Using Static Temperatures to More Accurately Predict Geothermal Gradients in the Williston Basin

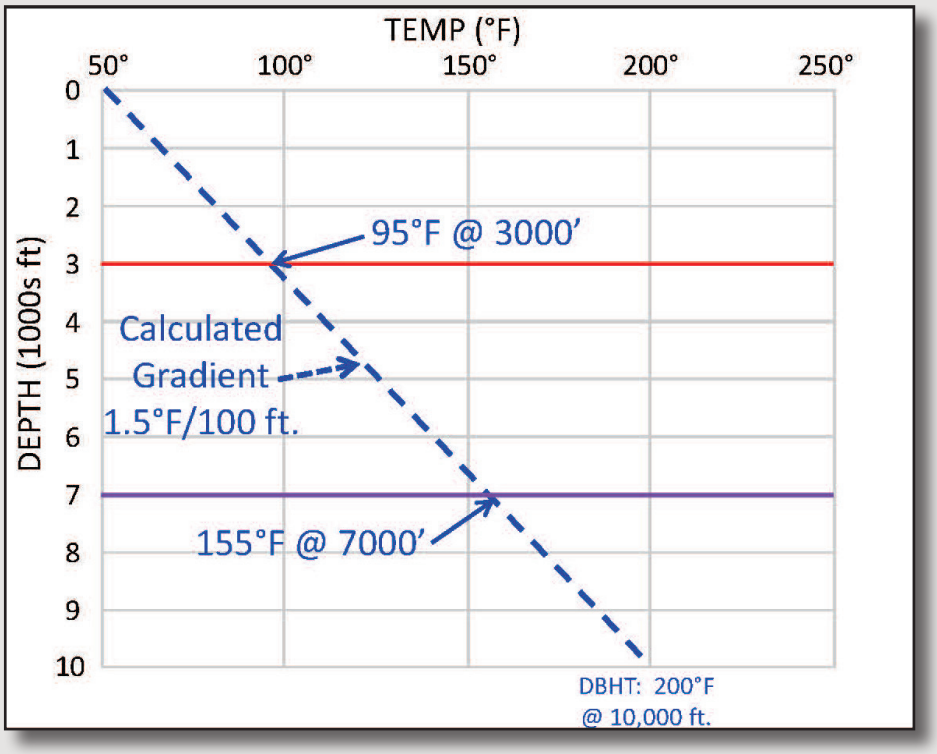
Travis Stolldorf

INTRODUCTION

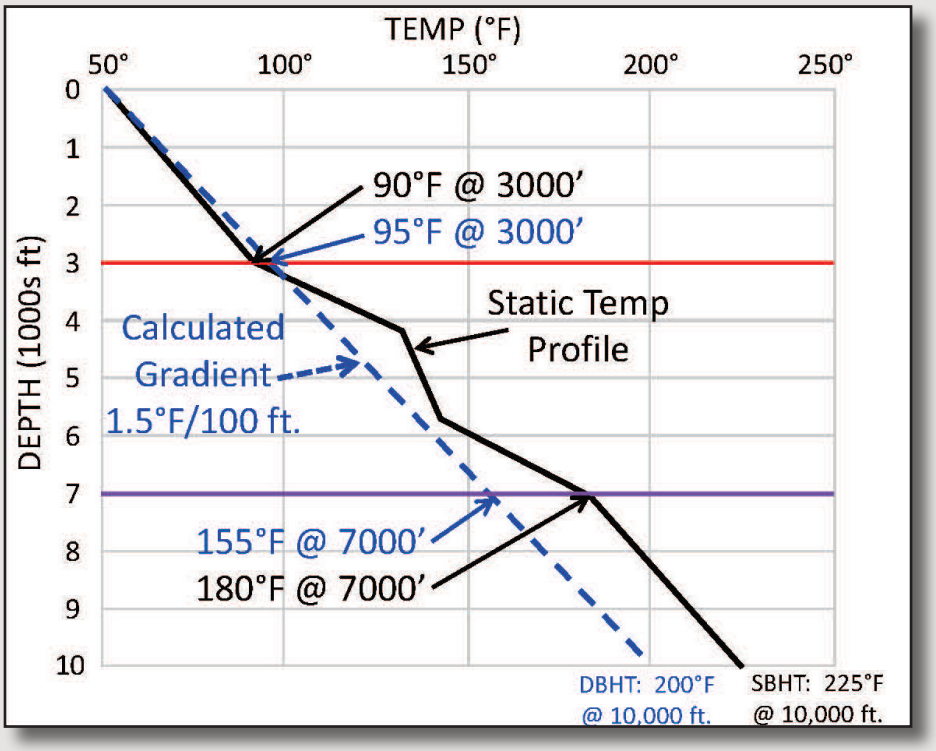
Geothermal gradients (subsurface temperature gradients) are a commonly utilized ratio in petroleum exploration and development. Gradients are calculated from known temperatures at depth and are presented in °F/ft. or, more commonly, °F/100 ft. In turn, these gradients are used to estimate subsurface temperatures. However, geothermal gradients are only as good as the data used to calculate them. As previously discussed, (Stolldorf, 2019) most reported temperatures are taken during the dynamic phase of a well's life (i.e. during or immediately after drilling has ceased) before temperatures within the wellbore have been allowed to equilibrate. Dynamic bottom hole temperatures can vary substantially from static bottom hole temperatures, measurements taken after temperatures have equilibrated, and often underestimate the actual bottom hole temperature (Fig. 1).

Furthermore, most geothermal gradients aren't linear from the surface to the geologic basement, but rather a series of linear gradients (Fig. 1). These gradients are a product of the interaction between basement heat flow and the thermal conductivity of the overlying rock. The thermal conductivity of the rock is affected by its mineral composition (e.g. more quartz sand versus carbonate limestone), formation fluid type and salinity, among other things that can vary substantially both horizontally and vertically in the basin. McDonald (2015) further demonstrated how basement

Geothermal Gradient Calculated using DBHT: 200°F @ 10,000 ft



Calculated Geothermal Gradient vs. Measured Temperature



heat flow also varies in the Williston Basin. The high variability of basement heat flow and thermal conductivity make estimating temperatures at depth very difficult.

NDGS Fills a Niche

Seizing an opportunity to substantially add to the scientific understanding of the subsurface, the North Dakota Geological Survey (NDGS) initiated a temperature logging program in 2014. To date, the NDGS has logged 25 wells with plans for additional wells in 2020. Static temperature logs are rarely taken, primarily due to economic realities. For a well to become a candidate for a static temperature log, the well must become temperature-equilibrated. This requires that all well activity (drilling, production, workovers, etc.) must be suspended for weeks or even months prior to temperature logging (the NDGS prefers a minimum of six months of inactivity prior to logging a well to provide ample time for temperatures to equilibrate in the wellbore). This typically occurs in the waning stages of a well's lifespan after production has ceased but prior to the final abandonment of the well. During this final phase of field development, operators are hesitant to invest money into projects that are nearing completion. While most operators recognize the value of static temperature logs, it is extremely difficult to quantify the value of such information in order to secure funding for post-production logging operations.

Inyan Kara Geothermal Gradient Map

Twenty-four static temperature curves penetrated the Inyan Kara Formation in North Dakota. Geothermal gradients were calculated for each well using a 41°F mean annual

Figure 1. (Top) Geothermal gradient calculated using a dynamic bottom hole temperature (DBHT) and (bottom) with the same calculated gradient compared to the static temperature profile of the well. This Figure demonstrates the shortcomings of using a single geothermal gradient in a wellbore. The error is further compounded if a DBHT is used rather than a static bottom hole temperature (SBHT).

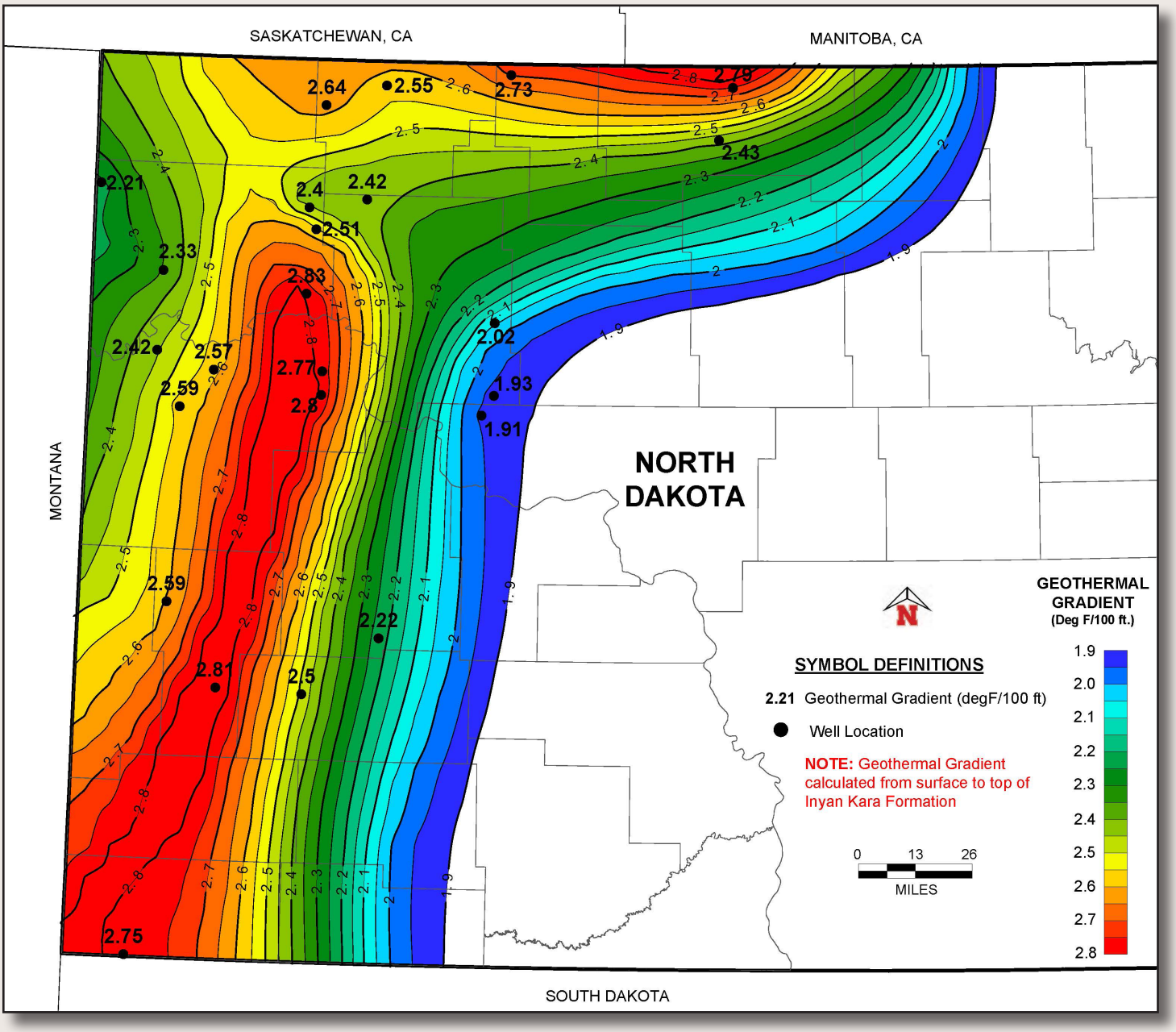


Figure 2. Map of Inyan Kara geothermal gradients in western North Dakota. Gradients range between 1.9°F/100 ft. and 2.8°F/100 ft. NOTE: These gradients are only applicable for the Inyan Kara Formation and should not be used to estimate temperatures outside of the Inyan Kara Formation.

surface temperature. Figure 2 shows calculated geothermal gradients based on depths and static temperatures taken from the Inyan Kara Formation. These gradients range between 2.8°F/100 ft. in west-central North Dakota to 1.9°F/100 ft. along the eastern flank of the basin. When applying the geothermal gradients shown, it is imperative to know that these gradients are only suitable to use when estimating temperatures within the Inyan Kara Formation. As shown in Figure 1, calculated temperatures based on geothermal gradients can vary wildly from actual temperature surveys if used incorrectly.

As the static temperature logging project progresses, the NDGS will continue to release geothermal gradient maps for individual formations throughout the Williston Basin. As more static temperature logs are run in areas where no static data currently exist, the gradient contours will become more accurate and will subsequently be added to published maps.

REFERENCES

McDonald, M.R., 2015, Preliminary results of temperature logging in the Williston Basin to determine heat flow, North Dakota Geological Survey, Report of Investigation No. 115, 170 p.

Stolldorf, T.D., 2019, Williston Basin static temperature logging program continues to yield results, North Dakota Geological Survey, Geo News, v. 46, no. 1, p. 14-16.