GEOGULF2021
AUSTIN
October 27–29, 2021

Basin Temperature Modelling Using Large Well Log and Bottom-Hole Temperature Datasets in the Haynesville Play: Texas and Louisiana

C. O'Reilly and I. Deighton

TGS, 10451 Clay Rd., Houston, Texas 77041

ABSTRACT

Understanding basin temperature variations is important to hydrocarbon exploration and increasingly relevant to the growing geothermal energy and carbon capture utilization and storage (CCUS) businesses. However, the geothermal industry lacks the large sets of temperature data required to understand subsurface temperature. TGS has over 4.8 million wells in the major basins onshore USA and Canada; with digital log data for over 3.1 million wells. Using these well data, we developed a methodology to create basin temperature models (BTMs) that combine a geological layer model built with outcrop data and many thousands of formation tops interpreted from log data with large numbers (10,000s) of indexed and quality-controlled bottom-hole temperature (BHT) data. Borehole temperatures tend to equilibrate, increasing towards ambient formation temperature with elapsed time since final drilling fluid circulation. We use the maximum BHTs recorded in a layer (normalized for depth) or cell rather than a corrected average or regression-based model. Present day temperature volumes are constructed with two methodologies. We first define a lateral and vertical varying interval geothermal gradient (IGG) function that models the maximum envelope of the BHTs recorded for each major lithostratigraphic unit: the MaxG method. We then construct the MaxG temperature volume by stacking IGGs for all units in the basin. With sufficiently dense data, we use the maximum BHT in each cell of the volume: the MaxBHT method. BTMs for new areas can be created in 4 months. TGS has developed 18 BTMs (periodically updated) across North America, delivered in SEG–Y format as 3D temperature-depth cubes for easy integration with other data. Originally intended for hydrocarbon exploration, they also serve in re-purposing old hydrocarbon fields to geothermal uses. The BTM method is illustrated here with examples from our recently (2021) completed BTM of the Haynesville Play in Texas and Louisiana.

O'Reilly, C., and I. Deighton, 2021, Basin temperature modelling using large well log and bottom-hole temperature datasets in the Haynesville play: Texas and Louisiana: GeoGulf Transactions, v. 71, p. 193–201.

INTRODUCTION

Temperature is an important parameter controlling chemical reactions in rocks. As a sediment layer is buried under successive layers of sediments, temperature and pressure tend to increase. Diagenetic reactions (e.g., carbonate dissolution, growth of authigenic cements, expulsion of bound water) will occur. If temperature exceeds 80–150°C for enough time (millions of years) then kerogen in source rocks transforms into oil and gas. The ambient temperature also relates to the pressure and volume of gases injected into the sub-surface (PV = nRT). So, planning of subsurface operations may be interested in predicting extant rock temperatures.

Basin temperature models (BTMs) are commonly built with sparse but diverse data sets from sources such as fluid inclusion and vitrinite reflectance data (which record past temperatures) and from current temperature sources such as bottom-hole temperature (BHT) and drill stem test (DST) data. The approach outlined here is to construct present-day structurally constrained temperature models from BHT data and rock formation data (Fig. 1). BHT data is measured by a maximum-reading thermostat incorporated into the logging tool and recorded (with the time since circulation of drilling mud: TSC) in the log header of most down-hole logs (Fig. 2). The layer model is built up of successive layers of geological significance to the thermal evolution of the basin from the surface down (Fig. 3).

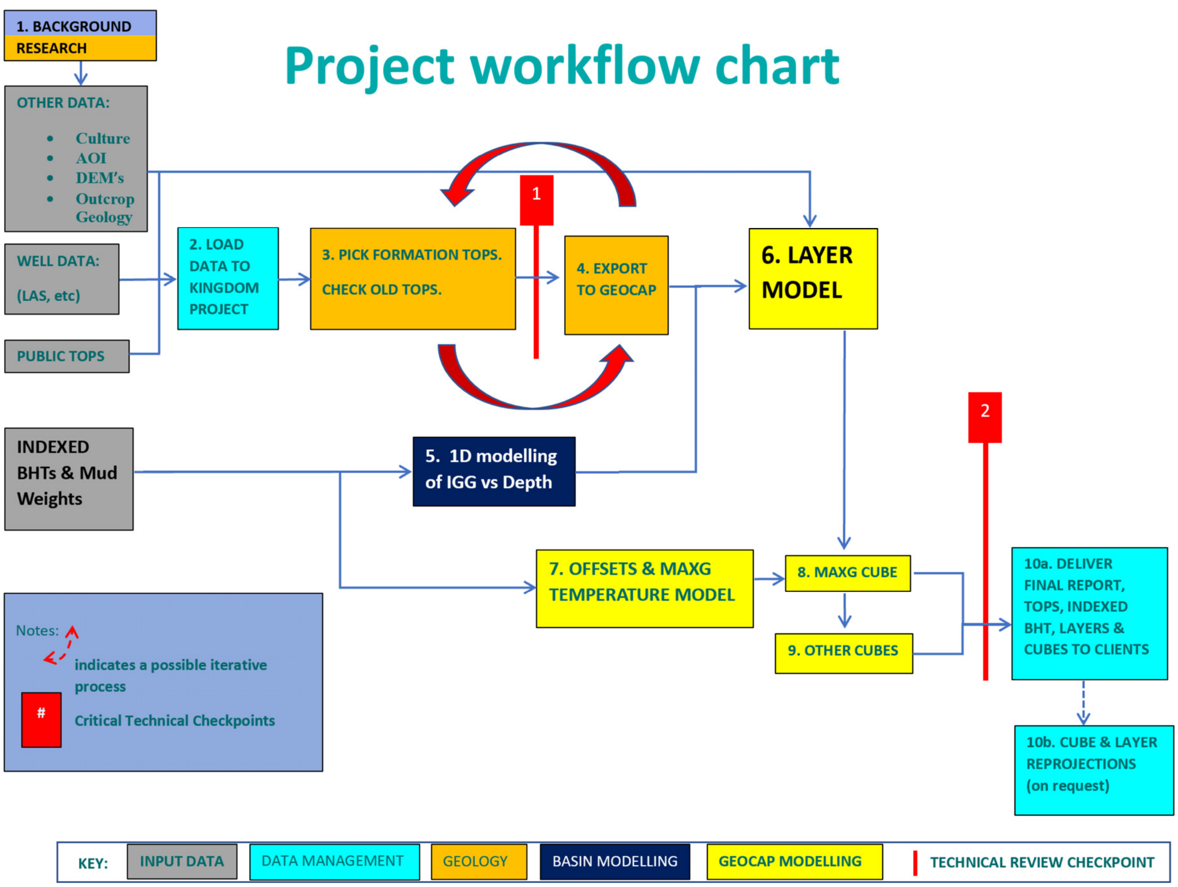

Figure 1. We combine a layer model (built from geological formation tops interpreted from well logs) with cleaned bottom hole temperature data (derived from well header data; Fig. 2) to construct our structurally constrained basin temperature models.

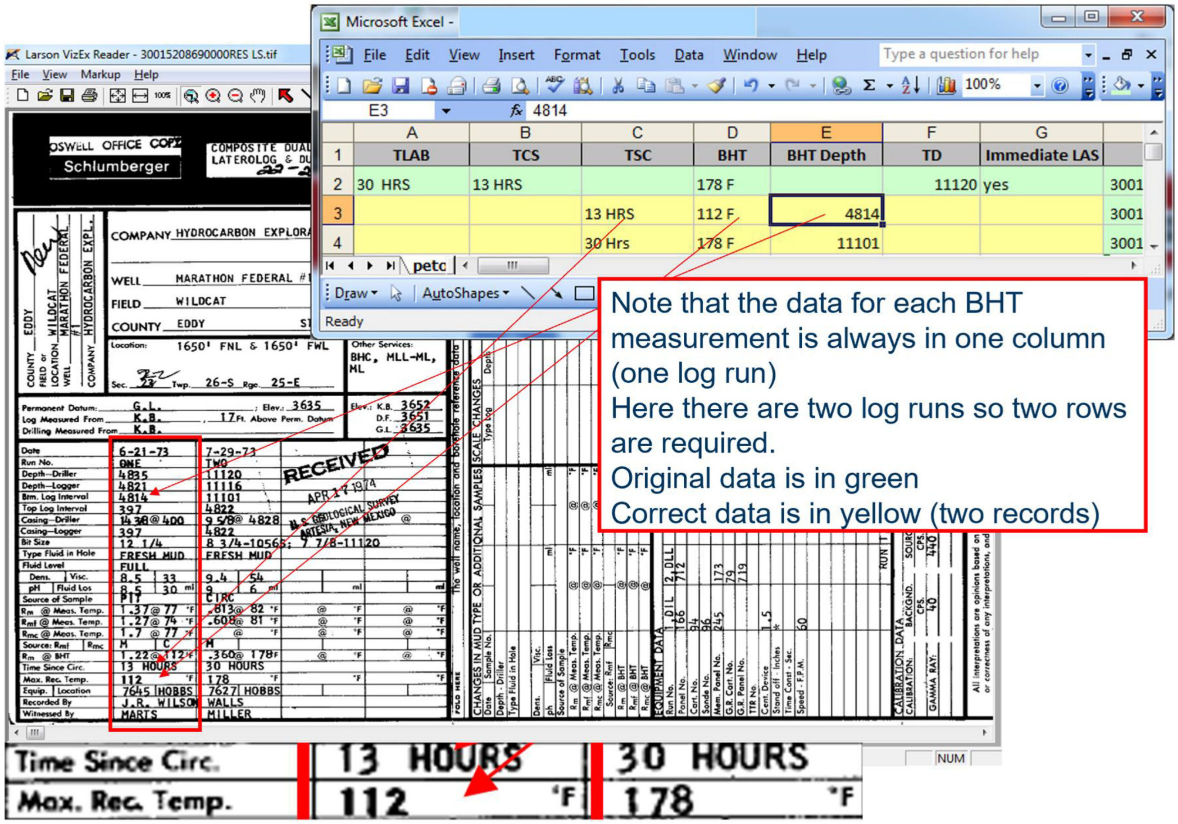

Figure 2. BHT values are recorded in most oil and gas wells. Critical information seen here includes the depth at which the measurement was taken, the time since circulation (TSC) and the maximum recorded temperature.

METHODS

The Haynesville BTM was built using the procedures described by Deighton et al. (2014) and outlined in Figure 1.

RESULTS

The Haynesville play straddles the Sabine high on the border of eastern Texas and western Louisiana. The study area and data available to the study are shown in Figure 4. In choosing which wells to use in the study, consideration was given to vertical extent (deepest wells preferred), geological range (wells with complete succession preferred), and curve content (quad-combo and areal distribution). The vertical distribution is particularly important as, in order to assess the MaxG cloud BHT data for each layer, a significant number of wells that reached total depth or were cased within each lithostratigraphic interval were needed. The G. P. Stewart–1 well was selected for 1D modelling as it is the only one of the 20 wells selected for petrophysical (lithofacies) analysis that has all interpreted horizons.

Standard basin modelling techniques relevant to the study were applied to well G. P. Stewart–1: decompaction, stretching-based basal heat flow and using a matrix of thermal conductivi-

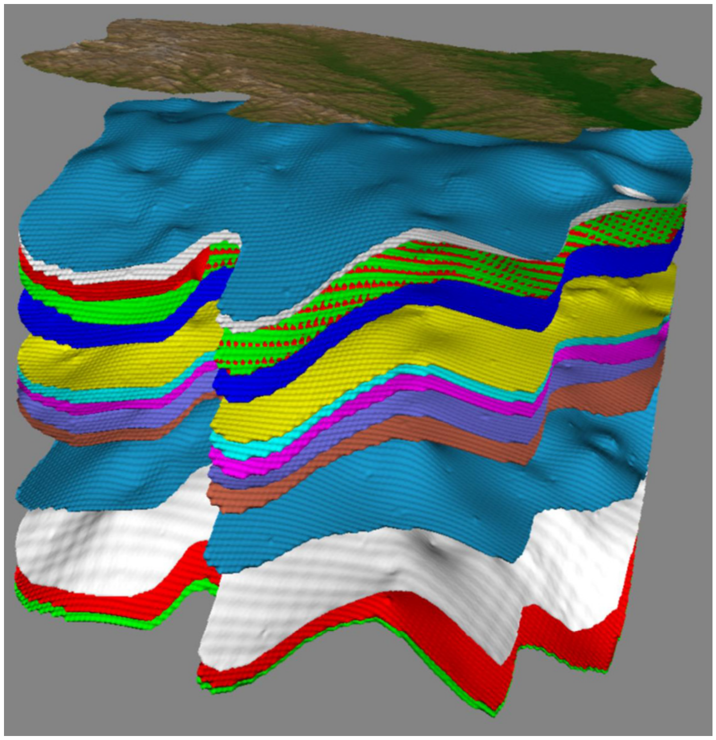

Figure 3. Structurally conformable layer model for the Haynesville Play of Texas and Louisiana—built comprising 15 layers from ground level (digital elevation model [DEM]; shallowest layer of the model) to the Upper Jurassic Haynesville Limestone (deepest layer of the model).

ty values for each lithological interval. The burial graph with temperature is shown in Figure 5. Uplift and erosion in the Late Cretaceous and Tertiary is related to local uplift events and global eustatic events. The model agrees with published vitrinite reflectance data and other published geohistory models.

The MaxG graphs for one of the 15 lithostratigraphic intervals within the Haynesville Play Basin Temperature Model is shown in Figure 6.

Figure 7 shows a 3D view of the structural layers (derived from interpretation of well formation tops) and the BHT data points used to construct the model.

Figure 8 shows the final MaxG temperature volume (delivered as a SEG–Y 3D cube). This is interpolated from the calculated depth and temperature values for each lithostratigraphic layer in the model.

SUMMARY AND CONCLUSIONS

The TGS methodology for constructing regional scale basin temperature models (BTMs) has been tried and tested for basins throughout North America (Fig. 9) and the results are in close agreement with those predicted from independent basin modelling studies. The MaxG method is best suited for predicting formation temperature for each interval in a basin. Other tempera-

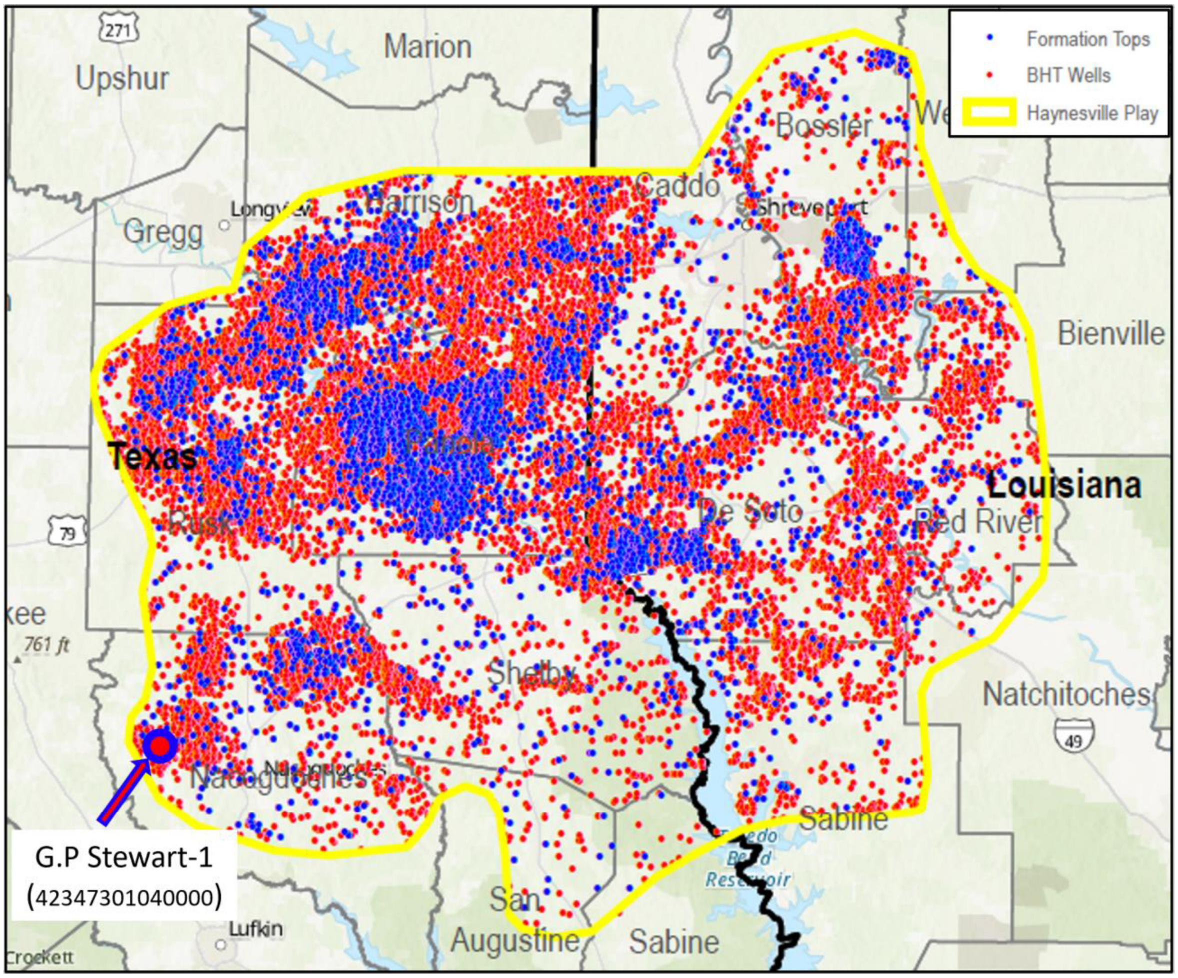

Figure 4. Haynesville Play study area (yellow outline). Blue dots show the 3324 wells within the study area polygon in which we interpreted formation tops to build our structural layer model. Red dots show the 23,135 wells from which BHT data was sourced. The BHT data were quality checked for elevation and temperature range to provide a valid dataset for the study. The BHT data were further quality checked to remove horizontal wells. The location of well G. P. Stewart–1, used for 1D modelling, is highlighted.

ture cube types are also available that capture the different temperature anomalies in the basin that may be hidden in the raw BHT data but which are masked by the MaxG/IGG methodology.

As with any basin-wide temperature models the potential uses include:

- Cross-correlation of prospective zones with the temperature cube to identify temperature optimum prospective areas.
- Cross-correlate temperature log data with temperature cube to identify areas of anomalous fluid flow and heat flow. Anomalies may be compared with:
    - gravity and magnetic data to evaluate basement architecture effects and
    - production data such as gas-to-oil ratio to identify prospective trends.

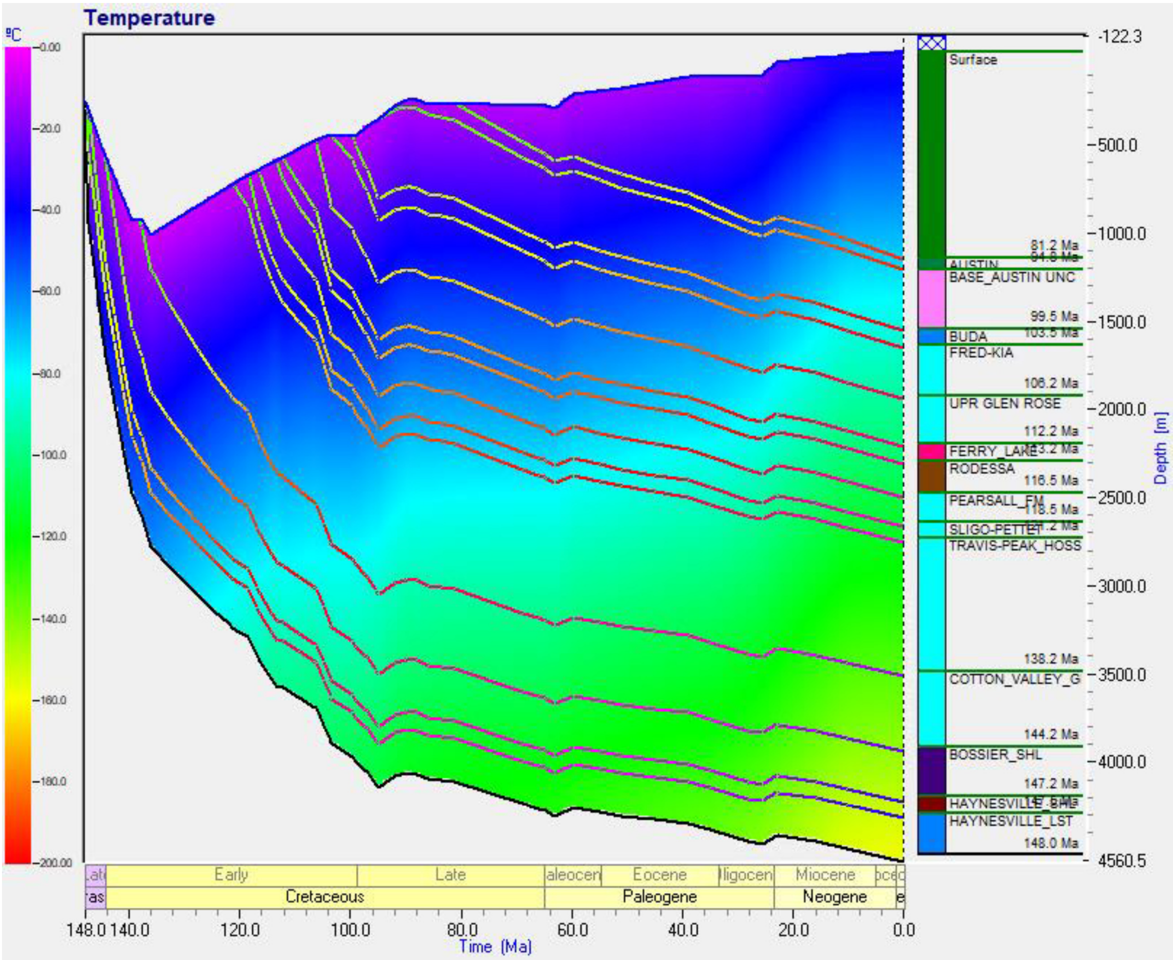

Figure 5. Geohistory plot with temperature overlay for well G. P. Stewart–1.

- Compare calculated pseudo-maturity (assuming present temperature is maximum) with measured maturity to identify paleo-temperature anomalies associated with high heat flow, uplift or volcanic activity.

The basin temperature volumes can be readily imported into 3D viewing and modeling software packages.

ACKNOWLEDGMENTS

We thank TGS for permission to publish this paper.

REFERENCE CITED

Deighton, I., E. Tibocha, and P. Dotsey, 2014, MaxG basin temperature modelling using bottom hole temperature datasets: Unconventional Resources Technology Conference URTEC–1920520–MS, Denver, Colorado, 16 p.

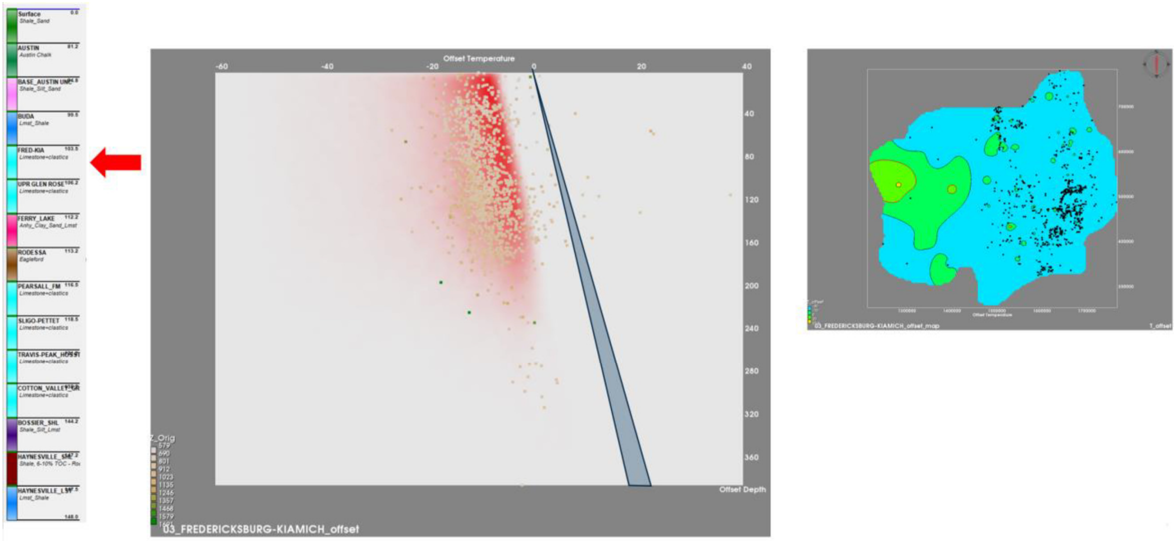

Figure 6. The Lower Cretaceous Fredericksburg Group was one of the 15 lithostratigraphic intervals used to create the Haynesville Play Basin Temperature Model. The central offset plot shows the data forming a trend sub-parallel to the interval geothermal gradient (IGG) model.

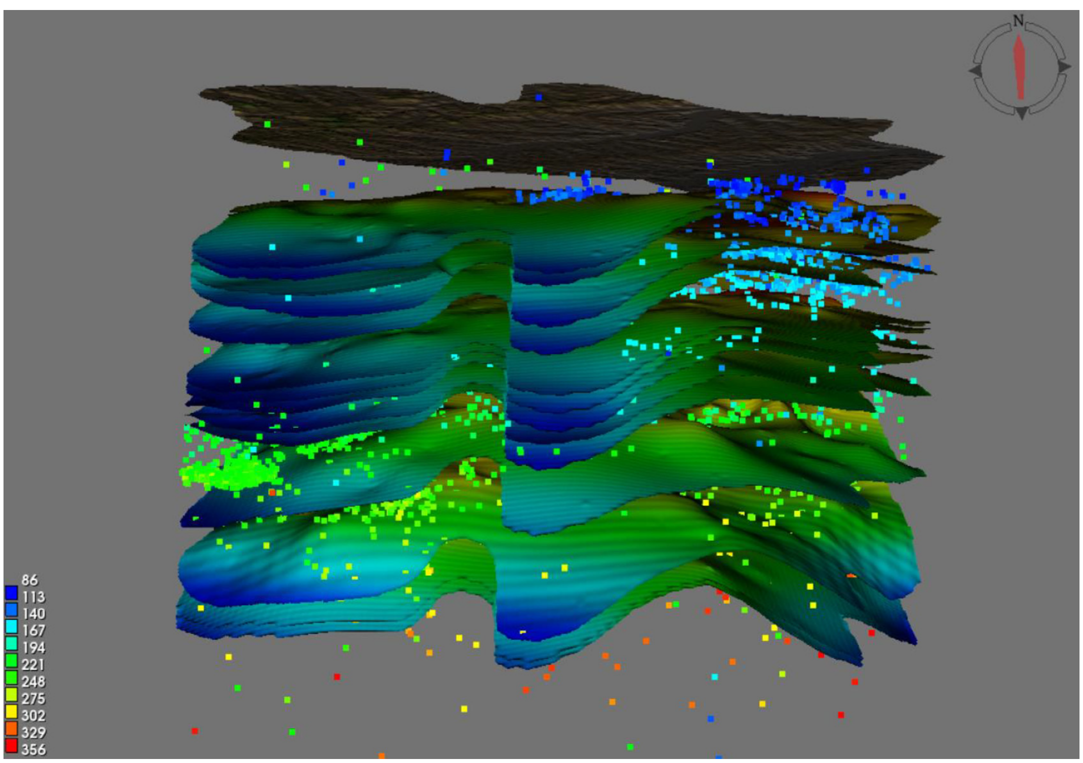

Figure 7. 3D view of BHT values (dots, colored in degrees Fahrenheit) with respect to the lithostratigraphic layer model. The surface layer is the DEM. The deepest layer is the Haynesville Limestone.

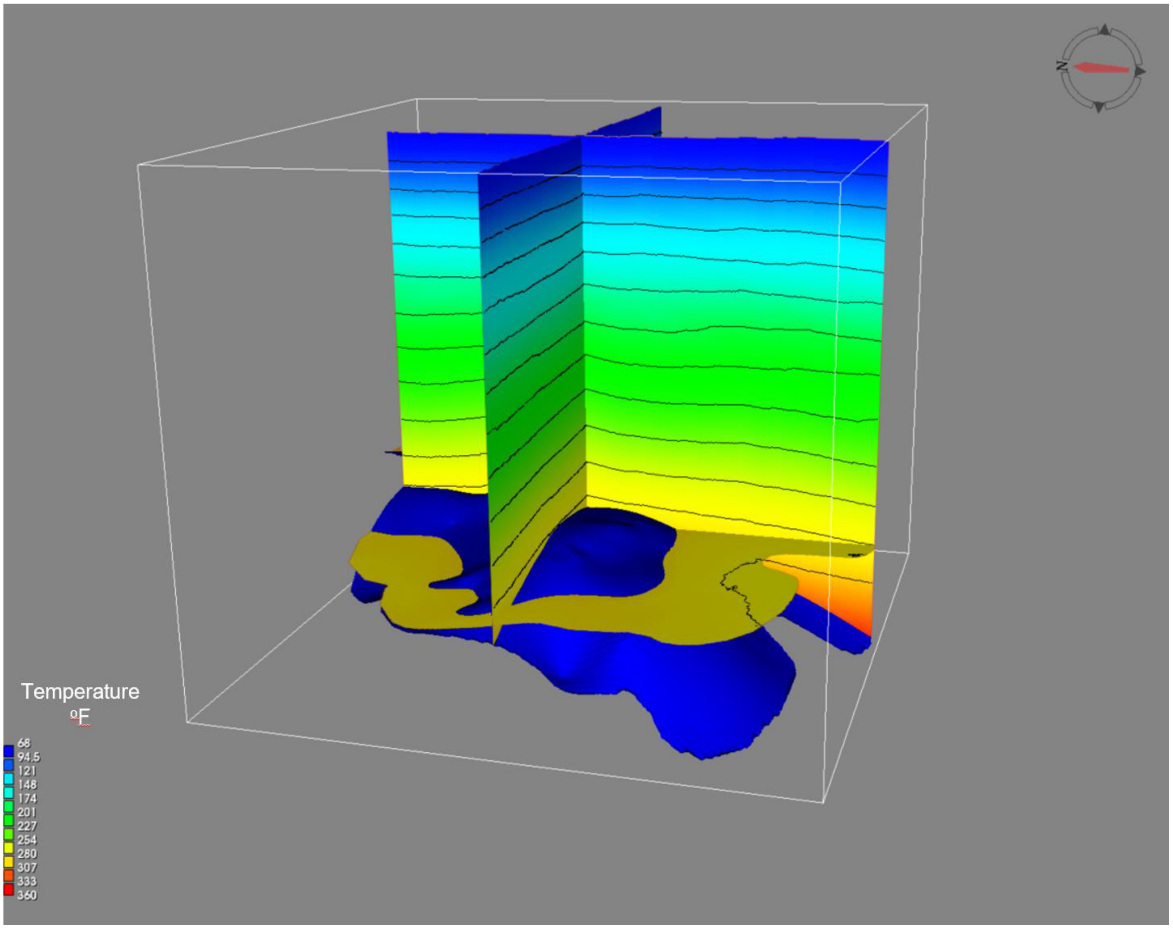

Figure 8. Haynesville Play MaxG temperature model. The figure shows three x, y, and z planes through the cube, which is cropped at ground level and at the basal lithostratigraphic layer (the Haynesville Limestone: dark blue layer). Contours are in 20°F intervals.

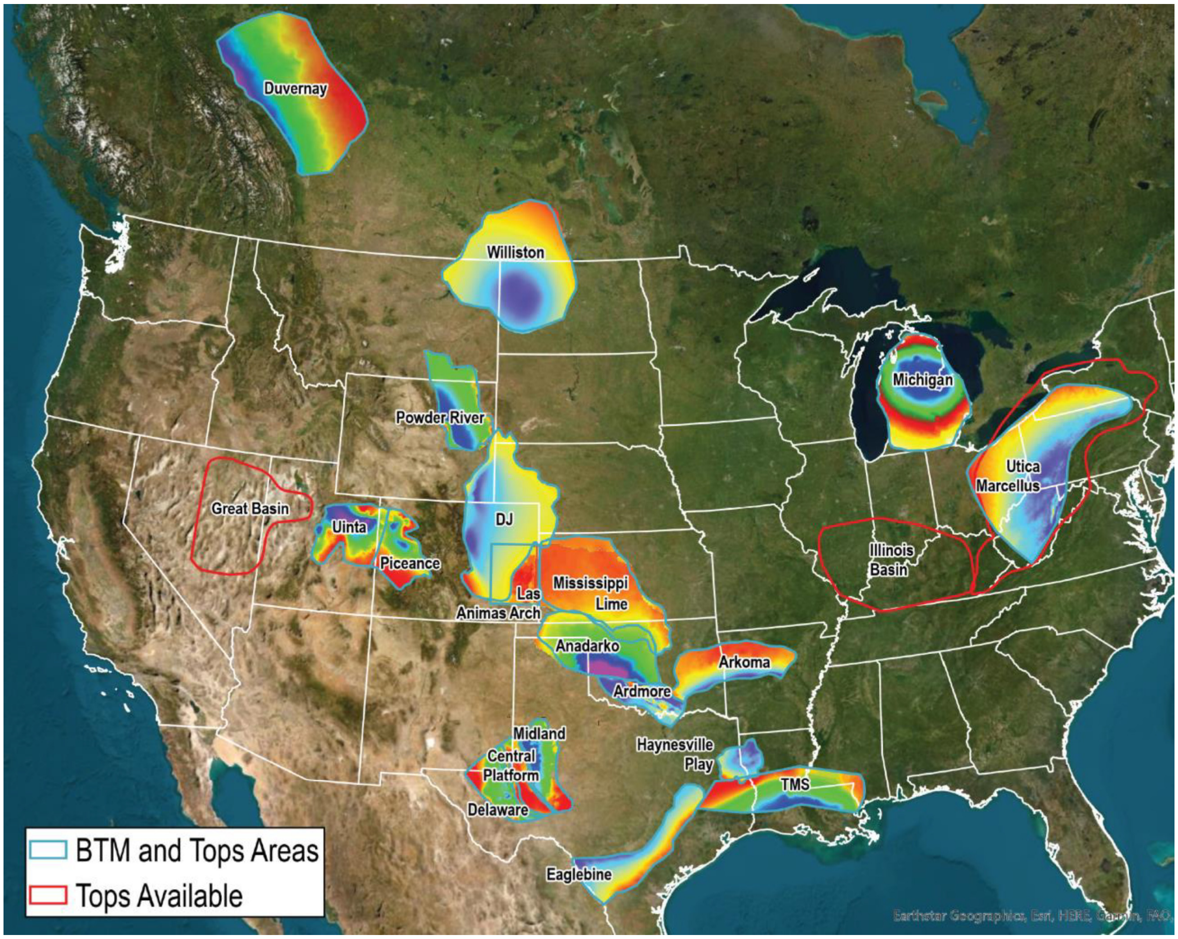

Figure 9. 18 basin temperature models have been constructed using a consistent workflow (Fig. 1) and our vast data library for selected major sedimentary basins throughout the USA and Canada. All are delivered in industry standard 3D SEG–Y format for easy integration and use. Colors represent the depth structure map (color-fill contours) of a particular horizon in each of the 18 basins in which we have BTMs—broadly, red = shallow and blue = deep, but the horizon and the depth range (and thus individual basin color bar) varies considerably from basin to basin.

NOTES