

Re-Evaluation of Bottom-Hole Temperature Corrections - New Insights from Two Wells in West Central Utah*

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Abstract

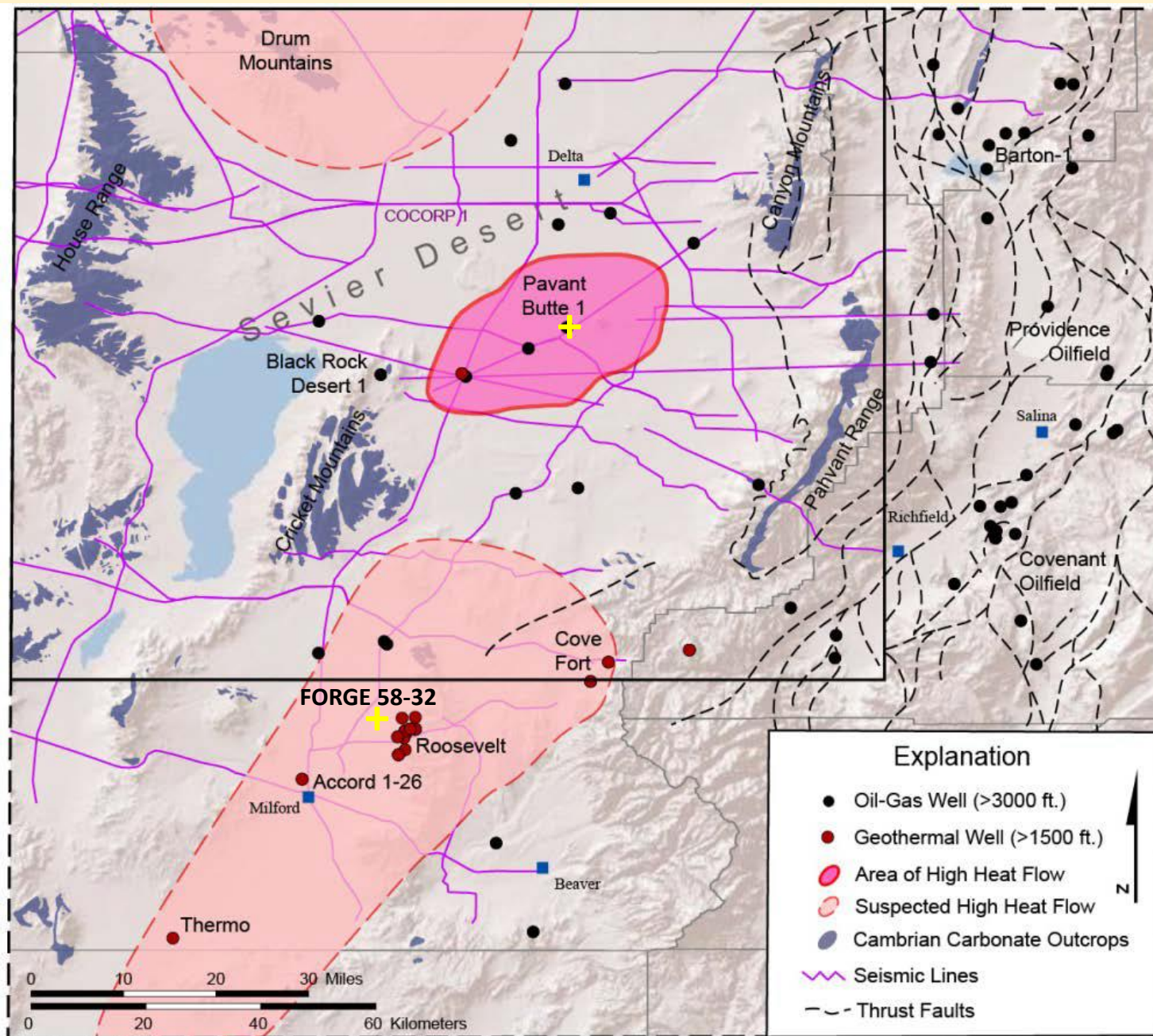
The in situ thermal regime in oil and gas exploration wells has often been assessed using Horner-type corrections, although numerous alternative empirical techniques have also been used. A common obstacle for many of these methods is the fact that critical data required to make an accurate correction to the drilling-disturbed temperature are rarely recorded. In the Pavant Butte 1 well, drilled by ARCO Oil and Gas Co. in 1981, geophysical logging at several depths allowed us to construct a geotherm based on Horner-type corrections. The geotherm indicated a temperature of $230 \pm 10^{\circ}\text{C}$ at the total depth (TD) of 3300 m. We subsequently received a previously confidential equilibrium temperature profile measured when Phillips Geothermal re-entered the well in 1984, three years after it was plugged and abandoned. The observed temperature at the bottom of the casing at 2133 m is 15°C hotter than previously predicted, and the temperature is estimated to be 250°C at TD. Ascencio et al. (2006) have shown from spherical-radial theory that transient temperatures at TD display a linear T versus $1/\sqrt{\text{time}}$ behavior, with an intercept equal to the undisturbed formation temperature. These authors comment that Horner-type corrections appear to underestimate the equilibrium temperature. Their simple correction technique does not appear to have been used in the petroleum literature. The opportunity to test the accuracy of the Horner-type correction and the Ascencio et al. method became available in a geothermal exploration well drilled in August-September of 2017. Four transient temperatures measured over 24 hours at an interim TD of 2073 m imply an equilibrium temperature of $185 \pm 10^{\circ}\text{C}$ using the Horner-type correction and $196 \pm 10^{\circ}\text{C}$ using the Ascencio et al. method. An equilibrium profile will be measured in this new well in November of 2017, approximately eight weeks after the well was shut-in, and will be compared with these predictions.

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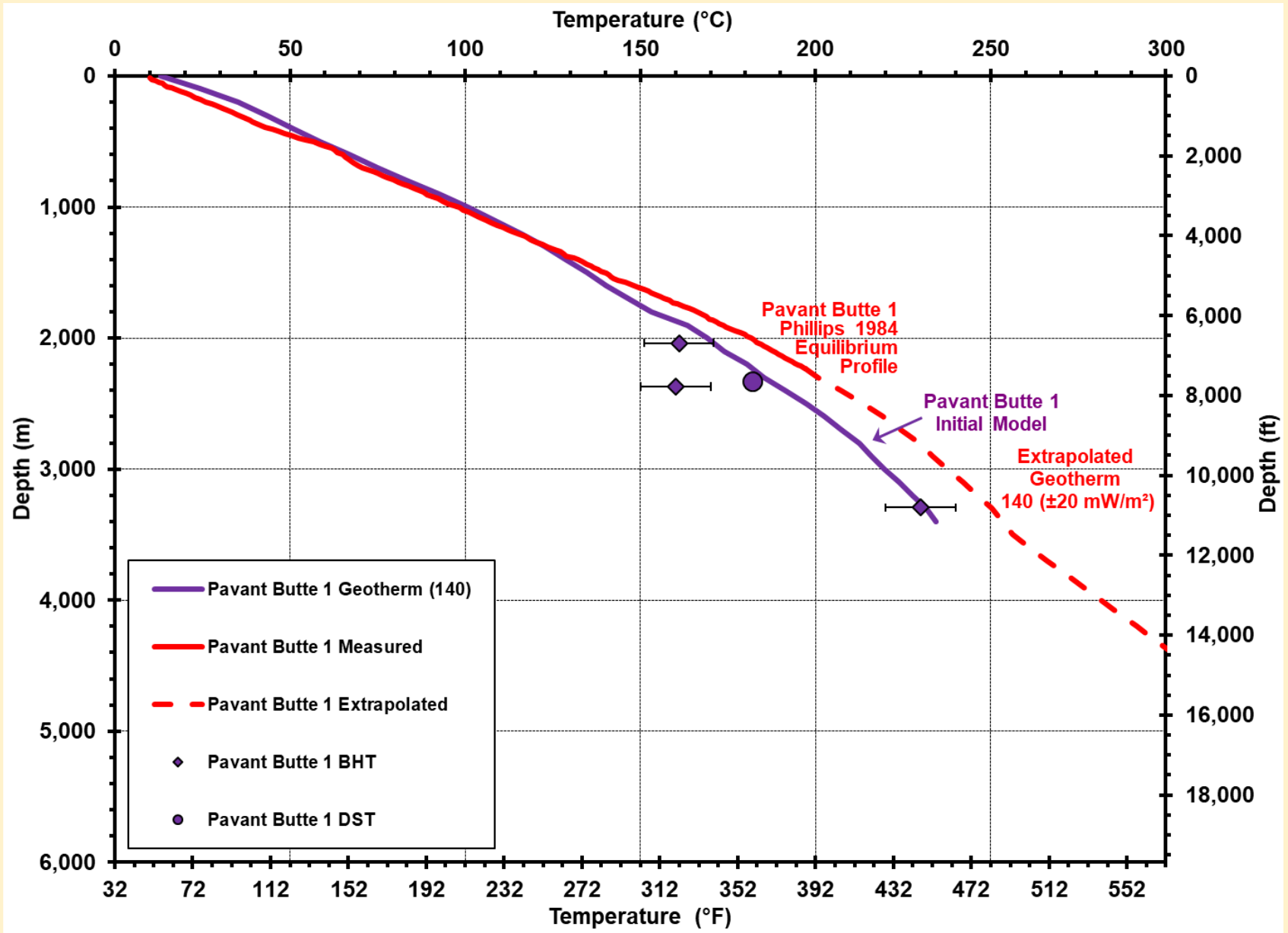






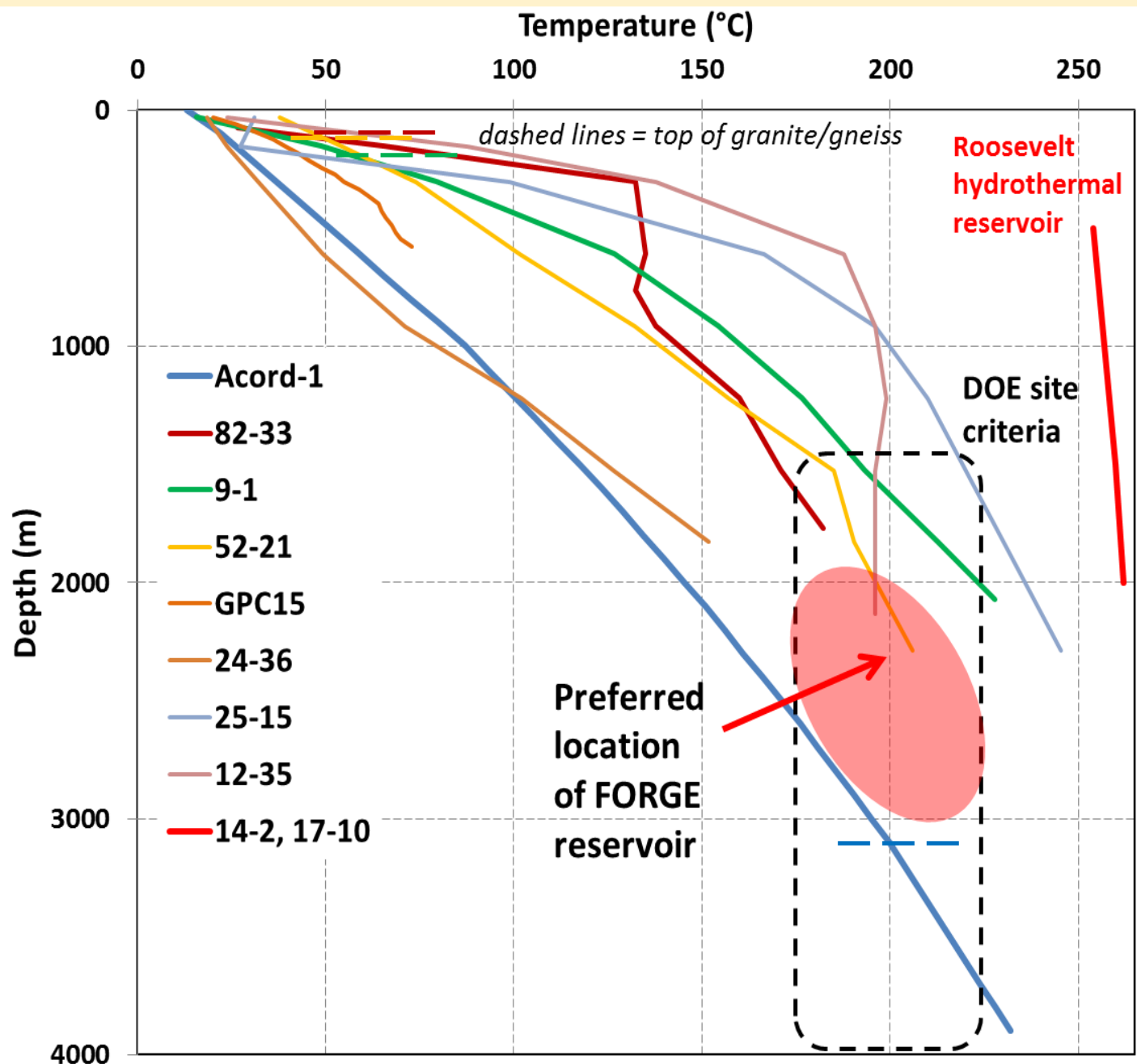
Arco - Pavant Butte 1

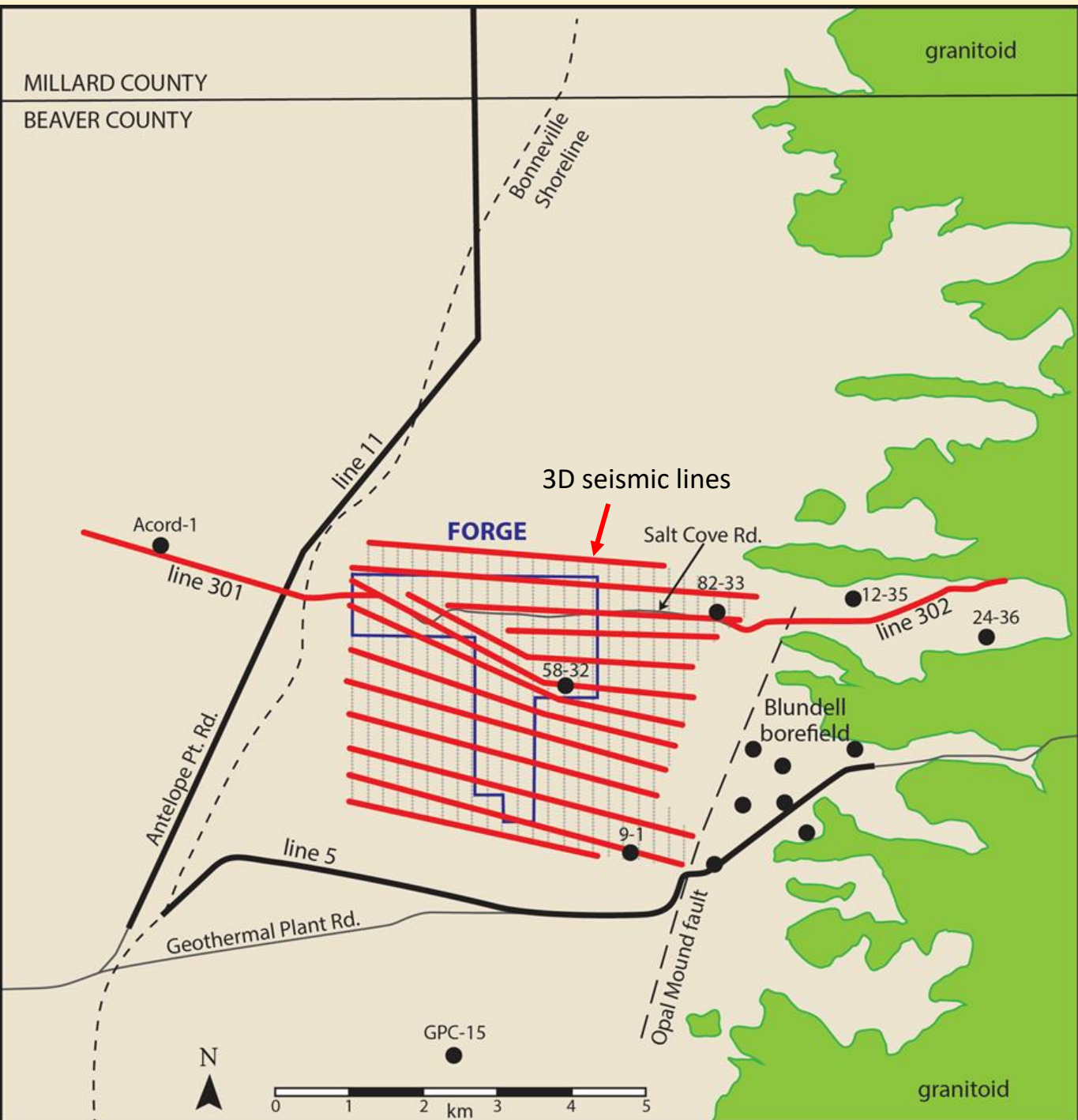
Phillips Geothermal re-entered Pavant Butte 1 about two years after Arco P & A'd the well in 1981. We obtained the previously confidential temperature log in 2013, and found our BHT Horner corrections were too conservative



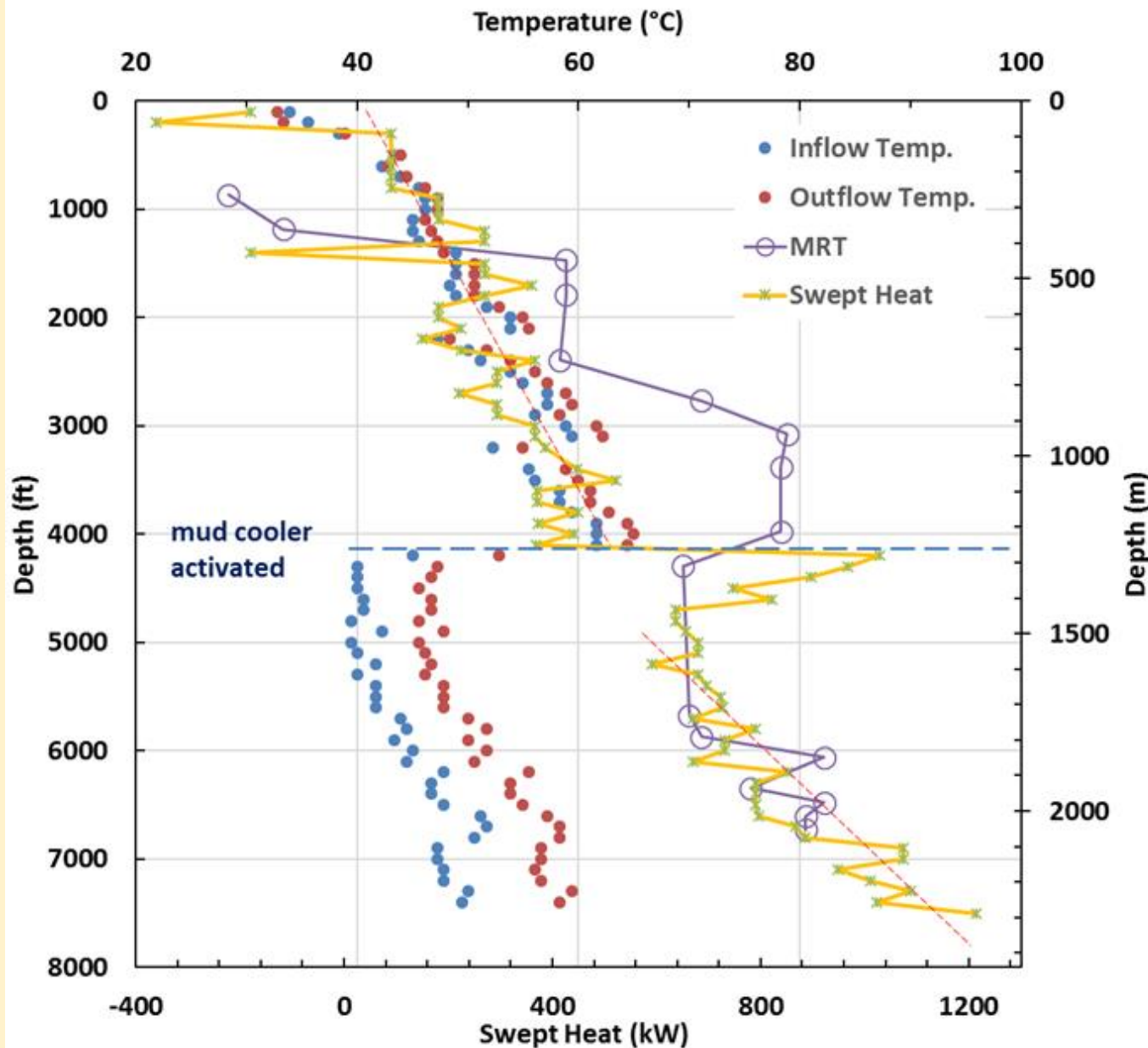
The Challenge:

With drilling rig costs of \$35k/day, how long do you have to stop for to be sure the bottom of the well is at $> 175^{\circ}\text{C}$ (one of DOE's site criteria?)





- The FORGE Milford site is 15 minutes' drive from the town of Milford
- Well 58-32 was drilled as part of Phase 2B to prove the site has the required characteristics – it is 3 km from the production borefield of Blundell (PacifiCorp; 35 MW gross)



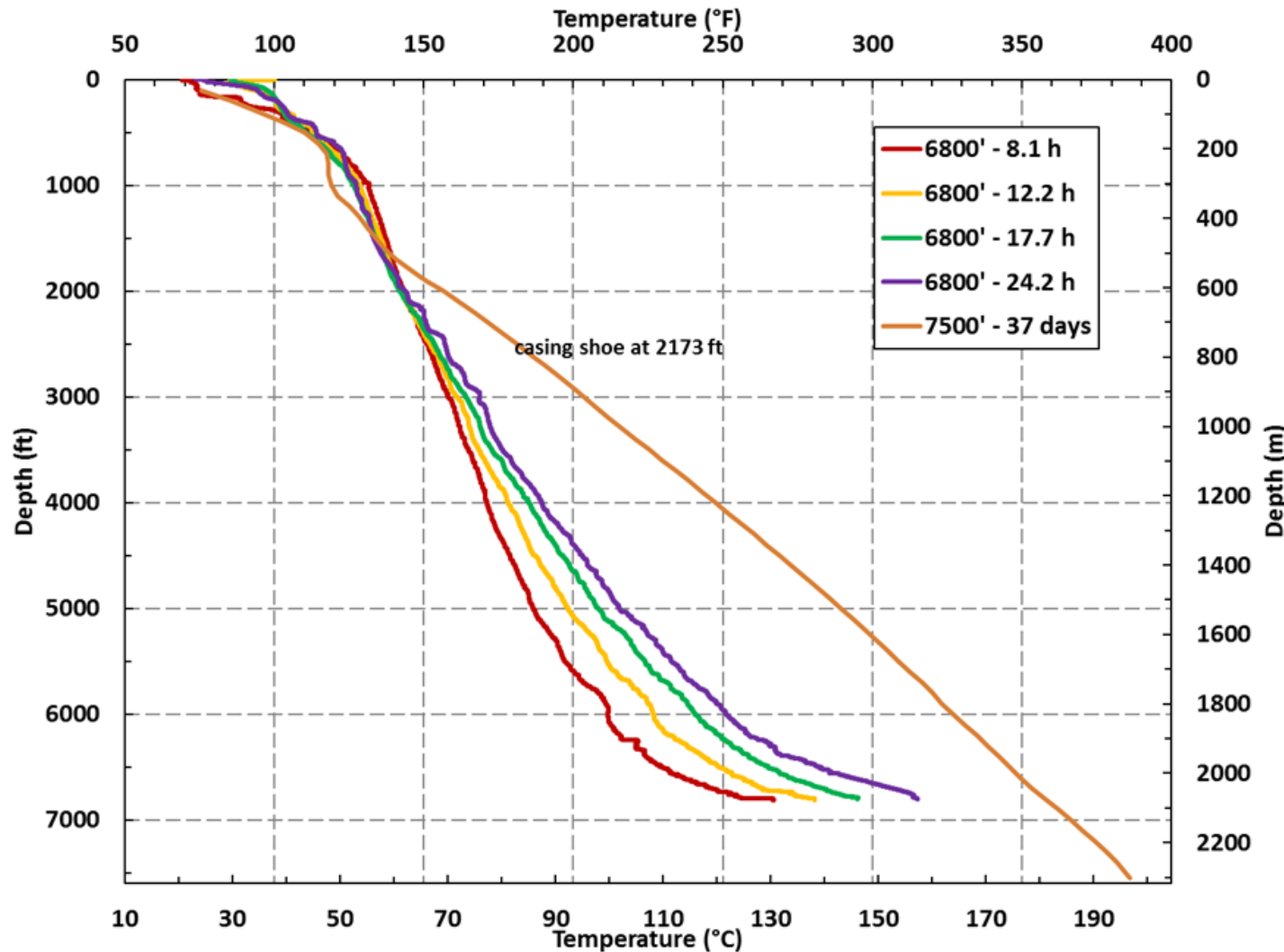
Drilling Indicators of Increasing Temperature with Depth

The maximum reading thermometer (MRT) was deployed every time there was a deviation measurement. These temperatures turned out to be not very useful –the MRT was ~ 90 ft above drillbit, and there was only ~ 1 hour of shut-in time after circulation stopped

“Heat Swept” could be useful as a parameter in other holes with similar drilling characteristics

- Drilling was stopped at 6800 ft for 24 hours to assess the temperature at that depth, and make decision on final depth of the hole
- There had been no drilling losses; drilling rate was ~ 10 ft /hour; the drilling disturbance at the bottom of the hole prior to pulling the rods out was estimated to be 2 ± 0.5 hours
- The hole was logged for times at ~ 6 hour intervals starting at 8 hours after drilling and circulation stopped



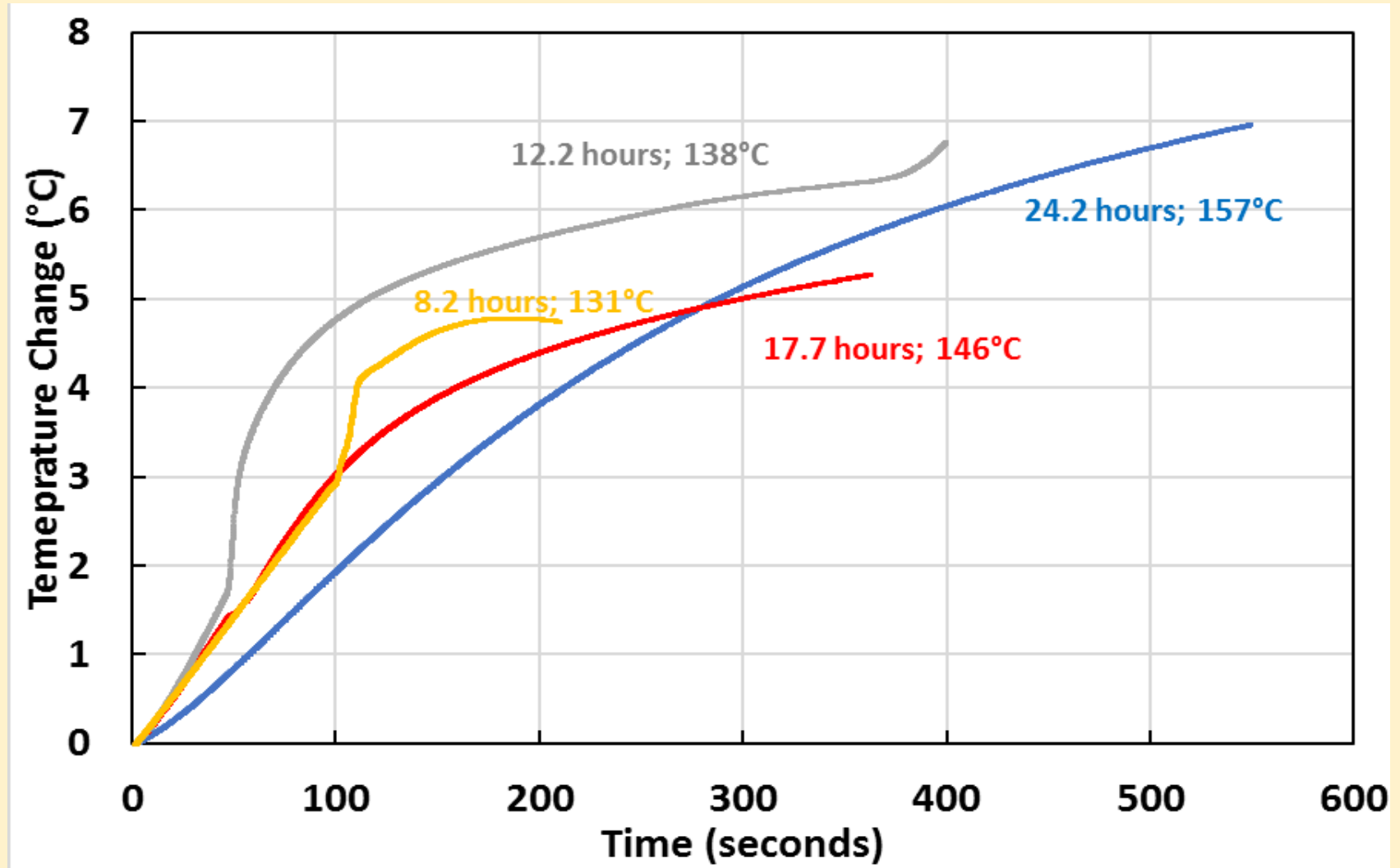


- The most useful temperature for quantifying the thermal recovery is right to the bottom of the hole
- Everywhere else higher in the hole the drilling disturbance is too large (there were no losses while drilling)
- Spend the logging time at the bottom of the hole (not running the profile in the rest of the hole)



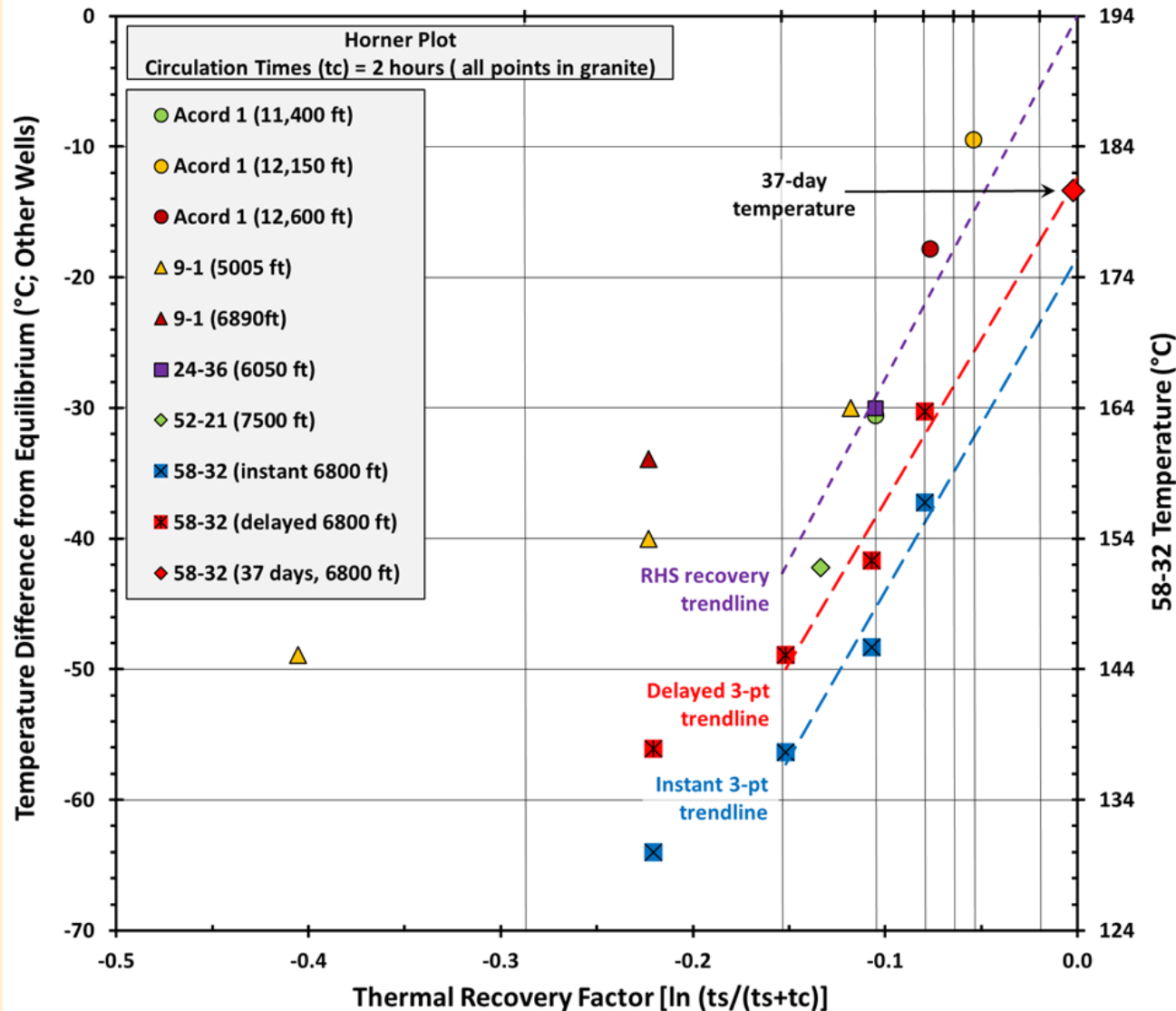
The thermal response time of the probe was a few seconds

Surprise! The temperature at the bottom of the hole was not stable



This response is attributed to radial temperature gradients in the rapidly heating hole, and mixing caused by the arrival of the probe

Shut-in Time (ts; Hours)



Horner Plot

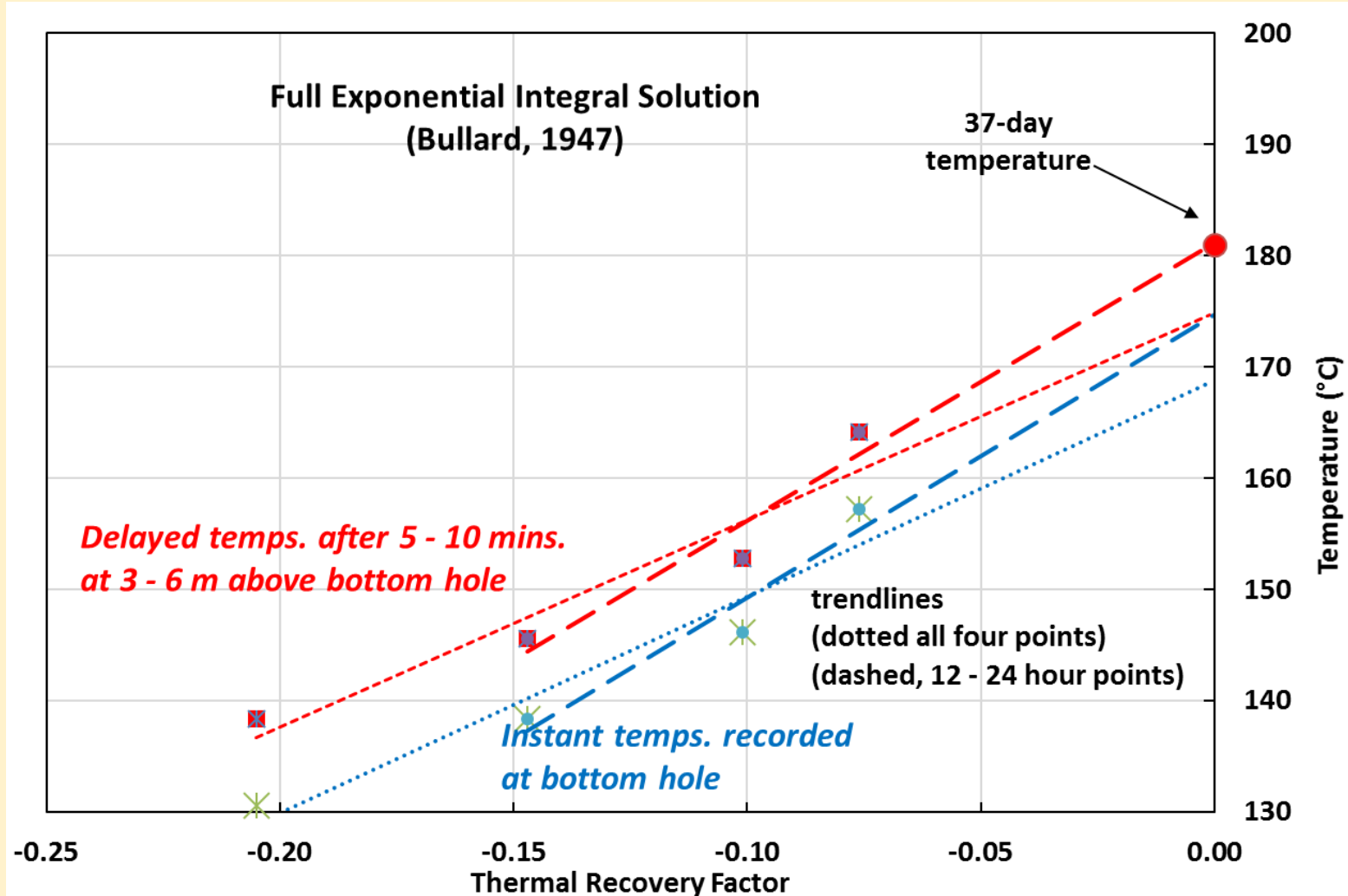
The best-fit line to the three temperatures between 12-24 hours correctly predict the 37-day temperature (using the delayed/mixed temperatures)

The recovery slope is similar to recovery points from several exploration wells around RHS drilled in the late 1970s (also in granite and with 8.75" drill bit)

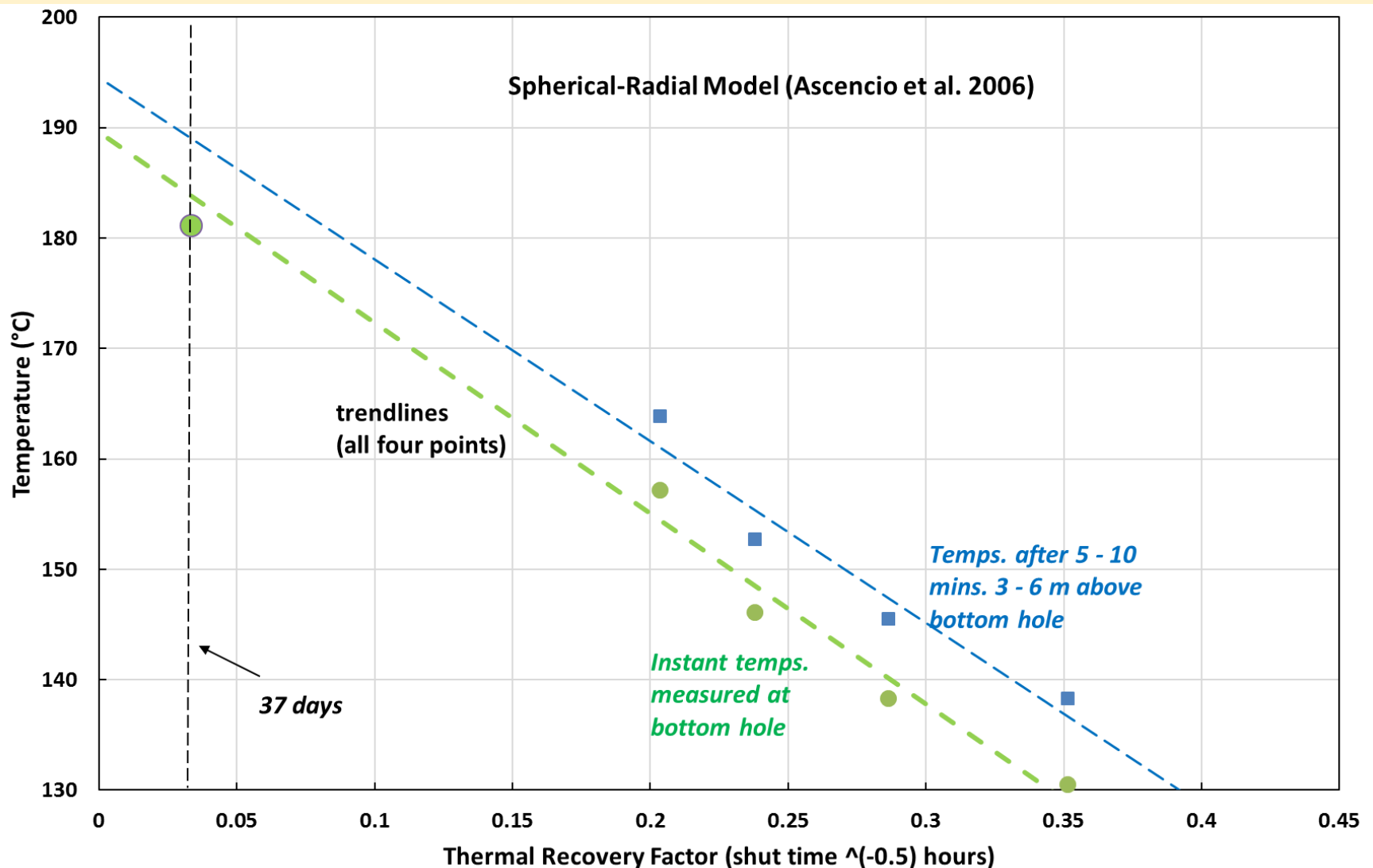
This slope may be a characteristic recovery parameter where there have been no drilling fluid losses

The Bullard solution doesn't help with short recovery times (i.e. the initial measurement at 8 hours).

The Horner plot is a long-time solution to the exponential integral



The Ascencio model over-predicts the equilibrium temperature – as Ascencio et al. have previously noted.



Lessons Learned

- Lower section of 58-32 was drilled in granite with 8.75" drill bit to 6800 ft at ~ 10 ft/h, with no drilling fluid losses
- When the drilling stopped for 24 hours to monitor the thermal recovery, the mud was returning to the surface at 57°C, and flowing into the well from the mud cooler at 50°C; the heat being swept by the mud was 900 kW – suggesting this is a possibly useful proxy of downhole temperature
- Near 6800 ft, the maximum reading thermometer was indicating only 80°C, but this was only 1 hour after circulation stopped, and about 90 ft above the drill bit. The MRT readings were a very a poor indicator of downhole temperature
- Our circulation time at the bottom of the hole when at 6800 ft was estimated to be 2 ± 0.5 hours



Lessons Learned (2)

- Temperatures at bottom-hole continued to rise for 5-10 minutes – attributed to radial thermal gradients as the hole was rapidly heating up (this effect was not present 37 days after drilling ceased) – Recommendation: wait for at least 15 minutes for temperatures to stabilize (i.e. borehole at TD to become mixed).
- The four measurements at bottom-hole did not form line on Horner, Bullard, or Ascencio plots. Measurements at less than 12 hours are probably not worth doing – Arrange for logging to start after 12 hours, and have more measurements between 12-24 hours.
- The trendline for the three readings (delayed) after 12 hours on a Horner recovery plot did correctly predict the equilibrium temperature to within a few degrees C.
- Is the logger willing to leave the probe recording temperature at bottom-hole from 12 to 24 hours after circulation stops?

