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New Method for Correcting Bottomhole Temperatures Acquired from Wireline Logging Measurements and Calibrated for the Onshore Gulf of Mexico Basin, U.S.A.

Open-File Report 2019–1143

U.S. Department of the Interior
U.S. Geological Survey

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Contents

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C=(°F-32)/1.8

Abbreviations

σ	standard deviation
AAPG	American Association of Petroleum Geologists
AIFE	American Institute of Formation Evaluation
BHT	bottomhole temperature
DST	drill stem test
IHS	IHS Markit
T_{CORR}	BHT correction
TSC	time since circulation
USGS	U.S. Geological Survey

New Method for Correcting Bottomhole Temperatures Acquired from Wireline Logging Measurements and Calibrated for the Onshore Gulf of Mexico Basin, U.S.A.

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Introduction

Bottomhole temperature (BHT) measurements offer a useful way to characterize the subsurface thermal regime as long as they are corrected to represent in situ reservoir temperatures. BHT correction methods calibrated for the domestic onshore Gulf of Mexico basin were established in this study. These corrections are empirically derived and based on newly compiled databases of BHT wireline measurements and, to a lesser extent, drill stem test data. A unified BHT correction for the onshore Gulf Coast region, as well as 12 distinct BHT correction equations for each of the 12 physiographic provinces within the onshore Gulf Coast region, are provided. This study also characterizes the geothermal gradient across the onshore Gulf of Mexico basin, which ranges from 1.89 degrees Fahrenheit per 100 feet in the Sabine Uplift area to 1.39 degrees Fahrenheit per 100 feet in the Southern Louisiana Salt Basin.

This report disseminates the slides presented at the 68th annual convention of the Gulf Coast Association of Geological Societies and the Gulf Coast Section of the Society of Economic Paleontologists and Mineralogists that was held September 30–October 2, 2018, in Shreveport, Louisiana. The associated paper by Burke and others (2018) was awarded the President's Award for best paper published in the peer-reviewed Gulf Coast Association of Geological Societies Journal for 2018.

Reference Cited

Burke, L.A., Pearson, O.N., Kinney, S.A., and Pitman, J.K., 2018, Methodology for correcting bottomhole temperatures acquired from wireline logging measurements in the onshore U.S. Gulf of Mexico basin to characterize the thermal regime of total petroleum systems—Gulf Coast Association of Geological Societies: GCAGS Journal, v. 7, p. 93–106.

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Presentation Overview

- Introduction and purpose
- Temperature correction approaches
- Gulf Coast regional study area and databases
- Statistical approach and resulting 12 correction equations
- Comparison of this method to other prominent methods
- Discussion and conclusions

Introduction

INTRODUCTION

- In-situ reservoir temperature is a fundamental property that is difficult to accurately measure in the subsurface due to lack of sufficient acquisition times for circulating mud to reach thermal equilibrium with the formation.
- Consequently, reservoir temperatures of the onshore Gulf of Mexico basin, U.S.A., remain largely uncharacterized in a regional or subregional context.

PURPOSE

- The purpose of this investigation is to create bottomhole temperature (BHT) correction equations specifically calibrated for the onshore Gulf of Mexico basin, U.S.A.
- These correction equations are empirically derived and based on large databases of temperatures obtained from wireline measurements and, to a lesser extent, from drill stem tests (DSTs).

Temperature Correction Approaches

- Because of the importance of obtaining accurate subsurface temperatures, a multitude of correction methods have been developed.
- These correction methods fall into one of three categories:
  (1) Application of a published correction,
  (2) Numerical modeling and finite element modeling, or
  (3) An empirical derivation calibrated with real data.

- The most widespread correction methods applied to the Gulf Coast region are
  (1) American Association of Petroleum Geologists (AAPG) correction (Kehle and others, 1970),
  (2) Blackwell and Steele (1989) correction from Southern Methodist University,
  (3) Zetaware Utilities (2006) correction, and
  (4) Waples and others (2004) correction.

Study region

- The onshore Gulf of Mexico basin, U.S.A., study area is vast and encompasses more than 300,000 square miles, extending from the U.S.-Mexico border through Texas, Arkansas, Louisiana, Alabama, Mississippi, Georgia, and Florida, and from State and Federal waters inland to the Ouachita and Appalachian Mountains and the Mississippi Embayment.

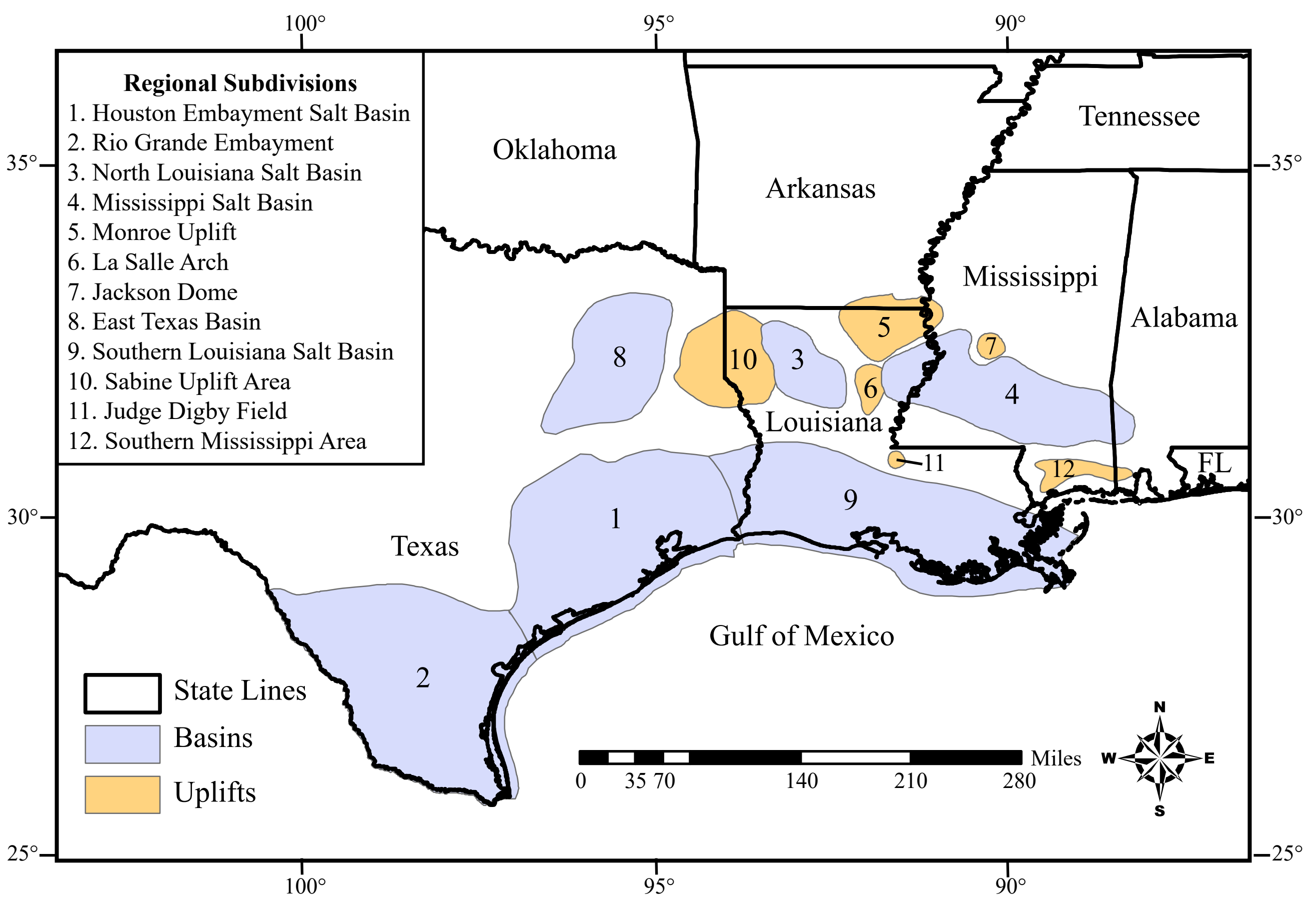
- The stratigraphic section extends from basement through Triassic, Jurassic, Cretaceous, and Tertiary strata, cumulative vertical thickness in excess of 30,000 feet (ft).

- Geographic variations in thermal gradients are expected to exist within the study area especially in regions exhibiting the presence of Jurassic Louann Salt.

- Simply applying a temperature correction that was developed for a different geographic location will not accurately correct BHTs for the onshore Gulf of Mexico basin, U.S.A.

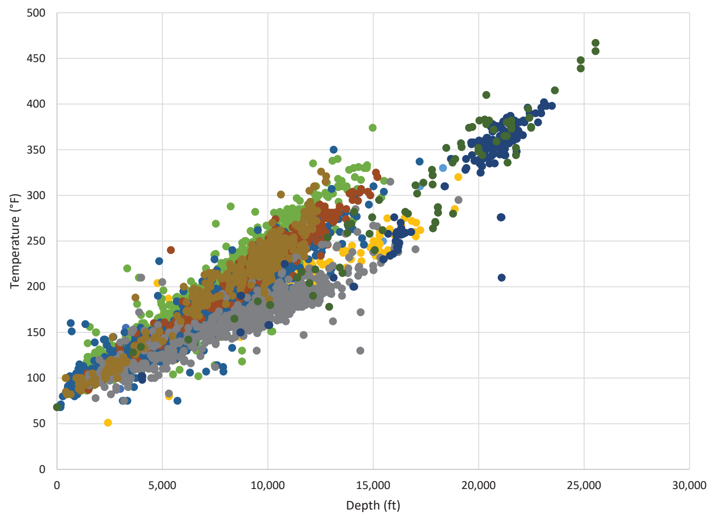
- This study develops a new method to correct BHTs and then calibrates that method specifically to BHT data acquired from wireline logging operations in the onshore Gulf Coast region.

- To capture geographic perturbations in this thermal regime, the study area was subdivided into 12 Gulf Coast subdivisions as illustrated.



Databases

This investigation represents one of the largest, most geographically extensive, data driven, publicly available studies of wireline temperature corrections and thermal gradients across the onshore Gulf of Mexico basin, U.S.A. Graph shows that temperature distributions for the 12 subdivisions are not unique.



Data Metrics

Depths range from 164 to 25,542 ft.
Temperatures range from 51 to 467 degrees Fahrenheit (°F).
Total number of depth-temperature data pairs is 5,825.

Regional subdivision	Data pairs (count)	Depth range (ft)	Temperature range (°F)
1. Houston Embayment Salt Basin	1,606	164–17,201	68–350
2. Rio Grande Embayment	1,899	512–15,509	85–374
3. North Louisiana Salt Basin	163	514–12,510	88–272
4. Mississippi Salt Basin	280	405–19,034	51–320
5. Monroe Uplift	20	1,914–9,770	100–224
6. La Salle Arch	6	2,536–5,008	106–138
7. Jackson Dome	9	2,365– 8,310	110–330
8. East Texas Basin	299	1,429–15,200	87–325
9. Southern Louisiana Salt Basin	577	1,100–20,986	75–356
10. Sabine Uplift Area	694	423–12,766	82–326
11. Judge Digby Field	191	4,010–23,472	98–402
12. Southern Mississippi	81	3,605–25,542	128–467

[°F, degrees Fahrenheit; ft, feet]

Approach

- We introduce the reasonable assertion that, on a regional scale, a discrete depth will exhibit a distinct formation temperature, irrespective of all the spurious measurements that attempt to capture that value.

- Thus, an individual uncorrected BHT is out of context and essentially meaningless on its own.

- We propose that, for sufficiently large populations of data or a collection of ultra-deep measurements, the maximum BHT envelope more accurately represents the formation temperature for that location, geographically and stratigraphically.

- Therefore, a large collection of wireline BHT measurements acquired in deep wellbores are more representative of an accurate formation temperature as compared to a standalone BHT that would be corrected individually.

Mathematics

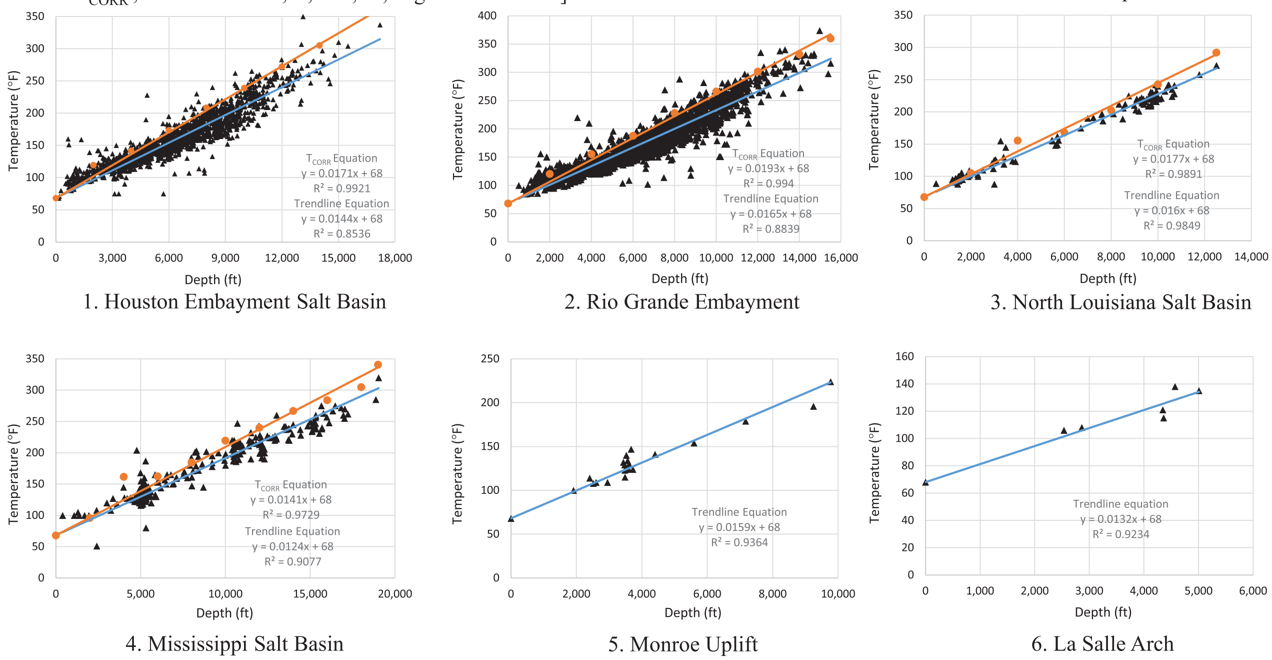
- BHT correction equations, also called T_{CORR} equations, were constructed using highly selective databases compiled from the deepest, hottest BHT measurements with the longest time since circulation (TSC) durations. A database was compiled for each of the 12 regional subdivisions.

- Location-specific BHT correction equations were individually derived for each of the 12 regional subdivisions using the following method:
    1. A temperature **trendline gradient** was determined for each population of data.
    2. Data were **binned by depth increments** to create locally controlled standard deviations (σ) in temperature. This ensures that shallow data would not overly influence the T_{CORR} linear envelope.
    3. **BHT correction equations were constructed** that represent +1.5 σ of depth-binned, locally controlled temperature data. Incidentally, a +1.5 σ sufficiently characterized the data for each of the 12 study regions.

- These BHT correction equations represent the maximum BHT envelope of the population of data while honoring the statistical properties of the data in a repeatable method.

Results (1) [BHT, bottomhole temperature; T_{CORR}, BHT correction; ft, feet; °F, degrees Fahrenheit]

Uncorrected BHT data
Depth bins
T_{CORR} equation
Trendline equation



Results (2) [BHT, bottomhole temperature; T_{CORR}, BHT correction; ft, feet; °F, degrees Fahrenheit]

Uncorrected BHT data
Depth bins
T_{CORR} equation
Trendline equation

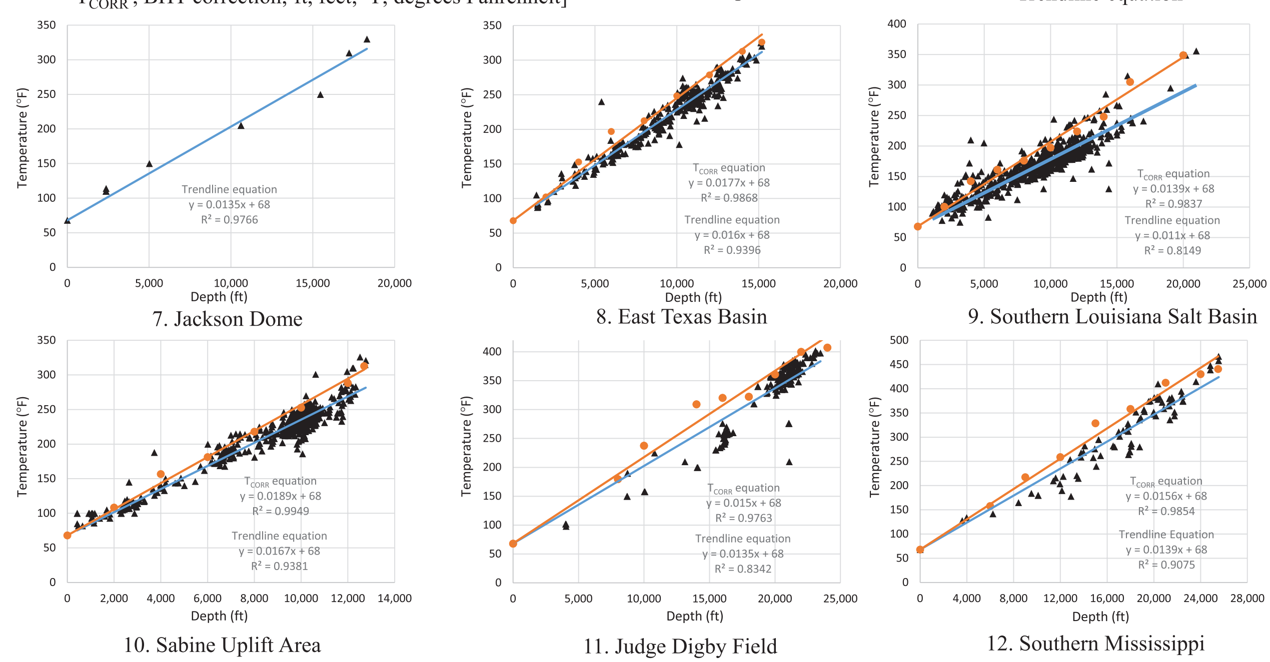


Table of Results

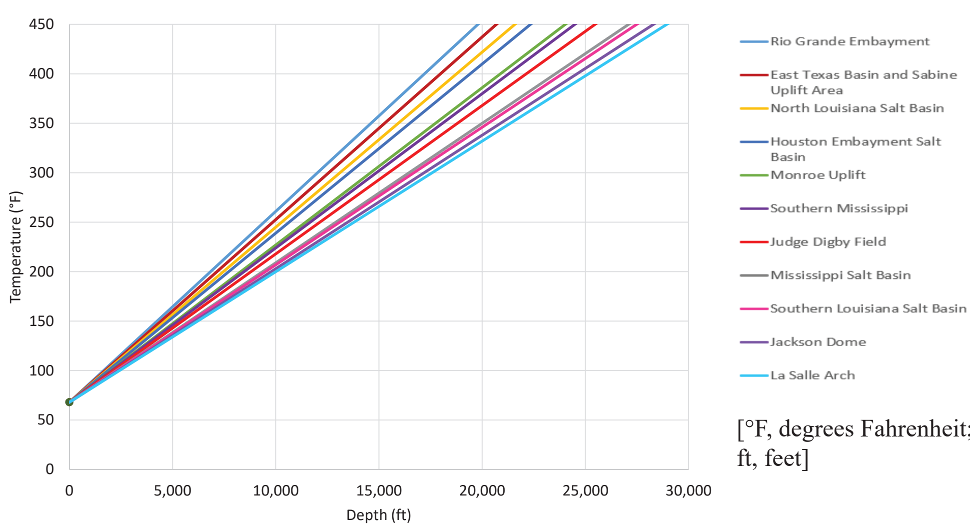
- Each of the 12 subdivisions within the onshore Gulf Coast region exhibits a unique T_{CORR} gradient, which is tabulated below.

Regional subdivision	Trendline gradient (°F/100 ft)	T_{CORR} gradient (°F/100 ft)	R^2 value of T_{CORR}
1. Houston Embayment Salt Basin	1.44	1.71	0.9921
2. Rio Grande Embayment	1.65	1.93	0.9908
3. North Louisiana Salt Basin	1.60	1.77	0.9823
4. Mississippi Salt Basin	1.24	1.41	0.9609
5. Monroe Uplift	1.59	1.59	0.9364
6. La Salle Arch	1.32	1.32	0.9234
7. Jackson Dome	1.35	1.35	0.9704
8. East Texas Basin	1.60	1.77	0.9796
9. Southern Louisiana Salt Basin	1.10	1.39	0.9777
10. Sabine Uplift Area	1.67	1.89	0.9918
11. Judge Digby Field	1.35	1.50	0.9455
12. Southern Mississippi	1.39	1.56	0.9743

[°F, degrees Fahrenheit; ft, feet; R^2, regression factor; T_{CORR}, bottomhole temperature correction]

Synopsis of results

- T_{CORR} gradients range from 1.39 °F/100 ft in the cooler thermal regimes found in the Southern Louisiana Salt Basin to 1.89 °F/100 ft T_{CORR} gradient in the warmer thermal regimes of the Sabine Uplift area.



[°F, degrees Fahrenheit; ft, feet]

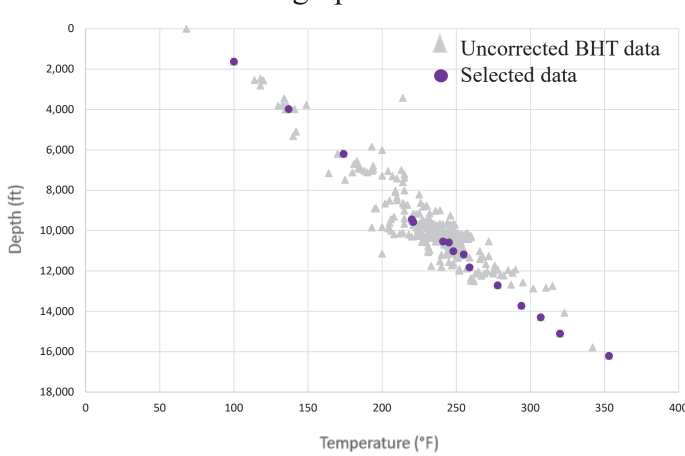
Comparison of This Correction Method with Other Methods

- The U.S. Geological Survey (USGS) correction method was compared with other correction methods that are available in the literature and are often used to correct Gulf Coast BHTs.
- Two databases were created from the uncorrected BHT data acquired over the Sabine Uplift area to test the two parameters of depth and TSC.
- These test datasets were corrected using several prominent methods from the literature as well as this USGS correction method.
- Each of these 2 test datasets contains 15 data triples, which contain the parameters of depth, temperature, and TSC obtained during a single logging measurement event.

Comparison Dataset 1

The stratigraphic dataset has depths ranging from 1,622 to 16,206 ft, and TSC durations ranging from 2.0 to 18.5 hours.

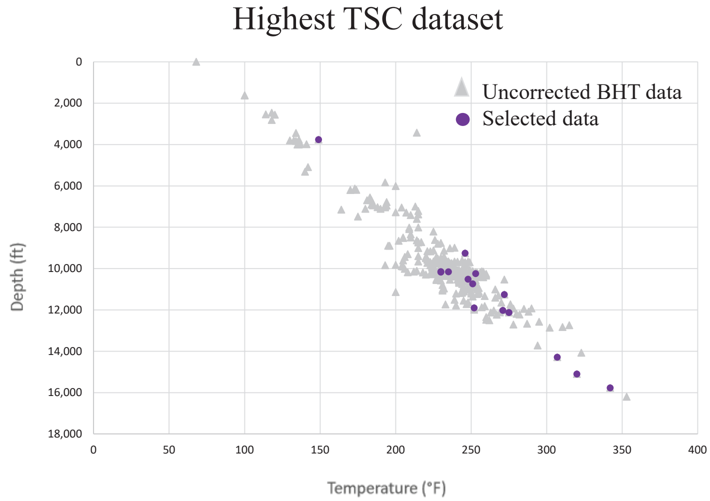
Stratigraphic dataset



[BHT, bottomhole temperature; ft, feet; °F, degrees Fahrenheit]

Comparison Dataset 2

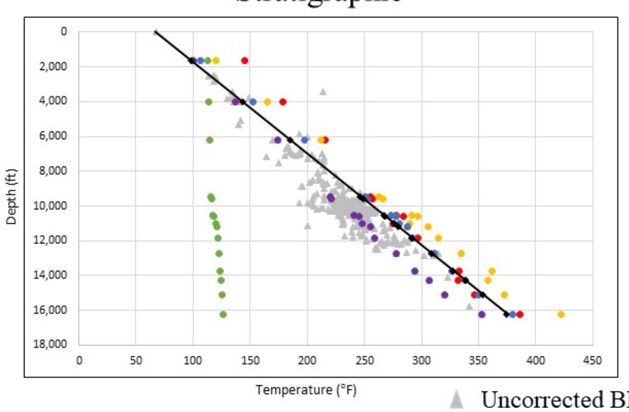
The highest time since circulation (TSC) dataset has depths ranging from 3,761 to 15,776 ft, and TSC durations ranging from 18.0 to 36.0 hours.



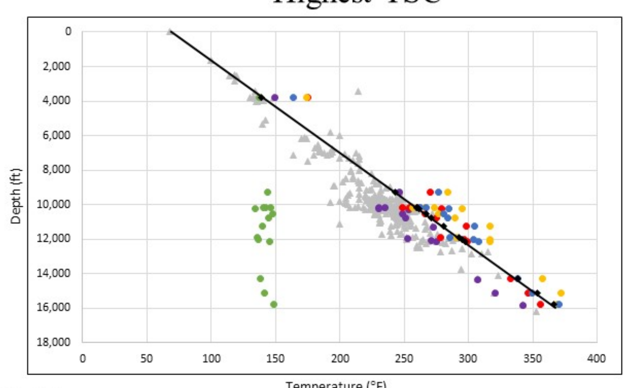
[BHT, bottomhole temperature; ft, feet; °F, degrees Fahrenheit]

Comparison of Correction Methods

Stratigraphic



Highest TSC



[ft, feet; °F, degrees Fahrenheit]

- Uncorrected BHT data
- Selected data
- USGS BHT correction
- Zetaware Utilities (2006) correction, TSC
- Waples and others (2004), shallow water, Mexico
- AAPG (Kehle and others, 1970) correction
- Blackwell and Steele (1989) correction

Discussion

- The USGS BHT correction method was compared to several other correction methods available in the literature.
- Findings indicate that the Blackwell and Steele (1989) correction method underestimates onshore Gulf Coast temperatures, as this method was calibrated using wells of intermediate depth in the Anadarko Basin, Oklahoma.
- The Waples and others (2004) correction method overestimates the onshore Gulf Coast temperatures, likely because this method was derived from shallow wellbore and shallow water data from a different region.
- The correction created by Kehle and others (1970), which is also called the AAPG correction, overestimates shallower temperatures but provides agreement with ultra-deep temperatures.
- The Kehle and others (1970) correction is also based on shallow wellbore data from the Anadarko Basin.
- The Zetaware Utilities (2006) correction overestimates temperatures at both shallow and intermediate depths, and underestimates temperatures at ultra-deep depths.
- In comparison to other correction methods commonly applied in this area, the USGS BHT correction methods most accurately characterize data from the Gulf Coast region because they were calibrated based on data from this region.

Conclusions

- This study establishes an empirical method for correcting wireline BHT measurements acquired in the borehole environment.
- Currently available temperature correction methods, either theoretical, numerical, or empirical, are not directly applicable to the onshore Gulf of Mexico basin, U.S.A., which is one of the most important domestic petroleum-producing provinces in the United States.
- The USGS BHT correction method is calibrated specifically for the onshore Gulf Coast region by statistically defining maximum BHT envelopes for 12 Gulf Coast regional subdivisions.
- Each region exhibits a distinct temperature profile.
- Consequently, a correction equation for one Gulf Coast region is not characteristic of a neighboring Gulf Coast region.
- Therefore, a T_{CORR} equation was developed for each of the 12 regional subdivisions to capture the thermal complexities of the onshore Gulf Coast region.
- The Sabine Uplift area (1.89 °F/100 ft) and Rio Grande Embayment (1.93 °F/100 ft) represent thermal maxima end members for the onshore Gulf Coast region. Conversely, Judge Digby Field in the Deep Tuscaloosa Trend (1.50 °F/100 ft) and Louisiana Salt Basin (1.32 °F/100 ft) exhibit thermal minima compared to the rest of the region.

Acknowledgments

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