Heat Flow and Thermal History of the Anadarko Basin, Oklahoma*

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Search and Discovery Article #10657 (2014)**

Posted November 3, 2014

*Adapted from oral presentation given at Granite Wash and Pennsylvanian Sand Forum, Oklahoma City, Oklahoma, September 25, 2014

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Abstract

Understanding the thermal regime of a sedimentary basin, both past and present, is one of the keys to successful exploration and development of hydrocarbon resources. Heat flow data collected in the Oklahoma portion of the Anadarko Basin have been used, in conjunction with other data, to help explain the patterns seen in thermal maturity data, estimate the past burial history, and to model present day basin temperatures. Detailed temperature logs, lithology logs, and ~250 thermal conductivity measurements are used to determine heat flow and the present thermal structure of the basin. In the Anadarko Basin, two main factors influence the thermal structure, basement heat production and lithologic variations within the basin. Heat flow is lowest in the southeast portion of the basin and increases to the north and west due to a change from mafic to granitic basement rocks. Within the basin, lateral changes in lithology caused by granite wash deltaic systems along the Mountain View fault zone, has resulted in large changes in thermal conductivity. This has affected the local temperature distribution since the time of deposition, resulting in complex patterns of thermal maturity within the deep portion of the basin.

References Cited


Heat Flow and Thermal History of the Anadarko Basin, Oklahoma

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The following presentation is a summary of the results and finding of two papers


Outline

» What is Heat flow?
  › Oil field temperatures
  › Thermal conductivity

» Heat flow in the Anadarko Basin
  › Conventional Measurements
  › Thermal Structure of basin
  › Temperature effects of the Granite Wash
  › Comparison to Vitrinite Reflectance

» Fission Track Studies

» Thermal History
What is Heat Flow?

» The amount of heat energy moving through an area in a given time

» Provides insights into the earth’s thermal regime, tectonics, structure, basement lithology, etc.

» In general, heat flow requires two types of data

Temperature data

» Ideal temperature data from high resolution temperature logs in equilibrated wells
  » Changes in temperature gradient correspond to lithologic changes

» Typical data is less than ideal
  » non-equilibrium logs
  » Pressure-Temperature logs
  » Bottom hole temperatures (BHTs)

Watson well, Miami County, Kansas. Blackwell and Steele, 1989b, Fig 2.4
Temperature Data

» 7 temperature logs from the Anadarko Basin

› Measured depths range from ~3,000 – 16,900 ft (900 – 5,150 m)

› Logs show conductive gradients with some drilling/production effects visible

› Gradients range from 0.5 – 2.5 °F/100ft (10 – 45 °C/km)

» Average gradients 0.8-1.1 °F/100ft (15-20 °C/km)
Thermal Conductivity

» Material property that describes how heat is transferred through the material

» Under steady state temperature conditions the conductivity of a material is inversely proportional to the temperature gradient

» Rocks range from 0.3 to 7 W/(m*K) (Coal to Quartzite)

Styrofoam keeps coffee hot and hand cool Due to its low conductivity

Copper lets coffee cool and burns hand Due to its high conductivity
Thermal Conductivity

» 238 thermal conductivity measurements made on core plugs

» Measured on a divided bar apparatus at SMU

» Sandstone has large variability
  › General increase in sandstone conductivity with depth due to decrease in porosity
  › Range is due to variable lithic fragments and shale laminae in cores
Heat Flow in the Anadarko Basin

» Lower values to Southeast
» Increasing to the north and west
» Variations in heat flow values are attributed to changes in basement lithology
  › Differences in heat production
  › Gabbro underlies southeast portion of the basin
  › Granite under the rest of the basin
Temperatures are related to various processes that affect basins:

- Tectonics
- Fluid motion
- Maturation
- Diagenetic changes

Understanding the past and present thermal structure is important to understanding where hydrocarbons may be found.

Bottom Hole Temperatures (BHT) are typically used.
Thermal Structure

» Gallardo and Blackwell, 1999

» Used heat flow and thermal conductivity data to calculate temperatures with the basin

» 63 wells with lithology recorded at 10 ft intervals

› Wells range in depth from 3,400 – 31,440 ft (1 – 9.6 km)

» Temperature vs Depth curves are calculated for the 63 wells

» Assumed 1-D steady state heat flow
Effect of the Granite Wash

Approximate extent of Granite Wash play
Pennsylvanian section in Bertha Rodgers well has significantly more granite wash compared to Harrell well

- BR - Sandstones and Conglomerates (high conductivity)
- H - Shale and sandstones (low conductivity)

Results in lower gradient and cooler temperatures in the Bertha Rodgers well
» Typically highest vitrinite values occur at the maximum depth

» Devonian Woodford Shale shows an offset of the highest values basinward

» Predicted temperatures follow the same pattern

» Indicates maturity pattern resulted from a conductive thermal regime

Vitrinite isoreflectance and temperatures at the top of the Woodford Shale Ro data from Cardott and Lambert (1985) and Cardott (1989)
Apatite Fission Tracks

» Used to date thermal history of continental crust, timing of volcanic events, etc.

» Fission tracks allow for dating of when a rock cools below ~230 °F (110°C)

» Tracks are crystal damage zones cause by particles emitted during natural $^{238}$U decay

» Above ~110 °C the tracks are annealed over time

» From 60-110 °C tracks are partially annealed
In study by Carter et al., 1998 apatite samples were collected from well cores from the basin. Samples from Wichita basement rock, Granite Wash, and Pennsylvanian Sandstones.
Well A sampled Cambrian basement

Well B & C sampled granite wash

Other wells sampled various Pennsylvanian sandstones
Apatite Fission Tracks

» Results

› Two trends seen in wells north and south of Mountain View Fault

› Samples from deeper in the basin give significantly younger ages than the stratigraphic ages
Possible interpretation

- The Wichita Mountains south of the Mountain View Fault cooled below annealing zone due to erosion during the Jurassic and Cretaceous
- North of the fault, granite wash remained buried above 110°C
- Formations above the granite wash began to erode during the early Cenozoic leading to ~5000 ft (1.5 km) of erosion
- Erosion has lead to cooling of at least 50°C during the Cenozoic within Pennsylvanian formations
Pennsylvanian formations experienced rapid burial during the Pennsylvanian and Permian.

Minor subsidence during the Mesozoic until the mid Cretaceous.

Up to 6000 ft of Cretaceous subsidence.

Subsequent erosion of Mesozoic formations throughout the Cenozoic.
Conclusions

» Heat flow is an important part of understanding the past and present thermal regime within sedimentary basins

» Relying on BHT data alone can lead to large variations in heat flow and temperatures within a basin

» Detailed lithologic log data along with thermal conductivity data can be used to calculate temperatures across the basin

» The observed vitrinite reflectance patterns are best explained by distribution of Pennsylvanian shales and washes
Future Work?

» Extend the heat flow and temperature calculations into the Texas portion of the basin

» SMU Geothermal Lab has the ability to run temperature logs

» Pressure-Temperature Logs
  › These data are useful tools for adding to the known temperatures in the basin
  › If your company has any…we would love to see the temperatures!
References

