# Heat flow and Supervised Learning in the Permian Basin: Applying The Magnetic Layer (TML) to control thermal property calculations

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## Objective

The Magnetic Layer (TML) is the crustal layer that lies between the top of crystalline crust (basement) and the Curie point depth. The Earth's magnetic field is dominated by anomalies produced within TML. We are motivated by the idea that the Curie point depth is also a temperature horizon, between ~550°C and ~590°C, where rocks gain or lose magnetization as they cool down or heat up. Thus, we present an integration of high-quality, detailed magnetic basement, with basement terranes and open-file station and well data, to map thermal elements in the Permian Basin and TML it sits upon.

## Data and Methods

*Data*. Except for the detailed basement depth interpretation, we use open-file thermal data from stations and wells, magnetic anomaly and Curie point depth grids, and a basement terrane interpretation.

*Heat Flow***.** We use inverted magnetic susceptibilities from a 3D model of TML to modify a published basement terrane map. Basement and TML geometries, and modified basement terranes control thermal calculations based on established heat flow equations and empirical relations:

(1) $\mathbf{Q = k \cdot dT/dZ}$ where $\mathbf{Q}$ is heat flow, $\mathbf{k}$ is thermal conductivity, $\mathbf{T}$ is temperature, and $\mathbf{Z}$ is depth (Fourier's Law);

(2) $\mathbf{Q_{TOT} = Q_{BG} + A_0D}$ where $\mathbf{Q_{TOT}}$ is total heat flow, $\mathbf{Q_{BG}}$ is background heat flow, $\mathbf{A_0}$ is heat produced from continental TML, and $\mathbf{D}$ is heat producing layer thickness in; and

(3) Global experiment: on average, $\mathbf{Q_{BG}}$ is 60% of $\mathbf{Q_{TOT}}$, and $\mathbf{A_0D}$ is 40% of $\mathbf{Q_{TOT}}$**.**

*Supervised Learning*. Several supervised machine learning regression methods are applied to estimate heat flow (the target) in areas of limited data coverage. Predictor variables include thermal conductivity, heat production, layer geometries, and logged temperatures. We compare several tuned and untuned models to predict heat flow from 1) basin-associated predictors, and 2) basin plus TML-associated predictors.

## Results and Discussion

Basin layer and TML thermal gradients are calculated between three temperature horizons: near surface, basement, and Curie point. Near surface temperatures are computed from surface and bottom hole temperatures. Heat flow stations are used to calculate basement temperature. Finally, thermal conductivity and thickness of the heat producing layer are calculated in TML.

The Curie point depth roughly tracks the base of the crust (Moho). It tends to be slightly shallower beneath continents and slightly deeper beneath oceans. Hence, it is much shallower than the Lithosphere-Asthenosphere Boundary (LAB, thought to be ~1330°C); and because it is shallower, it may be more accurately mapped. Therefore, the Curie point depth is superior to LAB as a boundary condition for thermal model studies.

Our final model was produced by a Multi-layer Perceptron Regression neural network supervised learning method using both basin and TML-associated variables, resulting in the best fit with measured heat flow station data. We estimate Heat flow values on a 4000-foot grid mesh throughout West Texas and found strong correlations of predicted heat flow anomalies with oil and gas fields where station data are sparse.

## Significance

Our method quantifies thermal properties in sedimentary basins as well as TML: temperature, thermal gradient, thermal conductivity, heat flow, heat production, and heat production layer thickness.

Critical elements of our study are: 1) high-quality, detailed basement interpretation, 2) integration of published terranes with magnetic anomaly and TML heat production data to map basement terranes, and 3) Supervised Learning analyses for heat flow prediction.

Our new method may be applied to any sedimentary basin; the workflow has been successfully employed in other areas world-wide.