North Dakota Geological Survey

Preliminary Results of Temperature Logging in the Williston Basin to determine Heat Flow

By

Mark R. McDonald

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Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources
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Abstract

The North Dakota Geological Survey (NDGS) has embarked on a temperature survey of the Williston Basin, North Dakota. To date, 23 temporarily abandoned oil and gas wells have been logged using a memory tool equipped with a temperature, gamma-ray, and casing collar locator probe lowered by a slickline. Several methods were used to estimate heat flow at the various locations including calculations based on average laboratory values of thermal conductivity, existing heat flow maps, the Bullard Method, and finding the harmonic mean of thermal conductivity. Although there is general agreement in calculated heat flow values between the various methods presented above, the results are largely predicated upon initial assumptions of either heat flow, thermal conductivity, or both.

While we are confident in the measurements obtained during this study with respect to thermal gradient, additional information with regard to thermal conductivity of the geologic formations will be required to estimate heat flow within the Williston Basin with better accuracy. Geologic formations can often be differentiated on the basis of "marker" beds, but there can be wide variations in mineralogy, lithology, porosity, permeability, density, etc., depending upon depositional environment, depth of burial and secondary processes from one location to another which can profoundly influence thermal conductivity and therefore greatly affect the calculated heat flow.

Introduction

In 2014, the North Dakota Geological Survey (NDGS) initiated a temperature logging program in the Williston Basin. The primary goal of the program is to gain further insight into the thermal history of the basin that may result in the development of improved models for use in exploration for oil and natural gas (Prensky, 1992). The program has also been designed to gather data useful in the evaluation of the geothermal potential of the Williston Basin. Insight into the timing of petroleum generation, migration, accumulation and preservation can be gained by determining the thermal maturity of hydrocarbons and/or by using the paleoheat flux of a sedimentary basin (Nuccio and Barker, 1990). Subsurface temperature is important to understanding the origin and evolution of sedimentary basins and can also be used in the determination of important kinetic factors as described by Nordeng and Nesheim (2011) and Nordeng (2012, 2013, 2014) that can ultimately be used to predict the oil generation potential of various geologic formations within the Williston Basin. These heat flow values represent critical data that are needed to validate and, where needed, update current heat flow maps (Blackwell and Richards, 2004). Heat flow together with thermal conductivity values of subsurface rocks, can be used to estimate subsurface temperatures at other locations and depths. This information can also be used in the evaluation, assessment and possible exploration and development of geothermal energy in the Williston Basin.

Methodology

While subsurface temperatures are routinely collected during logging and drill stem tests, true formation temperatures are rarely recorded because drilling, well completion and production operations can cause significant variations in the wellbore temperature from the actual temperature of the neighboring strata. These temperature differences can persist for days or weeks after drilling or production has ceased. For example, during drilling, the circulation of drilling mud can cool the rock, during completion operations curing of cement and acidizing are exothermic reactions that can heat the rock, and gas entering the wellbore during production cools by expansion. In order to confidently obtain accurate subsurface temperatures, care must be taken to assure that the well bore and formation temperatures are the same, i.e. that the temperatures have equilibrated. A number of correction schemes have been derived to account for variations between actual formation temperatures and the measured wellbore temperatures obtained during drilling or while the well is producing such as that developed by Cooper and Jones (1959) or the Horner Method (Lachenbruch and Brewer, 1959). However, the best alternative is to make use of well bores that have been idle for months or, if possible, years so that equilibrated temperatures have been reached. Given these constraints and a review of the pertinent literature, the NDGS concluded that wells that have been temporarily abandoned and undisturbed for at least three months would meet the requirements of this study.

The project consisted of lowering a GOWell Model GTC43C Pegasus® temperature probe with an accuracy of 0.5°C into 23 temporarily abandoned oil and gas wells to the bottom of the well (depth of the plug). The tool included a memory controller sub and was lowered by means of a 0.092 inch "slickline" (nonconductive cable) operated by Gibson Energy Inc. (WISCO division). The depth of the logging runs ranged between approximately 3, 000 feet (915 m) and 13,000 feet (3960 m). The wells were selected based on location, depth, length of time of being undisturbed, and the ability to obtain permission from the current well operators to perform the logging. Locations of the wells are shown in Figure 1.

After setting the equipment up over a well (Figures 2 and 3), a gauge ring (dummy or slug) was lowered down to verify that there were no obstructions within the wellbore and to determine the maximum depth that could be logged for wells that still contained production tubing or where other potential obstructions might exist within the wellbore. After removal of the gauge ring, a period of time (generally on the order of an hour or more) was allowed to elapse in order for the well fluid temperatures to re-equilibrate before lowering the logging tools. For wells that were known to not contain production tubing, the gauge ring was not deployed. The wells were then logged as the tool was lowered into the well to minimize temperature disturbance or mixing of the fluids arising from the displacement of fluids by the volume of the tool. In addition to temperature, the tool was also equipped with a Casing Collar Locator (CCL) and a Gamma Ray probe to aid in correlation of the temperature probe with depth and with the geologic formations (Figure 4). As noted above, a memory controller sub was used which recorded the probe readings at a rate of one reading every 40 milliseconds (ms). The readings were downloaded to a computer after the tool was brought back to the surface. For comparison purposes, the wells were also logged on the way out of the wellbore. Temperature versus depth profiles of all the wells are presented in Appendix A.

It should be noted that for two of the wells, the Capa Madison Unit H-205 (NDIC #1140) and the Frink 13-15 (NDIC #13132), it is postulated that paraffin may have interfered with the temperature readings by clogging the window of the temperature probe pictured in Figure 5. Paraffins are a white or colorless soft solid that consist of a mixture of hydrocarbon molecules

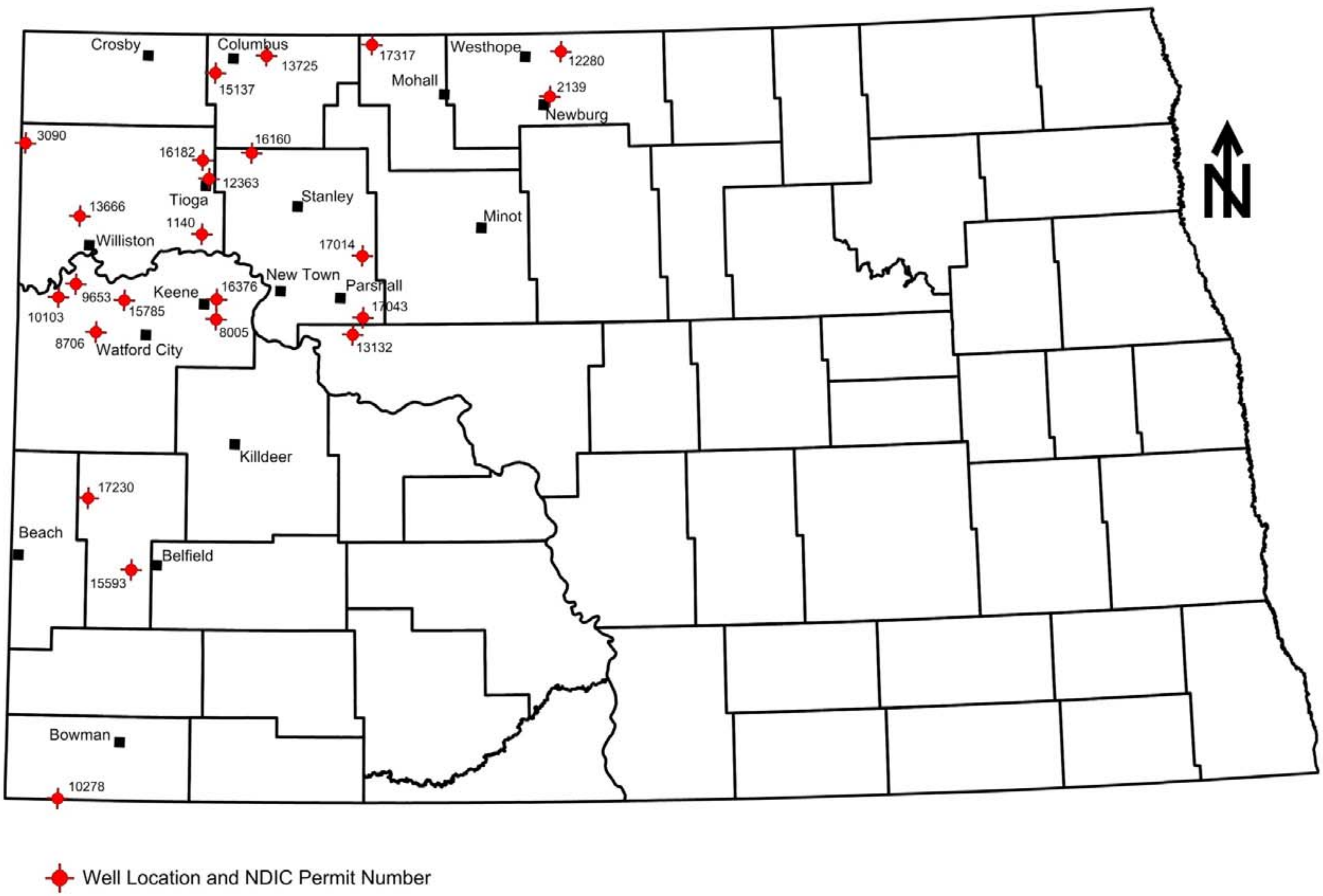

Figure 1. Well Locations.

Figure 2. Connecting the tool to the slickline. From left to right: Mike Harden, WISCO, David Smith, WISCO, Jay Jamali, GOWell, and Kevin Hammer, WISCO.

Figure 3. Slickline unit set up over NDIC Well # 12363, Astrid Ongstad 14-22 north of Tioga, ND.

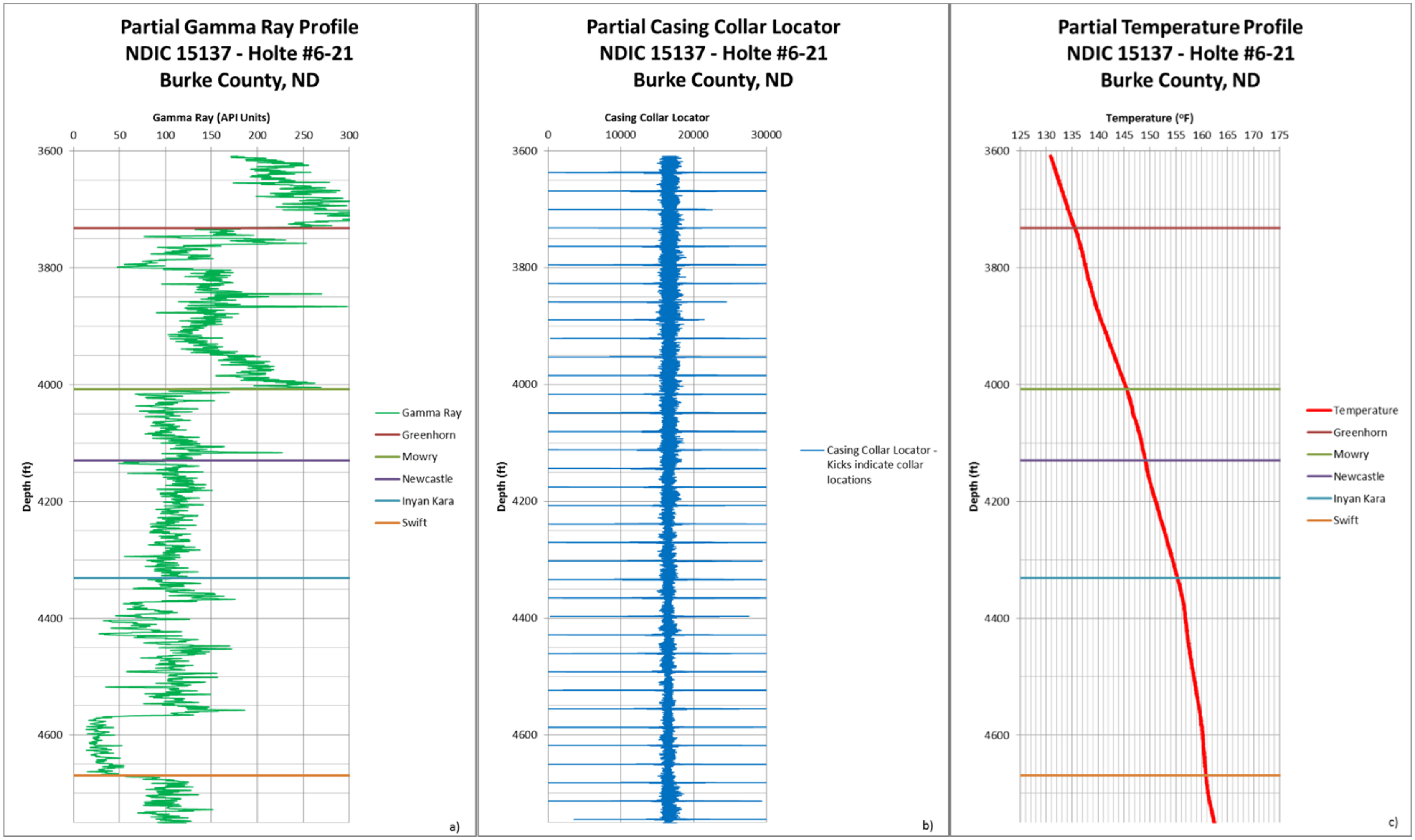

Figure 4. Partial profiles of the Holte #6-21 well: a) partial gamma ray profile illustrating formation top picks; b) partial casing collar locator profile; c) partial temperature gradient profile with formation top picks.

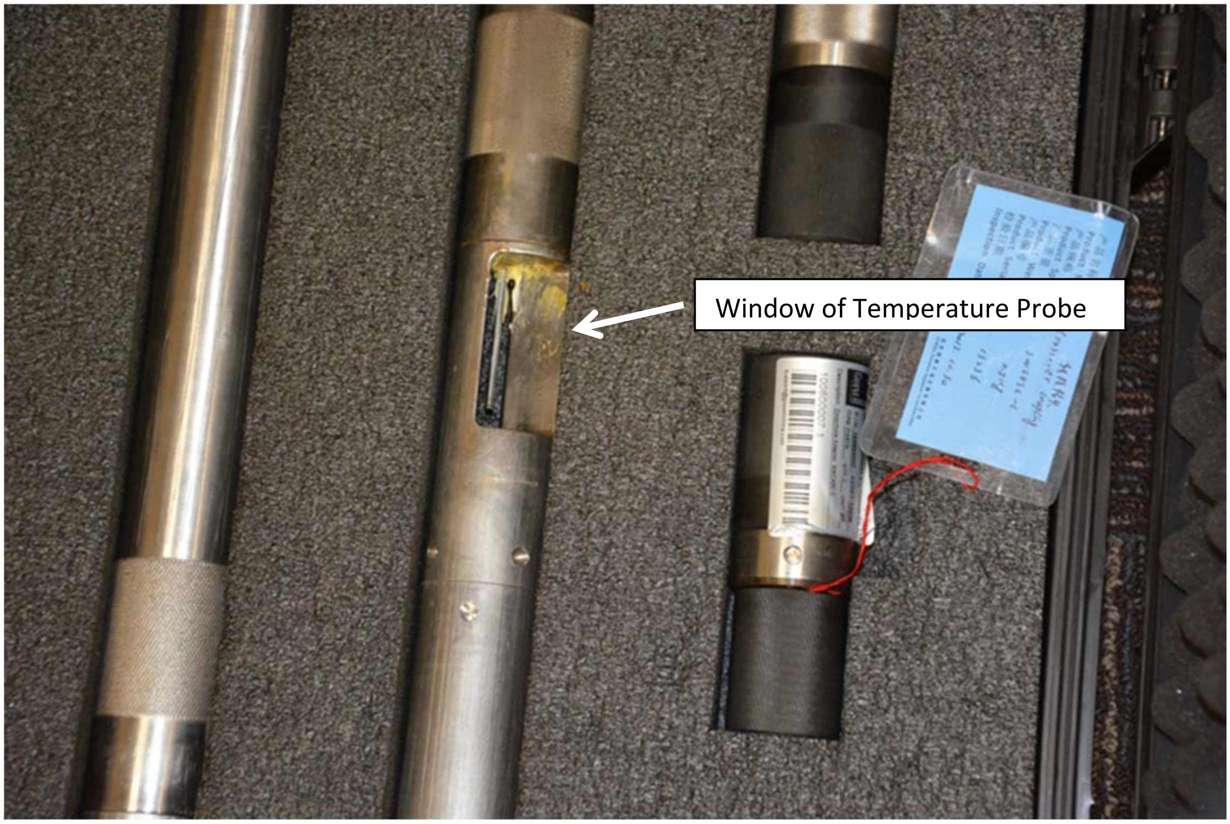

Figure 5. Window of Temperature Probe that may have been clogged by paraffins at two of the wells.

containing between twenty and forty carbon atoms. They are solid at room temperature and begin to melt above approximately 99 °F (37 °C). In these cases the up-hole readings were used for that portion of the profile that appeared to be influenced by the paraffin. Figure 6 shows the downhole and uphole temperature profiles of the Capa Madison Unit H-205 well illustrating how the temperatures appear to have been influenced.

Gradient or station stops were also made as the tool was lowered into the wells. In the first few wells, these stops were made more frequently (every 2000 ft) to ascertain the response time of the tool in an effort to optimize the logging speed and to obtain an indication of the tool precision. An example of one of the gradient stops is presented as Figure 7 and graphs and statistical calculations of all of the gradient stops for all of the wells are included in Appendix B. Once a reasonable logging speed was determined (60 ft/min provided good results), a ten minute gradient stop was typically made at the approximate midpoint of the well and at the bottom of the logging interval for the remaining wells.

Formation thicknesses were determined by initially using depths of formation tops as determined by the NDGS. This information was obtained from the North Dakota Industrial

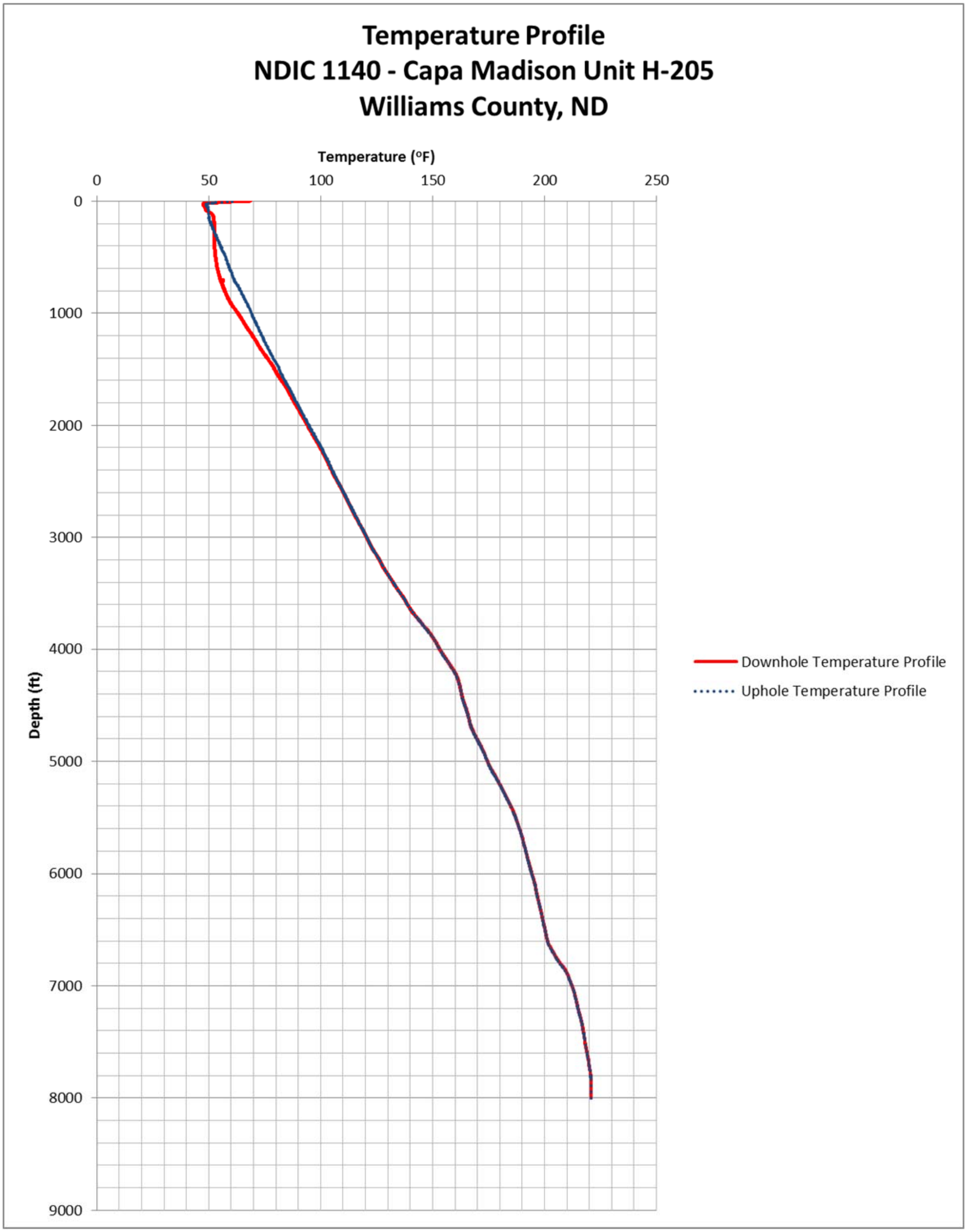

Figure 6. Downhole and Uphole Temperature Profiles of the Capa Madison H-205 well showing potential influence of paraffins clogging the temperature probe window.

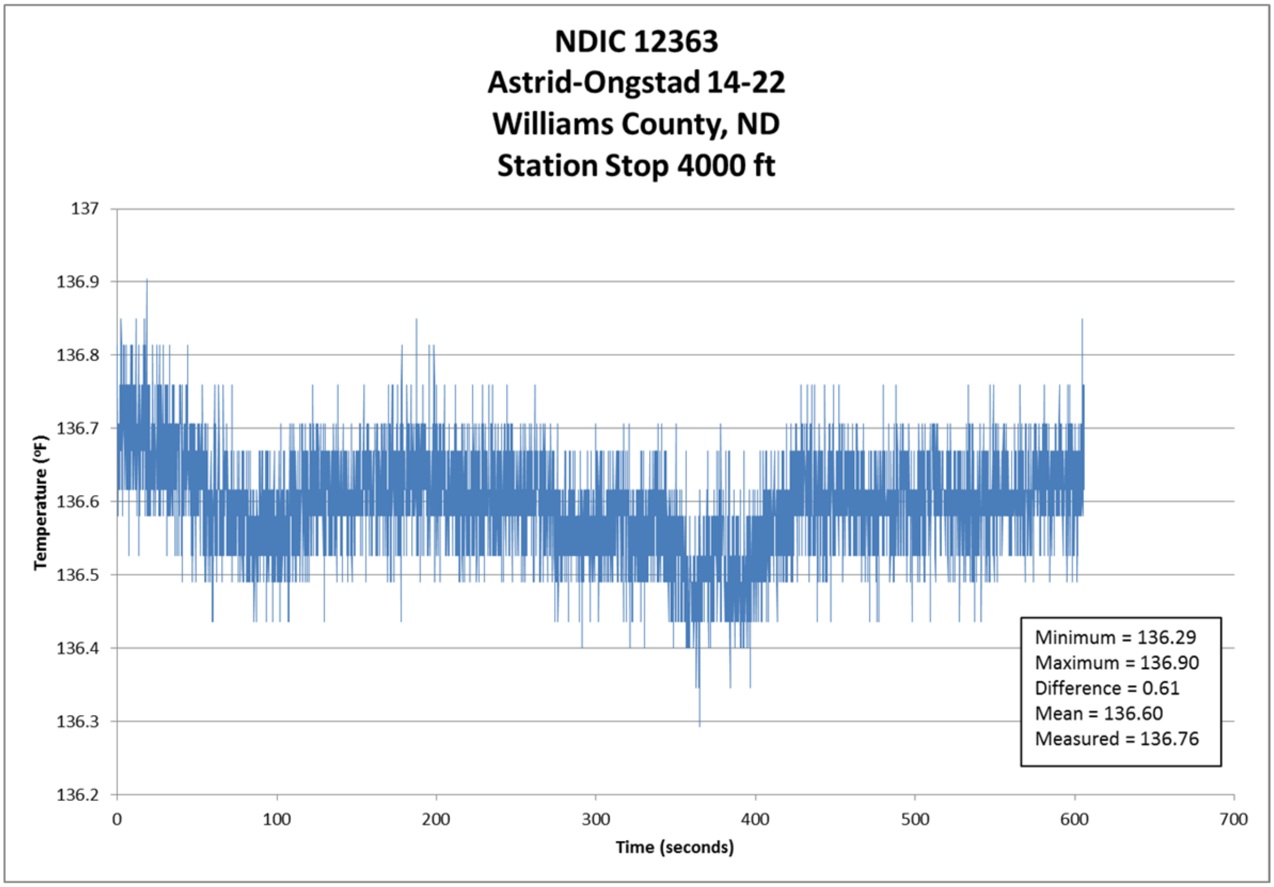

Figure 7. Variation of temperature vs. time at station stop at 4000 ft (1220 m) for NDIC well #12363 – Astrid-Ongstad 14-22 in Williams County, ND.

Commission's (NDIC) Scout Ticket database (https://www.dmr.nd.gov/oilgas/ subscriptionservice.asp). Formation thicknesses were subsequently adjusted by making corrections for Kelly busing elevations and evaluating the gamma-ray profile from each well to select formation tops. The formation tops have been graphical depicted with the temperature profiles that are presented in Appendix A.

The relationship between heat flow, thermal conductivity, and temperature gradient can be expressed by Fourier's Law:

$$q = \lambda \, \Delta T / \Delta Z, \qquad (1)$$

where: q = conductive heat flow;
λ = thermal conductivity; and
$\Delta T/\Delta Z$ = temperature gradient (change of temperature over change in depth).

As presented by Nordeng (2014), this equation can be re-arranged as:

$$\Delta T = q\ \Delta Z/\lambda. \qquad (2)$$

Estimates of the temperature at depth (T_n) are found by adding the temperature changes ($\Delta T_i = QZ_i/\lambda_i$) associated with each deeper stratigraphic unit (i=1…n) to the "average" surface temperature (T_o) as follows:

$$T_n = T_o + q\ (Z_1/\lambda_1 + Z_2/\lambda_2 + \ldots + Z_n/\lambda_n), \qquad (3)$$

where:

n = number of overlying stratigraphic units in the section, where i = 1…n (the deepest layer);
T_n = temperature at the base of the n^{th} unit;
T_o = average surface temperature;
Z_n = thickness of the n^{th} unit;
λ_n = thermal conductivity of the n^{th} layer.

Thus, to calculate the temperature at any point, it is necessary to know the average surface temperature, the thickness of the units (obtained from well logs), the thermal conductivities of the formations (obtained from the literature or direct measurements, e.g. Gosnold et al., 2012), and the conductive heat flow for the area (obtained from current heat flow maps, such as Blackwell and Richards, 2004). Although reasonable estimates of the average surface temperature and approximate thicknesses of the formations across the basin can be made, the biggest sources of error are caused by using inaccurate thermal conductivities or by assuming incorrect values of heat flow as current maps are based on a relatively limited dataset. Therefore, several methods were employed to calculate the heat flow for each of the wells using variations of equation 1, such that improved estimates of T_n can be made across the Williston Basin from equation (3). Initially, the temperature gradients measured in the wells that were logged and previously published values of thermal conductivity laboratory measurements, other literature values, and/or empirical estimates (Gosnold et al., 2012) were utilized to calculate the heat flow. The first method used was to match the graphical temperature gradient with assumed thermal conductivity and heat flow values using equation (3) above. Initially, heat flow was adjusted using the thermal conductivity values from the closest well as presented by Gosnold et al. (2012), and temperature at depth was modeled. Heat flow values were adjusted using a number of trials until the modeled temperatures were reasonably close to the measured values, as illustrated in Figure 8.

After a close match was obtained, the thermal conductivity values of each formation were incrementally adjusted until the modeled temperatures fell close to the measured profile. These thermal conductivity values were then used in the other three methods and corresponding algorithms to calculate heat flow as described below. It should be noted that the

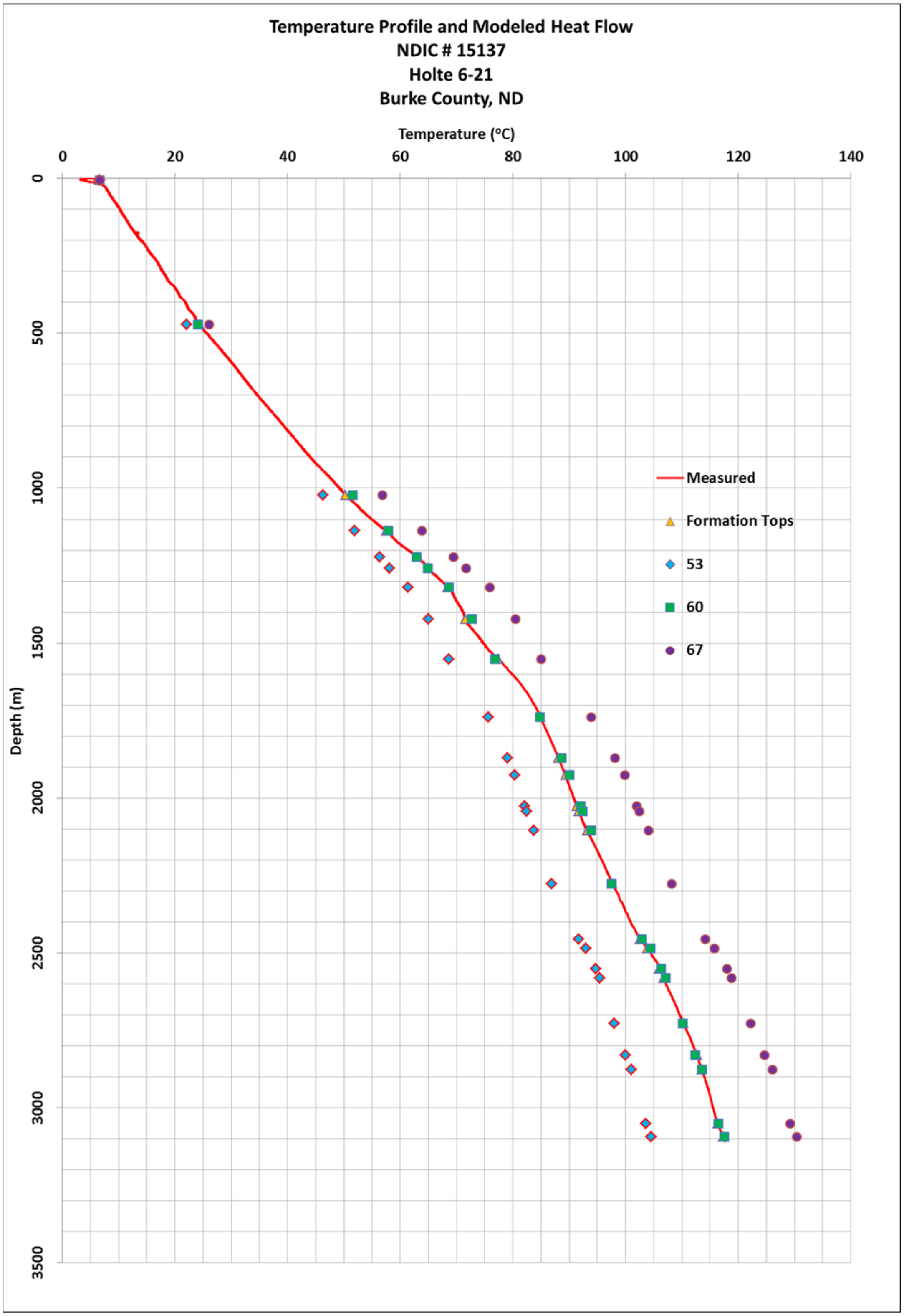

Figure 8. Measured temperature profile and modeled estimates using various assumed heat flow values. After a close was match is obtained, values of thermal conductivity are adjusted to further refine/match the measured profile. Heat flow units are mW m^{-2}.

heat flow of the upper 3000 to 5000 ft (1 to 1.5 km) was adjusted by a factor of about 90% to account for cooler surface temperatures during recent glacial periods and subsequent post-glacial warming per Majorowicz et al. (2012) and Gosnold et al. (2011). The graphical results of all of the wells are included as Appendix C.

The second method used equation (1) and heat flow for each formation was calculated using the thermal conductivities from the graphical method discussed above, and initial formation thickness as determined by the gamma-ray profile correlations discussed above. An average heat flow for all of the formations was then calculated. A weighted average was also determined by calculating a weighted thermal conductivity on the basis of formation thickness divided by the total well depth:

$$q = \lambda_w (\Delta T_t/\Delta Z_t)\text{; and} \qquad (4)$$

$$\lambda_w = \lambda_1 * \Delta Z_1/\Delta Z_t + \lambda_2 * \Delta Z_2/\Delta Z_t + \ldots. \lambda_n * \Delta Z_n/\Delta Z_t, \qquad (5)$$

where:

λ_w = weighted thermal conductivity;
ΔT_t = temperature change from surface to bottom of well;
ΔZ_t = total depth of well; and
n, Z_n, and λ_n are as before.

An example of the results is presented in Table 1. In addition, for comparison purposes, average heat flow and weighted heat flow estimates were calculated using the thermal conductivity values utilized by Nordeng and Nesheim (2011) and Nordeng (2014), the results of which are also presented in Table 1. Nordeng arrived at his thermal conductivity values by utilizing a digitized version of the North American heat flow map published by Blackwell and Richards (2004) and back calculating the thermal conductivity values for each formation from the Rauch Shapiro Fee #21-9 well (NDIC #7591) located in Billings County, North Dakota.

The third approach employed the methodology of Bullard (1939), as cited by Beardsmore and Cull (2001). This method uses what Bullard refers to as the Thermal Resistance (R) plotted against the temperature. The thermal resistance is defined as:

$$R_i = R_{(i-1)} + \Delta Z_i/\lambda_i, \qquad (6)$$

where:

R_i = thermal resistance of formation i;
ΔZ_i = depth range (formation thickness); and
λ_i = formation thermal conductivity.

Heat flow is determined by calculating the slope of the best fit line of temperature versus thermal resistance as illustrated in Figure 9. As in method 1, separate slopes were calculated for

Table 1. Heat Flow Calculations for the Vernie Chapin 13-21 Well (NDIC #16376) in McKenzie County, ND.

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(°C)		$W\ m^{-1}K^{-1}$				$W\ K^{-1}$		$W\ m^{-1}K^{-1}$	$^{o}C\ km^{-1}$	$mW\ m^{-2}$				
FU/HC/FH[11]	0.0	503.2	5.2	22.5	1.40	1.72	0.18	0.22	359.45	359.45				62.5	76.8		
Pierre	503.2	783.6	27.6	39.8	1.15	1.62	0.23	0.32	681.43	1040.87	0.48	44.65		58.4	82.3		21.6
Greenhorn	1286.9	125.0	67.4	8.1	1.10	1.62	0.03	0.05	113.61	1154.48	1.11	48.38		71.2	104.8		53.9
Mowry	1411.8	29.0	75.5	1.6	1.20	1.80	0.01	0.01	24.13	1178.61	1.20	49.82		64.7	97.0		59.7
Newcastle	1440.8	79.9	77.1	4.5	1.50	1.80	0.03	0.04	53.24	1231.85	1.17	49.90		85.3	102.3		58.4
Inyan Kara	1520.6	107.9	81.6	3.0	1.60	2.35	0.04	0.06	67.44	1299.29	1.17	50.27		43.9	64.5		58.8
Swift	1628.5	179.2	84.6	7.0	1.40	2.10	0.06	0.10	128.02	1427.30	1.14	48.76		54.5	81.8		55.6
Rierdon	1807.8	151.5	91.6	6.0	1.60	2.10	0.06	0.08	94.68	1521.98	1.19	47.78		63.1	82.8		56.8
Spearfish	1959.3	155.8	97.5	3.6	2.40	3.04	0.09	0.12	64.90	1586.88	1.23	47.14		54.7	69.3		58.2
Opeche	2115.0	126.5	101.1	2.6	2.20	3.04	0.07	0.10	57.50	1644.37	1.29	45.34		44.8	62.0		58.3
Amsden	2241.5	82.6	103.7	1.7	3.80	3.04	0.08	0.06	21.74	1666.11	1.35	43.93		76.4	61.1		59.1
Tyler	2324.1	69.2	105.3	4.3	1.60	2.68	0.03	0.05	43.24	1709.35	1.36	43.09		99.2	166.1		58.6
Big Snowy	2393.3	104.5	109.6	3.3	1.40	3.62	0.04	0.10	74.68	1784.03	1.34	43.63		43.7	112.9		58.5
Kibbey	2497.8	47.2	112.9	1.0	2.70	3.62	0.03	0.04	17.50	1801.53	1.39	43.11		55.9	74.9		59.8
Madison	2545.1	187.8	113.8	3.3	3.05	3.45	0.14	0.16	61.56	1863.09	1.37	42.70		53.0	59.9		58.3
Ratcliffe	2732.8	75.3	117.1	1.6	3.05	3.45	0.06	0.07	24.68	1887.77	1.45	40.96		65.7	74.3		59.3
Frobisher	2808.1	183.2	118.7	4.5	2.80	3.45	0.13	0.16	65.42	1953.19	1.44	40.44		68.9	84.9		58.1
Lodgepole	2991.3	243.8	123.2	7.3	2.30	3.45	0.14	0.21	106.02	2059.21	1.45	39.47		69.1	103.6		57.3
Bakken	3235.1	35.1	130.6	1.5	1.00	4.00	0.01	0.04	35.05	2094.26	1.54	38.75		43.4	173.7		59.9
Three Forks	3270.2	59.4	132.1	1.6	2.70	4.00	0.04	0.06	22.01	2116.28	1.55	38.80		74.4	110.3		60.0
Birdbear	3329.6	25.3	133.7	0.6	2.80	4.00	0.02	0.03	9.04	2125.31	1.57	38.60		63.9	91.4		60.5
Duperow	3354.9	125.9	134.3	3.0	2.60	4.00	0.08	0.13	48.42	2173.73	1.54	38.49		61.4	94.4		59.4
Souris River	3480.8	79.6	137.3	2.0	2.80	3.09	0.06	0.06	28.41	2202.14	1.58	37.95		68.6	75.7		60.0
Dawson Bay	3560.4	32.0	139.2	0.8	2.75	3.09	0.02	0.02	11.64	2213.78	1.61	37.65		65.4	73.5		60.5
Prairie	3592.4	86.9	140.0	1.7	4.00	2.18	0.09	0.05	21.72	2235.50	1.61	37.52		76.7	41.8		60.3
Winnipegosis	3679.2	34.4	141.6	0.9	2.99	2.83	0.03	0.02	11.52	2247.01	1.64	37.09		75.7	71.7		60.7
Ashern	3713.7	36.3	142.5	1.0	2.99	2.83	0.03	0.03	12.13	2259.15	1.64	36.98		83.8	79.3		60.8
Interlake	3750.0	211.2	143.5	4.6	3.77	3.72	0.20	0.20	56.03	2315.17	1.62	36.90		81.2	80.1		59.8
BOH	3961.2		148.1														
						Σ =	2.03	2.58									
Notes											Average			65.3	87.6	61	57.5
1 - Thermal conductivity derived from graphical method											Wtd Average			73.3	93.0		
2 - Thermal conductivity used by Nordeng and Nesheim (2011) and Nordeng (2014)											Shallow					58.4	37.8
3 - Weighted average of graphical thermal conductivity											Deep		60			60.3	59.1
4 - Weighted average of Nordeng's thermal conductivity																	
5 - Harmonic mean of thermal conductivity																	
6 - Heat flow derived from graphical method																	
7- Heat flow derived from Equation 1 for each formation																	
8 - Heat Flow derived from Equation 1 and Nordengs λ																	
9 - Heat flow derived from Bullard's Method																	
10 - Heat flow derived using harmonic mean method																	
11- FU/HC/FH - Fort Union Group/Hell Creek Formation/Fox Hills Formation combined																	

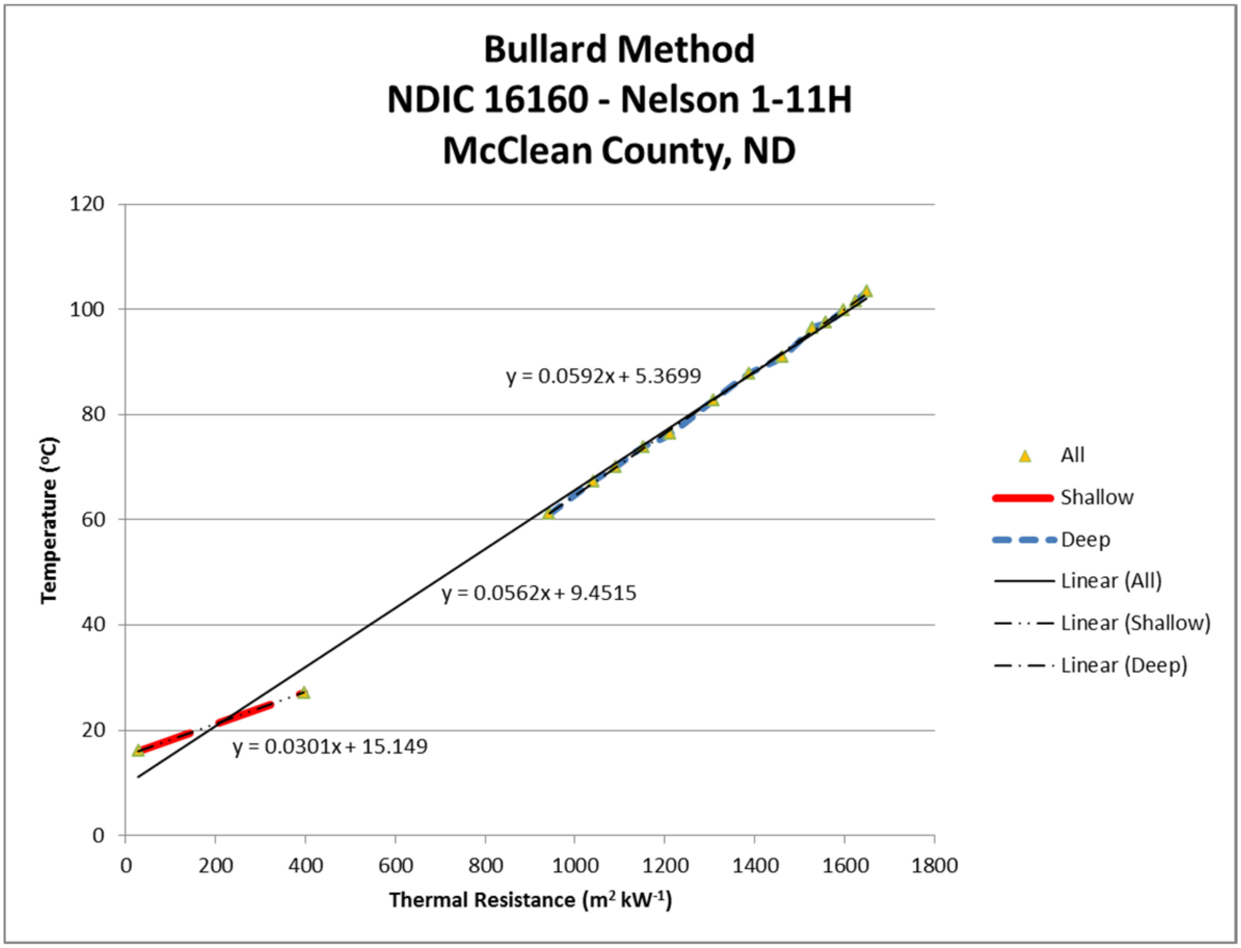

Figure 9. Example of a Bullard Plot. Slope of best fit line is the heat flow.

the shallow portions (upper 1 to 1.5 km) of the well bore that have been influenced by Pleistocene glacial climates and deeper portions that may be more representative of heat flow within the basin that has not been influenced by climatic changes. Results of example calculations are presented in Table 1.

The last method employed to estimate heat flow was to determine the harmonic mean of the thermal conductivity as described by Beardsmore and Cull (2011). This method calculates the harmonic mean of the thermal conductivity by dividing the depth to the top of each formation by the thermal resistance calculated using equation (6):

$$\lambda_{hi} = Z_i/R_i \qquad (7)$$

where:

λ_{hi} = harmonic mean thermal conductivity;
Z_i = depth to top of formation; and
R_i = as above.

Next, the gradient is determined by dividing the difference between the temperature at the top of the formation and the temperature at the top of the stratigraphic column by the difference between the depth to the top of the formation and the depth to the top of the stratigraphic column under consideration:

$$grad_i = (T_i - T_s)/ (Z_i - Z_s), \quad (8)$$

Where:

$grad_i$ = temperature gradient to top of formation i;
T_i = temperature at top of formation i;
T_s = temperature at top of stratigraphic column;
Z_i = depth to top of formation i; and
Z_s = depth to top of stratigraphic column.

Heat flow for each formation is then calculated by taking the product of harmonic thermal conductivity times the gradient:

$$q_{hi} = \lambda_{hi} * grad_i. \quad (9)$$

An example calculation is provided in Table 1 and summaries of the complete results are presented in Table 2. Tables of the calculations for each method are attached as Appendix D. Figure 10 presents a map showing the average of the values obtained from the graphical, harmonic mean, Bullard and the weighted average methods. Figure 11 presents the same results (colors) overlain by a structure contour map (contour lines) of the top of the Three Forks Formation from data obtained from the NDIC database.

Discussion and Conclusions

Results of the preliminary study are presented in Table 2. While there is general agreement in calculated heat flow values between the various methods presented above, the results are largely predicated upon initial assumptions of either heat flow, thermal conductivity, or both. This is clearly illustrated by the large discrepancies between the values obtained by using Nordeng's thermal conductivity values and the values obtained using the other methods. In addition, the average and weighted average of method 2 results in relatively large differences in heat flow between formations. With the exception of the surface temperature forcing signal resulting from global climatic variations during the last ice age and subsequent post-glacial warming, calculated heat flow across the various formations should be nearly equivalent, if the thermal conductivity values used in the analyses are close to actual values.

The results of the harmonic method described above seem to yield the most consistent heat flow values between the formations (Table 1). However this issue still reduces down to a "chicken or egg" scenario in that heat flow and thermal conductivity are dependent upon each other and inaccurate assumptions of one profoundly affects the other. While we are confident in the measurements obtained during this study with respect to thermal gradients, it is evident that additional information with regard to thermal conductivities of the geologic formations will

Table 2. Summary of Heat Flow Estimates by Well

Well #	Well Name		Tabular	Nordeng's	Bullard	Harmonic	Graphical	Average	Use
			$mW\ m^{-2}$						
2139	**NSCU V-706**	Average	43.0	66.5		44			
	Northeast of Newburg, ND	Wtd Avg.	46.7	74.6					
		Shallow[a]				23.2			
		Deep			47.5	44.5	48	46.7	46.7
8005	**Sivertson 29-23R1**	Average	62.2	80.9		61.5			
	Southeast of Keene, ND	Wtd Avg.	76.2	94.4					
		Shallow				43.9			
		Deep[c]			61.3	63.0	60.3	61.7	61.7
16376	**Vernie Chapin 32-21**	Average	65.3	87.6		56.8			
	Southeast of Keene, ND	Wtd Avg.	73.3	93.0					
		Shallow				37.8			
		Deep			61.0	59.1	60.0	61.4	61.4
9653	**Cutlip #1**	Average	49.3	75.4		45.9			
	Northwest of Alexander, ND	Wtd Avg.	52.0	74.8					
		Shallow				33.0			
		Deep			47.9	47.6	48.0	48.2	48.2
10103	**Iverson State A-1**	Average	49.9	76.3		52.7			
	Northwest of Alexander, ND	Wtd Avg.	54.9	74.9					
		Shallow				43.3			
		Deep			52.1	54.2	50.2	51.6	51.6
12363	**Astrid-Ongstad**	Average	54.2	82.2		51.4			
	Northeast of Tioga, ND	Wtd Avg.	61.1	87.2					
		Shallow				38.6			
		Deep			52.7	52.7	52.0		52.9
16182	**2004 JV-P NDCA 7**	Average	53.8	86.5		45.8			
	North of Tioga, ND	Wtd Avg.	56.6	85.2					
		Shallow				33.1	44.1		
		Deep			50.4	47.8	49.0		50.3
13666	**Rieder 1-9 SWD**	Average	49.8	79.4		45.0			
	North of Williston, ND	Wtd Avg.	52.1	77.9					
		Shallow				34.5			
		Deep			48.0	46.7	48.5	48.3	48.3
15137	**Holte 6-21**	Average	60.0	87.1		58.0			
	Southwest of Columbus, ND	Wtd Avg.	70.3	90.0					
		Shallow			55.6	57.8			
		Deep			60.8	60.4	60.0	60.3	60.3
15593	**FHMU K-810**	Average	60.5	87.9		52.4			
	West of Fryburg, ND	Wtd Avg.	64.1	86.2					
		Shallow			55.8	37.9			
		Deep			58.8	55.3	58.0	58.2	58.2
17043	**St. Andes 151-89-2413H-1**	Average	41.6	60.8		40.1			
	Southeast of Parshall, ND	Wtd Avg.	52.3	69.5					
		Shallow				28.3			
		Deep			41.5	40.5	42.0	41.4	41.4
13132	**Frink 13-15**	Average	39.7	63.4		34.2			
	South of Parshall, ND	Wtd Avg.	43.1	61.8					
		Shallow				13.3			
		Deep			39.9	38.4	40.0	39.5	39.5
16160	**Nelson 1-11H**	Average	78.3	110.3		51.5			
	South of Powers Lake, ND	Wtd Avg.	64.7	80.4					
		Shallow			30.1	24.0			
		Deep			59.2	56.1	59.0	58.1	58.1

Notes: a - Shallow is the upper 1 to 1.5 km that may reflect influence of Paleoclimate and subsequent post-glacial warming.
b - Glacial periods may reduce heat flow by 10 to 15% per Majorowicz et al. (2012) and Gosnold et al. (2011).
c - Deep are values calculated below 1 to 1.5 km

Table 2 (cont.) Summary of Heat Flow Estimates by Well									
			Tabular	Nordeng's	Bullard	Harmonic	Graphical	Average	Use
Well #	Well Name		mW m^{-2}						
17317	**E-M Emmel 10-3**	Average	60.9	78.7		49.9			
	West of Sherwood, ND	Wtd Avg.	73.3	84.8					
		Shallow			56.1	13.7			
		Deep			56.8	53.7	59.0	57.6	57.6
12280	**Brandjord 1-20**	Average	45.2	68.8					
	East of Westhope, ND	Wtd Avg.	51.7	73.7					
		Shallow							
		Deep			52.7	49.8	54.0	52.0	52.0
1140	**Capa-Madison Unit H-205**	Average	75.2	93.5		58.1			
	South of Tioga, ND	Wtd Avg.	85.8	101.6					
		Shallow			39.2	10.5			
		Deep			68.2	65.4	71.0	68.2	68.2
8706	**Berge C 1**	Average	51.5	77.5		46.8			
	Southeast of Alexander, ND	Wtd Avg.	56.0	81.0					
		Shallow				32.4			
		Deep			50.8	48.9	52.0	50.8	50.8
17230	**Roosevelt Federal 2-4H**	Average	56.8	75.7		48.9			
	Northeast of Beach, ND	Wtd Avg.	63.1	82.3					
		Shallow			54.3	29.6			
		Deep			52.7	51.2	55.0	53.9	53.9
15785	**Ann 1**	Average	52.5	77.8		45.2			
	North of Arnegard, ND	Wtd Avg.	59.3	81.3					
		Shallow			49.3	17.6			
		Deep			50.9	50.0	52.0	51.4	51.4
10278	**Mud Buttes State 1-36**	Average	53.9	76.0		47.8			
	South of Rhame, ND	Wtd Avg.	59.5	84.0					
		Shallow				41.7			
		Deep			52.2	49.3	52.0	51.8	51.8
17014	**Edwards 1-33BH**	Average	48.9	70.2		34.0			
	Northwest of Plaza, ND	Wtd Avg.	48.5	66.4					
		Shallow			37.1	26.1			
		Deep			41.0	38.6	40.0	39.9	39.9
3090	**Grenora-Madison Unit 08**	Average	43.1	73.6	45.5	43.1			
	Southwest of Grenora, ND	Wtd Avg.	45.6	74.2					
		Shallow			44.6	25.6			
		Deep			44.0	47.9	45.5	45.1	45.1
13725	**JC Wodds 26H-1**	Average	50.8	76.4	52.2	38.8			
	North of Lignite, ND	Wtd Avg.	53.8	78.7					
		Shallow			50.6	25.4			
		Deep			53.6	48.9	54.0	51.8	51.8

Notes: a - Shallow is the upper 1 to 1.5 km that may reflect influence of Paleoclimate and subsequent post-glacial warming.
b - Glacial periods may reduce heat flow by 10 to 15% per Majorowicz et al. (2012) and Gosnold et al. (2011).
c - Deep are values calculated below 1 to 1.5 km

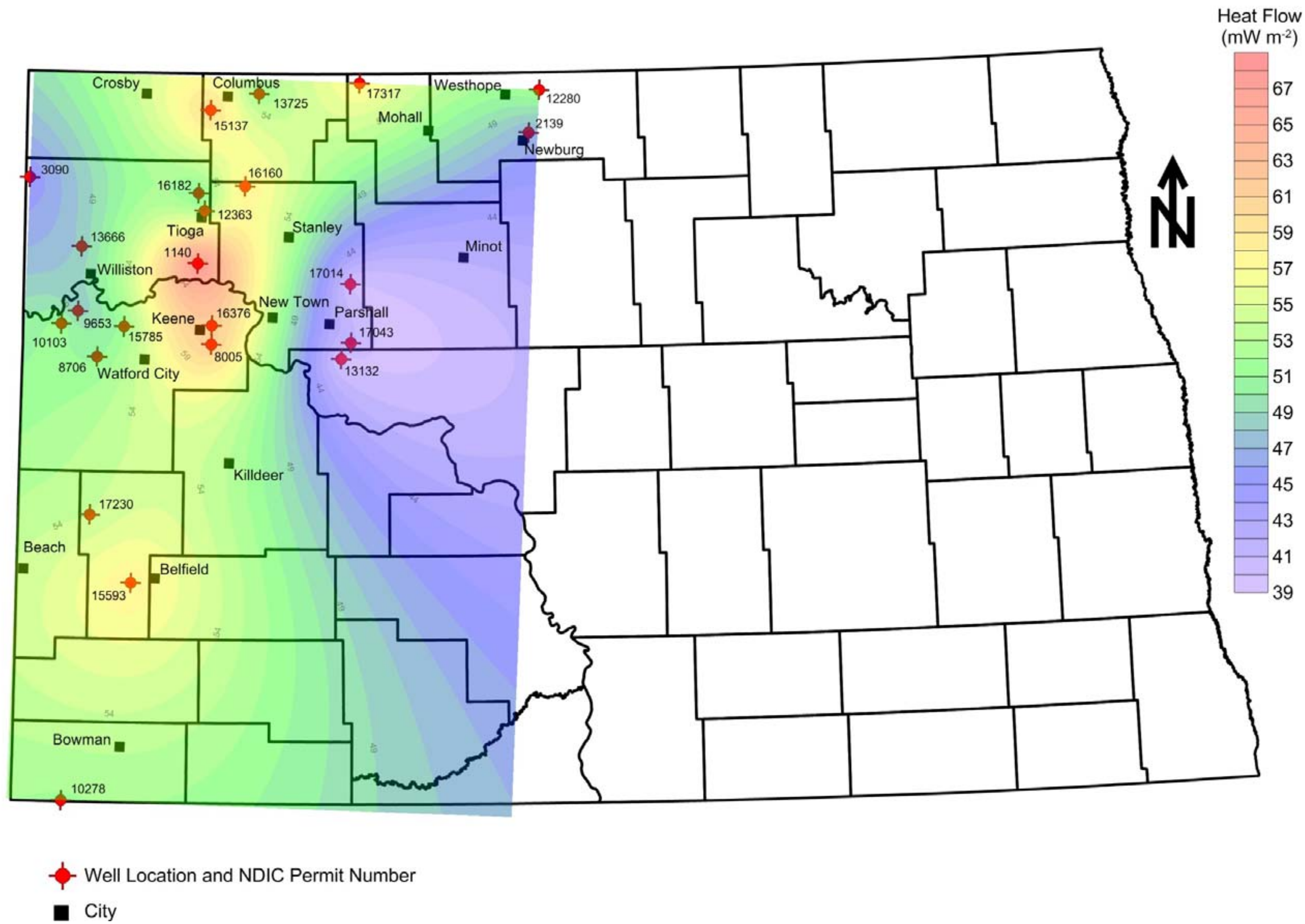

Figure 10. Mean heat flow of the graphical, harmonic mean, the Bullard method and the weighted average methods.

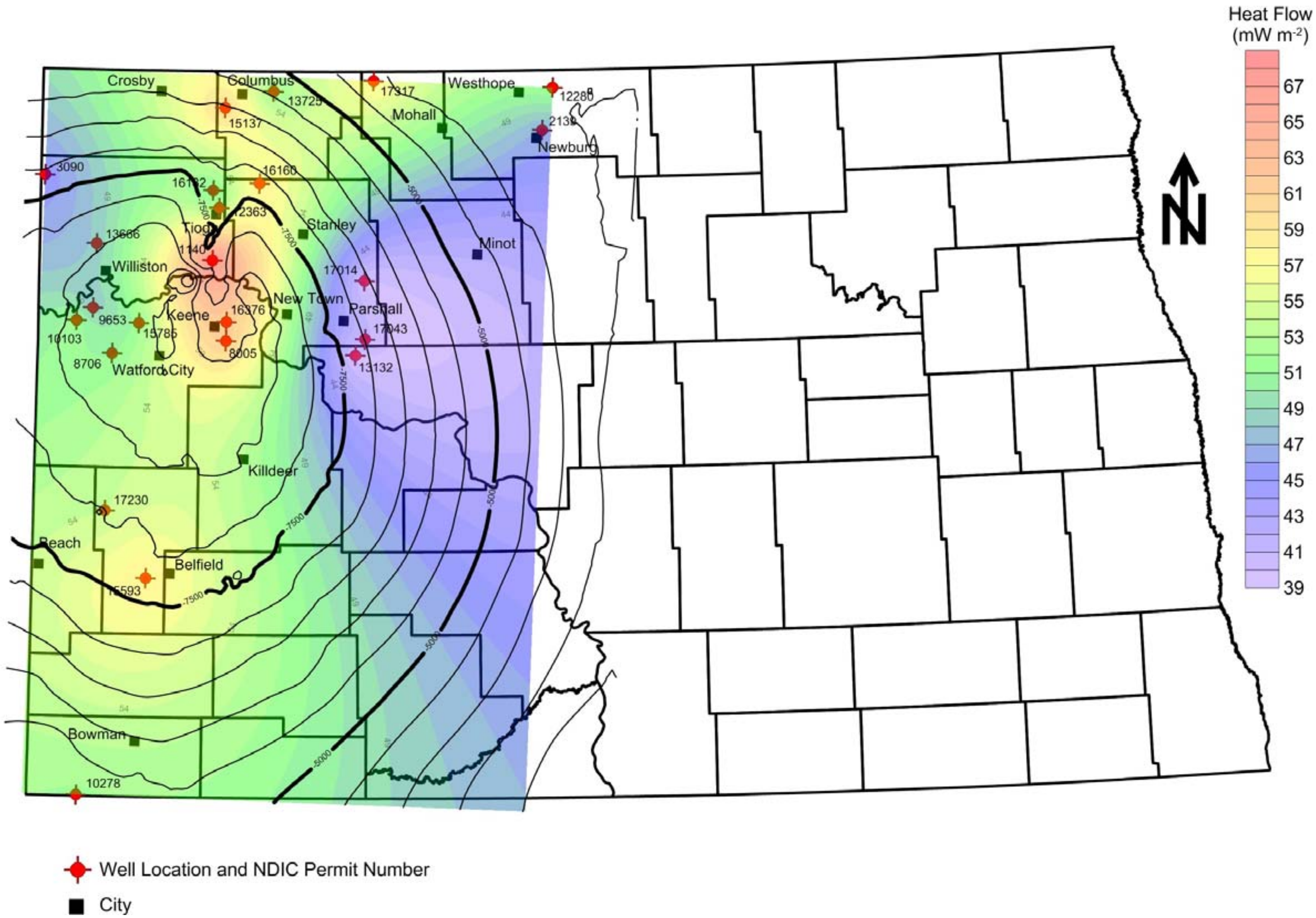

Figure 11. Heat Flow (colors) overlain by structure contours of the top of the Three Forks Formation.

be required to accurately determine heat flow within the Williston Basin. Geologic formations can often be differentiated on the basis of “marker” beds; however there can be wide variations in mineralogy, lithology, porosity, permeability, density, etc., depending upon depositional environment, depth of burial, secondary processes, etc., from one location to another within the same formation.

These criteria can profoundly influence thermal conductivity and therefore greatly influence the calculated heat flow.

Future Work

The NDGS currently has plans to log an additional 20 to 30 wells over the next several years. However, as noted above, some funding may be redirected to obtain additional thermal conductivity information from the wells that are being logged. Ideally, thermal conductivity values from core samples obtained from the wells that are logged would allow for the calculation of a reasonable estimate of heat flow from specific locations. This may also allow for better estimates of thermal conductivity by reverse modeling for the various formations at these locations that do not have core samples. This information, combined with thermal maturity estimates obtained by other methods (Nordeng and Nesheim, 2011) would provide better estimates of heat flow within the Williston Basin, better predictions of thermal maturity of hydrocarbons and the geothermal potential of the region.

Acknowledgements

Funding for this project was provided by the North Dakota Petroleum Council and the State of North Dakota. We would also like to acknowledge Hess Corporation, Jordan Exploration, Inc., Missouri Basin Well Service Inc., Enduro Operating, LLC, Liberty Resources LLC, Vanguard Operating LLC, Whiting Oil and Gas Corporation, Legacy Reserves Operating LP, Triangle USA Petroleum Corporation, Eagle Operating, Inc., TAQA North USA and Citation Oil and Gas Corporation for their cooperation and assistance in allowing us access to their wells.

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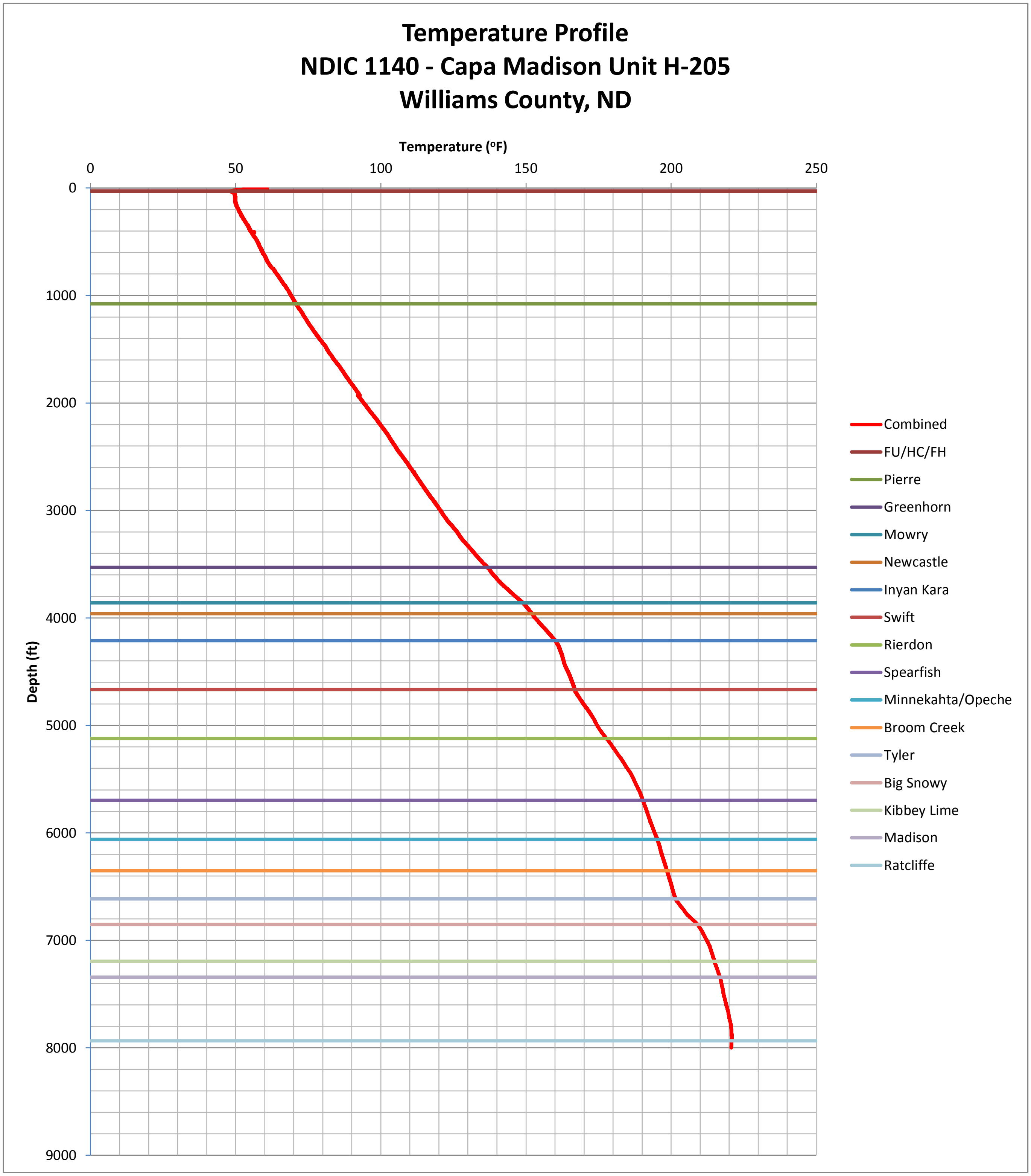
APPENDIX A

TEMPERATURE PROFILES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Williams County, ND
Temperature (°F)
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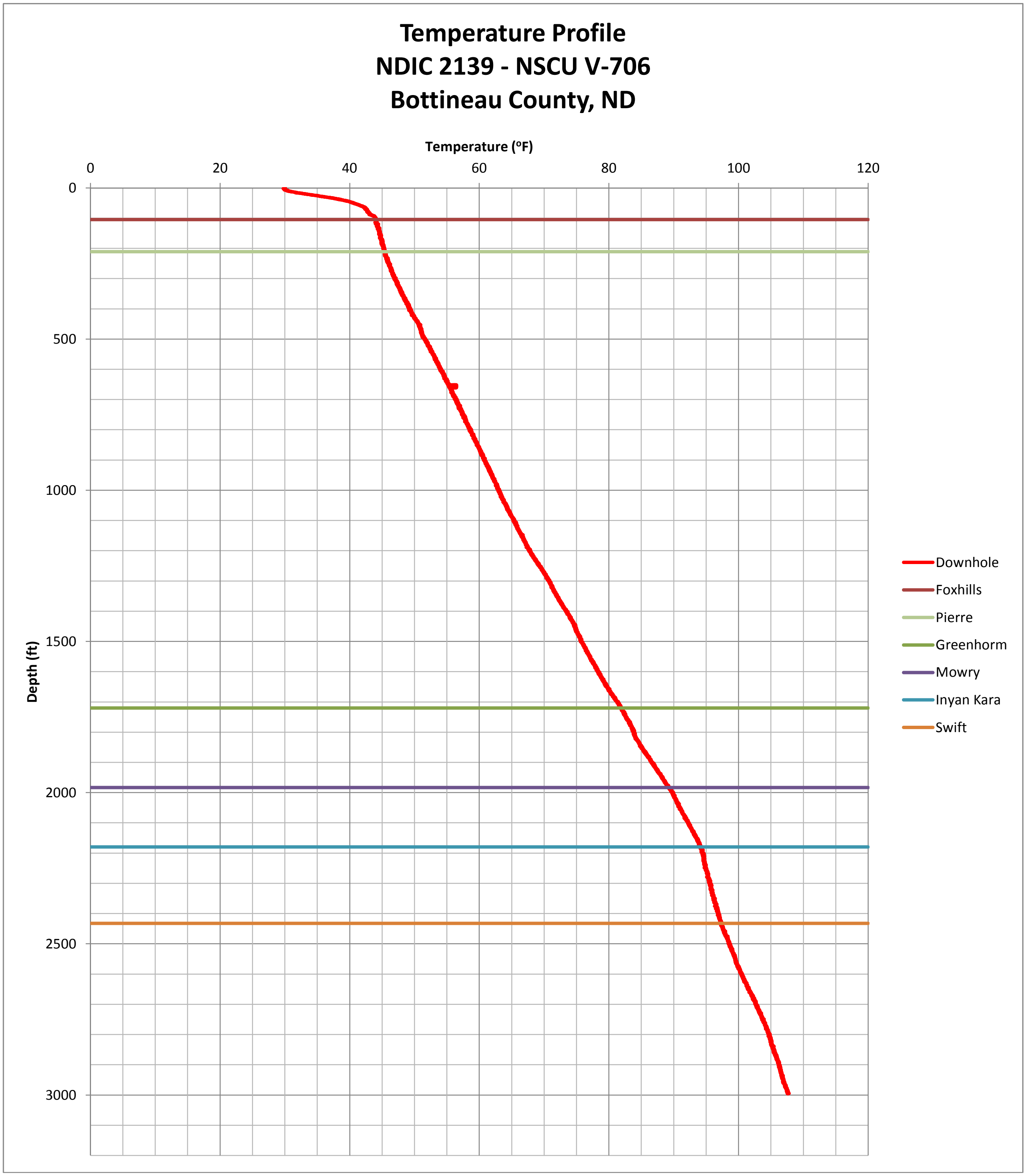
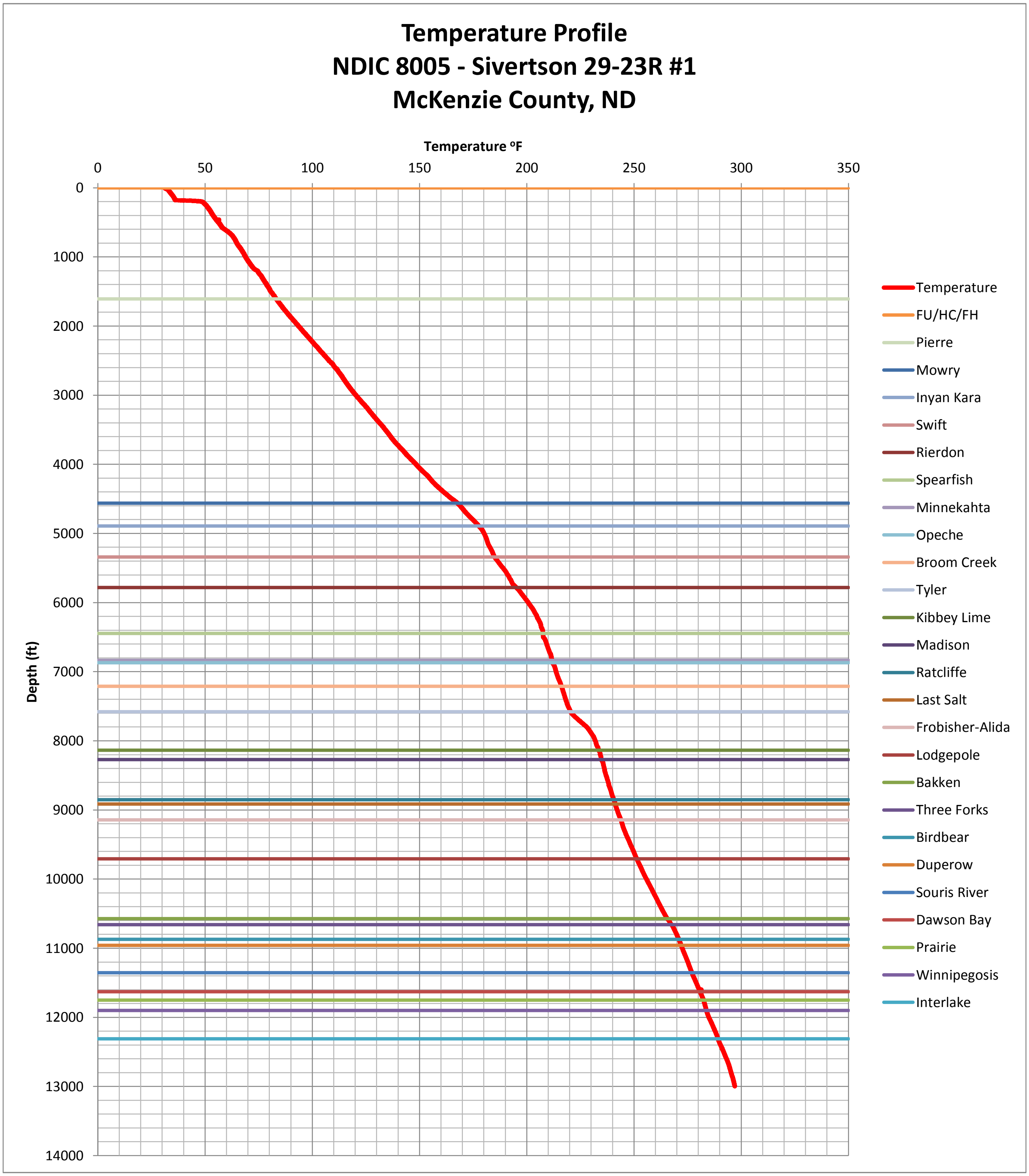
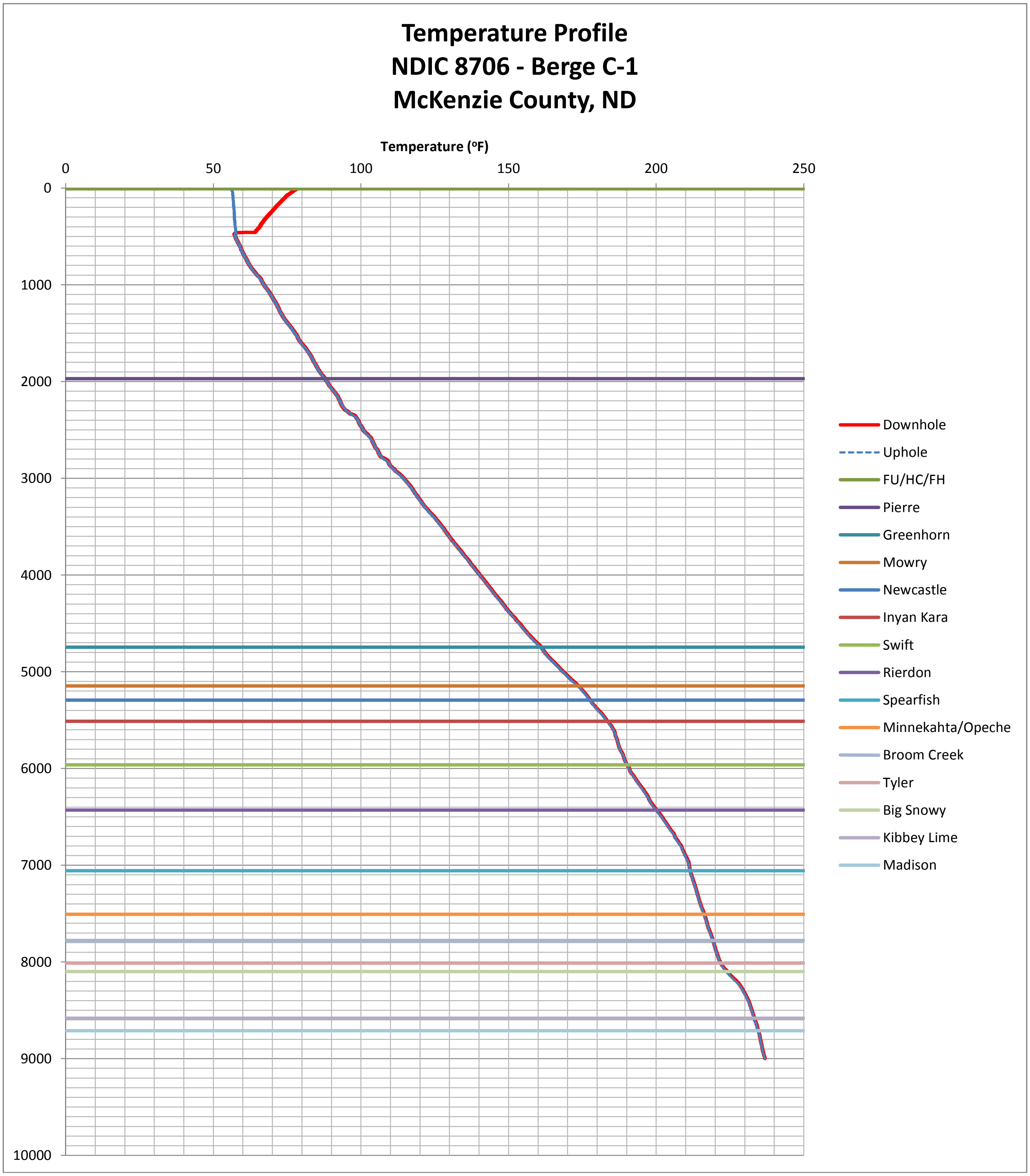
50
100
150
200
250
Depth (ft)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Combined
FU/HC/FH
Pierre
Greenhorn
Mowry
Newcastle
Inyan Kara
Swift
Rierdon
Spearfish
Minnekahta/Opeche
Broom Creek
Tyler
Big Snowy
Kibbey Lime
Madison
Ratcliffe

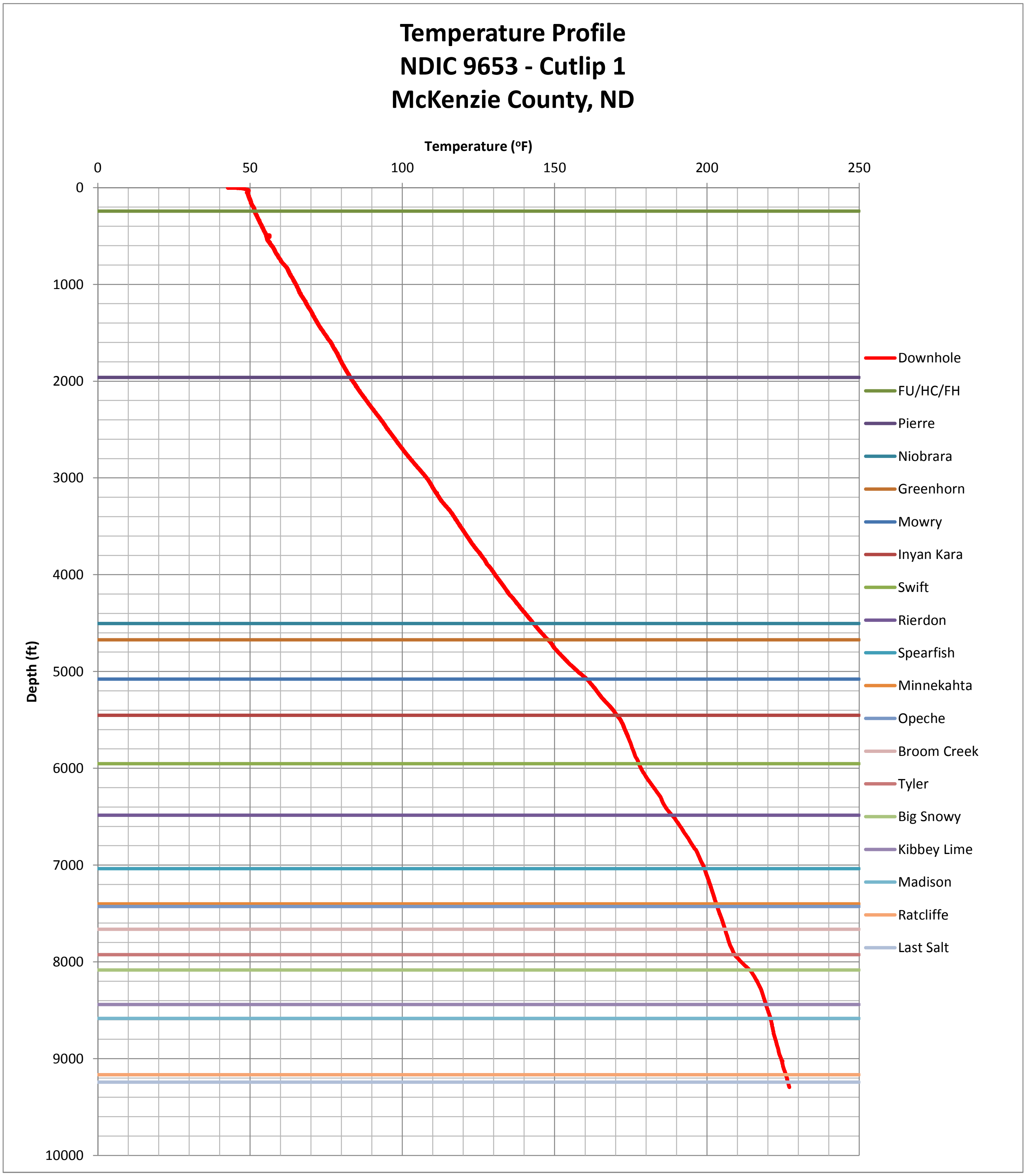

Temperature Profile
NDIC 2139 - NSCU V-706
Bottineau County, ND
Temperature (°F)
0
20
40
60
80
100
120
0
500
1000
1500
2000
2500
3000
Depth (ft)
Downhole
Foxhills
Pierre
Greenhorm
Mowry
Inyan Kara
Swift

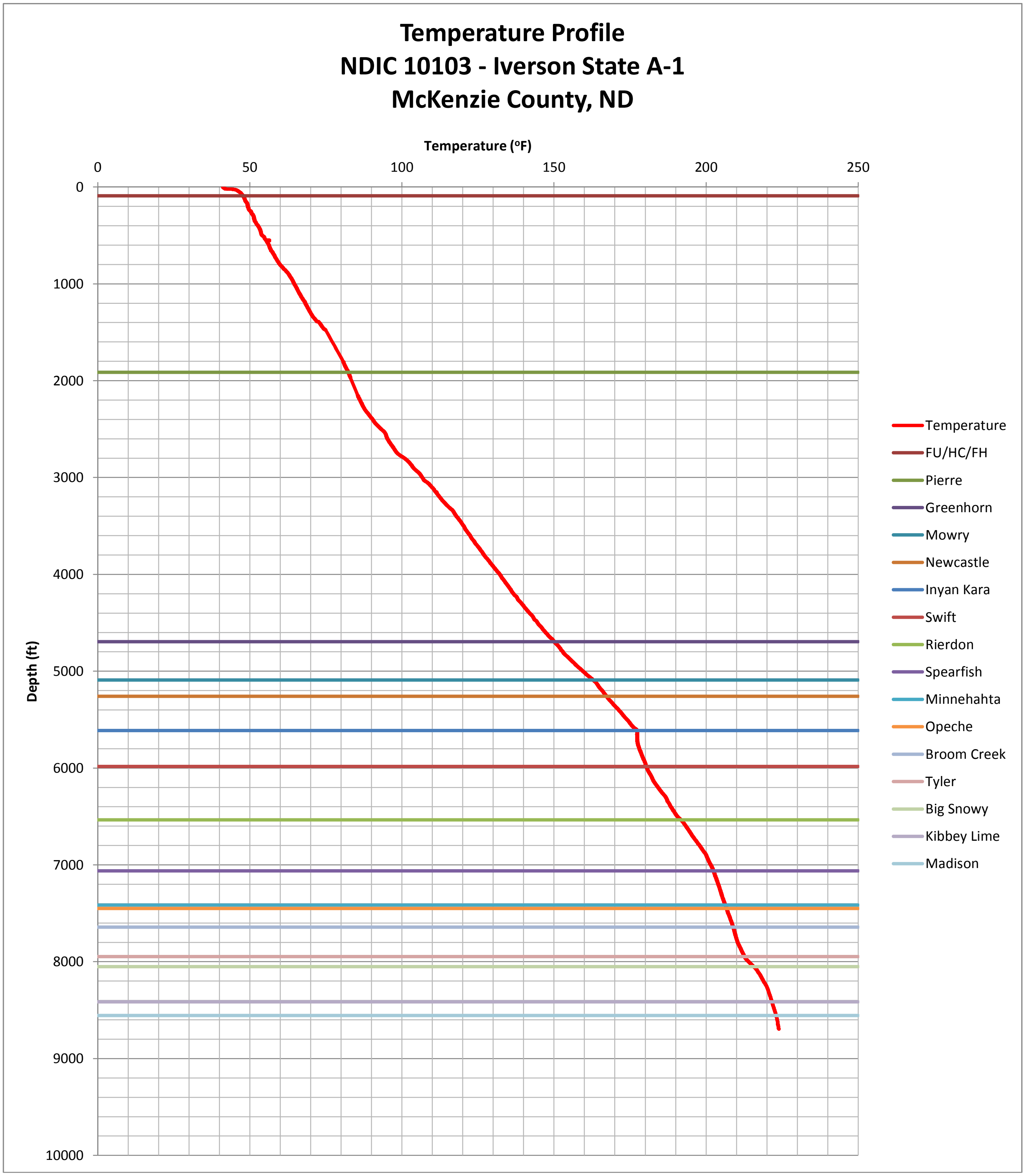


Temperature Profile
NDIC 8005 - Sivertson 29-23R #1
McKenzie County, ND
Temperature °F
0
50
100
150
200
250
300
350
Depth (ft)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
Temperature
FU/HC/FH
Pierre
Mowry
Inyan Kara
Swift
Rierdon
Spearfish
Minnekahta
Opeche
Broom Creek
Tyler
Kibbey Lime
Madison
Ratcliffe
Last Salt
Frobisher-Alida
Lodgepole
Bakken
Three Forks
Birdbear
Duperow
Souris River
Dawson Bay
Prairie
Winnipegosis
Interlake

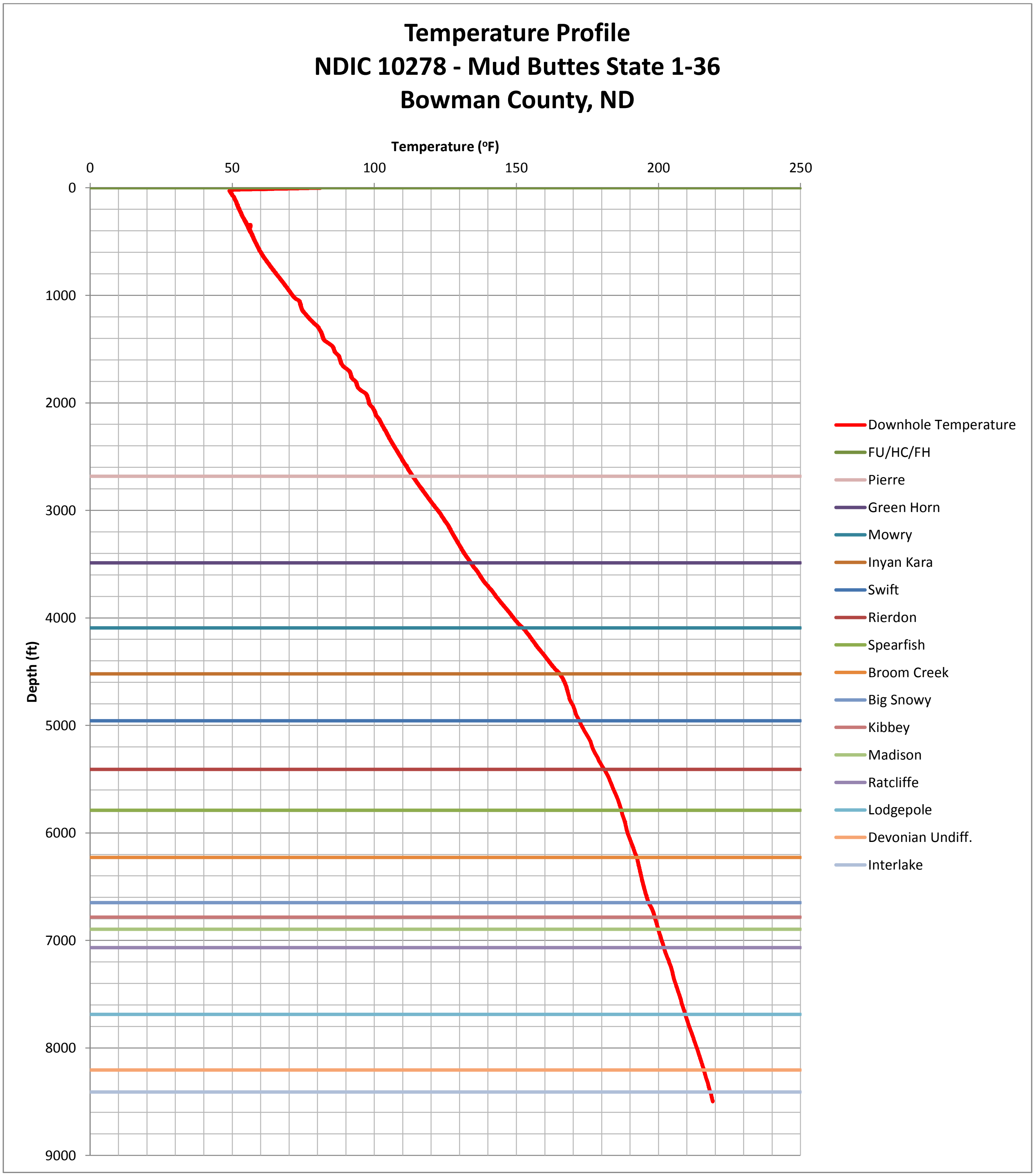


Temperature Profile
NDIC 8706 - Berge C-1
McKenzie County, ND
Temperature (°F)
0
50
100
150
200
250
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Downhole
Uphole
FU/HC/FH
Pierre
Greenhorn
Mowry
Newcastle
Inyan Kara
Swift
Rierdon
Spearfish
Minnekahta/Opeche
Broom Creek
Tyler
Big Snowy
Kibbey Lime
Madison

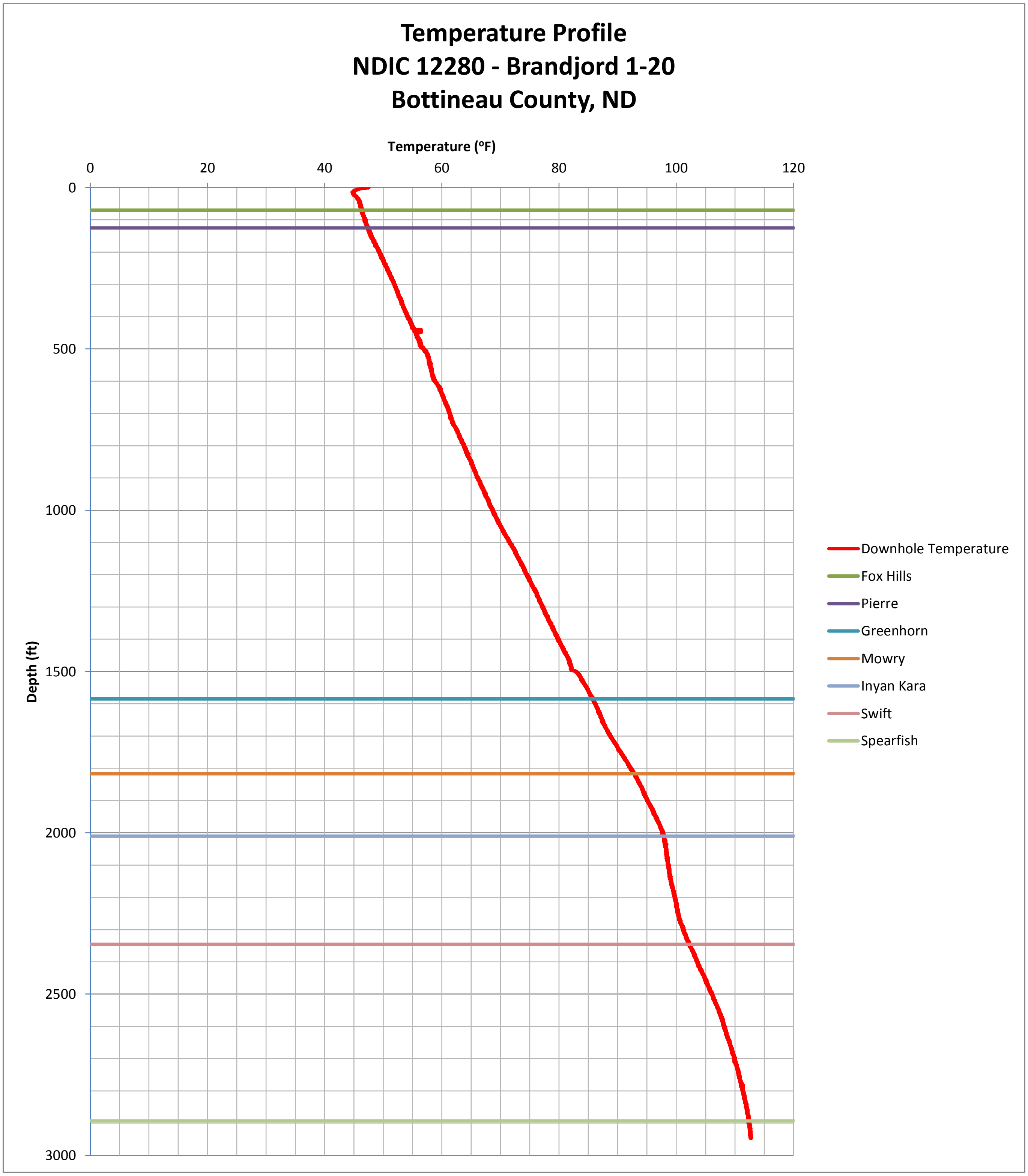

Temperature Profile
NDIC 9653 - Cutlip 1
McKenzie County, ND
Temperature (°F)
0
50
100
150
200
250
Depth (ft)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Downhole
FU/HC/FH
Pierre
Niobrara
Greenhorn
Mowry
Inyan Kara
Swift
Rierdon
Spearfish
Minnekahta
Opeche
Broom Creek
Tyler
Big Snowy
Kibbey Lime
Madison
Ratcliffe
Last Salt

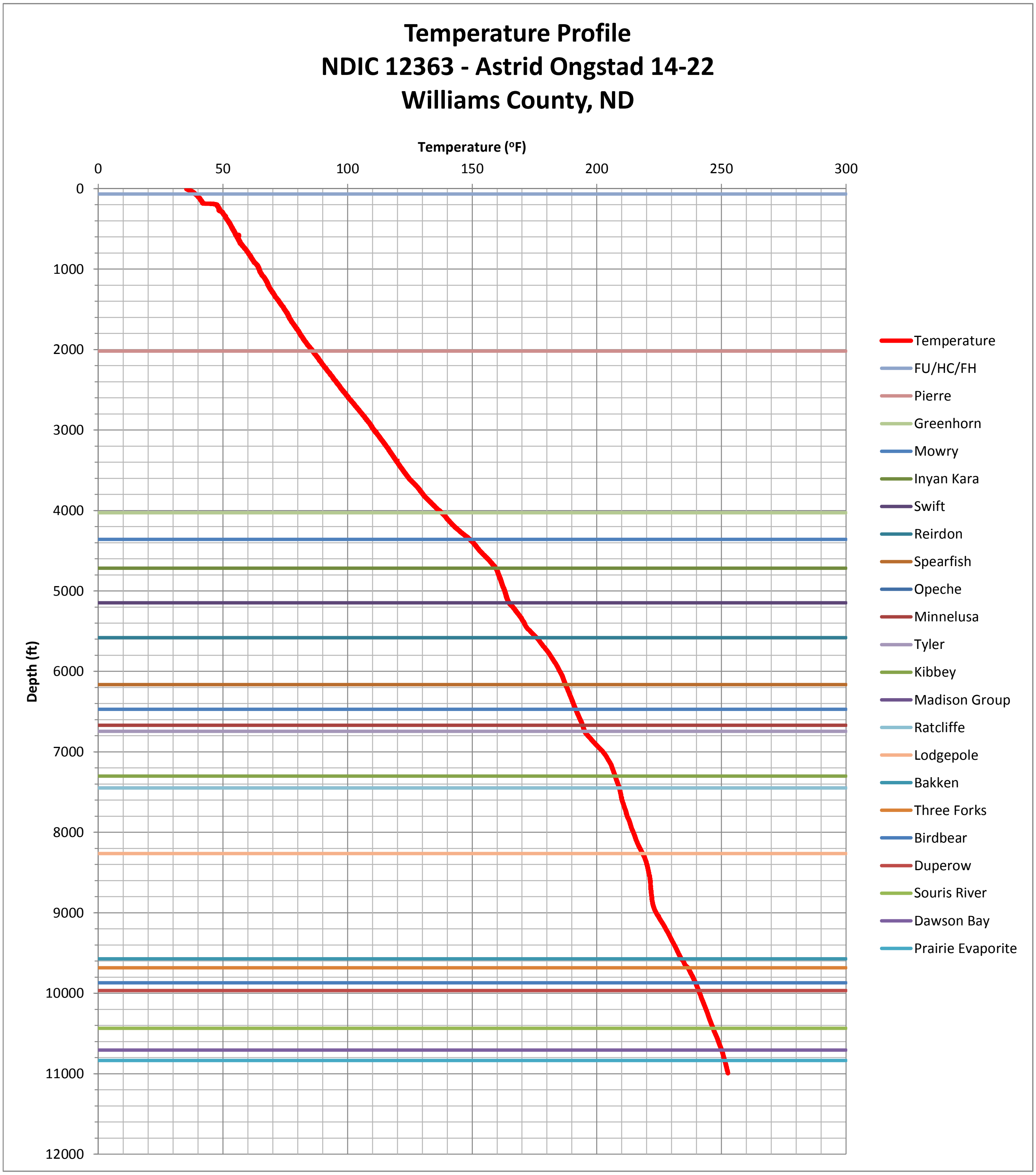


Temperature Profile
NDIC 10103 - Iverson State A-1
McKenzie County, ND
Temperature (°F)
0
50
100
150
200
250
Depth (ft)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Temperature
FU/HC/FH
Pierre
Greenhorn
Mowry
Newcastle
Inyan Kara
Swift
Rierdon
Spearfish
Minnehahta
Opeche
Broom Creek
Tyler
Big Snowy
Kibbey Lime
Madison



Temperature Profile
NDIC 10278 - Mud Buttes State 1-36
Bowman County, ND
Temperature (ºF)
0
50
100
150
200
250
Depth (ft)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Downhole Temperature
FU/HC/FH
Pierre
Green Horn
Mowry
Inyan Kara
Swift
Rierdon
Spearfish
Broom Creek
Big Snowy
Kibbey
Madison
Ratcliffe
Lodgepole
Devonian Undiff.
Interlake


Temperature Profile
NDIC 12280 - Brandjord 1-20
Bottineau County, ND
Temperature (°F)
0
20
40
60
80
100
120
Depth (ft)
0
500
1000
1500
2000
2500
3000
Downhole Temperature
Fox Hills
Pierre
Greenhorn
Mowry
Inyan Kara
Swift
Spearfish


Temperature Profile
NDIC 12363 - Astrid Ongstad 14-22
Williams County, ND
Temperature (°F)
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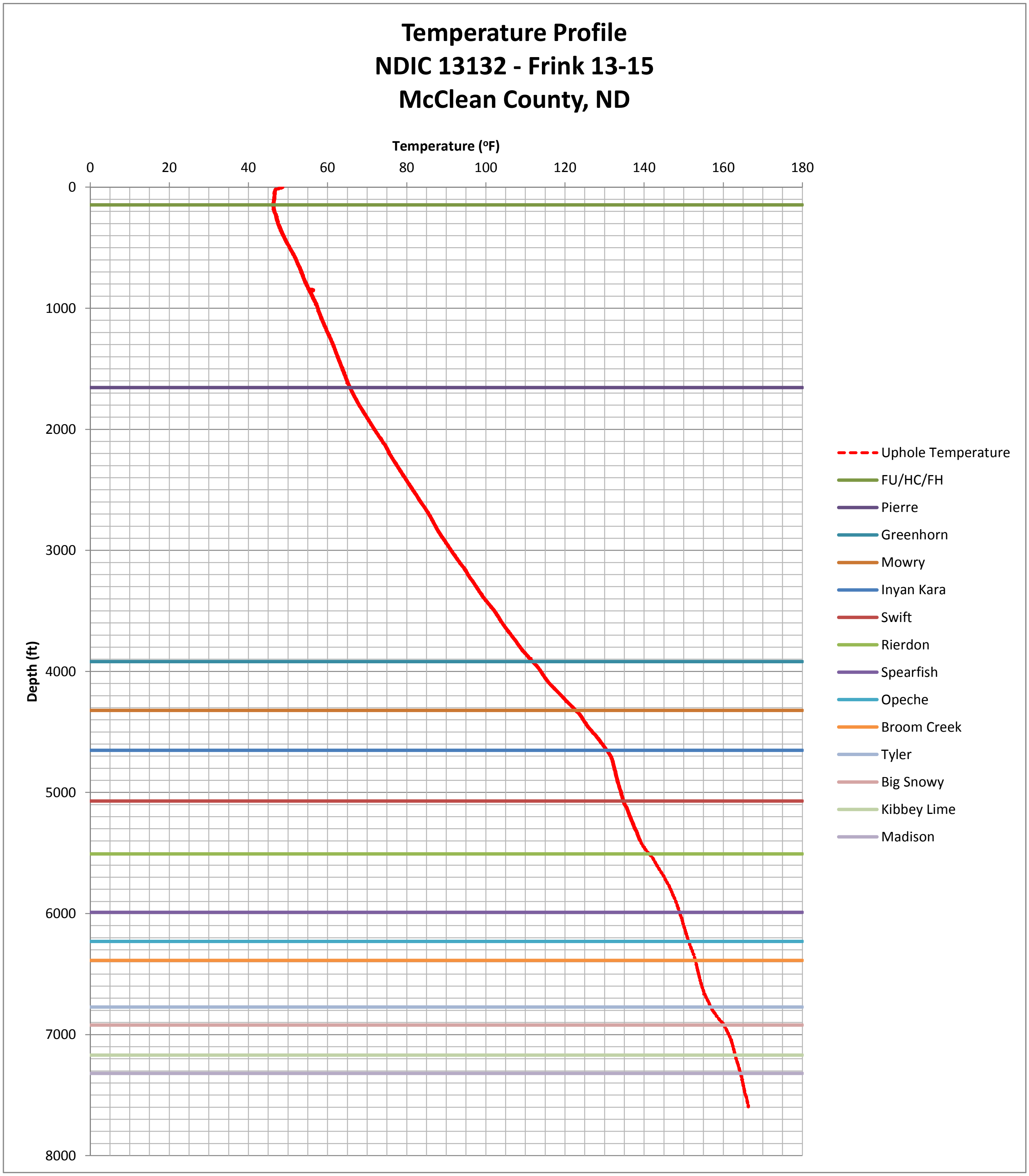
50
100
150
200
250
300
Depth (ft)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
Temperature
FU/HC/FH
Pierre
Greenhorn
Mowry
Inyan Kara
Swift
Reirdon
Spearfish
Opeche
Minnelusa
Tyler
Kibbey
Madison Group
Ratcliffe
Lodgepole
Bakken
Three Forks
Birdbear
Duperow
Souris River
Dawson Bay
Prairie Evaporite



Temperature Profile
NDIC 13132 - Frink 13-15
McClean County, ND
Temperature (°F)
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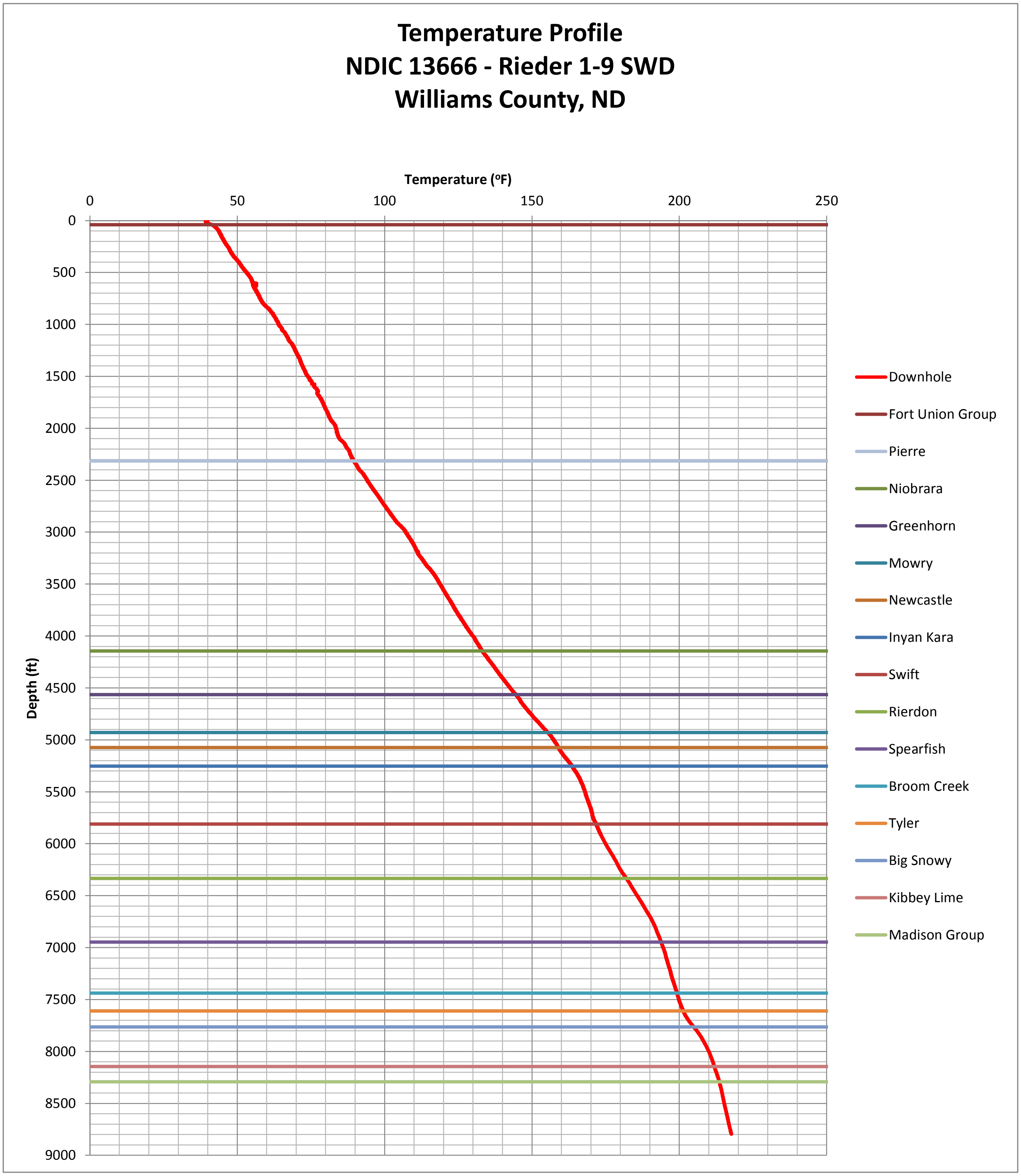
20
40
60
80
100
120
140
160
180
0
1000
2000
3000
4000
5000
6000
7000
8000
Depth (ft)
Uphole Temperature
FU/HC/FH
Pierre
Greenhorn
Mowry
Inyan Kara
Swift
Rierdon
Spearfish
Opeche
Broom Creek
Tyler
Big Snowy
Kibbey Lime
Madison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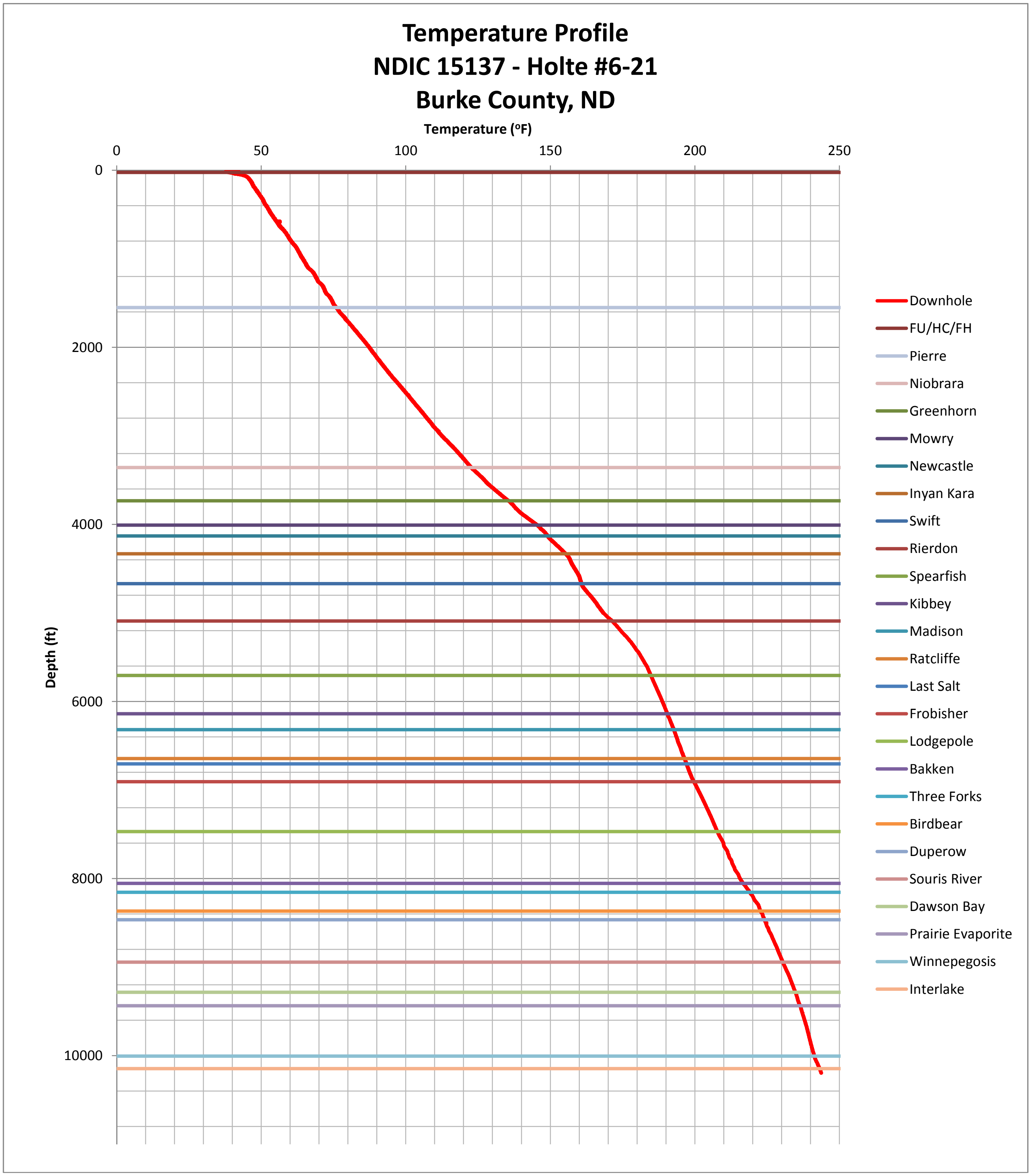
50
100
150
200
250
Depth (ft)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
Downhole
Fort Union Group
Pierre
Niobrara
Greenhorn
Mowry
Newcastle
Inyan Kara
Swift
Rierdon
Spearfish
Broom Creek
Tyler
Big Snowy
Kibbey Lime
Madison Group


Temperature Profile
NDIC 15137 - Holte #6-21
Burke County, ND
Temperature (°F)
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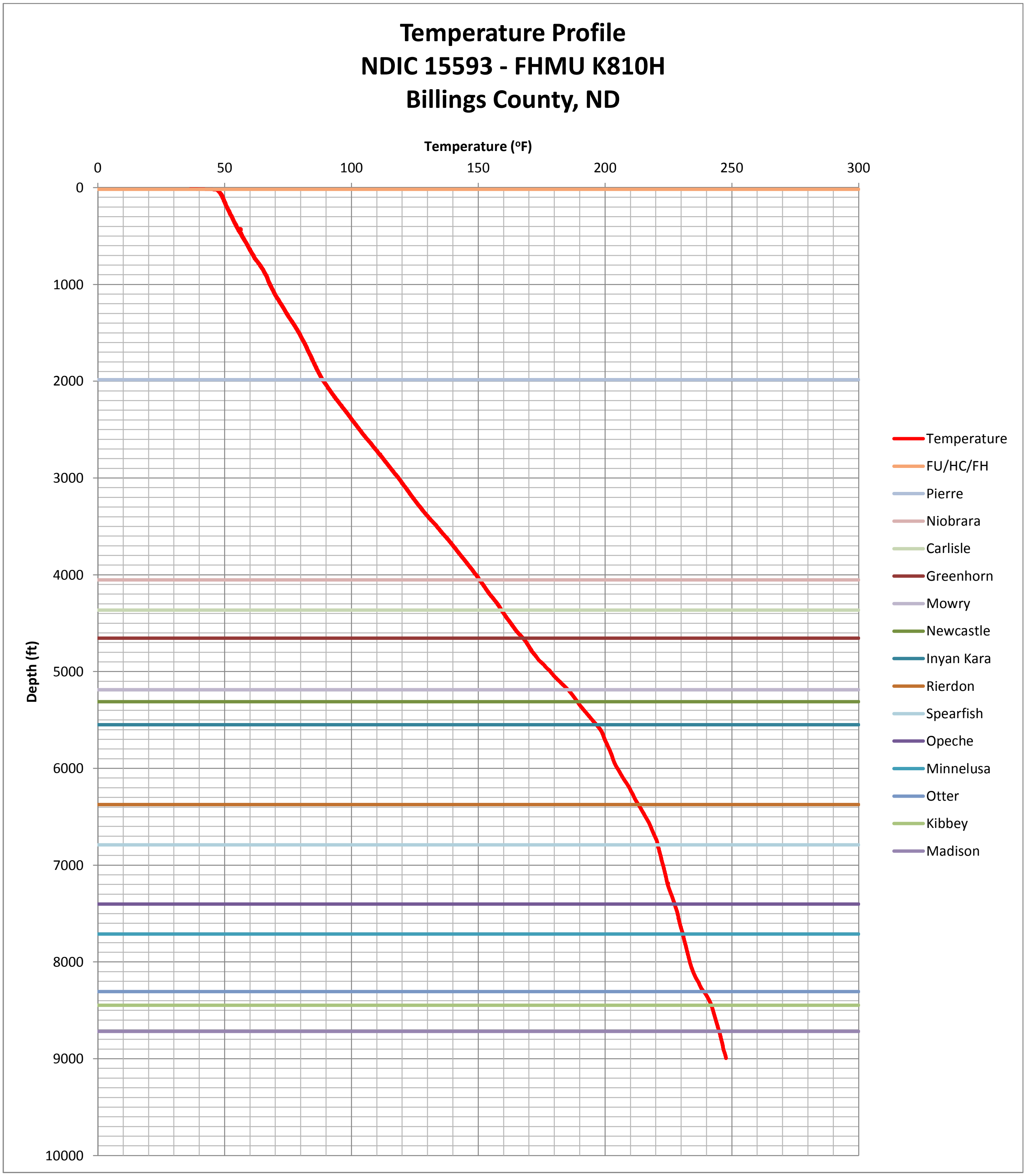
50
100
150
200
250
Depth (ft)
0
2000
4000
6000
8000
10000
Downhole
FU/HC/FH
Pierre
Niobrara
Greenhorn
Mowry
Newcastle
Inyan Kara
Swift
Rierdon
Spearfish
Kibbey
Madison
Ratcliffe
Last Salt
Frobisher
Lodgepole
Bakken
Three Forks
Birdbear
Duperow
Souris River
Dawson Bay
Prairie Evaporite
Winnepegosis
Interlake


Temperature Profile
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Billings County, ND
Temperature (°F)
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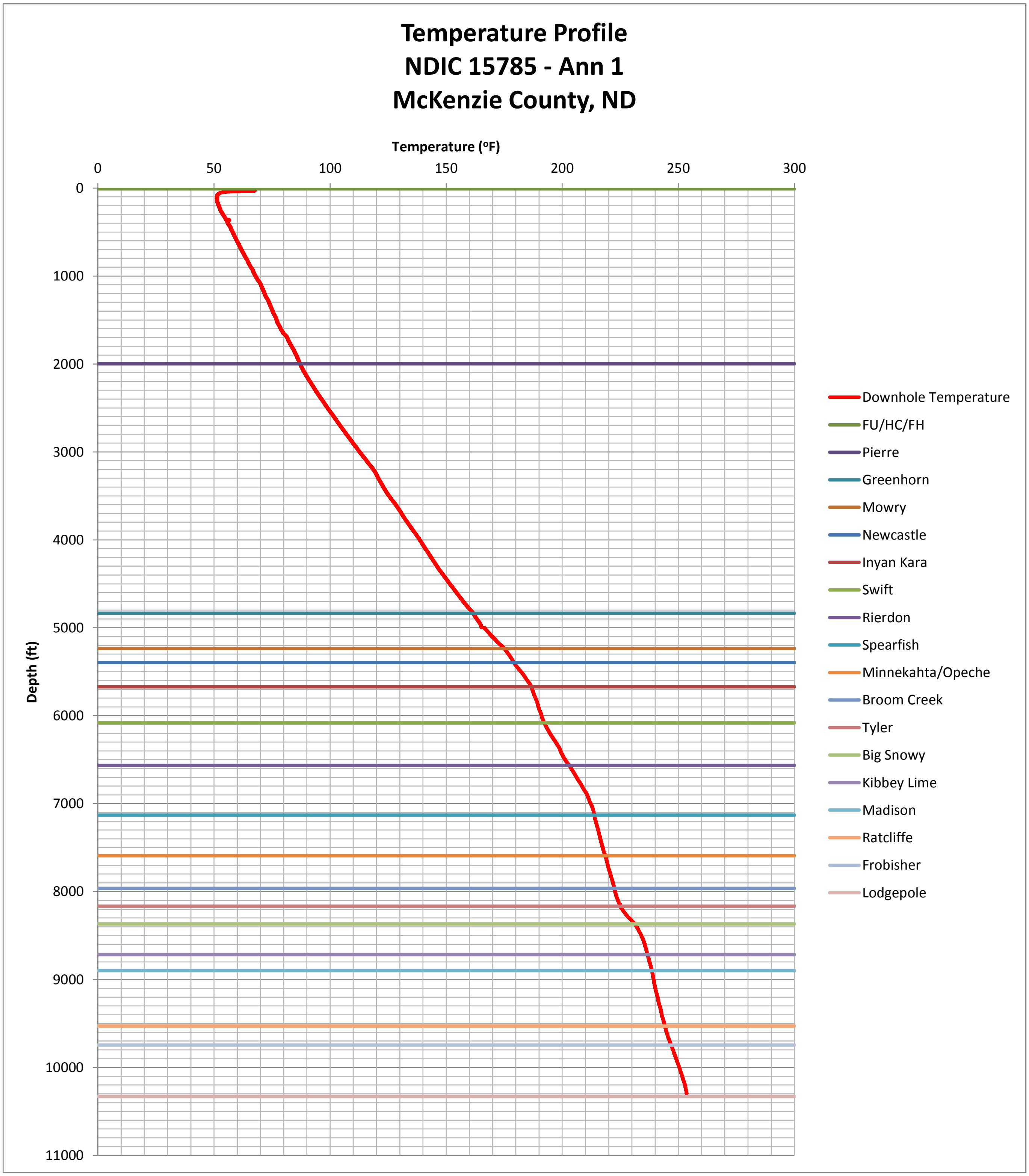
50
100
150
200
250
300
Depth (ft)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Temperature
FU/HC/FH
Pierre
Niobrara
Carlisle
Greenhorn
Mowry
Newcastle
Inyan Kara
Rierdon
Spearfish
Opeche
Minnelusa
Otter
Kibbey
Madison


Temperature Profile
NDIC 15785 - Ann 1
McKenzie County, ND
Temperature (°F)
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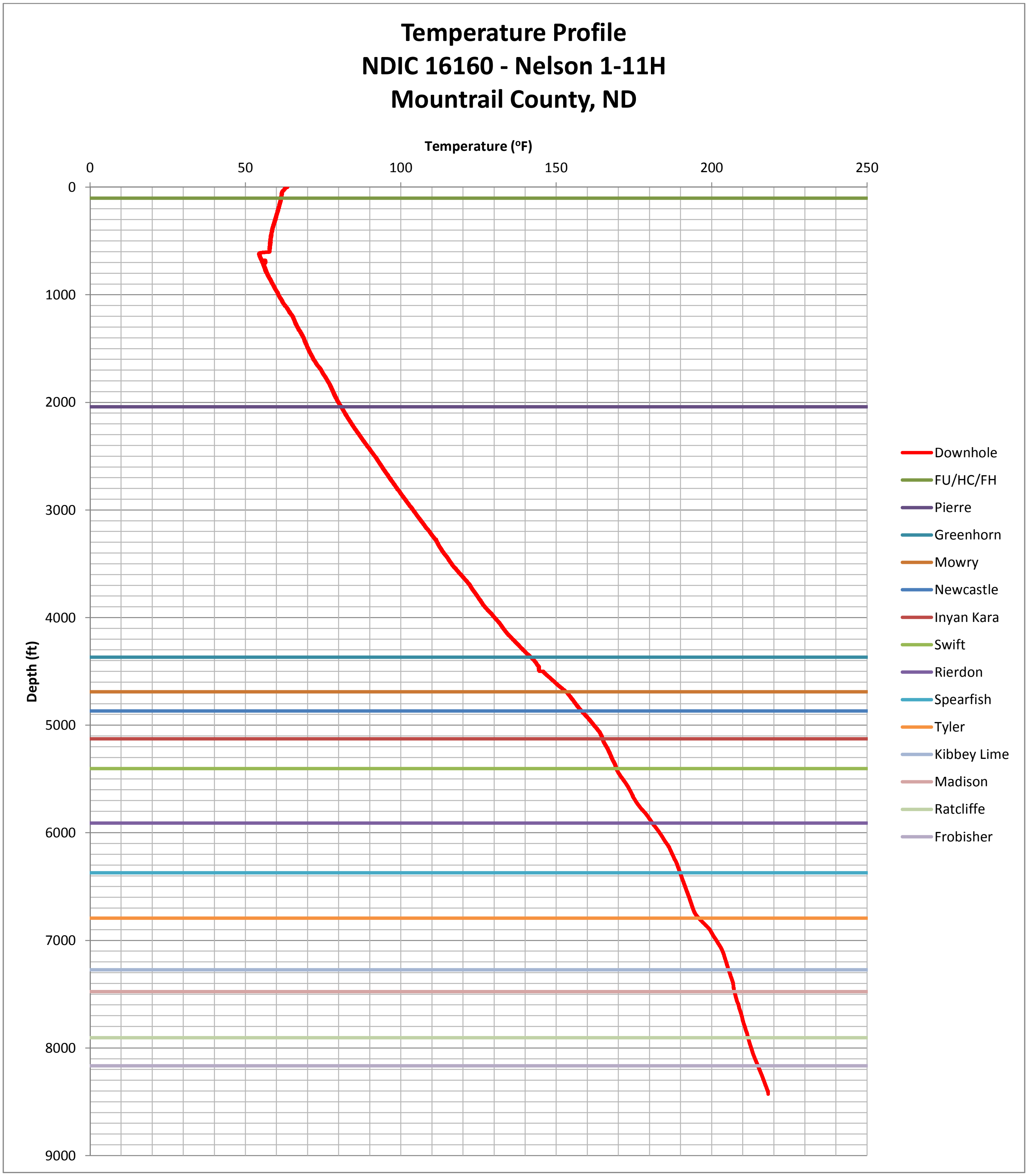
50
100
150
200
250
300
Depth (ft)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
Downhole Temperature
FU/HC/FH
Pierre
Greenhorn
Mowry
Newcastle
Inyan Kara
Swift
Rierdon
Spearfish
Minnekahta/Opeche
Broom Creek
Tyler
Big Snowy
Kibbey Lime
Madison
Ratcliffe
Frobisher
Lodgepole


Temperature Profile
NDIC 16160 - Nelson 1-11H
Mountrail County, ND
Temperature (°F)
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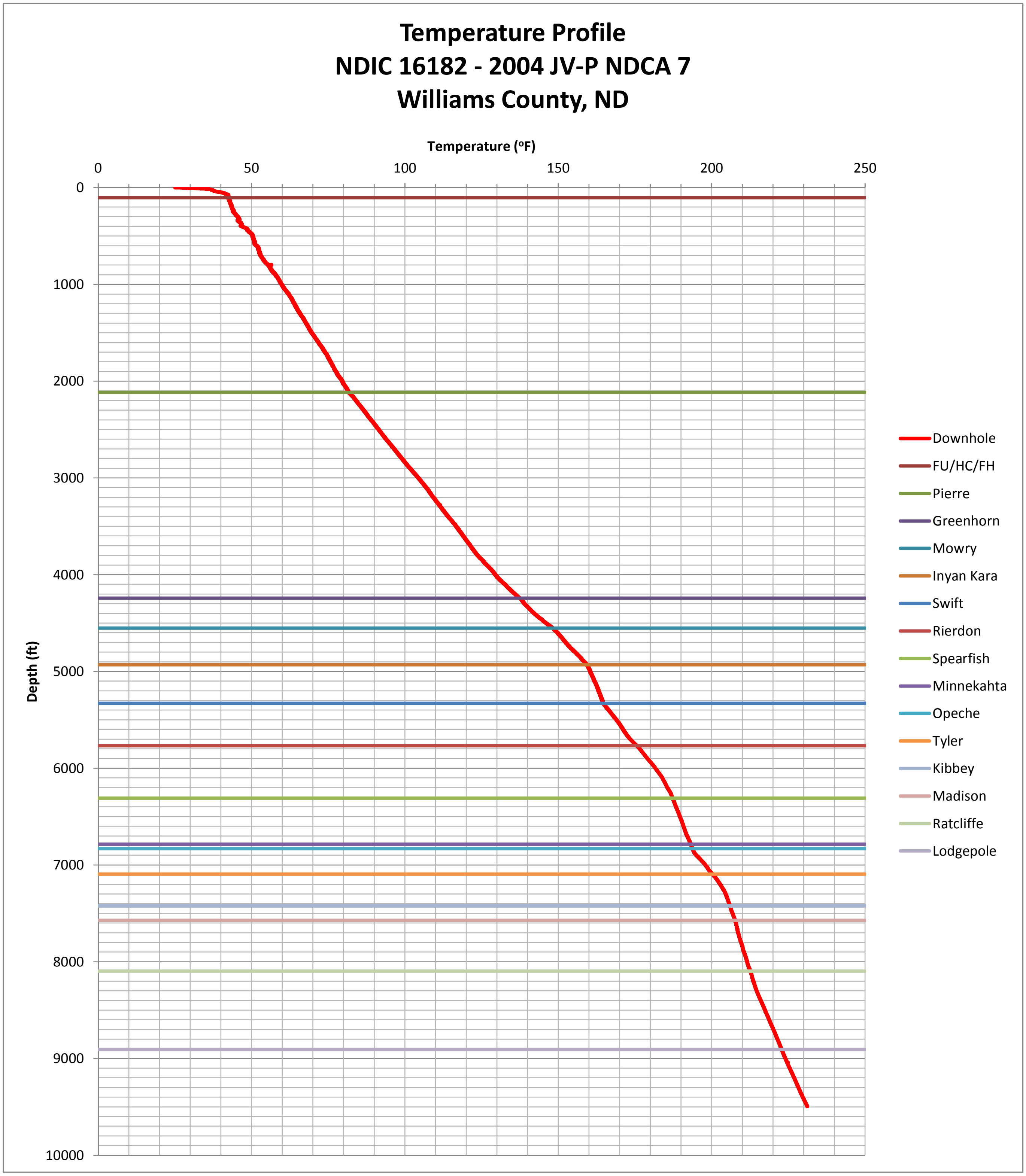
50
100
150
200
250
Depth (ft)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Downhole
FU/HC/FH
Pierre
Greenhorn
Mowry
Newcastle
Inyan Kara
Swift
Rierdon
Spearfish
Tyler
Kibbey Lime
Madison
Ratcliffe
Frobisher


Temperature Profile
NDIC 16182 - 2004 JV-P NDCA 7
Williams County, ND
Temperature (ºF)
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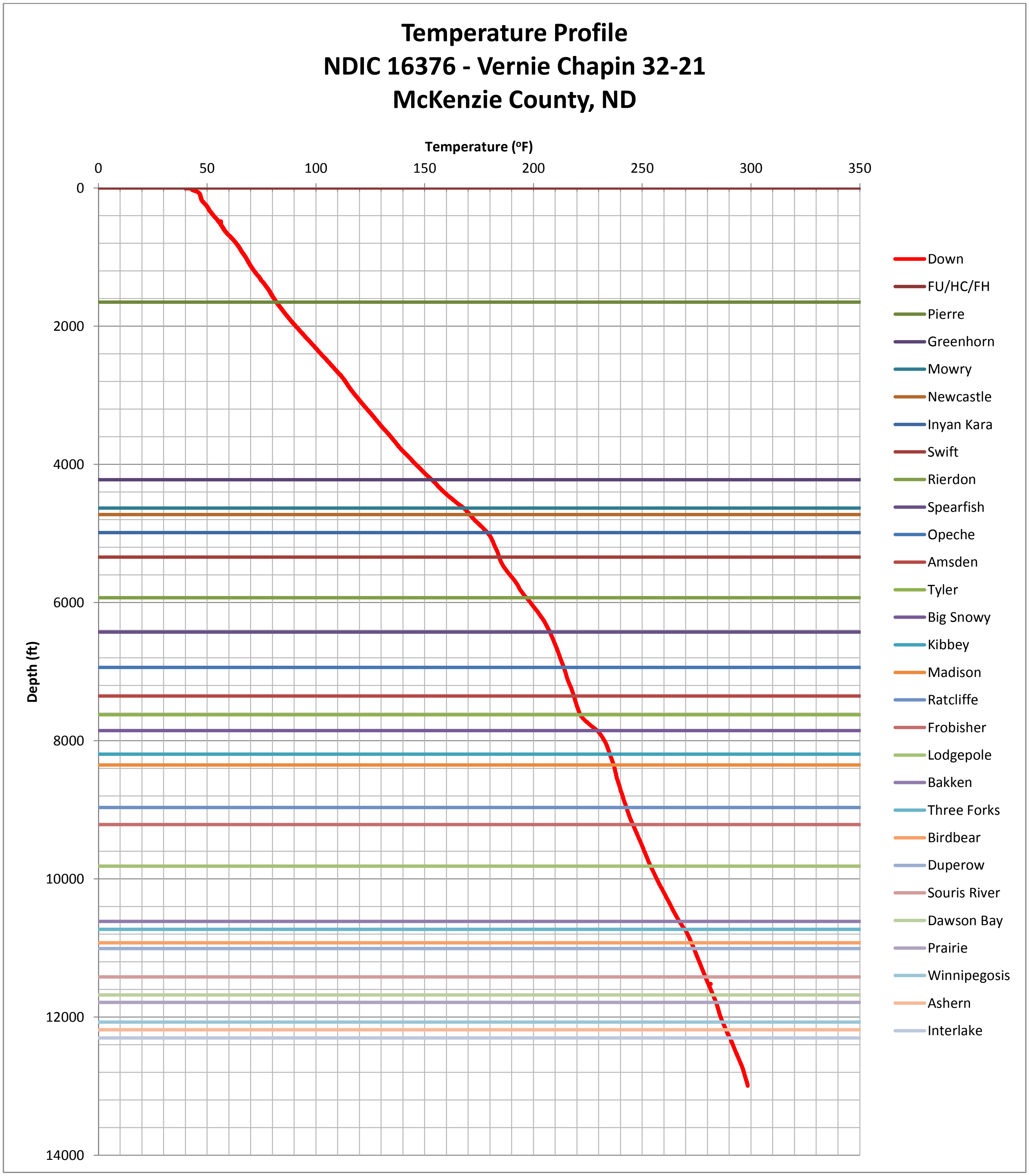
50
100
150
200
250
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Depth (ft)
Downhole
FU/HC/FH
Pierre
Greenhorn
Mowry
Inyan Kara
Swift
Rierdon
Spearfish
Minnekahta
Opeche
Tyler
Kibbey
Madison
Ratcliffe
Lodgepole


Temperature Profile
NDIC 16376 - Vernie Chapin 32-21
McKenzie County, ND
Temperature (ºF)
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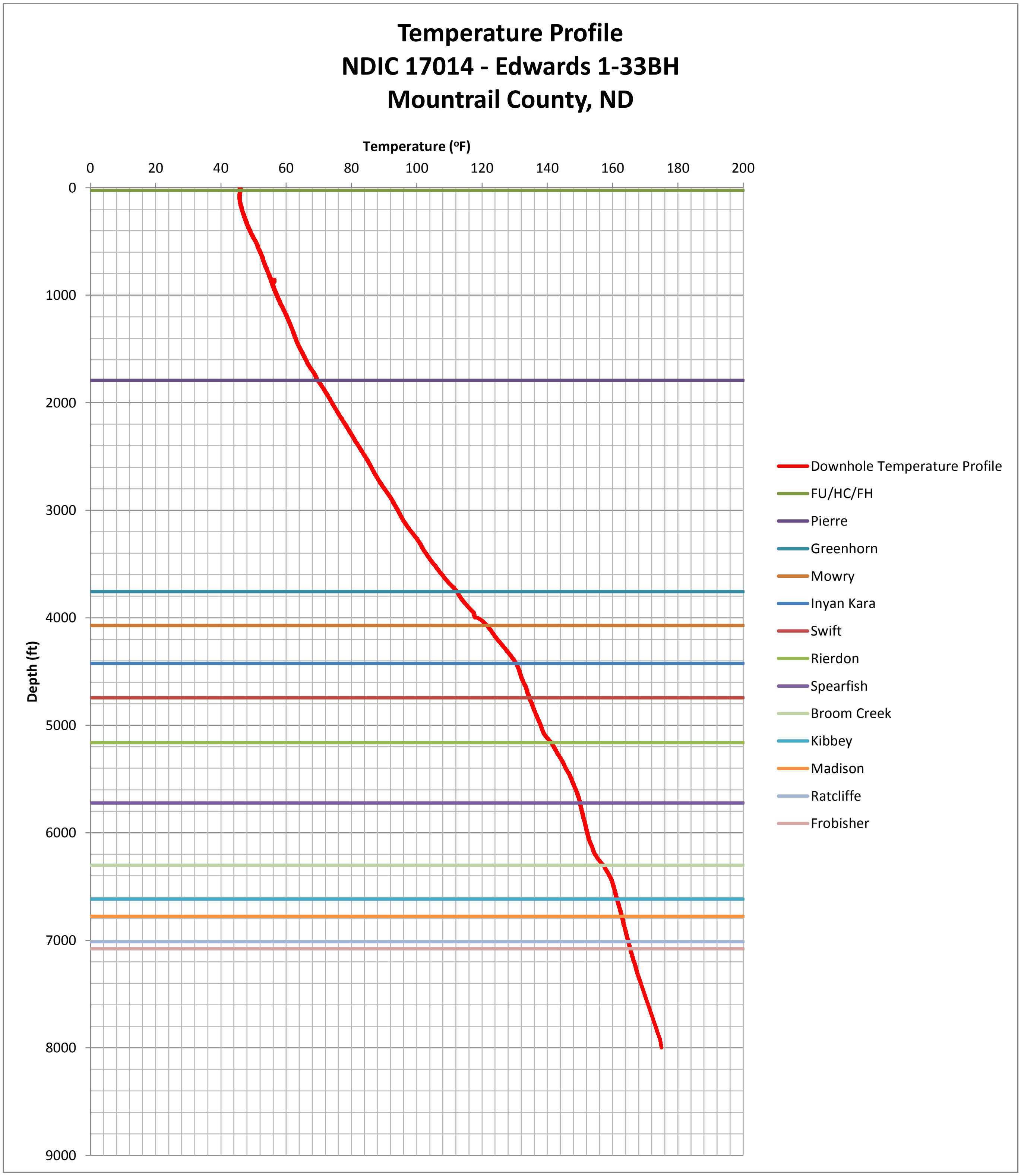
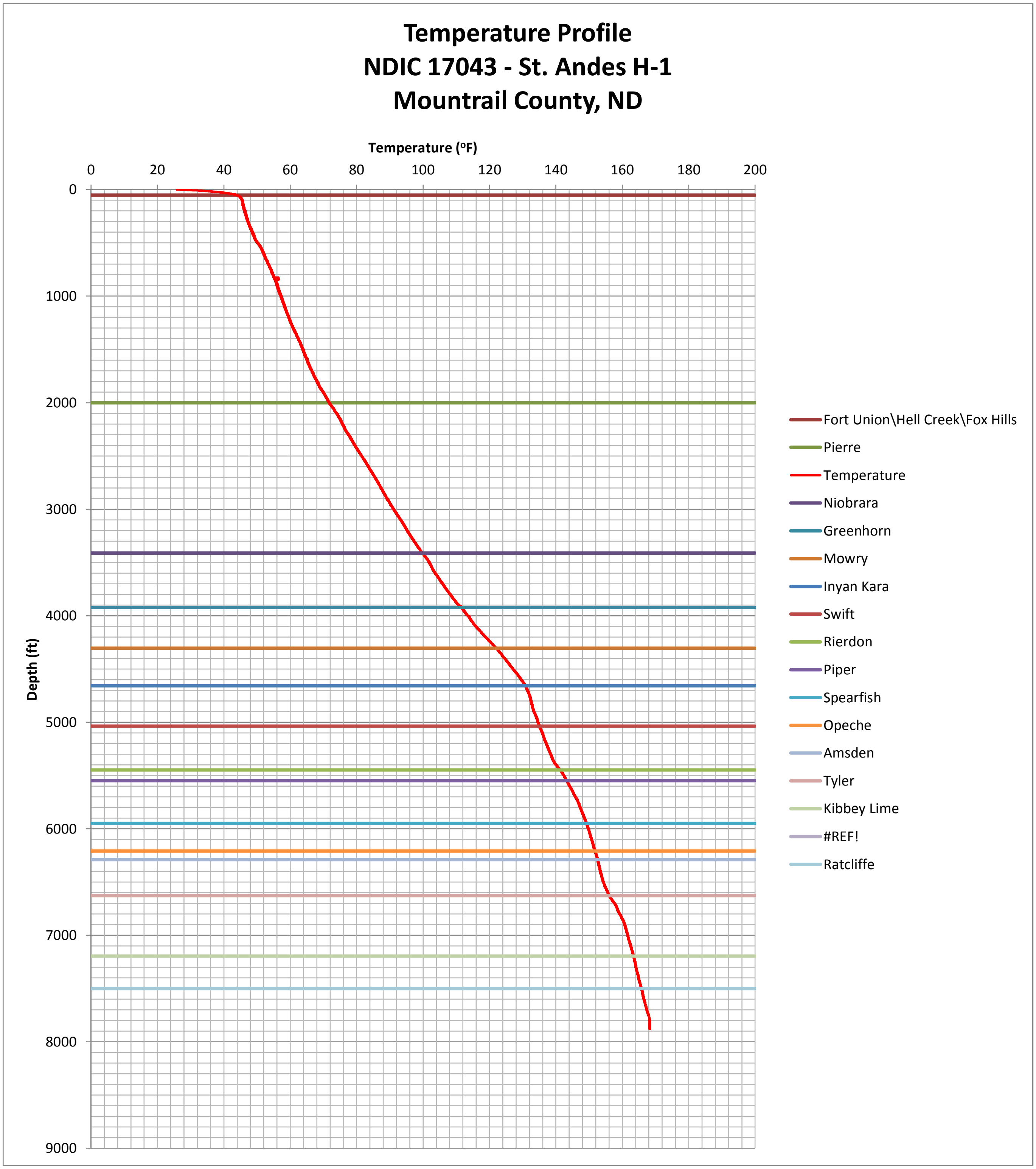
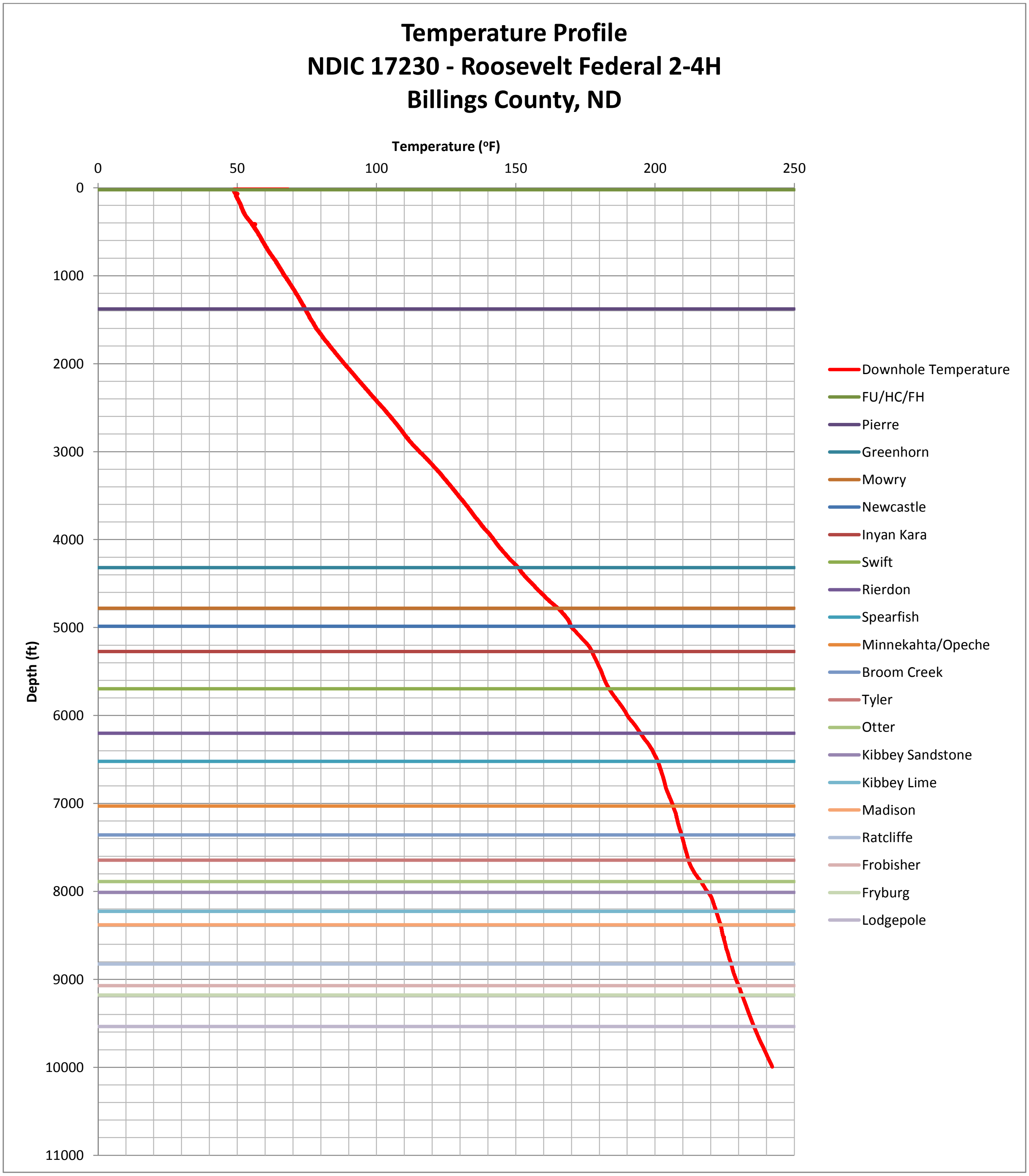
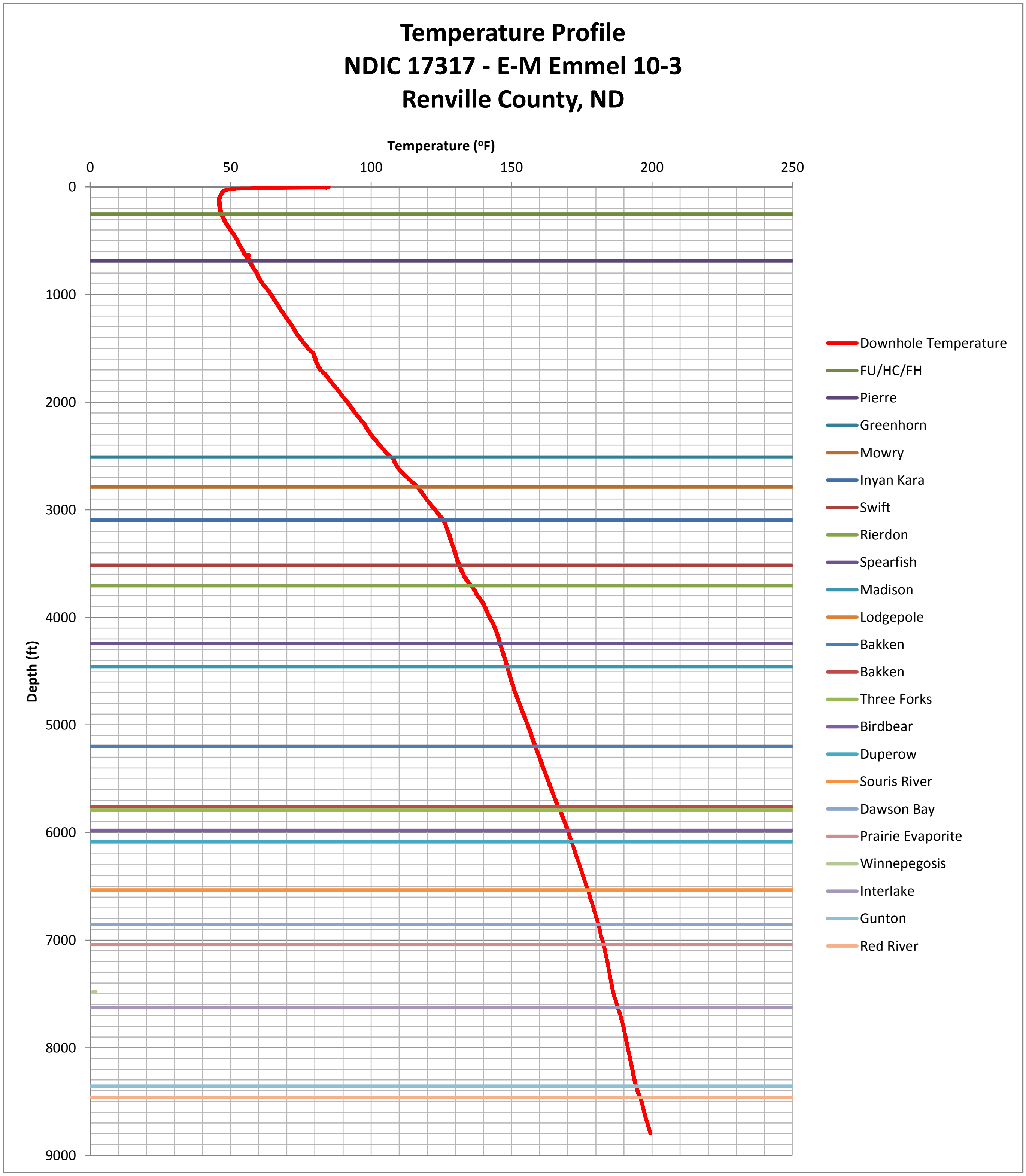
50
100
150
200
250
300
350
Depth (ft)
0
2000
4000
6000
8000
10000
12000
14000
Down
FU/HC/FH
Pierre
Greenhorn
Mowry
Newcastle
Inyan Kara
Swift
Rierdon
Spearfish
Opeche
Amsden
Tyler
Big Snowy
Kibbey
Madison
Ratcliffe
Frobisher
Lodgepole
Bakken
Three Forks
Birdbear
Duperow
Souris River
Dawson Bay
Prairie
Winnipegosis
Ashern
Interlake

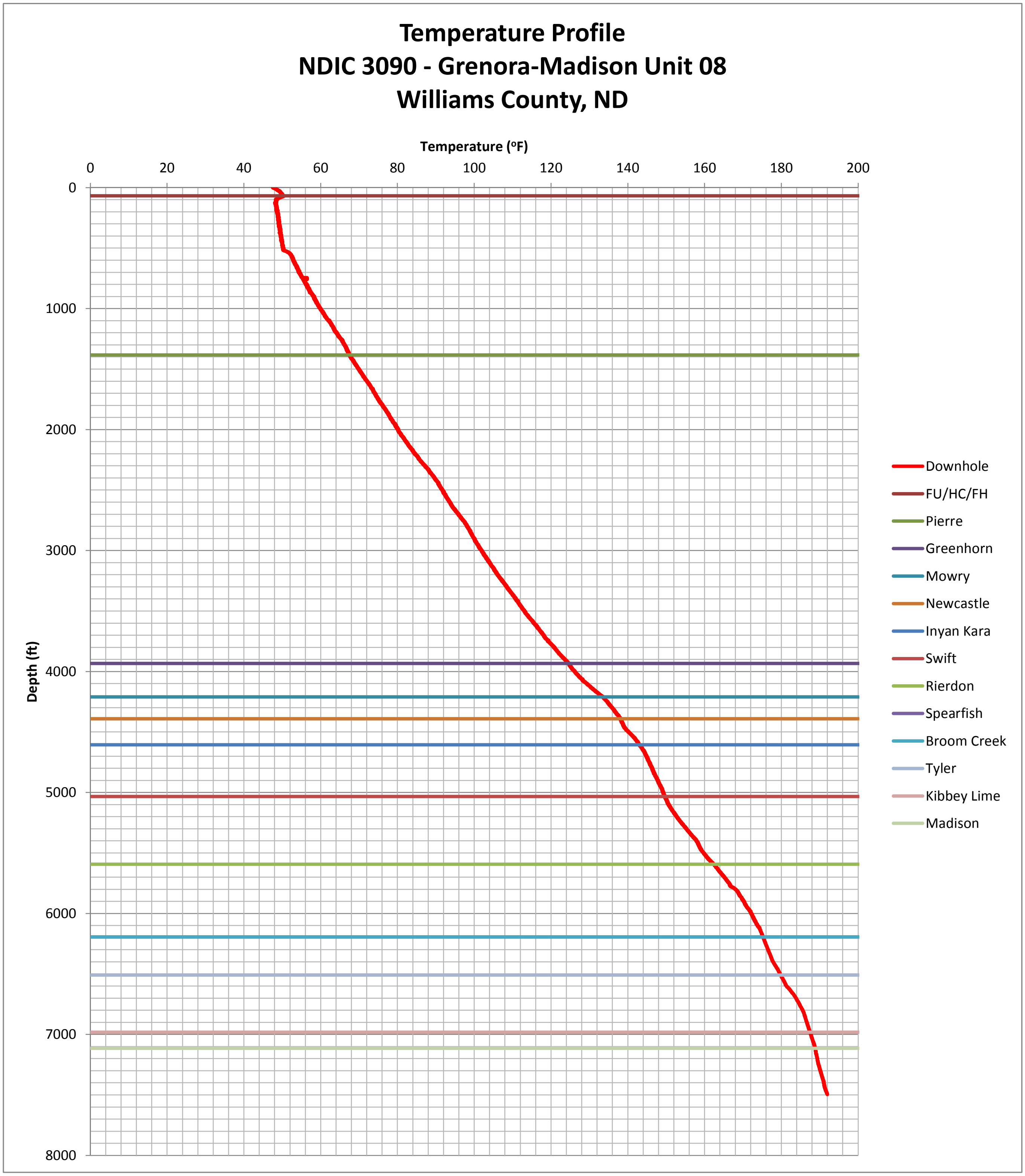


Temperature Profile
NDIC 17014 - Edwards 1-33BH
Mountrail County, ND
Temperature (°F)
0
20
40
60
80
100
120
140
160
180
200
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Depth (ft)
Downhole Temperature Profile
FU/HC/FH
Pierre
Greenhorn
Mowry
Inyan Kara
Swift
Rierdon
Spearfish
Broom Creek
Kibbey
Madison
Ratcliffe
Frobisher

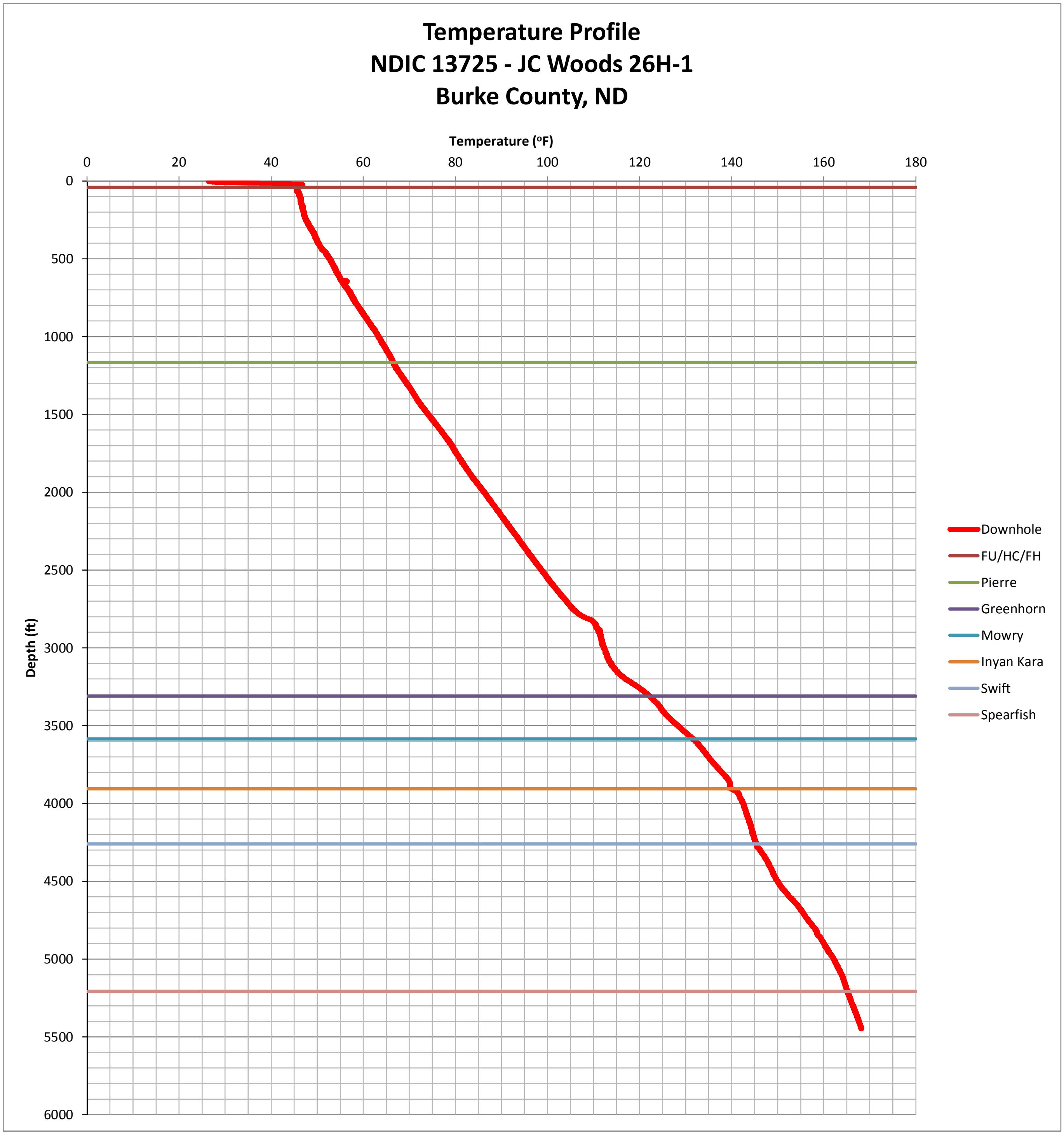

Temperature Profile
NDIC 17043 - St. Andes H-1
Mountrail County, ND
Temperature (ºF)
0
20
40
60
80
100
120
140
160
180
200
Depth (ft)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Fort Union\Hell Creek\Fox Hills
Pierre
Temperature
Niobrara
Greenhorn
Mowry
Inyan Kara
Swift
Rierdon
Piper
Spearfish
Opeche
Amsden
Tyler
Kibbey Lime
#REF!
Ratcliffe


Temperature Profile
NDIC 17230 - Roosevelt Federal 2-4H
Billings County, ND
Temperature (°F)
0
50
100
150
200
250
Depth (ft)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
Downhole Temperature
FU/HC/FH
Pierre
Greenhorn
Mowry
Newcastle
Inyan Kara
Swift
Rierdon
Spearfish
Minnekahta/Opeche
Broom Creek
Tyler
Otter
Kibbey Sandstone
Kibbey Lime
Madison
Ratcliffe
Frobisher
Fryburg
Lodgepole


Temperature Profile
NDIC 17317 - E-M Emmel 10-3
Renville County, ND
Temperature (°F)
0
50
100
150
200
250
Depth (ft)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Downhole Temperature
FU/HC/FH
Pierre
Greenhorn
Mowry
Inyan Kara
Swift
Rierdon
Spearfish
Madison
Lodgepole
Bakken
Bakken
Three Forks
Birdbear
Duperow
Souris River
Dawson Bay
Prairie Evaporite
Winnepegosis
Interlake
Gunton
Red River

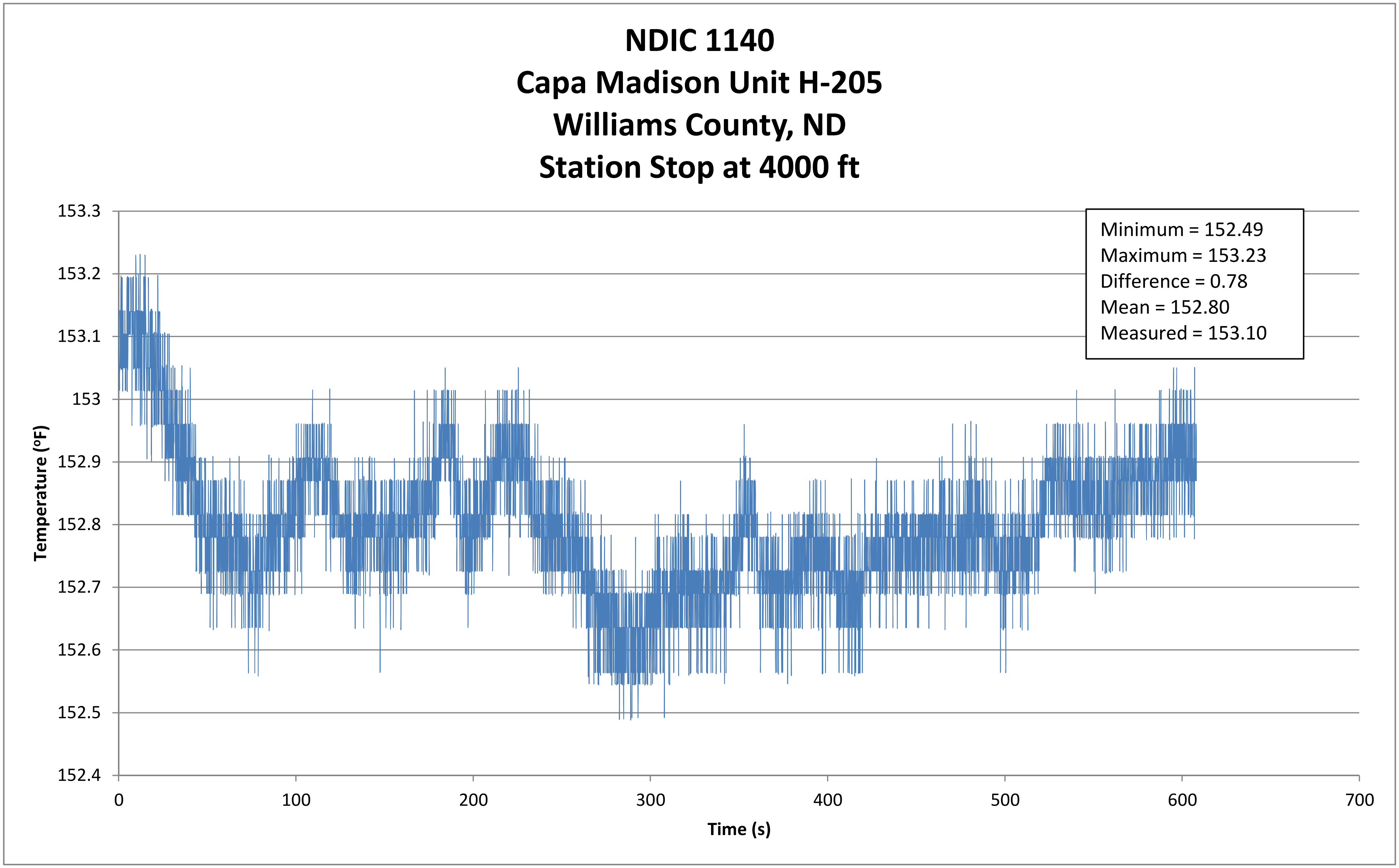


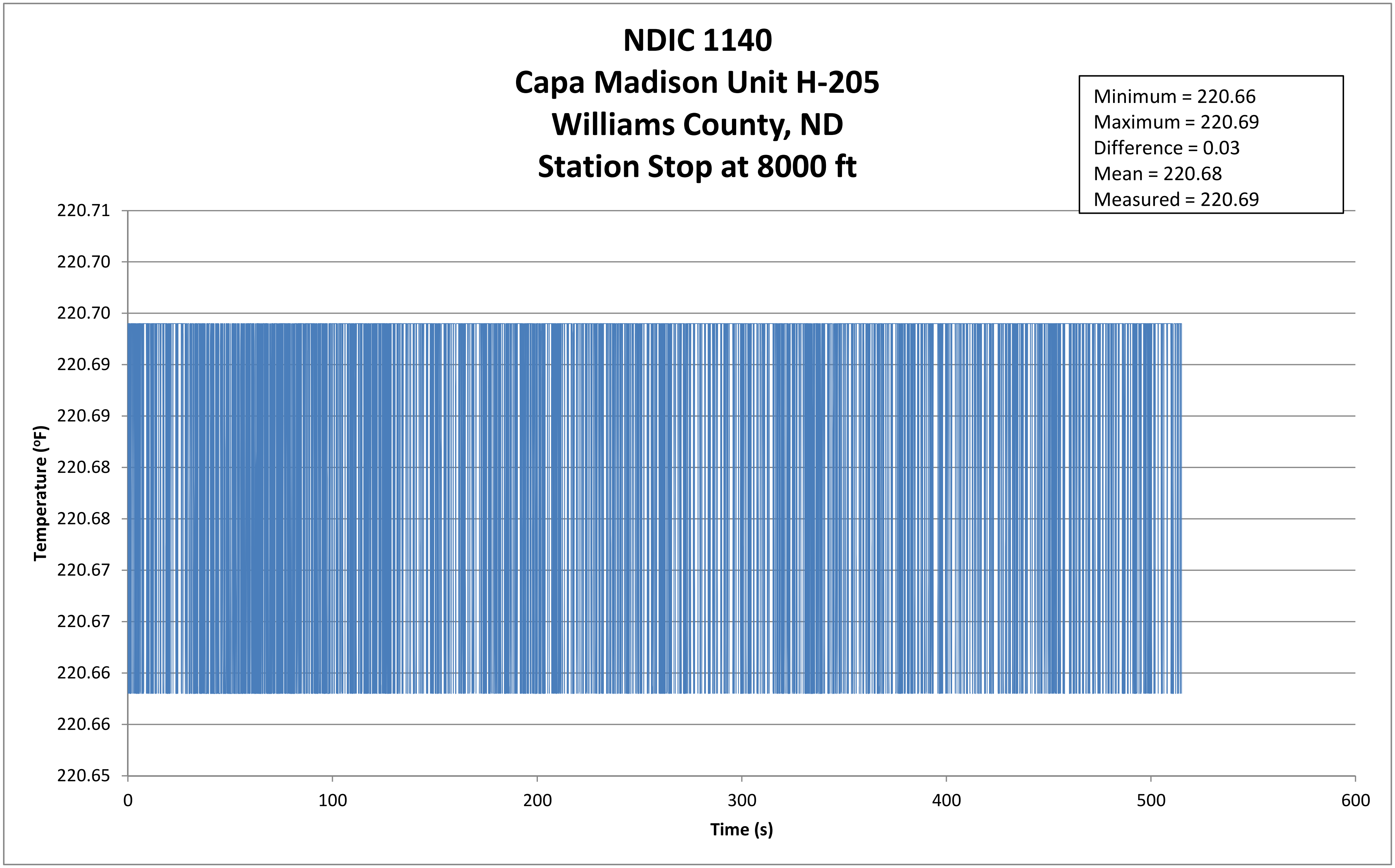
Temperature Profile
NDIC 3090 - Grenora-Madison Unit 08
Williams County, ND
Temperature (°F)
0
20
40
60
80
100
120
140
160
180
200
0
1000
2000
3000
4000
5000
6000
7000
8000
Depth (ft)
Downhole
FU/HC/FH
Pierre
Greenhorn
Mowry
Newcastle
Inyan Kara
Swift
Rierdon
Spearfish
Broom Creek
Tyler
Kibbey Lime
Madison

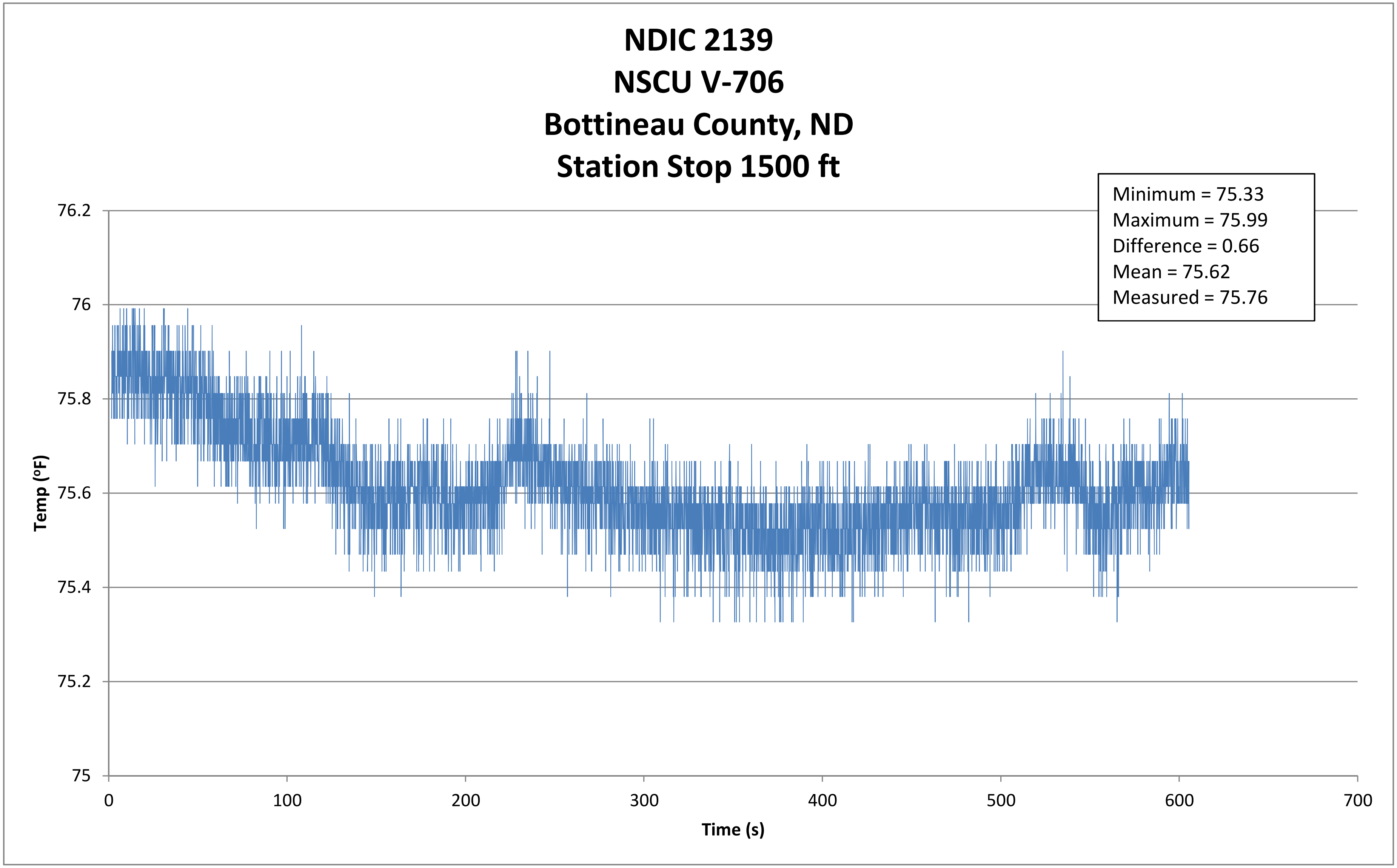

Temperature Profile
NDIC 13725 - JC Woods 26H-1
Burke County, ND
Temperature (°F)
0
20
40
60
80
100
120
140
160
180
Depth (ft)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
Downhole
FU/HC/FH
Pierre
Greenhorn
Mowry
Inyan Kara
Swift
Spearfish

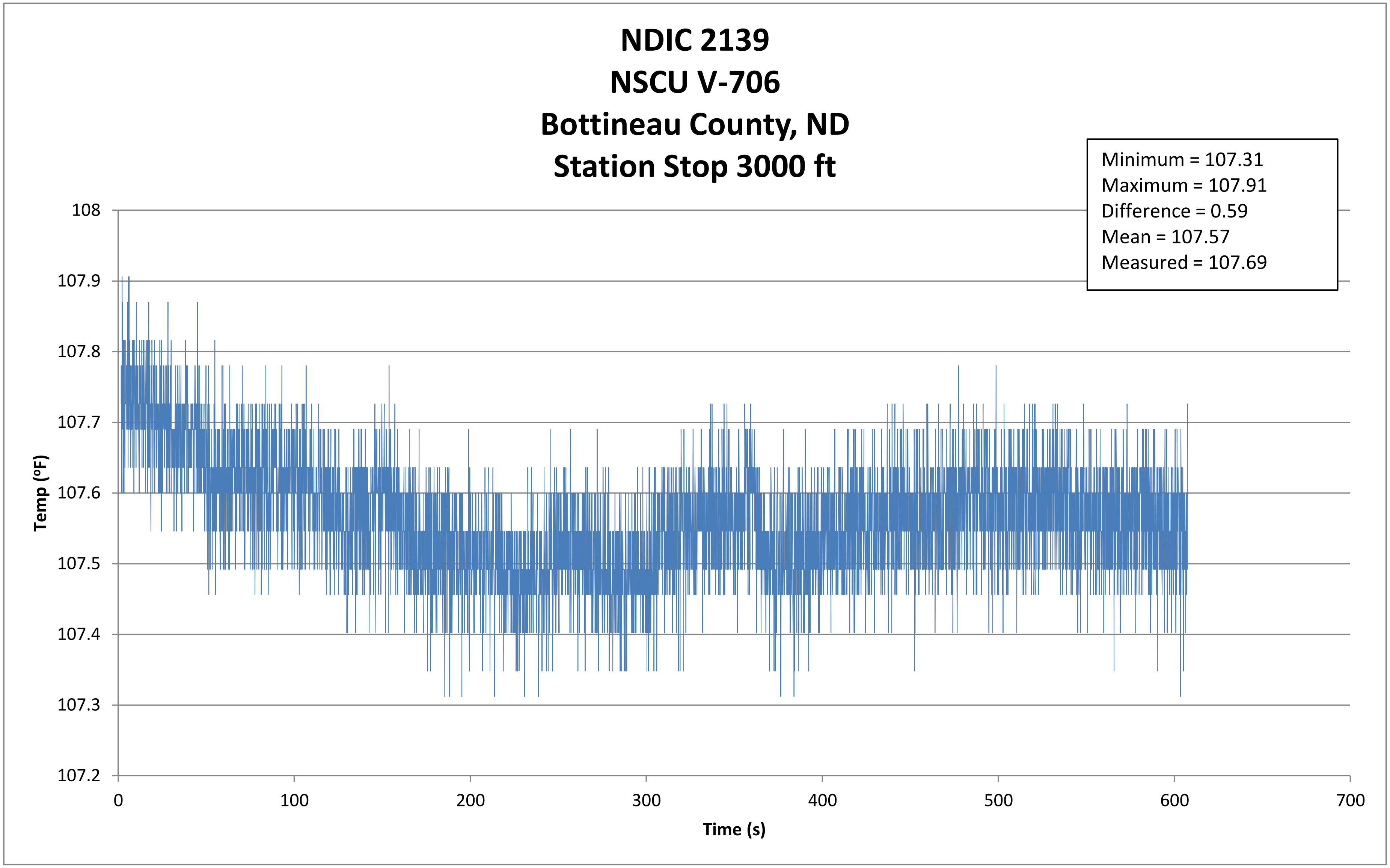
APPENDIX B

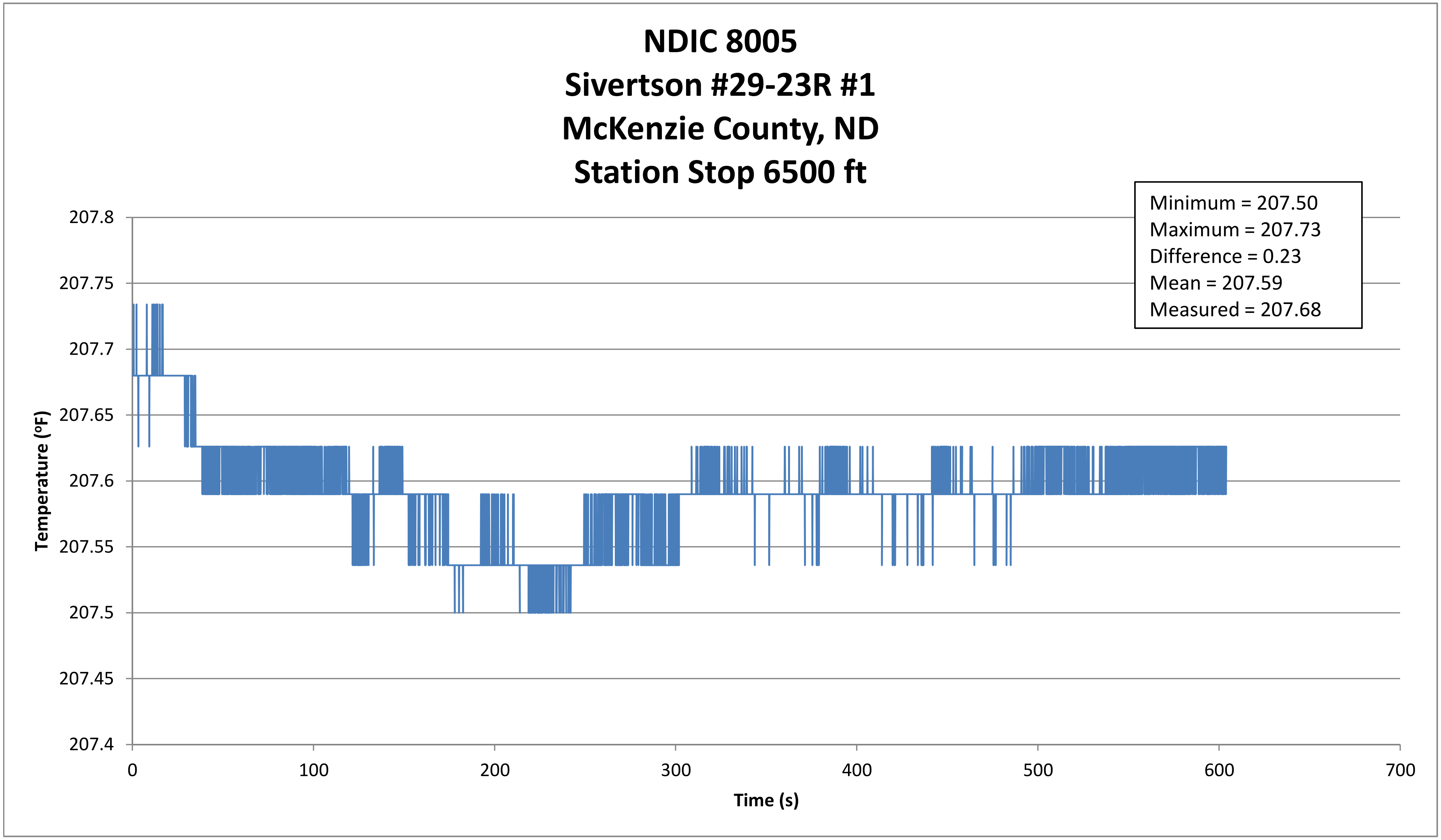
STATION STOPS

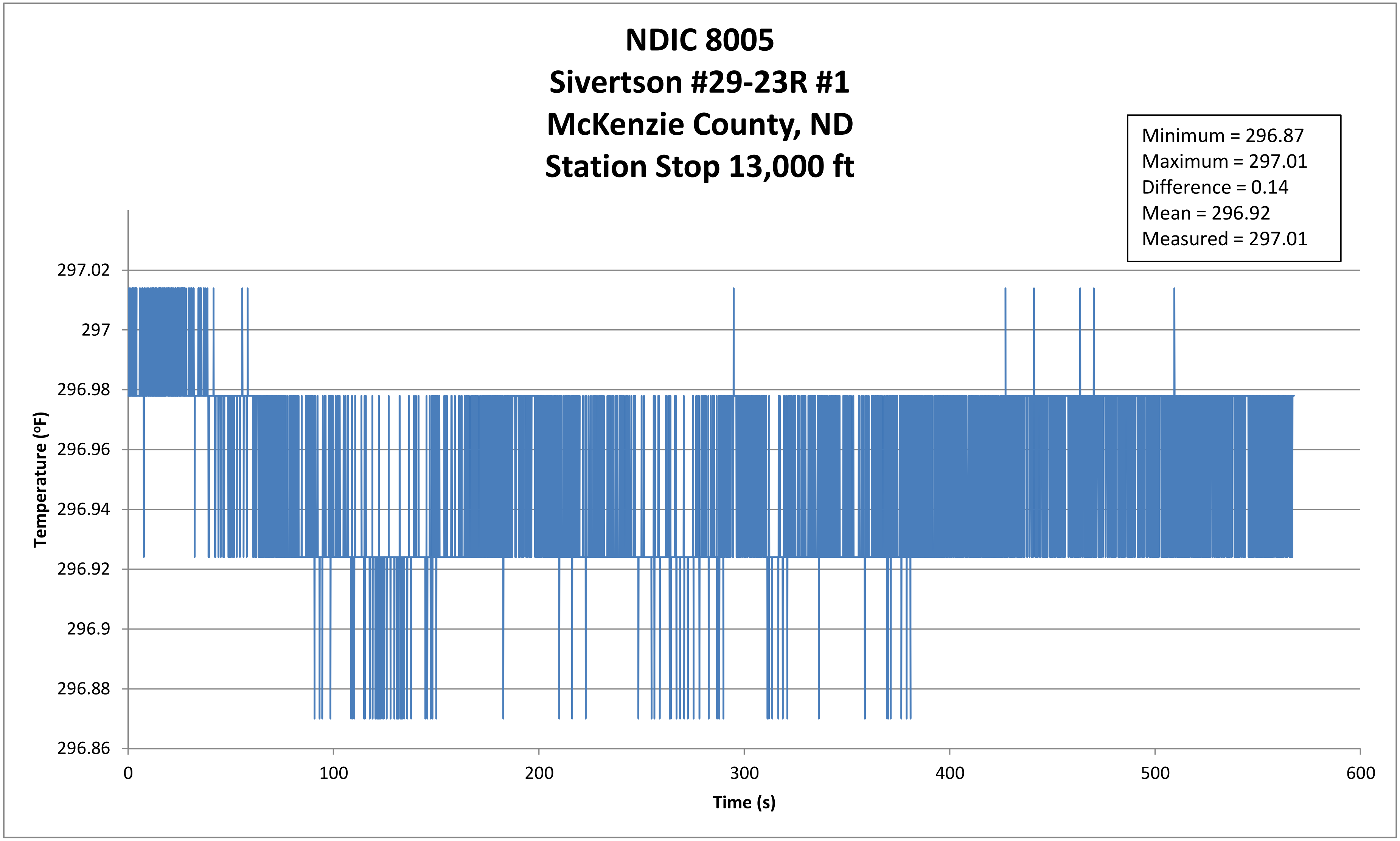

NDIC 1140
Capa Madison Unit H-205
Williams County, ND
Station Stop at 4000 ft
Minimum = 152.49
Maximum = 153.23
Difference = 0.78
Mean = 152.80
Measured = 153.10
Temperature (ºF)
153.3
153.2
153.1
153
152.9
152.8
152.7
152.6
152.5
152.4
0
100
200
300
400
500
600
700
Time (s)

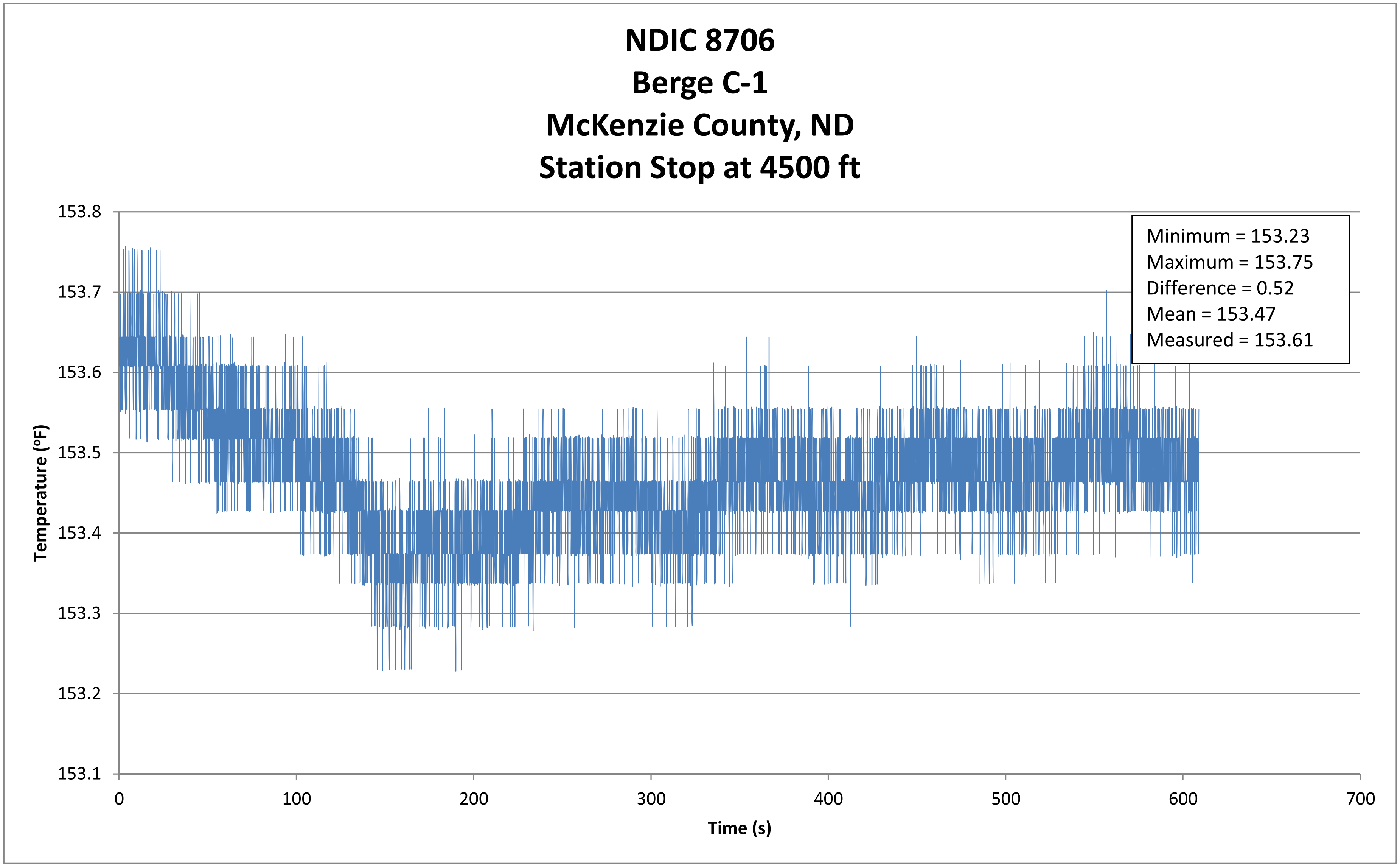

NDIC 1140
Capa Madison Unit H-205
Williams County, ND
Station Stop at 8000 ft
Minimum = 220.66
Maximum = 220.69
Difference = 0.03
Mean = 220.68
Measured = 220.69
Temperature (ºF)
220.71
220.70
220.70
220.69
220.69
220.68
220.68
220.67
220.67
220.66
220.66
220.65
0
100
200
300
400
500
600
Time (s)


NDIC 2139
NSCU V-706
Bottineau County, ND
Station Stop 1500 ft
Minimum = 75.33
Maximum = 75.99
Difference = 0.66
Mean = 75.62
Measured = 75.76
Temp (ºF)
76.2
76
75.8
75.6
75.4
75.2
75
0
100
200
300
400
500
600
700
Time (s)

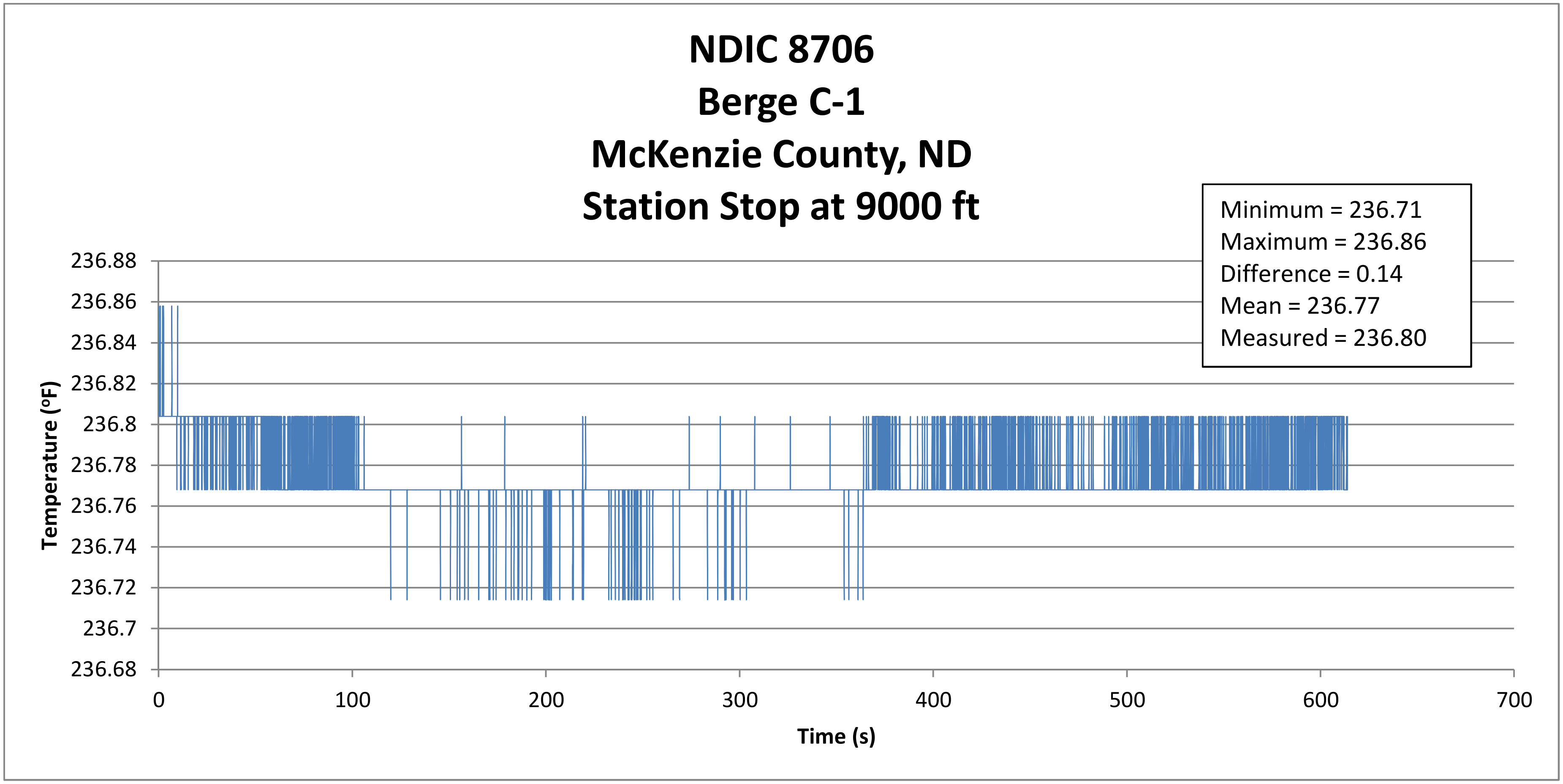

NDIC 2139
NSCU V-706
Bottineau County, ND
Station Stop 3000 ft
Minimum = 107.31
Maximum = 107.91
Difference = 0.59
Mean = 107.57
Measured = 107.69
Temp (ºF)
108
107.9
107.8
107.7
107.6
107.5
107.4
107.3
107.2
0
100
200
300
400
500
600
700
Time (s)

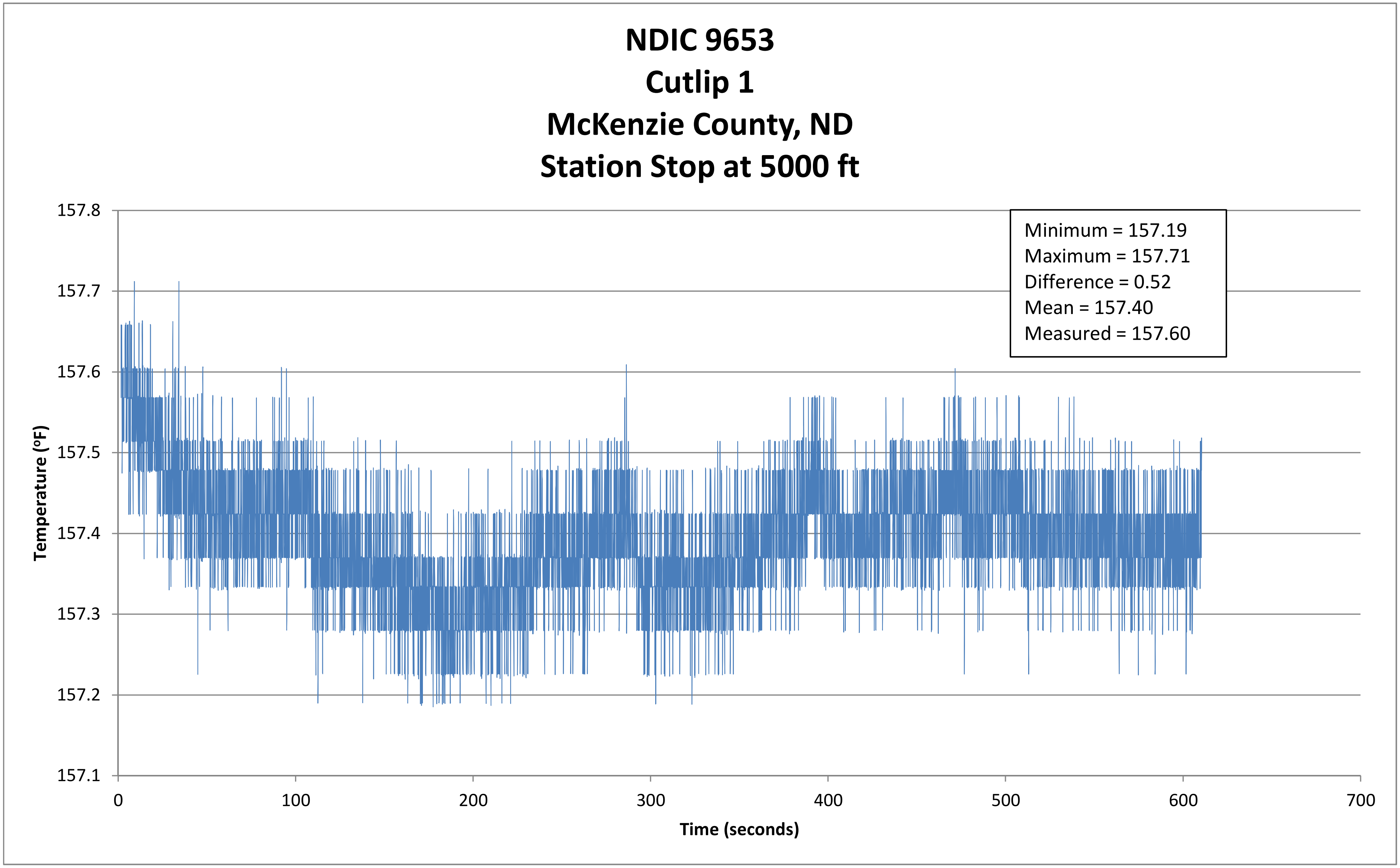

NDIC 8005
Sivertson #29-23R #1
McKenzie County, ND
Station Stop 6500 ft
Minimum = 207.50
Maximum = 207.73
Difference = 0.23
Mean = 207.59
Measured = 207.68
207.8
207.75
207.7
207.65
207.6
207.55
207.5
207.45
207.4
Temperature (ºF)
0
100
200
300
400
500
600
700
Time (s)

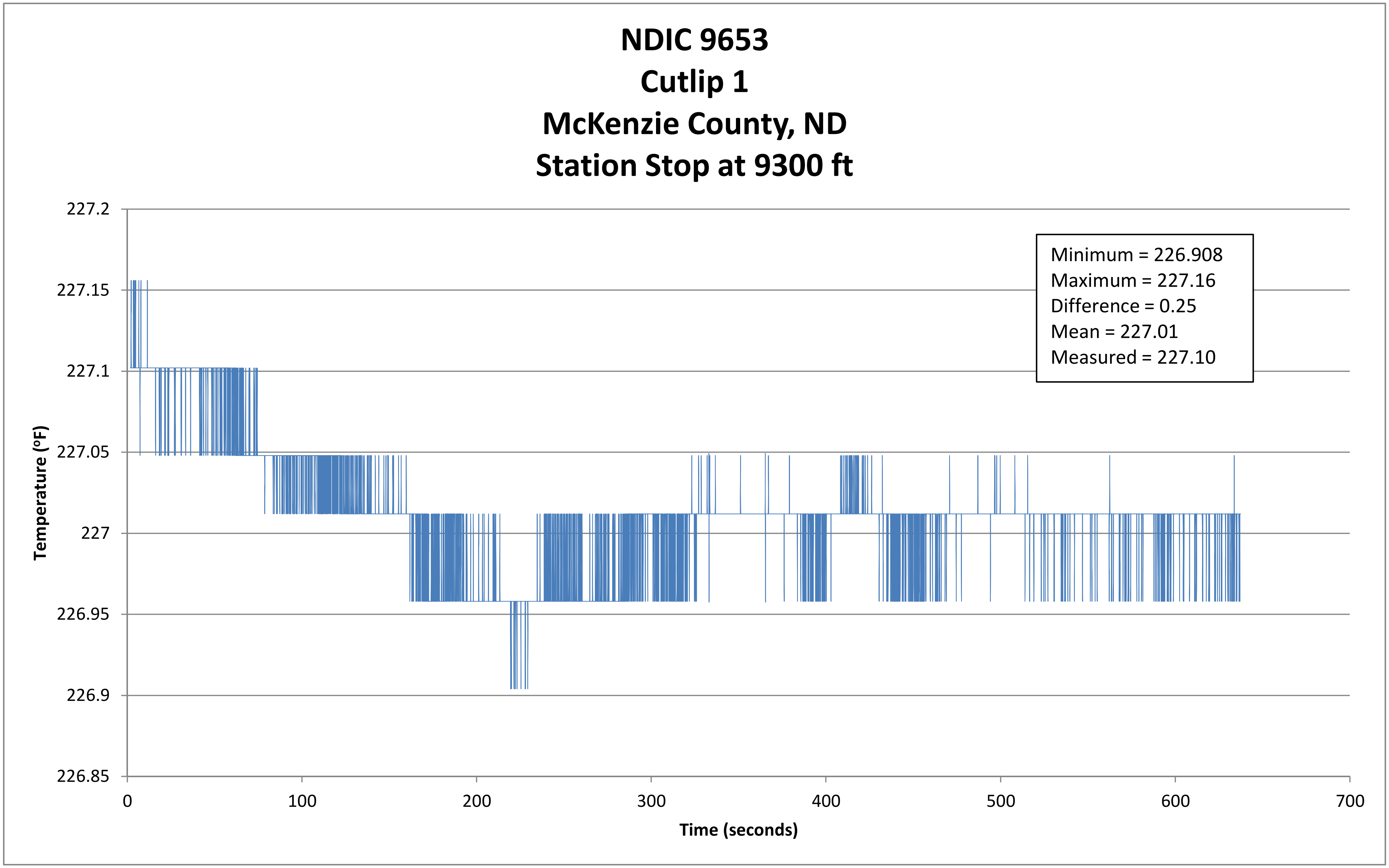

NDIC 8005
Sivertson #29-23R #1
McKenzie County, ND
Station Stop 13,000 ft
Minimum = 296.87
Maximum = 297.01
Difference = 0.14
Mean = 296.92
Measured = 297.01
Temperature (ºF)
297.02
297
296.98
296.96
296.94
296.92
296.9
296.88
296.86
0
100
200
300
400
500
600
Time (s)

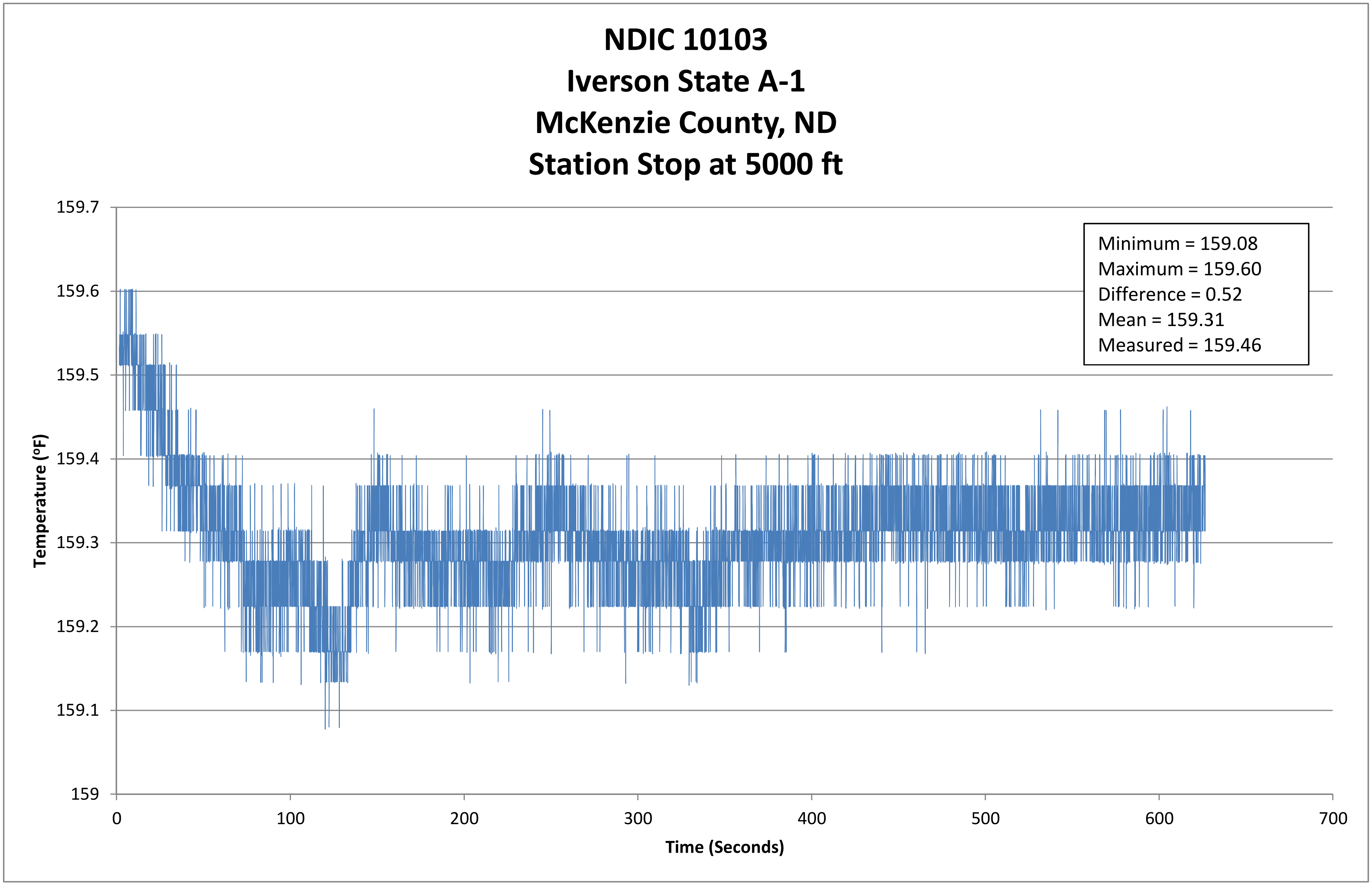


NDIC 8706
Berge C-1
McKenzie County, ND
Station Stop at 4500 ft
153.8
153.7
153.6
153.5
153.4
153.3
153.2
153.1
Temperature (ºF)
0
100
200
300
400
500
600
700
Time (s)
Minimum = 153.23
Maximum = 153.75
Difference = 0.52
Mean = 153.47
Measured = 153.61

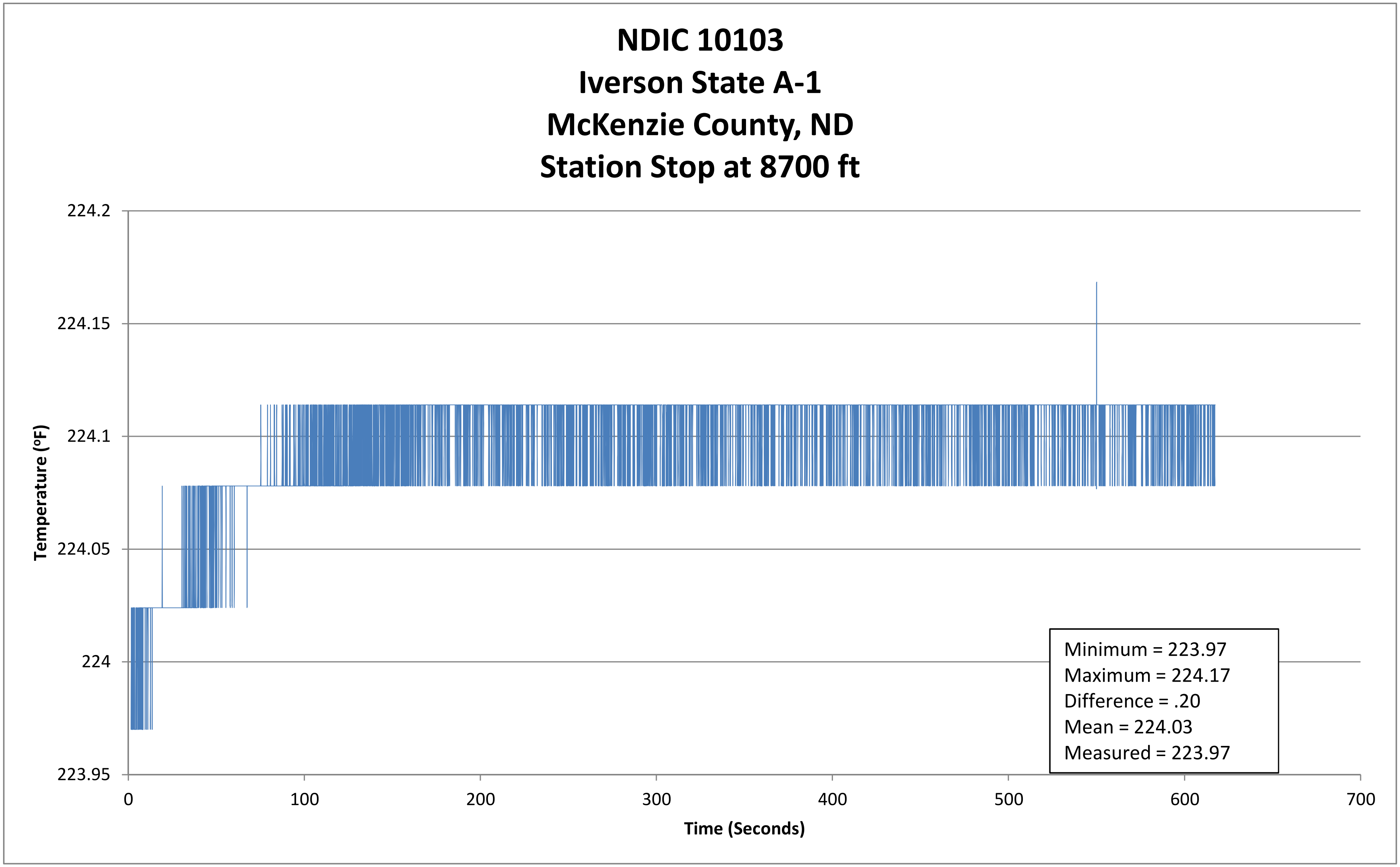

NDIC 8706
Berge C-1
McKenzie County, ND
Station Stop at 9000 ft
Minimum = 236.71
Maximum = 236.86
Difference = 0.14
Mean = 236.77
Measured = 236.80
236.88
236.86
236.84
236.82
236.8
236.78
236.76
236.74
236.72
236.7
236.68
Temperature (°F)
0
100
200
300
400
500
600
700
Time (s)

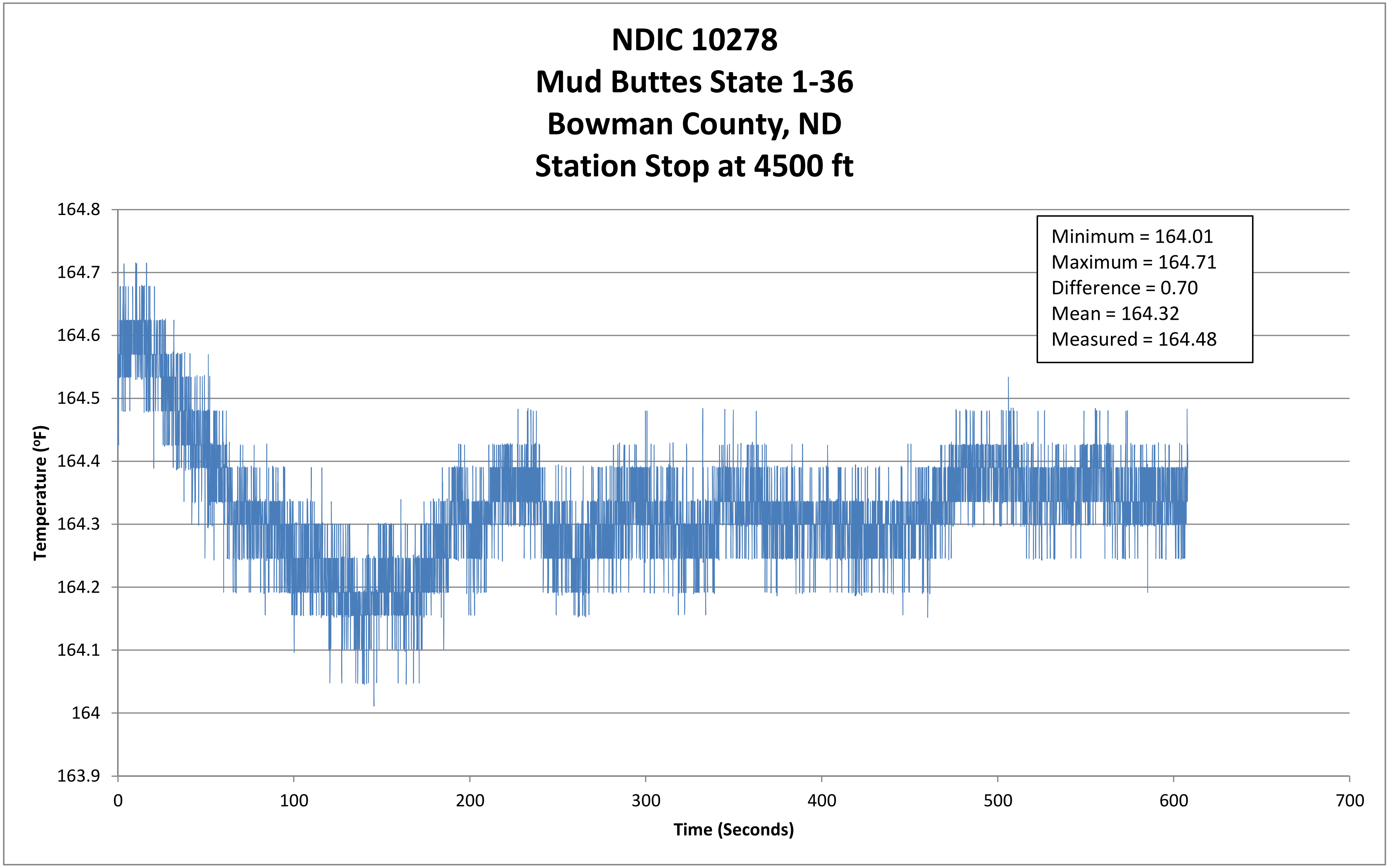

NDIC 9653
Cutlip 1
McKenzie County, ND
Station Stop at 5000 ft
Minimum = 157.19
Maximum = 157.71
Difference = 0.52
Mean = 157.40
Measured = 157.60
157.8
157.7
157.6
157.5
157.4
157.3
157.2
157.1
Temperature (ºF)
0
100
200
300
400
500
600
700
Time (seconds)

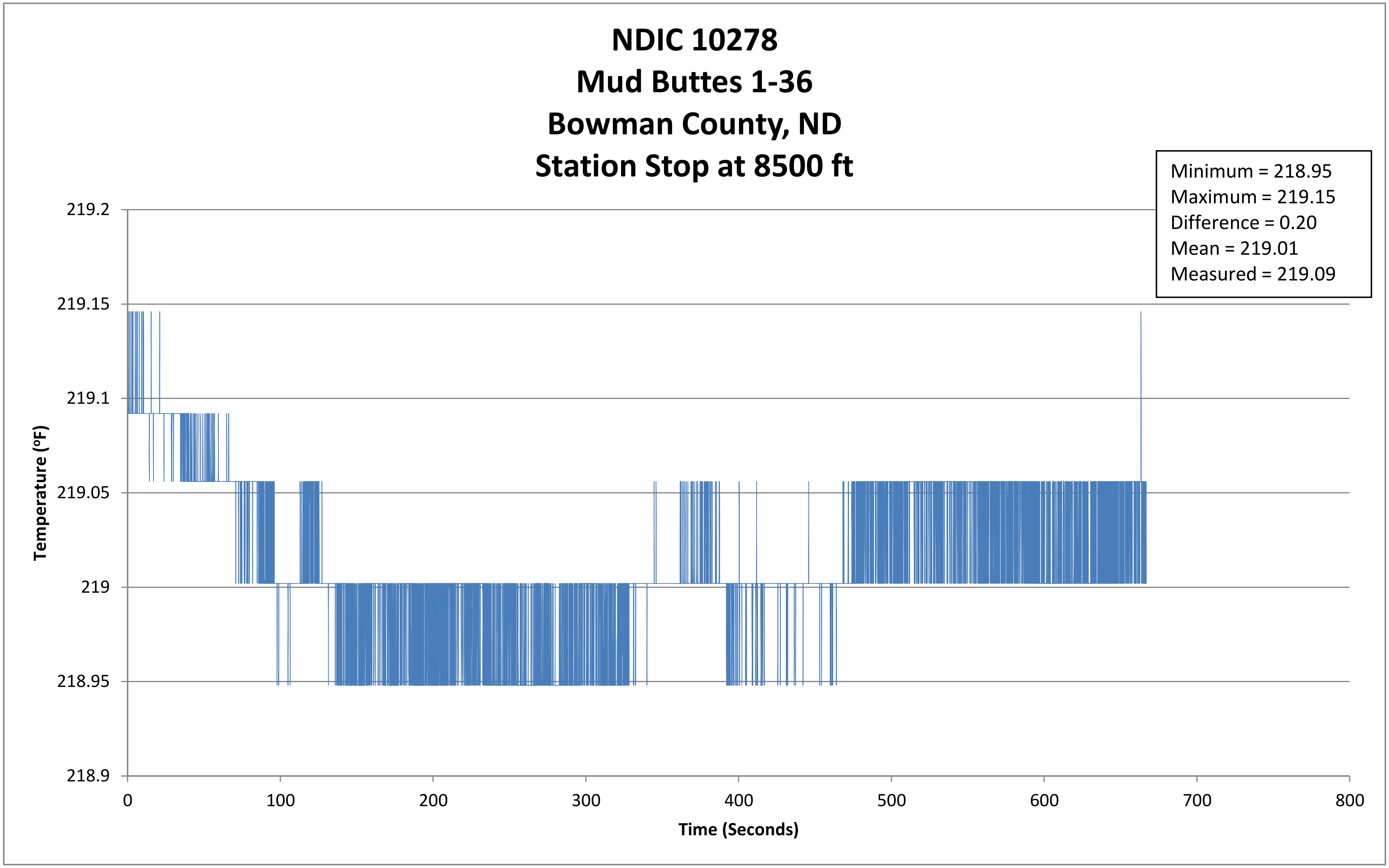

NDIC 9653
Cutlip 1
McKenzie County, ND
Station Stop at 9300 ft
Minimum = 226.908
Maximum = 227.16
Difference = 0.25
Mean = 227.01
Measured = 227.10
Temperature (ºF)
Time (seconds)
227.2
227.15
227.1
227.05
227
226.95
226.9
226.85
0
100
200
300
400
500
600
700

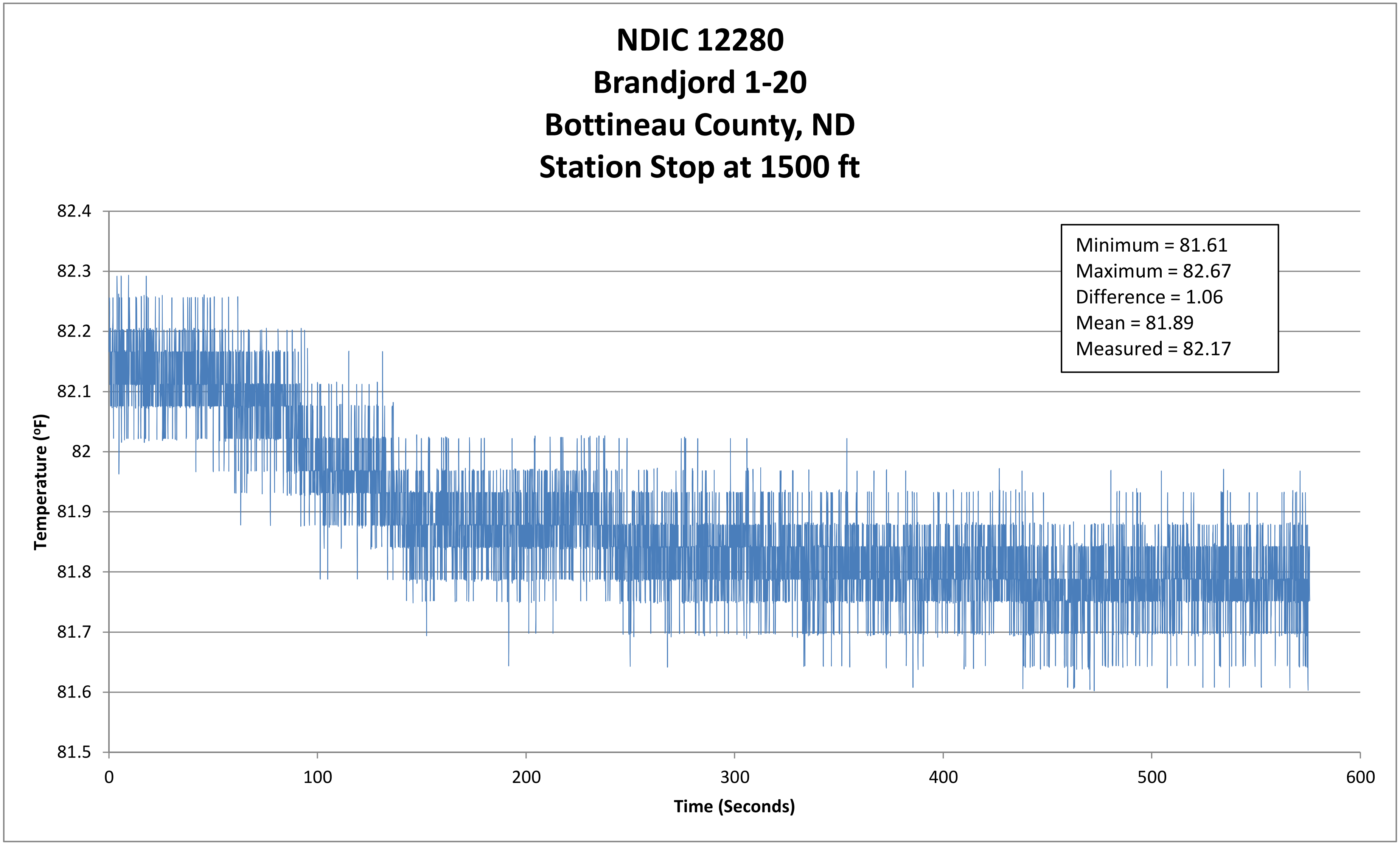


NDIC 10103
Iverson State A-1
McKenzie County, ND
Station Stop at 5000 ft
Minimum = 159.08
Maximum = 159.60
Difference = 0.52
Mean = 159.31
Measured = 159.46
Temperature (ºF)
159.7
159.6
159.5
159.4
159.3
159.2
159.1
159
0
100
200
300
400
500
600
700
Time (Seconds)

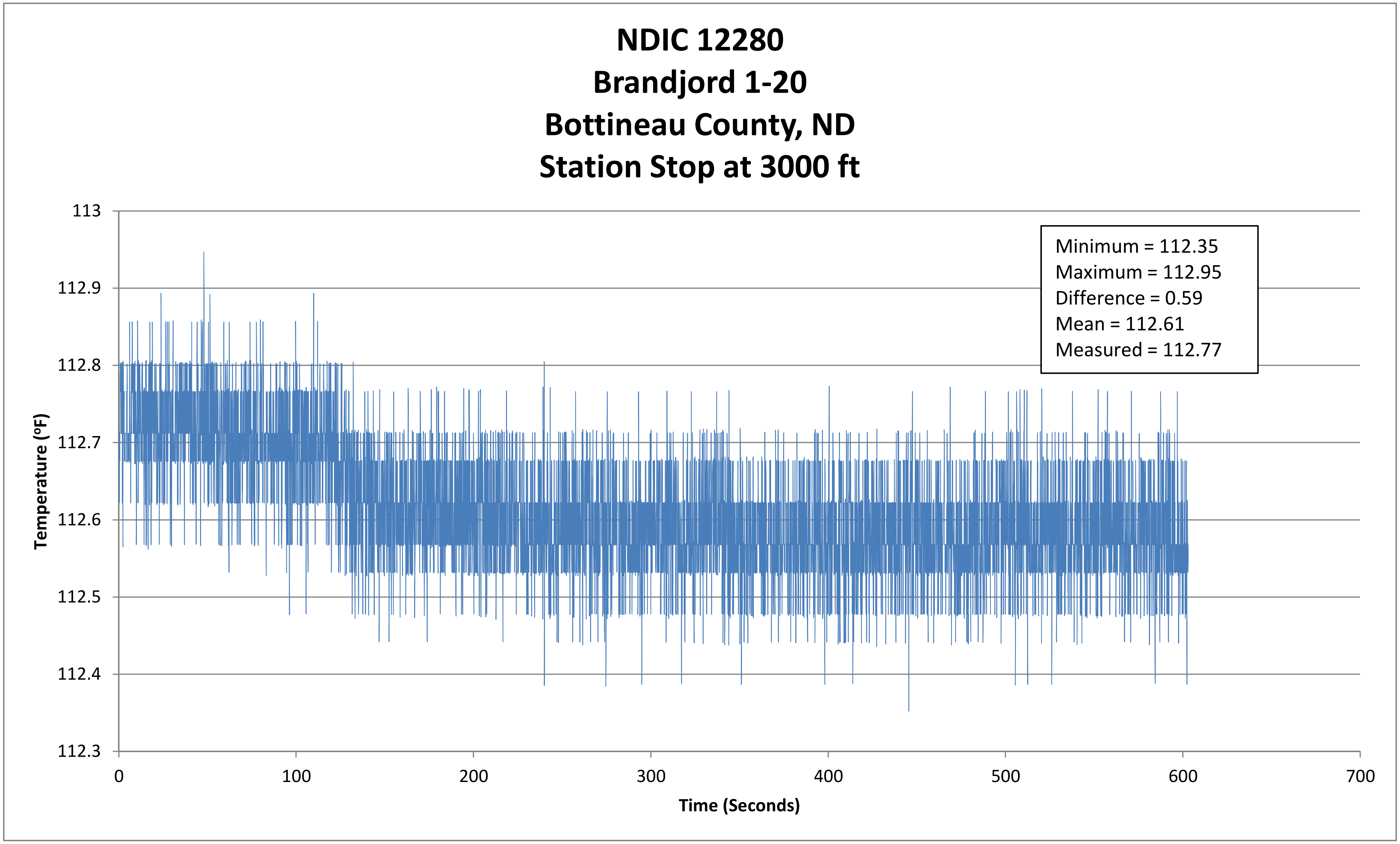

NDIC 10103
Iverson State A-1
McKenzie County, ND
Station Stop at 8700 ft
224.2
224.15
224.1
224.05
224
223.95
Temperature (ºF)
0
100
200
300
400
500
600
700
Time (Seconds)
Minimum = 223.97
Maximum = 224.17
Difference = .20
Mean = 224.03
Measured = 223.97

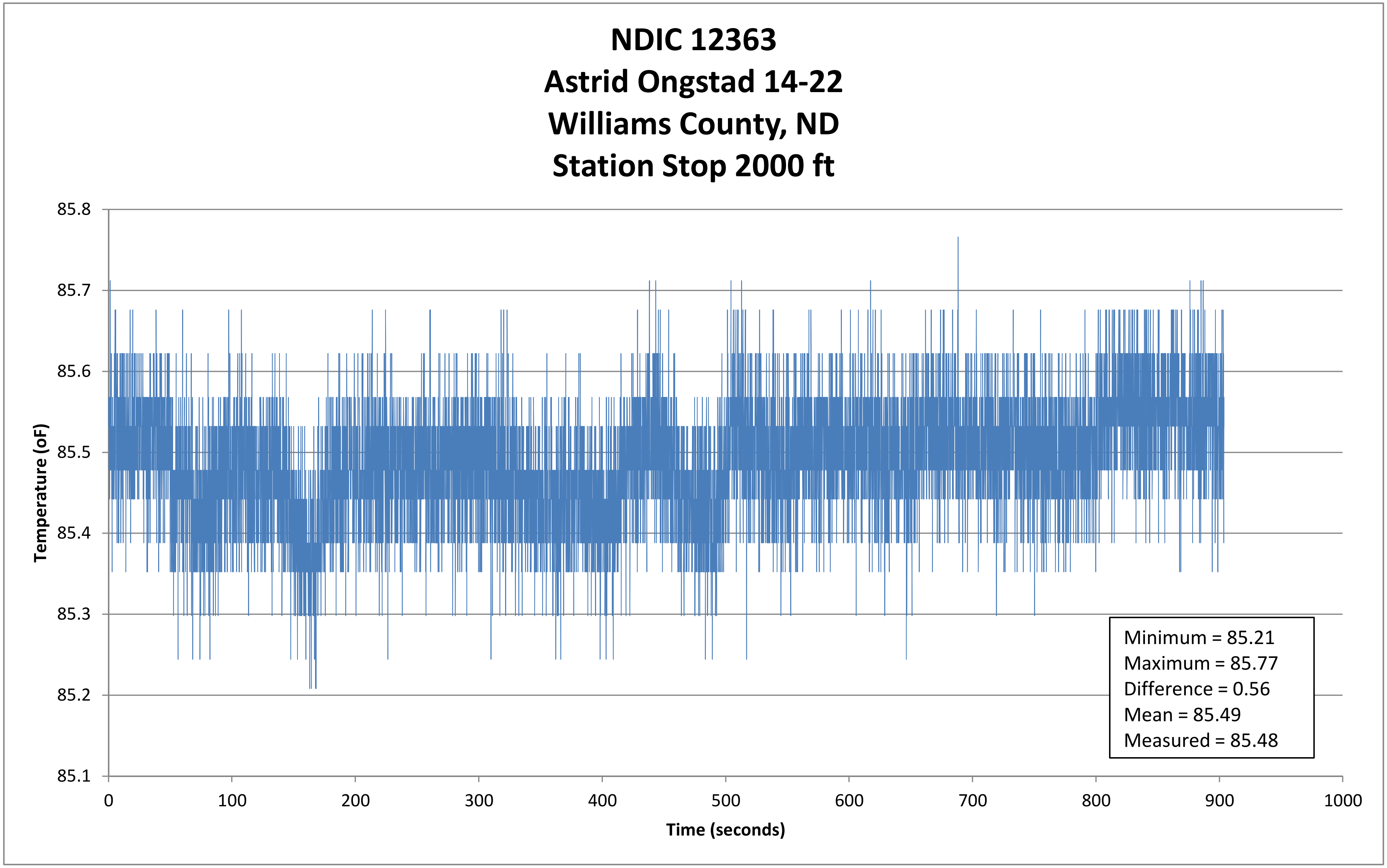

NDIC 10278
Mud Buttes State 1-36
Bowman County, ND
Station Stop at 4500 ft
Minimum = 164.01
Maximum = 164.71
Difference = 0.70
Mean = 164.32
Measured = 164.48
Temperature (ºF)
164.8
164.7
164.6
164.5
164.4
164.3
164.2
164.1
164
163.9
0
100
200
300
400
500
600
700
Time (Seconds)

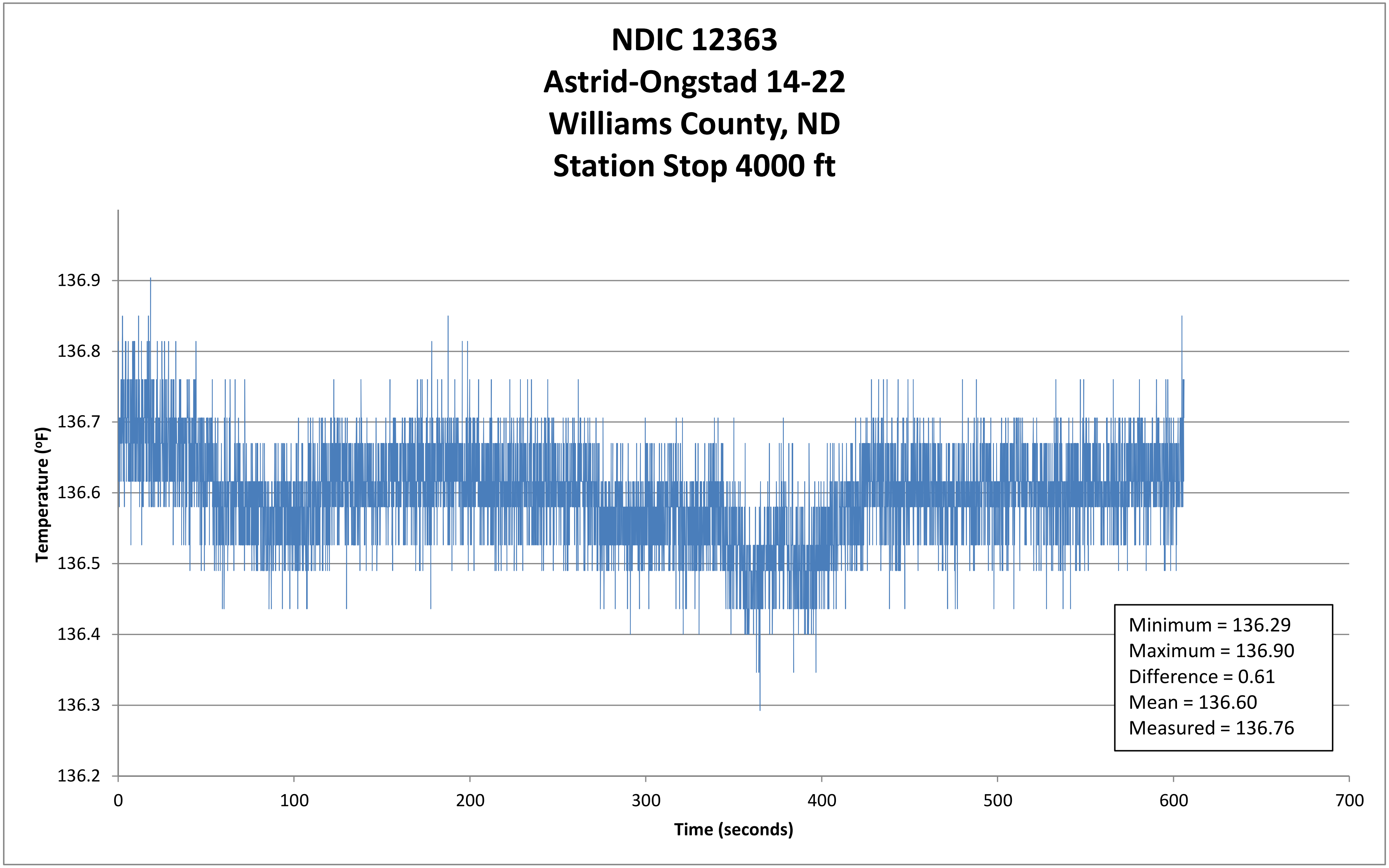

NDIC 10278
Mud Buttes 1-36
Bowman County, ND
Station Stop at 8500 ft
Minimum = 218.95
Maximum = 219.15
Difference = 0.20
Mean = 219.01
Measured = 219.09
Temperature (ºF)
219.2
219.15
219.1
219.05
219
218.95
218.9
0
100
200
300
400
500
600
700
800
Time (Seconds)

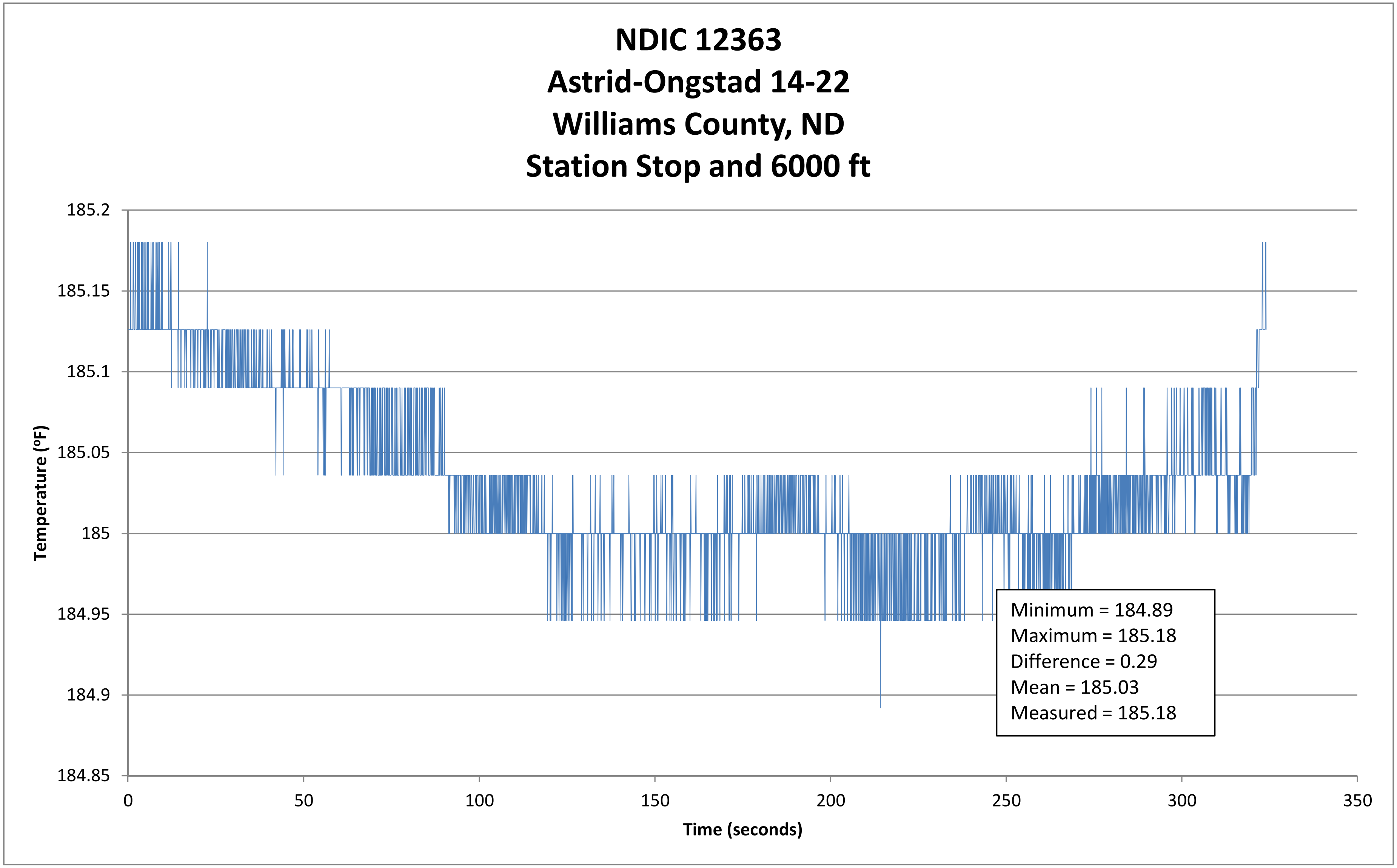


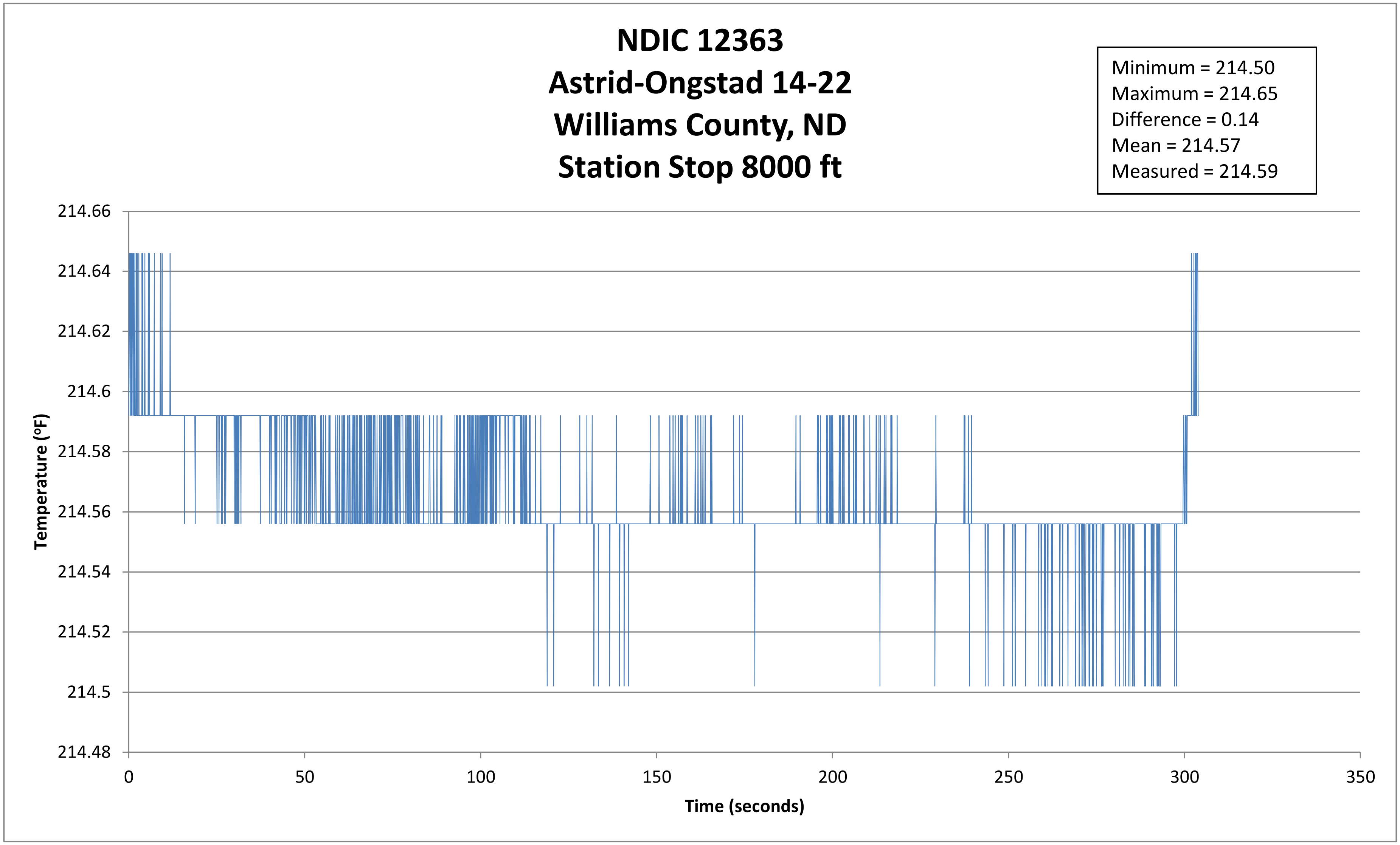
NDIC 12280
Brandjord 1-20
Bottineau County, ND
Station Stop at 1500 ft
Minimum = 81.61
Maximum = 82.67
Difference = 1.06
Mean = 81.89
Measured = 82.17
Temperature (ºF)
82.4
82.3
82.2
82.1
82
81.9
81.8
81.7
81.6
81.5
0
100
200
300
400
500
600
Time (Seconds)

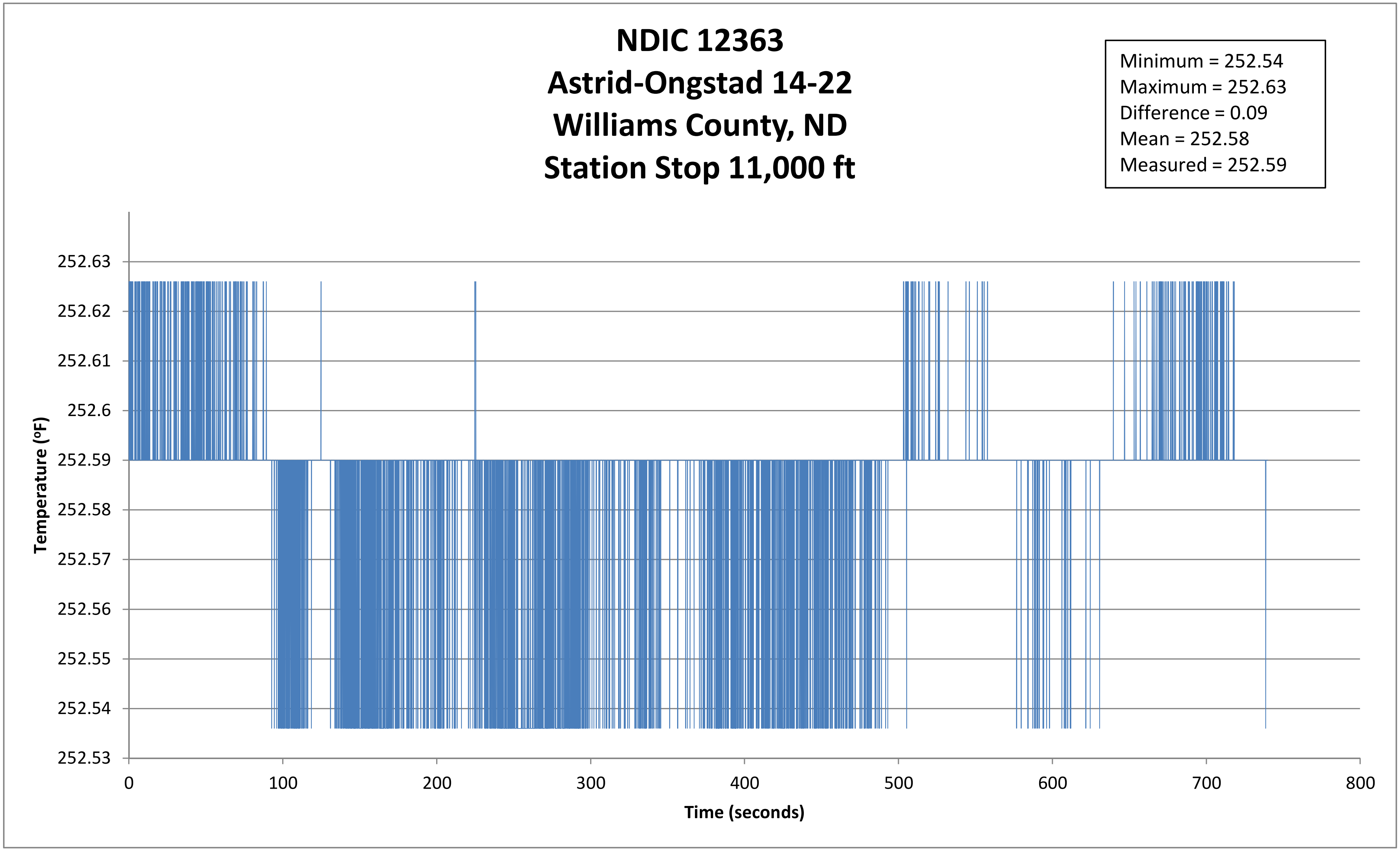

NDIC 12280
Brandjord 1-20
Bottineau County, ND
Station Stop at 3000 ft
Minimum = 112.35
Maximum = 112.95
Difference = 0.59
Mean = 112.61
Measured = 112.77
113
112.9
112.8
112.7
112.6
112.5
112.4
112.3
Temperature (ºF)
0
100
200
300
400
500
600
700
Time (Seconds)

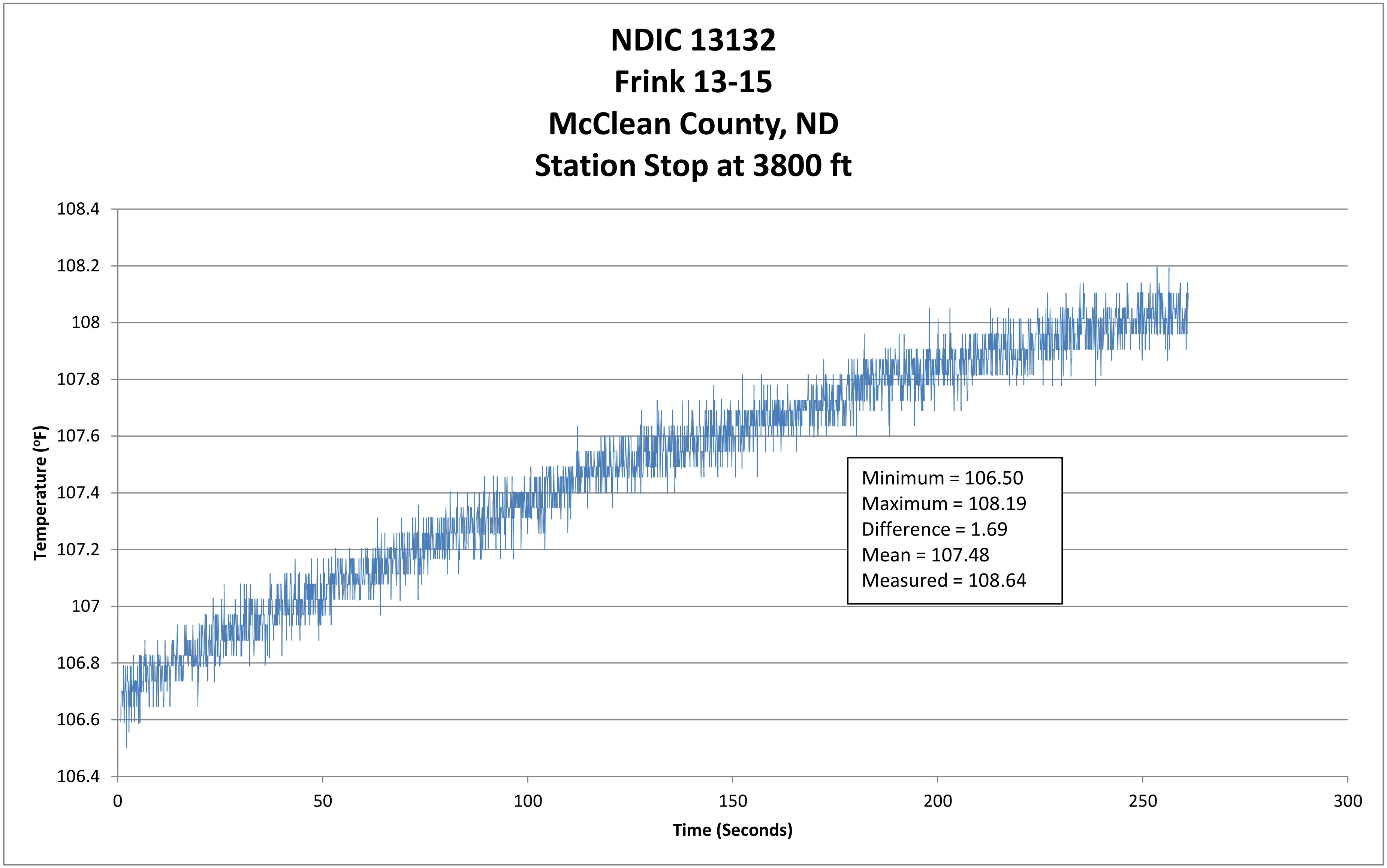

NDIC 12363
Astrid Ongstad 14-22
Williams County, ND
Station Stop 2000 ft
85.8
85.7
85.6
85.5
85.4
85.3
85.2
85.1
Temperature (oF)
0
100
200
300
400
500
600
700
800
900
1000
Time (seconds)
Minimum = 85.21
Maximum = 85.77
Difference = 0.56
Mean = 85.49
Measured = 85.48


NDIC 12363
Astrid-Ongstad 14-22
Williams County, ND
Station Stop 4000 ft
Temperature (ºF)
136.9
136.8
136.7
136.6
136.5
136.4
136.3
136.2
0
100
200
300
400
500
600
700
Time (seconds)
Minimum = 136.29
Maximum = 136.90
Difference = 0.61
Mean = 136.60
Measured = 136.76

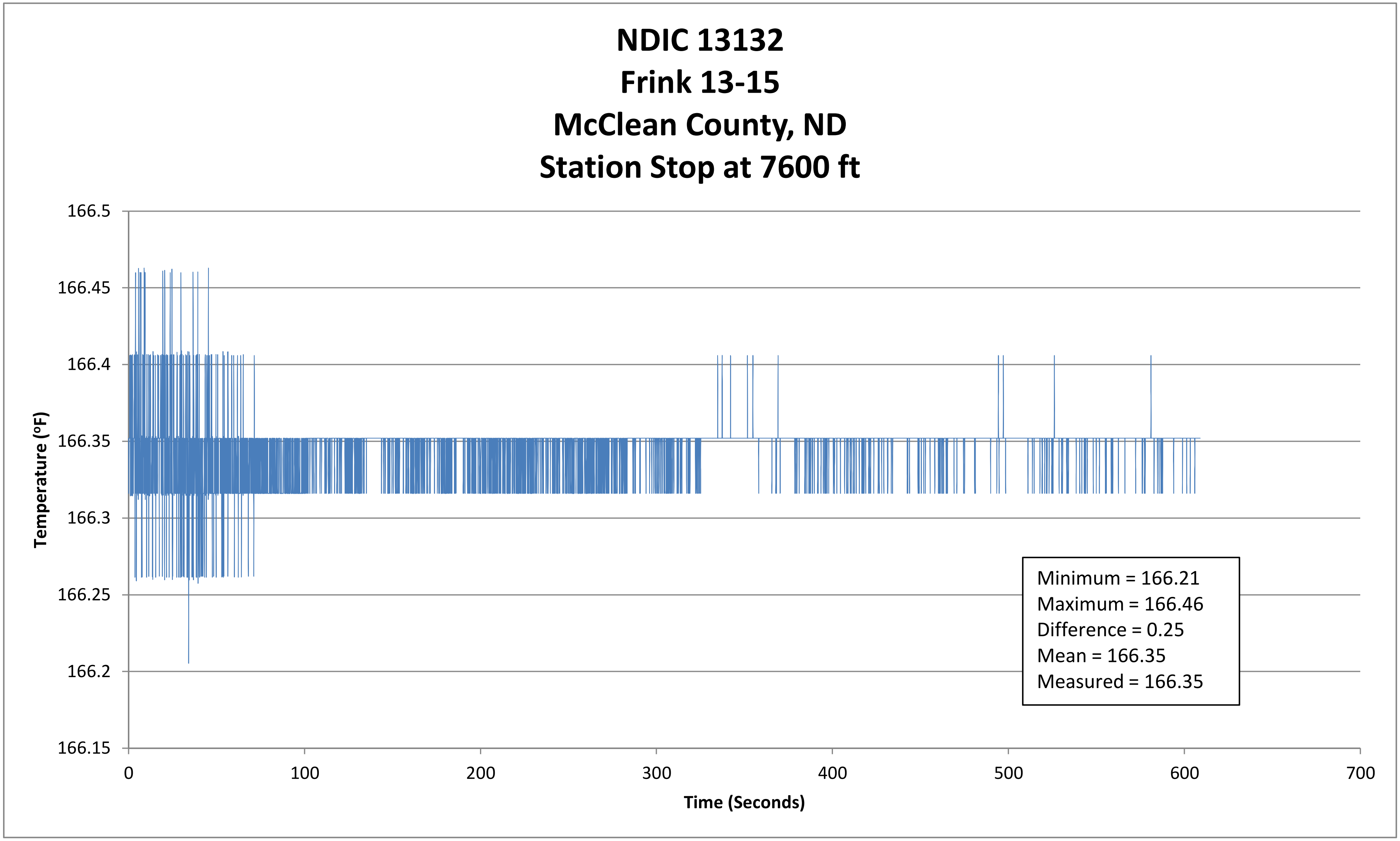

NDIC 12363
Astrid-Ongstad 14-22
Williams County, ND
Station Stop and 6000 ft
Temperature (ºF)
Time (seconds)
185.2
185.15
185.1
185.05
185
184.95
184.9
184.85
0
50
100
150
200
250
300
350
Minimum = 184.89
Maximum = 185.18
Difference = 0.29
Mean = 185.03
Measured = 185.18

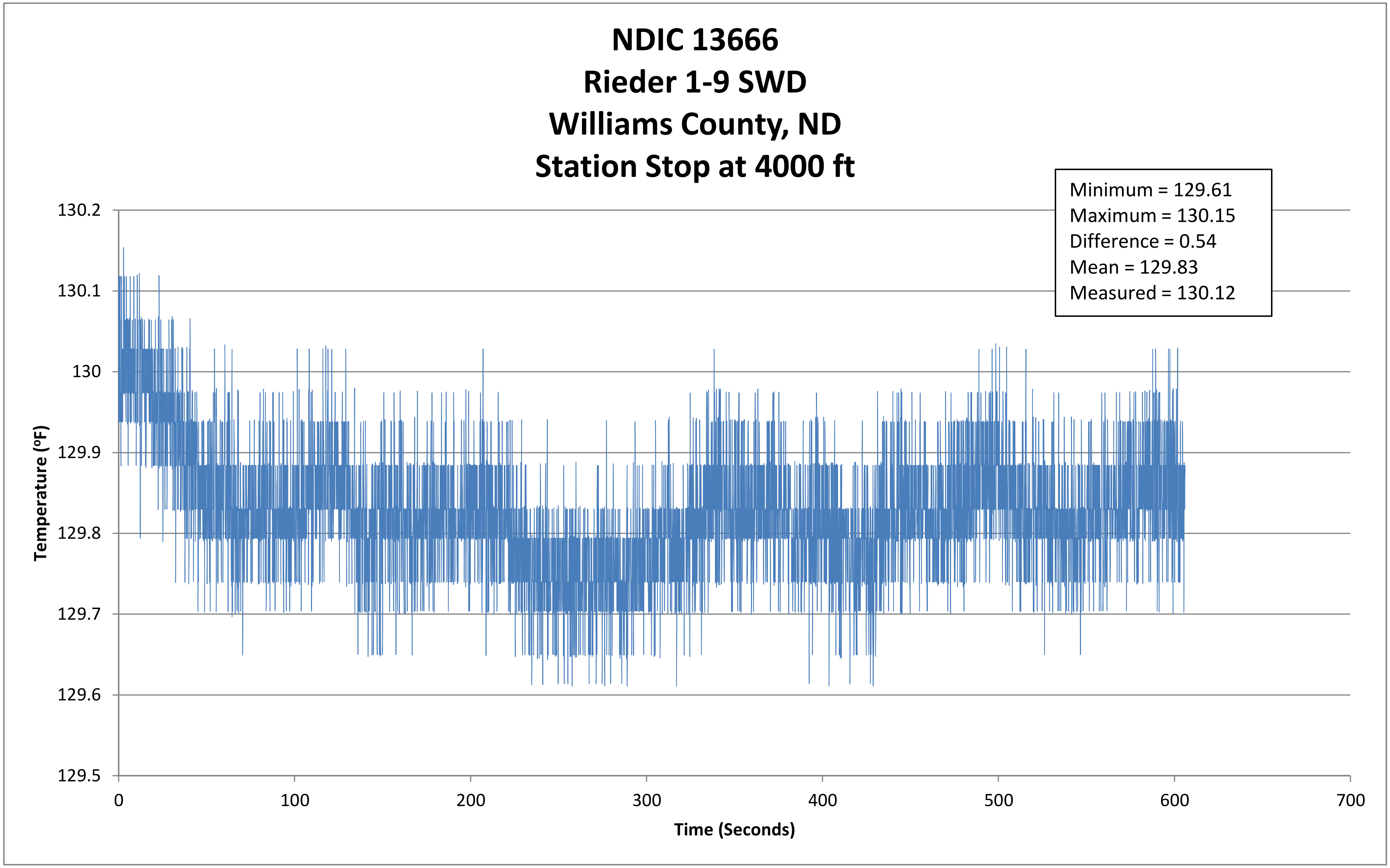

NDIC 12363
Astrid-Ongstad 14-22
Williams County, ND
Station Stop 8000 ft
Minimum = 214.50
Maximum = 214.65
Difference = 0.14
Mean = 214.57
Measured = 214.59
214.66
214.64
214.62
214.6
214.58
214.56
214.54
214.52
214.5
214.48
Temperature (ºF)
0
50
100
150
200
250
300
350
Time (seconds)

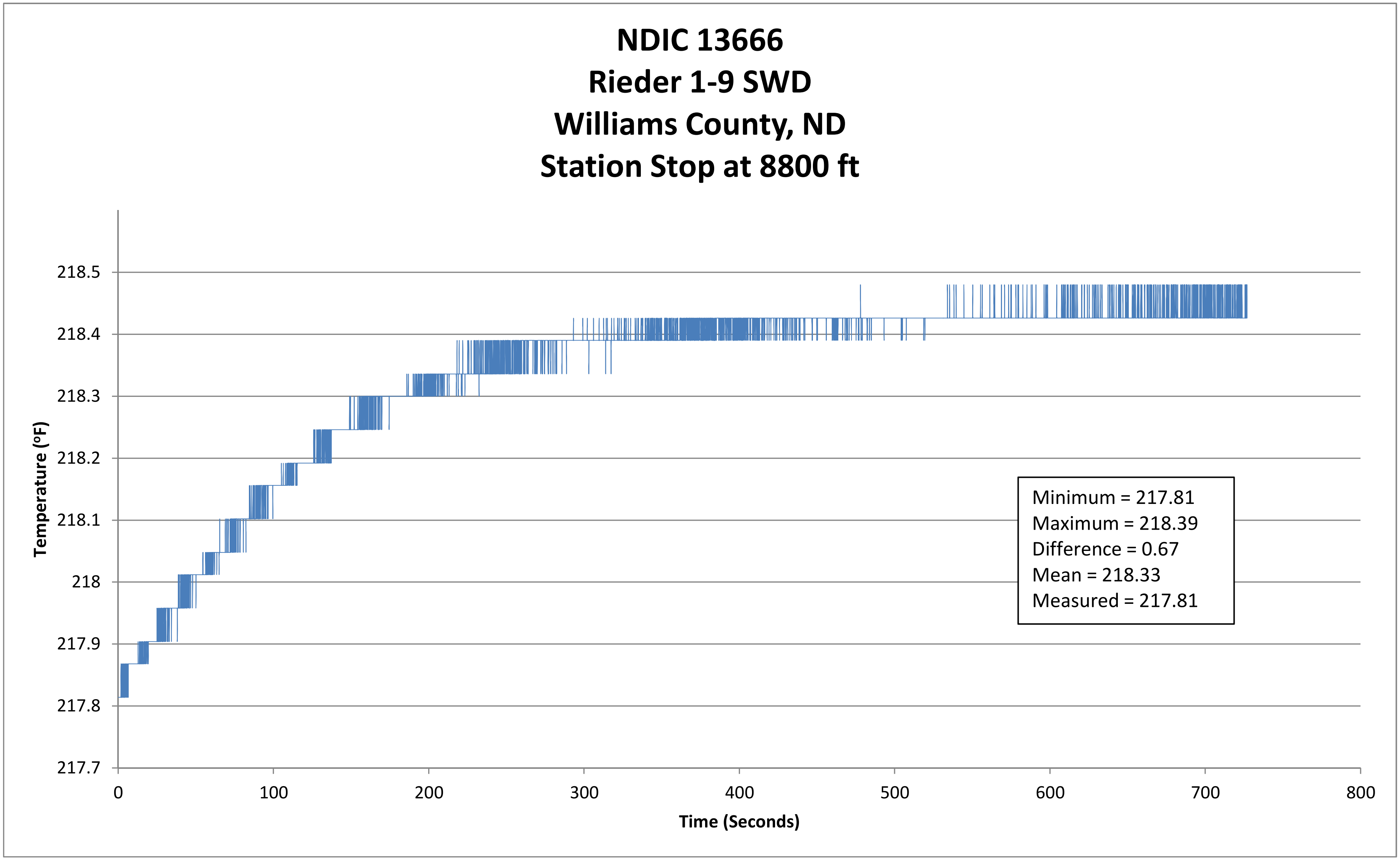

NDIC 12363
Astrid-Ongstad 14-22
Williams County, ND
Station Stop 11,000 ft
Minimum = 252.54
Maximum = 252.63
Difference = 0.09
Mean = 252.58
Measured = 252.59
Temperature (ºF)
252.63
252.62
252.61
252.6
252.59
252.58
252.57
252.56
252.55
252.54
252.53
0
100
200
300
400
500
600
700
800
Time (seconds)

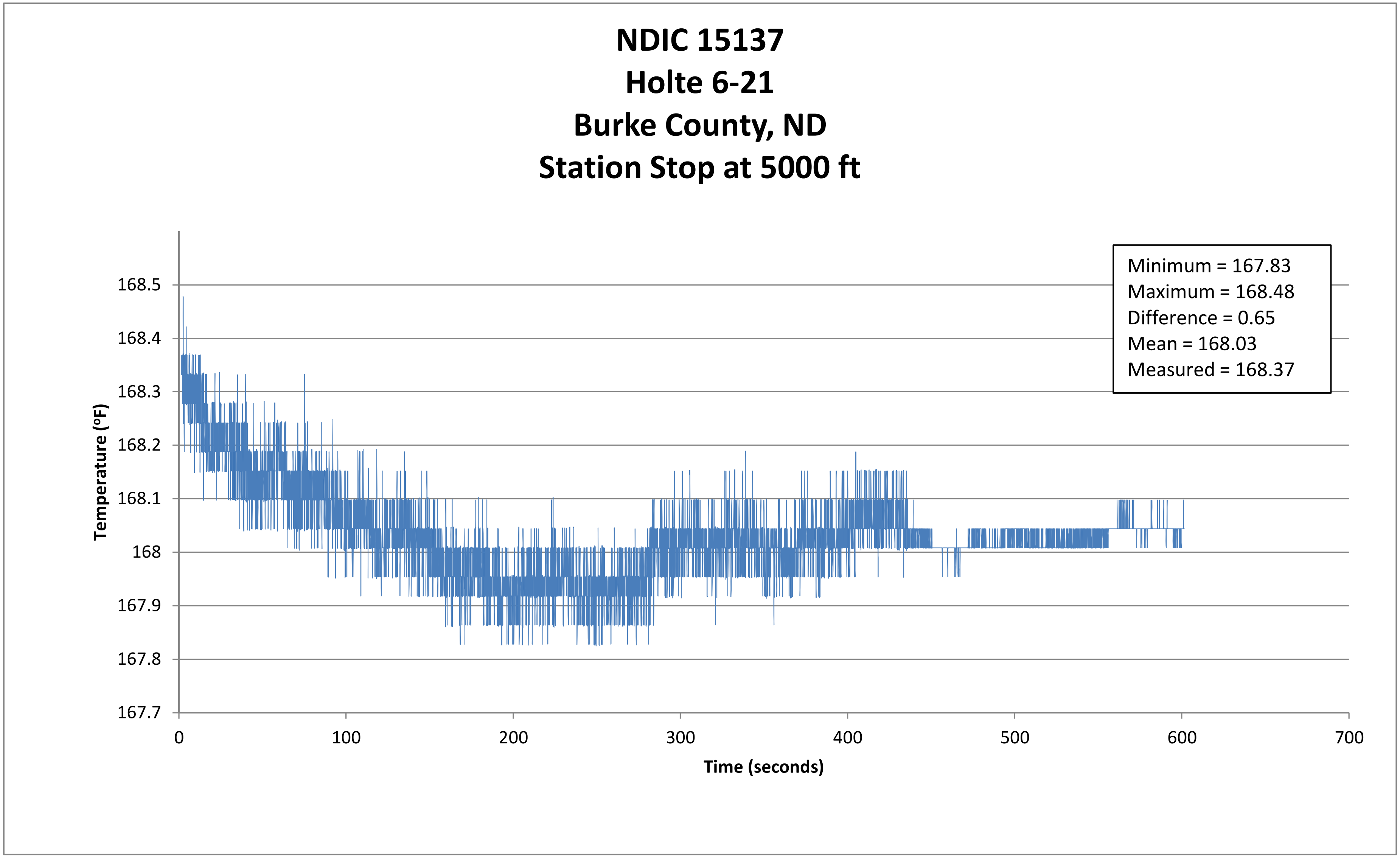


NDIC 13132
Frink 13-15
McClean County, ND
Station Stop at 3800 ft
Temperature (ºF)
108.4
108.2
108
107.8
107.6
107.4
107.2
107
106.8
106.6
106.4
0
50
100
150
200
250
300
Time (Seconds)
Minimum = 106.50
Maximum = 108.19
Difference = 1.69
Mean = 107.48
Measured = 108.64

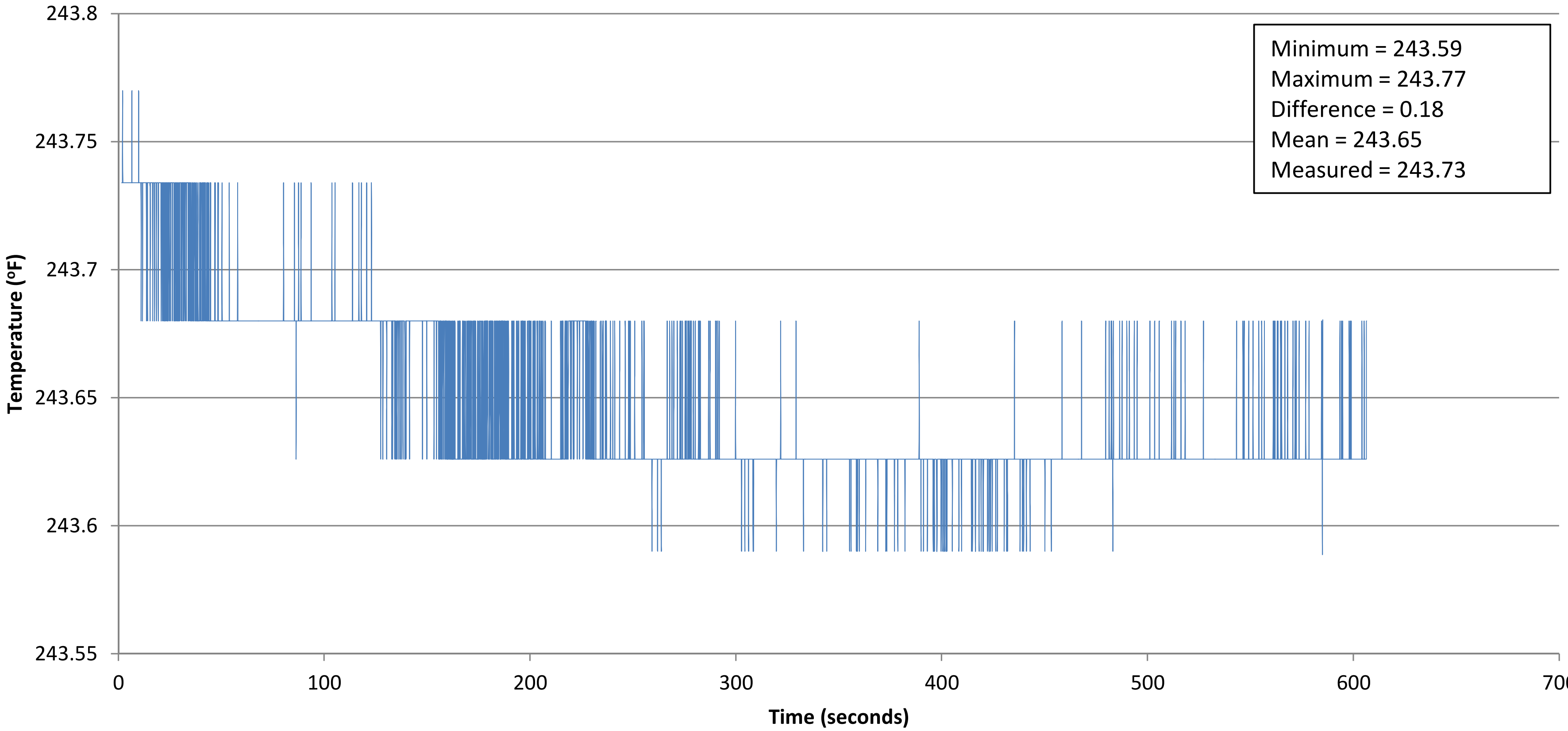

NDIC 13132
Frink 13-15
McClean County, ND
Station Stop at 7600 ft
166.5
166.45
166.4
166.35
166.3
166.25
166.2
166.15
Temperature (°F)
0
100
200
300
400
500
600
700
Time (Seconds)
Minimum = 166.21
Maximum = 166.46
Difference = 0.25
Mean = 166.35
Measured = 166.35

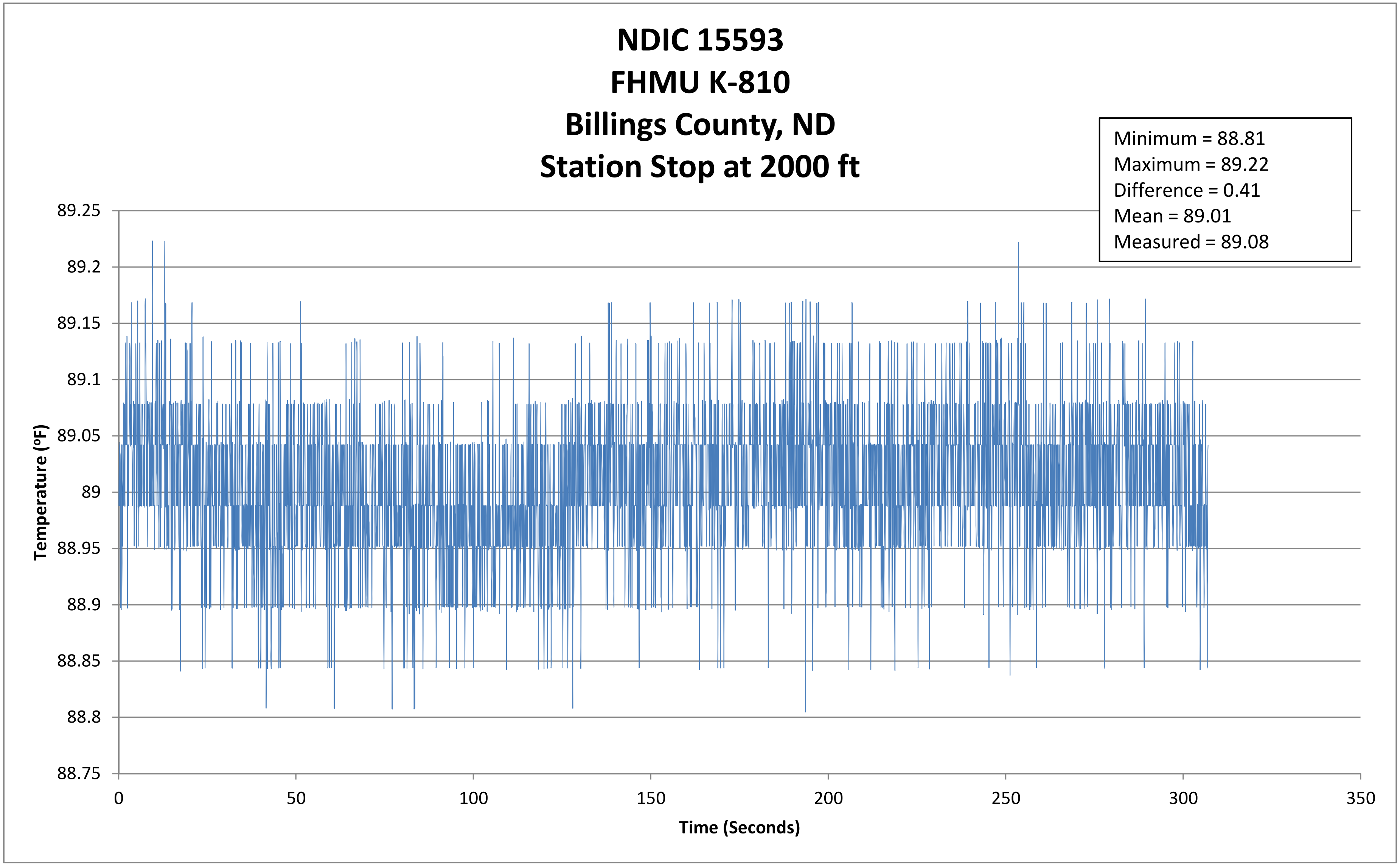

NDIC 13666
Rieder 1-9 SWD
Williams County, ND
Station Stop at 4000 ft
Minimum = 129.61
Maximum = 130.15
Difference = 0.54
Mean = 129.83
Measured = 130.12
130.2
130.1
130
129.9
129.8
129.7
129.6
129.5
Temperature (ºF)
0
100
200
300
400
500
600
700
Time (Seconds)


NDIC 13666
Rieder 1-9 SWD
Williams County, ND
Station Stop at 8800 ft
Temperature (ºF)
218.5
218.4
218.3
218.2
218.1
218
217.9
217.8
217.7
0
100
200
300
400
500
600
700
800
Time (Seconds)
Minimum = 217.81
Maximum = 218.39
Difference = 0.67
Mean = 218.33
Measured = 217.81

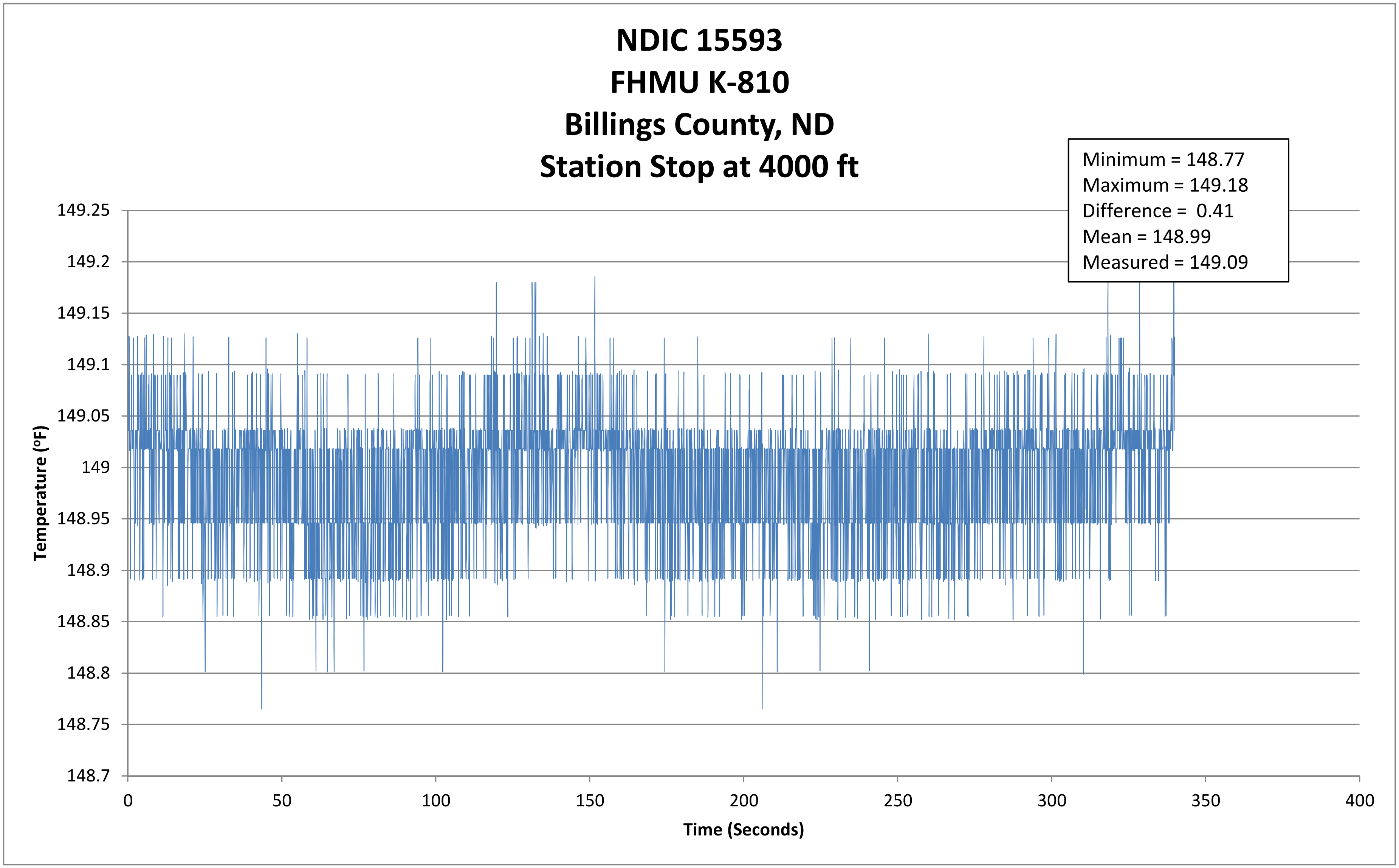

NDIC 15137
Holte 6-21
Burke County, ND
Station Stop at 5000 ft
Minimum = 167.83
Maximum = 168.48
Difference = 0.65
Mean = 168.03
Measured = 168.37
Temperature (ºF)
168.5
168.4
168.3
168.2
168.1
168
167.9
167.8
167.7
0
100
200
300
400
500
600
700
Time (seconds)

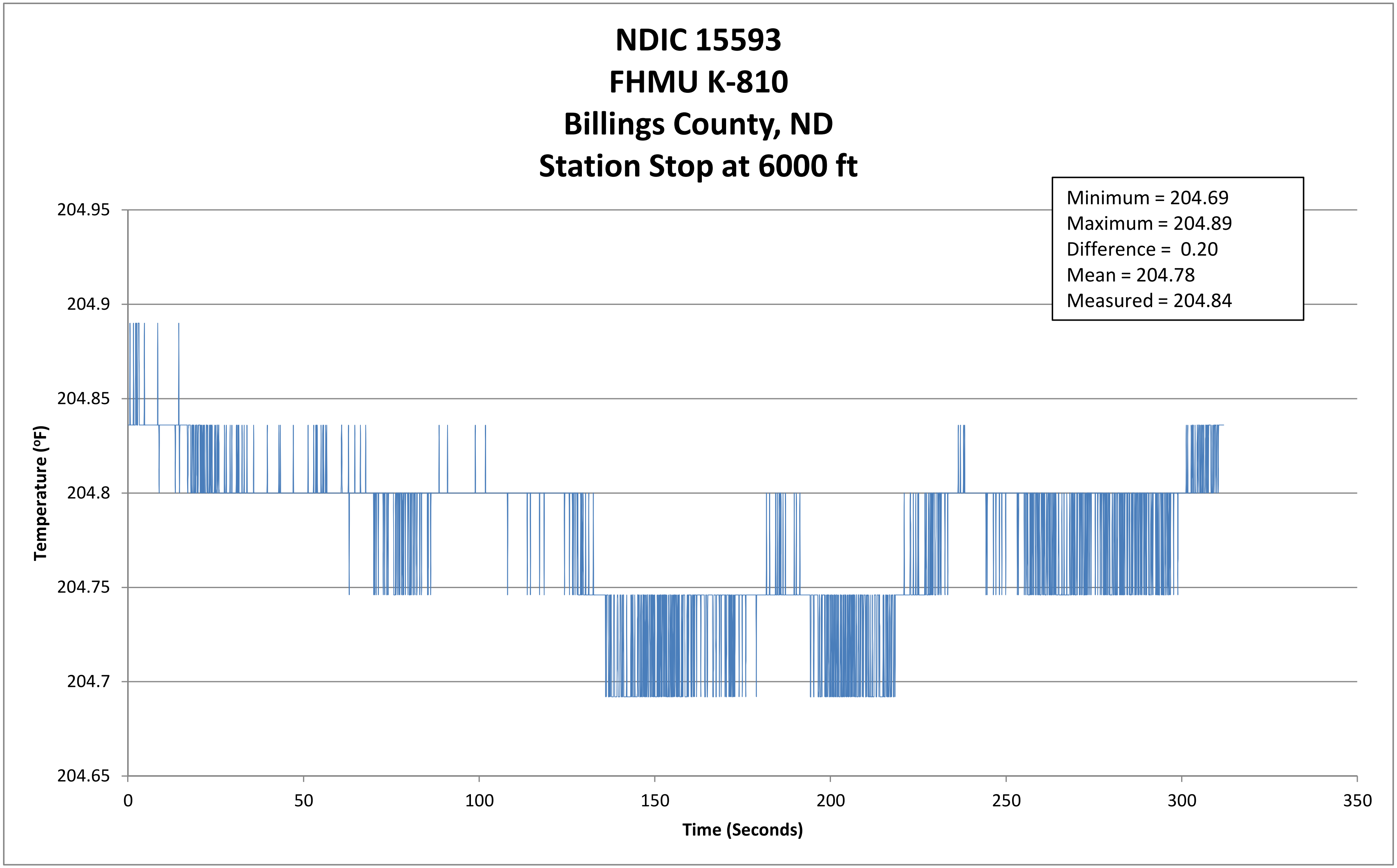
NDIC 15137
Holte 6-21
Burke County, ND
Station Stop at 10,200 ft

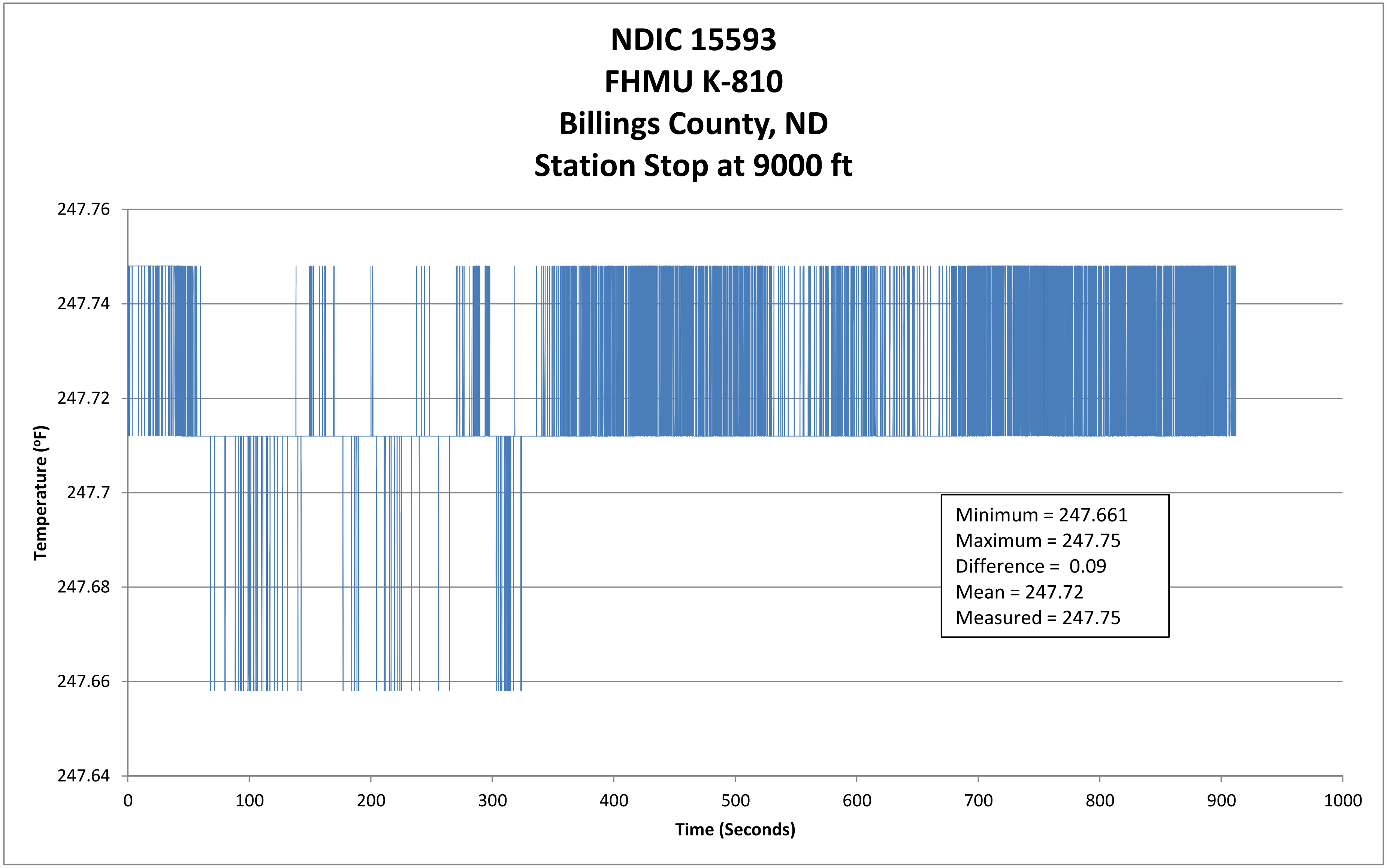


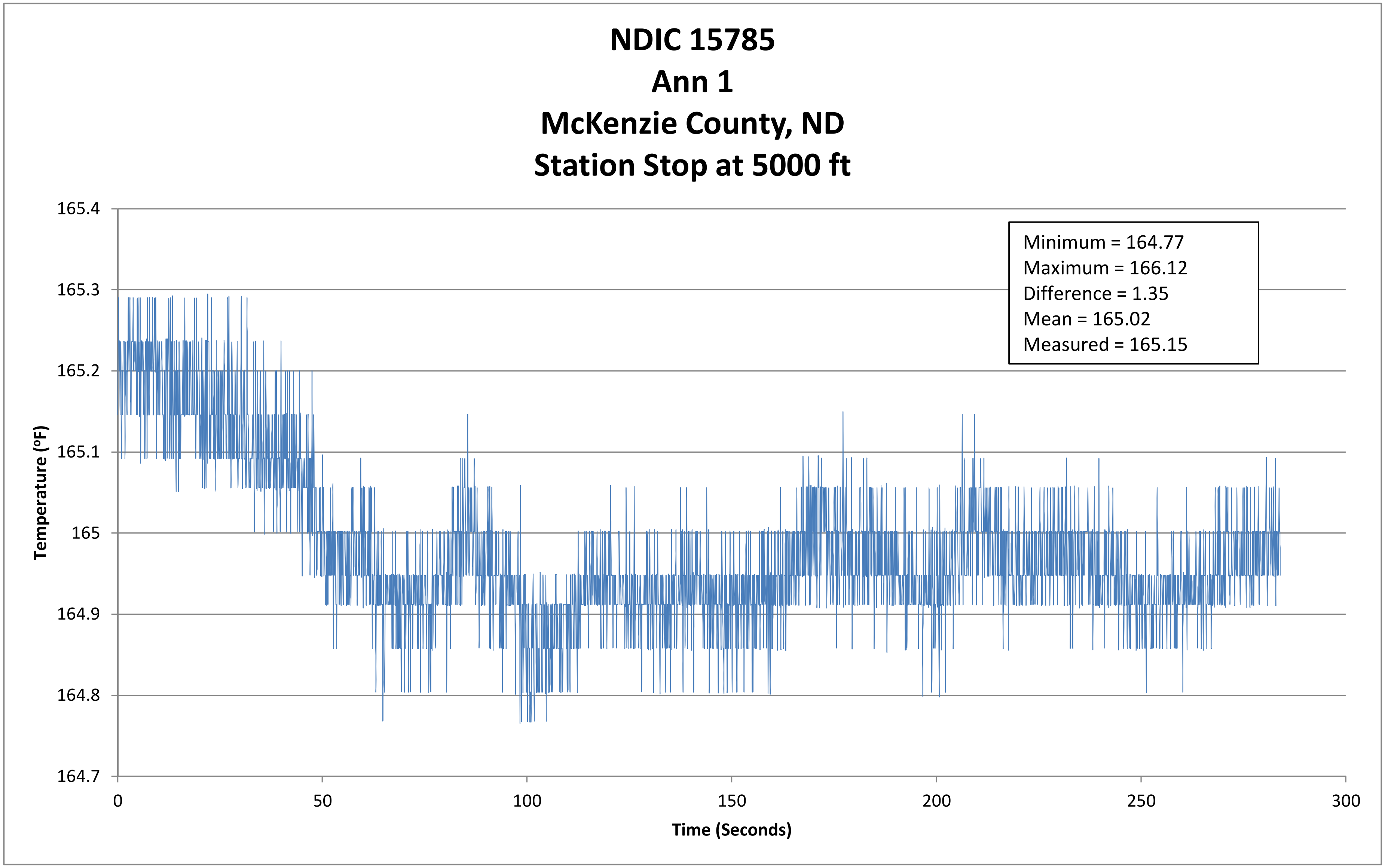


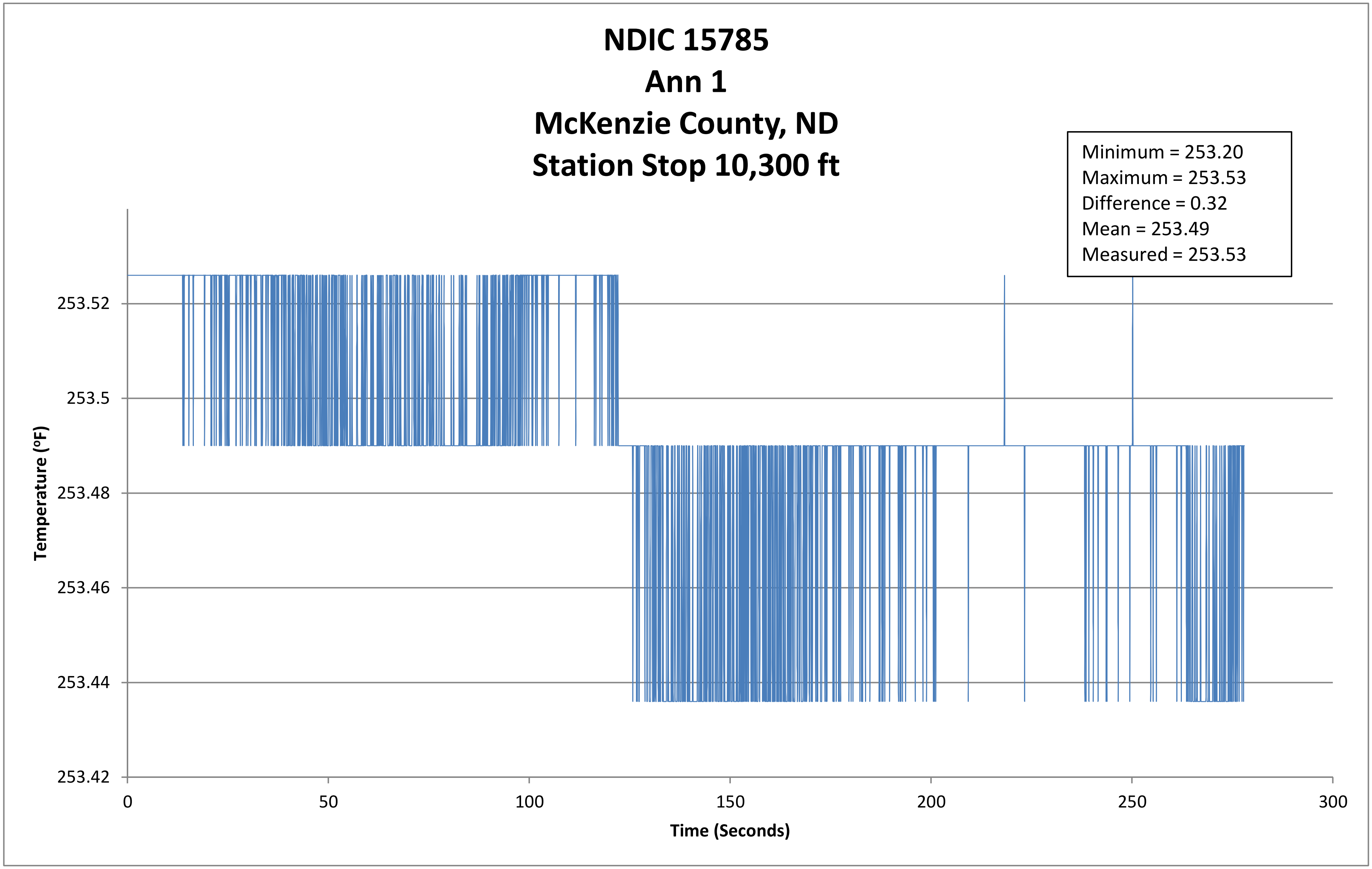
NDIC 15593
FHMU K-810
Billings County, ND
Station Stop at 2000 ft
Minimum = 88.81
Maximum = 89.22
Difference = 0.41
Mean = 89.01
Measured = 89.08
89.25
89.2
89.15
89.1
89.05
89
88.95
88.9
88.85
88.8
88.75
Temperature (ºF)
0
50
100
150
200
250
300
350
Time (Seconds)

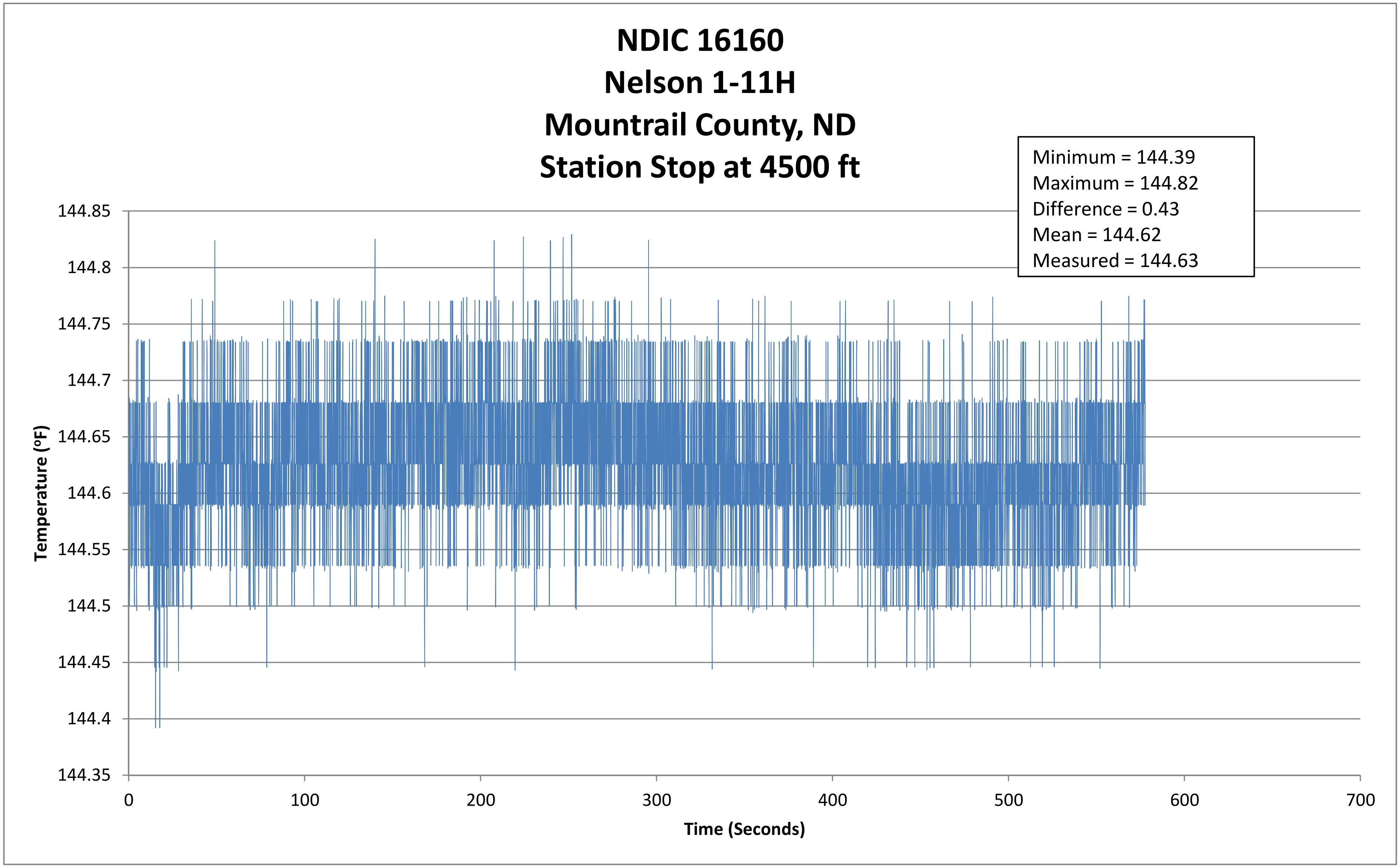

NDIC 15593
FHMU K-810
Billings County, ND
Station Stop at 4000 ft
Minimum = 148.77
Maximum = 149.18
Difference = 0.41
Mean = 148.99
Measured = 149.09
Temperature (ºF)
Time (Seconds)
149.25
149.2
149.15
149.1
149.05
149
148.95
148.9
148.85
148.8
148.75
148.7
0
50
100
150
200
250
300
350
400

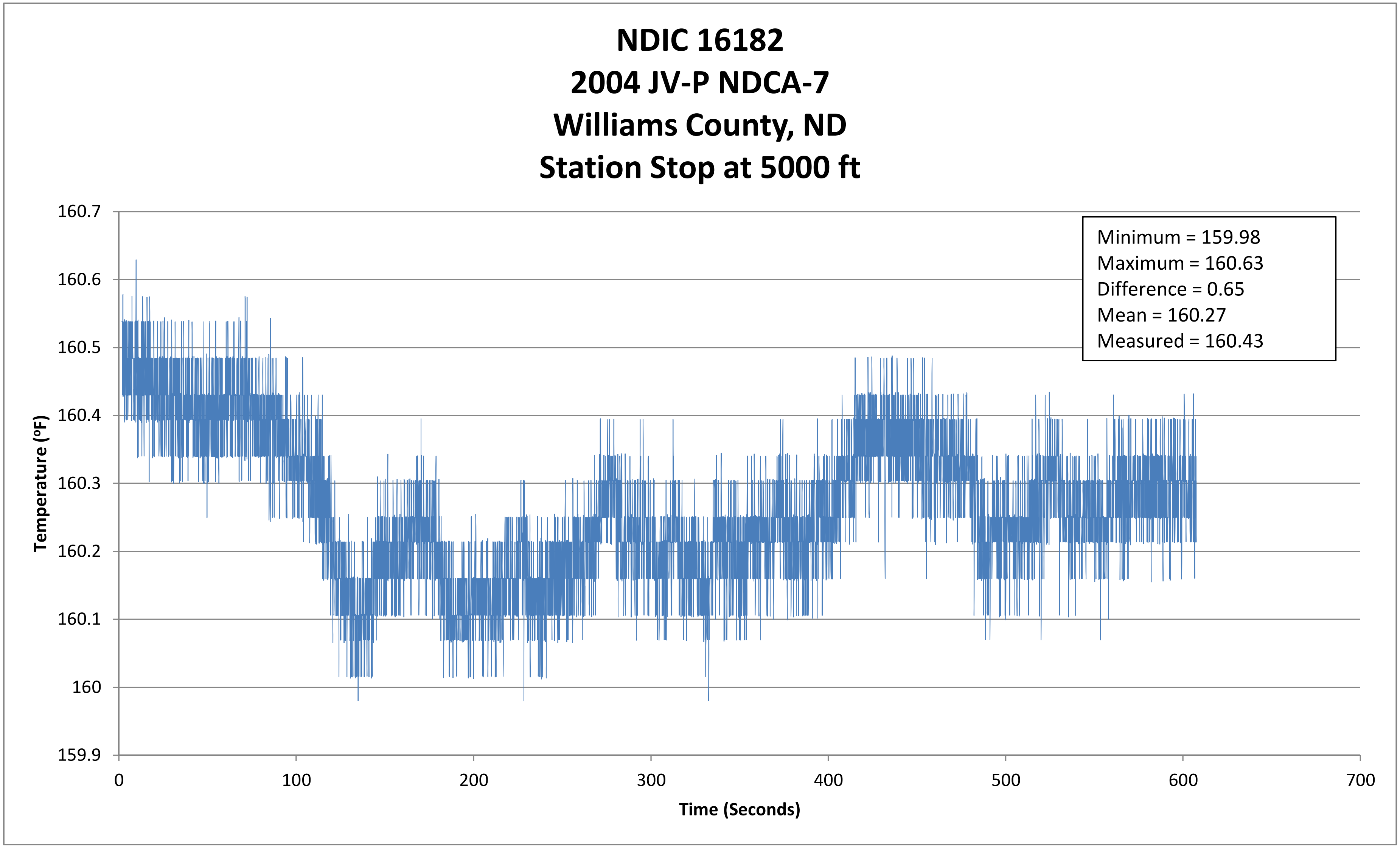

NDIC 15593
FHMU K-810
Billings County, ND
Station Stop at 6000 ft
Minimum = 204.69
Maximum = 204.89
Difference = 0.20
Mean = 204.78
Measured = 204.84
204.95
204.9
204.85
204.8
204.75
204.7
204.65
Temperature (ºF)
0
50
100
150
200
250
300
350
Time (Seconds)

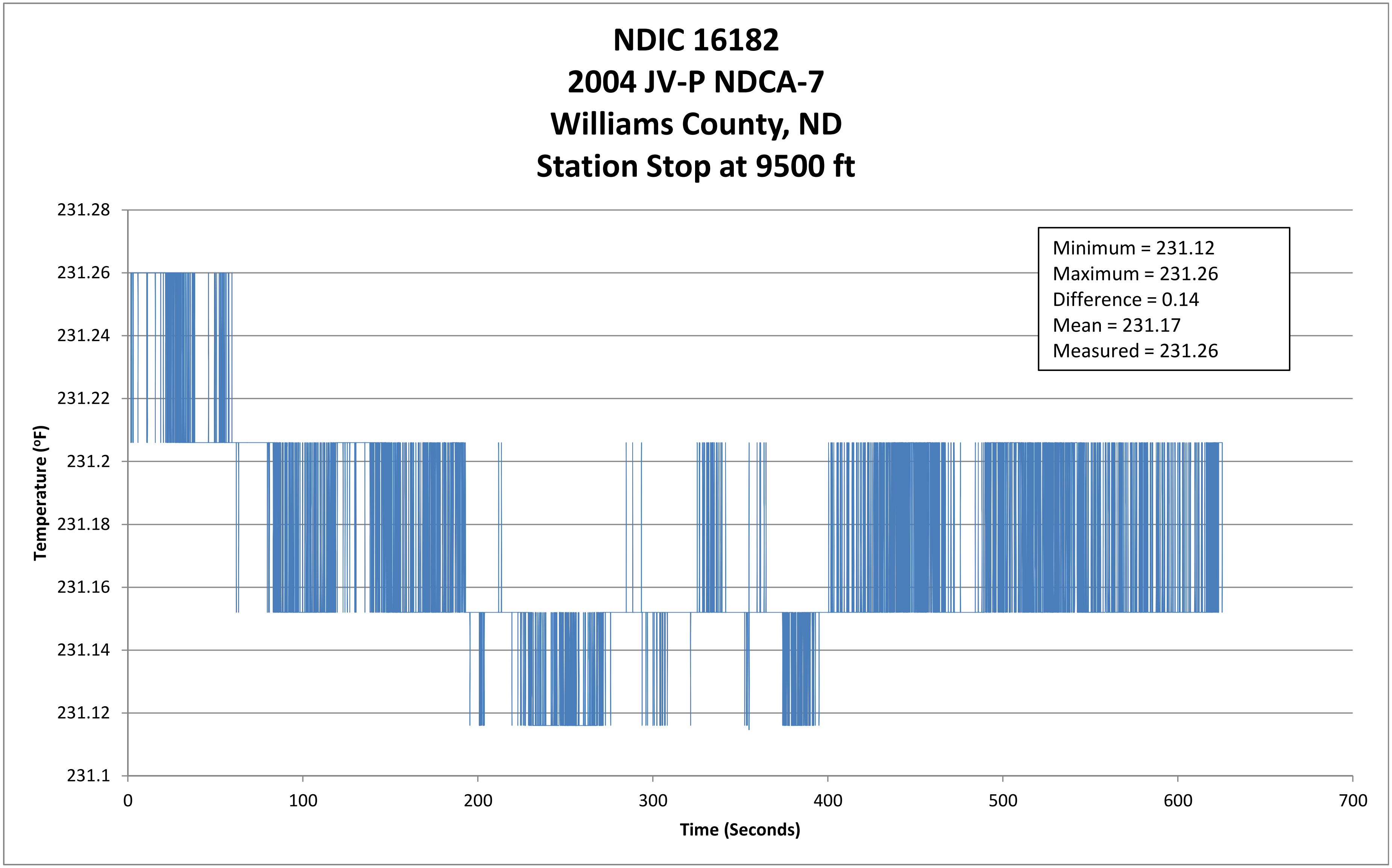

NDIC 15593
FHMU K-810
Billings County, ND
Station Stop at 9000 ft
247.76
247.74
247.72
247.7
247.68
247.66
247.64
Temperature (ºF)
0
100
200
300
400
500
600
700
800
900
1000
Time (Seconds)
Minimum = 247.661
Maximum = 247.75
Difference = 0.09
Mean = 247.72
Measured = 247.75

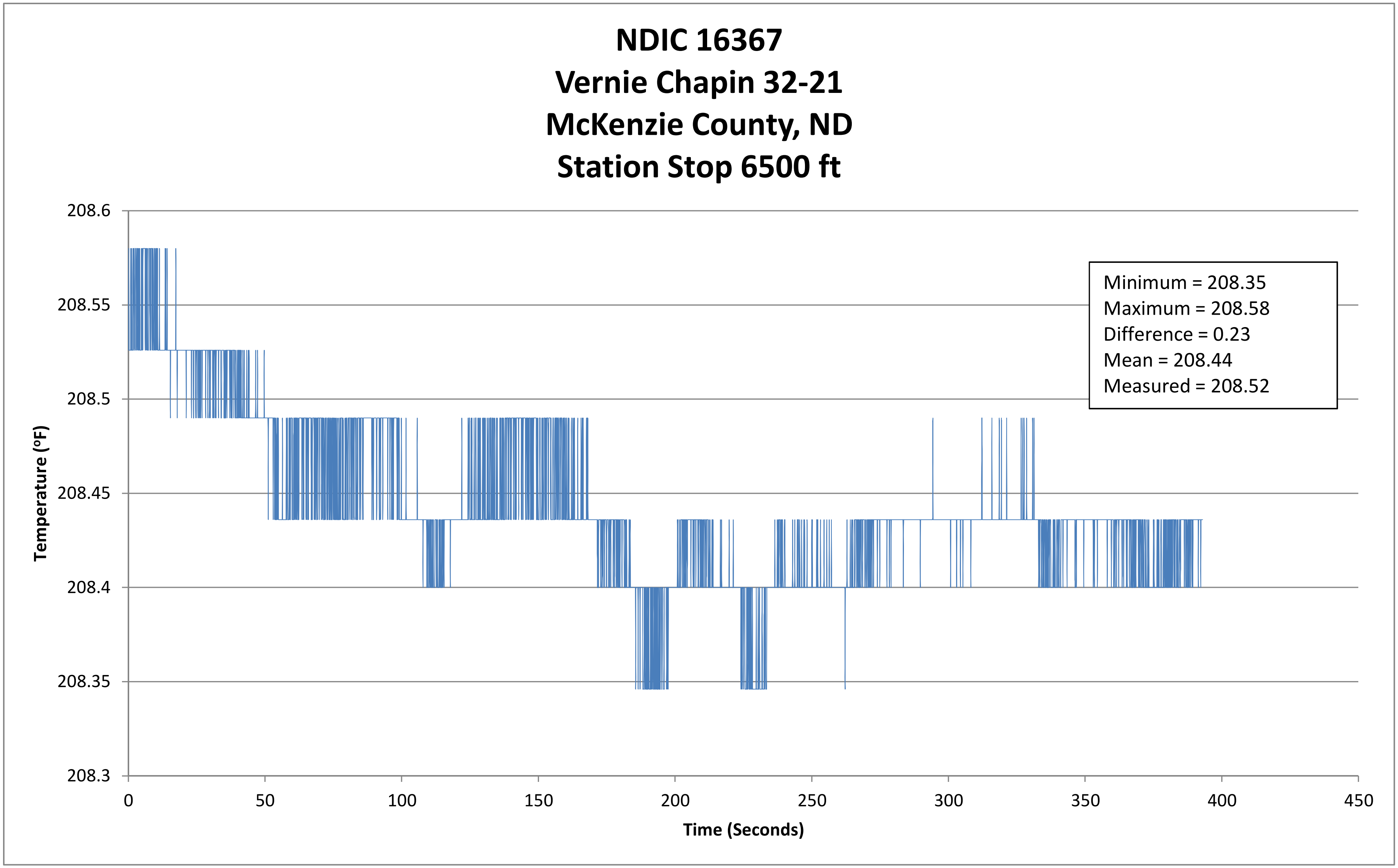

NDIC 15785
Ann 1
McKenzie County, ND
Station Stop at 5000 ft
Minimum = 164.77
Maximum = 166.12
Difference = 1.35
Mean = 165.02
Measured = 165.15
Temperature (ºF)
165.4
165.3
165.2
165.1
165
164.9
164.8
164.7
0
50
100
150
200
250
300
Time (Seconds)

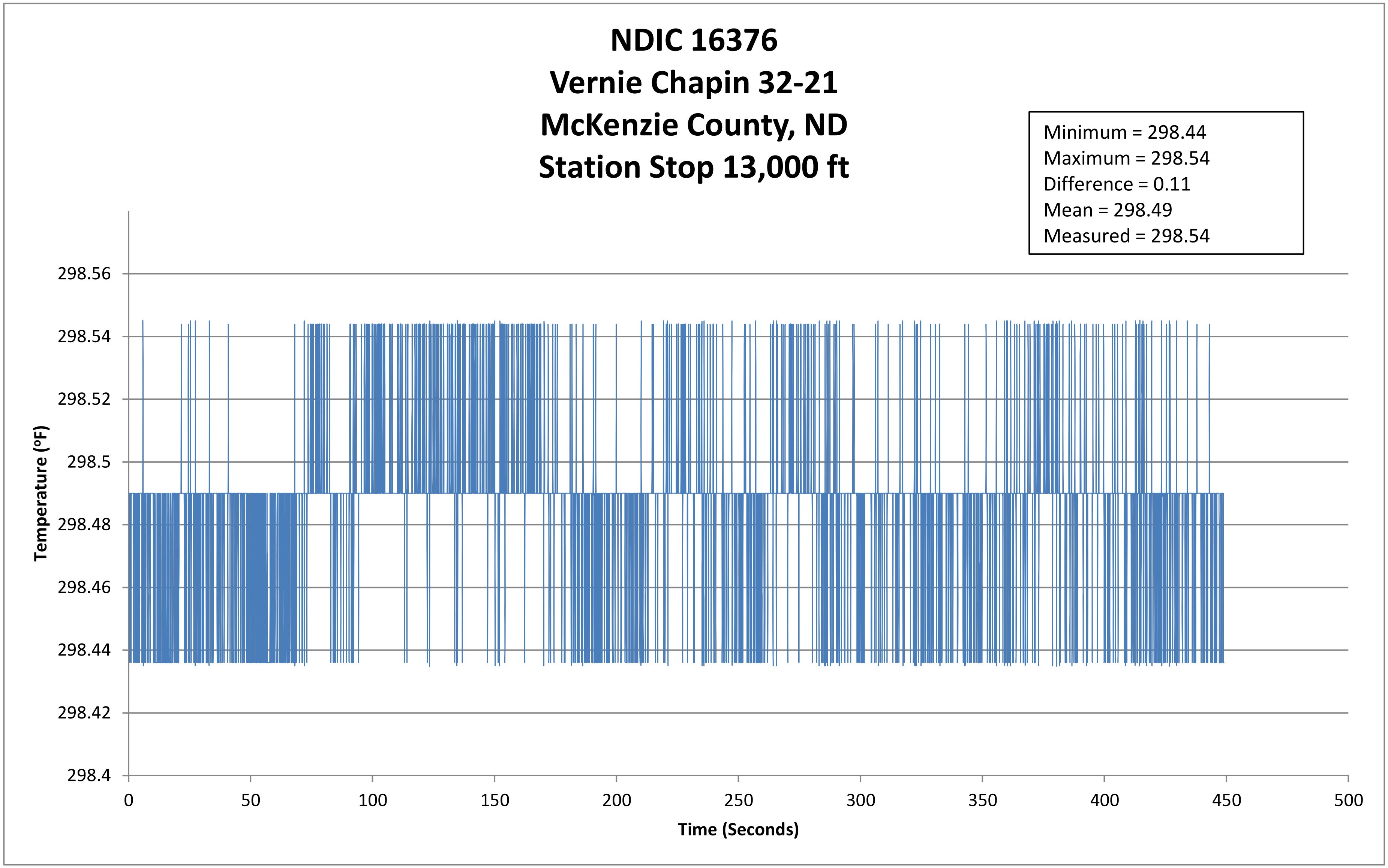

NDIC 15785
Ann 1
McKenzie County, ND
Station Stop 10,300 ft
Minimum = 253.20
Maximum = 253.53
Difference = 0.32
Mean = 253.49
Measured = 253.53
Temperature (ºF)
253.52
253.5
253.48
253.46
253.44
253.42
0
50
100
150
200
250
300
Time (Seconds)

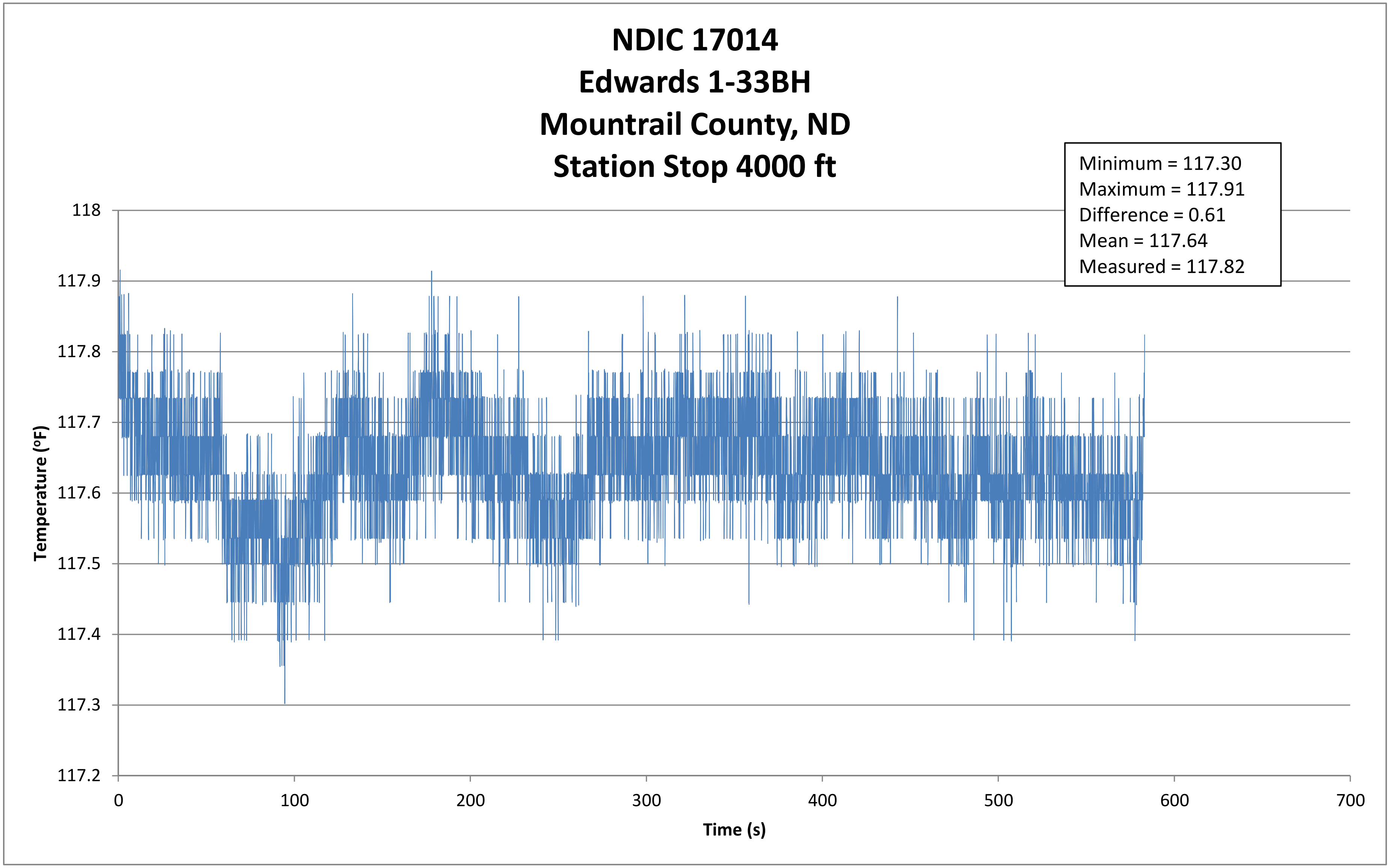

NDIC 16160
Nelson 1-11H
Mountrail County, ND
Station Stop at 4500 ft
Minimum = 144.39
Maximum = 144.82
Difference = 0.43
Mean = 144.62
Measured = 144.63
Temperature (ºF)
144.85
144.8
144.75
144.7
144.65
144.6
144.55
144.5
144.45
144.4
144.35
0
100
200
300
400
500
600
700
Time (Seconds)

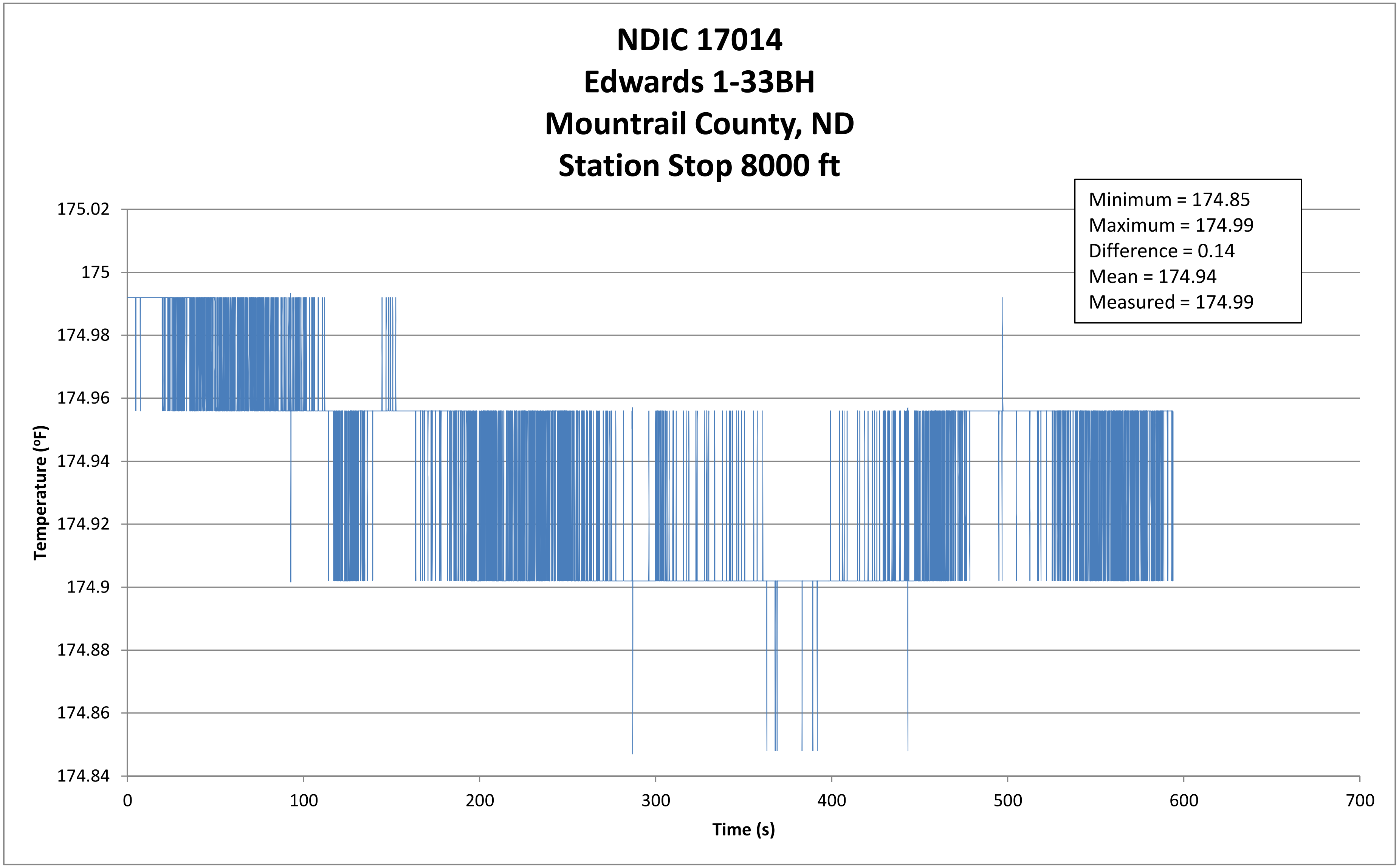

NDIC 16182
2004 JV-P NDCA-7
Williams County, ND
Station Stop at 5000 ft
Minimum = 159.98
Maximum = 160.63
Difference = 0.65
Mean = 160.27
Measured = 160.43
Temperature (ºF)
160.7
160.6
160.5
160.4
160.3
160.2
160.1
160
159.9
0
100
200
300
400
500
600
700
Time (Seconds)

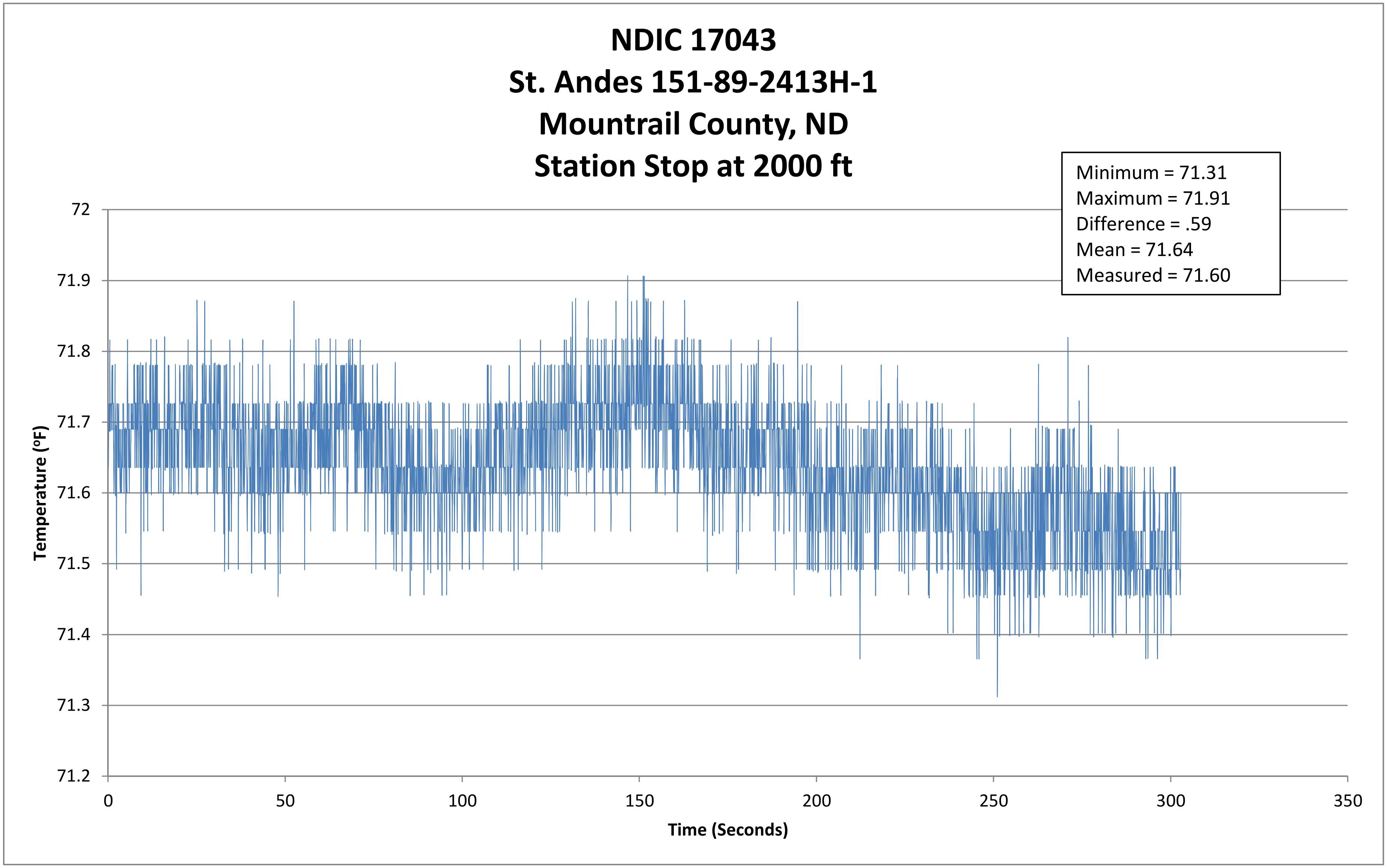

NDIC 16182
2004 JV-P NDCA-7
Williams County, ND
Station Stop at 9500 ft
Minimum = 231.12
Maximum = 231.26
Difference = 0.14
Mean = 231.17
Measured = 231.26
Temperature (ºF)
231.28
231.26
231.24
231.22
231.2
231.18
231.16
231.14
231.12
231.1
0
100
200
300
400
500
600
700
Time (Seconds)

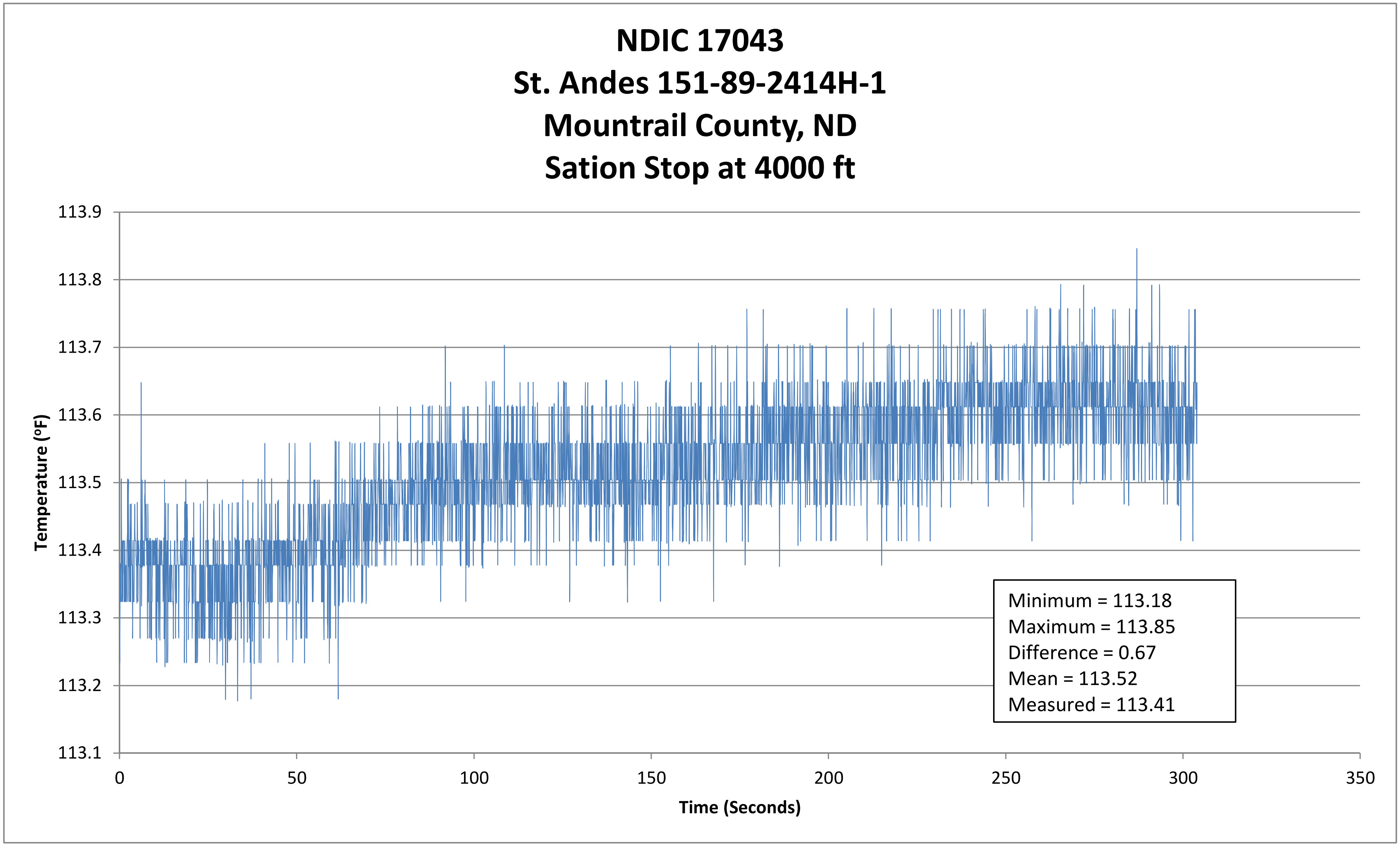

NDIC 16367
Vernie Chapin 32-21
McKenzie County, ND
Station Stop 6500 ft
Minimum = 208.35
Maximum = 208.58
Difference = 0.23
Mean = 208.44
Measured = 208.52
Temperature (ºF)
Time (Seconds)
208.6
208.55
208.5
208.45
208.4
208.35
208.3
0
50
100
150
200
250
300
350
400
450

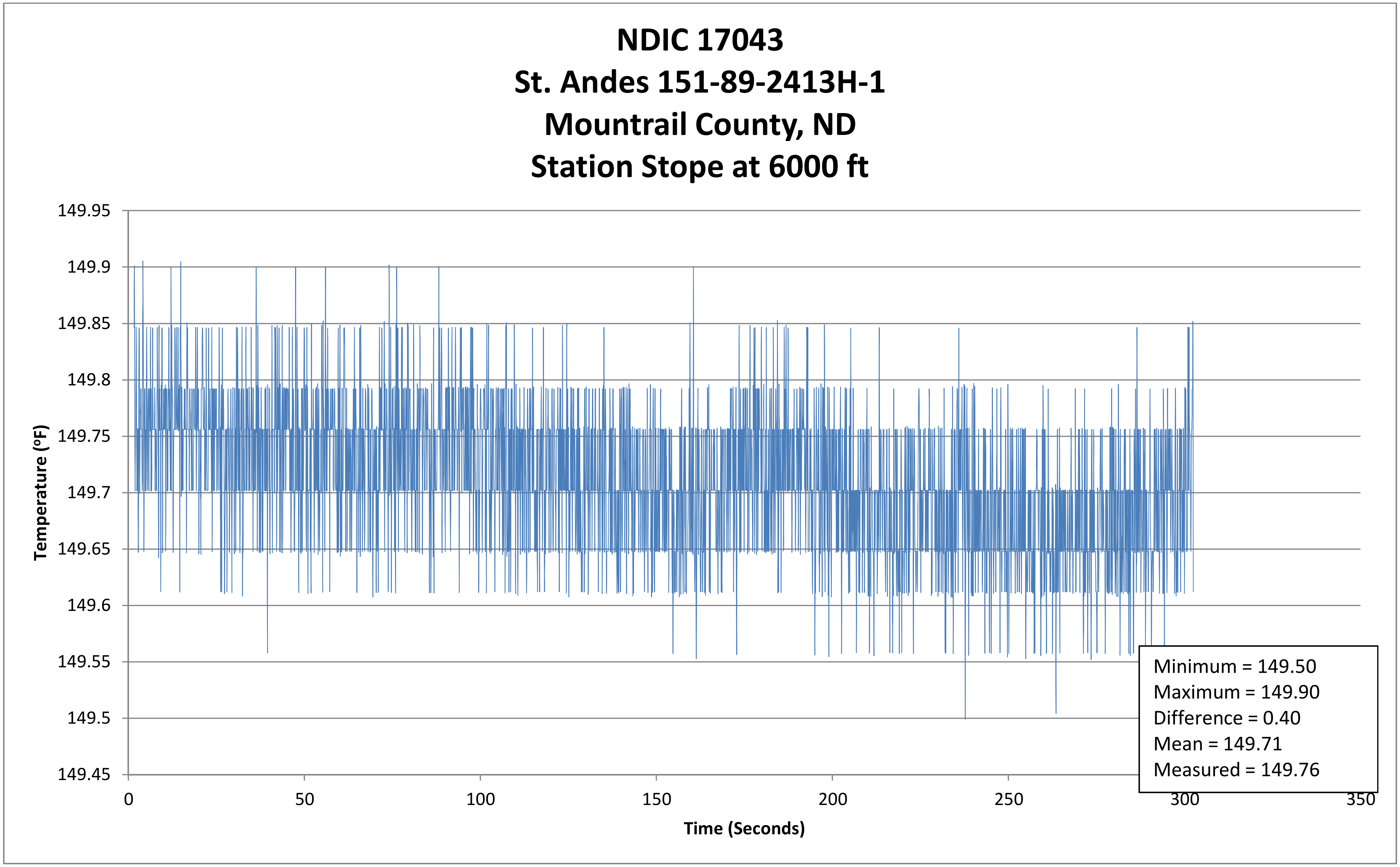

NDIC 16376
Vernie Chapin 32-21
McKenzie County, ND
Station Stop 13,000 ft
Minimum = 298.44
Maximum = 298.54
Difference = 0.11
Mean = 298.49
Measured = 298.54
Temperature (ºF)
298.56
298.54
298.52
298.5
298.48
298.46
298.44
298.42
298.4
0
50
100
150
200
250
300
350
400
450
500
Time (Seconds)

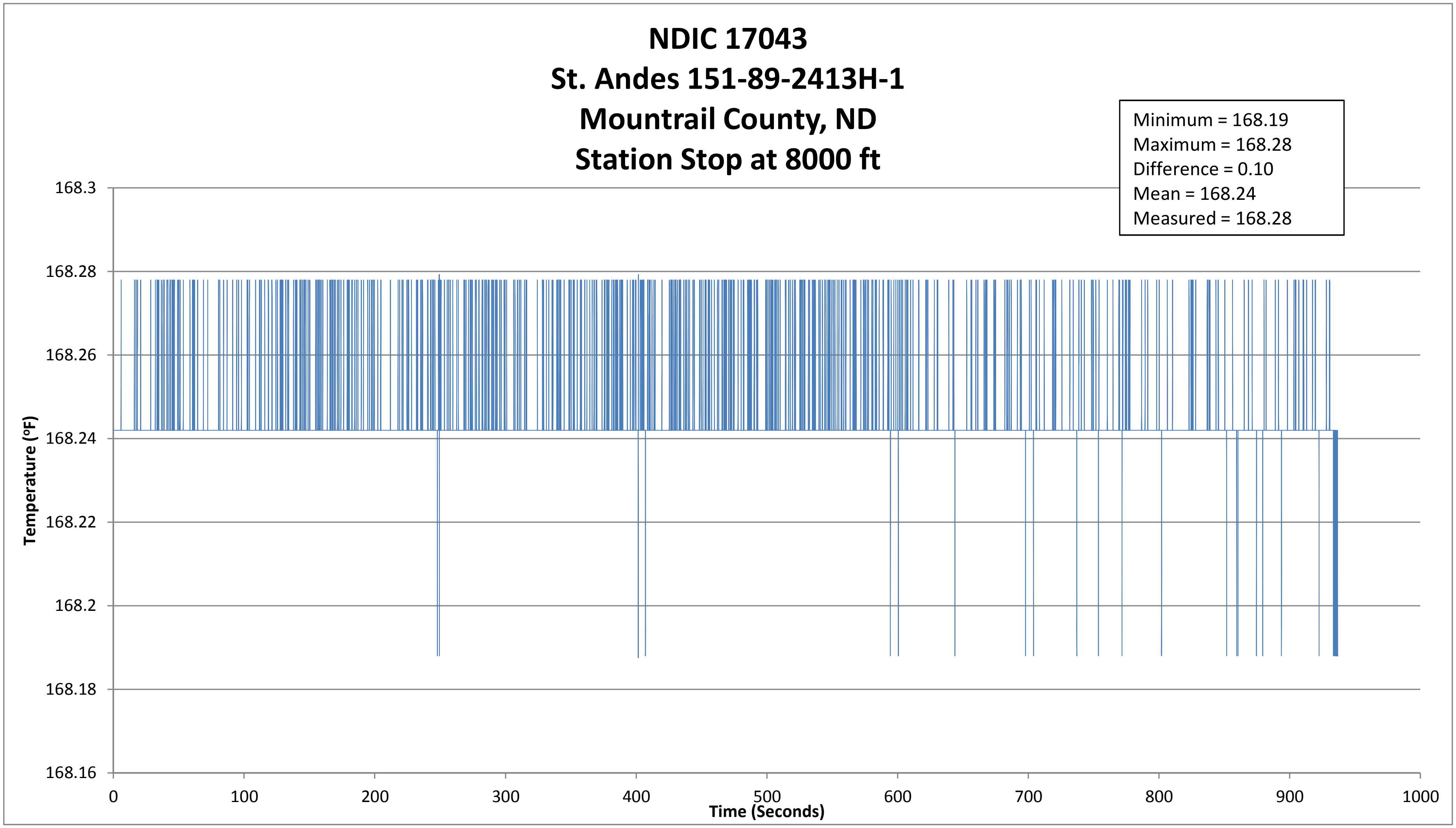

NDIC 17014
Edwards 1-33BH
Mountrail County, ND
Station Stop 4000 ft
Minimum = 117.30
Maximum = 117.91
Difference = 0.61
Mean = 117.64
Measured = 117.82
Temperature (ºF)
118
117.9
117.8
117.7
117.6
117.5
117.4
117.3
117.2
0
100
200
300
400
500
600
700
Time (s)

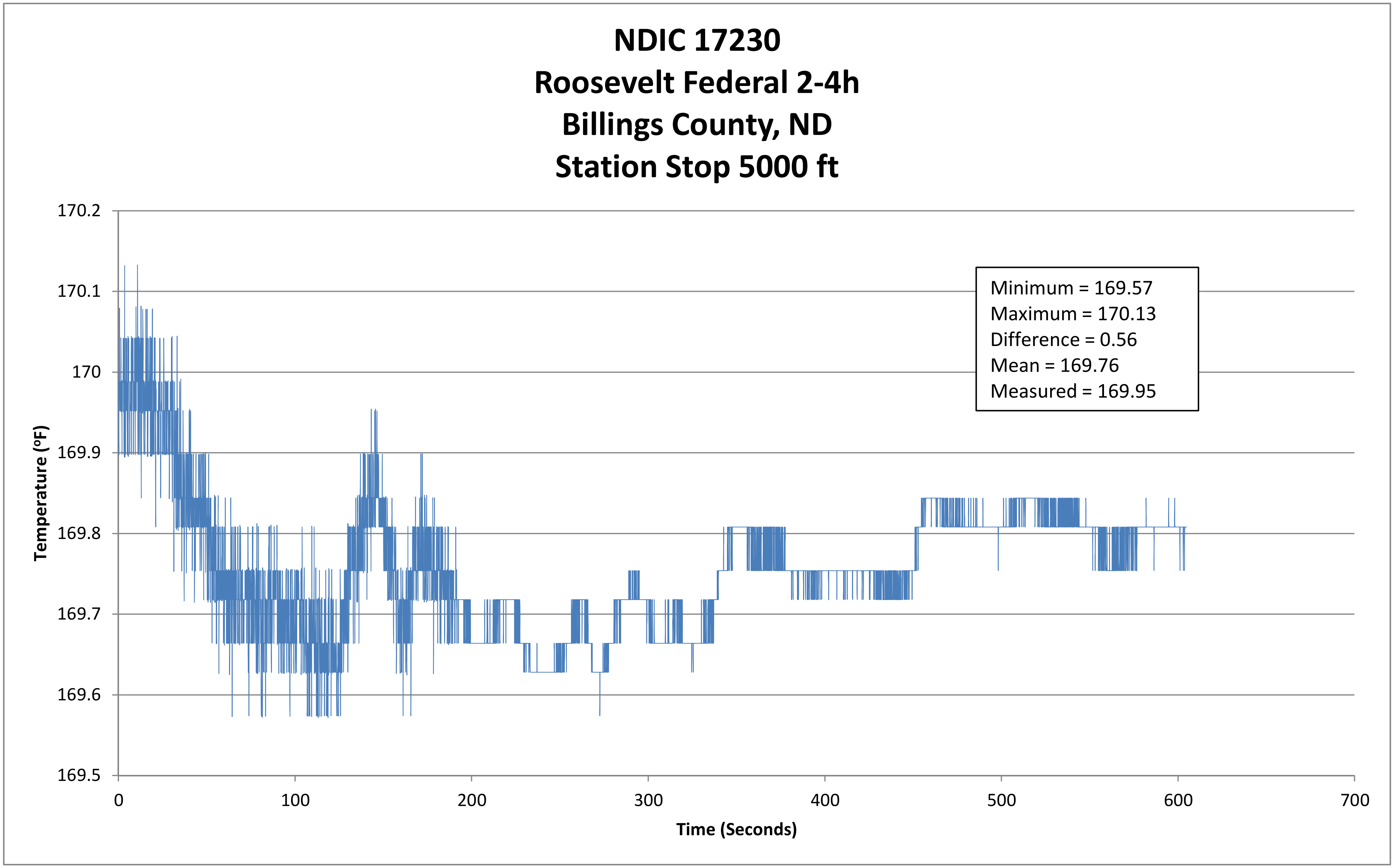

NDIC 17014
Edwards 1-33BH
Mountrail County, ND
Station Stop 8000 ft
Minimum = 174.85
Maximum = 174.99
Difference = 0.14
Mean = 174.94
Measured = 174.99
Temperature (ºF)
175.02
175
174.98
174.96
174.94
174.92
174.9
174.88
174.86
174.84
0
100
200
300
400
500
600
700
Time (s)

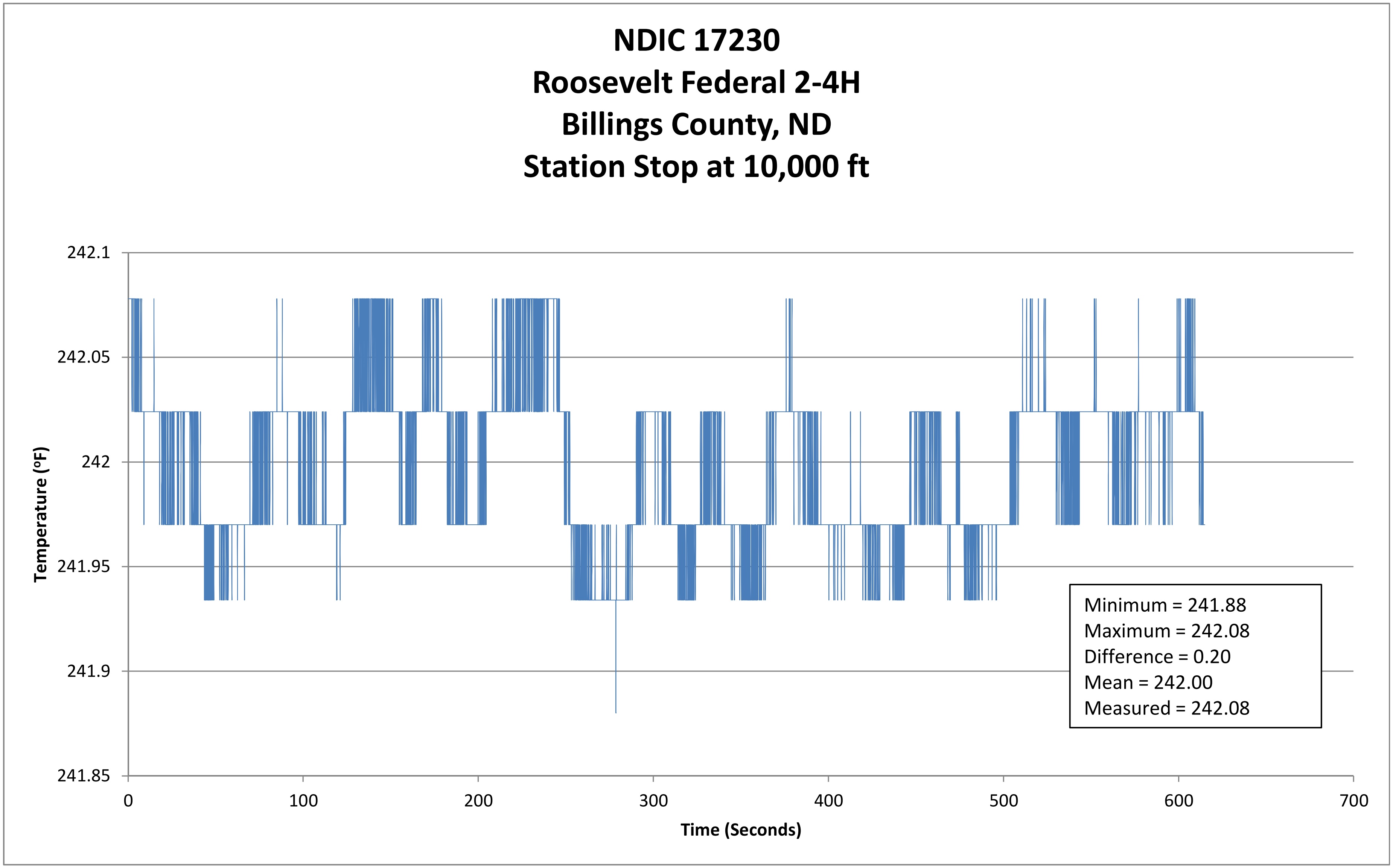

NDIC 17043
St. Andes 151-89-2413H-1
Mountrail County, ND
Station Stop at 2000 ft
Minimum = 71.31
Maximum = 71.91
Difference = .59
Mean = 71.64
Measured = 71.60
Temperature (ºF)
72
71.9
71.8
71.7
71.6
71.5
71.4
71.3
71.2
0
50
100
150
200
250
300
350
Time (Seconds)

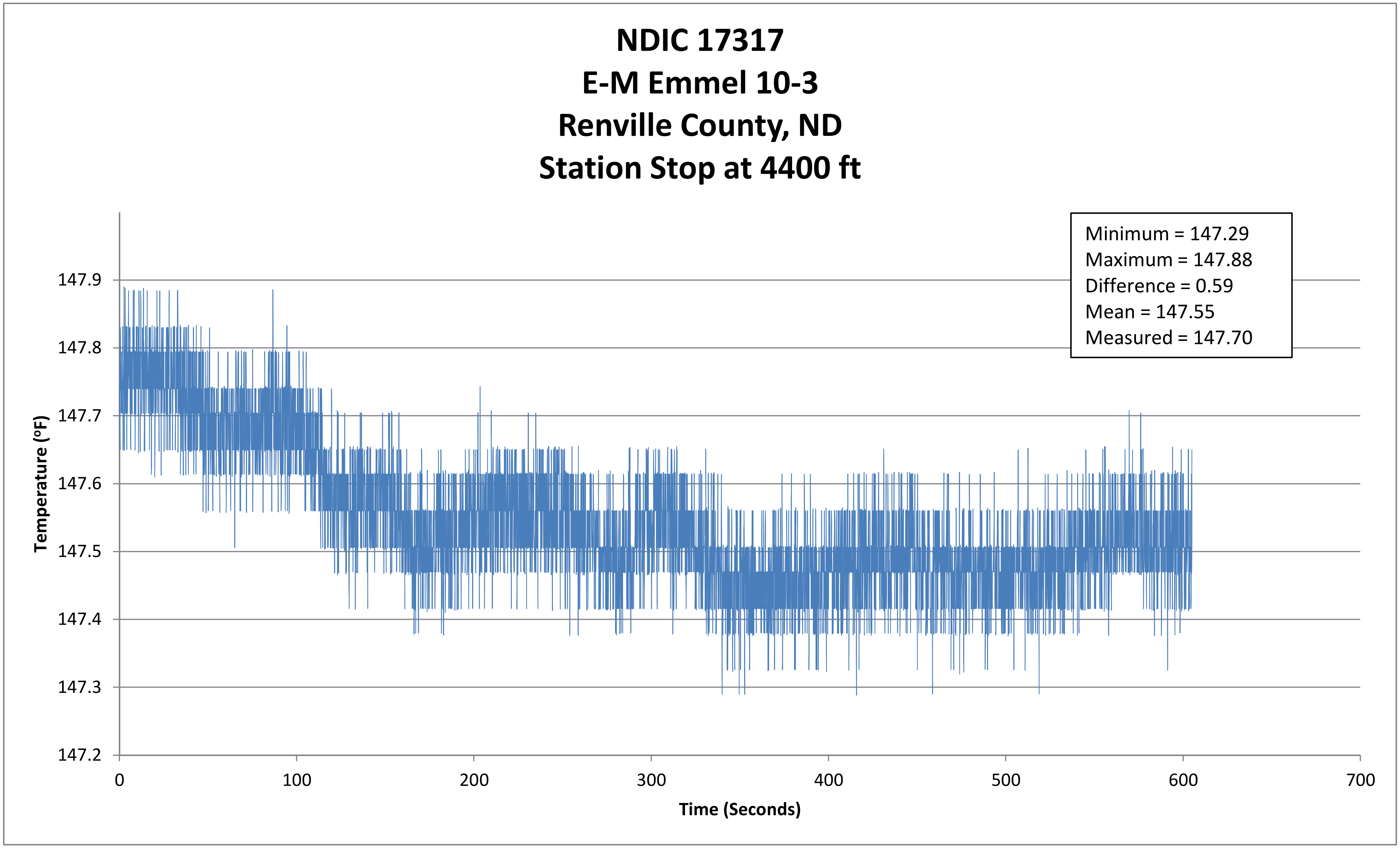

NDIC 17043
St. Andes 151-89-2414H-1
Mountrail County, ND
Sation Stop at 4000 ft
113.9
113.8
113.7
113.6
113.5
113.4
113.3
113.2
113.1
Temperature (°F)
0
50
100
150
200
250
300
350
Time (Seconds)
Minimum = 113.18
Maximum = 113.85
Difference = 0.67
Mean = 113.52
Measured = 113.41

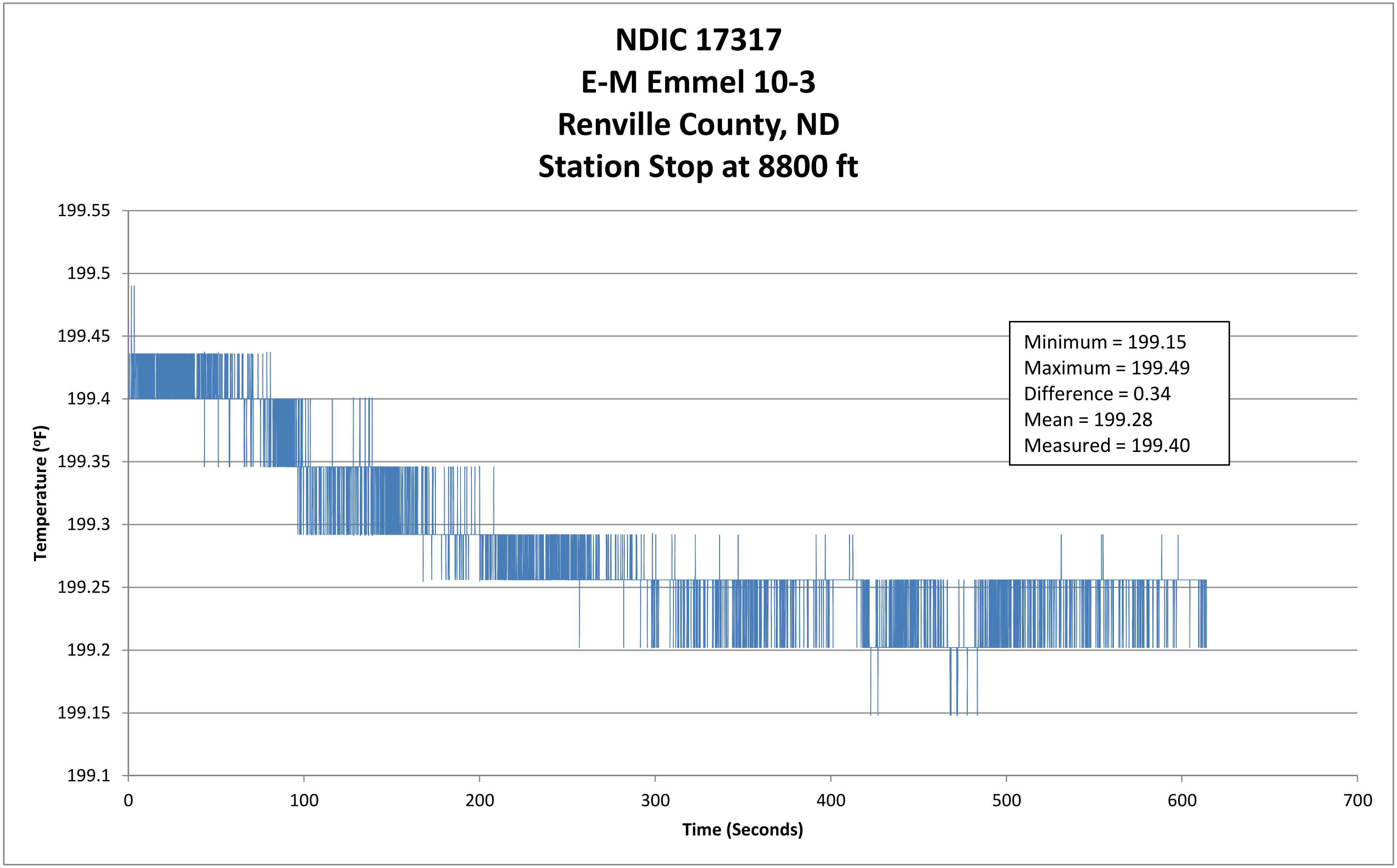

NDIC 17043
St. Andes 151-89-2413H-1
Mountrail County, ND
Station Stope at 6000 ft
149.95
149.9
149.85
149.8
149.75
149.7
149.65
149.6
149.55
149.5
149.45
Temperature (ºF)
0
50
100
150
200
250
300
350
Time (Seconds)
Minimum = 149.50
Maximum = 149.90
Difference = 0.40
Mean = 149.71
Measured = 149.76

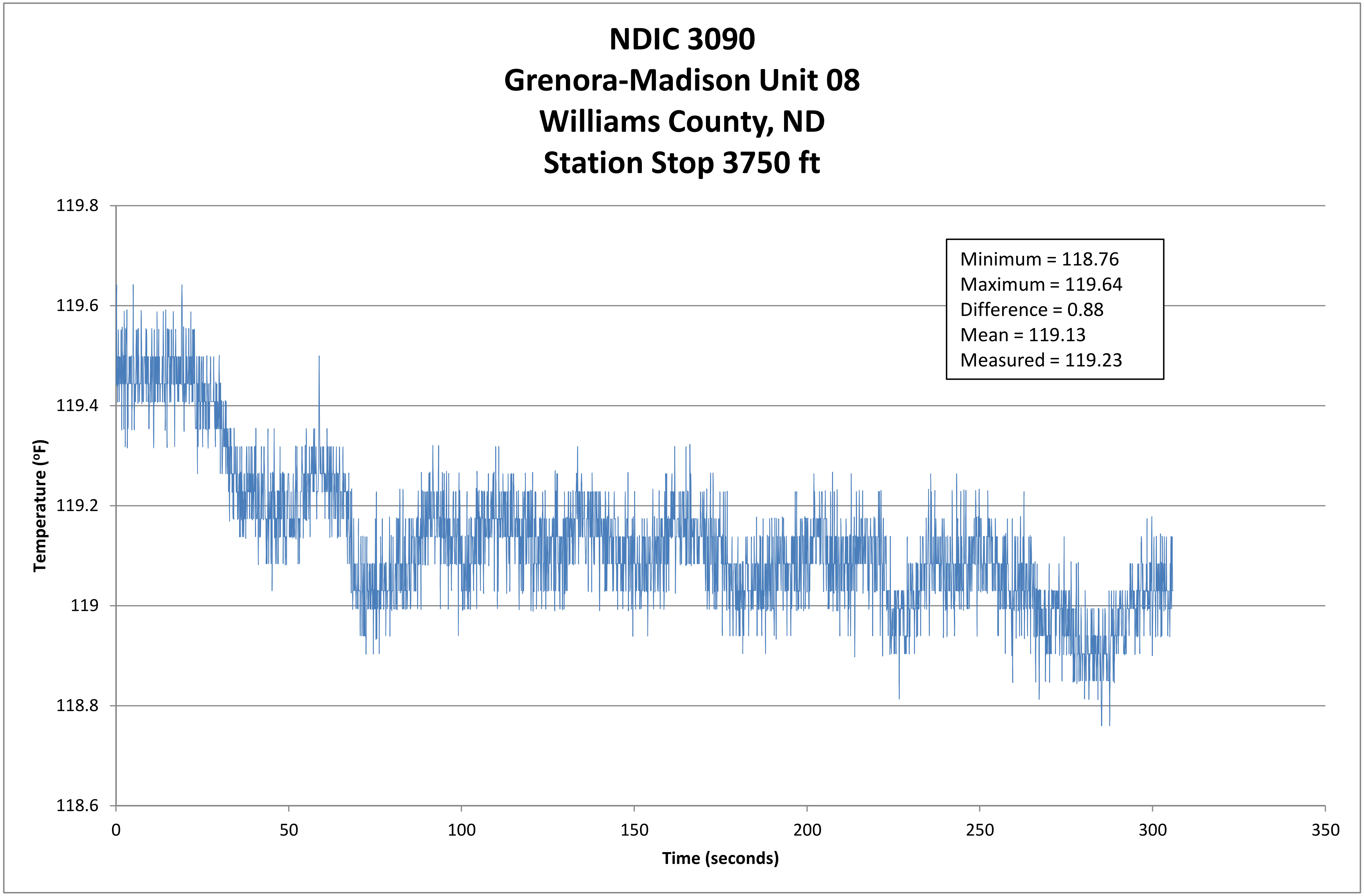

NDIC 17043
St. Andes 151-89-2413H-1
Mountrail County, ND
Station Stop at 8000 ft
Minimum = 168.19
Maximum = 168.28
Difference = 0.10
Mean = 168.24
Measured = 168.28
Temperature (ºF)
168.3
168.28
168.26
168.24
168.22
168.2
168.18
168.16
0
100
200
300
400
500
600
700
800
900
1000
Time (Seconds)

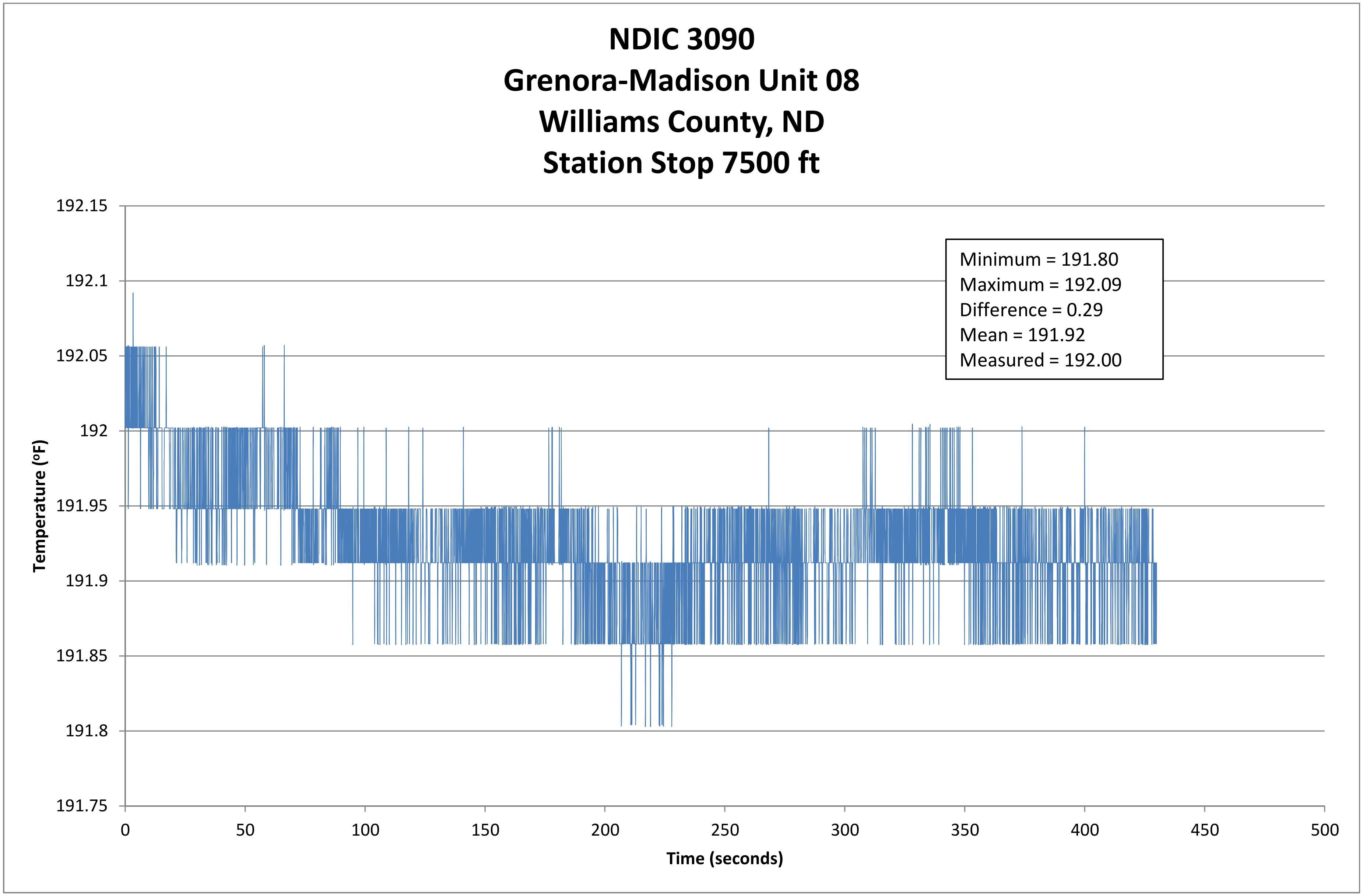

NDIC 17230
Roosevelt Federal 2-4h
Billings County, ND
Station Stop 5000 ft
Minimum = 169.57
Maximum = 170.13
Difference = 0.56
Mean = 169.76
Measured = 169.95
Temperature (ºF)
170.2
170.1
170
169.9
169.8
169.7
169.6
169.5
0
100
200
300
400
500
600
700
Time (Seconds)

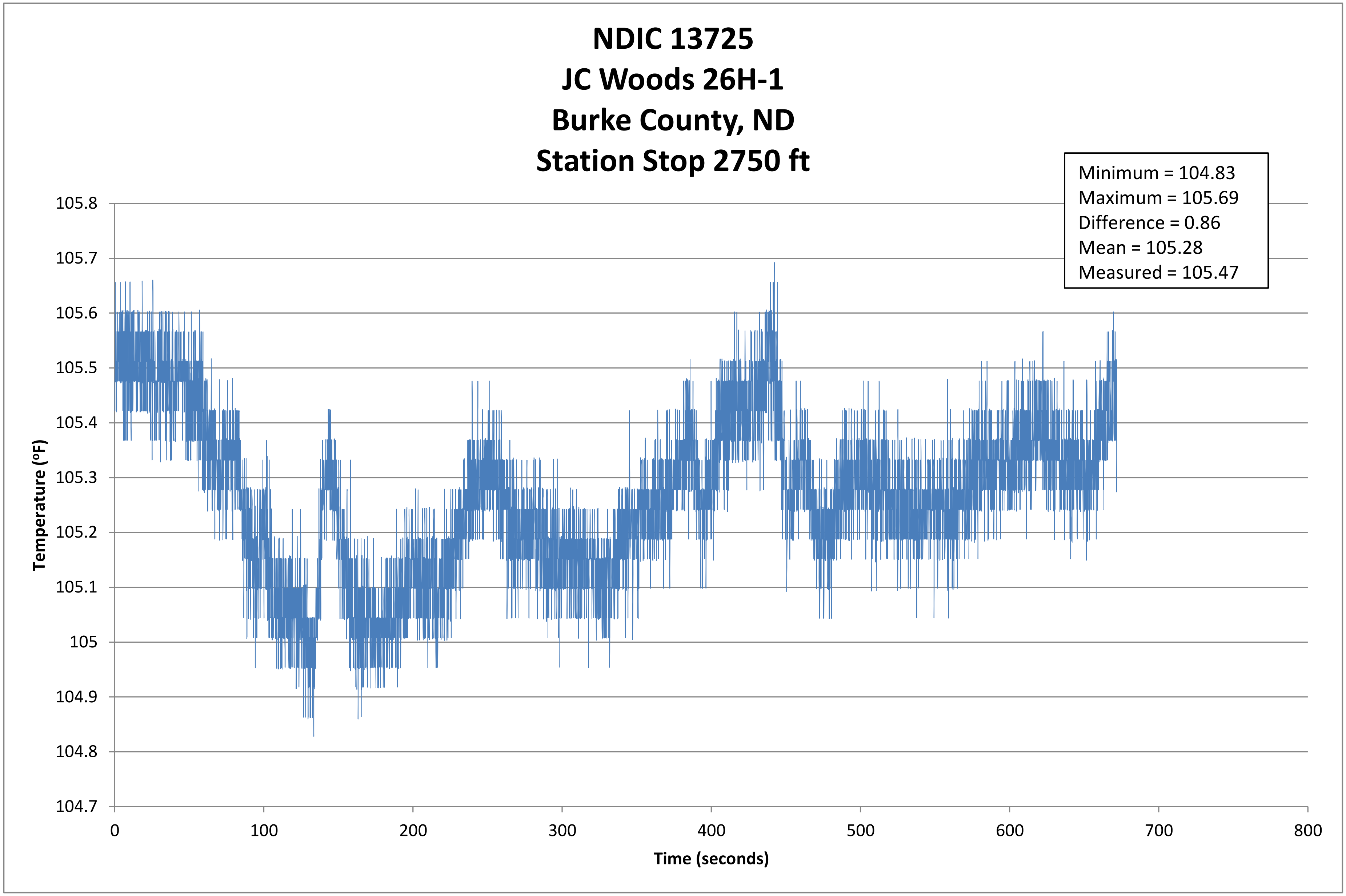

NDIC 17230
Roosevelt Federal 2-4H
Billings County, ND
Station Stop at 10,000 ft
242.1
242.05
242
241.95
241.9
241.85
Temperature (ºF)
0
100
200
300
400
500
600
700
Time (Seconds)
Minimum = 241.88
Maximum = 242.08
Difference = 0.20
Mean = 242.00
Measured = 242.08

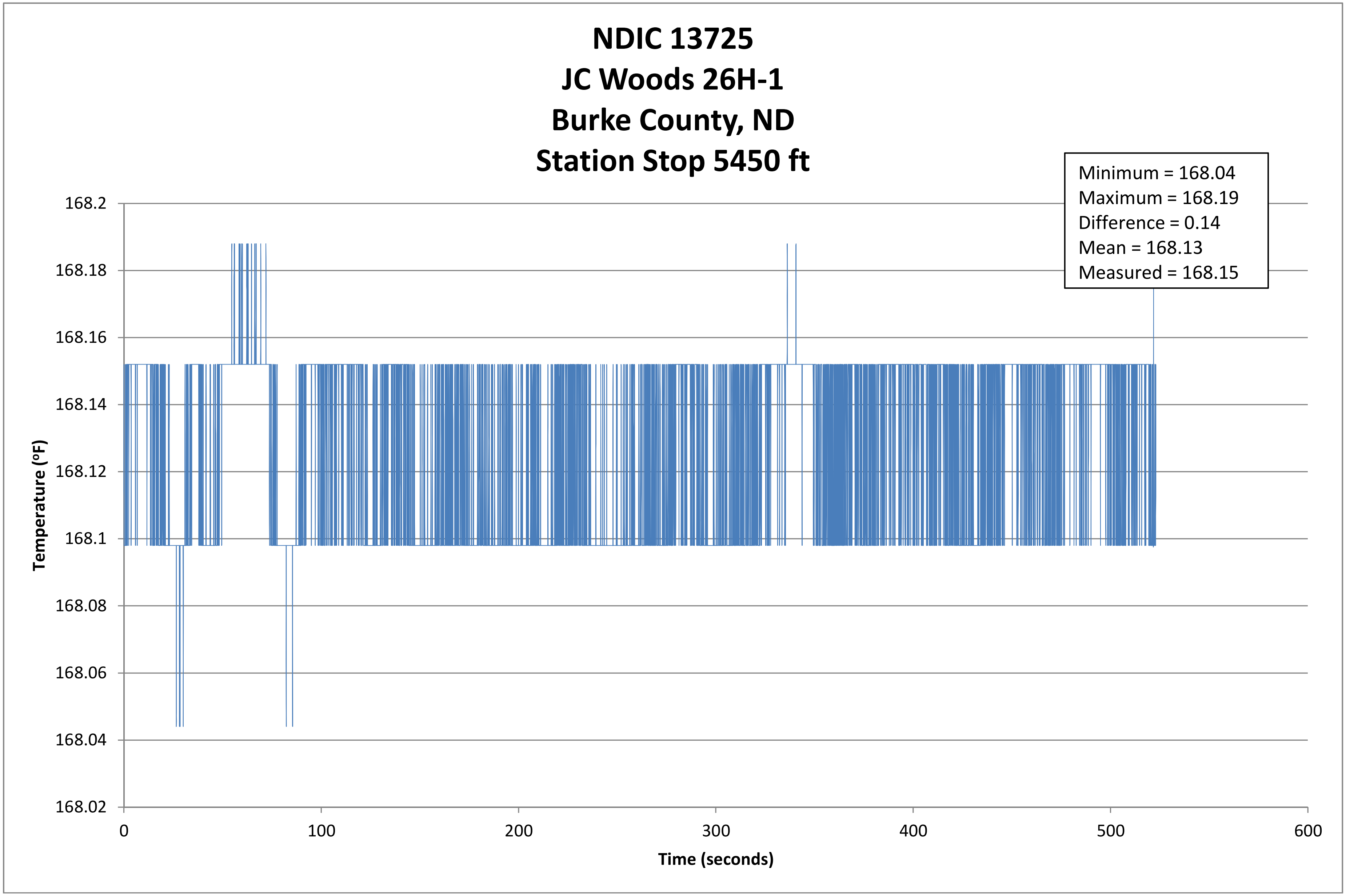

NDIC 17317
E-M Emmel 10-3
Renville County, ND
Station Stop at 4400 ft
Minimum = 147.29
Maximum = 147.88
Difference = 0.59
Mean = 147.55
Measured = 147.70
Temperature (ºF)
147.9
147.8
147.7
147.6
147.5
147.4
147.3
147.2
0
100
200
300
400
500
600
700
Time (Seconds)


NDIC 17317
E-M Emmel 10-3
Renville County, ND
Station Stop at 8800 ft
Minimum = 199.15
Maximum = 199.49
Difference = 0.34
Mean = 199.28
Measured = 199.40
Temperature (ºF)
199.55
199.5
199.45
199.4
199.35
199.3
199.25
199.2
199.15
199.1
0
100
200
300
400
500
600
700
Time (Seconds)


NDIC 3090
Grenora-Madison Unit 08
Williams County, ND
Station Stop 3750 ft
Minimum = 118.76
Maximum = 119.64
Difference = 0.88
Mean = 119.13
Measured = 119.23
Temperature (ºF)
Time (seconds)
119.8
119.6
119.4
119.2
119
118.8
118.6
0
50
100
150
200
250
300
350


NDIC 3090
Grenora-Madison Unit 08
Williams County, ND
Station Stop 7500 ft
Minimum = 191.80
Maximum = 192.09
Difference = 0.29
Mean = 191.92
Measured = 192.00
192.15
192.1
192.05
192
191.95
191.9
191.85
191.8
191.75
Temperature (ºF)
0
50
100
150
200
250
300
350
400
450
500
Time (seconds)

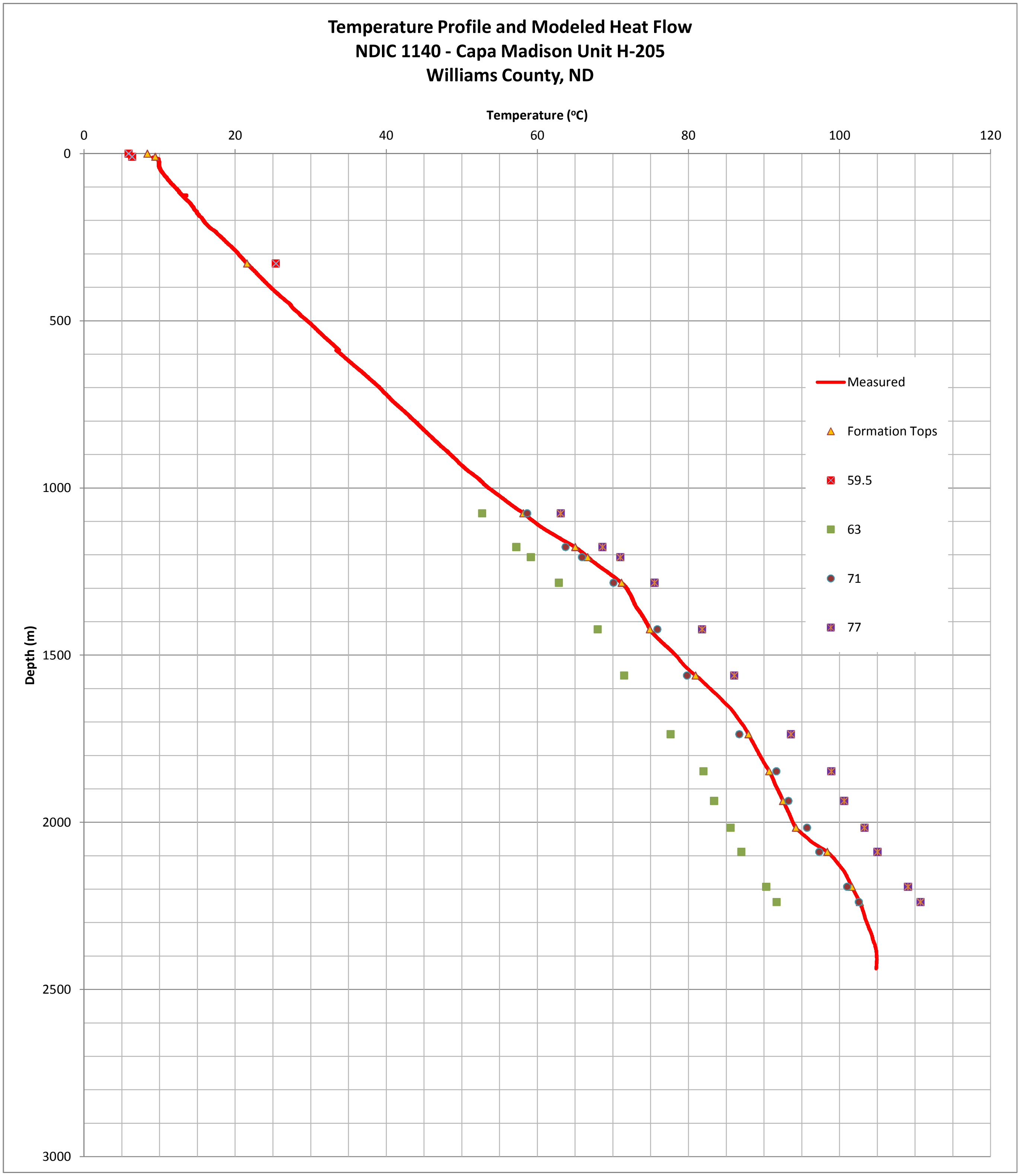

NDIC 13725
JC Woods 26H-1
Burke County, ND
Station Stop 2750 ft
Minimum = 104.83
Maximum = 105.69
Difference = 0.86
Mean = 105.28
Measured = 105.47
Temperature (ºF)
105.8
105.7
105.6
105.5
105.4
105.3
105.2
105.1
105
104.9
104.8
104.7
0
100
200
300
400
500
600
700
800
Time (seconds)



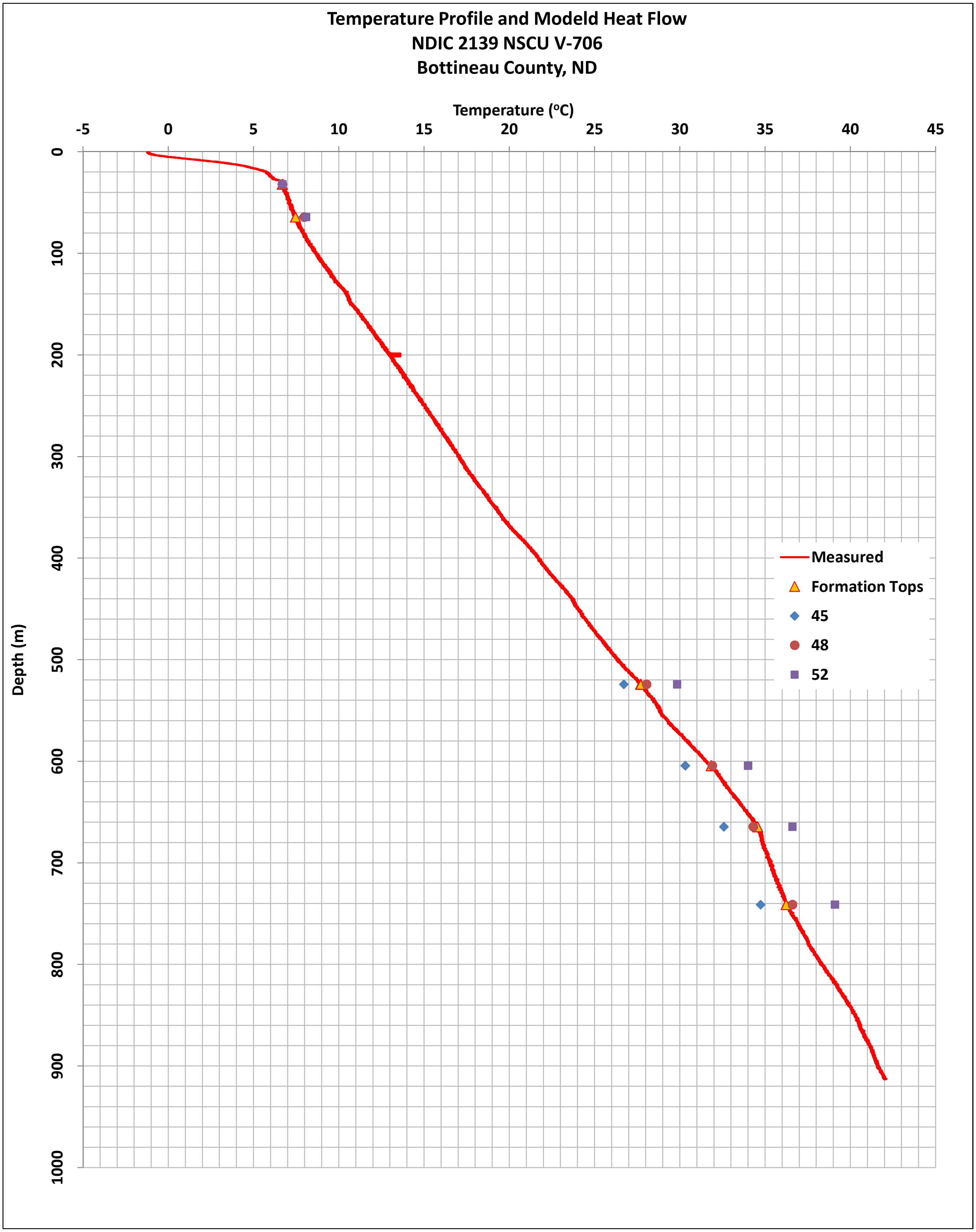
NDIC 13725
JC Woods 26H-1
Burke County, ND
Station Stop 5450 ft
Minimum = 168.04
Maximum = 168.19
Difference = 0.14
Mean = 168.13
Measured = 168.15
Temperature (ºF)
168.2
168.18
168.16
168.14
168.12
168.1
168.08
168.06
168.04
168.02
0
100
200
300
400
500
600
Time (seconds)

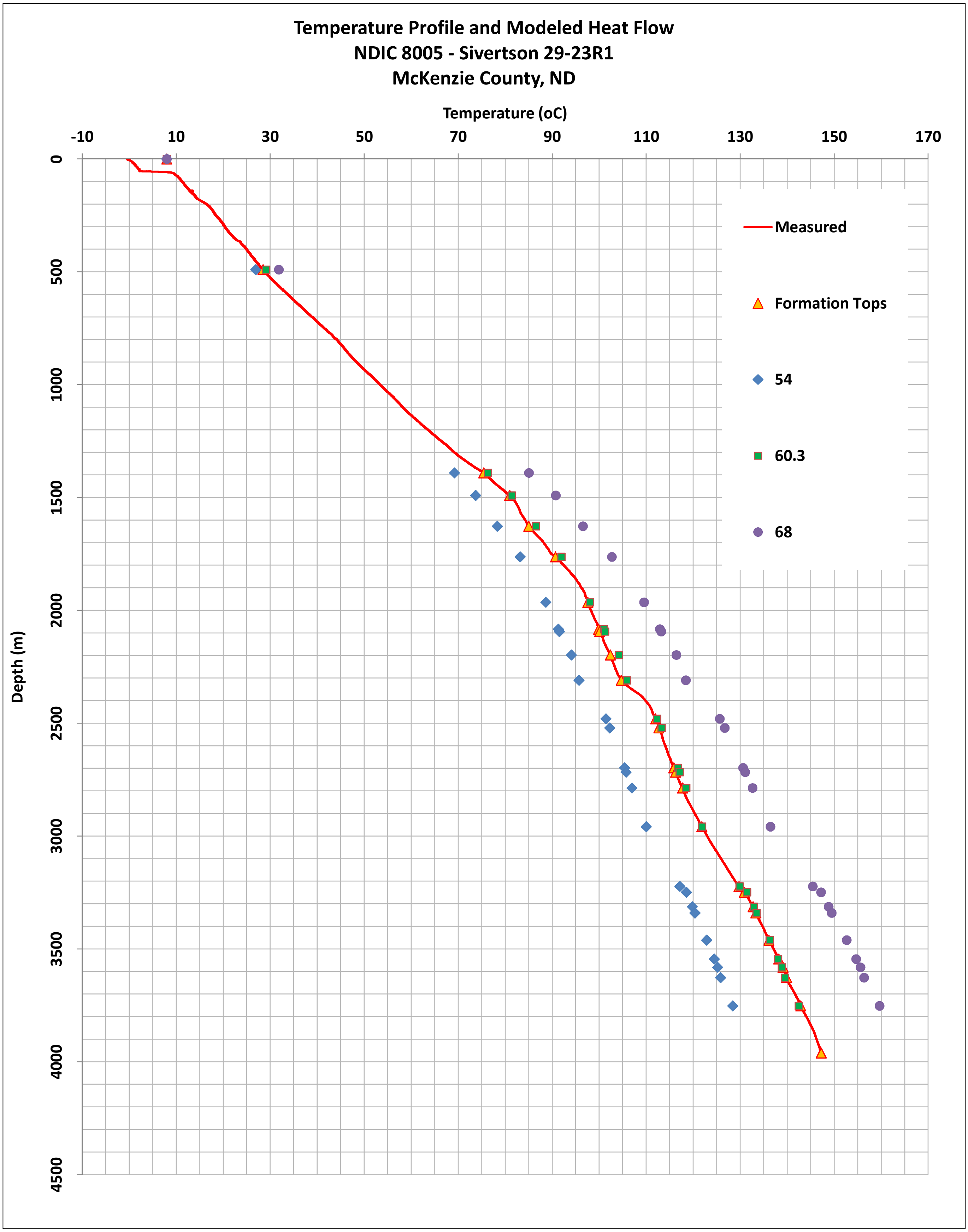
APPENDIX C

TEMPERATURE PROFILES AND MODELED HEAT FLOW

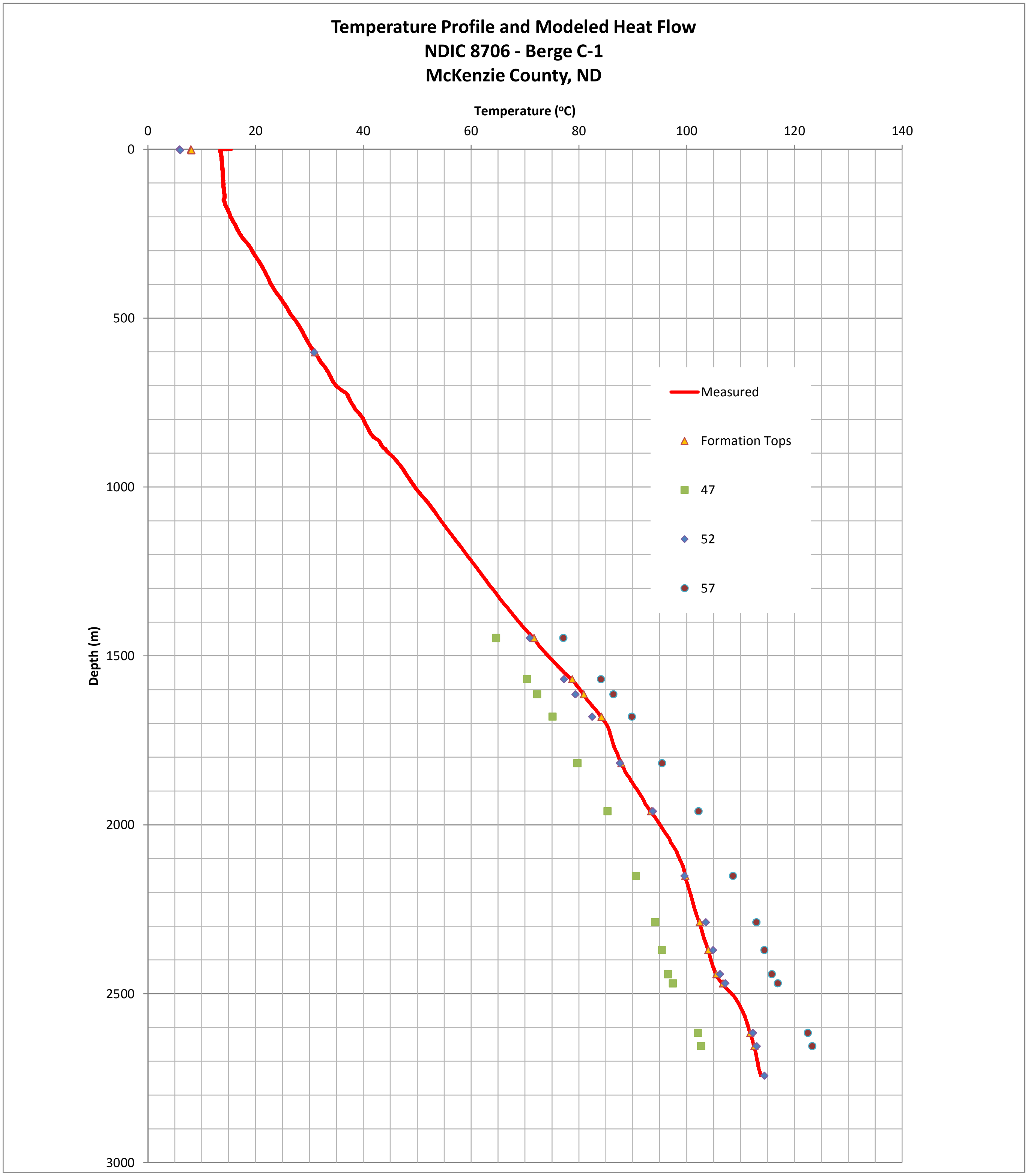


Temperature Profile and Modeled Heat Flow
NDIC 1140 - Capa Madison Unit H-205
Williams County, ND
Temperature (ºC)
0
20
40
60
80
100
120
Depth (m)
0
500
1000
1500
2000
2500
3000
Measured
Formation Tops
59.5
63
71
77

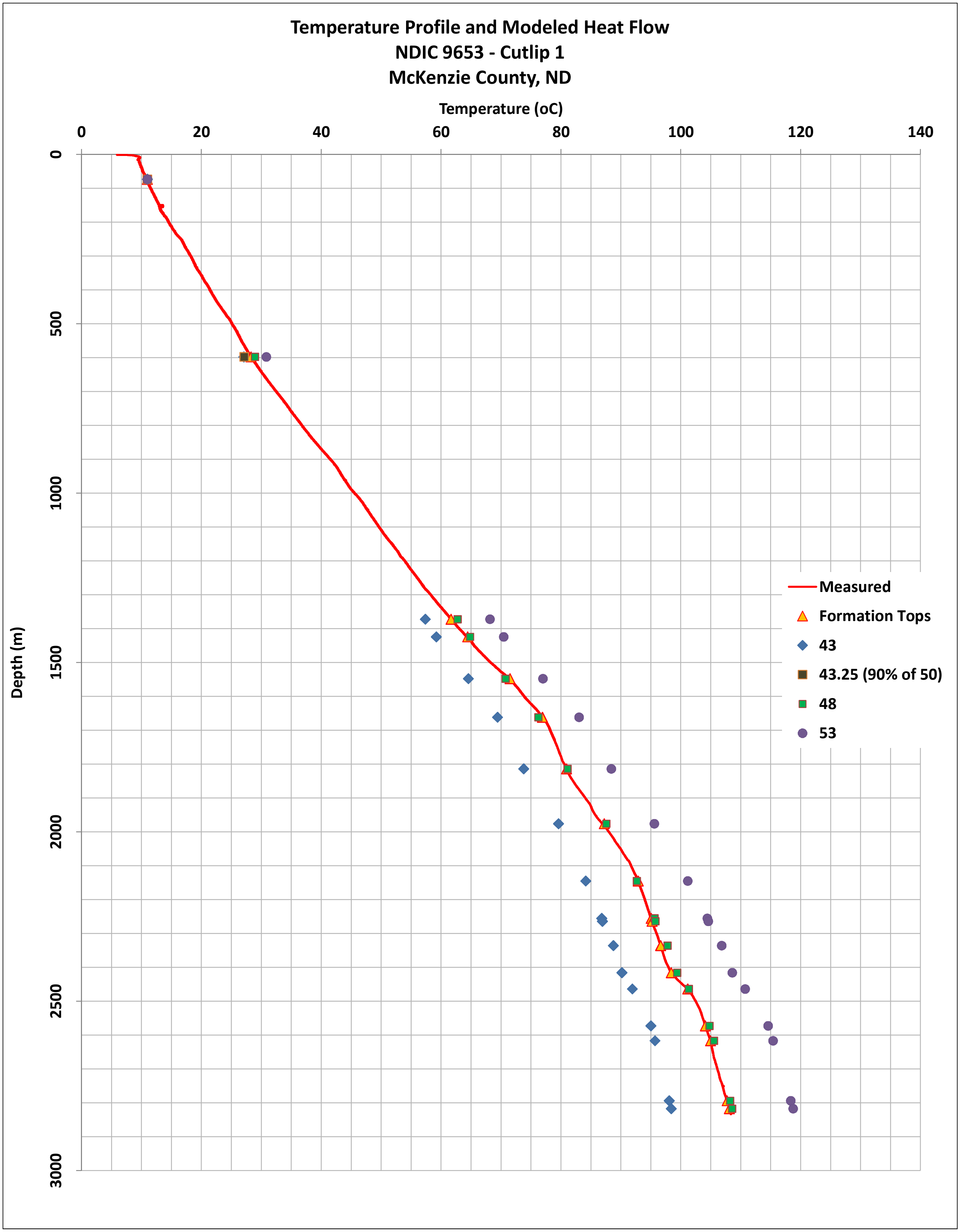

Temperature Profile and Modeld Heat Flow
NDIC 2139 NSCU V-706
Bottineau County, ND
Temperature (°C)
-5
0
5
10
15
20
25
30
35
40
45
Depth (m)
0
100
200
300
400
500
600
700
800
900
1000
Measured
Formation Tops
45
48
52



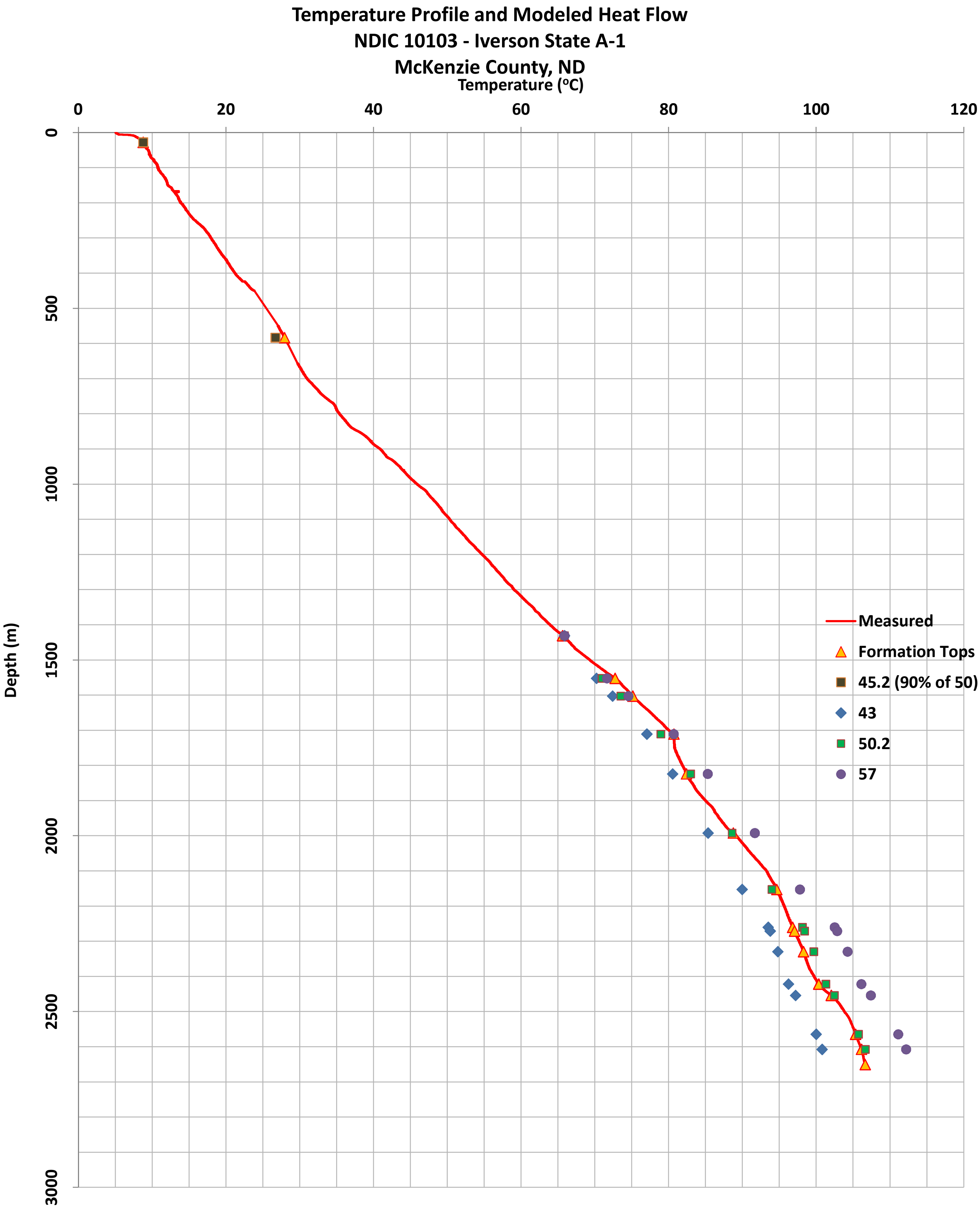
Temperature Profile and Modeled Heat Flow
NDIC 8005 - Sivertson 29-23R1
McKenzie County, ND
Temperature (oC)
-10
10
30
50
70
90
110
130
150
170
Depth (m)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Measured
Formation Tops
54
60.3
68



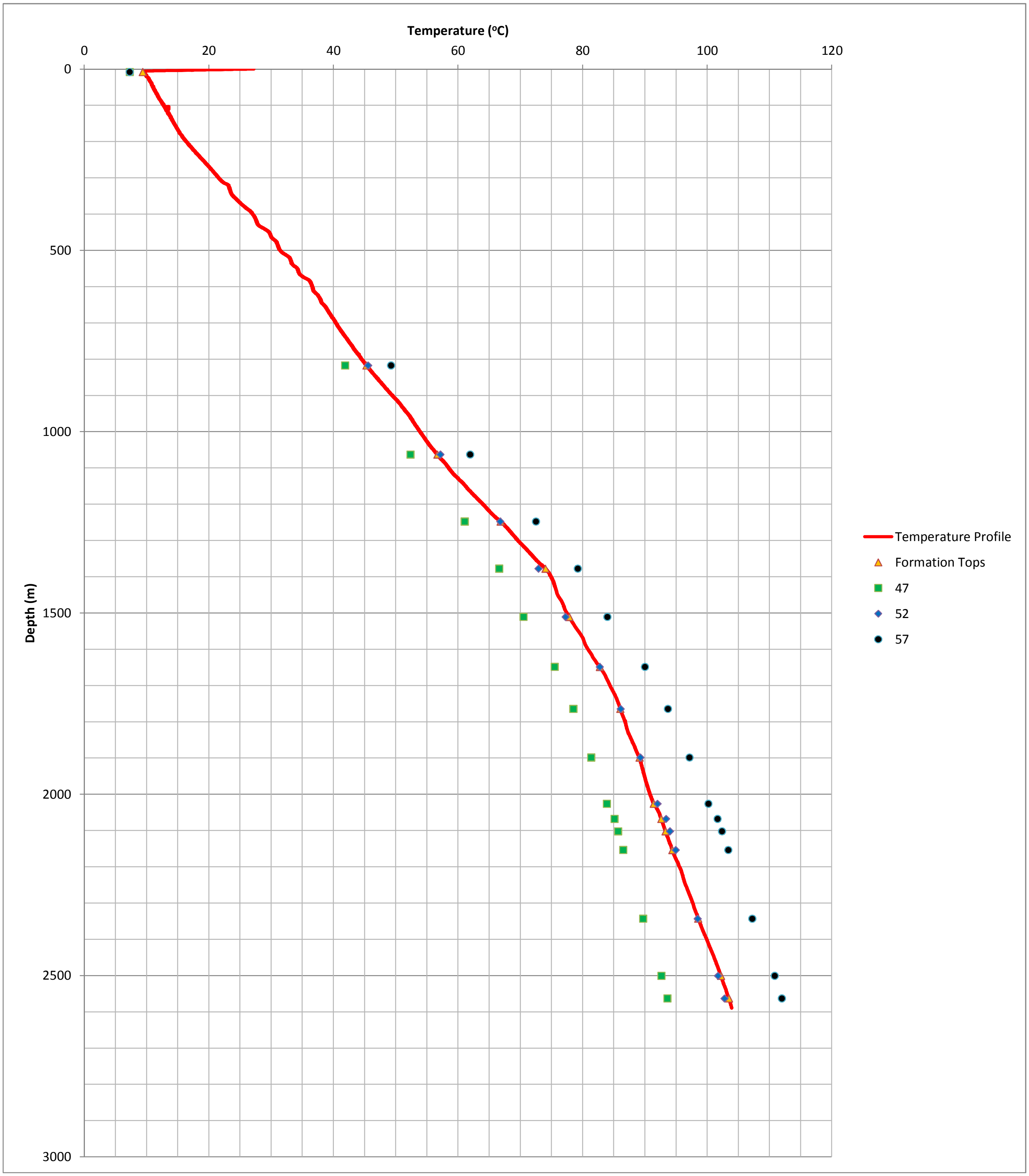
Temperature Profile and Modeled Heat Flow
NDIC 8706 - Berge C-1
McKenzie County, ND
Temperature (ºC)
0
20
40
60
80
100
120
140
0
500
1000
1500
2000
2500
3000
Depth (m)
Measured
Formation Tops
47
52
57

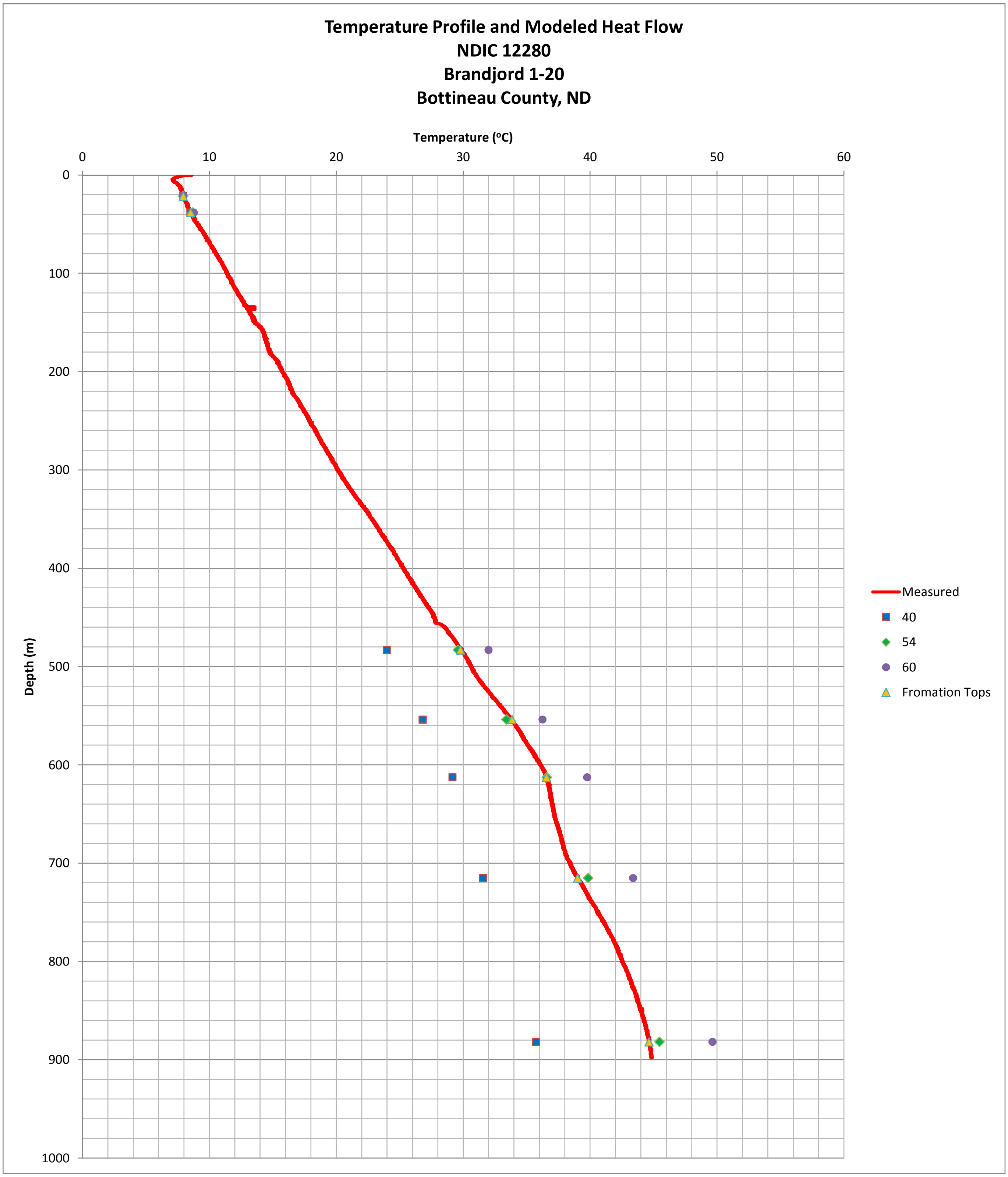


Temperature Profile and Modeled Heat Flow
NDIC 9653 - Cutlip 1
McKenzie County, ND
Temperature (oC)
0
20
40
60
80
100
120
140
Depth (m)
0
500
1000
1500
2000
2500
3000
Measured
Formation Tops
43
43.25 (90% of 50)
48
53

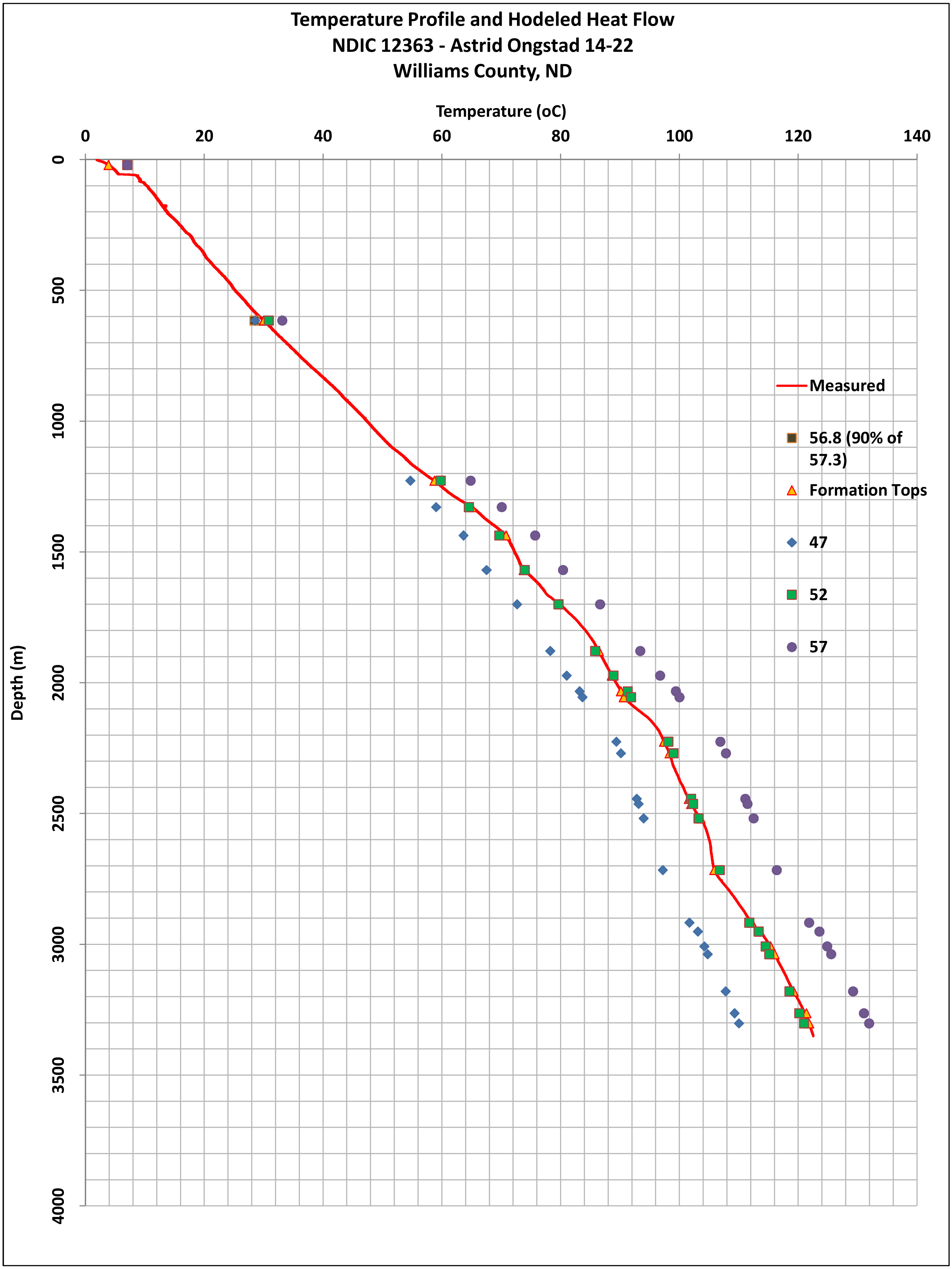

Temperature Profile and Modeled Heat Flow
NDIC 10103 - Iverson State A-1
McKenzie County, ND
Temperature (°C)
0
20
40
60
80
100
120
Depth (m)
0
500
1000
1500
2000
2500
3000
Measured
Formation Tops
45.2 (90% of 50)
43
50.2
57

Temperature Profile and Modeled Heat Flow
NDIC 10278 - Mud Buttes State 1-36
Bowman County, ND

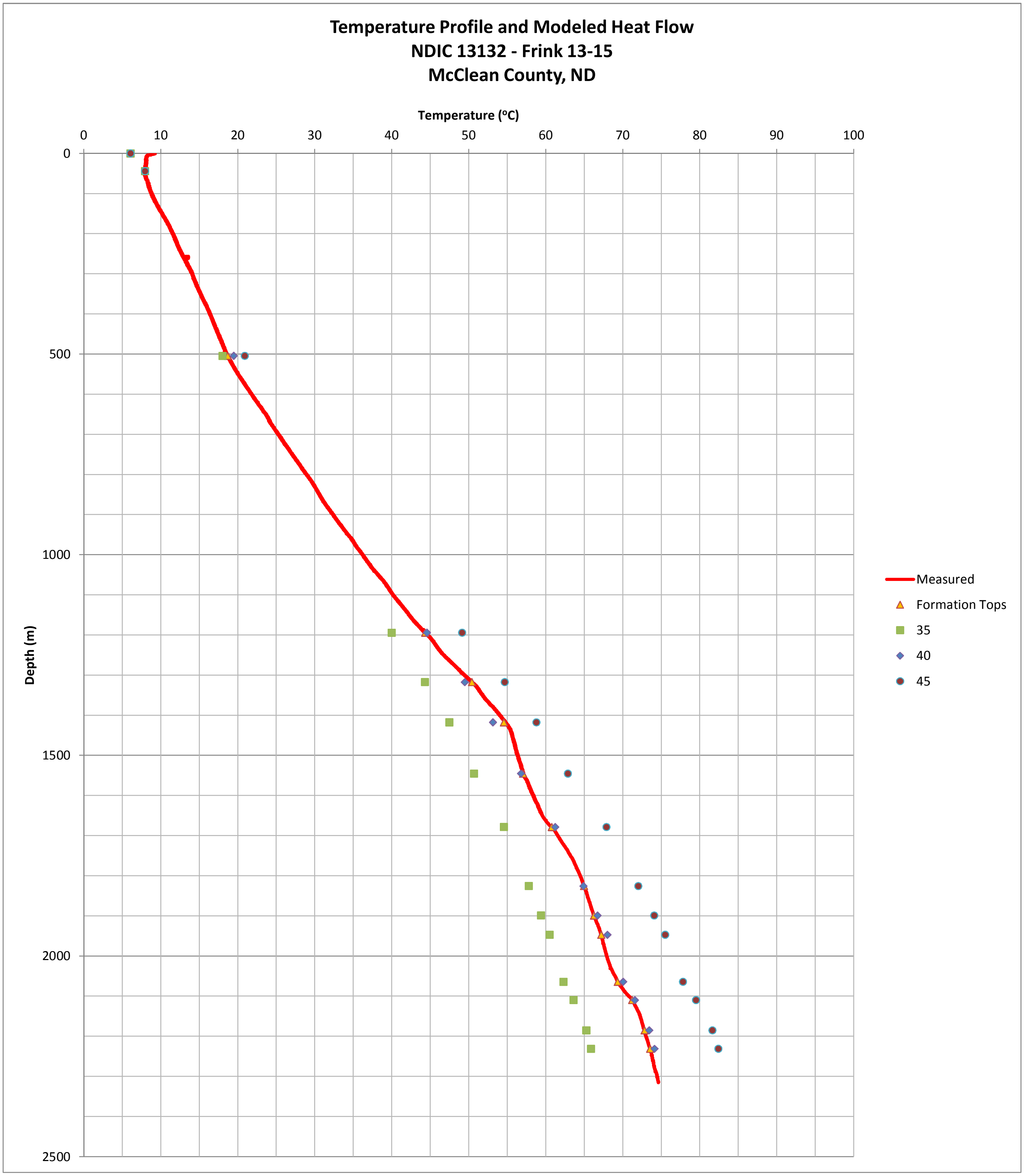


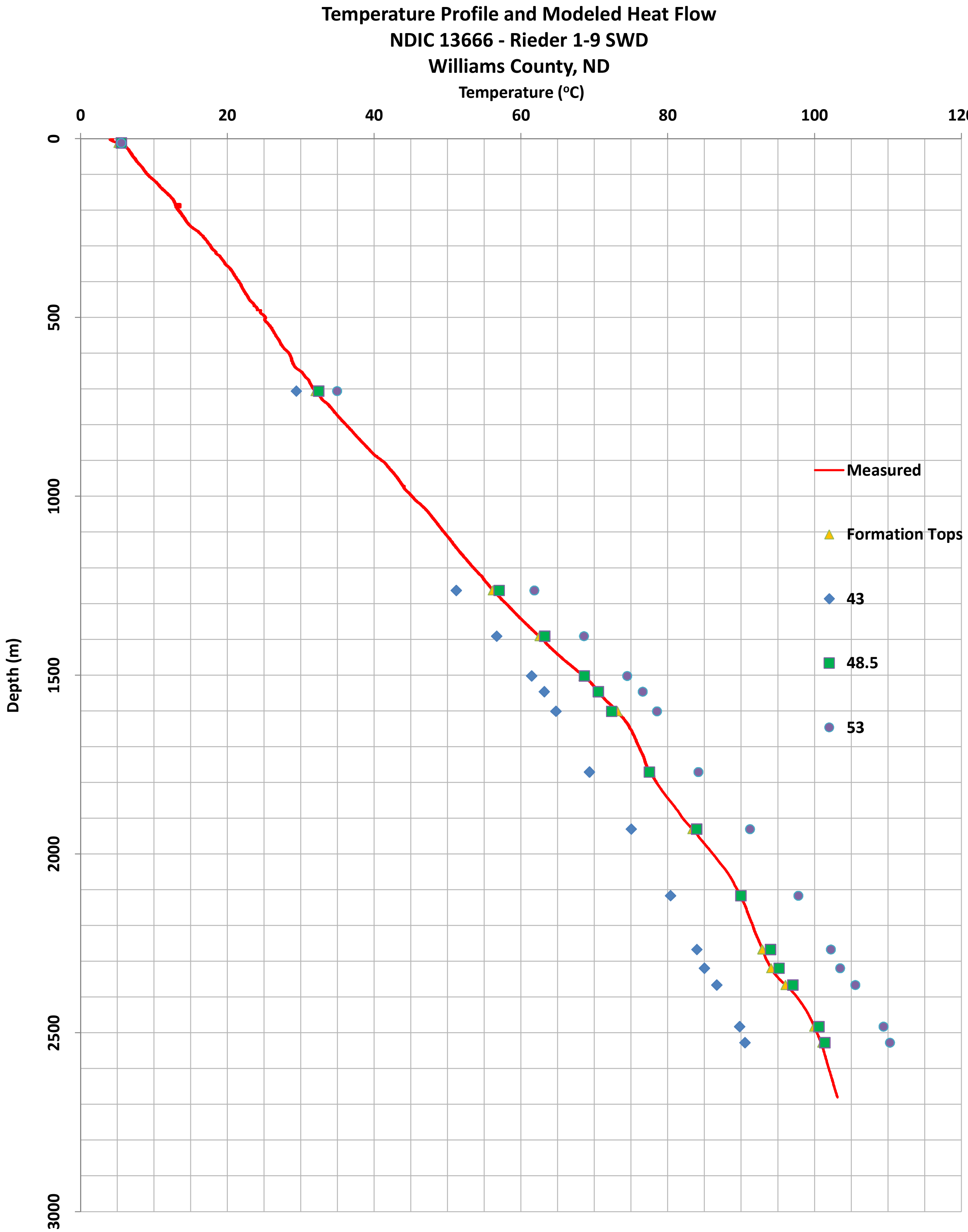


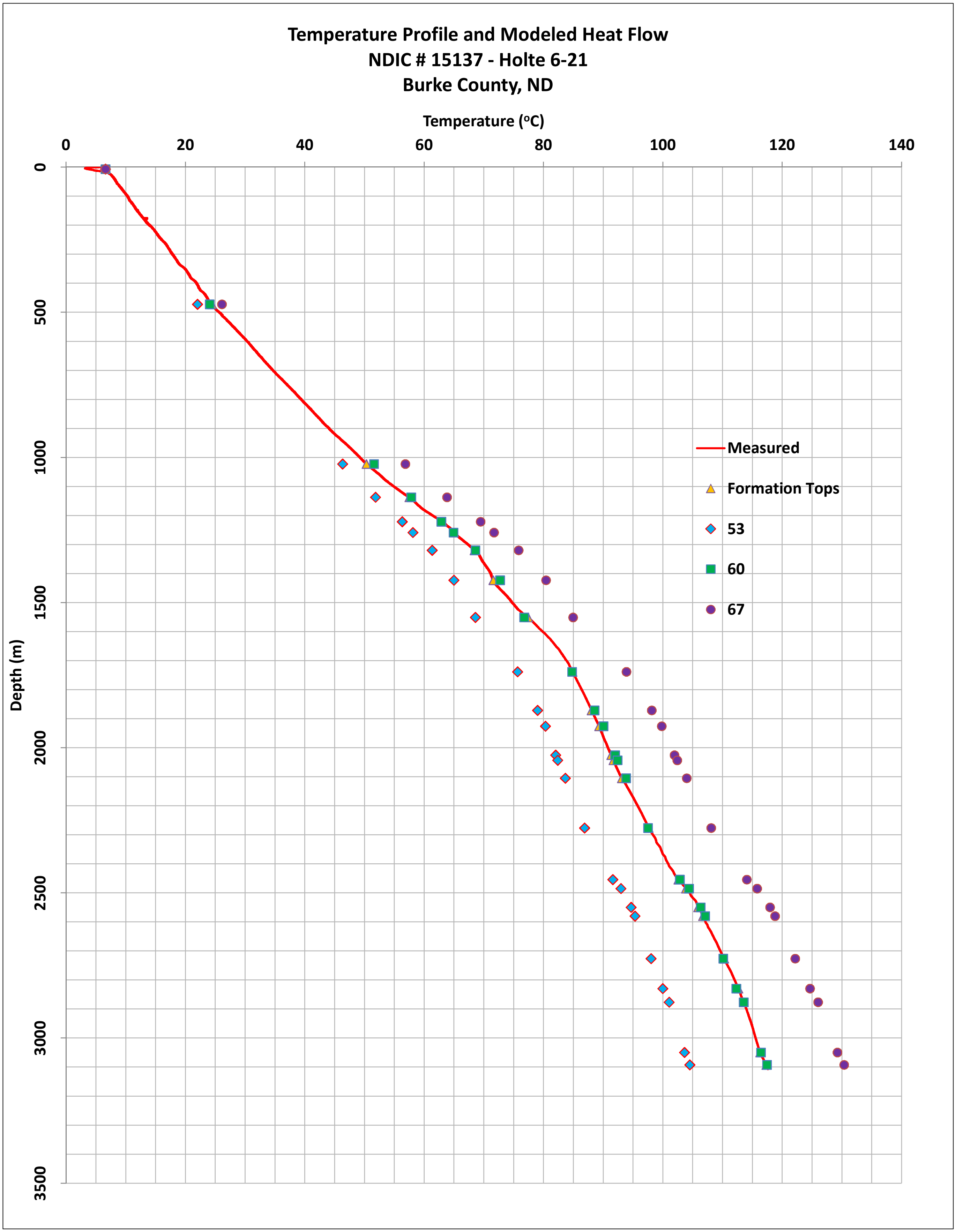
Temperature Profile and Modeled Heat Flow
NDIC 12280
Brandjord 1-20
Bottineau County, ND
Temperature (°C)
0
10
20
30
40
50
60
Depth (m)
0
100
200
300
400
500
600
700
800
900
1000
Measured
40
54
60
Fromation Tops

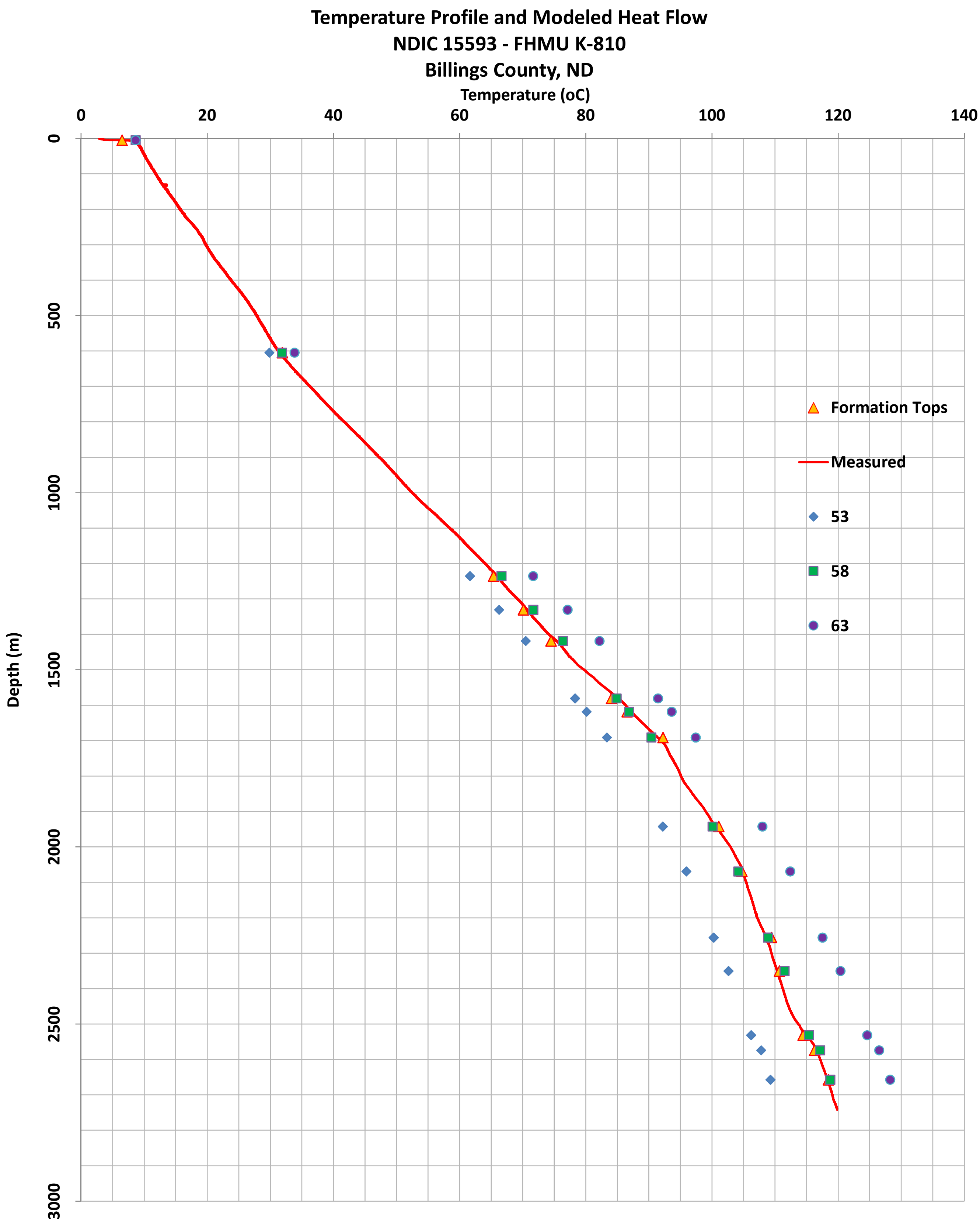


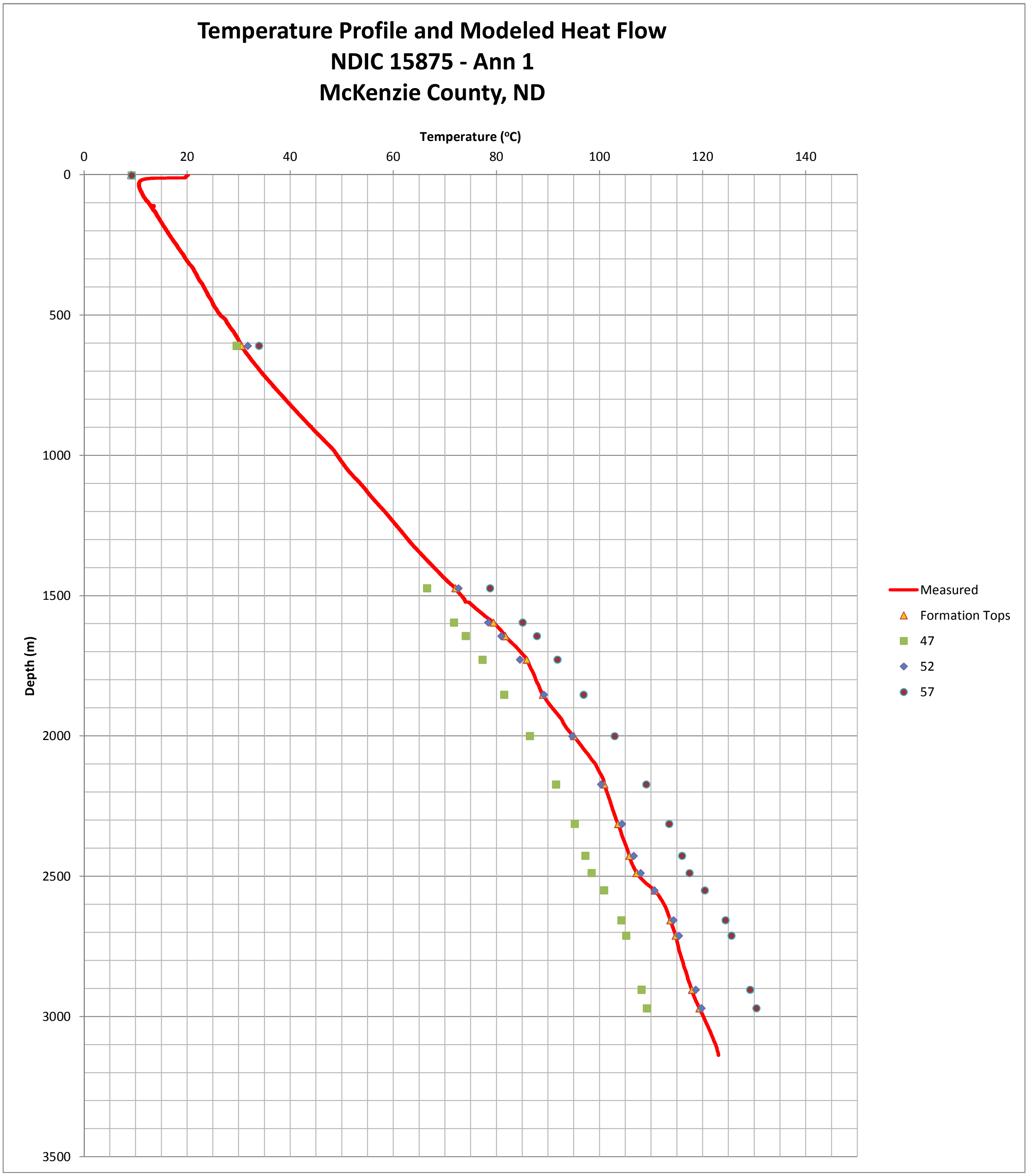
Temperature Profile and Hodeled Heat Flow
NDIC 12363 - Astrid Ongstad 14-22
Williams County, ND
Temperature (oC)
0
20
40
60
80
100
120
140
Depth (m)
0
500
1000
1500
2000
2500
3000
3500
4000
Measured
56.8 (90% of 57.3)
Formation Tops
47
52
57


Temperature Profile and Modeled Heat Flow
NDIC 13132 - Frink 13-15
McClean County, ND
Temperature (ºC)
0
10
20
30
40
50
60
70
80
90
100
Depth (m)
0
500
1000
1500
2000
2500
Measured
Formation Tops
35
40
45

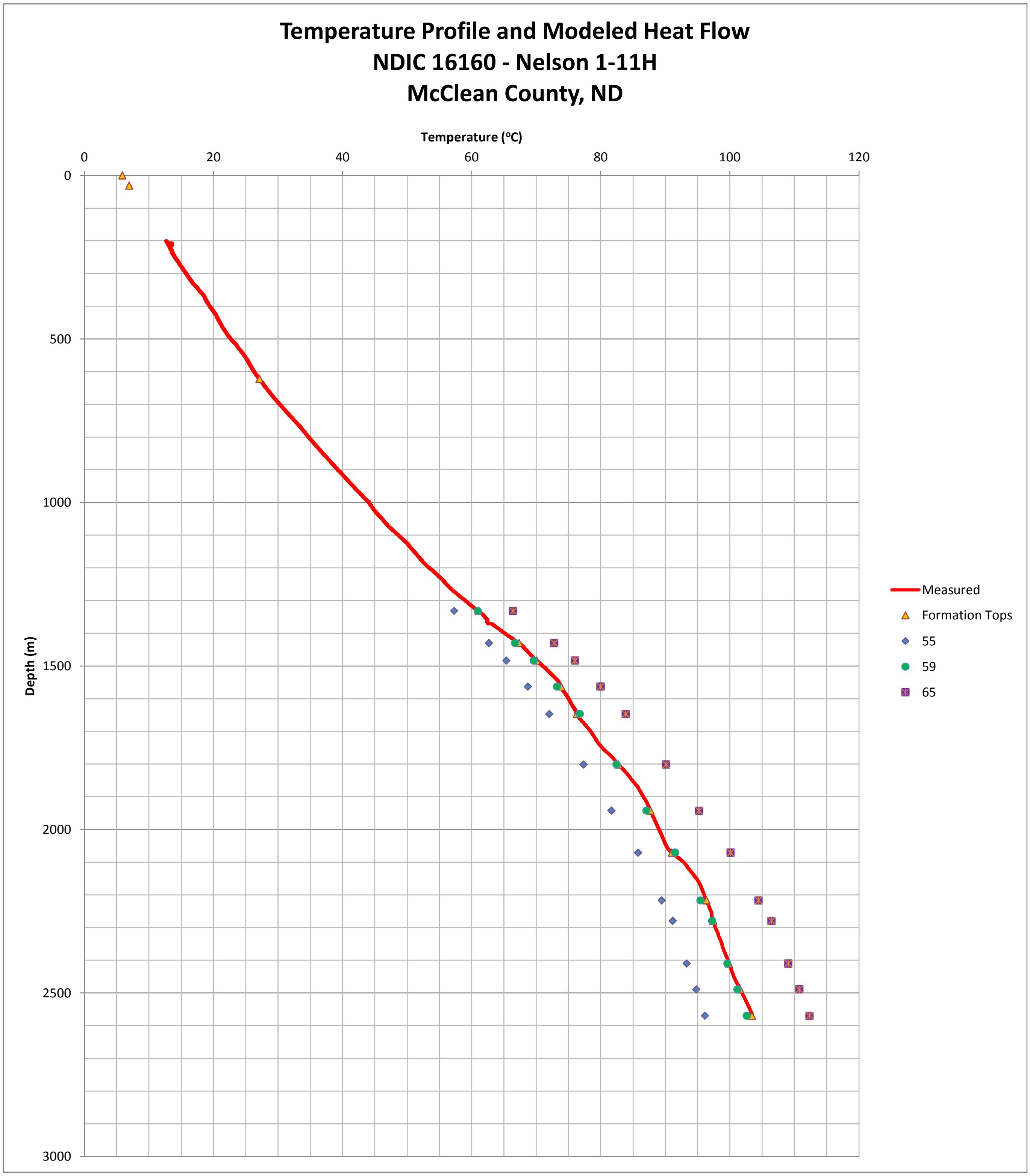

Temperature Profile and Modeled Heat Flow
NDIC 13666 - Rieder 1-9 SWD
Williams County, ND
Temperature (°C)
0
20
40
60
80
100
120
Depth (m)
0
500
1000
1500
2000
2500
3000
Measured
Formation Tops
43
48.5
53

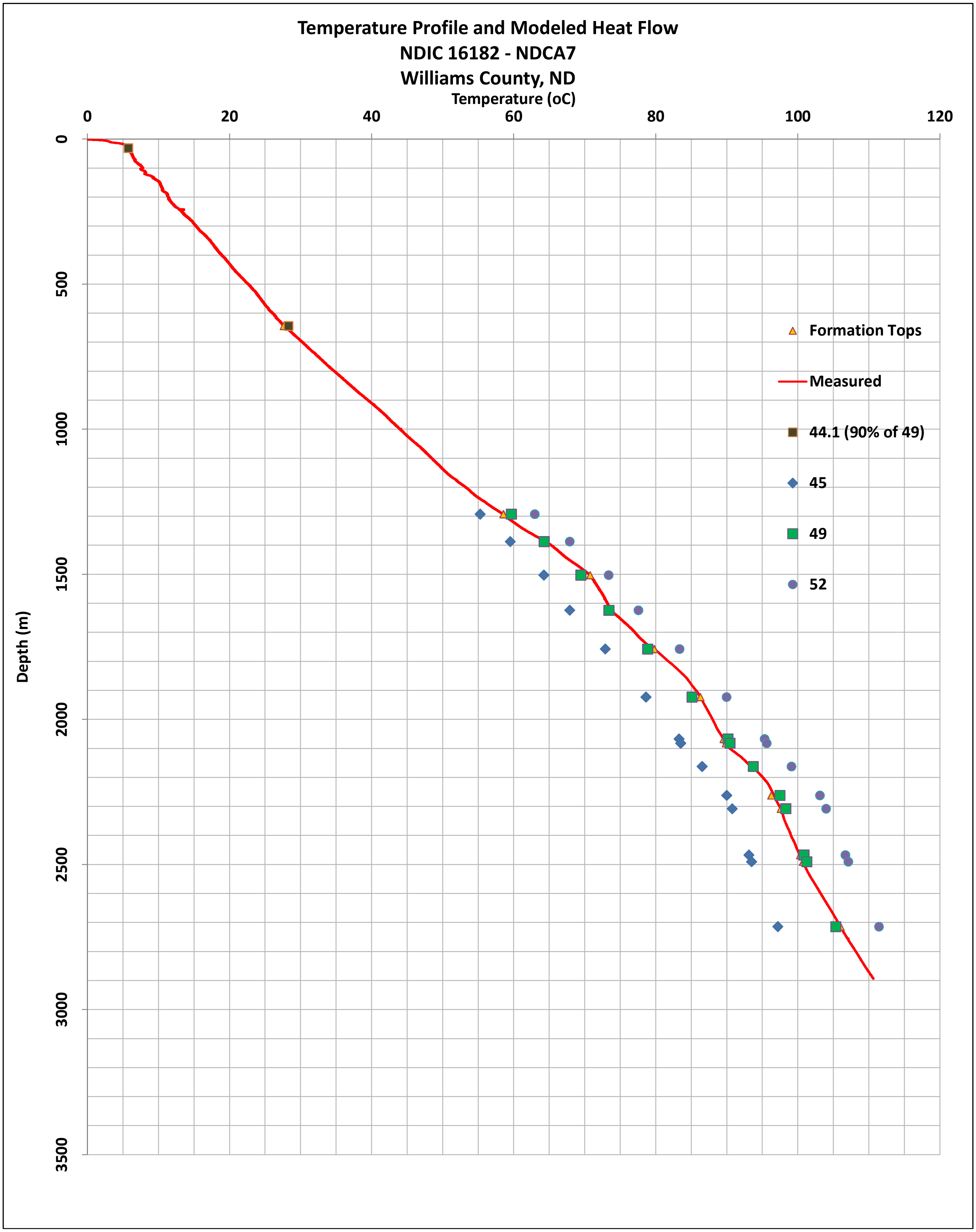

Temperature Profile and Modeled Heat Flow
NDIC # 15137 - Holte 6-21
Burke County, ND
Temperature (°C)
0
20
40
60
80
100
120
140
Depth (m)
0
500
1000
1500
2000
2500
3000
3500
Measured
Formation Tops
53
60
67

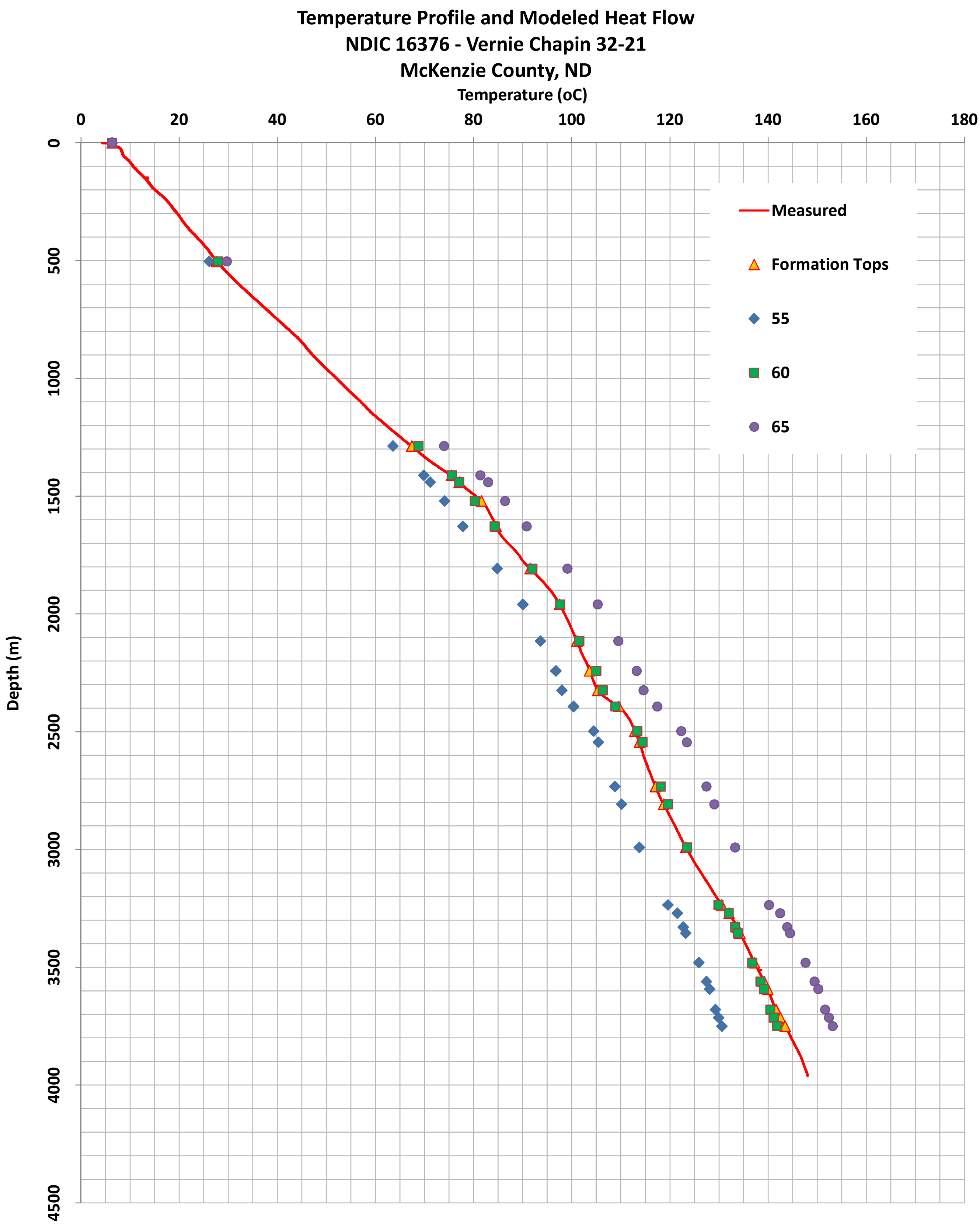

Temperature Profile and Modeled Heat Flow
NDIC 15593 - FHMU K-810
Billings County, ND
Temperature (oC)
0
20
40
60
80
100
120
140
Depth (m)
0
500
1000
1500
2000
2500
3000
Formation Tops
Measured
53
58
63

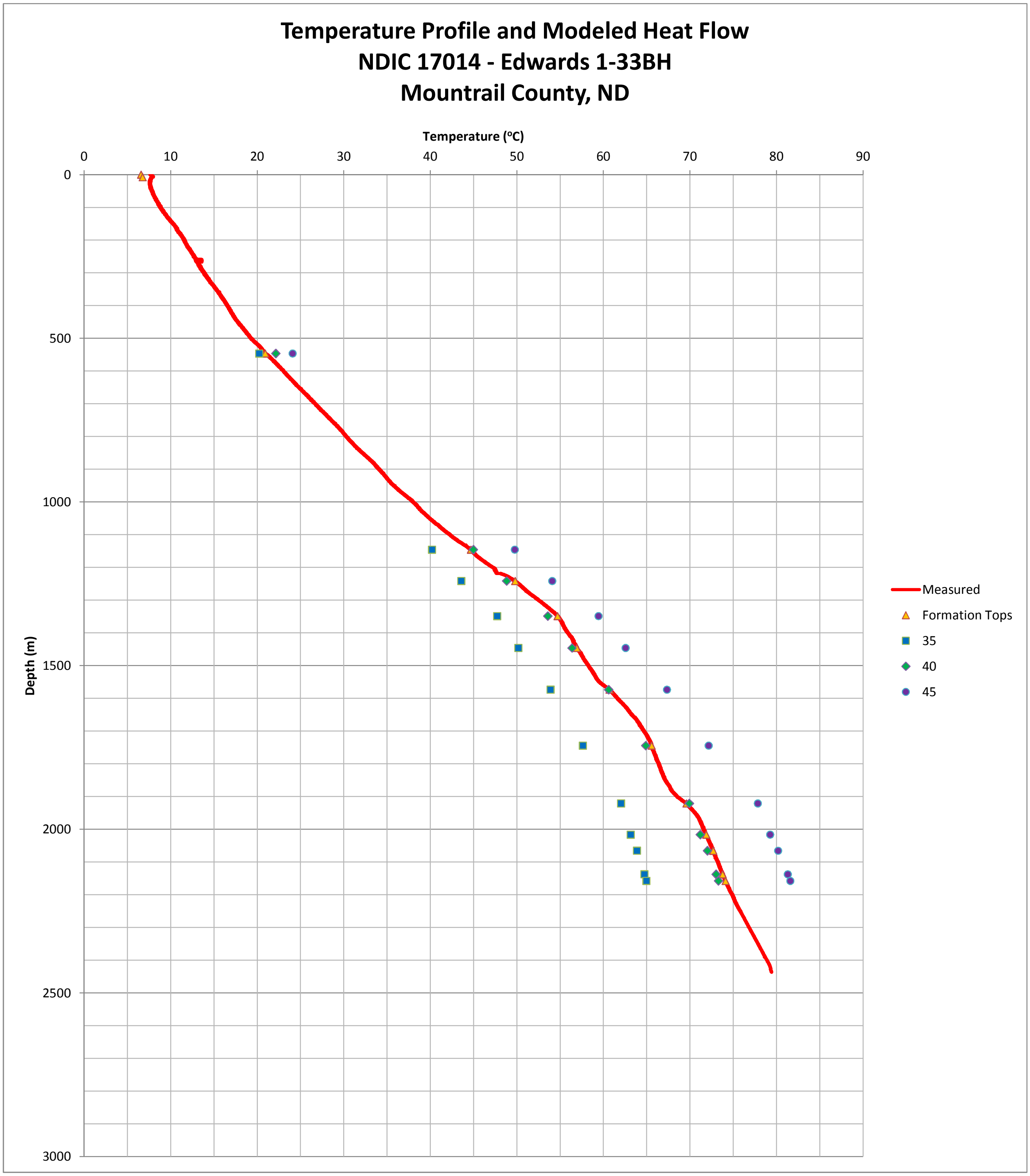


Temperature Profile and Modeled Heat Flow
NDIC 15875 - Ann 1
McKenzie County, ND
Temperature (°C)
0
20
40
60
80
100
120
140
0
500
1000
1500
2000
2500
3000
3500
Depth (m)
Measured
Formation Tops
47
52
57

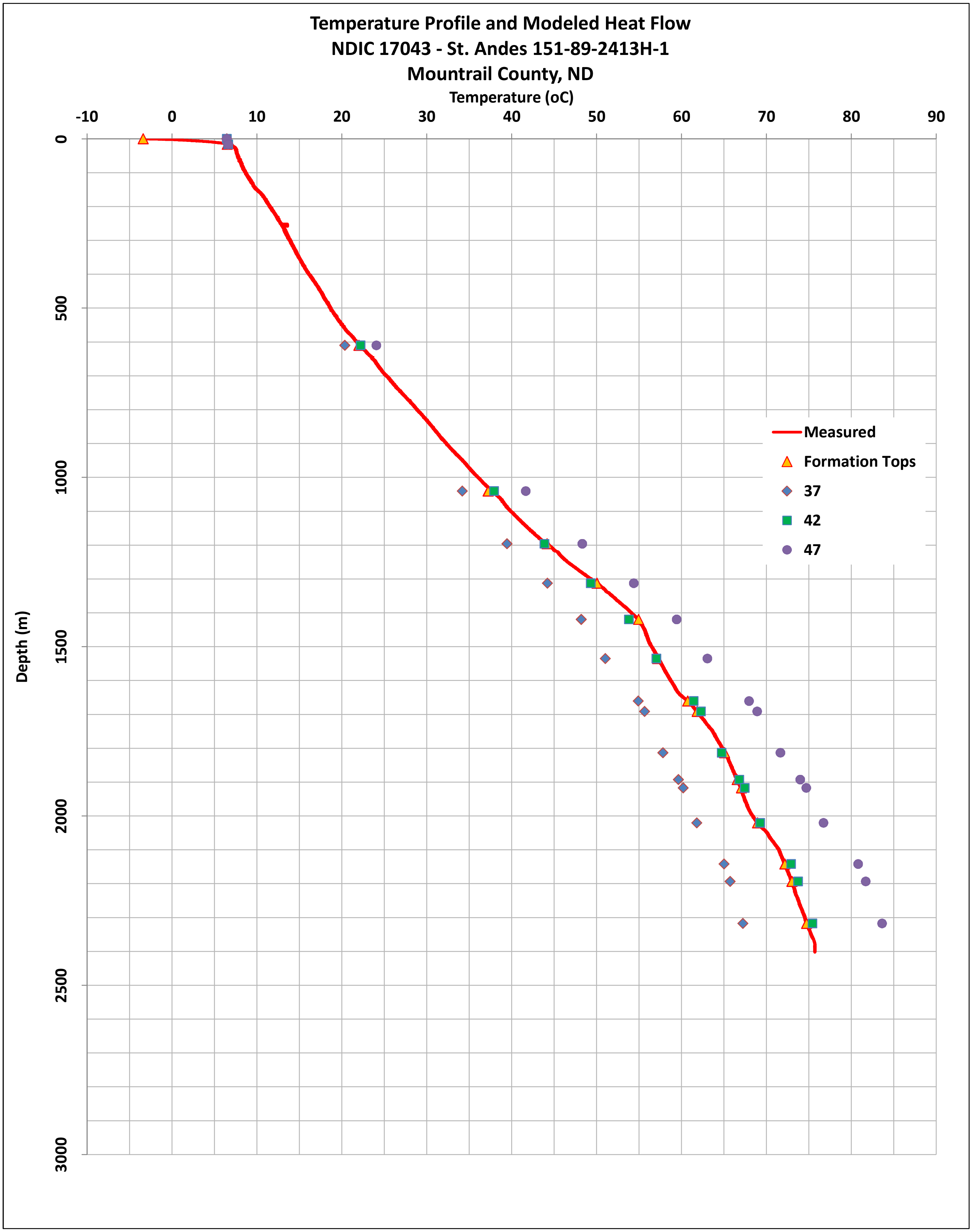

Temperature Profile and Modeled Heat Flow
NDIC 16160 - Nelson 1-11H
McClean County, ND
Temperature (°C)
0
20
40
60
80
100
120
0
500
1000
1500
2000
2500
3000
Depth (m)
Measured
Formation Tops
55
59
65

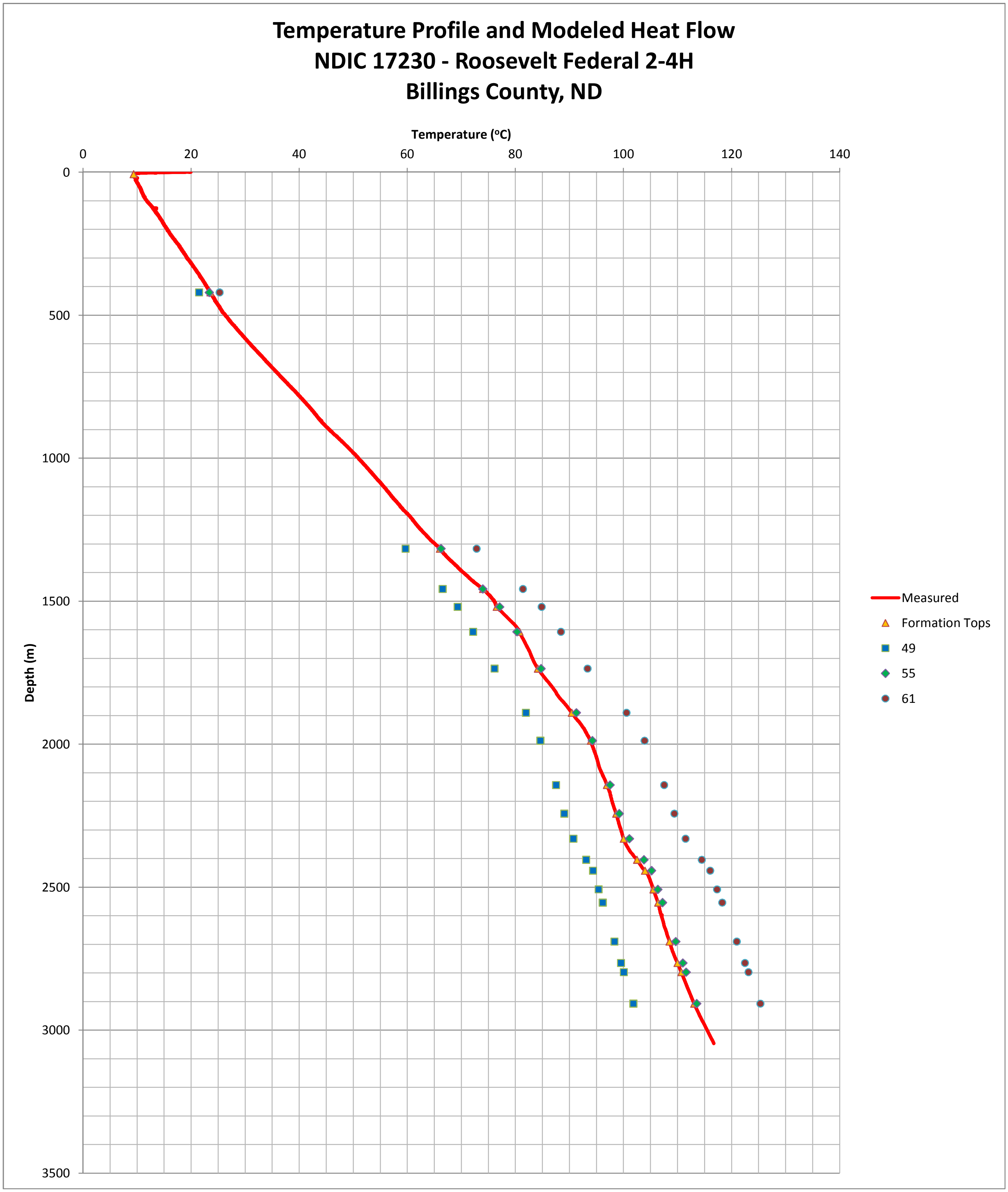

Temperature Profile and Modeled Heat Flow
NDIC 16182 - NDCA7
Williams County, ND
Temperature (oC)
0
20
40
60
80
100
120
Depth (m)
0
500
1000
1500
2000
2500
3000
3500
Formation Tops
Measured
44.1 (90% of 49)
45
49
52

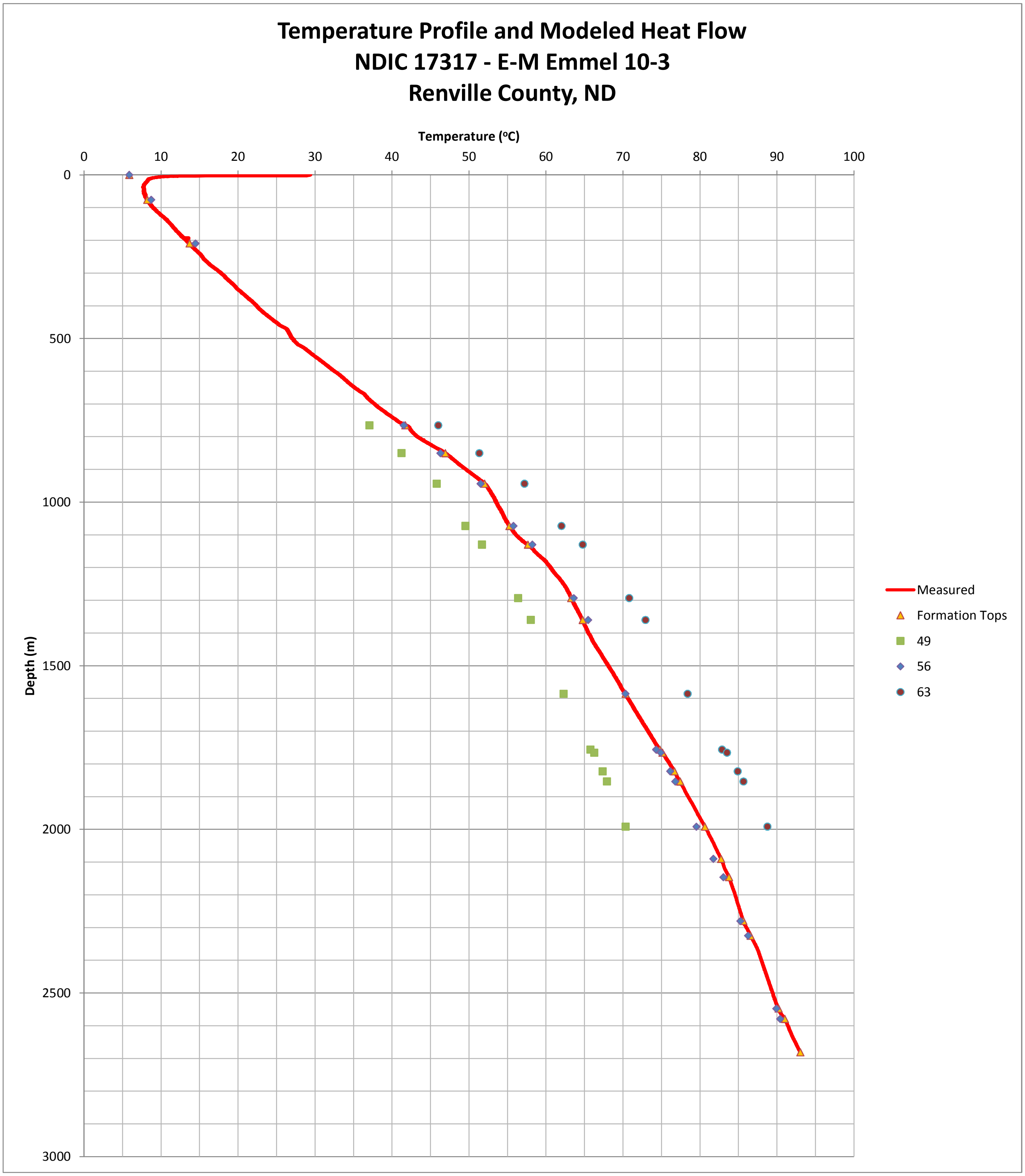

Temperature Profile and Modeled Heat Flow
NDIC 16376 - Vernie Chapin 32-21
McKenzie County, ND
Temperature (oC)
0
20
40
60
80
100
120
140
160
180
Depth (m)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Measured
Formation Tops
55
60
65



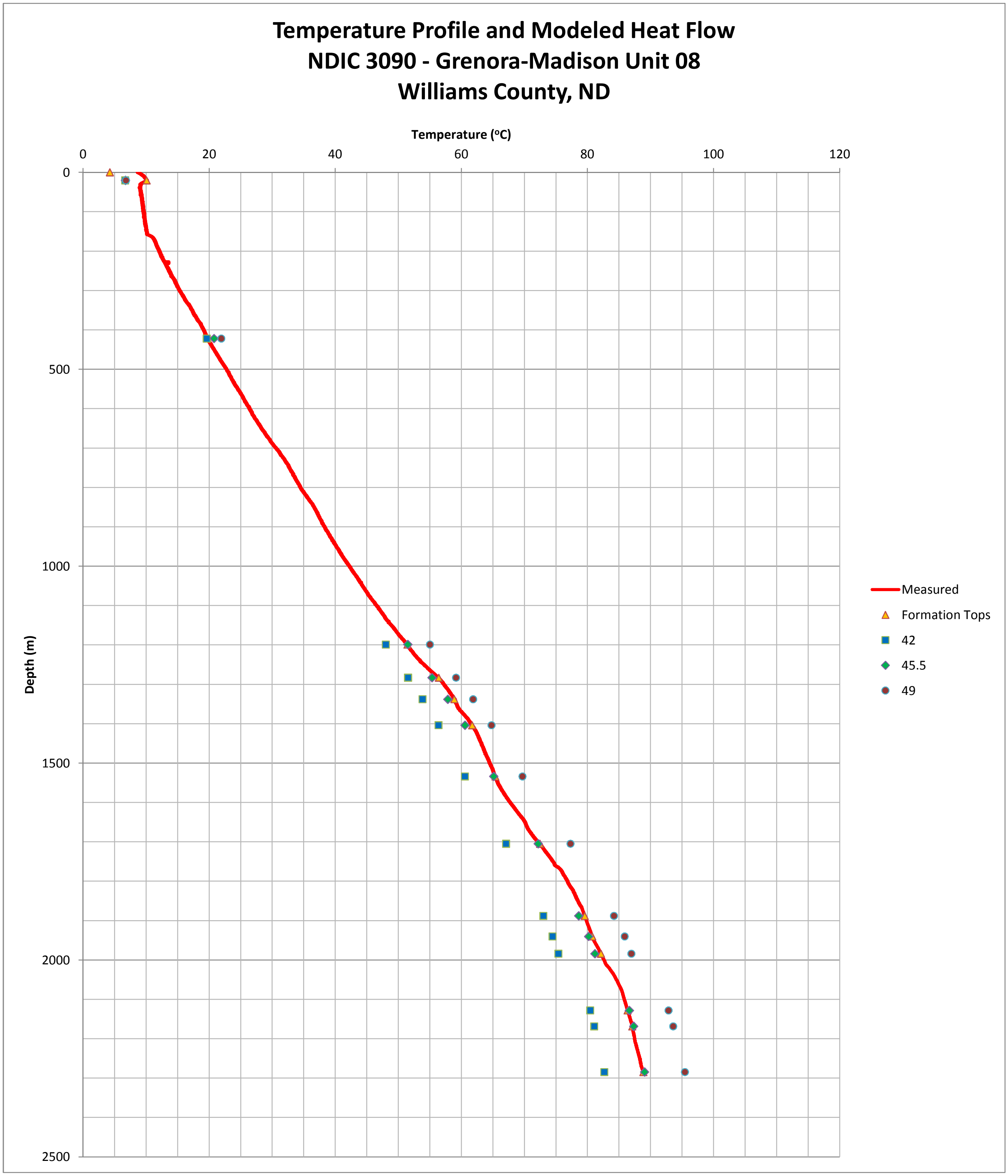
Temperature Profile and Modeled Heat Flow
NDIC 17014 - Edwards 1-33BH
Mountrail County, ND
Temperature (°C)
0
10
20
30
40
50
60
70
80
90
Depth (m)
0
500
1000
1500
2000
2500
3000
Measured
Formation Tops
35
40
45

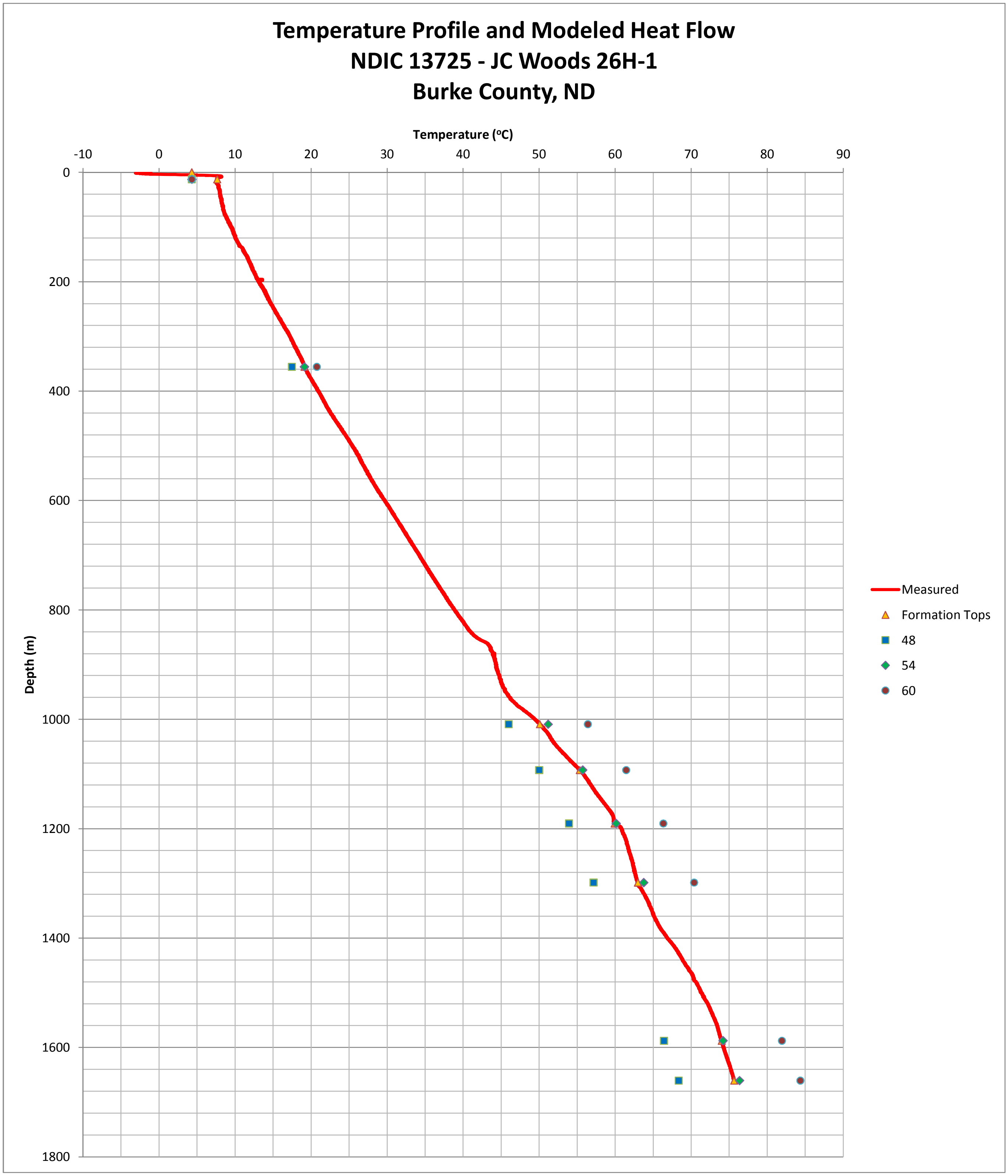

Temperature Profile and Modeled Heat Flow
NDIC 17043 - St. Andes 151-89-2413H-1
Mountrail County, ND
Temperature (oC)
-10
0
10
20
30
40
50
60
70
80
90
Depth (m)
0
500
1000
1500
2000
2500
3000
Measured
Formation Tops
37
42
47


Temperature Profile and Modeled Heat Flow
NDIC 17230 - Roosevelt Federal 2-4H
Billings County, ND
Temperature (°C)
0
20
40
60
80
100
120
140
Depth (m)
0
500
1000
1500
2000
2500
3000
3500
Measured
Formation Tops
49
55
61



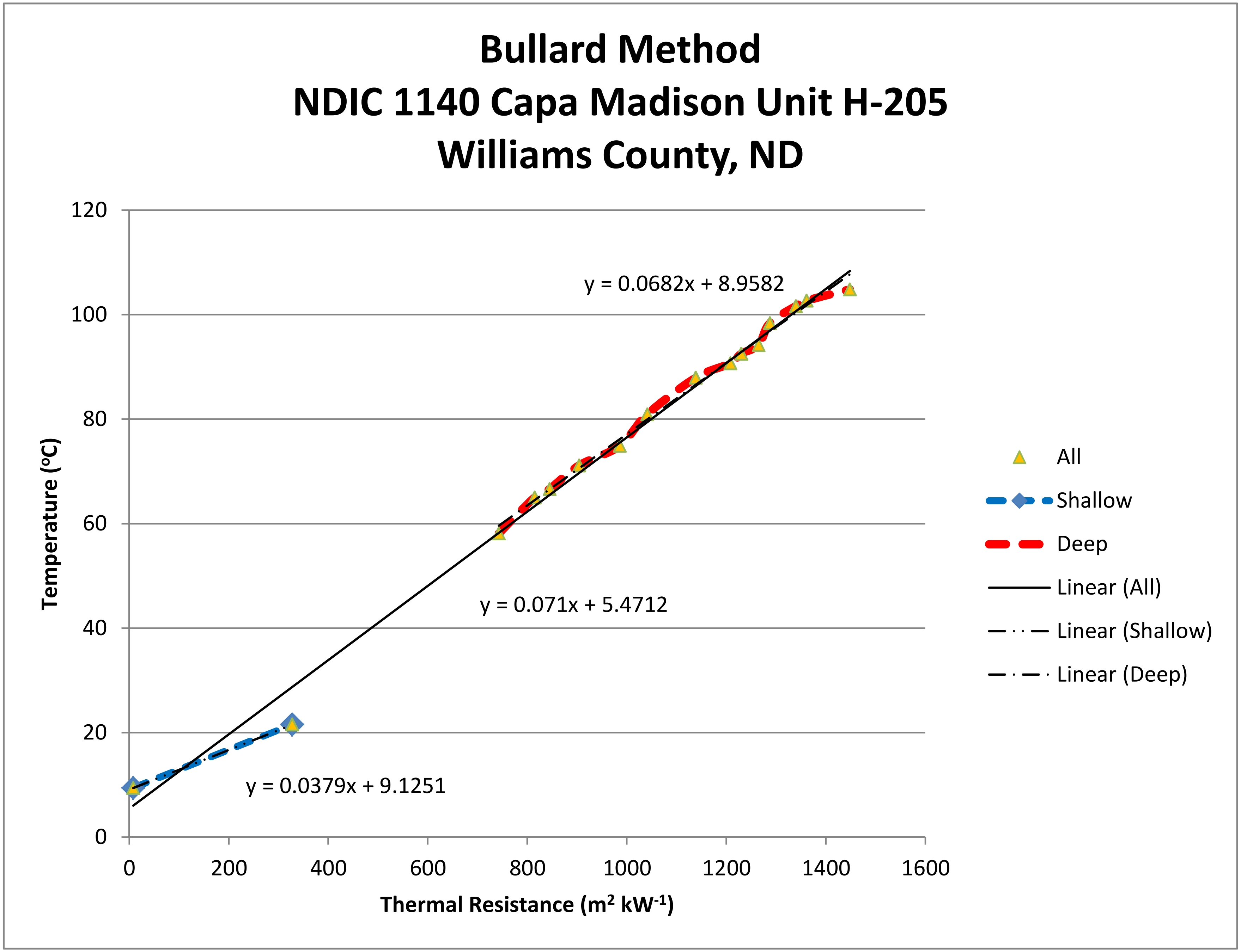
Temperature Profile and Modeled Heat Flow
NDIC 17317 - E-M Emmel 10-3
Renville County, ND
Temperature (°C)
0
10
20
30
40
50
60
70
80
90
100
0
500
1000
1500
2000
2500
3000
Depth (m)
Measured
Formation Tops
49
56
63

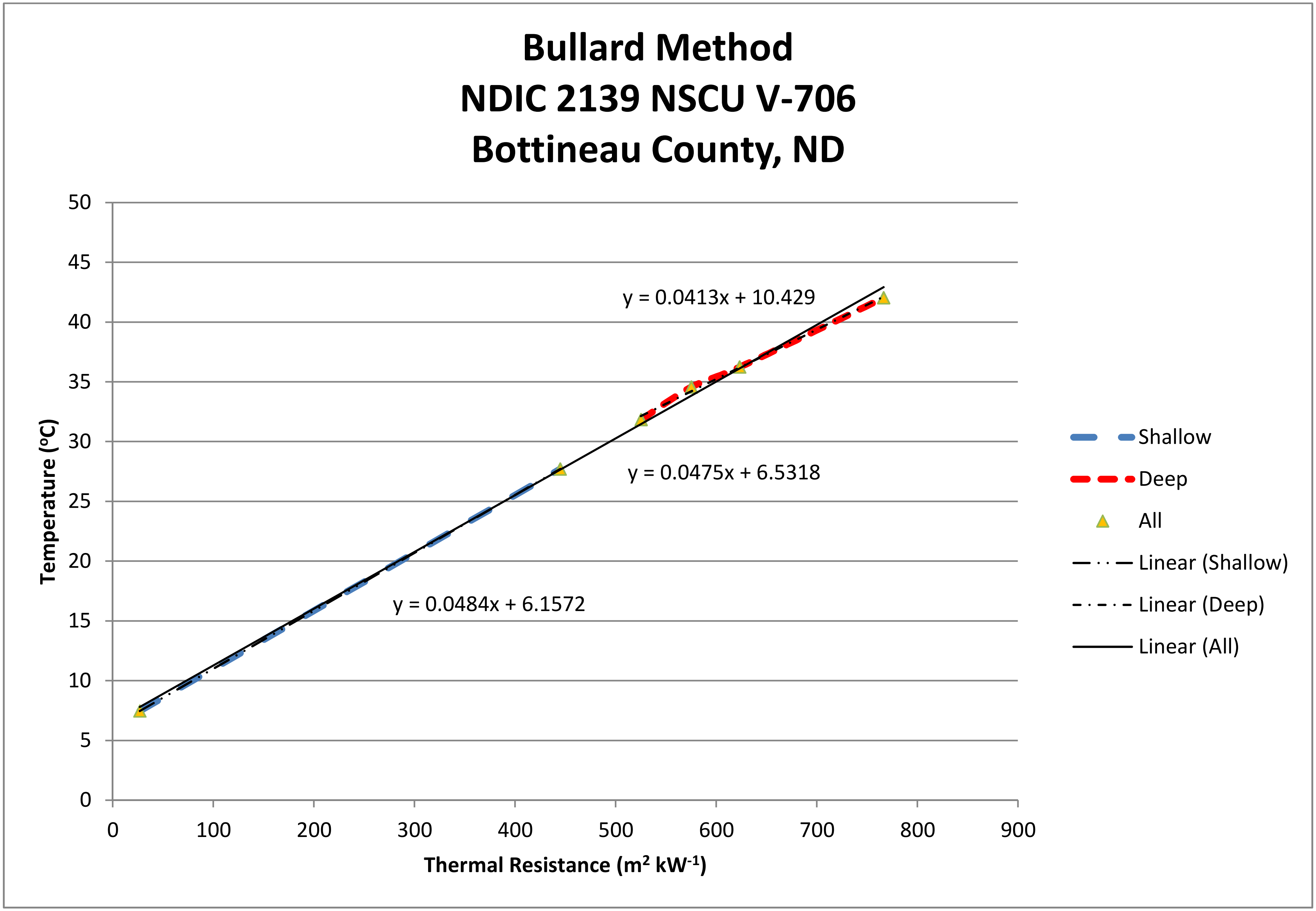

Temperature Profile and Modeled Heat Flow
NDIC 3090 - Grenora-Madison Unit 08
Williams County, ND
Temperature (°C)
0
20
40
60
80
100
120
Depth (m)
0
500
1000
1500
2000
2500
Measured
Formation Tops
42
45.5
49

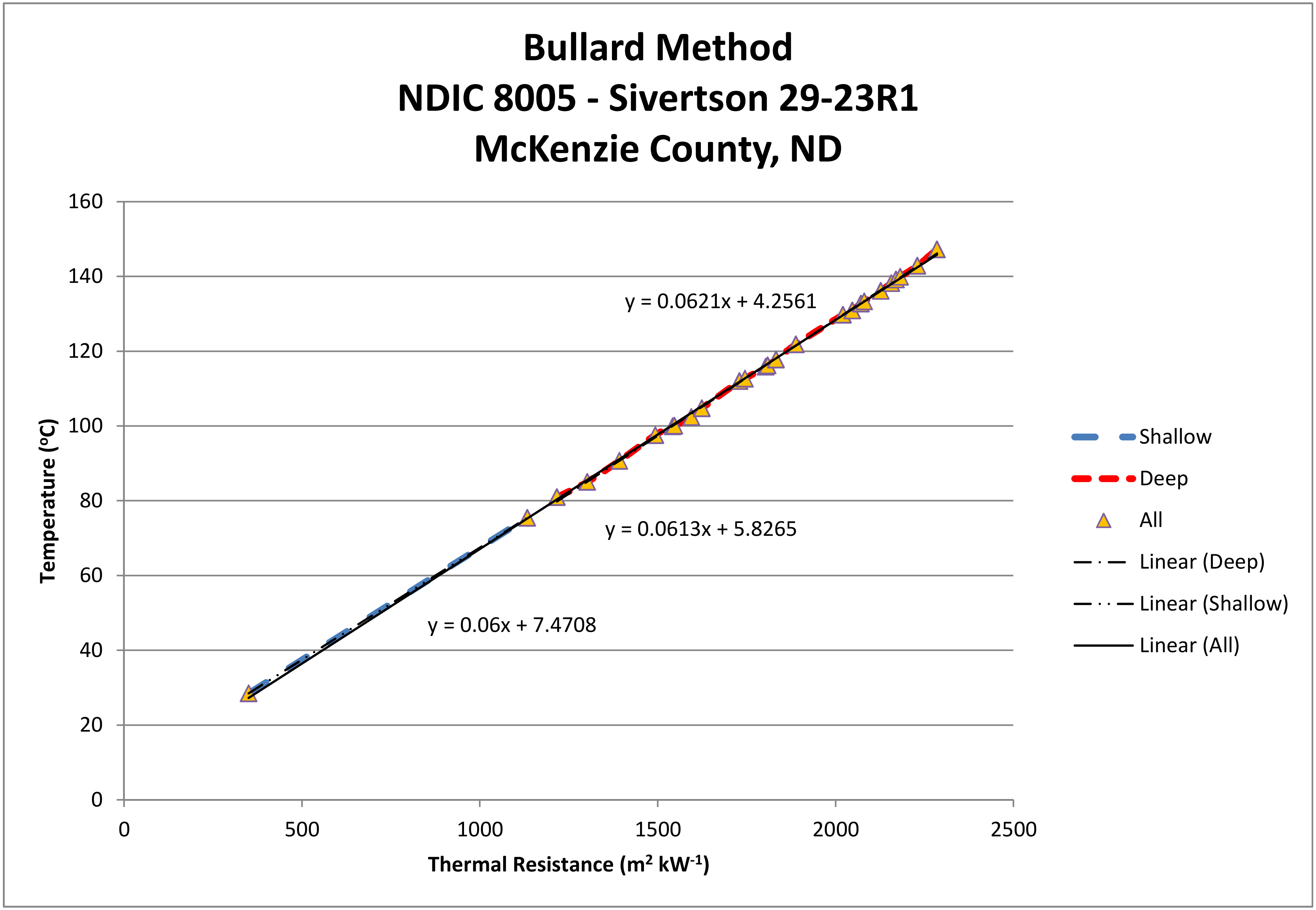

Temperature Profile and Modeled Heat Flow
NDIC 13725 - JC Woods 26H-1
Burke County, ND
Temperature (°C)
-10
0
10
20
30
40
50
60
70
80
90
Depth (m)
0
200
400
600
800
1000
1200
1400
1600
1800
Measured
Formation Tops
48
54
60

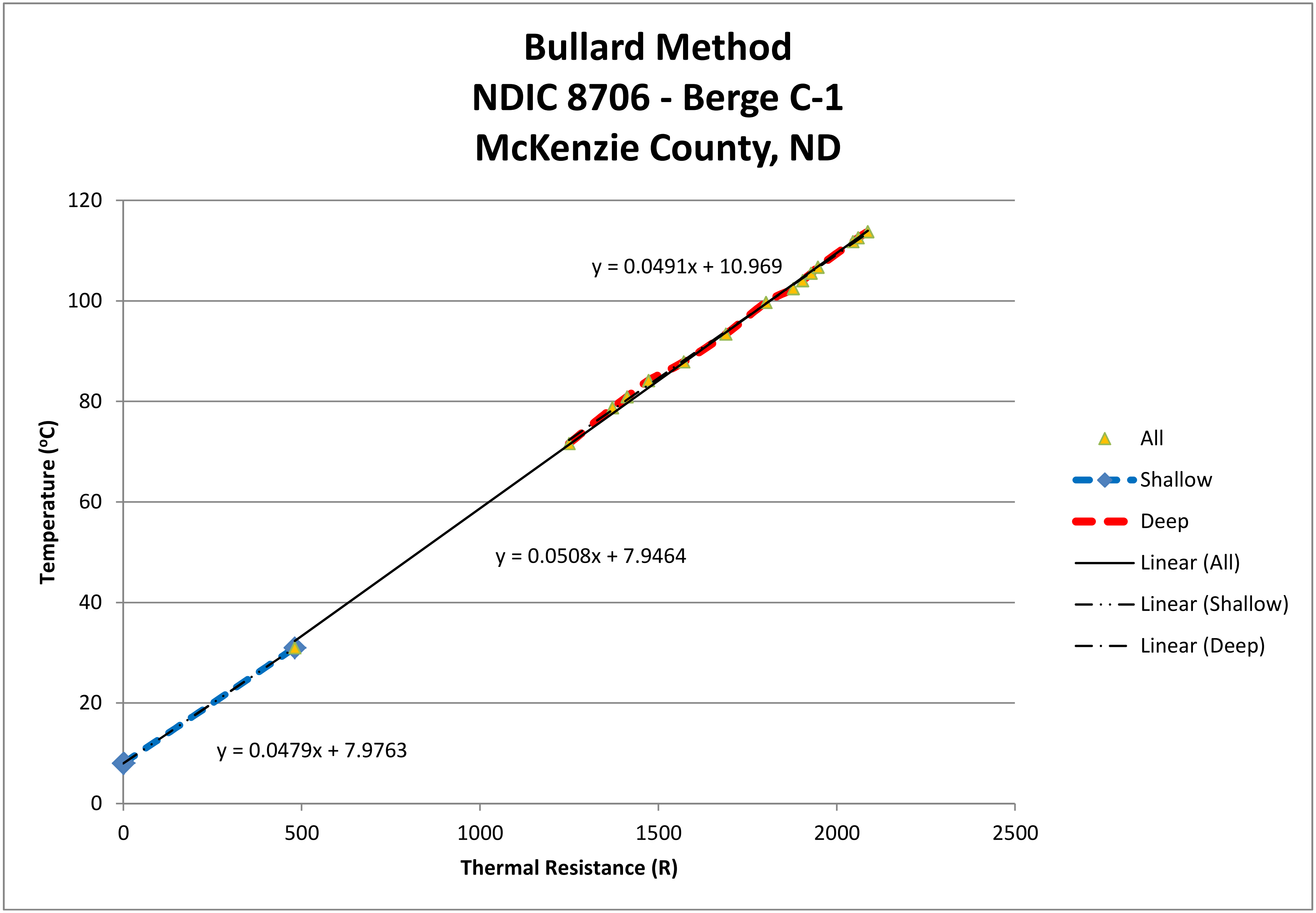
APPENDIX D

BULLARD METHOD PLOTS

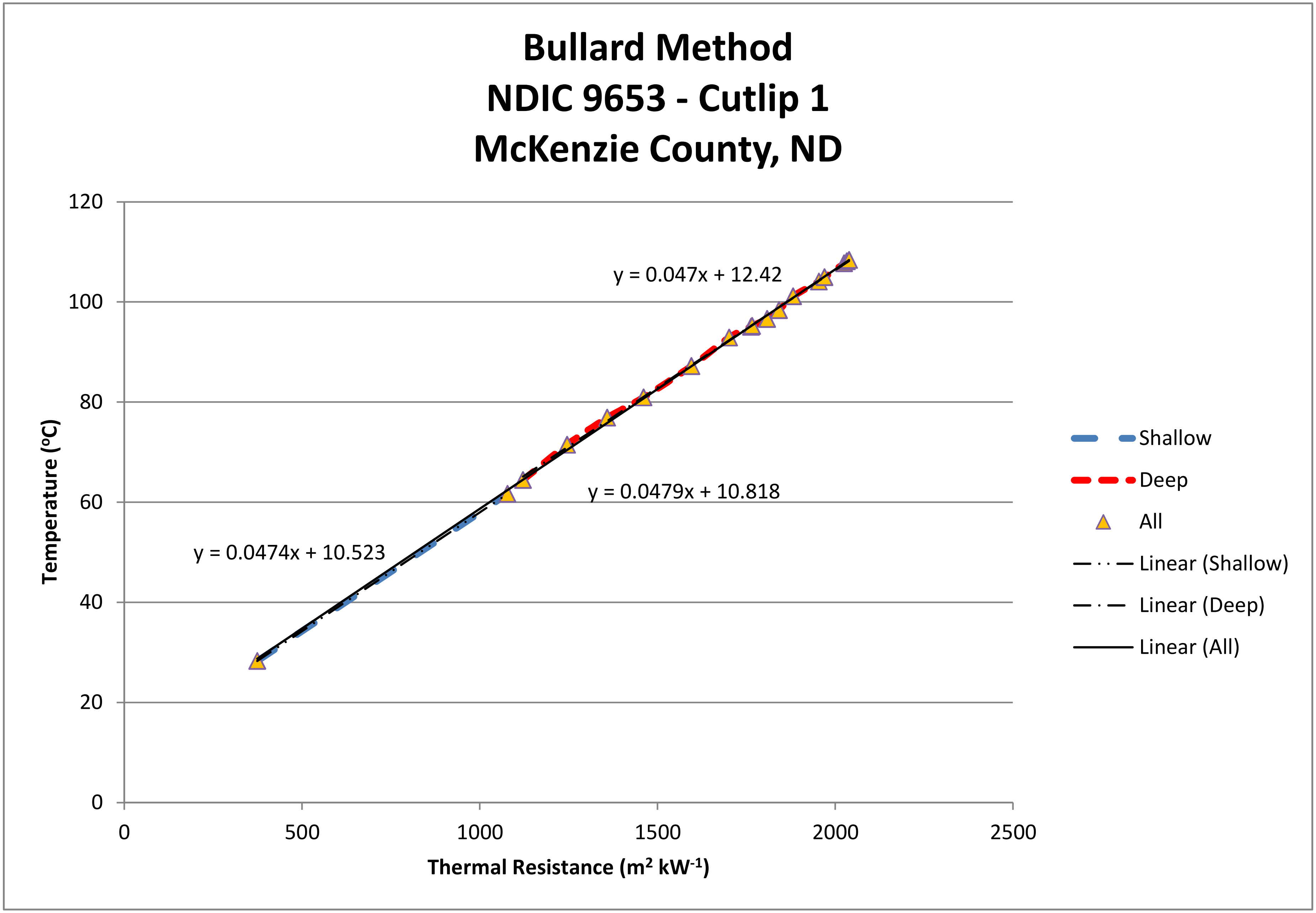

Bullard Method
NDIC 1140 Capa Madison Unit H-205
Williams County, ND
y = 0.0682x + 8.9582
y = 0.071x + 5.4712
y = 0.0379x + 9.1251
Temperature (°C)
Thermal Resistance (m² kW⁻¹)
0
20
40
60
80
100
120
0
200
400
600
800
1000
1200
1400
1600
All
Shallow
Deep
Linear (All)
Linear (Shallow)
Linear (Deep)

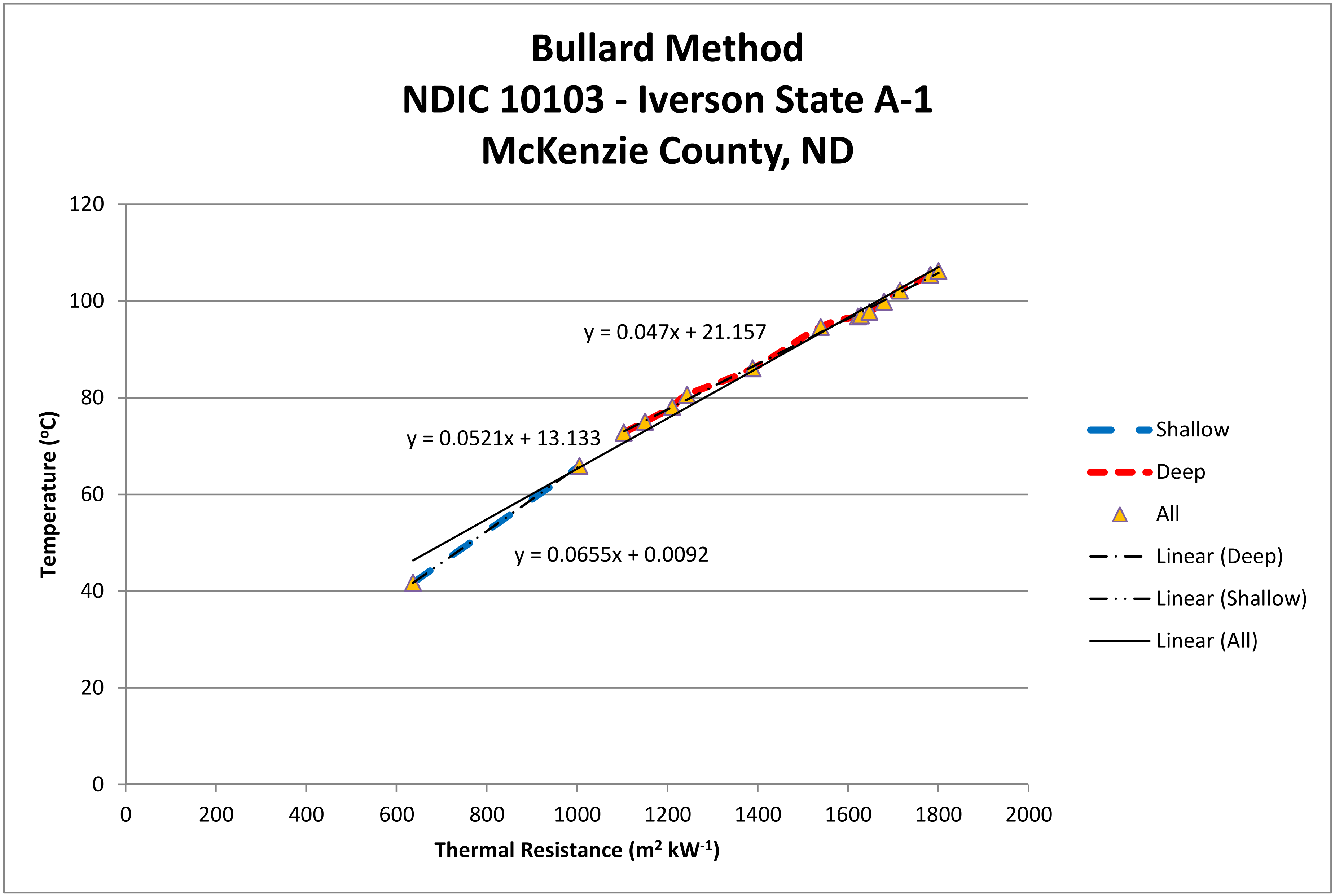

Bullard Method
NDIC 2139 NSCU V-706
Bottineau County, ND
y = 0.0413x + 10.429
y = 0.0475x + 6.5318
y = 0.0484x + 6.1572
Temperature (°C)
Thermal Resistance (m² kW⁻¹)
50
45
40
35
30
25
20
15
10
5
0
0
100
200
300
400
500
600
700
800
900
Shallow
Deep
All
Linear (Shallow)
Linear (Deep)
Linear (All)

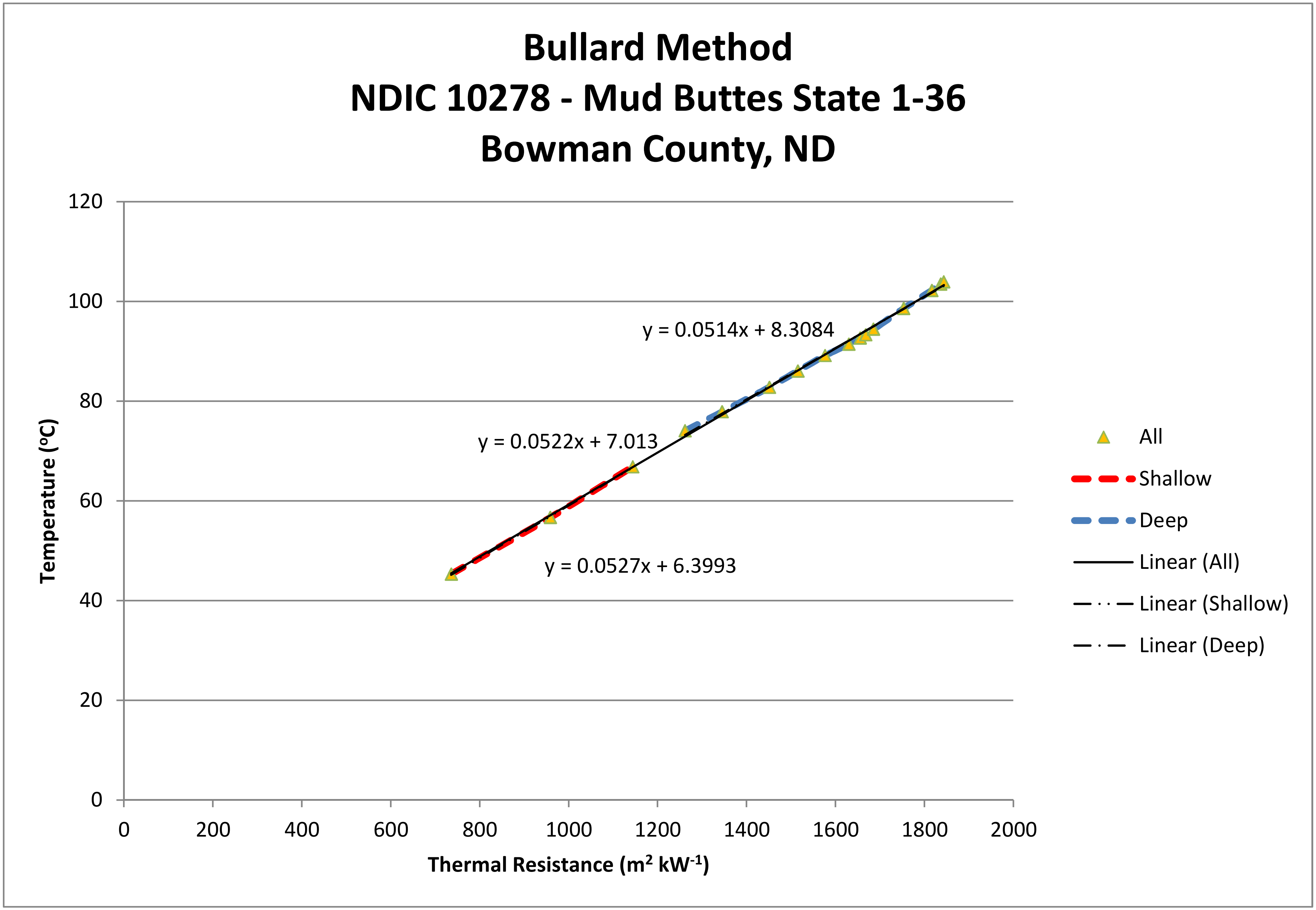

Bullard Method
NDIC 8005 - Sivertson 29-23R1
McKenzie County, ND
y = 0.0621x + 4.2561
y = 0.0613x + 5.8265
y = 0.06x + 7.4708
Temperature (ºC)
Thermal Resistance (m² kW⁻¹)
0
20
40
60
80
100
120
140
160
0
500
1000
1500
2000
2500
Shallow
Deep
All
Linear (Deep)
Linear (Shallow)
Linear (All)

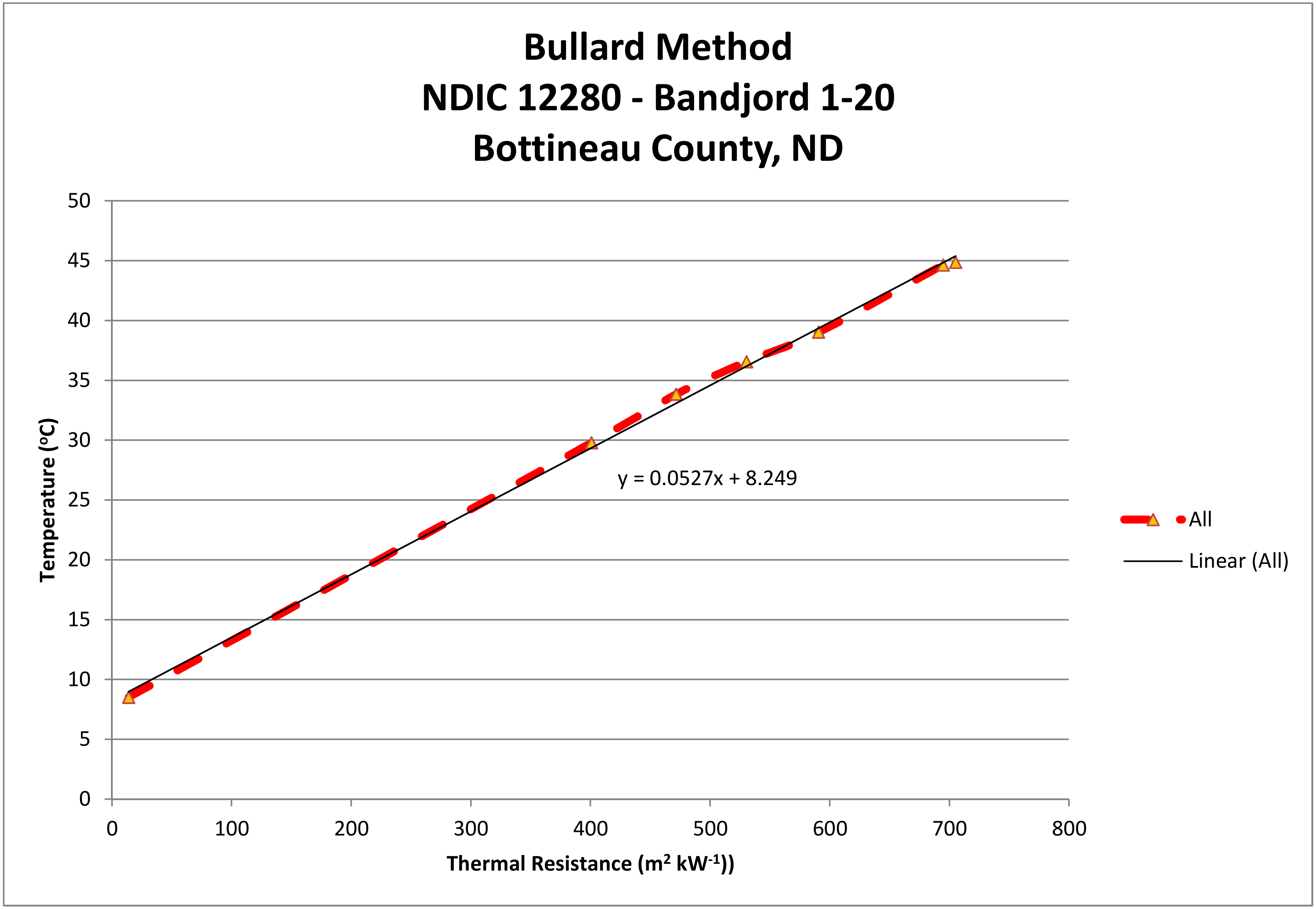


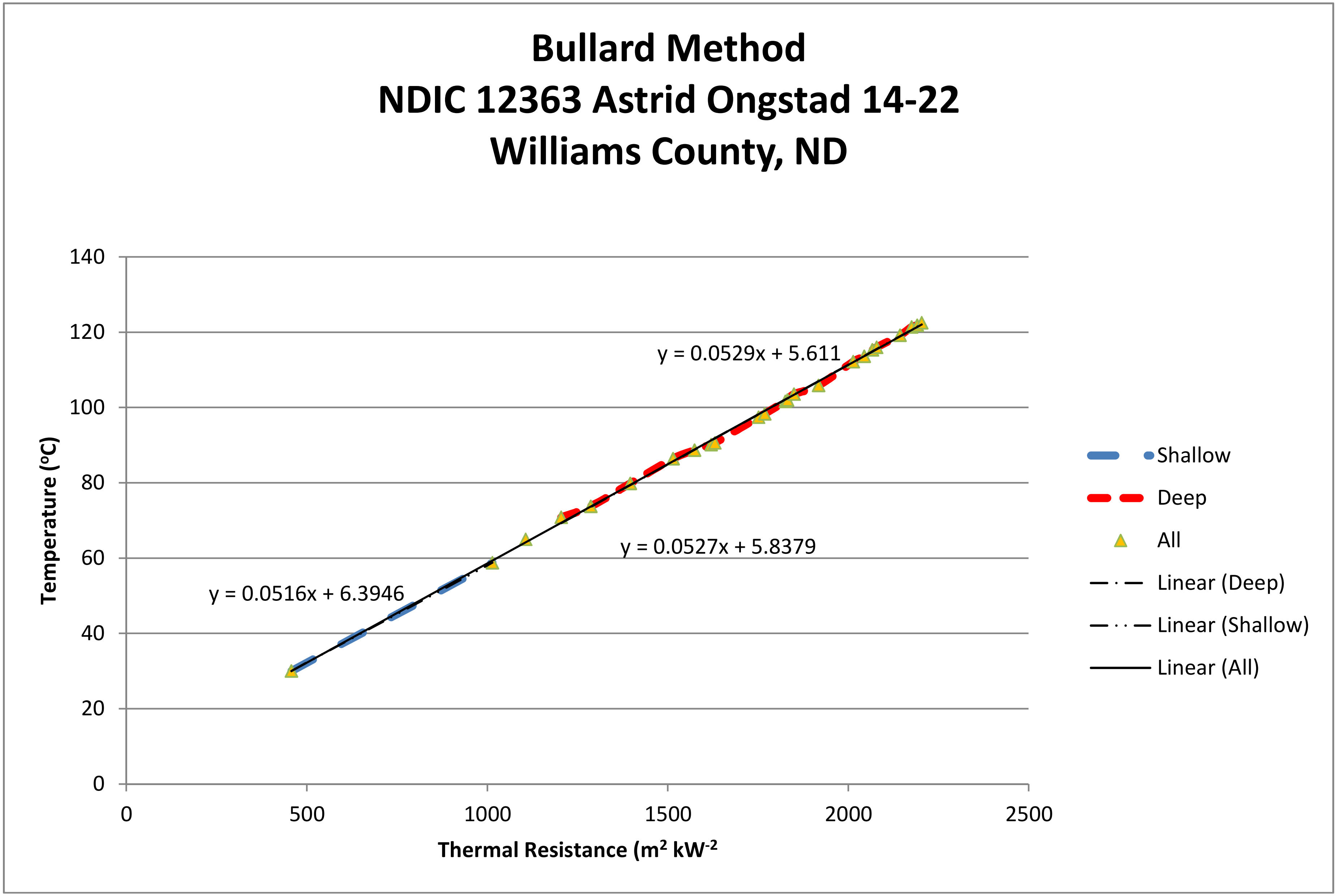
Bullard Method
NDIC 8706 - Berge C-1
McKenzie County, ND
Temperature (°C)
Thermal Resistance (R)
120
100
80
60
40
20
0
0
500
1000
1500
2000
2500
y = 0.0491x + 10.969
y = 0.0508x + 7.9464
y = 0.0479x + 7.9763
All
Shallow
Deep
Linear (All)
Linear (Shallow)
Linear (Deep)


Bullard Method
NDIC 9653 - Cutlip 1
McKenzie County, ND
120
100
80
60
40
20
0
Temperature (ºC)
0
500
1000
1500
2000
2500
Thermal Resistance (m² kW⁻¹)
y = 0.047x + 12.42
y = 0.0479x + 10.818
y = 0.0474x + 10.523
Shallow
Deep
All
Linear (Shallow)
Linear (Deep)
Linear (All)

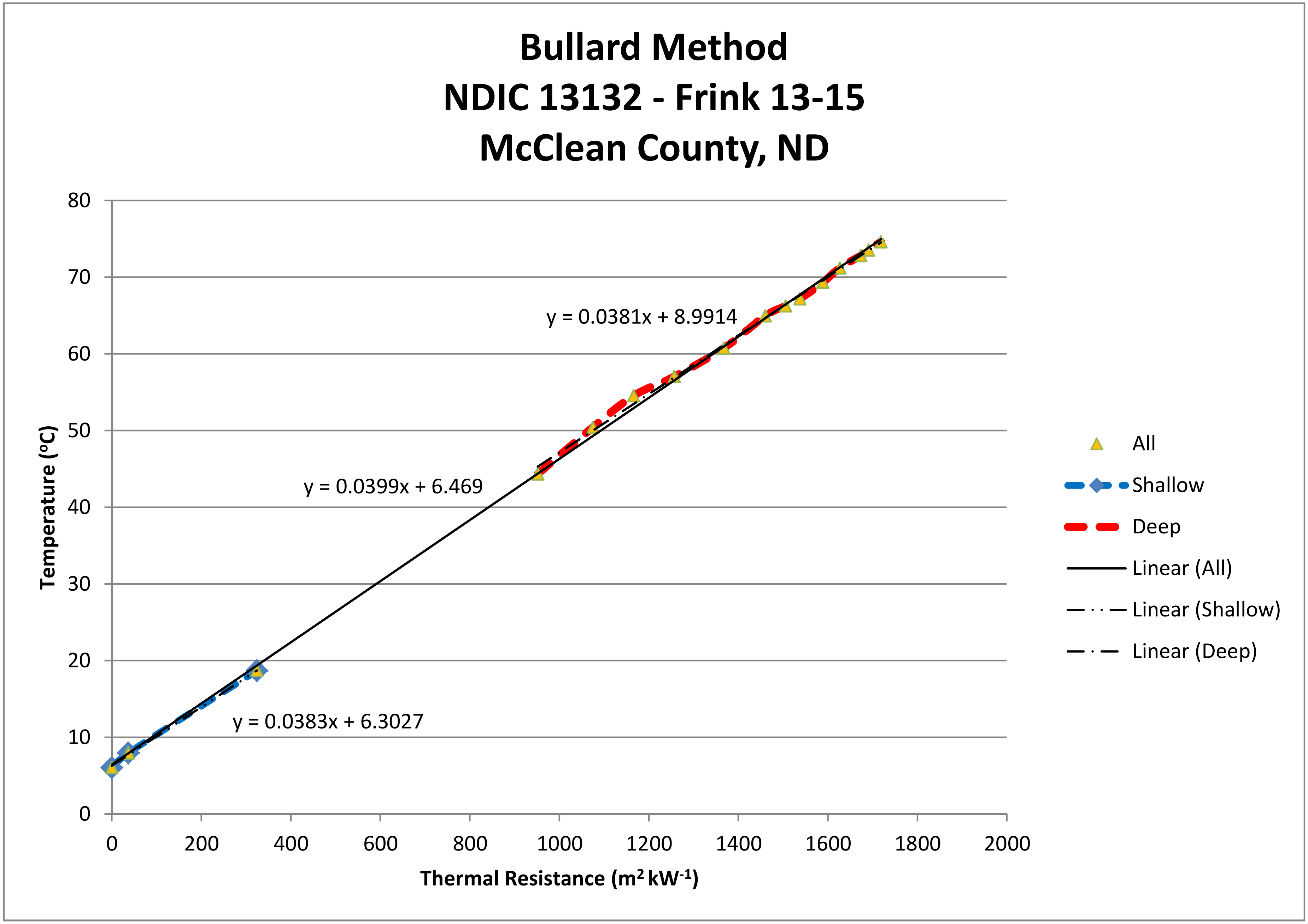

Bullard Method
NDIC 10103 - Iverson State A-1
McKenzie County, ND
y = 0.047x + 21.157
y = 0.0521x + 13.133
y = 0.0655x + 0.0092
Temperature (°C)
Thermal Resistance (m² kW⁻¹)
0
20
40
60
80
100
120
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Shallow
Deep
All
Linear (Deep)
Linear (Shallow)
Linear (All)


Bullard Method
NDIC 10278 - Mud Buttes State 1-36
Bowman County, ND
y = 0.0514x + 8.3084
y = 0.0522x + 7.013
y = 0.0527x + 6.3993
Temperature (oC)
Thermal Resistance (m2 kW-1)
0
20
40
60
80
100
120
0
200
400
600
800
1000
1200
1400
1600
1800
2000
All
Shallow
Deep
Linear (All)
Linear (Shallow)
Linear (Deep)

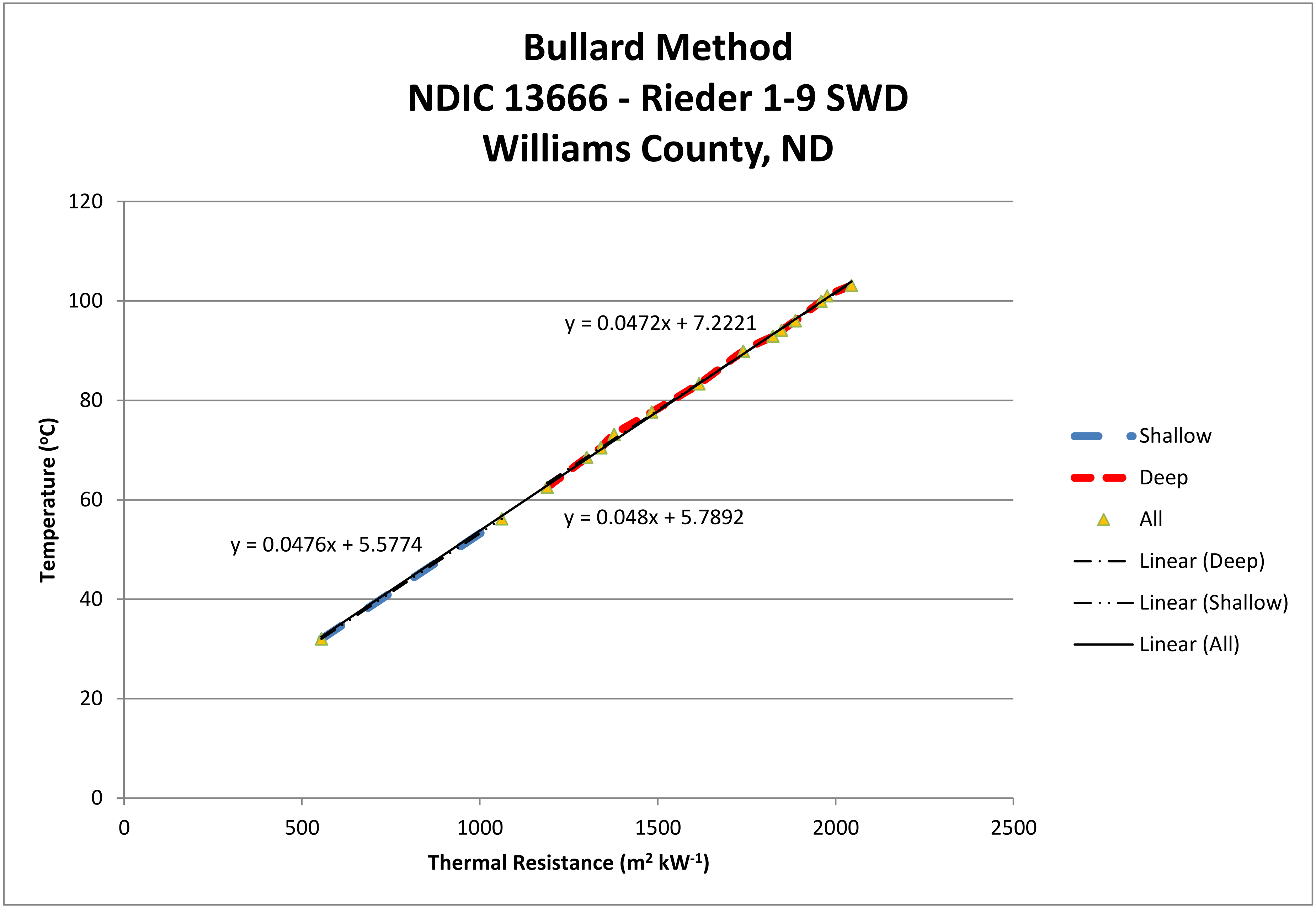

Bullard Method
NDIC 12280 - Bandjord 1-20
Bottineau County, ND
Temperature (°C)
50
45
40
35
30
25
20
15
10
5
0
0
100
200
300
400
500
600
700
800
Thermal Resistance (m² kW⁻¹))
y = 0.0527x + 8.249
All
Linear (All)

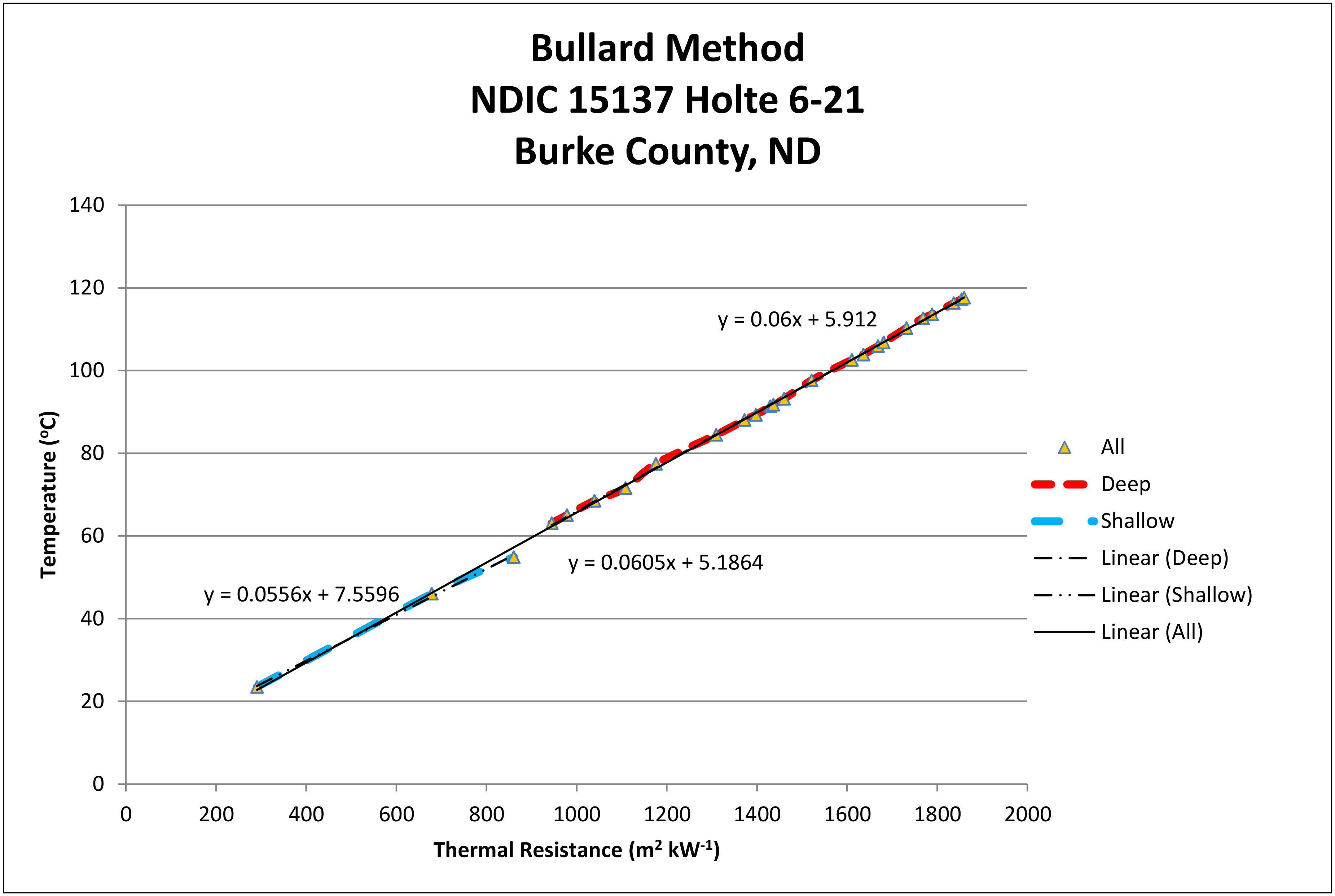


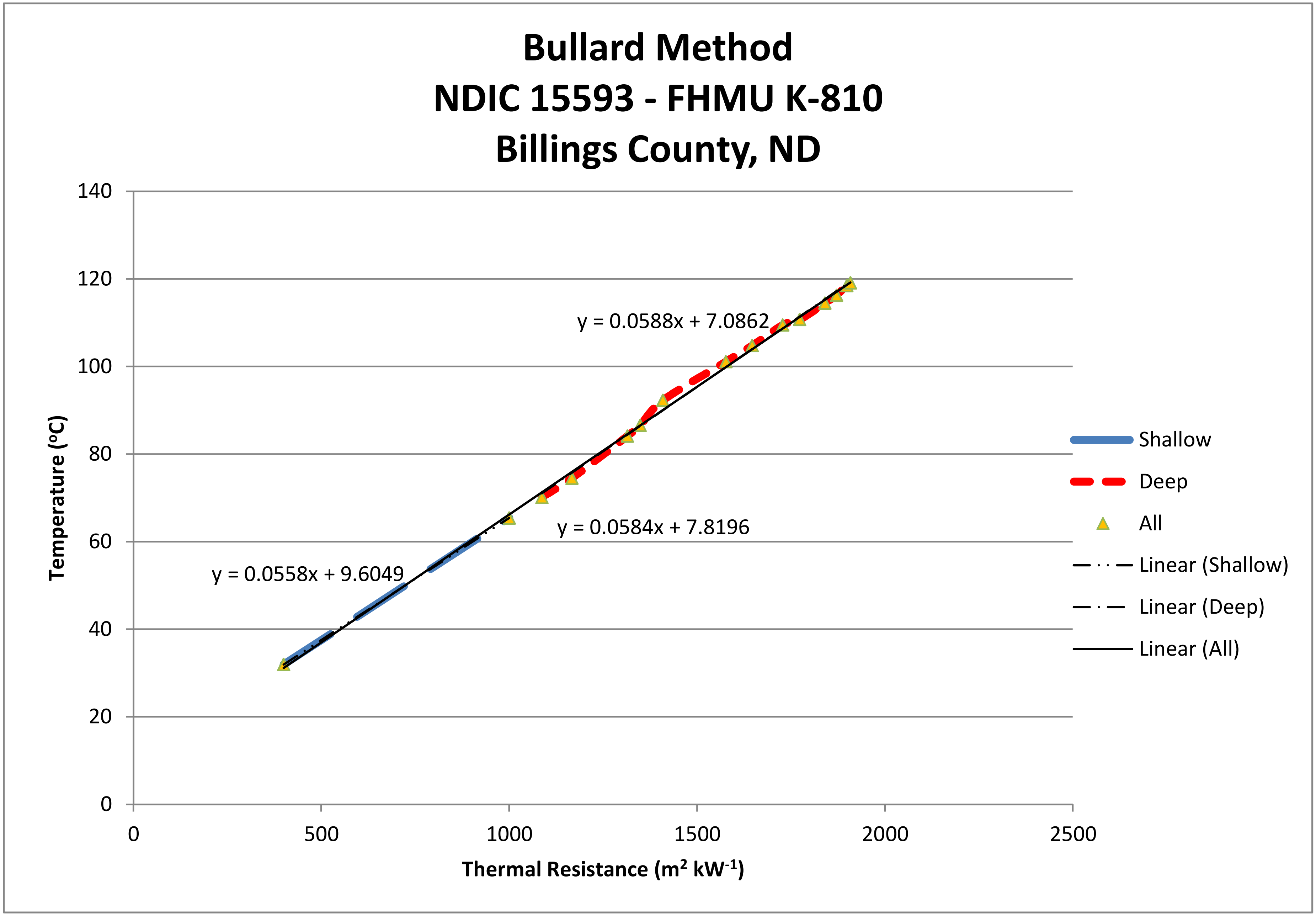
Bullard Method
NDIC 12363 Astrid Ongstad 14-22
Williams County, ND
Temperature (ºC)
Thermal Resistance (m² kW⁻²
140
120
100
80
60
40
20
0
0
500
1000
1500
2000
2500
y = 0.0529x + 5.611
y = 0.0527x + 5.8379
y = 0.0516x + 6.3946
Shallow
Deep
All
Linear (Deep)
Linear (Shallow)
Linear (All)



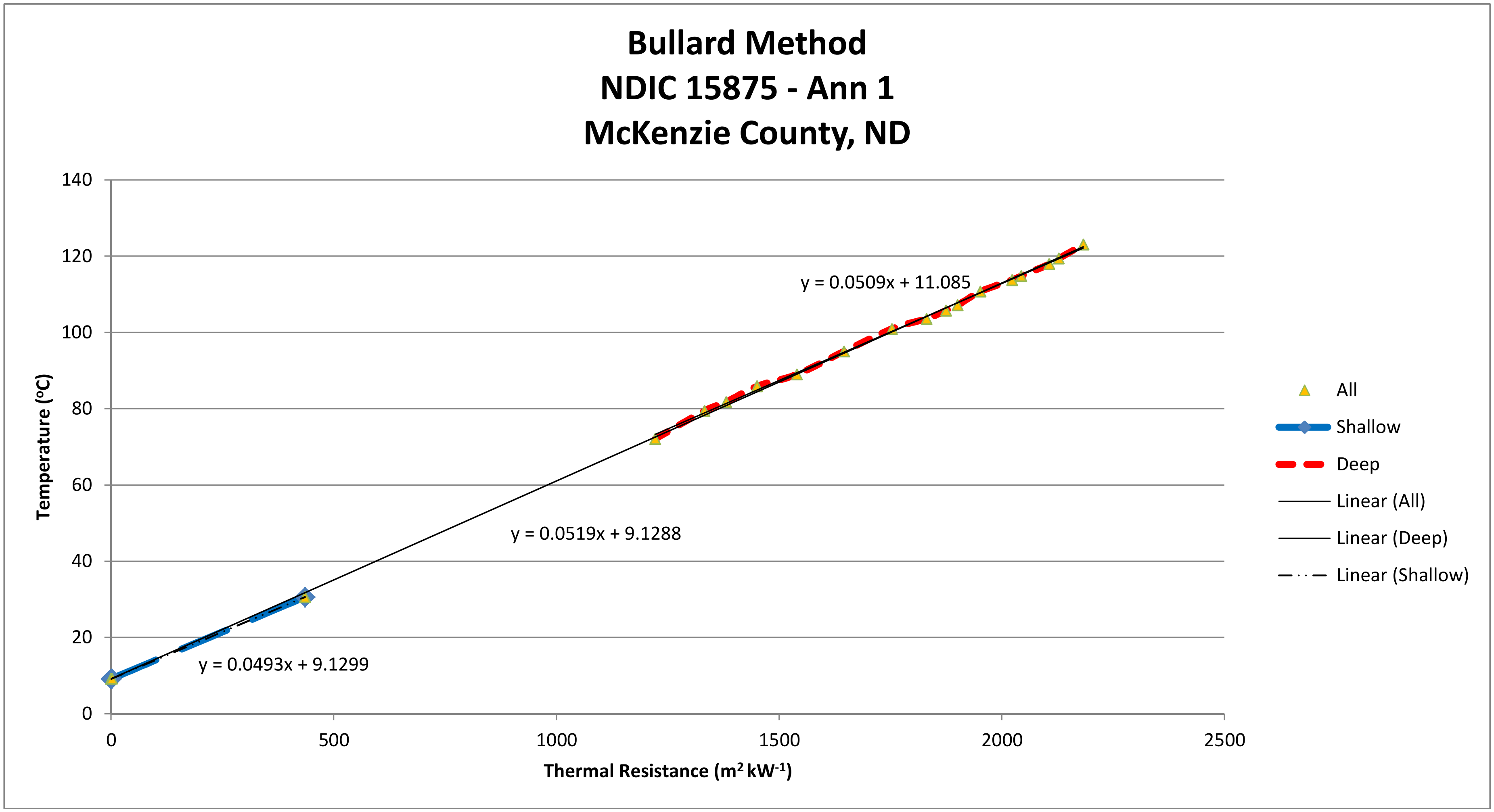
Bullard Method
NDIC 13132 - Frink 13-15
McClean County, ND
80
70
60
50
40
30
20
10
0
Temperature (°C)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Thermal Resistance (m² kW⁻¹)
y = 0.0381x + 8.9914
y = 0.0399x + 6.469
y = 0.0383x + 6.3027
All
Shallow
Deep
Linear (All)
Linear (Shallow)
Linear (Deep)

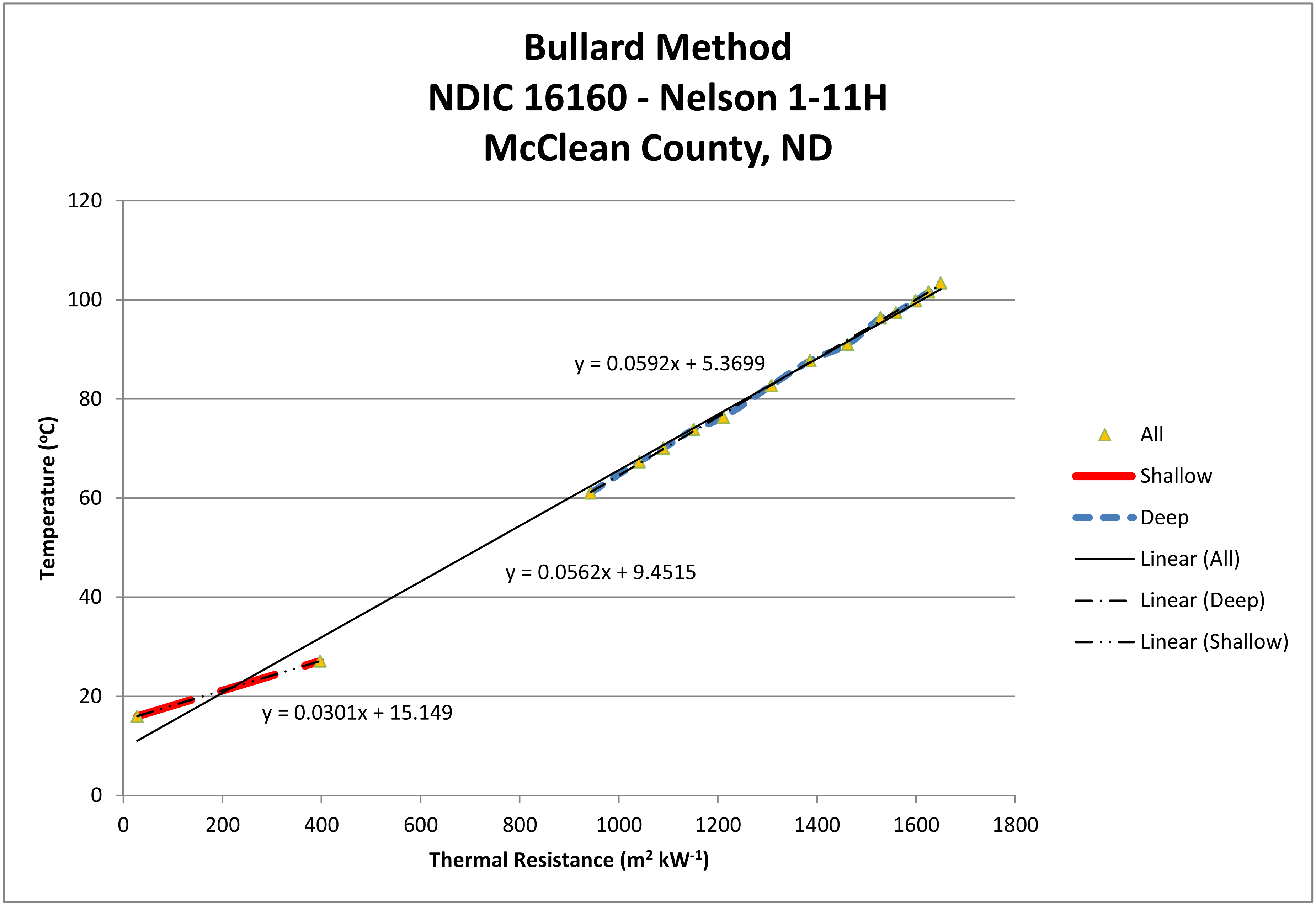

Bullard Method
NDIC 13666 - Rieder 1-9 SWD
Williams County, ND
120
100
80
60
40
20
0
Temperature (°C)
y = 0.0472x + 7.2221
y = 0.048x + 5.7892
y = 0.0476x + 5.5774
0
500
1000
1500
2000
2500
Thermal Resistance (m² kW⁻¹)
Shallow
Deep
All
Linear (Deep)
Linear (Shallow)
Linear (All)

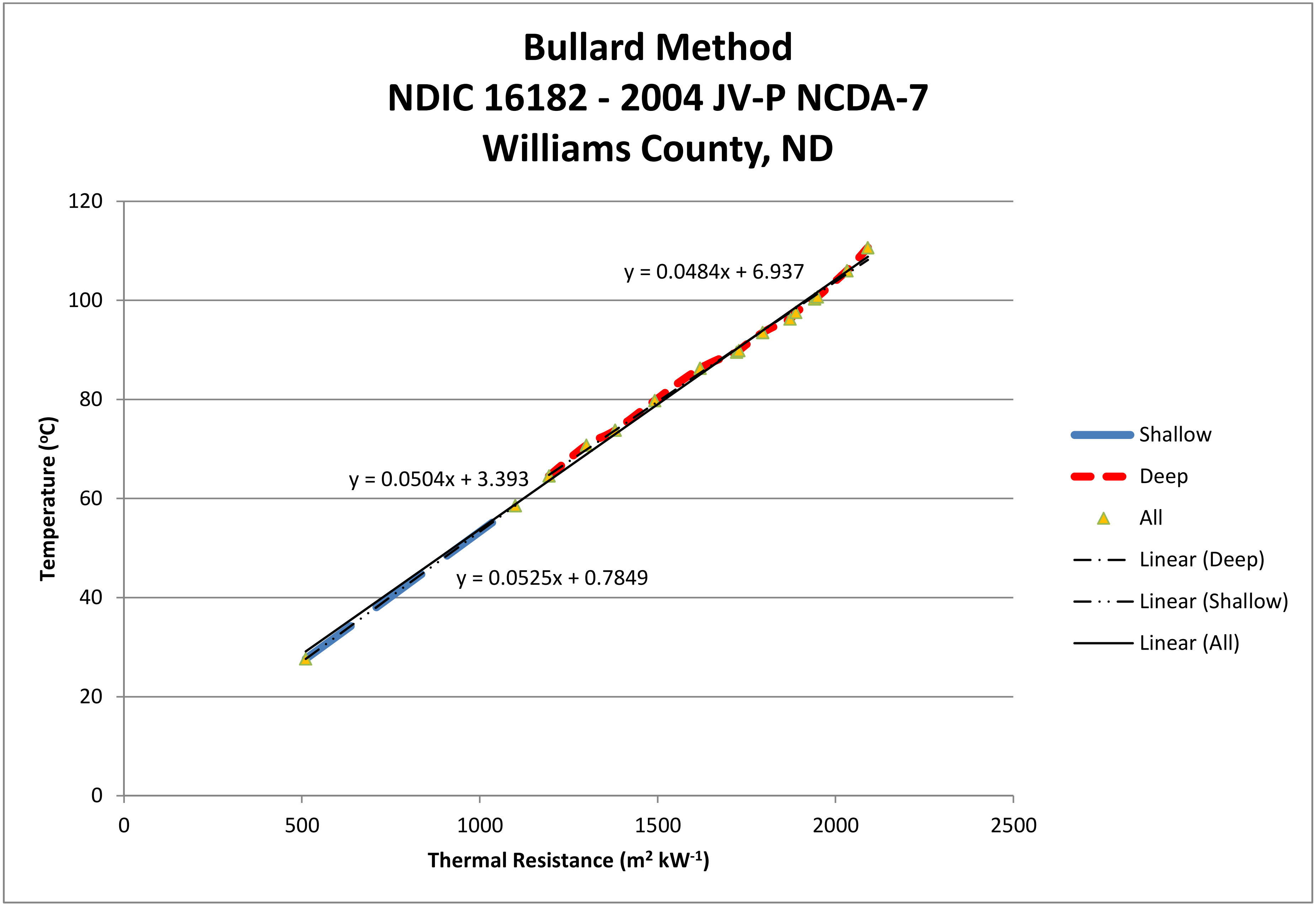

Bullard Method
NDIC 15137 Holte 6-21
Burke County, ND
Temperature (°C)
Thermal Resistance (m² kW⁻¹)
y = 0.06x + 5.912
y = 0.0605x + 5.1864
y = 0.0556x + 7.5596
All
Deep
Shallow
Linear (Deep)
Linear (Shallow)
Linear (All)



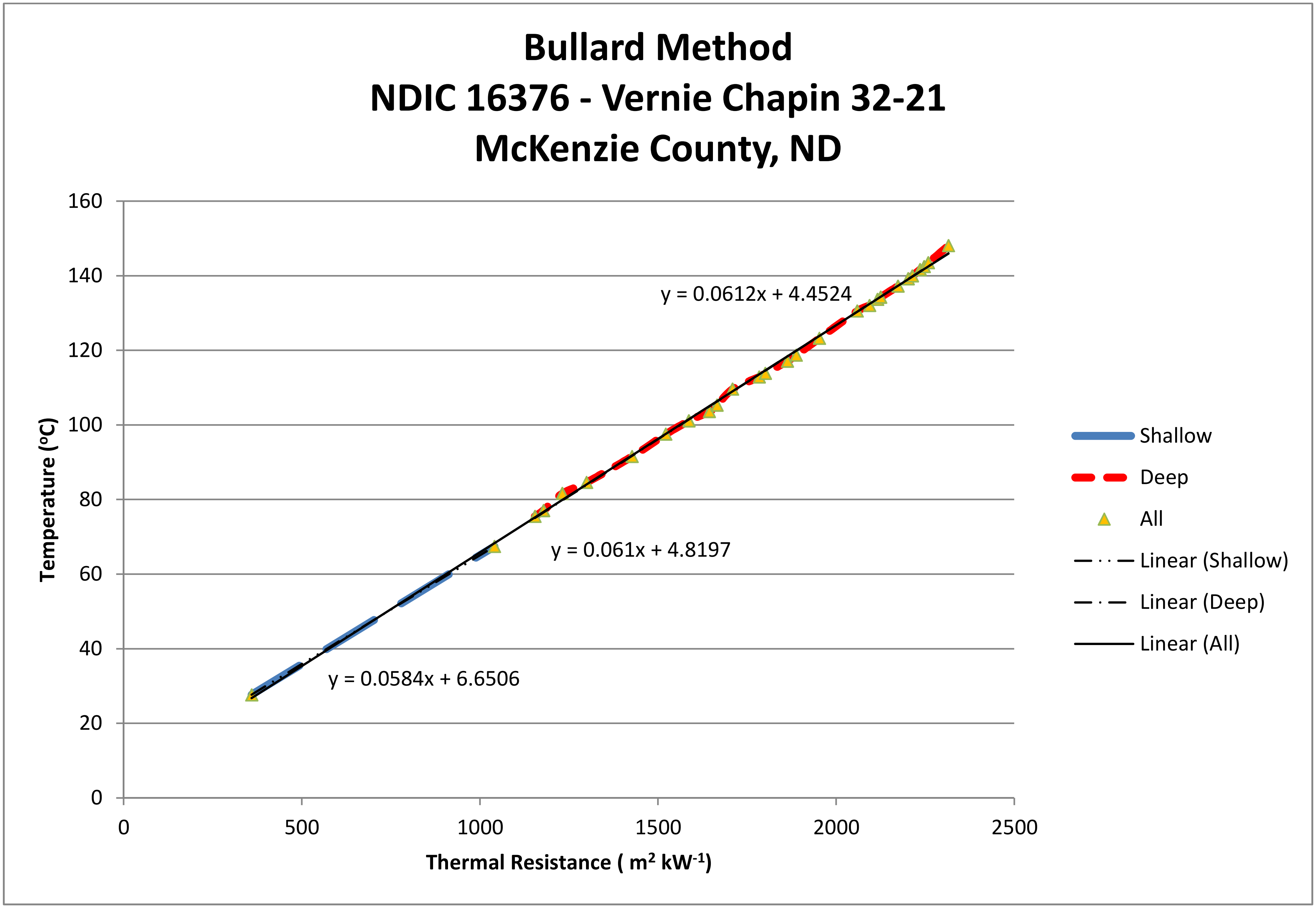
Bullard Method
NDIC 15593 - FHMU K-810
Billings County, ND
140
120
100
80
60
40
20
0
Temperature (oC)
0
500
1000
1500
2000
2500
Thermal Resistance (m2 kW-1)
y = 0.0588x + 7.0862
y = 0.0584x + 7.8196
y = 0.0558x + 9.6049
Shallow
Deep
All
Linear (Shallow)
Linear (Deep)
Linear (All)

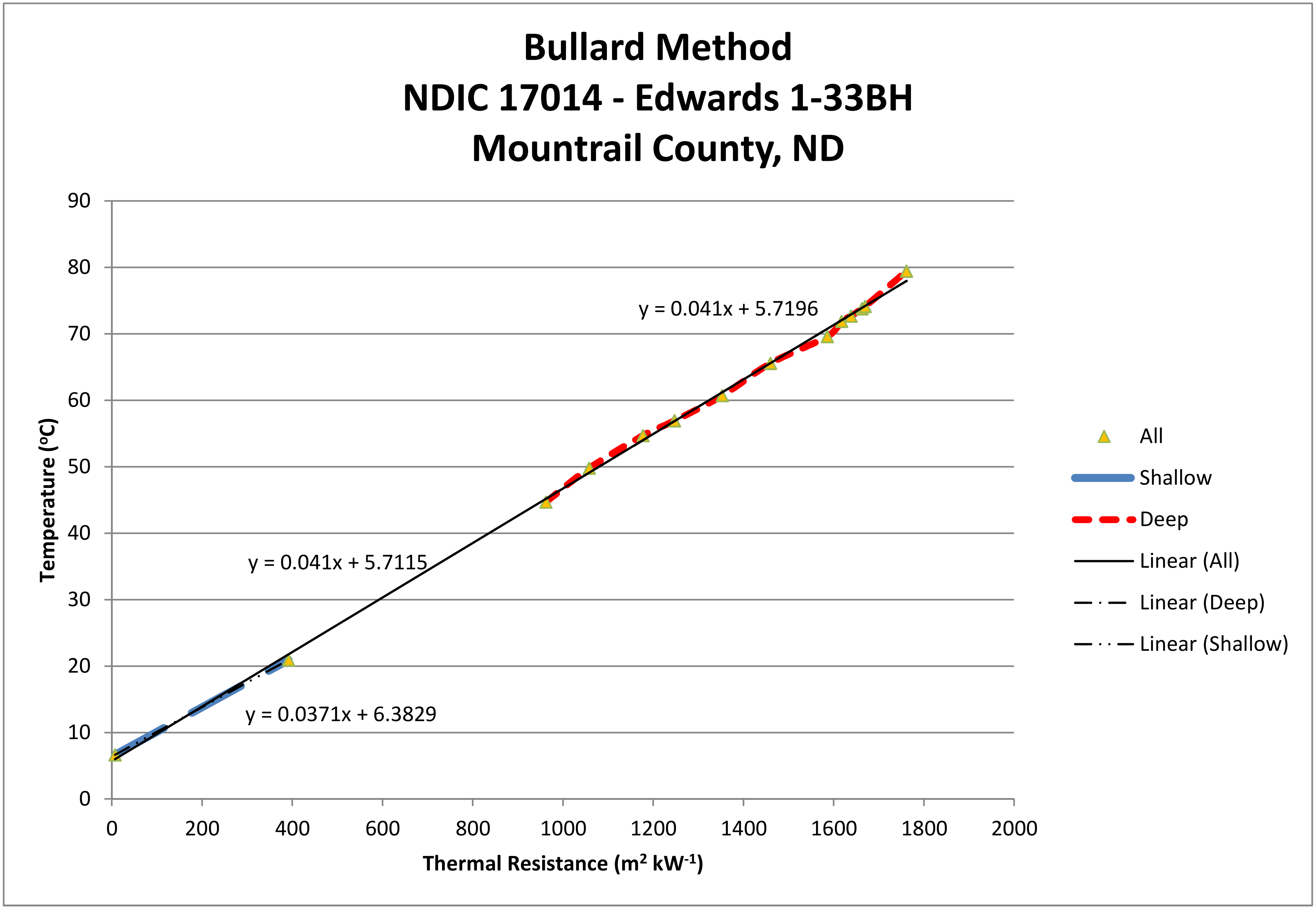

Bullard Method
NDIC 15875 - Ann 1
McKenzie County, ND
140
120
100
80
60
40
20
0
Temperature (ºC)
0
500
1000
1500
2000
2500
Thermal Resistance (m² kW⁻¹)
y = 0.0509x + 11.085
y = 0.0519x + 9.1288
y = 0.0493x + 9.1299
All
Shallow
Deep
Linear (All)
Linear (Deep)
Linear (Shallow)

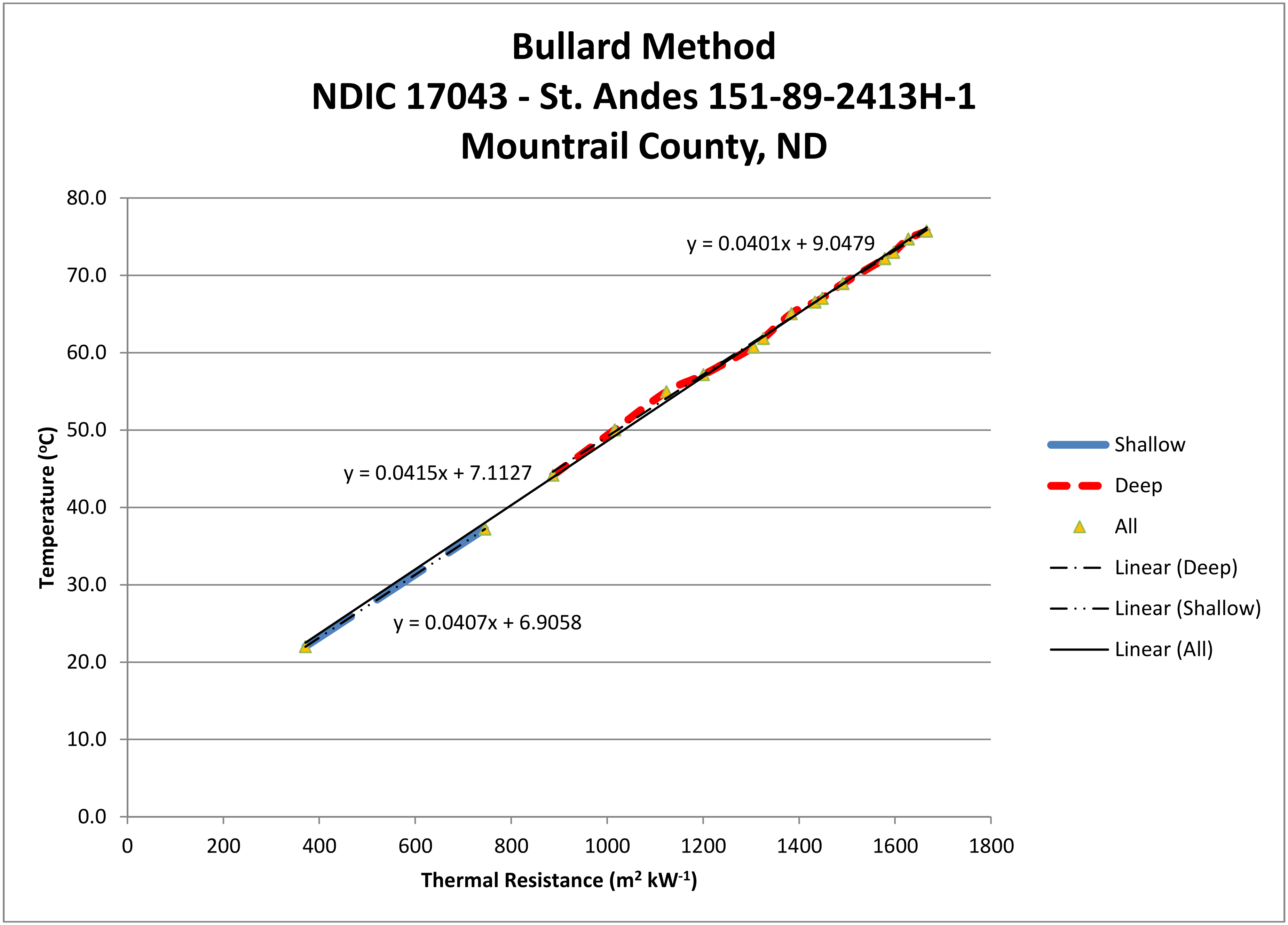

Bullard Method
NDIC 16160 - Nelson 1-11H
McClean County, ND
Temperature (°C)
Thermal Resistance (m² kW⁻¹)
y = 0.0592x + 5.3699
y = 0.0562x + 9.4515
y = 0.0301x + 15.149
All
Shallow
Deep
Linear (All)
Linear (Deep)
Linear (Shallow)
0
20
40
60
80
100
120
0
200
400
600
800
1000
1200
1400
1600
1800

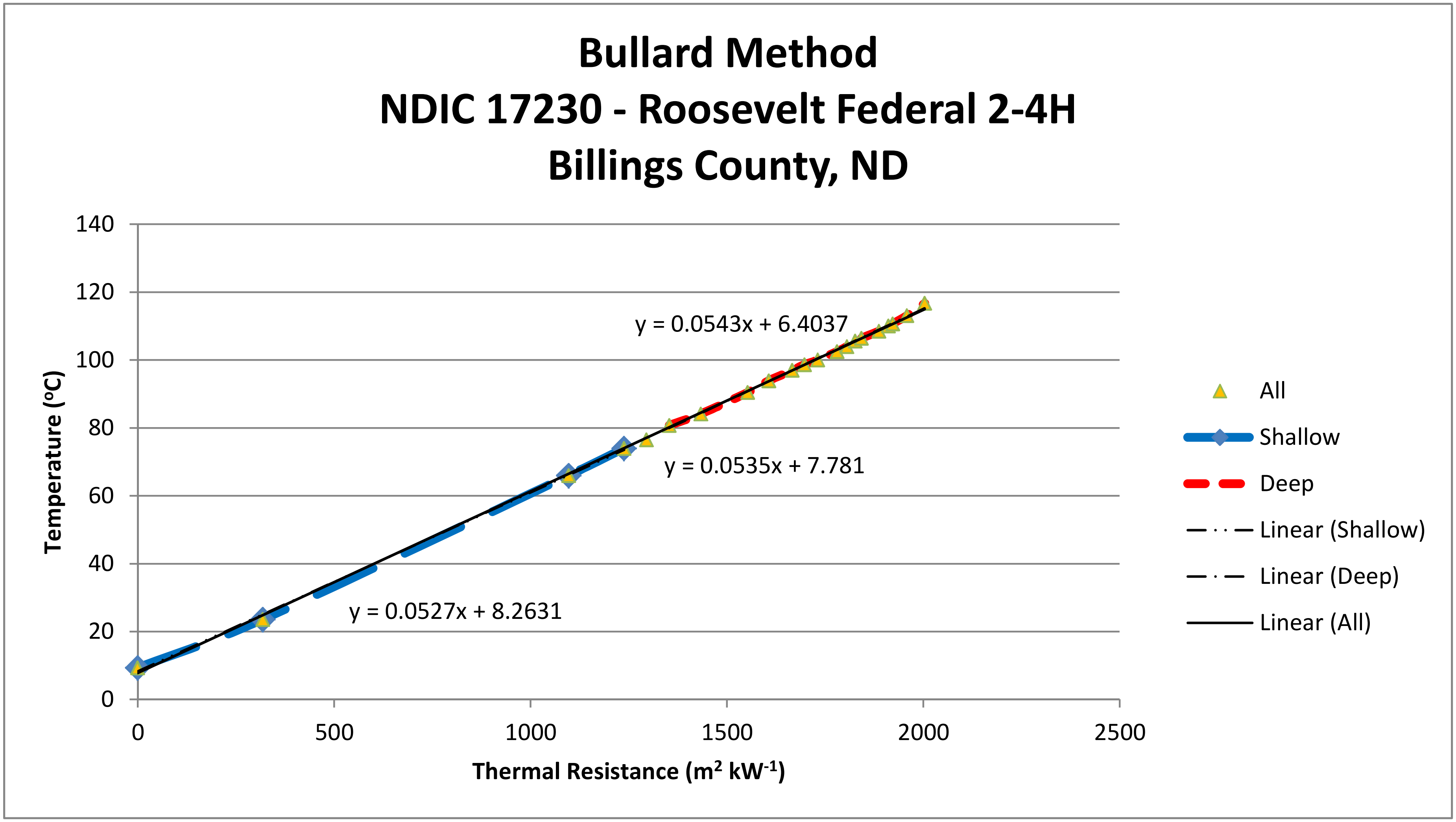


Bullard Method
NDIC 16182 - 2004 JV-P NCDA-7
Williams County, ND
y = 0.0484x + 6.937
y = 0.0504x + 3.393
y = 0.0525x + 0.7849
Temperature (°C)
Thermal Resistance (m² kW⁻¹)
0
20
40
60
80
100
120
0
500
1000
1500
2000
2500
Shallow
Deep
All
Linear (Deep)
Linear (Shallow)
Linear (All)

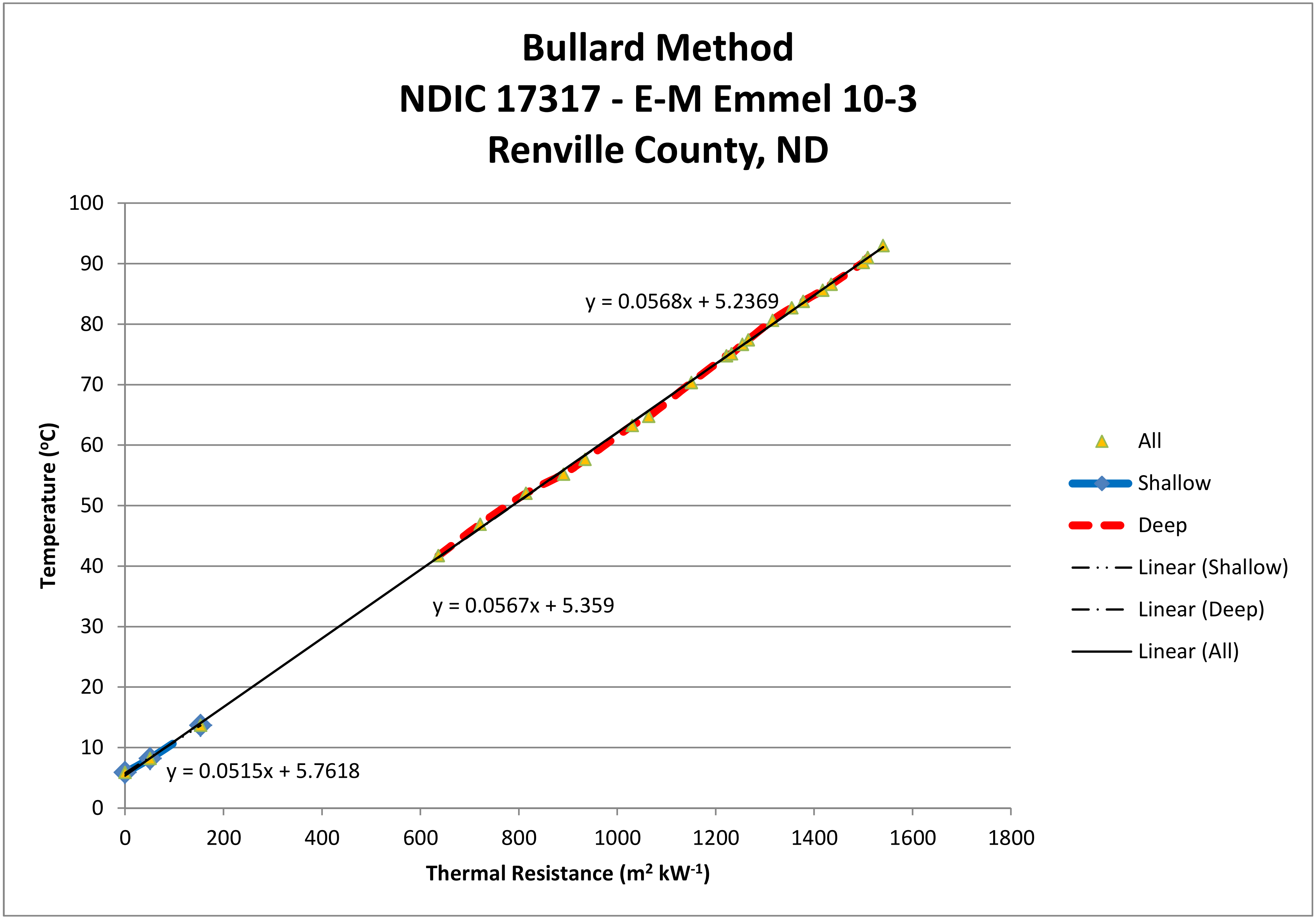

Bullard Method
NDIC 16376 - Vernie Chapin 32-21
McKenzie County, ND
160
140
120
100
80
60
40
20
0
0
500
1000
1500
2000
2500
Temperature (°C)
Thermal Resistance (m² kW⁻¹)
y = 0.0612x + 4.4524
y = 0.061x + 4.8197
y = 0.0584x + 6.6506
Shallow
Deep
All
Linear (Shallow)
Linear (Deep)
Linear (All)

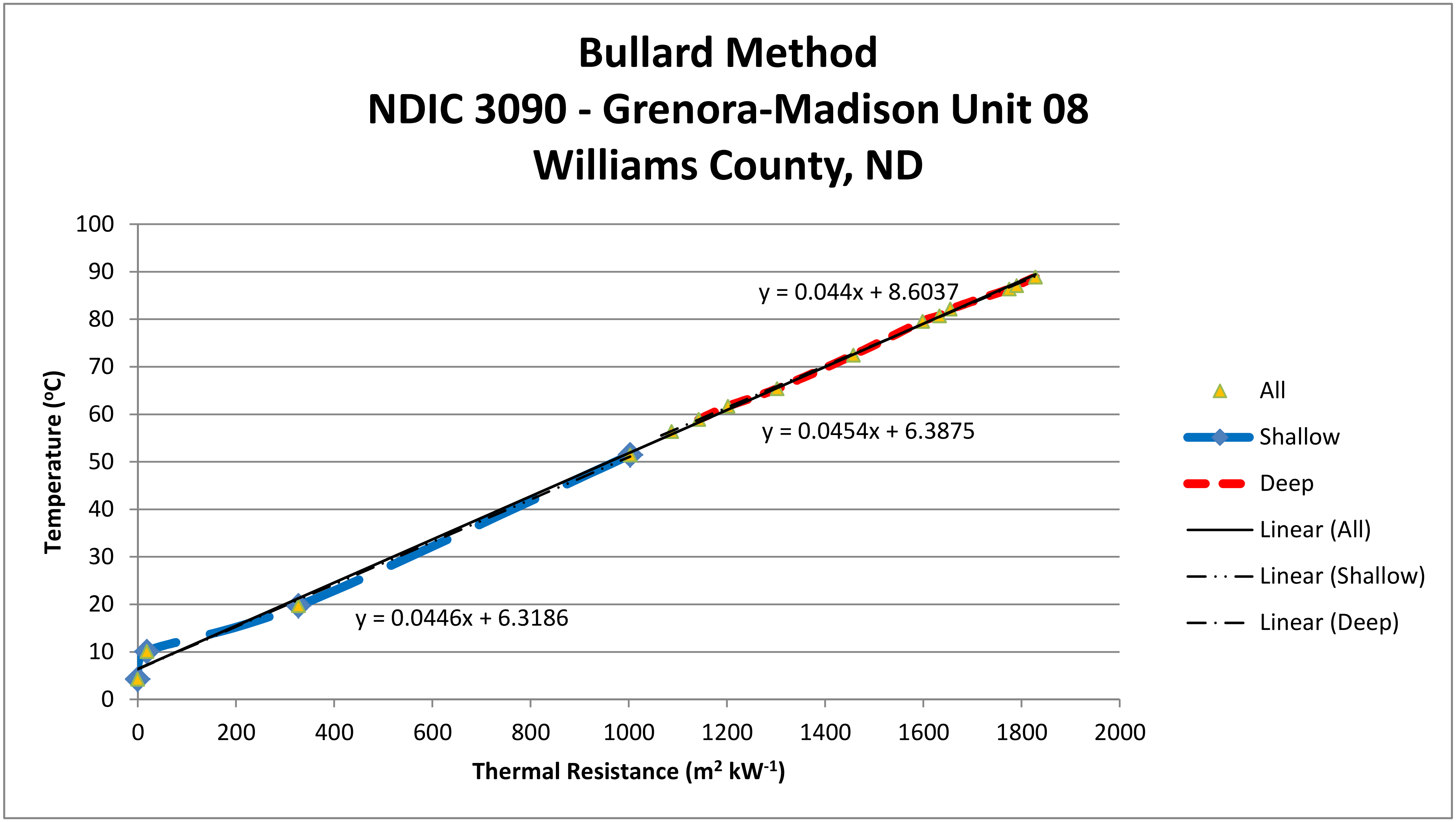

Bullard Method
NDIC 17014 - Edwards 1-33BH
Mountrail County, ND
Temperature (°C)
Thermal Resistance (m² kW⁻¹)
0
10
20
30
40
50
60
70
80
90
0
200
400
600
800
1000
1200
1400
1600
1800
2000
y = 0.041x + 5.7196
y = 0.041x + 5.7115
y = 0.0371x + 6.3829
All
Shallow
Deep
Linear (All)
Linear (Deep)
Linear (Shallow)

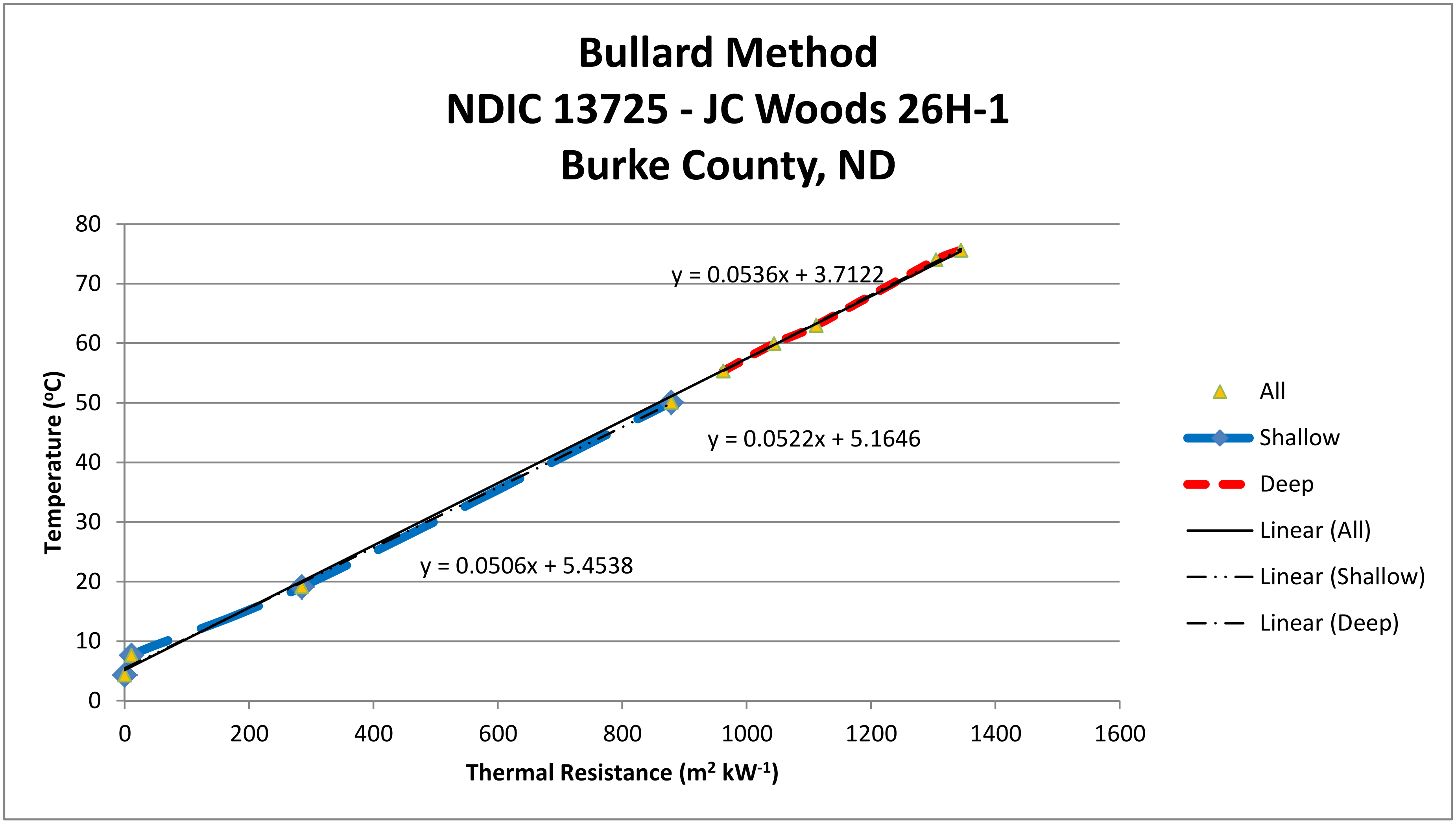

Bullard Method
NDIC 17043 - St. Andes 151-89-2413H-1
Mountrail County, ND
Temperature (ºC)
Thermal Resistance (m² kW⁻¹)
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
200
400
600
800
1000
1200
1400
1600
1800
y = 0.0401x + 9.0479
y = 0.0415x + 7.1127
y = 0.0407x + 6.9058
Shallow
Deep
All
Linear (Deep)
Linear (Shallow)
Linear (All)



Bullard Method
NDIC 17230 - Roosevelt Federal 2-4H
Billings County, ND
140
120
100
80
60
40
20
0
0
500
1000
1500
2000
2500
Temperature (°C)
Thermal Resistance (m² kW⁻¹)
y = 0.0543x + 6.4037
y = 0.0535x + 7.781
y = 0.0527x + 8.2631
All
Shallow
Deep
Linear (Shallow)
Linear (Deep)
Linear (All)


Bullard Method
NDIC 17317 - E-M Emmel 10-3
Renville County, ND
Temperature (°C)
Thermal Resistance (m² kW⁻¹)
100
90
80
70
60
50
40
30
20
10
0
0
200
400
600
800
1000
1200
1400
1600
1800
y = 0.0568x + 5.2369
y = 0.0567x + 5.359
y = 0.0515x + 5.7618
All
Shallow
Deep
Linear (Shallow)
Linear (Deep)
Linear (All)


Bullard Method
NDIC 3090 - Grenora-Madison Unit 08
Williams County, ND
100
90
80
70
60
50
40
30
20
10
0
Temperature (°C)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Thermal Resistance (m² kW⁻¹)
y = 0.044x + 8.6037
y = 0.0454x + 6.3875
y = 0.0446x + 6.3186
All
Shallow
Deep
Linear (All)
Linear (Shallow)
Linear (Deep)


Bullard Method
NDIC 13725 - JC Woods 26H-1
Burke County, ND
Temperature (ºC)
Thermal Resistance (m² kW⁻¹)
0
10
20
30
40
50
60
70
80
0
200
400
600
800
1000
1200
1400
1600
y = 0.0536x + 3.7122
y = 0.0522x + 5.1646
y = 0.0506x + 5.4538
All
Shallow
Deep
Linear (All)
Linear (Shallow)
Linear (Deep)

APPENDIX E

SUMMARIES OF HEAT FLOW CALCULATIONS

Summary of Heat Flow Calculations
NDIC 1140
Capa Madison Unit H-205
Williams County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(^oC)		$W\ m^{-1}K^{-1}$				$W\ K^{-1}$		$W\ m^{-1}K^{-1}$	$^oC\ km^{-1}$	$mW\ m^{-2}$				
Till	0.0	8.8	8.4	1.1	1.10	1.72	0.00	0.01	8.04	8.04				133.2	208.2		
FU/HC/FH	8.8	319.7	9.4	12.1	1.00	1.72	0.14	0.25	319.74	327.77	0.03	121.05		37.9	65.3		3.3
Pierre	328.6	747.4	21.6	36.6	1.80	1.62	0.60	0.54	415.21	742.98	0.44	40.17		88.1	79.3		17.8
Greenhorn	1075.9	100.6	58.2	6.9	1.40	1.62	0.06	0.07	71.85	814.82	1.32	46.28		95.5	110.5		61.1
Mowry	1176.5	30.5	65.0	1.6	1.00	1.80	0.01	0.02	30.48	845.30	1.39	48.15		53.8	96.9		67.0
Newcastle	1207.0	76.5	66.7	4.5	1.30	1.80	0.04	0.06	58.85	904.15	1.33	48.29		76.5	105.9		64.5
Inyan Kara	1283.5	139.0	71.2	3.7	1.70	2.35	0.11	0.15	81.76	985.91	1.30	48.92		45.7	63.2		63.7
Swift	1422.5	138.4	74.9	6.1	2.50	2.10	0.15	0.13	55.35	1041.26	1.37	46.77		109.3	91.8		63.9
Rierdon	1560.9	175.6	80.9	7.0	1.80	2.10	0.14	0.16	97.54	1138.80	1.37	46.50		71.8	83.7		63.7
Spearfish	1736.4	110.6	87.9	2.7	1.60	3.04	0.08	0.15	69.15	1207.95	1.44	45.83		39.6	75.3		65.9
Minnekahta/Opech	1847.1	88.7	90.7	1.8	4.00	3.04	0.16	0.12	22.17	1230.12	1.50	44.57		83.0	63.1		66.9
Broom Creek	1935.8	80.2	92.5	1.7	2.30	3.04	0.08	0.11	34.85	1264.98	1.53	43.48		48.5	64.1		66.5
Tyler	2015.9	72.2	94.2	4.2	3.20	2.68	0.10	0.09	22.57	1287.55	1.57	42.59		185.2	155.1		66.7
Big Snowy	2088.2	104.5	98.4	3.2	2.00	3.62	0.09	0.17	52.27	1339.82	1.56	43.11		62.0	112.2		67.2
Kibbey Lime	2192.7	45.4	101.6	1.1	2.10	3.62	0.04	0.07	21.63	1361.45	1.61	42.54		48.6	83.7		68.5
Madison	2238.1	200.0	102.7	2.1	2.30	3.45	0.21	0.31	86.95	1448.40	1.55	42.14		24.7	37.1		65.1
BOH	2438.1		104.8		1.20	4.00					1.50	40.42					
						Σ =	2.04	2.41									
											Average			75.2	93.4	71	58.1
											Wtd Average			85.8	101.5		
											Shallow					37.9	10.5
											Deep		71			68.2	65.4

Notes
1 - Thermal conductivity derived from graphical method
2 - Thermal conductivity used by Nordeng and Nesheim (2011) and Nordeng (2014)
3 - Weighted average of graphical thermal conductivity
4 - Weighted average of Nordeng's thermal conductivity
5 - Harmonic mean of thermal conductivity
6 - Heat flow derived from graphical method
7- Heat flow derived from Equation 1 for each formation
8 - Heat Flow derived from Equation 1 and Nordengs λ
9 - Heat flow derived from Bullard's Method
10 - Heat flow derived using harmonic mean method
11- FU/HC/FH - Fort Union Group/Hell Creek Formation/Fox Hills Formation combined

Summary of Heat Flow Calculations
NDIC 2139
NSCU V-706
Bottineau County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(°C)		$W\ m^{-1}K^{-1}$				$W\ K^{-1}$		$W\ m^{-1}K^{-1}$	$°C\ km^{-1}$	$mW\ m^{-2}$				
Foxhills	32.0	9.8	6.7	0.8	1.20	1.72	0.04	0.07	26.92	26.92				28.7	41.1		
Pierre	64.3	19.6	7.5	20.3	1.10	1.62	0.57	0.88	418.13	445.05	0.14	23.90		48.4	71.3		3.5
Greenhorm	524.3	159.8	27.7	4.1	1.00	1.62	0.09	0.15	80.16	525.22	1.00	42.71		51.5	83.4		42.6
Mowry	604.4	184.2	31.8	2.7	1.20	1.80	0.08	0.13	50.04	575.25	1.05	43.94		54.4	81.6		46.2
Inyan Kara	664.5	202.5	34.6	1.7	1.60	2.35	0.14	0.21	48.01	623.26	1.07	44.07		34.7	51.0		47.0
Swift	741.3	225.9	36.2	5.8	1.20	2.10	0.23	0.43	143.15	766.41	0.97	41.65		40.5	70.8		40.3
BOH	913.1		42.0									40.10					
						Σ =	1.16	1.86									

	Q_{graph}	Q_2	Q_N	$Q_{Bullard}$	Q_{hi}
Average		43.0	66.5	47.5	44
Wtd Average		46.6	75.6		
Shallow				48.4	23.2
Deep	48			41.3	44.5

Notes
1 - Thermal conductivity derived from graphical method
2 - Thermal conductivity used by Nordeng and Nesheim (2011) and Nordeng (2014)
3 - Weighted average of graphical thermal conductivity
4 - Weighted average of Nordeng's thermal conductivity
5 - Harmonic mean of thermal conductivity
6 - Heat flow derived from graphical method
7- Heat flow derived from Equation 1 for each formation
8 - Heat Flow derived from Equation 1 and Nordengs λ
9 - Heat flow derived from Bullard's Method
10 - Heat flow derived using harmonic mean method

Summary of Heat Flow Calculations
NDIC 8005
Sivertson 29-23R1
McKenzie County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(°C)		$W\ m^{-1}K^{-1}$				$W\ K^{-1}$		$W\ m^{-1}K^{-1}$	°C km^{-1}	$mW\ m^{-2}$				
FU/HC/FH[11]	0.0	490.4	-0.4	28.9	1.40	1.72	0.17	0.21	350.30	350.30				82.5	101.4		
Cretaceous Shale ?	490.4	900.4	28.5	46.9	1.15	1.62	0.26	0.37	782.94	1133.24	0.43	58.93		60.0	84.5		25.5
Mowry	1390.8	100.3	75.4	5.5	1.20	1.80	0.03	0.05	83.57	1216.81	1.14	54.53		66.1	99.2		62.3
Inyan Kara	1491.1	136.6	80.9	4.1	1.60	2.35	0.06	0.08	85.34	1302.15	1.15	54.57		47.8	70.3		62.5
Swift	1627.6	135.3	85.0	5.7	1.50	2.10	0.05	0.07	90.22	1392.37	1.17	52.50		62.7	87.8		61.4
Rierdon	1763.0	201.5	90.7	6.9	2.00	2.10	0.10	0.11	100.74	1493.11	1.18	51.68		68.2	71.6		61.0
Spearfish	1964.4	118.9	97.6	2.3	2.40	2.10	0.07	0.06	49.53	1542.64	1.27	49.88		47.2	41.3		63.5
Minnekahta	2083.3	10.4	99.9	0.2	2.40	3.04	0.01	0.01	4.32	1546.96	1.35	48.15		37.3	47.3		64.8
Opeche	2093.7	104.2	100.1	2.3	2.20	3.04	0.06	0.08	47.38	1594.34	1.31	47.99		48.8	67.4		63.0
Broom Creek	2197.9	111.9	102.4	2.3	3.80	3.04	0.11	0.09	29.44	1623.78	1.35	46.77		79.5	63.6		63.3
Tyler	2309.8	170.4	104.7	7.3	1.60	2.68	0.07	0.12	106.49	1730.27	1.33	45.51		68.3	114.4		60.8
Kibbey Lime	2480.2	41.1	112.0	0.7	2.70	3.62	0.03	0.04	15.24	1745.51	1.42	45.32		46.3	62.1		64.4
Madison	2521.3	176.8	112.7	3.2	3.05	3.45	0.14	0.15	57.96	1803.47	1.40	44.86		54.9	62.1		62.7
Ratcliffe	2698.1	18.6	115.9	0.4	3.05	3.45	0.01	0.02	6.10	1809.56	1.49	43.10		60.1	68.0		64.3
Last Salt	2716.7	70.4	116.2	1.5	3.05	3.45	0.05	0.06	23.08	1832.65	1.48	42.94		65.0	73.5		63.7
Frobisher-Alida	2787.1	171.6	117.7	4.1	3.05	3.45	0.13	0.15	56.26	1888.91	1.48	42.39		72.9	82.4		62.6
Lodgepole	2958.7	264.3	121.8	7.9	2.00	3.45	0.13	0.23	132.13	2021.04	1.46	41.32		60.0	103.4		60.5
Bakken	3223.0	26.2	129.8	1.1	1.00	4.00	0.01	0.03	26.21	2047.25	1.57	40.39		42.4	169.6		63.6
Three Forks	3249.2	64.0	130.9	1.9	2.70	4.00	0.04	0.06	23.71	2070.96	1.57	40.41		78.8	116.8		63.4
Birdbear	3313.2	27.1	132.7	0.6	2.80	4.00	0.02	0.03	9.69	2080.65	1.59	40.19		62.8	89.8		64.0
Duperow	3340.3	121.0	133.3	2.8	2.60	4.00	0.08	0.12	46.54	2127.19	1.57	40.05		59.3	91.3		62.9
Souris River	3461.3	83.5	136.1	2.1	2.80	3.09	0.06	0.07	29.83	2157.02	1.60	39.44		70.8	78.1		63.3
Dawson Bay	3544.8	36.6	138.2	0.9	2.75	3.09	0.03	0.03	13.30	2170.32	1.63	39.11		68.9	77.4		63.9
Prairie	3581.4	46.0	139.1	0.8	4.00	2.18	0.05	0.03	11.51	2181.82	1.64	38.97		66.1	36.1		64.0
Winnipegosis	3627.4	125.0	139.9	3.0	2.60	2.83	0.08	0.09	48.06	2229.89	1.63	38.68		62.2	67.7		62.9
Interlake	3752.4	208.7	142.9	4.35	3.77	3.72	0.19863	0.19599	55.3564	2285.24	1.64	38.19		78.5817	77.5395		62.7091
BOH	3961.1		147.2														
						Σ =	2.04	2.53									

	Q_{graph}	Q_2	Q_N	$Q_{Bullard}$	Q_{hi}
Average		62.2	80.9	61.3	61.5
Wtd Average		76.2	94.4		
Shallow				60.0	43.9
Deep	61			62.1	63.0

Notes
1 - Thermal conductivity derived from graphical method
2 - Thermal conductivity used by Nordeng and Nesheim (2011) and Nordeng (2014)
3 - Weighted average of graphical thermal conductivity
4 - Weighted average of Nordeng's thermal conductivity
5 - Harmonic mean of thermal conductivity
6 - Heat flow derived from graphical method
7- Heat flow derived from Equation 1 for each formation
8 - Heat Flow derived from Equation 1 and Nordengs λ
9 - Heat flow derived from Bullard's Method
10 - Heat flow derived using harmonic mean method
11- FU/HC/FH - Fort Union Group/Hell Creek Formation/Fox Hills Formation combined

Summary of Heat Flow Calculations
NDIC8706
Berge C-1
McKenzie County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(°C)		$W\ m^{-1}K^{-1}$				$W\ K^{-1}$		$W\ m^{-1}K^{-1}$	°C km^{-1}	$mW\ m^{-2}$				
Till	0.0	2.4	8.0	0.1	1.20	1.72	0.00	0.00	2.03	2.03				44.3	63.5		
FU/HC/FH[11]	2.4	598.3	8.1	22.9	1.25	1.72	0.27	0.38	478.66	480.69	0.01	36.91		47.9	65.9		0.2
Pierre	600.8	845.8	31.0	40.6	1.10	1.62	0.34	0.50	768.93	1249.62	0.48	38.32		52.9	77.8		18.4
Greenhorn	1446.6	122.2	71.6	7.1	1.00	1.62	0.04	0.07	122.22	1371.84	1.05	44.01		58.0	94.0		46.4
Mowry	1568.8	44.5	78.7	2.2	1.10	1.80	0.02	0.03	40.46	1412.30	1.11	45.10		54.1	88.6		50.1
Newcastle	1613.3	66.4	80.9	3.3	1.10	1.80	0.03	0.04	60.41	1472.70	1.10	45.21		54.0	88.3		49.5
Inyan Kara	1679.8	137.8	84.2	3.7	1.40	2.35	0.07	0.12	98.41	1571.11	1.07	45.36		37.4	62.8		48.5
Swift	1817.5	142.0	87.9	5.6	1.20	2.10	0.06	0.11	118.36	1689.47	1.08	43.95		47.0	82.2		47.3
Rierdon	1959.6	191.4	93.4	6.3	1.70	2.10	0.12	0.15	112.60	1802.07	1.09	43.60		56.0	69.2		47.4
Spearfish	2151.0	137.2	99.7	2.7	1.80	3.04	0.09	0.15	76.20	1878.27	1.15	42.66		35.3	59.6		48.8
Minnekahta/Opeche	2288.1	82.6	102.4	1.6	3.20	3.04	0.10	0.09	25.81	1904.08	1.20	41.27		62.0	58.9		49.6
Broom Creek	2370.7	71.3	104.0	1.5	2.90	3.04	0.08	0.08	24.59	1928.68	1.23	40.51		60.2	63.1		49.8
Tyler	2442.1	26.8	105.5	1.2	1.40	2.68	0.01	0.03	19.16	1947.84	1.25	39.93		64.2	122.9		50.1
Big Snowy	2468.9	146.9	106.7	5.1	1.50	3.62	0.08	0.19	97.94	2045.78	1.21	40.00		51.9	125.2		48.3
Kibbey Lime	2615.8	39.3	111.8	0.8	2.80	3.62	0.04	0.05	14.04	2059.82	1.27	39.69		54.1	70.0		50.4
Madison	2655.1	87.4	112.6	1.2	3.20	3.45	0.10	0.11	27.31	2087.13	1.27	39.39		44.3	47.8		50.1
BOH	2742.5		113.8								1.46	41.32					60.5
						Σ =	1.45	2.10									
											Average			51.5	77.5	50.8	46.7673
											Wtd Average			56.0	81.0		
											Shallow					47.9	32.4
											Deep		52			49.1	48.9

Notes
1 - Thermal conductivity derived from graphical method
2 - Thermal conductivity used by Nordeng and Nesheim (2011) and Nordeng (2014)
3 - Weighted average of graphical thermal conductivity
4 - Weighted average of Nordeng's thermal conductivity
5 - Harmonic mean of thermal conductivity
6 - Heat flow derived from graphical method
7- Heat flow derived from Equation 1 for each formation
8 - Heat Flow derived from Equation 1 and Nordengs λ
9 - Heat flow derived from Bullard's Method
10 - Heat flow derived using harmonic mean method
11- FU/HC/FH - Fort Union Group/Hell Creek Formation/Fox Hills Formation combined

Summary of Heat Flow Calculations
NDIC 9653
Cutlip 1
McKenzie County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(°C)		$W m^{-1} K^{-1}$				$W K^{-1}$		$W m^{-1} K^{-1}$	°C km^{-1}	$mW m^{-2}$				
FU/HC/FH[11]	73.8	524.3	11.0	17.3	1.40	1.72	0.26	0.32	374.47	374.47				82.5	101.4		
Pierre	598.0	774.5	28.3	33.4	1.10	1.62	0.30	0.45	704.09	1078.56	0.55	33.01		60.0	84.5		25.5
Niobrara	1372.5	51.8	61.7	2.8	1.20	1.62	0.02	0.03	43.18	1121.74	1.22	39.03		66.1	99.2		62.3
Greenhorn	1424.3	123.7	64.4	7.1	1.00	1.62	0.04	0.07	123.75	1245.49	1.14	39.58		47.8	70.3		62.5
Mowry	1548.1	113.7	71.5	5.4	1.00	1.80	0.04	0.07	113.69	1359.18	1.14	41.04		62.7	87.8		61.4
Inyan Kara	1661.8	152.4	76.9	4.1	1.50	2.35	0.08	0.13	101.60	1460.78	1.14	41.51		68.2	71.6		61.0
Swift	1814.2	162.2	80.9	6.3	1.20	2.10	0.07	0.12	135.13	1595.90	1.14	40.20		47.2	41.3		63.5
Rierdon	1976.3	168.9	87.2	5.7	1.60	2.10	0.10	0.13	105.54	1701.44	1.16	40.07		37.3	47.3		64.8
Spearfish	2145.2	110.6	92.9	2.2	1.80	3.04	0.07	0.12	61.47	1762.91	1.22	39.55		48.8	67.4		63.0
Minnekahta	2255.8	8.2	95.1	0.2	2.60	3.04	0.01	0.01	3.17	1766.07	1.28	38.53		79.5	63.6		63.3
Opeche	2264.1	71.9	95.2	1.4	1.70	3.04	0.04	0.08	42.31	1808.39	1.25	38.46		68.3	114.4		60.8
Broom Creek	2336.0	0.0	96.6	1.8	2.40	3.04	0.07	0.09	33.27	1841.66	1.27	37.86		46.3	62.1		64.4
Tyler	2336.0	79.9	98.4	2.8	1.20	2.68	0.02	0.05	40.39	1882.05	1.28	37.32		54.9	62.1		62.7
Big Snowy	2415.8	48.5	101.2	3.0	1.50	3.62	0.06	0.14	72.34	1954.39	1.26	37.72		60.1	68.0		64.3
Kibbey Lime	2464.3	152.4	104.1	0.8	2.80	3.62	0.04	0.06	15.68	1970.06	1.31	37.27		65.0	73.5		63.7
Madison	2616.7	177.4	104.9	2.8	3.20	3.45	0.20	0.22	55.44	2025.50	1.29	36.95		72.9	82.4		62.6
Ratcliffe	2794.1	23.5	107.7	0.4	3.05	3.45	0.03	0.03	7.69	2033.19	1.37	35.56		60.0	103.4		60.5
Last Salt	2817.6	15.8	108.1	0.3	2.80	3.45	0.02	0.02	5.63	2038.82	1.38	35.40		42.4	169.6		63.6
BOH	2833.3		108.4														
						Σ =	1.47	2.11									
											Average			49.3	75.4	47.9	45.9246
											Wtd Average			52.0	74.8		
											Shallow					47.4	33.0
											Deep		48			47	47.6

Notes
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11- FU/HC/FH - Fort Union Group/Hell Creek Formation/Fox Hills Formation combined

Summary of Heat Flow Calculations
NDIC 10103
Iverson State A-1
McKenzie County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(°C)		$W m^{-1}K^{-1}$				$W K^{-1}$		$W m^{-1}K^{-1}$	°C km^{-1}	$mW m^{-2}$				
FU/HC/FH[11]	27.7	555.7	8.8	19.2	1.40	1.72	0.29	0.36	636.81	636.81				48.3	59.3		
Pierre	583.4	847.3	28.0	37.7	1.40	1.62	0.45	0.52	368.81	1005.62	0.91	36.98		62.3	72.0		33.8
Greenhorn	1430.7	121.3	65.6	7.1	1.20	1.62	0.05	0.07	98.04	1103.67	1.30	40.58		70.6	95.3		52.8
Mowry	1552.0	50.9	72.8	2.4	1.00	1.80	0.02	0.03	47.24	1150.91	1.35	41.96		47.4	85.3		56.6
Newcastle	1602.9	107.9	75.2	5.5	1.00	1.80	0.04	0.07	59.74	1210.65	1.32	42.16		51.3	92.4		55.7
Inyan Kara	1710.8	113.1	80.7	1.7	1.40	2.35	0.06	0.10	33.31	1243.96	1.33	42.44		21.2	35.6		56.6
Swift	1823.9	167.9	82.4	6.4	1.50	2.10	0.10	0.13	145.29	1389.25	1.23	42.78		56.8	79.5		52.6
Rierdon	1991.9	160.6	88.8	5.9	1.50	2.10	0.09	0.13	150.57	1539.82	1.25	40.75		55.1	77.1		50.9
Spearfish	2152.5	107.6	94.7	2.1	1.30	3.04	0.05	0.12	82.53	1622.35	1.33	40.45		25.8	60.3		53.6
Minnehahta	2260.1	10.7	96.8	0.3	1.80	3.04	0.01	0.01	5.93	1628.28	1.39	39.48		44.1	74.4		54.7
Opeche	2270.8	58.8	97.1	1.2	2.40	3.04	0.05	0.07	19.81	1648.09	1.38	39.39		49.2	62.3		54.2
Broom Creek	2329.6	92.4	98.3	2.1	2.80	3.04	0.10	0.11	31.90	1679.98	1.38	38.90		62.5	67.8		53.6
Tyler	2421.9	31.7	100.3	1.7	1.40	2.68	0.02	0.03	35.71	1715.69	1.40	38.31		75.6	144.7		53.7
Big Snowy	2453.6	110.6	102.1	3.3	1.70	3.62	0.07	0.15	66.88	1782.57	1.38	38.47		50.9	108.3		53.0
Kibbey Lime	2564.3	43.0	105.4	0.8	2.30	3.62	0.04	0.06	18.16	1800.72	1.43	38.04		42.2	66.4		54.3
Madison	2607.3	43.2	106.2	0.5	3.10	3.45	0.05	0.06	12.74	1813.47	1.44	37.71		35.9	40.0		54.3
BOH	2650.4		106.7														
						Σ =	1.49	2.03									
											Average			49.9	76.3	52.1	52.7
											Wtd Average			54.9	74.9		
											Shallow		45.2			65.5	43.3
											Deep		50.2			47	54.2

Notes
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11- FU/HC/FH - Fort Union Group/Hell Creek Formation/Fox Hills Formation combined

Summary of Heat Flow Calculations
NDIC 10278
Mud Buttes 1-36
Bowman County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ^1	$\lambda_N{}^2$	$\lambda_{wtd}{}^3$	$\lambda_{Nwtd}{}^4$	$\Delta Z_i/\lambda$	R_i	$\lambda_{hi}{}^5$	$grad_i$	$Q_{graph}{}^6$	$Q_2{}^7$	$Q_N{}^8$	$Q_{Bullard}{}^9$	$Q_{hi}{}^{10}$
	(m)		(°C)		$W\ m^{-1}K^{-1}$				$W\ K^{-1}$		$W\ m^{-1}K^{-1}$	$°C\ km^{-1}$	$mW\ m^{-2}$				
FU/HC/FH[11]	7.8	809.7	9.4	35.9	1.10	1.72	0.34	0.54	736.10	736.10				48.8	76.3		
Pierre	817.5	245.4	45.3	11.4	1.10	1.62	0.10	0.15	223.06	959.16	0.85	44.34		51.0	75.1		37.8
Green Horn	1062.8	185.0	56.7	10.2	1.00	1.62	0.07	0.12	185.01	1144.18	0.93	44.81		54.9	88.9		41.6
Mowry	1247.9	129.8	66.8	7.2	1.10	1.80	0.06	0.09	118.04	1262.22	0.99	46.31		61.1	100.0		45.8
Inyan Kara	1377.7	133.2	74.1	3.8	1.60	2.35	0.08	0.12	83.25	1345.46	1.02	47.18		45.8	67.2		48.3
Swift	1510.9	137.8	77.9	4.9	1.30	2.10	0.07	0.11	105.98	1451.44	1.04	45.54		46.4	75.0		47.4
Rierdon	1648.7	115.8	82.8	3.3	1.80	2.10	0.08	0.09	64.35	1515.79	1.09	44.71		51.1	59.7		48.6
Spearfish	1764.5	134.1	86.1	3.1	2.20	3.04	0.11	0.16	60.96	1576.75	1.12	43.64		50.4	69.6		48.8
Broom Creek	1898.6	127.7	89.1	2.3	2.40	3.04	0.12	0.15	53.21	1629.96	1.16	42.17		43.2	54.7		49.1
Big Snowy	2026.3	41.5	91.4	1.2	1.60	3.62	0.03	0.06	25.91	1655.87	1.22	40.64		45.9	103.9		49.7
Kibbey	2067.8	34.1	92.6	0.7	2.80	3.62	0.04	0.05	12.19	1668.06	1.24	40.40		55.8	72.1		50.1
Madison	2101.9	51.8	93.3	1.1	2.90	3.45	0.06	0.07	17.87	1685.93	1.25	40.06		62.1	73.9		49.9
Ratcliffe	2153.7	189.3	94.4	4.1	2.80	3.45	0.20	0.25	67.60	1753.53	1.23	39.61		61.4	75.6		48.7
Lodgepole	2343.0	157.9	98.6	3.6	2.50	3.45	0.15	0.21	63.15	1816.68	1.29	38.18		57.6	79.5		49.2
Devonian Undiff.	2500.9	62.2	102.2	1.3	3.10	4.00	0.07	0.10	20.06	1836.74	1.36	37.22		64.3	83.0		50.7
Interlake	2563.1	26.7	103.5	0.4	3.77	3.72	0.04	0.04	7.09	1843.83	1.39	36.82		62.1	61.3		51.2
BOH	2589.8		103.9		3.05												
						Σ =	1.63	2.30									
											Average			53.9	76.0	52.2	47.8
											Wtd Average			59.5	84.0		
											Shallow					52.7	41.7
											Deep		52.0			51.4	49.3

Notes
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11- FU/HC/FH - Fort Union Group/Hell Creek Formation/Fox Hills Formation combined

Summary of Heat Flow Calculations
NDIC 12280
Brandjord 1-20
Bottineau County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(°C)		$W\ m^{-1}K^{-1}$				$W\ K^{-1}$		$W\ m^{-1}K^{-1}$	°C km^{-1}	$mW\ m^{-2}$				
Fox Hills	21.3	55.0	7.94	0.57	1.20	1.72	0.02	0.03	13.97	13.97				40.8	58.5		
Pierre	38.1	1460.0	8.51	21.28	1.15	1.62	0.57	0.80	386.96	400.93	0.10	34.00		55.0	77.5		3.2
Greenhorm	483.1	232.0	29.79	4.05	1.00	1.62	0.08	0.13	70.71	471.65	1.02	47.32		57.3	92.8		48.5
Mowry	553.8	193.0	33.84	2.72	1.00	1.80	0.07	0.12	58.83	530.47	1.04	48.64		46.2	83.2		50.8
Inyan Kara	612.6	336.0	36.56	2.46	1.70	2.35	0.19	0.27	60.24	590.72	1.04	48.40		40.8	56.4		50.2
Swift	715.1	547.0	39.02	5.62	1.60	2.10	0.30	0.39	104.20	694.92	1.03	44.80		53.9	70.8		46.1
Spearfish	881.8	54.1	44.64	0.23	1.60	3.04	0.03	0.06	10.30	705.22	1.25	42.65		22.3	42.4		53.3
Bottom of Well	898.3		44.87														
						Σ =	1.26	1.79									
											Average			45.2	68.8		
											Wtd Average			51.7	73.7		
											Shallow						
											Deep		54			52.7	49.8

Notes
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9 - Heat flow derived from Bullard's Method
10 - Heat flow derived using harmonic mean method

Summary of Heat Flow Calculations
NDIC 12363
Astrid Ongstad 14-22
Williams County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(°C)		$W\ m^{-1}K^{-1}$				$W\ K^{-1}$		$W\ m^{-1}K^{-1}$	$^oC\ km^{-1}$	$mW\ m^{-2}$				
FU/HC/FH[11]	20.7	595.0	3.9	26.1	1.30	1.72	0.23	0.31	457.7	457.7				57.1	75.5		
Pierre	615.7	612.3	30.0	28.7	1.10	1.62	0.20	0.30	556.7	1014.3	0.61	43.92		51.6	76.0		26.7
Greenhorn	1228.0	100.9	58.8	6.3	1.10	1.62	0.03	0.05	91.7	1106.1	1.11	45.45		68.3	100.5		50.5
Mowry	1328.9	108.5	65.0	5.8	1.10	1.80	0.04	0.06	98.6	1204.7	1.10	46.73		58.7	96.0		51.5
Inyan Kara	1437.4	131.7	70.8	3.0	1.60	2.35	0.06	0.09	82.3	1287.0	1.12	47.24		36.0	52.9		52.8
Swift	1569.1	131.4	73.8	6.1	1.20	2.10	0.05	0.08	109.5	1396.5	1.12	45.14		55.6	97.2		50.7
Reirdon	1700.5	178.0	79.9	6.6	1.50	2.10	0.08	0.11	118.7	1515.1	1.12	45.23		55.4	77.6		50.8
Spearfish	1878.5	94.2	86.4	2.2	1.60	3.04	0.04	0.09	58.9	1574.0	1.19	44.44		37.2	70.7		53.0
Opeche	1972.7	60.4	88.6	1.5	1.30	3.04	0.02	0.05	46.4	1620.4	1.22	43.41		32.8	76.7		52.8
Broom Creek/Amsd	2033.0	22.9	90.2	0.5	2.20	3.04	0.02	0.02	10.4	1630.8	1.25	42.87		46.0	63.5		53.4
Tyler	2055.9	169.5	90.6	6.8	1.40	2.68	0.07	0.14	121.0	1751.9	1.17	42.62		56.1	107.4		50.0
Kibbey	2225.3	44.5	97.4	0.9	2.70	3.62	0.04	0.05	16.5	1768.4	1.26	42.43		55.6	74.6		53.4
Madison Group	2269.8	174.3	98.3	3.3	3.05	3.45	0.16	0.18	57.2	1825.5	1.24	41.99		57.0	64.5		52.2
Ratcliffe	2444.2	18.9	101.6	0.4	3.05	3.45	0.02	0.02	6.2	1831.7	1.33	40.32		64.6	73.0		53.8
Base of Last Salt	2463.1	55.5	102.0	1.6	3.05	3.45	0.05	0.06	18.2	1849.9	1.33	40.17		85.2	96.4		53.5
Frobisher-Alida	2518.6	198.1	103.6	2.3	2.90	3.45	0.17	0.20	68.3	1918.2	1.31	39.90		34.2	40.7		52.4
Lodgepole	2716.7	200.9	105.9	6.3	2.10	3.45	0.13	0.21	95.6	2013.9	1.35	37.83		65.7	108.0		51.0
Bakken	2917.5	33.5	112.2	1.4	1.10	4.00	0.01	0.04	30.5	2044.3	1.43	37.38		46.7	169.7		53.3
Three Forks	2951.1	57.3	113.6	1.7	2.50	4.00	0.04	0.07	22.9	2067.3	1.43	37.44		75.9	121.4		53.4
Birdbear	3008.4	29.6	115.3	0.7	2.50	4.00	0.02	0.04	11.8	2079.1	1.45	37.30		57.8	92.4		54.0
Duperow	3037.9	142.3	116.0	3.2	2.20	4.00	0.09	0.17	64.7	2143.8	1.42	37.16		49.5	90.1		52.7
Souris River	3180.3	83.2	119.2	2.2	2.60	3.09	0.06	0.08	32.0	2175.8	1.46	36.50		67.4	80.0		53.4
Dawson Bay	3263.5	38.7	121.4	0.4	2.50	3.09	0.03	0.04	15.5	2191.3	1.49	36.23		28.7	35.5		54.0
Prairie Evaporite	3302.2	49.3	121.8	0.7	4.00	2.18	0.06	0.03	12.3	2203.6	1.50	35.94		58.6	31.9		53.9
BOH	3351.5		122.6														
						Σ =	1.73	2.46									
											Average			54.2	82.2	52.7	51.4
											Wtd Average			61.1	87.2		
											Shallow					51.6	38.6
											Deep		52.0			52.9	52.7

Notes
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11- FU/HC/FH - Fort Union Group/Hell Creek Formation/Fox Hills Formation combined

Summary of Heat Flow Calculations
NDIC 13132
Frink 13-15
McClean County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ^1	$\lambda_N{}^2$	$\lambda_{wtd}{}^3$	$\lambda_{Nwtd}{}^4$	$\Delta Z_i/\lambda$	R_i	$\lambda_{hi}{}^5$	$grad_i$	$Q_{graph}{}^6$	$Q_2{}^7$	$Q_N{}^8$	$Q_{Bullard}{}^9$	$Q_{hi}{}^{10}$
	(m)		(°C)		$W\ m^{-1}K^{-1}$				$W\ K^{-1}$		$W\ m^{-1}K^{-1}$	°C km^{-1}	$mW\ m^{-2}$				
Till	0.0	44.2	6.1	1.9	1.20	1.72	0.02	0.03	36.83	36.83				51.4	73.7		
FU/HC/FH[11]	44.2	460.2	8.0	10.7	1.60	1.72	0.32	0.34	287.66	324.49	0.14	42.85		37.3	40.1		5.8
Pierre	504.4	690.1	18.7	25.6	1.10	1.62	0.33	0.48	627.33	951.82	0.53	25.05		40.9	60.2		13.3
Greenhorn	1194.5	122.8	44.4	6.1	1.00	1.62	0.05	0.09	122.83	1074.65	1.11	32.04		49.4	80.1		35.6
Mowry	1317.3	100.6	50.4	4.1	1.10	1.80	0.05	0.08	91.44	1166.09	1.13	33.66		45.3	74.1		38.0
Inyan Kara	1417.9	127.4	54.6	2.5	1.40	2.35	0.08	0.13	91.00	1257.10	1.13	34.19		27.4	45.9		38.6
Swift	1545.3	133.2	57.1	3.7	1.20	2.10	0.07	0.12	111.00	1368.10	1.13	32.99		33.6	58.8		37.3
Rierdon	1678.5	147.2	60.8	4.2	1.60	2.10	0.10	0.13	92.01	1460.11	1.15	32.59		45.5	59.8		37.5
Spearfish	1825.8	73.2	65.0	1.3	1.60	3.04	0.05	0.10	45.72	1505.83	1.21	32.26		28.2	53.6		39.1
Opeche	1898.9	48.2	66.3	0.9	1.50	3.04	0.03	0.06	32.11	1537.93	1.23	31.69		29.3	59.3		39.1
Broom Creek	1947.1	117.3	67.2	2.1	2.30	3.04	0.12	0.15	51.02	1588.95	1.23	31.39		41.9	55.4		38.5
Tyler	2064.4	45.4	69.3	1.9	1.20	2.68	0.02	0.05	37.85	1626.80	1.27	30.65		49.9	111.5		38.9
Big Snowy	2109.8	75.3	71.2	1.6	1.60	3.62	0.05	0.12	47.05	1673.85	1.26	30.88		34.2	77.4		38.9
Kibbey Lime	2185.1	46.0	72.8	0.7	2.70	3.62	0.05	0.07	17.05	1690.90	1.29	30.55		41.7	55.8		39.5
Madison	2231.1	84.5	73.6	1.1	3.05	3.45	0.11	0.13	27.71	1718.61	1.30	30.24		39.3	44.5		39.3
BOH	2315.7		74.6														59.5
						Σ =	1.46	2.09									
Notes											Average			39.7	63.4	39.9	34.2
1 - Thermal conductivity derived from graphical method											Wtd Average			43.1	61.8		
2 - Thermal conductivity used by Nordeng and Nesheim (2011) and Nordeng (2014)											Shallow					38.1	13.3
3 - Weighted average of graphical thermal conductivity											Deep		40			38.3	38.4
4 - Weighted average of Nordeng's thermal conductivity																	
5 - Harmonic mean of thermal conductivity																	
6 - Heat flow derived from graphical method																	
7- Heat flow derived from Equation 1 for each formation																	
8 - Heat Flow derived from Equation 1 and Nordengs λ																	
9 - Heat flow derived from Bullard's Method																	
10 - Heat flow derived using harmonic mean method																	
11- FU/HC/FH - Fort Union Group/Hell Creek Formation/Fox Hills Formation combined																	

Summary of Heat Flow Calculations
NDIC 13666
Rieder 1-9 SWD
Williams County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(°C)		$W\ m^{-1}K^{-1}$				$W\ K^{-1}$		$W\ m^{-1}K^{-1}$	°C km^{-1}	$mW\ m^{-2}$				
FU/HC/FH[11]	12.2	693.7	5.2	26.9	1.25	1.72	0.32	0.44	554.98	554.98				48.4	66.6		
Pierre	705.9	557.5	32.0	24.1	1.10	1.62	0.22	0.33	506.80	1061.78	0.66	38.72		47.6	70.1		25.7
Niobrara	1263.4	128.0	56.2	6.4	1.00	1.62	0.05	0.08	128.02	1189.80	1.06	40.76		49.8	80.6		43.3
Greenhorn	1391.4	110.9	62.5	6.0	1.00	1.62	0.04	0.07	110.95	1300.74	1.07	41.60		54.1	87.6		44.5
Mowry	1502.4	43.9	68.5	2.0	1.10	1.80	0.02	0.03	39.90	1340.64	1.12	42.53		48.9	80.0		47.7
Newcastle	1546.3	55.2	70.5	2.7	1.50	1.80	0.03	0.04	36.78	1377.42	1.12	42.58		72.8	87.4		47.8
Inyan Kara	1601.4	169.8	73.2	4.5	1.60	2.35	0.10	0.15	106.11	1483.53	1.08	42.79		42.4	62.3		46.2
Swift	1771.2	159.4	77.7	5.7	1.20	2.35	0.07	0.14	132.84	1616.37	1.10	41.22		43.0	84.2		45.2
Rierdon	1930.6	186.5	83.4	6.5	1.50	2.35	0.10	0.16	124.36	1740.73	1.11	40.77		52.5	82.2		45.2
Spearfish	2117.1	150.0	89.9	3.0	1.80	3.04	0.10	0.17	83.31	1824.04	1.16	40.26		36.0	60.8		46.7
Broom Creek	2267.1	52.7	92.9	1.2	2.20	3.04	0.04	0.06	23.97	1848.01	1.23	38.91		49.4	68.2		47.7
Tyler	2319.8	46.6	94.1	2.0	1.20	2.68	0.02	0.05	38.86	1886.87	1.23	38.53		50.9	113.7		47.4
Big Snowy	2366.5	116.4	96.1	3.9	1.60	3.62	0.07	0.15	72.77	1959.64	1.21	38.61		53.4	120.9		46.6
Kibbey Lime	2482.9	44.8	99.9	1.1	2.70	3.62	0.04	0.06	16.59	1976.24	1.26	38.37		67.3	90.2		48.2
Madison Group	2527.7	208.1	101.1	2.1	3.05	3.62	0.23	0.28	68.23	2044.47	1.24	38.13		30.7	36.4		47.1
BOH	2735.8		103.2														
						Σ =	1.45	2.18									
Notes											Average			49.8	79.4	48	45
1 - Thermal conductivity derived from graphical method											Wtd Average			52.1	77.9		
2 - Thermal conductivity used by Nordeng and Nesheim (2011) and Nordeng (2014)											Shallow					47.6	34.5
3 - Weighted average of graphical thermal conductivity											Deep		48.5			47.2	46.7
4 - Weighted average of Nordeng's thermal conductivity																	
5 - Harmonic mean of thermal conductivity																	
6 - Heat flow derived from graphical method																	
7- Heat flow derived from Equation 1 for each formation																	
8 - Heat Flow derived from Equation 1 and Nordengs λ																	
9 - Heat flow derived from Bullard's Method																	
10 - Heat flow derived using harmonic mean method																	
11- FU/HC/FH - Fort Union Group/Hell Creek Formation/Fox Hills Formation combined																	

Summary of Heat Flow Calculations
NDIC 15137
Holte 6-21
Burke County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(°C)		$W\ m^{-1}K^{-1}$				$W\ K^{-1}$		$W\ m^{-1}K^{-1}$	$°C\ km^{-1}$	$mW\ m^{-2}$				
FU/HC/FH[11]	6.7	465.7	3.7	20.8	1.60	1.72	0.24	0.26	388.11	388.11				51.1	73.3		
Pierre	472.4	550.5	24.5	25.9	1.20	1.62	0.21	0.29	366.98	755.09	0.70	42.62		72.5	78.4		28.8
Niobrara	1022.9	114.6	50.3	7.2	1.10	1.62	0.04	0.06	143.26	898.35	1.09	45.49		35.6	72.0		45.0
Greenhorn	1137.5	84.1	57.5	5.6	1.00	1.62	0.03	0.04	70.10	968.45	1.20	45.31		117.0	157.9		50.6
Mowry	1221.6	37.2	63.1	1.9	1.10	1.80	0.01	0.02	41.32	1009.77	1.25	48.92		46.5	93.0		56.4
Newcastle	1258.8	61.3	65.0	3.4	1.00	1.80	0.02	0.04	55.70	1065.46	1.21	49.01		62.6	102.5		55.3
Inyan Kara	1320.1	103.0	68.4	3.2	1.50	2.35	0.05	0.08	64.39	1129.85	1.19	49.38		48.1	70.7		55.3
Swift	1423.1	128.3	71.6	5.8	1.90	2.10	0.08	0.09	53.47	1183.32	1.21	47.97		108.7	95.1		55.4
Rierdon	1551.4	187.1	77.4	7.5	1.40	2.10	0.08	0.13	74.86	1258.18	1.18	47.75		94.0	78.9		56.6
Spearfish	1738.6	132.6	84.9	3.2	2.10	3.04	0.09	0.13	88.39	1346.57	1.27	46.65		40.7	82.4		58.1
Kibbey	1871.2	54.9	88.1	1.3	2.20	3.64	0.04	0.06	30.48	1377.05	1.34	45.26		41.4	83.7		59.4
Madison	1926.0	99.4	89.3	2.0	3.10	3.45	0.10	0.11	32.58	1409.63	1.35	44.63		62.2	70.4		58.9
Ratcliffe	2025.4	18.0	91.3	0.4	2.60	3.45	0.02	0.02	7.49	1417.12	1.41	43.43		51.9	74.6		60.0
Last Salt	2043.4	61.6	91.7	1.4	2.60	3.45	0.05	0.07	18.66	1435.78	1.40	43.24		76.2	79.7		59.5
Frobisher	2104.9	171.3	93.2	4.5	2.80	3.45	0.15	0.19	47.58	1483.36	1.38	42.65		94.6	90.6		58.6
Lodgepole	2276.2	178.3	97.7	5.0	2.00	3.45	0.11	0.20	50.95	1534.31	1.41	41.41		97.2	95.8		59.5
Bakken	2454.6	30.8	102.6	1.3	1.20	4.00	0.01	0.04	30.78	1565.09	1.50	40.42		41.9	167.5		61.4
Three Forks	2485.3	64.6	103.9	2.0	2.00	4.00	0.04	0.08	26.92	1592.02	1.49	40.44		75.5	125.9		61.2
Birdbear	2550.0	29.9	105.9	0.8	2.40	4.00	0.02	0.04	19.91	1611.93	1.52	40.21		42.1	112.3		61.7
Duperow	2579.8	146.6	106.7	3.5	2.90	4.00	0.14	0.19	43.12	1655.05	1.49	40.07		81.4	95.8		60.6
Souris River	2726.4	103.3	110.3	2.4	2.80	3.09	0.09	0.10	35.63	1690.68	1.54	39.20		67.5	71.9		61.4
Dawson Bay	2829.8	46.6	112.7	0.9	2.30	3.09	0.03	0.05	21.20	1711.88	1.58	38.62		42.2	59.3		62.0
Prairie Evaporite	2876.4	173.1	113.6	2.7	3.60	2.18	0.20	0.12	41.22	1753.10	1.57	38.30		66.4	34.5		61.1
Winnepegosis	3049.5	43.0	116.3	1.0	2.50	2.83	0.03	0.04	15.92	1769.02	1.64	37.02		61.4	64.4		62.1
Interlake	3092.5	15.2	117.3	0.3	2.70	3.72	0.01	0.02	5.06	1774.07	1.66	36.82		67.0	83.1		62.4
Bottom of Well	3107.7		117.6		3	3.72					1.67	36.75					
						Σ =	1.92	2.45									
											Average			60.0	87.7	60.5	58
											Wtd Average			70.3	90.0		
											Shallow					55.6	57.8
											Deep		60			60.8	60.4

Notes
1 - Thermal conductivity derived from graphical method
2 - Thermal conductivity used by Nordeng and Nesheim (2011) and Nordeng (2014)
3 - Weighted average of graphical thermal conductivity
4 - Weighted average of Nordeng's thermal conductivity
5 - Harmonic mean of thermal conductivity
6 - Heat flow derived from graphical method
7- Heat flow derived from Equation 1 for each formation
8 - Heat Flow derived from Equation 1 and Nordengs λ
9 - Heat flow derived from Bullard's Method
10 - Heat flow derived using harmonic mean method
11- FU/HC/FH - Fort Union Group/Hell Creek Formation/Fox Hills Formation combined

Summary of Heat Flow Calculations
NDIC 15593
FHMU K-810
Billings County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(°C)		$W\ m^{-1}K^{-1}$				$W\ K^{-1}$		$W\ m^{-1}K^{-1}$	$^{o}C\ km^{-1}$		$mW\ m^{-2}$			
FU/HC/FH[11]	0.0	599.9	8.7	23.3	1.50	1.72	0.33	0.38	399.92	399.92				58.2	66.7		
Pierre	585.2	630.3	31.9	33.5	1.05	1.62	0.25	0.38	600.31	1000.23	0.60	38.78		55.8	86.1		52.4
Niobrara	1236.3	95.4	65.4	4.7	1.10	1.62	0.04	0.06	86.73	1086.96	1.14	46.14		54.3	79.9		52.9
Carlisle	1332.0	88.1	70.1	4.4	1.10	1.62	0.04	0.05	80.08	1167.04	1.14	46.37		54.7	80.6		50.3
Greenhorn	1413.4	162.2	74.5	9.6	1.10	1.62	0.07	0.10	147.41	1314.45	1.08	46.58		65.0	95.8		56.1
Mowry	1579.5	37.5	84.1	2.5	1.10	1.80	0.02	0.03	34.08	1348.53	1.17	47.87		72.5	118.7		55.5
Newcastle	1618.5	72.8	86.6	5.7	1.20	1.80	0.03	0.05	60.71	1409.24	1.15	48.29		93.7	140.6		53.2
Inyan Kara	1696.2	251.5	92.3	8.8	1.50	2.35	0.14	0.22	167.64	1576.88	1.07	49.58		52.7	82.6		56.3
Rierdon	1943.7	126.5	101.1	3.7	1.80	2.10	0.08	0.10	70.27	1647.15	1.18	47.71		52.3	61.1		55.8
Spearfish	2077.0	186.8	104.8	4.7	2.30	3.04	0.16	0.21	81.24	1728.39	1.20	46.57		57.8	76.4		57.0
Opeche	2268.7	94.5	109.5	1.2	2.10	3.05	0.07	0.11	44.99	1773.38	1.27	44.79		27.7	40.2		55.6
Minnelusa	2364.2	181.3	110.7	3.8	2.70	3.04	0.18	0.21	67.14	1840.52	1.28	43.51		56.0	63.1		56.7
Otter	2531.9	42.5	114.5	1.8	1.40	3.62	0.02	0.06	30.39	1870.91	1.35	41.88		59.2	153.1		56.8
Kibbey	2574.4	82.7	116.3	2.2	3.00	3.62	0.09	0.11	27.57	1898.48	1.36	41.89		79.8	96.3		57.7
Madison	2657.1	29.1	118.5	0.7	3.05	3.45	0.03	0.04	9.53	1908.01	1.39	41.41		68.2	77.2		58.6
Bottom of Well	2694.3		119.1														
						Σ =	1.56	2.10									
											Average			60.5	87.9	58.4	52.4
											Wtd Average			64.1	86.2		
											Shallow					55.8	37.9
											Deep		58.0			58.8	55.3

Notes
1 - Thermal conductivity derived from graphical method
2 - Thermal conductivity used by Nordeng and Nesheim (2011) and Nordeng (2014)
3 - Weighted average of graphical thermal conductivity
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5 - Harmonic mean of thermal conductivity
6 - Heat flow derived from graphical method
7- Heat flow derived from Equation 1 for each formation
8 - Heat Flow derived from Equation 1 and Nordengs λ
9 - Heat flow derived from Bullard's Method
10 - Heat flow derived using harmonic mean method
11- FU/HC/FH - Fort Union Group/Hell Creek Formation/Fox Hills Formation combined

Summary of Heat Flow Calculations
NDIC 15875
Ann 1
McKenzie County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(°C)		$W\ m^{-1}K^{-1}$				$W\ K^{-1}$		$W\ m^{-1}K^{-1}$	°C km^{-1}	$mW\ m^{-2}$				
Till	0.0	2.4	9.1	0.1	1.20	1.72	0.00	0.00	2.03	2.03				39.4	56.4		
FU/HC/FH[11]	2.4	606.9	9.2	21.4	1.40	1.72	0.27	0.33	433.47	435.50	0.01	32.81		49.3	60.6		0.2
Pierre	609.3	864.7	30.6	41.5	1.10	1.62	0.30	0.45	786.11	1221.61	0.50	35.24		52.7	77.7		17.6
Greenhorn	1474.0	121.9	72.1	7.4	1.10	1.62	0.04	0.06	110.84	1332.44	1.11	42.69		66.5	97.9		47.2
Mowry	1595.9	48.5	79.4	2.3	1.00	1.80	0.02	0.03	48.46	1380.91	1.16	44.05		47.5	85.4		50.9
Newcastle	1644.4	83.8	81.7	4.2	1.20	1.80	0.03	0.05	69.85	1450.76	1.13	44.15		59.4	89.1		50.0
Inyan Kara	1728.2	125.0	85.9	3.1	1.40	2.35	0.06	0.09	89.26	1540.02	1.12	44.41		34.8	58.5		49.8
Swift	1853.2	147.8	89.0	6.0	1.40	2.10	0.07	0.10	105.59	1645.61	1.13	43.09		57.0	85.5		48.5
Rierdon	2001.0	172.2	95.0	5.9	1.60	2.10	0.09	0.12	107.63	1753.24	1.14	42.92		55.0	72.2		49.0
Spearfish	2173.2	140.5	100.9	2.7	1.80	3.04	0.08	0.14	78.06	1831.31	1.19	42.24		34.1	57.5		50.1
Minnekahta/Opech	2313.7	113.4	103.6	2.2	2.60	3.04	0.09	0.11	43.61	1874.92	1.23	40.83		50.0	58.4		50.4
Broom Creek	2427.1	61.9	105.8	1.4	2.40	3.04	0.05	0.06	25.78	1900.70	1.28	39.82		53.1	67.3		50.8
Tyler	2489.0	61.9	107.2	3.6	1.20	2.68	0.02	0.05	51.56	1952.26	1.27	39.38		69.2	154.6		50.2
Big Snowy	2550.9	106.1	110.7	3.0	1.50	3.62	0.05	0.12	70.71	2022.97	1.26	39.82		43.0	103.7		50.2
Kibbey Lime	2656.9	55.2	113.8	1.0	2.70	3.62	0.05	0.06	20.43	2043.41	1.30	39.38		49.9	66.9		51.2
Madison	2712.1	192.6	114.8	3.1	3.05	3.45	0.19	0.21	63.16	2106.56	1.29	38.95		49.7	56.2		50.1
Ratcliffe	2904.7	65.8	117.9	1.5	3.05	3.45	0.06	0.07	21.59	2128.15	1.36	37.45		68.1	77.0		51.1
Frobisher	2970.6	168.0	119.4	3.7	3.05	3.45	0.16	0.18	55.08	2183.24	1.36	37.11		66.8	75.6		50.5
Bottom of Well	3138.6		123.1														
						Σ =	1.63	2.24									
											Average			52.5	77.8	51.9	45.2
											Wtd Average			59.3	81.3		
											Shallow					49.3	17.6
											Deep		52.0			50.9	50.0

Notes
1 - Thermal conductivity derived from graphical method
2 - Thermal conductivity used by Nordeng and Nesheim (2011) and Nordeng (2014)
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7- Heat flow derived from Equation 1 for each formation
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9 - Heat flow derived from Bullard's Method
10 - Heat flow derived using harmonic mean method
11- FU/HC/FH - Fort Union Group/Hell Creek Formation/Fox Hills Formation combined

Summary of Heat Flow Calculations
NDIC 16160
Nelson 1-11H
McClean County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(°C)		$W\ m^{-1}K^{-1}$				$W\ K^{-1}$		$W\ m^{-1}K^{-1}$	$°C\ km^{-1}$	$mW\ m^{-2}$				
Till	0.0	31.1	5.9	1.1	1.10	1.72	0.01	0.02	28.26	28.26				370.4	579.2		
FU/HC/FH[11]	31.1	590.7	6.9	20.2	1.60	1.72	0.37	0.40	369.19	397.45	0.08	325.51		29.2	31.4		25.5
Pierre	621.8	709.6	27.1	34.0	1.30	1.62	0.36	0.45	545.83	943.28	0.66	34.16		62.2	77.5		22.5
Greenhorn	1331.4	98.1	61.1	6.3	1.00	1.62	0.04	0.06	98.15	1041.42	1.28	41.45		64.0	103.7		53.0
Mowry	1429.5	53.9	67.4	2.7	1.10	1.80	0.02	0.04	49.05	1090.47	1.31	43.00		55.5	90.8		56.4
Newcastle	1483.5	79.2	70.1	3.8	1.30	1.80	0.04	0.06	60.96	1151.43	1.29	43.27		62.2	86.1		55.7
Inyan Kara	1562.7	84.1	73.9	2.4	1.40	2.35	0.05	0.08	60.09	1211.52	1.29	43.50		40.6	68.2		56.1
Swift	1646.8	154.2	76.3	6.4	1.60	2.10	0.10	0.13	96.39	1307.91	1.26	42.76		66.7	87.6		53.8
Rierdon	1801.1	141.1	82.7	5.0	1.80	2.10	0.10	0.12	78.40	1386.31	1.30	42.67		63.5	74.1		55.4
Spearfish	1942.2	128.3	87.7	3.3	1.70	3.04	0.08	0.15	75.48	1461.80	1.33	42.13		43.9	78.4		56.0
Tyler	2070.5	146.3	91.0	5.3	2.20	2.68	0.13	0.15	66.50	1528.30	1.35	41.12		80.3	97.8		55.7
Kibbey Lime	2216.8	62.2	96.4	1.1	2.00	3.62	0.05	0.09	31.09	1559.39	1.42	40.82		34.1	61.7		58.0
Madison	2279.0	130.5	97.4	2.4	3.30	3.45	0.17	0.18	39.53	1598.92	1.43	40.17		61.2	64.0		57.3
Ratcliffe	2409.4	79.2	99.8	1.8	3.00	3.45	0.09	0.11	26.42	1625.33	1.48	39.00		66.6	76.6		57.8
Frobisher	2488.7	80.7	101.6	1.8	3.30	3.45	0.10	0.11	24.45	1649.78	1.51	38.46		74.4	77.8		58.0
Bottom of Well	2569.4		103.4		3.30												
						Σ =	1.70	2.12									
											Average			78.3	110.3	56.2	51.5
											Wtd Average			64.7	80.4		
											Shallow					30.1	24.0
											Deep		59.0			59.2	56.1

Notes
1 - Thermal conductivity derived from graphical method
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9 - Heat flow derived from Bullard's Method
10 - Heat flow derived using harmonic mean method
11- FU/HC/FH - Fort Union Group/Hell Creek Formation/Fox Hills Formation combined

Summary of Heat Flow Calculations
NDIC 16182
NDCA7
Williams County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(°C)		$W m^{-1} K^{-1}$				$W K^{-1}$		$W m^{-1} K^{-1}$	°C km^{-1}	$mW m^{-2}$				
FU/HC/FH[11]	31.6	613.0	5.8	21.9	1.20	1.72	0.25	0.36	510.84	510.84				42.8	61.3		
Pierre	644.7	648.3	27.6	31.0	1.10	1.62	0.25	0.36	589.37	1100.22	0.59	35.64		52.5	77.3		20.9
Greenhorn	1293.0	94.5	58.6	6.0	1.00	1.62	0.03	0.05	94.49	1194.71	1.08	41.86		63.5	103.0		45.3
Mowry	1387.4	115.8	64.6	6.2	1.10	2.35	0.04	0.09	105.29	1300.00	1.07	43.37		59.0	126.1		46.3
Inyan Kara	1503.3	121.0	70.8	3.0	1.50	2.10	0.06	0.09	80.67	1380.67	1.09	44.18		37.2	52.1		48.1
Swift	1624.3	133.5	73.8	6.0	1.20	2.10	0.06	0.10	111.25	1491.92	1.09	42.71		53.9	94.4		46.5
Rierdon	1757.8	165.5	79.8	6.5	1.30	3.04	0.07	0.17	127.31	1619.23	1.09	42.88		51.1	119.4		46.5
Spearfish	1923.3	144.5	86.3	3.3	1.40	3.40	0.07	0.17	103.20	1722.43	1.12	42.56		31.7	77.0		47.5
Minnekahta	2067.8	14.6	89.6	0.3	2.55	3.04	0.01	0.02	5.74	1728.17	1.20	41.15		54.2	64.6		49.2
Opeche	2082.4	80.2	89.9	3.6	1.20	3.04	0.03	0.08	66.80	1794.97	1.16	41.01		54.5	138.0		47.6
Tyler	2162.6	100.0	93.5	2.8	1.30	2.68	0.04	0.09	76.90	1871.87	1.16	41.17		35.9	74.0		47.6
Kibbey	2262.5	45.7	96.3	1.3	2.70	3.62	0.04	0.06	16.93	1888.81	1.20	40.57		79.1	106.0		48.6
Madison	2308.3	159.4	97.6	2.7	3.05	3.45	0.17	0.19	52.27	1941.07	1.19	40.34		51.9	58.7		48.0
Ratcliffe	2467.7	23.5	100.3	0.4	2.90	3.45	0.02	0.03	8.09	1949.17	1.27	38.81		51.5	61.2		49.1
Last Salt	2491.1	223.7	100.7	5.3	2.70	3.45	0.21	0.27	82.86	2032.03	1.23	38.61		63.9	81.6		47.3
Lodgepole	2714.9	179.5	106.0	4.6	3.05	3.45	0.19	0.21	58.84	2090.86	1.30	37.37		78.5	88.8		48.5
Bottom of Well	2894.3		110.6														
						Σ =	1.56	2.35									
											Average			53.8	86.5	50.4	45.8
											Wtd Average			56.6	85.2		
											Shallow					52.5	33.1
											Deep		49			48.4	47.8

Notes
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10 - Heat flow derived using harmonic mean method
11- FU/HC/FH - Fort Union Group/Hell Creek Formation/Fox Hills Formation combined

Summary of Heat Flow Calculations
NDIC 16376
Vernie Chapin 32-21
McKenzie County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(°C)		W $m^{-1}K^{-1}$				W K^{-1}		W $m^{-1}K^{-1}$	°C km^{-1}	mW m^{-2}				
FU/HC/FH[11]	0.0	503.2	5.2	22.5	1.40	1.72	0.18	0.22	359.45	359.45				62.5	76.8		
Pierre	503.2	783.6	27.6	39.8	1.15	1.62	0.23	0.32	681.43	1040.87	0.48	44.65		58.4	82.3		21.6
Greenhorn	1286.9	125.0	67.4	8.1	1.10	1.62	0.03	0.05	113.61	1154.48	1.11	48.38		71.2	104.8		53.9
Mowry	1411.8	29.0	75.5	1.6	1.20	1.80	0.01	0.01	24.13	1178.61	1.20	49.82		64.7	97.0		59.7
Newcastle	1440.8	79.9	77.1	4.5	1.50	1.80	0.03	0.04	53.24	1231.85	1.17	49.90		85.3	102.3		58.4
Inyan Kara	1520.6	107.9	81.6	3.0	1.60	2.35	0.04	0.06	67.44	1299.29	1.17	50.27		43.9	64.5		58.8
Swift	1628.5	179.2	84.6	7.0	1.40	2.10	0.06	0.10	128.02	1427.30	1.14	48.76		54.5	81.8		55.6
Rierdon	1807.8	151.5	91.6	6.0	1.60	2.10	0.06	0.08	94.68	1521.98	1.19	47.78		63.1	82.8		56.8
Spearfish	1959.3	155.8	97.5	3.6	2.40	3.04	0.09	0.12	64.90	1586.88	1.23	47.14		54.7	69.3		58.2
Opeche	2115.0	126.5	101.1	2.6	2.20	3.04	0.07	0.10	57.50	1644.37	1.29	45.34		44.8	62.0		58.3
Amsden	2241.5	82.6	103.7	1.7	3.80	3.04	0.08	0.06	21.74	1666.11	1.35	43.93		76.4	61.1		59.1
Tyler	2324.1	69.2	105.3	4.3	1.60	2.68	0.03	0.05	43.24	1709.35	1.36	43.09		99.2	166.1		58.6
Big Snowy	2393.3	104.5	109.6	3.3	1.40	3.62	0.04	0.10	74.68	1784.03	1.34	43.63		43.7	112.9		58.5
Kibbey	2497.8	47.2	112.9	1.0	2.70	3.62	0.03	0.04	17.50	1801.53	1.39	43.11		55.9	74.9		59.8
Madison	2545.1	187.8	113.8	3.3	3.05	3.45	0.14	0.16	61.56	1863.09	1.37	42.70		53.0	59.9		58.3
Ratcliffe	2732.8	75.3	117.1	1.6	3.05	3.45	0.06	0.07	24.68	1887.77	1.45	40.96		65.7	74.3		59.3
Frobisher	2808.1	183.2	118.7	4.5	2.80	3.45	0.13	0.16	65.42	1953.19	1.44	40.44		68.9	84.9		58.1
Lodgepole	2991.3	243.8	123.2	7.3	2.30	3.45	0.14	0.21	106.02	2059.21	1.45	39.47		69.1	103.6		57.3
Bakken	3235.1	35.1	130.6	1.5	1.00	4.00	0.01	0.04	35.05	2094.26	1.54	38.75		43.4	173.7		59.9
Three Forks	3270.2	59.4	132.1	1.6	2.70	4.00	0.04	0.06	22.01	2116.28	1.55	38.80		74.4	110.3		60.0
Birdbear	3329.6	25.3	133.7	0.6	2.80	4.00	0.02	0.03	9.04	2125.31	1.57	38.60		63.9	91.4		60.5
Duperow	3354.9	125.9	134.3	3.0	2.60	4.00	0.08	0.13	48.42	2173.73	1.54	38.49		61.4	94.4		59.4
Souris River	3480.8	79.6	137.3	2.0	2.80	3.09	0.06	0.06	28.41	2202.14	1.58	37.95		68.6	75.7		60.0
Dawson Bay	3560.4	32.0	139.2	0.8	2.75	3.09	0.02	0.02	11.64	2213.78	1.61	37.65		65.4	73.5		60.5
Prairie	3592.4	86.9	140.0	1.7	4.00	2.18	0.09	0.05	21.72	2235.50	1.61	37.52		76.7	41.8		60.3
Winnipegosis	3679.2	34.4	141.6	0.9	2.99	2.83	0.03	0.02	11.52	2247.01	1.64	37.09		75.7	71.7		60.7
Ashern	3713.7	36.3	142.5	1.0	2.99	2.83	0.03	0.03	12.13	2259.15	1.64	36.98		83.8	79.3		60.8
Interlake	3750.0	211.2	143.5	4.6	3.77	3.72	0.20	0.20	56.03	2315.17	1.62	36.90		81.2	80.1		59.8
BOH	3961.2		148.1														
						Σ =	2.03	2.58									
											Average			65.3	87.6	61	57.5
											Wtd Average			73.3	93.0		
											Shallow					58.4	37.8
											Deep		60			60.3	59.1

Notes
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10 - Heat flow derived using harmonic mean method
11- FU/HC/FH - Fort Union Group/Hell Creek Formation/Fox Hills Formation combined

Summary of Heat Flow Calculations
NDIC 17014
Edwards 1-33BH
Mountrail County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(°C)		$W\ m^{-1}K^{-1}$				$W\ K^{-1}$		$W\ m^{-1}K^{-1}$	°C km^{-1}	$mW\ m^{-2}$				
Till	0.0	7.6	6.6	0.2	1.10	1.72	0.00	0.01	6.93	6.93				102.5	160.3		
FU/HC/FH[11]	7.6	538.6	6.8	14.2	1.40	1.72	0.31	0.38	384.70	391.63	0.02	93.18		37.1	45.6		1.8
Pierre	546.2	599.2	20.9	23.8	1.05	1.62	0.26	0.40	570.70	962.33	0.57	27.44		41.7	64.3		15.6
Greenhorn	1145.4	96.0	44.7	5.1	1.00	1.62	0.04	0.06	96.01	1058.34	1.08	33.84		53.1	86.1		36.6
Mowry	1241.5	107.0	49.8	4.9	0.90	1.80	0.04	0.08	118.87	1177.21	1.05	35.33		41.2	82.4		37.3
Inyan Kara	1348.4	97.5	54.7	2.2	1.40	2.35	0.06	0.09	69.67	1246.88	1.08	36.16		32.0	53.7		39.1
Swift	1446.0	127.4	56.9	3.8	1.20	2.10	0.06	0.11	106.17	1353.05	1.07	35.26		35.7	62.5		37.7
Rierdon	1573.4	171.0	60.7	4.9	1.60	2.10	0.11	0.15	106.87	1459.93	1.08	34.82		45.5	59.7		37.5
Spearfish	1744.4	176.5	65.6	4.0	1.40	3.04	0.10	0.22	126.06	1585.98	1.10	34.19		32.0	69.4		37.6
Broom Creek	1920.8	95.7	69.6	2.3	3.00	2.68	0.12	0.11	31.90	1617.88	1.19	33.15		71.8	64.1		39.4
Kibbey	2016.6	49.1	71.9	0.8	2.40	3.62	0.05	0.07	20.45	1638.33	1.23	32.71		38.6	58.3		40.3
Madison	2065.6	71.9	72.7	1.1	2.90	3.45	0.09	0.10	24.80	1663.14	1.24	32.31		44.3	52.8		40.1
Ratcliffe	2137.6	20.1	73.8	0.3	3.00	3.45	0.02	0.03	6.71	1669.84	1.28	31.74		50.7	58.3		40.6
Frobisher	2157.7	279.7	74.1	5.3	3.05	3.45	0.35	0.40	91.70	1761.54	1.22	31.60		58.0	65.6		38.7
Bottom of Well	2437.4		79.4		3.05												
						Σ =	1.61	2.20									

	Q_{graph}	Q_2	Q_N	$Q_{Bullard}$	Q_{hi}
Average		48.9	70.2	41.0	34.0
Wtd Average		48.5	66.4		
Shallow				37.1	26.1
Deep	40.0			41.0	38.6

Notes
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9 - Heat flow derived from Bullard's Method
10 - Heat flow derived using harmonic mean method
11- FU/HC/FH - Fort Union Group/Hell Creek Formation/Fox Hills Formation combined

Summary of Heat Flow Calculations
NDIC 17043
St. Andes 151-89-2413H-1
Mountrail County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(°C)		W $m^{-1}K^{-1}$				W K^{-1}		W $m^{-1}K^{-1}$	°C km^{-1}	mW m^{-2}				
FU/HC/FH[11]	15.8	593.8	6.5	15.5	1.60	1.72	0.40	0.43	371.09	371.09				41.8	44.9		
Pierre	609.6	430.4	22.0	15.2	1.15	1.62	0.21	0.29	374.24	745.34	0.82	26.11		40.7	57.3		21.4
Niobrara	1040.0	156.1	37.2	6.9	1.10	1.62	0.07	0.11	141.87	887.21	1.17	30.00		48.9	72.1		35.2
Greenhorn	1196.0	116.1	44.2	5.9	0.90	1.62	0.04	0.08	129.03	1016.24	1.18	31.92		45.6	82.2		37.6
Mowry	1312.2	107.3	50.1	4.9	1.00	1.80	0.04	0.08	107.29	1123.53	1.17	33.60		45.6	82.0		39.2
Inyan Kara	1419.5	115.5	54.9	2.2	1.50	2.35	0.07	0.11	77.01	1200.54	1.18	34.51		28.9	45.2		40.8
Swift	1535.0	125.6	57.2	3.6	1.20	2.10	0.06	0.11	104.65	1305.19	1.18	33.35		34.0	59.5		39.2
Rierdon	1660.6	30.5	60.7	1.1	1.50	2.10	0.02	0.03	20.32	1325.51	1.25	32.97		54.7	76.6		41.3
Piper	1691.0	122.2	61.8	3.2	2.10	2.10	0.11	0.11	58.20	1383.71	1.22	33.03		55.4	55.4		40.4
Spearfish	1813.3	78.9	65.1	1.5	1.60	3.04	0.05	0.10	49.34	1433.05	1.27	32.58		30.4	57.8		41.2
Opeche	1892.2	24.7	66.6	0.5	1.60	3.04	0.02	0.03	15.43	1448.48	1.31	32.01		32.4	61.6		41.8
Amsden	1916.9	103.3	67.1	1.9	2.40	3.04	0.10	0.13	43.05	1491.53	1.29	31.85		43.9	55.6		40.9
Tyler	2020.2	121.6	68.9	3.2	1.40	2.68	0.07	0.14	86.87	1578.40	1.28	31.15		37.1	71.0		39.9
Kibbey Lime	2141.8	51.2	72.2	0.8	2.70	3.62	0.06	0.08	18.97	1597.37	1.34	30.89		43.9	58.9		41.4
Madison	2193.0	93.0	73.0	1.7	3.05	3.45	0.12	0.13	30.48	1627.85	1.35	30.54		56.5	63.9		41.1
Ratcliffe	2317.4	116.1	74.7	1.0	3.05	3.45	0.15	0.17	38.08	1665.92	1.37	30.05		26.3	29.7		41.2
Bottom of Well	2402.1		75.7														
						Σ =	1.59	2.11									
											Average			41.6	60.8	41.5	40.1
											Wtd Average			52.3	69.5		
											Shallow					40.7	28.3
											Deep		42			40.1	40.5

Notes
1 - Thermal conductivity derived from graphical method
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3 - Weighted average of graphical thermal conductivity
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6 - Heat flow derived from graphical method
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10 - Heat flow derived using harmonic mean method
11- FU/HC/FH - Fort Union Group/Hell Creek Formation/Fox Hills Formation combined

Summary of Heat Flow Calculations
NDIC 17230
Roosevelt Federal 2-4H
Billings County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(°C)		$W\ m^{-1}K^{-1}$				$W\ K^{-1}$		$W\ m^{-1}K^{-1}$	°C km^{-1}	$mW\ m^{-2}$				
FU/HC/FH[11]	6.7	413.3	9.4	14.2	1.30	1.72	0.18	0.28	317.93	317.93				44.8	59.2		
Pierre	420.0	896.4	23.6	42.4	1.15	1.62	0.34	0.48	779.49	1097.42	0.38	34.43		54.4	76.7		13.2
Greenhorn	1316.4	140.5	66.0	8.0	1.00	1.62	0.05	0.07	140.51	1237.94	1.06	43.27		56.8	92.0		46.0
Mowry	1456.9	62.8	74.0	2.5	1.10	1.80	0.02	0.04	57.08	1295.02	1.13	44.58		44.3	72.5		50.2
Newcastle	1519.7	87.2	76.5	4.2	1.50	1.80	0.04	0.05	58.12	1353.13	1.12	44.40		72.8	87.3		49.9
Inyan Kara	1606.9	128.9	80.8	3.4	1.60	2.35	0.07	0.10	80.58	1433.71	1.12	44.63		42.1	61.8		50.0
Swift	1735.8	154.2	84.2	6.3	1.30	2.10	0.07	0.11	118.64	1552.35	1.12	43.26		53.0	85.6		48.4
Rierdon	1890.1	97.8	90.4	3.5	1.80	2.10	0.06	0.07	54.36	1606.71	1.18	43.06		64.0	74.7		50.6
Spearfish	1987.9	154.5	93.9	3.0	2.60	3.04	0.13	0.15	59.44	1666.14	1.19	42.69		50.8	59.4		50.9
Minnekahta/Opech	2142.4	100.0	96.9	1.7	3.20	3.04	0.11	0.10	31.24	1697.38	1.26	41.01		54.1	51.4		51.8
Broom Creek	2242.4	88.1	98.6	1.4	2.60	3.04	0.08	0.09	33.88	1731.26	1.30	39.93		41.0	48.0		51.7
Tyler	2330.5	73.5	100.0	2.5	1.50	2.68	0.04	0.06	48.97	1780.24	1.31	39.02		50.6	90.5		51.1
Otter	2404.0	38.1	102.5	1.5	1.50	3.62	0.02	0.05	25.40	1805.64	1.33	38.86		57.9	139.7		51.7
Kibbey Sandstone	2442.1	65.5	104.0	1.6	3.10	3.62	0.07	0.08	21.14	1826.77	1.34	38.85		74.7	87.3		51.9
Kibbey Lime	2507.6	46.3	105.6	0.9	3.00	3.62	0.05	0.06	15.44	1842.22	1.36	38.47		56.3	68.0		52.4
Madison	2553.9	135.9	106.4	2.1	3.05	3.45	0.14	0.15	44.57	1886.79	1.35	38.11		47.1	53.3		51.6
Ratcliffe	2689.9	75.0	108.5	1.5	3.05	3.45	0.08	0.08	24.58	1911.37	1.41	36.96		60.6	68.6		52.0
Frobisher	2764.8	32.3	110.0	0.7	3.05	3.45	0.03	0.04	10.59	1921.97	1.44	36.50		65.1	73.7		52.5
Fryburg	2797.1	109.7	110.7	2.4	3.05	3.45	0.11	0.12	35.98	1957.94	1.43	36.32		65.9	74.5		51.9
Lodgepole	2906.9	139.8	113.1	3.6	3.05	3.45	0.14	0.16	45.83	2003.77	1.45	35.76		79.4	89.8		51.9
Bottom of Well	3046.7		116.7														
						Σ =	1.79	2.33									
											Average			56.8	75.7	53.5	48.9
											Wtd Average			63.1	82.3		
											Shallow					54.3	29.6
											Deep		55.0			52.7	51.2

Notes
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6 - Heat flow derived from graphical method
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11- FU/HC/FH - Fort Union Group/Hell Creek Formation/Fox Hills Formation combined

Summary of Heat Flow Calculations
NDIC 17317
E-M Emmel 10-3
Renville County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(°C)		W m^{-1}K^{-1}				W K^{-1}		W m^{-1}K^{-1}	°C km^{-1}	mW m^{-2}				
Glacial	0	76.2	5.88	2.32	1.2	1.72	0.03	0.07	50.8	50.8				36.5	52.4		
FU/HC/FH[11]	76.2	133.2	8.2	5.5	1.20	1.72	0.06	0.09	102.46	153.26	0.50	30.45		49.6	71.2		15.1
Pierre	209.4	556.0	13.7	28.0	1.10	1.62	0.23	0.34	483.44	636.70	0.33	37.39		55.4	81.6		12.3
Greenhorn	765.4	84.7	41.7	5.2	1.10	1.62	0.03	0.05	84.73	721.43	1.06	46.84		67.4	99.2		49.7
Mowry	850.1	93.3	46.9	5.1	1.20	1.80	0.04	0.06	93.27	814.70	1.04	48.28		65.6	98.4		50.4
Inyan Kara	943.4	129.5	52.0	3.2	1.60	2.35	0.08	0.11	76.20	890.90	1.06	48.91		39.6	58.2		51.8
Swift	1072.9	57.0	55.2	2.4	1.20	2.10	0.03	0.04	43.84	934.75	1.15	46.00		50.9	89.2		52.8
Rierdon	1129.9	163.1	57.7	5.6	1.60	2.10	0.10	0.13	95.92	1030.67	1.10	45.82		55.0	72.2		50.2
Spearfish	1293.0	66.8	63.3	1.5	1.60	3.04	0.04	0.08	33.38	1064.04	1.22	44.38		36.0	68.3		53.9
Madison	1359.7	225.6	64.8	5.6	3.05	3.45	0.26	0.29	86.75	1150.80	1.18	43.30		75.5	85.4		51.2
Lodgepole	1585.3	171.0	70.3	4.4	3.05	3.45	0.19	0.22	71.25	1222.04	1.30	40.66		79.2	89.6		52.7
Bakken	1756.3	9.1	74.8	0.3	1.10	4.00	0.00	0.01	10.16	1232.20	1.43	39.23		40.9	148.7		55.9
Three Forks	1765.4	57.3	75.1	1.6	3.10	4.00	0.07	0.09	22.04	1254.24	1.41	39.22		84.9	109.6		55.2
Birdbear	1822.7	31.1	76.7	0.7	3.13	4.00	0.04	0.05	11.96	1266.20	1.44	38.85		73.5	93.9		55.9
Duperow	1853.8	137.8	77.4	3.2	3.19	4.00	0.16	0.21	49.20	1315.40	1.41	38.59		74.8	93.8		54.4
Souris River	1991.6	98.5	80.7	2.1	2.92	3.09	0.11	0.11	39.38	1354.78	1.47	37.54		61.7	65.3		55.2
Dawson Bay	2090.0	55.8	82.7	1.1	2.75	3.09	0.06	0.06	23.24	1378.02	1.52	36.77		51.8	58.2		55.8
Prairie Evaporite	2145.8	134.1	83.8	1.8	4.00	2.18	0.20	0.11	39.44	1417.47	1.51	36.30		55.2	30.1		55.0
Winnepegosis	2279.9	45.1	85.6	0.9	2.99	2.83	0.05	0.05	17.35	1434.82	1.59	34.98		62.3	59.0		55.6
Interlake	2325.0	222.2	86.6	3.6	3.77	3.72	0.31	0.31	65.35	1500.17	1.55	34.71		61.8	60.9		53.8
Gunton	2547.2	31.7	90.2	0.8	3.79	3.72	0.04	0.04	9.06	1509.23	1.69	33.11		98.0	96.2		55.9
Red River	2578.9	102.2	91.0	2.0	3.28	2.55	0.13	0.10	31.16	1540.39	1.67	33.02		63.9	49.7		55.3
Bottom of Well	2681.1		93.0														
						Σ =	2.26	2.61									
											Average			60.9	78.7	56.7	49.9
											Wtd Average			73.4	84.8		
											Shallow					56.1	13.7
											Deep		59.0			56.8	53.7

Notes
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10 - Heat flow derived using harmonic mean method
11- FU/HC/FH - Fort Union Group/Hell Creek Formation/Fox Hills Formation combined

Summary of Heat Flow Calculations
NDIC 3090
Grenora-Madison Unit 08
Williams County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(°C)		$W\ m^{-1}K^{-1}$				$W\ K^{-1}$		$W\ m^{-1}K^{-1}$	°C km^{-1}	$mW\ m^{-2}$				
FU/HC/FH[11]	20.4	401.4	10.1	9.6	1.30	1.62	0.44	0.55	18.6	18.6	0.06	286.72		26.3	41.2		17.9
Pierre	421.8	776.9	19.7	31.7	1.15	1.62	0.04	0.06	308.8	327.4	0.42	36.66		53.1	66.2		15.4
Greenhorn	1198.8	84.4	51.4	5.0	1.00	1.80	0.02	0.04	675.6	1002.9	1.10	39.37		67.7	95.4		43.4
Mowry	1283.2	54.9	56.4	2.5	1.00	1.80	0.03	0.05	84.4	1087.4	1.12	40.65		45.2	81.4		45.7
Newcastle	1338.1	65.8	58.9	2.8	1.10	2.35	0.06	0.13	54.9	1142.2	1.11	40.84		42.5	76.6		45.5
Inyan Kara	1403.9	130.1	61.7	3.7	1.30	2.10	0.10	0.16	59.9	1202.1	1.08	40.92		31.3	66.8		44.1
Swift	1534.1	170.7	65.4	7.1	1.10	2.10	0.09	0.17	100.1	1302.2	1.05	39.86		53.9	87.1		42.0
Rierdon	1704.7	183.2	72.5	7.1	1.30	3.04	0.03	0.07	155.2	1457.4	1.07	40.02		42.6	81.4		42.7
Spearfish	1887.9	52.1	79.6	1.2	1.50	3.04	0.03	0.06	140.9	1598.3	1.16	39.90		29.7	69.4		46.1
Broom Creek	1940.1	43.9	80.8	1.4	2.00	2.68	0.13	0.17	34.7	1633.0	1.17	39.44		46.8	94.9		46.2
Tyler	1983.9	144.2	82.1	4.2	1.20	3.62	0.02	0.06	21.9	1655.0	1.12	39.26		58.7	78.6		43.9
Kibbey Lime	2128.1	40.5	86.4	0.7	2.70	3.45	0.14	0.18	120.1	1775.1	1.19	38.59		21.9	66.1		45.9
Madison	2168.7	116.0	87.1	1.8	3.05	3.45	1.32	2.00	15.0	1790.1	1.19	38.21		41.0	52.3		45.3
BOH	2284.7		88.9														
						Σ =	2.45	3.70									
											Average			43.1	73.6	45.5	43.1
											Wtd Average			45.6	74.2		
											Shallow					44.6	25.6
											Deep		45.5			44	47.9

Notes
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9 - Heat flow derived from Bullard's Method
10 - Heat flow derived using harmonic mean method
11- FU/HC/FH - Fort Union Group/Hell Creek Formation/Fox Hills Formation combined

Summary of Heat Flow Calculations
NDIC 13725
JC Woods 26H-1
Burke County, ND

Formation	Depth (Z)	ΔZ	Temp (T)	ΔT	λ[1]	λ_N[2]	λ_{wtd}[3]	λ_{Nwtd}[4]	$\Delta Z_i/\lambda$	R_i	λ_{hi}[5]	$grad_i$	Q_{graph}[6]	Q_2[7]	Q_N[8]	$Q_{Bullard}$[9]	Q_{hi}[10]
	(m)		(°C)		$W m^{-1}K^{-1}$				$W K^{-1}$		$W m^{-1}K^{-1}$	°C km^{-1}	$mW m^{-2}$				
FU/HC/FH[11]	12.8	342.6	7.6	11.5	1.25	1.72	0.26	0.35	274.1	284.7	0.04	259.34		41.9	57.6		11.7
Pierre	355.4	653.5	19.1	31.0	1.10	1.62	0.43	0.64	594.1	878.8	0.40	41.64		52.1	76.8		16.8
Greenhorn	1008.9	83.8	50.1	5.3	1.00	1.62	0.05	0.08	83.8	962.6	1.05	45.38		62.8	101.7		47.6
Mowry	1092.7	97.8	55.4	4.6	1.20	1.80	0.07	0.11	81.5	1044.2	1.05	46.71		56.1	84.1		48.9
Inyan Kara	1190.5	107.9	59.9	3.1	1.60	2.35	0.10	0.15	67.4	1111.6	1.07	46.71		45.2	66.4		50.0
Swift	1298.4	289.3	63.0	11.0	1.50	2.10	0.26	0.37	192.8	1304.5	1.00	45.18		57.2	80.1		45.0
Spearfish	1587.7	72.7	74.0	1.6	1.80	3.04	0.08	0.13	40.4	1344.8	1.18	43.89		40.4	68.2		51.8
BOH	1660.4		75.6														
						Σ =	1.26	1.83									
											Average			50.8	76.4	52.2	38.8
											Wtd Average			53.8	78.7		
											Shallow					50.6	25.4
											Deep		54.0			53.6	48.9

Notes

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5 - Harmonic mean of thermal conductivity

6 - Heat flow derived from graphical method

7- Heat flow derived from Equation 1 for each formation

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9 - Heat flow derived from Bullard's Method

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