Canada | Alberta Deep Basin | Elmworth Field |
| 10 | Castle and Burns, 1998 | Silurian | Grimsby Sandstone of Medina Group | Pennsylvania | Appalachian Basin | Cooperstown Field |
| 11 | Cazier and others, 1995 | Oligocene | Mirador Formation | Colombia | Llanos Basin Foothills | Cusiana Field |
| 13 | Clark and Reinson, 1990 | Early Cretaceous | Viking Formation | Alberta, Canada | Cretaceous Western Interior Basin | Crystal Field |
| 14 | Corcoran and others, 1994 | Eocene | Wilcox Group | Louisiana | Louisiana Gulf Coast | Wildsville Field |
| 15 | Cox and others, 1994 | Jurassic | Nugget Sandstone | Wyoming | Overthrust Belt | Anschutz Ranch East Field |
| 16 | Dickinson, 1996 | Jurassic | Fulmar Formation, Humber Group | North Sea | Central Graben | Puffin Field |
| 17 | Dolly and Mullarkey, 1996 | Pennsylvanian | Morrow Sandstone | Colorado | Las Animas Arch | Nee Noche Field |
| 18 | Dolly and Mullarkey, 1996 | Devonian | Misener Sandstone | Oklahoma | Nemaha Uplift | Nash Northeast Field |
| 19 | Dolly and Mullarkey, 1996 | Early Cretaceous | Muddy Sandstone | Wyoming | Powder River Basin | Collums Field |
| 20 | Dolly and Mullarkey, 1996 | Late Cretaceous | Frontier Sandstone | Wyoming | La Barge Platform | Lincoln Roads Field |
| 21 | Dutton and Willis, 1998 | Early Cretaceous | Fall River Formation | Wyoming | Powder River Basin | Buck Draw Field |
| 22 | Dutton and others, 2003 | Permian | Bell Canyon Formation | Texas | Delaware Basin | East Ford Unit |
| 23 | Ehrenberg, 1990 | Middle Jurassic | Garn Formation | North Sea | Haltenbanken Area | Smorbukk and other fields |
| 24 | Estes-Jackson and others, 2001 | Cretaceous | Muddy Formation | Wyoming | Wind River Basin | Riverton Dome Field |
| 25 | Ganer, 1985 | Jurassic | Cotton Valley Formation | Louisiana | North Louisiana Salt Basin | Terryville Field |
| 26 | Gaupp and others, 1993 | Permian | Schneverdingen and other formations | Germany | North German Basin | basin-wide study |
| 27 | Grau, 2000 | Jurassic | Brae Formation | United Kingdom | South Viking Graben | East Brae Field |
| 28 | Grigsby and others, 1992 | Paleocene | Wilcox Group | Texas | Houston Embayment | Lake Creek Field |
| 29 | Hall and Link, 1990 | Late Miocene | Webster Zone, Monterey Formation | California | Southern San Joaquin Basin | Midway-Sunset Field |
| | *… 70 data sets, 49 basins worldwide* | | | | | |
| 67 | Tillman and Martinsen, 1987 | Late Cretaceous | Shannon Sandstone | Wyoming | Powder River Basin | Hartzog Draw Field |
| 68 | Trevena and Clark, 1986 | Miocene | various and unnamed | Gulf of Thailand | Pattani Basin | Baanpot and other fields |
| 69 | Wendlandt and Bhuyan,1990 | Cretaceous | Mesaverde Group | Utah | Book Cliffs Area | none |
| 70 | Worden and others, 2000 | Oligocene and Miocene | unnamed formation | South China Sea | Nam Con Son Basin | various and unnamed |

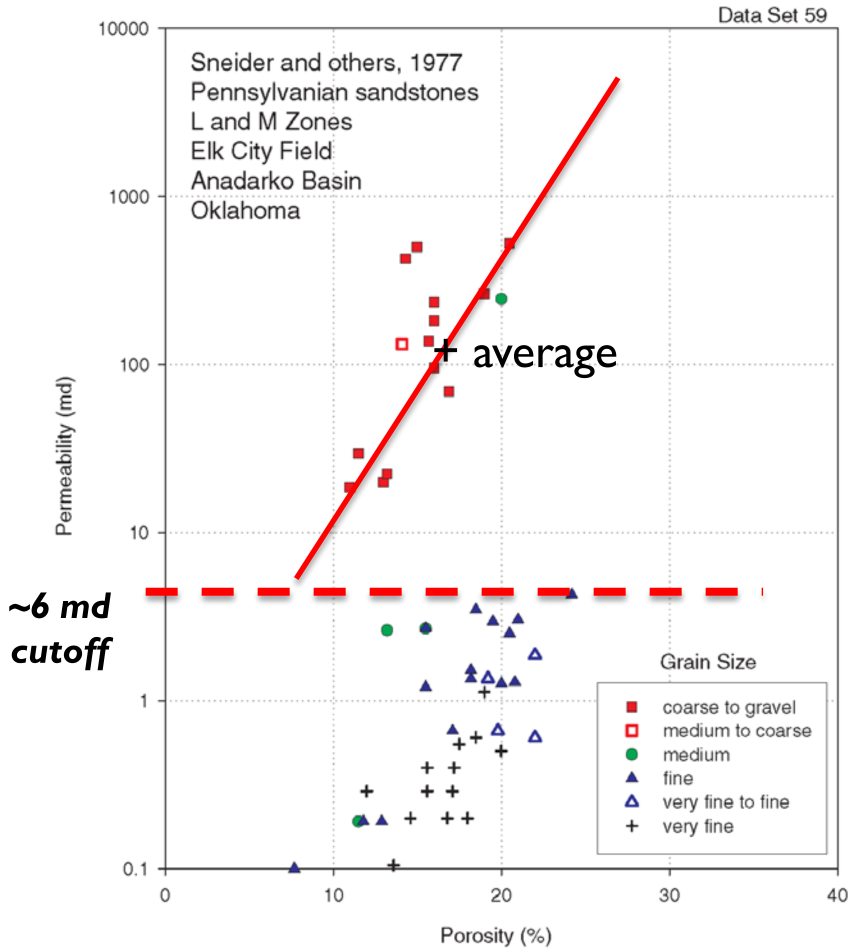
Nelson, Philip H. and Joyce E. Kibler, 2003, **A Catalog of Porosity and Permeability from Core Plugs in Siliciclastic Rocks**: U.S. Geological Survey Open-File Report 03-420.

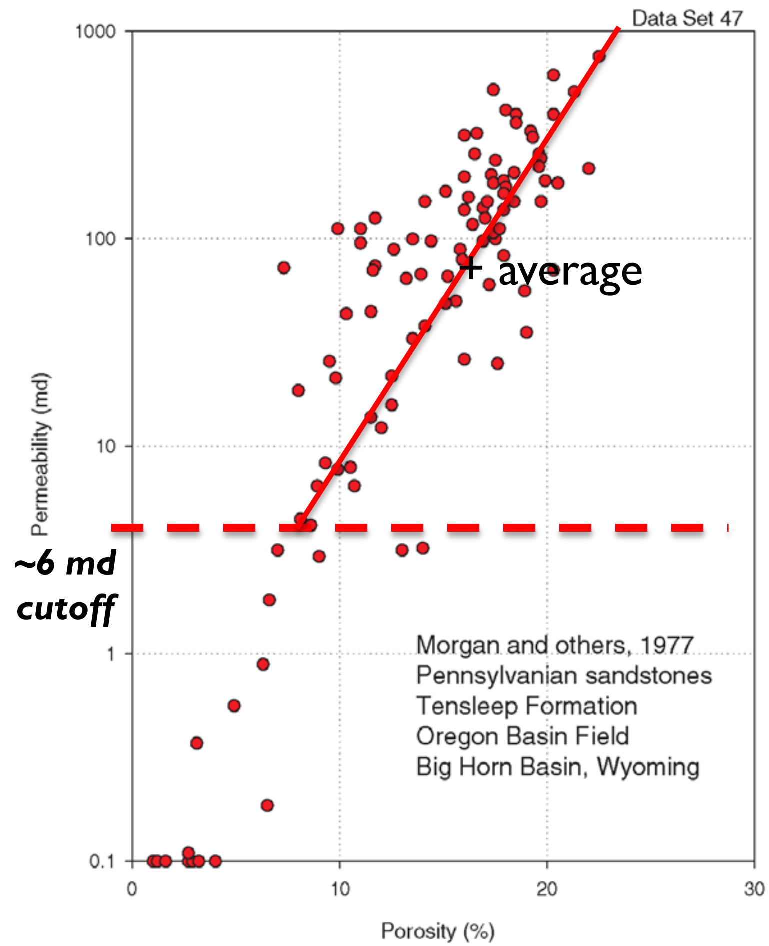
# Sources, Ages, and Locations of Porosity-Permeability Data Sets*

| No. | Authors and Date | Geologic Age | Formation | Location | Basin | Field | Max. Φ % | Max. K md |
|---|---|---|---|---|---|---|---|---|
| 59 | Sneider and others, 1977 | Pennsylvanian | L & M zones | Oklahoma | Anadarko Basin | Elk City Field | 24.2 | 524.8 |
| 47 | Morgan and others, 1977 | Pennsylvanian | Tensleep | Wyoming | Big Horn Basin | Oregon Basin Field | 22.5 | 758.8 |
| 22 | Dutton and others, 2003 | Permian | Bell Canyon | Texas | Delaware Basin | East Ford Unit | 30.6 | 249.0 |
| 44 | Montgomery, 1997 | Permian | Bone Spring | New Mexico | Delaware Basin | Red Tank Field | 20.6 | 19.1 |
| 61 | Spain, 1992 | Permian | Cherry Canyon | Texas | Delaware Basin | Rhoda Walker Field | 29.5 | 169.8 |
| 20 | Dolly and Mullarkey, 1996 | Late Cretaceous | Frontier Sand | Wyoming | Green River Basin | Lincoln Roads Field | 23.7 | 25.0 |
| 33 | Keighin and others, 1989 | Late Cretaceous | Almond | Wyoming | Green River Basin | various fields | 22.1 | 44.0 |
| 49 | Muller and Coalson, 1989 | Early Cretaceous | Dakota | Wyoming | Green River Basin | Henry Field | 22.2 | 630.9 |
| 14 | Corcoran and others, 1994 | Eocene | Wilcox Group | Louisiana | Gulf Coast | Wildsville Field | 34.7 | 1990.0 |
| 25 | Ganer, 1985 | Jurassic | Cotton Valley | Louisiana | Gulf Coast | Terryville Field | 16.9 | 416.9 |
| 28 | Grigsby and others, 1992 | Paleocene | Wilcox Group | Texas | Gulf Coast | Lake Creek Field | 16.0 | 7.8 |
| 32 | Hosseini and Hayatdavoudi, 1986 | Cretaceous | Tuscaloosa | Louisiana | Gulf Coast | wildcat | 31.2 | 193.0 |
| 36 | Langford and others, 1990 | Oligocene | Vicksburg | Texas | Gulf Coast | McAllen Ranch Field | 20.5 | 2.9 |
| 38 | Luffel and others, 1991 | Early Cretaceous | Travis Peak | Texas | Gulf Coast | four counties in E. Texas | 17.2 | 75.9 |
| 41 | Miller and Groth, 1990 | Cretaceous | Tuscaloosa | Louisiana | Gulf Coast | Baywood Field | 18.0 | 316.0 |
| 56 | Smith, 1985 | mid-Cretaceous | Tuscaloosa | Louisiana | Gulf Coast | Rigolets & Ft. Pike Fields | 22.5 | 851.1 |
| 57 | Smith, 1985 | mid-Cretaceous | Tuscaloosa | Louisiana | Gulf Coast | False River Field | 28.8 | 1258.9 |
| 58 | Smith, 1985 | mid-Cretaceous | Tuscaloosa | Louisiana | Gulf Coast | Judge Digby & False River | 28.5 | 1621.8 |
| 63 | Stricklin, 1999 | Late Cretaceous | Woodbine | Texas | Gulf Coast | Double A Wells Field | 22.4 | 1215.0 |
| 8 | Bowker and Jackson, 1989 | Permian-Pennsylvanian | Weber Sand | Colorado | Piceance Basin | Rangely Field | 18.2 | 173.8 |
| 19 | Dolly and Mullarkey, 1996 | Early Cretaceous | Muddy Sand | Wyoming | Powder River Basin | Collums Field | 29.6 | 56.0 |
| 21 | Dutton and Willis, 1998 | Early Cretaceous | Fall River | Wyoming | Powder River Basin | Buck Draw Field | 13.3 | 89.1 |
| 67 | Tillman and Martinsen, 1987 | Late Cretaceous | Shannon Sand | Wyoming | Powder River Basin | Hartzog Draw Field | 17.7 | 94.0 |
| 29 | Hall and Link, 1990 | Late Miocene | Monterey | California | San Joaquin Basin | Midway-Sunset Field | 37.0 | 1445.0 |
| 42 | Miller and others, 1990 | Pleistocene | Tulare | California | San Joaquin Basin | South Belridge Field | 40.6 | 10000.0 |
| 64 | Taylor and Soule, 1993 | Oligocene | 64-zone Sand | California | San Joaquin Basin | North Belridge Field | 19.1 | 281.8 |
| 54 | Shade and Hansen, 1992 | Tertiary-Cretaceous | Wasatch | Utah | Uinta Basin | Natural Buttes Field | 14.5 | 7.8 |
| 69 | Wendlandt and Bhuyan,1990 | Cretaceous | Mesaverde | Utah | Uinta/Book Cliffs | none | 23.3 | 1393.6 |
| 60 | Soeder and Randolph, 1987 | Late Cretaceous | Mesaverde | Colorado | Uinta/Piceance Basin | Rulison Field | 11.5 | 1.0 |
| 24 | Estes-Jackson and others, 2001 | Cretaceous | Muddy Sand | Wyoming | Wind River Basin | Riverton Dome Field | 22.4 | 4.3 |

*Subset, sorted by basin, *from* Nelson, Philip H. and Joyce E. Kibler, 2003, **A Catalog of Porosity and Permeability from Core Plugs in Siliciclastic Rocks**: U.S. Geological Survey Open-File Report 03-420.

# Plots of Permeability (in md) versus Porosity (in %) For Units in Two Basins




Nelson, Philip H. and Joyce E. Kibler, 2003, **A Catalog of Porosity and Permeability from Core Plugs in Siliciclastic Rocks**: U.S. Geological Survey Open-File Report 03-420.

# Compilation of Porosity and Permeability Data Representing Basins Studied - I

| Basins | GeoCol | Formation | Ref* | Ave Poro | Ave Perm | Max Poro | Max Perm |
|---|---|---|---|---|---|---|---|
| Anadarko | 8 | Pennsylvanian L&M | 59 | 15.0 | 100.0 | 24.2 | 524.8 |
| Bighorn | 4 | Tensleep | 47 | 16.6 | 100.0 | 22.5 | 758.8 |
| Delaware-Permian | 5 | Bone Spring | 44 | 14.4 | 2.0 | 20.6 | 19.1 |
| | | Bell Canyon | 22 | 24.0 | 40.0 | 30.6 | 249.0 |
| | | Cherry Canyon | 61 | 12.5 | 10.0 | 29.5 | 169.8 |
| Denver-Julesberg | 2 | Lyons Sandstone | CRC | 13.0 | 100.0 | 18.8 | 1400.0 |
| | | Lyons Sandstone | CRC | 15.0 | 45.0 | 18.8 | 159.0 |
| | | Ingleside | CRC | 19.0 | 100.0 | 31.0 | 1905.0 |
| Fort Worth | 3 | Ellenburger | RRC | 15.0 | 50.0 | 18.0 | 100.0 |
| Great Basin | 6 | Paleozoic carbonates | UGS | 10.0 | 75.0 | 18.0 | 200.0 |
| Green River | 10 | Frontier Sandstone | 20 | 15.0 | 0.7 | 23.7 | 25.0 |
| | | Almond | 33 | 18.0 | 10.0 | 22.1 | 44.0 |
| | | Dakota | 49 | 14.0 | 40.0 | 22.2 | 630.9 |
| *Gulf Coast* | *6* | *Travis Peak* | *69E* | 9.0 | 1.0 | 22.0 | 300.0 |
| | | Wilcox Group | 14 | 28.5 | 100.0 | 34.7 | 1990.0 |
| | | Cotton Valley | 25 | 12.5 | 25.0 | 16.9 | 416.9 |
| | | Tuscaloosa | 32 | 28.0 | 100.0 | 31.2 | 193.0 |
| | | Tuscaloosa | 57 | 22.0 | 85.0 | 28.8 | 1258.9 |
| | | Vicksburg | 36 | 19.5 | 2.5 | 20.5 | 2.9 |
| | | Travis Peak | 38 | 12.0 | 9.0 | 17.2 | 75.9 |
| | | Woodbine | 63 | 18.0 | 100.0 | 22.4 | 1215.0 |
| | | Edwards carbonate | *70* | 25.0 | 179.0 | n/a | n/a |
| | | Wilcox sandstone | *70* | 24.0 | 488.0 | n/a | n/a |
| | | Jackson-Yegua sands | *70* | 31.0 | 604.0 | n/a | n/a |
| | | Frio fluvial sandstone | *70* | 25.0 | 432.0 | n/a | n/a |

| | |
|---|---|
| poor | <= 10 |
| moderate | 11 to 99 |
| good | >= 100 |

Primary source: Nelson, Philip H. and Joyce E. Kibler, 2003, **A Catalog of Porosity and Permeability from Core Plugs in Siliciclastic Rocks**: U.S. Geological Survey Open-File Report 03-420.

Other sources: USGS Core Research Center, Texas Railroad Commission, Utah Geological Survey, U.S. Dept of Energy

# Compilation of Porosity and Permeability Data Representing Basins Studied - 2

| Basins | GeoCol | Formation | Ref* | Ave Poro | Ave Perm | Max Poro | Max Perm |
|---|---|---|---|---|---|---|---|
| Hanna-Shirley-Laramie | 2 | *Tensleep (from PRB)* | *DOE* | *11.0* | *20.0* | *21.1* | *296.0* |
| *Imperial Valley* | 3 | Palm Springs | DOE | 25.0 | 250.0 | 33.0 | 2100.0 |
| Powder River | 6 | Muddy Sandstone | 19 | 24.0 | 10.0 | 29.6 | 56.0 |
| | | Fall River (Dakota) | 21 | 11.0 | 25.0 | 13.3 | 89.1 |
| | | Shannon Sandstone | 67 | 14.0 | 20.0 | 17.7 | 94.0 |
| | | Tensleep | DOE | 11.0 | 20.0 | 21.1 | 296.0 |
| | | Madison | PP | 17.5 | 30.0 | 31.4 | 390.0 |
| Raton | 2 | Trinidad Sandstone | CRC | 7.0 | 1.0 | 13.5 | 1.0 |
| | | Entrada | CRC | 16.0 | 2.0 | n/a | n/a |
| Sacramento-San Joaquin | 5 | Monterey | 29 | 32.0 | 800.0 | 37.0 | 1445.0 |
| | | Tulare | 42 | 35.0 | 700.0 | 40.6 | 10000.0 |
| | | 64-zone Sandstone | 64 | 14.5 | 30.0 | 19.1 | 281.8 |
| Uinta-Piceance | 4 | Weber Sandstone | 8 | 12.5 | 10.0 | 18.2 | 173.8 |
| | | Mesaverde Group | 60 | 7.5 | 0.3 | 11.5 | 1.0 |
| | | Wasatch | 54 | 10.0 | 1.0 | 14.5 | 7.8 |
| | | Mesaverde Group | 69 | 18.0 | 75.0 | 23.3 | 1393.6 |
| Williston | 2 | Lodgepole | CRC | 7.3 | 0.1 | 20.0 | 165.0 |
| | | Interlake | CRC | 11.5 | 30.0 | 16.1 | 320.0 |
| | | Interlake | CRC | 10.0 | 20.0 | 16.6 | 220.0 |
| | | Red River | CRC | 15.0 | 10.0 | 24.7 | 158.0 |
| | | Red River | CRC | 13.0 | 12.0 | 21.7 | 108.0 |
| Wind River | 5 | Muddy | 24 | 17.5 | 0.5 | 22.4 | 4.3 |
| | | Tensleep | CRC | 15.0 | 70.0 | 22.0 | 1000.0 |

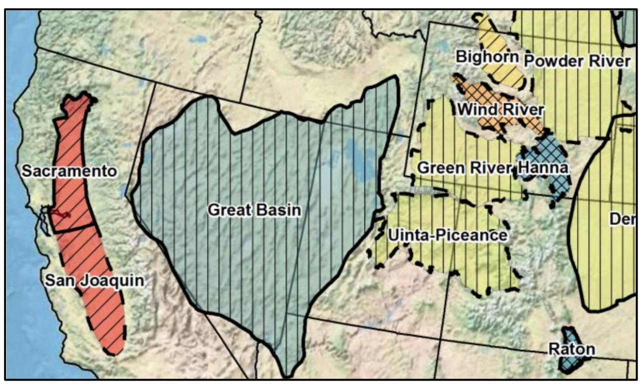
| | |
|---|---|
| poor | <= 10 |
| moderate | 11 to 99 |
| good | >= 100 |

Primary source: Nelson, Philip H. and Joyce E. Kibler, 2003, **A Catalog of Porosity and Permeability from Core Plugs in Siliciclastic Rocks**: U.S. Geological Survey Open-File Report 03-420.

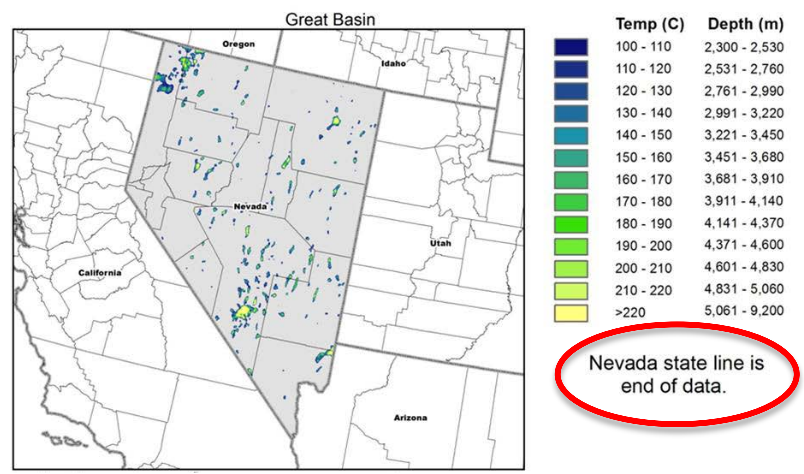
# Summary of Permeability Data by Lithologic Unit for the Great Basin

| | | Depth (m) | | | Permeability (mD) | | |
|---|---|---|---|---|---|---|---|
| Lithologic Unit | n[1] | Median | Minimum | Maximum | Median | Minimum | Maximum |
| Great Basin basin fill | 97 | 110 | 4.2 | 686 | 4467 | 0.08 | 177038 |
| Great Basin igneous rocks | 253 | 749 | 48.8 | 2243 | 100 | 0.00 | 241387 |
| All carbonate rocks | 250 | 1750 | 13.9 | 7214 | 41 | 0.13 | 1111438 |
| All siliciclastic rocks | 588 | 1999 | 58.2 | 5530.9 | 25 | 0.26 | 6054 |
| Utah and Great Basin carbonate rocks | 55 | 1106 | 13.9 | 3792.9 | 292 | 0.13 | 1111438 |
| Utah and Great Basin siliciclastic rocks | 59 | 1535 | 100 | 4774.1 | 32 | 0.26 | 6054 |

[1] Number of occurrences

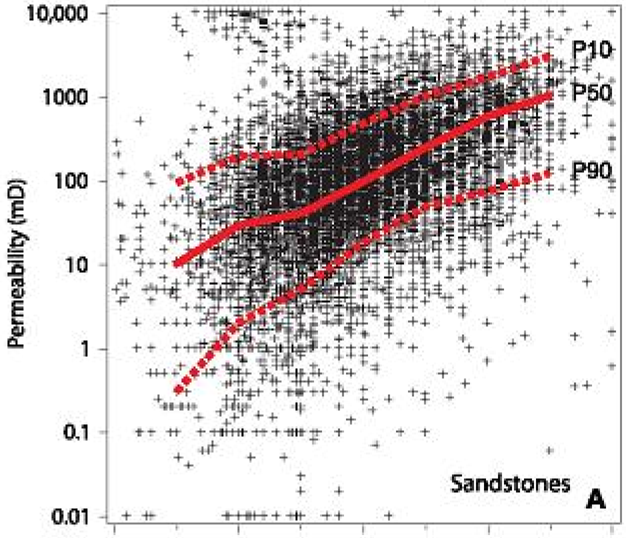


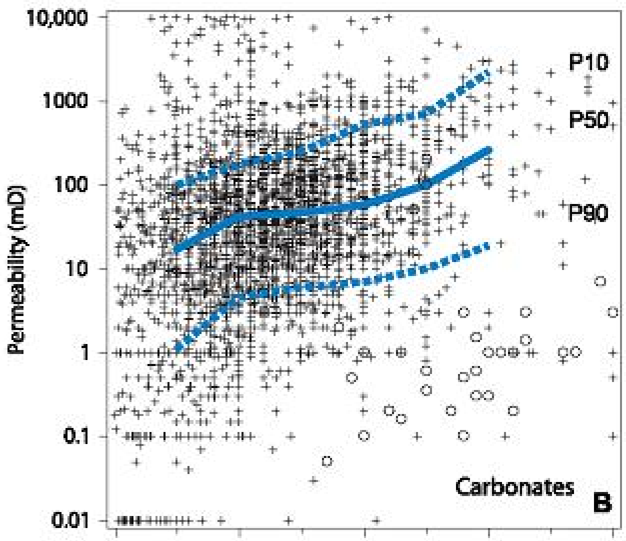

Kirby, Stefan M., 2012, **Summary of compiled permeability with depth measurements for basin fill, igneous, carbonate, and siliciclastic rocks in the Great Basin and adjoining regions**: Utah Geological Survey Open-File Report, 11 p. plus data tables.

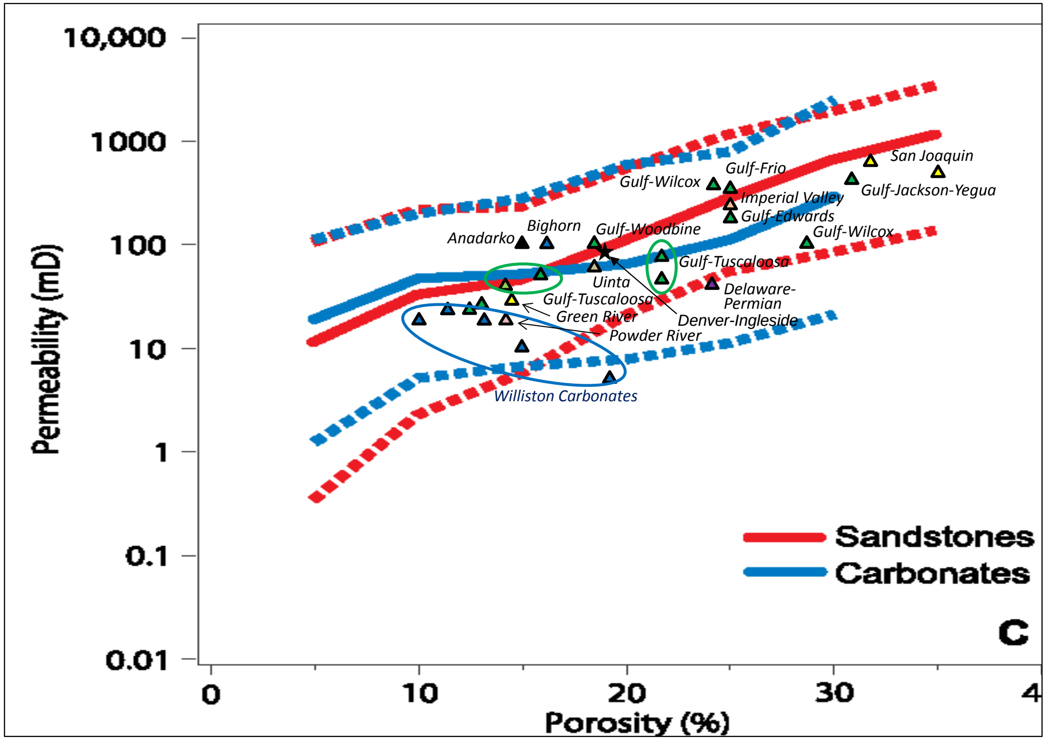



*Great Basin as defined by Porro, et al (2012)*

# Average Permeability vs. Average Porosity for Global Petroleum Reservoirs



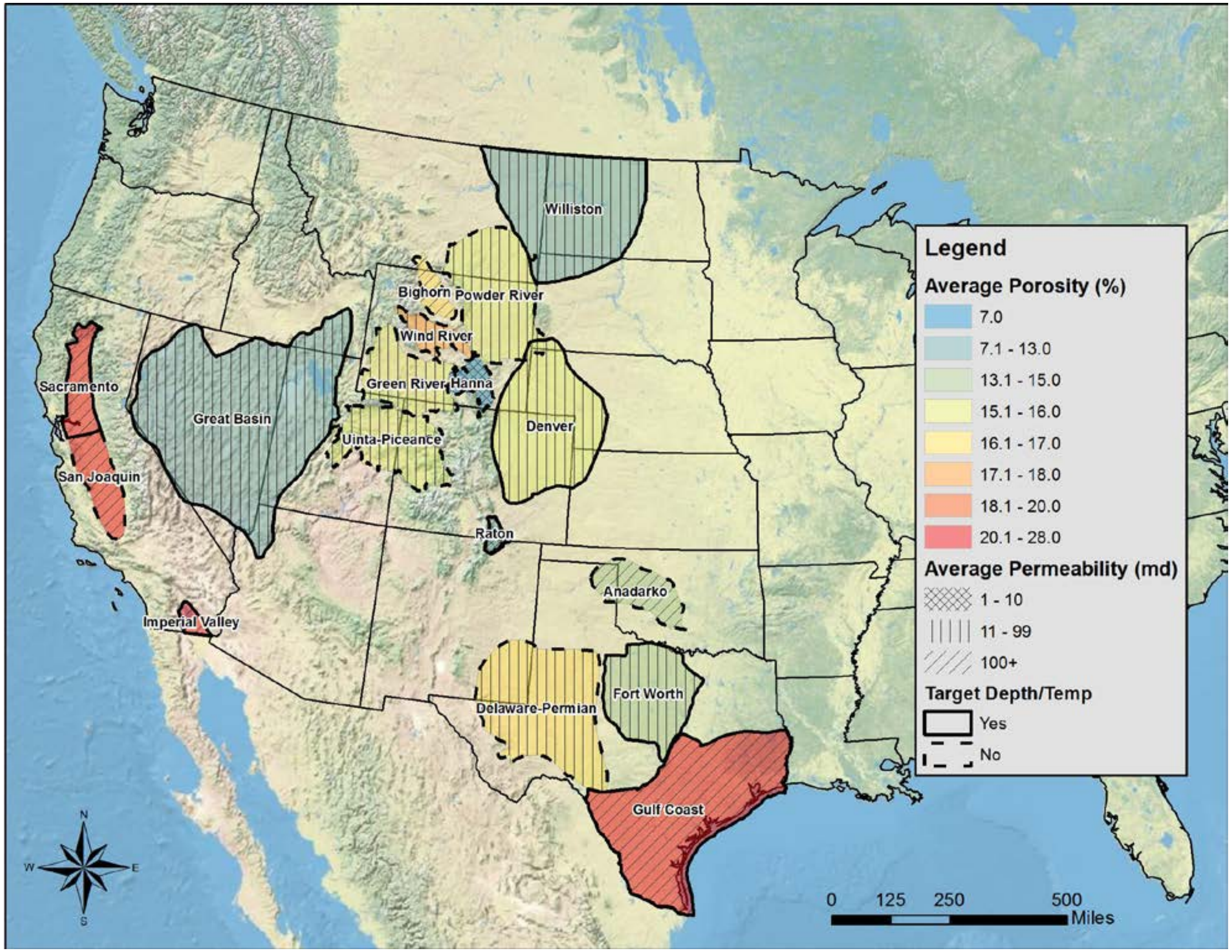




**Data points from Table 2 overlaid and annotated on trends**

Ehrenberg, S.N., and P.H. Nadeau, 2005, **Sandstone vs. carbonate petroleum reservoirs: A global perspective on porosity-depth and porosity-permeability relationships**: AAPG Bulletin, v. 89/4, p. 435-445.

# Symbolic Representation of Porosity, Permeability, Depth, and Temperature for Sedimentary Basins in the Western U.S.




*Application of screening thresholds of < 4 km depth and > 125 °C temperatures show the only basins meeting the threshold maximum depth and minimum temperature (solid outlines) are the Williston, Denver, Great Basin, Fort Worth, Sacramento, and Raton Basins, plus the Gulf Coast and Imperial Valley added to Porro et al (2012). As a way to show the combined results, the three parameters of Average Porosity, Average Permeability, and Target Depth/ Temperature criteria are illustrated with different display attributes*

# Conclusions

The following basins have adequate temperatures (>125 °C) within maximum depths (<4km), and porous (>10%) reservoir rocks to be considered for additional evaluation and modeling:

- Denver
- Fort Worth
- **Great Basin**
- **Gulf Coast**
- **Imperial Valley**
- *Raton*
- Sacramento
- *Williston*

*The best basins identified are highlighted in bold text in this list (**Great Basin** and **Gulf Coast**). The **Imperial Valley** is a special case, since there is existing geothermal development and electrical production that can be expanded upon.*

When considering permeability, based on reservoir data evaluated so far, two basins don't make the cut of minimum acceptable permeability (approx. 50-100 md): the *Raton* and the *Williston*, thus they are italicized in this list.

The Denver Basin has mid-range potential and should be further evaluated. Recent bottom-hole temperature (BHT) corrected data analysis by Crowell et al (2012) indicates the Denver Basin Dakota Group has better temperatures than previously thought. This is expected to be even better in the Paleozoic (Permian) Ingleside Dolomite, which has excellent porosity (19%) and permeability (100 md), is not a known producing hydrocarbon zone, and at a depth of 4 km, temperatures could be at > 180 °C.

*Crowell, A. M., A. T. Oschner, and W. Gosnold, 2012.* ***Correcting bottom-hole temperatures in the Denver Basin****.*
*Geothermal Resources Council Transactions, Vol. 36, p. 201-206.*

# Acknowledgements

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This work built upon and extended the pioneering basin screening work by: Porro, Colleen, A. Esposito, C. Augustine, and B. Roberts, 2012, **An Estimate of the Geothermal Energy Resource in the Major Sedimentary Basins in the United States;** Geothermal Resources Council Transactions, Vol. 36.

# Questions?