PREDICTION OF FINAL TEMPERATURE

Gary W. Crosby
Phillips Petroleum Company

Introduction

The engineering necessity of achieving maximum cooling of the borehole during drilling and logging operations on geothermal wells prohibits the determination of equilibrium temperature in the subsurface before virtual rebound from the drilling disturbance some months after operations cease. Clearly, substantial economic benefits would accrue, in many cases, if a reasonable prediction of equilibrium temperature can be made while the rig is still over the borehole. Certain flow tests are desirable when commercial temperatures are known to be present in the reservoir. The manner in which the well is to be completed depends on its anticipated uses in the future. Before the rig is released a decision must be made as to the drilling of a confirmation well.

Several methods have been worked out to predict equilibrium temperatures; all are based on (1) rebound following the physical law of logarithmic decay, and (2) rebound being by conductive processes. Perhaps the most sophisticated method is one worked out by Albright (1975); unfortunately, the amount of data required to apply the method is not generated in the course of normal drilling operations. Since temperature rebound follows the same logarithmic decay law as does pressure buildup following a reservoir flow test, a Horner plot is suggested as a graphical method of predicting equilibrium temperature, and the Horner plot is a commonly used device. Its mathematical expression in several forms is given as the Lachenbruch-Brewer equations (1959, p. 79) which are applied herein.

The purpose of this brief report is to provide an abbreviated explanation of the physical principles of temperature rebound and provide a convenient plotting method similar to the Horner plot in order to standardize temperature prediction in Geothermal Operations. It has the further purpose of outlining methods to determine an approximate thermal conductivity value for reservoir rocks and rebound times after drilling from the nature of the rebound curve.

During the drilling of geothermal wells the drilling fluids serve the additional purpose of cooling the rocks adjacent to the bore in order to prolong the life of bits and drill string, and to control potential blowouts. The temperature of the fluid changes with cooling variations of the mud on the surface and with depth as the wallrock temperature changes.

Fluids moving in or out of the borehole via fractures transfer heat by nonconductive processes; and, if such fluid movements involve large volumes at or near the depth where equilibrium temperature is to be predicted, the conductive methods treated here are not applicable. If the well trys to produce, however, a relatively short flow test makes possible an approximate determination of reservoir temperature.

Line Source Solution

The well bore closely approximates a line source heat sink during drilling operations. All subsequent temperature measurements are made on this line, usually during multiple log runs.

Assuming the rock intersected by the bore is homogeneous, heat (cooling) of strength Q, applied instantaneously along the axial line at time $t = t_o$, produces rebound according to:

$$T_f - T_n = \frac{Q}{4\pi K}\,\frac{1}{t_n - t_o} \qquad t_n > t_o \tag{1}$$

where T_f is final equilibrium temperature, T_n is temperature measured at some time after t_o, and K is thermal conductivity. The quantity t is time since the drill bit first reached the depth in question.

But cooling at a given depth is applied not instantaneously but over a period of time, usually irregularly. Rebound is obtained by

$$T_f - T_n = \frac{Q}{4\pi K}\int_o^s \frac{q\,(\Delta t)}{t_n - \Delta t}\,dt \qquad t > s \tag{2}$$

where q(t) is a continuous source in units of heat per unit time per unit depth and s is the time elapsed since the bit reached the depth in question to the time drilling (circulation) ceased. Ordinarily s, like t, is different for each depth.

If q(t) is a constant, or is averaged and applied during time s, that is, $q(t) = \bar{q}s$, then the solution of the integral is

$$-\Delta T = T_f - T_n = \frac{\bar{q}s}{4\pi K}\,\ln\frac{t_n}{t_n - s} \qquad t > s \tag{3}$$

Graphical solution

The last equation forms the basis for the graphical solution of final temperature (Fig. 1); it was solved repeatedly to produce the graph. In practice the T_n's, T_1, T_2, $T_3 \cdots$, are plotted against the log term, to graphically solve for the final temperature, T_f.

After the first maximum borehole temperature, T_1 is obtained, from the first logging run, a convenient temperature value is chosen and labeled on the bottom line. This value, in general, is a multiple of ten next below T_1. After this datum value is chosen, the ordinate is labeled at the same scale as the upper part of the graph. Each temperature is plotted against $\ln t_n/t_n - s$ as it becomes available with each logging run.

The last tool to go into the hole is ordinarily a continuous temperature log. This run provides an opportunity to determine the depth of the maximum temperature, which is not always at T.D. The same maximum reading thermometers, clamped in turn onto the Schlumberger logging line, should be placed onto the wire line of the temperature sonde in order to check the correlation between the two tools. The maximum reading thermometers, usually two or three run simultaneously, should be clamped onto the Agnew and Sweet wire line 30 ft. above the bottom of the tool. This is the approximate average height of the thermometers above the base of the Schlumberger sondes.

After all the temperatures are plotted, the best fit straight line is passed through the points. When the fit is difficult, the last few data obtained should be given more weight. This is because the short term fluctuations of temperature during drilling damp out early and the later measurements better follow the average heat sink temperatures assumed in construction of the graph. The line projected through the plots, and perhaps even some of the control points may plot into the upper part of the graph. This is of no consequence.

The intersection of the line with the $\ln t_n/t_n - s = 0$ ordinate gives the predicted final temperature, T_f.

In the event tables or a calculator are not available for calculating the natural logarithms, the ratio t/s, can be worked out by longhand and plotted using the logarithmic scale across the top of the graph. Plotting with a logarithmic scale is a little less accurate, however.

The graph is designed for two further operations. With a parallel ruler the best fit line is moved into the upper part of graph to the position at which it passes through the "origin" of the family of guidelines, at the left side of the graph. The interpolated value of the guideline that coincides with the plotted line is then determined. This guideline value is the ratio, $\bar{q}s/K$, in equation (3). If either value of the quotient is known, the other can be determined. This also can be solved graphically with the small graph in the upper right corner.

Knowledge of the term $\bar{q}s$ is of no particular intrinsic value, but thermal conductivity, K, is. No convenient method for determining $\bar{q}s$ can be outlined at this time; however, the duration of the disturbance, s, is known and it is possible that $\bar{q}$ can be estimated empirically from flow line temperatures or some other indicator, but further work to demonstrate this is required. When K can be determined, the information will aid in interpreting other temperature data on the prospect and will make possible a calculation of rebound time.

Two dashed lines pass through the larger graph, one labeled 5° and the other 1°. These lines indicate the times when the well has rebounded to within $5^{\circ}C$ and $1^{\circ}C$ respectively of the final equilibrium temperature. These specific rebound times can be determined by picking the $\ln t_n/t_n - s$ value where the plotted line intersects the 5° or 1° line, whichever is of interest, say the 5° line. With this $\ln t_n/t_n - s$ value, enter the graph in the lower right corner through the bottom scale and move vertically up to intersection with the appropriate s line, the duration of the temperature disturbance. Moving to the left scale gives the rebound time, $t - s$, in hours, and moving to the right scale gives $t - s$ in days.

Knowledge of rebound time to temperatures within 5° and 1° of complete rebound is helpful in planning followup temperature surveys. Without this knowledge more surveys may be run than are necessary, and each cost between \$1000 and \$2000.

Example

Roosevelt Hot Springs #9 - 1 data from Utah are tabulated and plotted in figure 2 to illustrate the method. The drilling history indicates that the duration of circulation, s, at a depth of 1518 m., prior to taking temperature measurements, was 15 hours, distributed in drilling, coring and well conditioning. The scatter about the best fit straight line is not large, and probably reflects, in the main, small inaccuracies in time and temperature measurements.

The line projects to $186.3^{\circ}C$ at $\ln t_n/t_n - s = 0$. After the logging runs that produced these temperature readings, Well #9 - 1 was deepened to 2096 m., reaching this T.D. on April 8, 1975. Approximately three months later, on July 14, 1975, a continuous temperature log was run to T.D. This log shows a temperature of $192.8^{\circ}C$ at depth 1518 m. Thus, this prediction scheme predicted a final temperature below steady state equilibrium temperature by a minimum of $6.5^{\circ}C$.

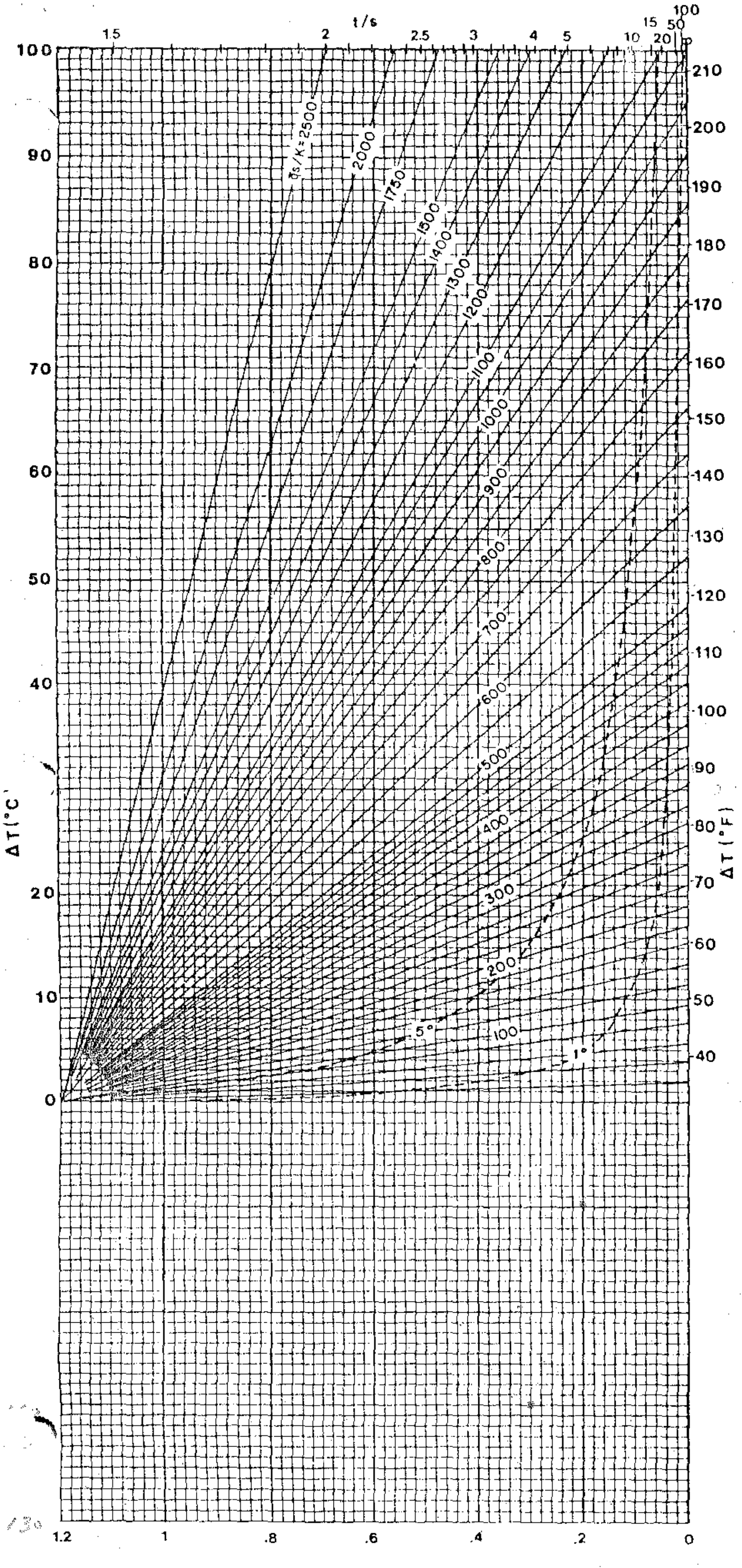
Moving the best fit line into the upper part of the diagram, using parallel rulers, to the position at which it passes through the "origin" of the family of curves, the interpolated value for $\bar{q}s/K$ is 508. Making use of the diagram in the upper right corner, the quantity $\bar{q}s$ is 508 when K = 1, 254 when K = 2, 169 when K = 3, and so on. The units of $\bar{q}$ are calories per unit depth per second times $3.6 X 10^3$. Flow line temperature during drilling and coring at this depth averaged 50°C, but they are unknown during circulation to condition the hole. A core was obtained a few feet below the point of temperature measurements; namely, in the interval 1524-1525.5m. Thermal conductivity measurements on recovered granodiorite produced a K value of 4.77. In this case, where K and s are known, $\bar{q}$ is restrained at 107. When enough data of these types are available, it may be possible to determine a reasonable value for thermal conductivity by estimating $\bar{q}$ through flow line temperatures.

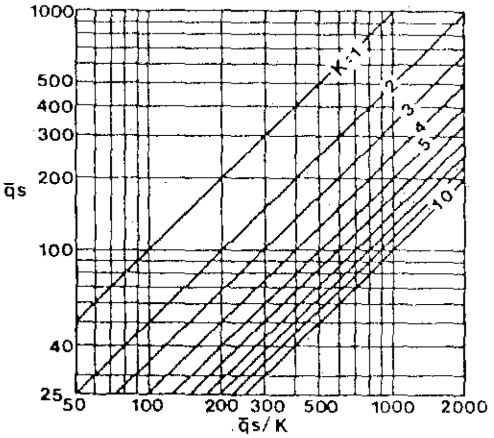
It is important to know how far from complete rebound the well was on July 14, 97 days after circulation ceased, when the last temperatures were measured. The best answer can only be an approximation in this case because the well was deepened after the temperature measurements were made, and thus s changed. Using the data available to complete the example, however, the best fit line, with $\bar{q}s/K = 508$, intersects the 5° and 1° dashed lines at $\ln t_n/t_n - s = .13$, and $= .03$, respectively. Entering the graph in the lower right corner with these values the well was within 5°C of final temperature in about 5 days, and within 1° in about 22 days. Thus, the temperature on the run of July 14 was probably less than 1°C from equilibrium.

References Cited

Albright, J. N., 1975, A new and more accurate method for the direct measurement of earth temperature gradients in deep boreholes: Proc., Second U. N. Symposium on Development and Use of Geothermal Resources, San Francisco, p. 847 - 851

Lachenbruch, A. H. and Brewer, M. C., 1959, Dissipation of the temperature effect of drilling a well in Arctic Alaska: U. S. Geothermal Survey Bull. 1083 - C, p. 73 - 109.





	t	T	Ln t_n/t_n-s
s			
t_1			
t_2			
t_3			
t_4			
t_5			
t_6			
t_7			

Well ______ Field ______

Co ______ St. ______

Date ______ Int. ______

Comments ______

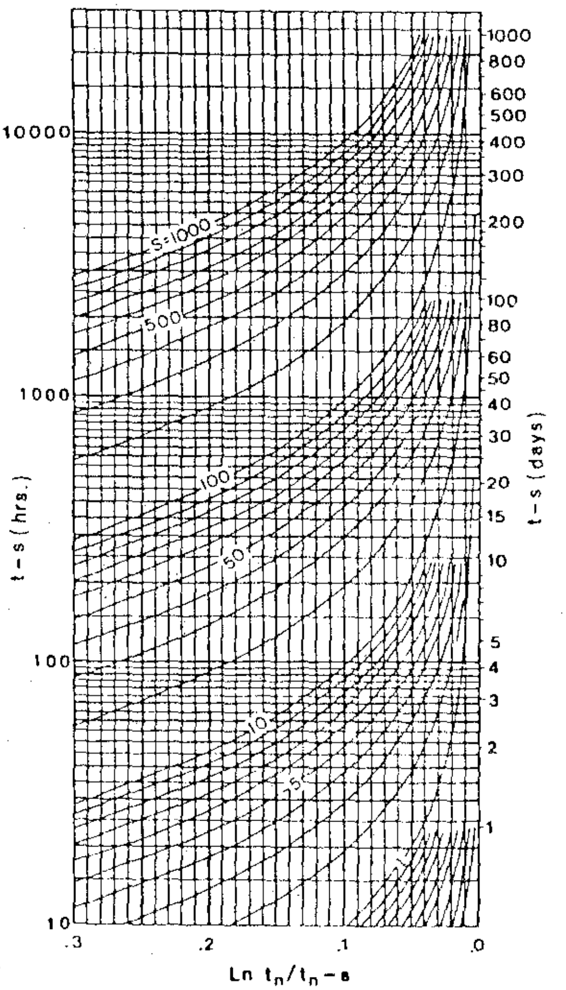


Figure 1

163 — 197 2½ hrs.

⓪ — @ 266 mins 6 mins.

16 mins. chk.

10/6/78

314 mins (chart started)
on bottom

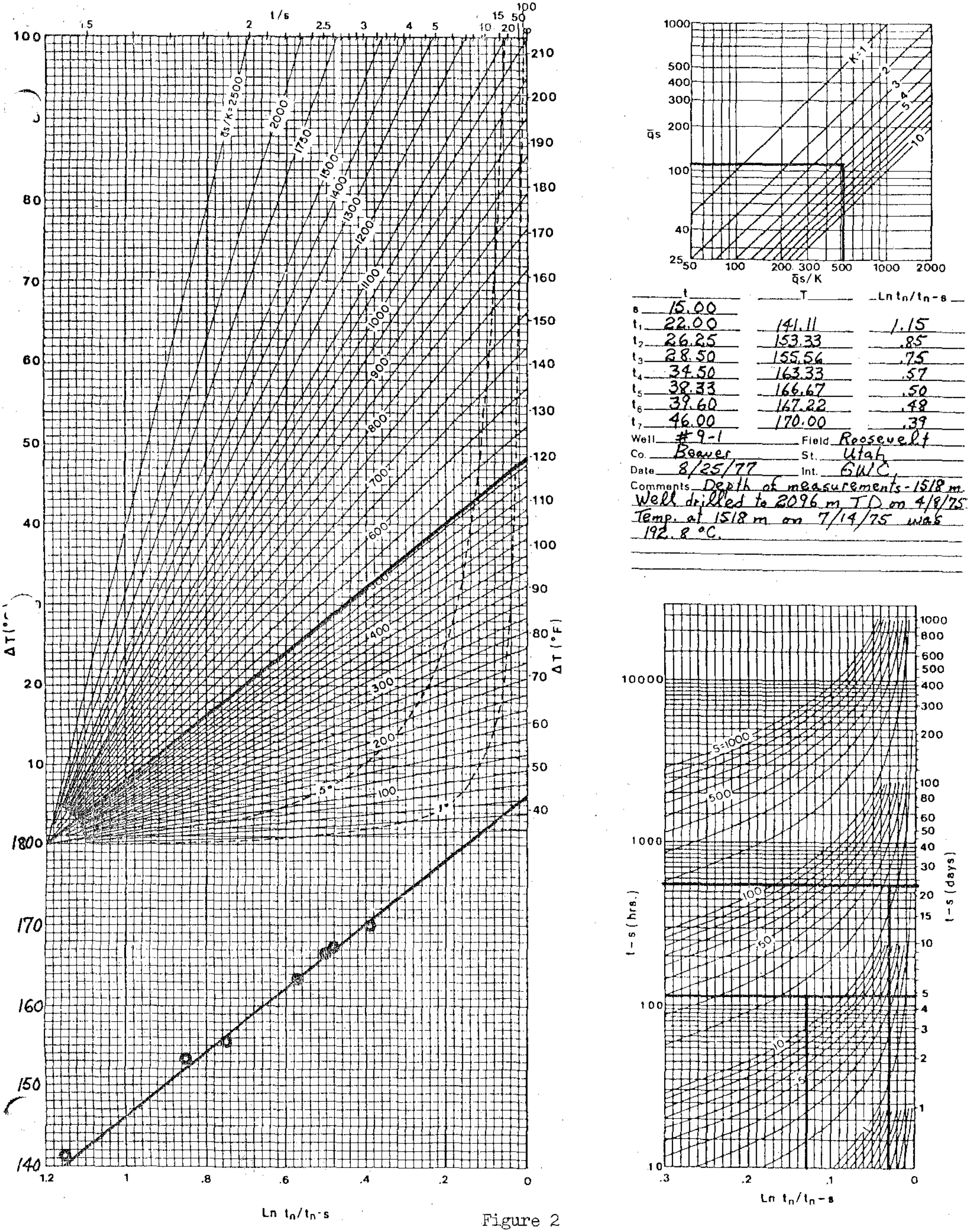
need to 558 mins 5874'

5.23	314	—	162.91	72.73
5.73	344	—	174.31	79.06
6.23	374	—	182.44	83.58
6.73	404	—	188.99 5 6	86.7
7.23	434	—	194.06 6 2	90.03
7.63	458	—	197.77 6 5 1	92.09

bottom

K = 8.6 - 9.4

152 — 161
in out



	t	T	Ln t_n/t_n-s
s	15.00		
t_1	22.00	141.11	1.15
t_2	26.25	153.33	.85
t_3	28.50	155.56	.75
t_4	34.50	163.33	.57
t_5	38.33	166.67	.50
t_6	39.60	167.22	.48
t_7	46.00	170.00	.39

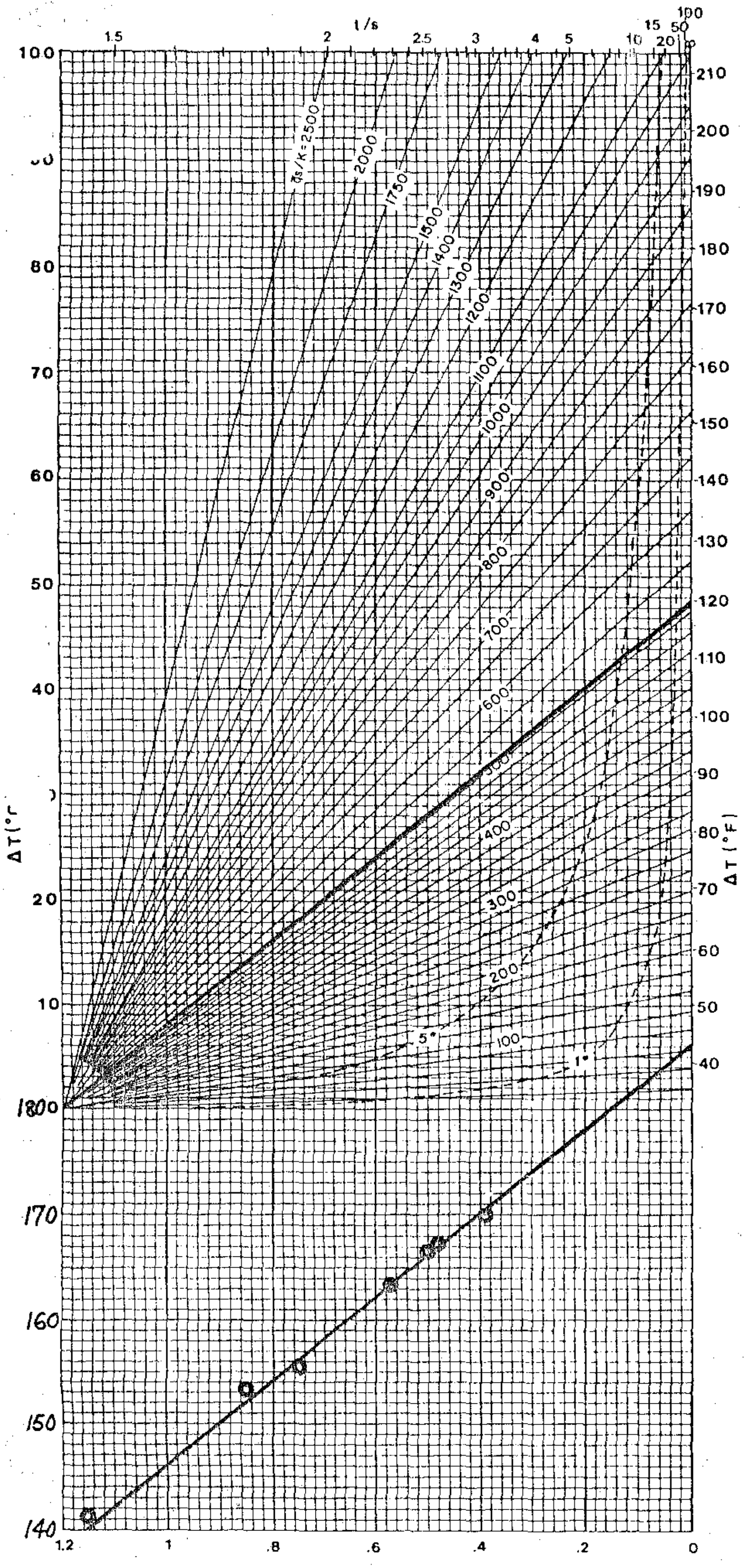
Well #9-1 Field Roosevelt

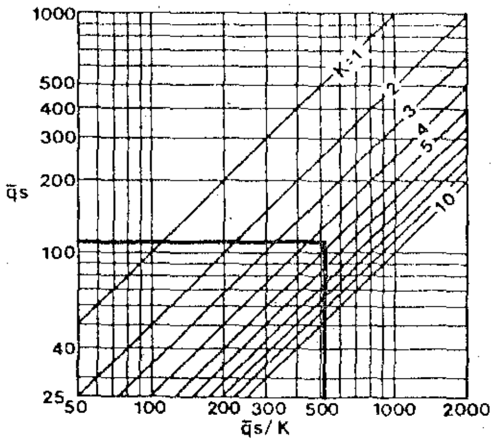
Co. Beaver St. Utah

Date 8/25/77 Int. GWC

Comments Depth of measurements-1518 m. Well drilled to 2096 m TD on 4/8/75. Temp. at 1518 m on 7/14/75 was 192.8 °C.

Figure 2





	t	T	Ln t_n/t_{n-s}
s	15.00		
t_1	22.00	141.11	1.15
t_2	26.25	153.33	.85
t_3	28.50	155.56	.75
t_4	34.50	163.33	.57
t_5	38.33	166.67	.50
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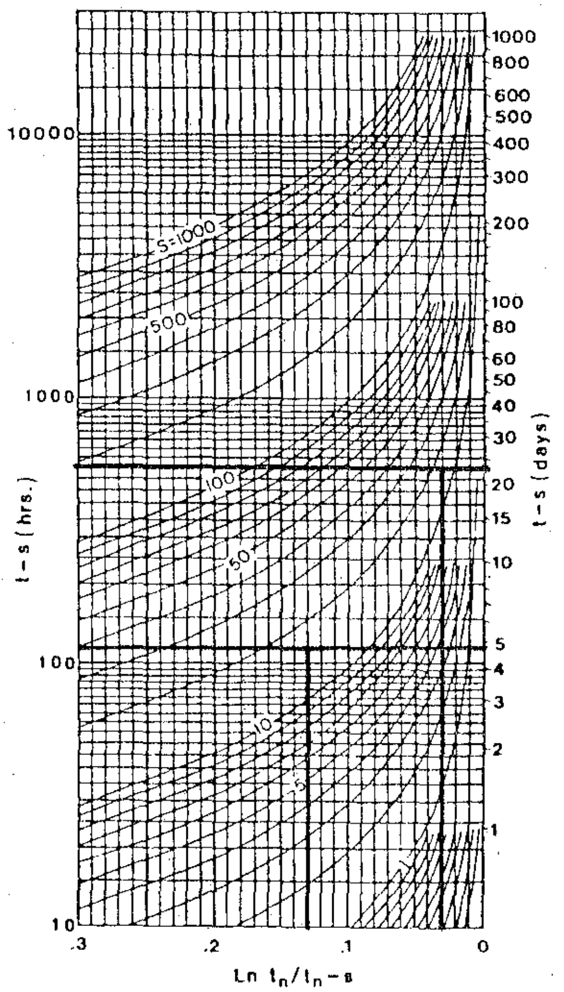
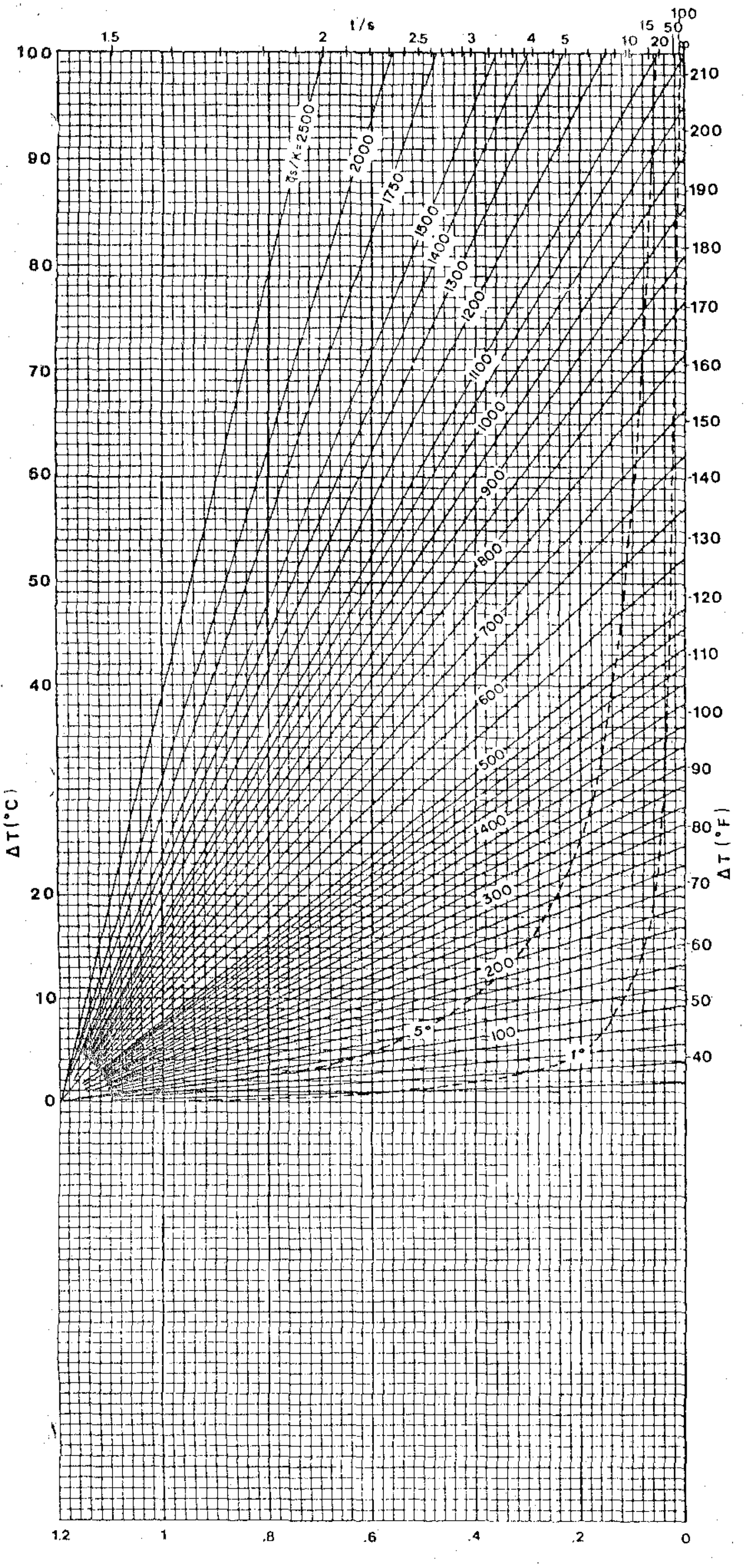
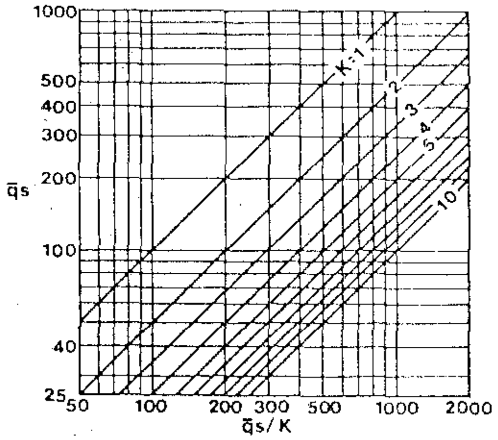


Figure 2





	t	T	$Ln\ t_n/t_{n-s}$
s			
t_1			
t_2			
t_3			
t_4			
t_5			
t_6			
t_7			

Well ____________ Field ____________

Co ____________ St. ____________

Date ____________ Int. ____________

Comments ____________

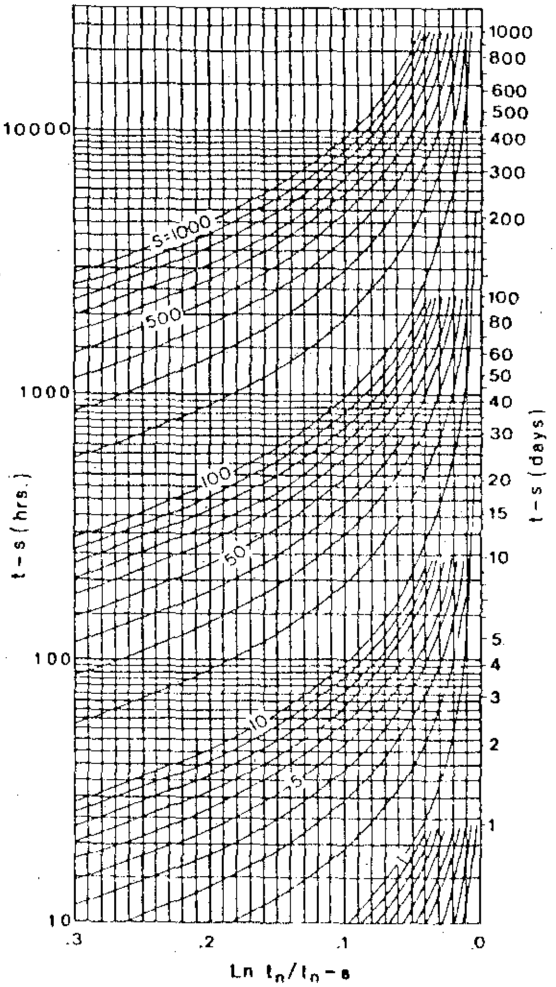


Figure 1

RECIPROCALS, CIRCUMFERENCES, AND AREAS OF CIRCLES

n	$1000/n$	Circum. of circle πn	Area of circle $\pi n^2/4$	n	$1000/n$	Circum. of circle πn	Area of circle $\pi n^2/4$
900	1.111 111	2 827.433	636 172.5	950	1.052 632	2 984.513	708 821.8
901	1.109 878	2 830.575	637 587.0	951	1.051 525	2 987.655	710 314.9
902	1.108 647	2 833.717	639 003.1	952	1.050 420	2 990.796	711 809.5
903	1.107 420	2 836.858	640 420.7	953	1.049 318	2 993.938	713 305.7
904	1.106 195	2 840.000	641 839.9	954	1.048 218	2 997.079	714 803.4
905	1.104 972	2 843.141	643 260.7	955	1.047 120	3 000.221	716 302.8
906	1.103 753	2 846.283	644 683.1	956	1.046 025	3 003.363	717 803.7
907	1.102 536	2 849.425	646 107.0	957	1.044 932	3 006.504	719 306.1
908	1.101 322	2 852.566	647 532.5	958	1.043 841	3 009.646	720 810.2
909	1.100 110	2 855.708	648 959.6	959	1.042 753	3 012.787	722 315.8
910	1.098 901	2 858.849	650 388.2	960	1.041 667	3 015.929	723 822.9
911	1.097 695	2 861.991	651 818.4	961	1.040 583	3 019.071	725 331.7
912	1.096 491	2 865.133	653 250.2	962	1.039 501	3 022.212	726 842.0
913	1.095 290	2 868.274	654 683.6	963	1.038 422	3 025.354	728 353.9
914	1.094 092	2 871.416	656 118.5	964	1.037 344	3 028.495	729 867.4
915	1.092 896	2 874.557	657 555.0	965	1.036 269	3 031.637	731 382.4
916	1.091 703	2 877.699	658 993.0	966	1.035 197	3 034.779	732 899.0
917	1.090 513	2 880.840	660 432.7	967	1.034 126	3 037.920	734 417.2
918	1.089 325	2 883.982	661 873.9	968	1.033 058	3 041.062	735 936.9
919	1.088 139	2 887.124	663 316.7	969	1.031 992	3 044.203	737 458.2
920	1.086 957	2 890.265	664 761.0	970	1.030 928	3 047.345	738 981.1
921	1.085 776	2 893.407	666 206.9	971	1.029 866	3 050.486	740 505.6
922	1.084 599	2 896.548	667 654.4	972	1.028 807	3 053.628	742 031.6
923	1.083 424	2 899.690	669 103.5	973	1.027 749	3 056.770	743 559.2
924	1.082 251	2 902.832	670 554.1	974	1.026 694	3 059.911	745 088.4
925	1.081 081	2 905.973	672 006.3	975	1.025 641	3 063.053	746 619.1
926	1.079 914	2 909.115	673 460.1	976	1.024 590	3 066.194	748 151.4
927	1.078 749	2 912.256	674 915.4	977	1.023 541	3 069.336	749 685.3
928	1.077 586	2 915.398	676 372.3	978	1.022 495	3 072.478	751 220.8
929	1.076 426	2 918.540	677 830.8	979	1.021 450	3 075.619	752 757.8
930	1.075 269	2 921.681	679 290.9	980	1.020 408	3 078.761	754 296.4
931	1.074 114	2 924.823	680 752.5	981	1.019 368	3 081.902	755 836.6
932	1.072 961	2 927.964	682 215.7	982	1.018 330	3 085.044	757 378.3
933	1.071 811	2 931.106	683 680.5	983	1.017 294	3 088.186	758 921.6
934	1.070 664	2 934.248	685 146.8	984	1.016 260	3 091.327	760 466.5
935	1.069 519	2 937.389	686 614.7	985	1.015 228	3 094.469	762 012.9
936	1.068 376	2 940.531	688 084.2	986	1.014 199	3 097.610	763 561.0
937	1.067 236	2 943.672	689 555.2	987	1.013 171	3 100.752	765 110.5
938	1.066 098	2 946.814	691 027.9	988	1.012 146	3 103.894	766 661.7
939	1.064 963	2 949.956	692 502.1	989	1.011 122	3 107.035	768 214.4
940	1.063 830	2 953.097	693 977.8	990	1.010 101	3 110.177	769 768.7
941	1.062 699	2 956.239	695 455.2	991	1.009 082	3 113.318	771 324.6
942	1.061 571	2 959.380	696 934.1	992	1.008 065	3 116.460	772 882.1
943	1.060 445	2 962.522	698 414.5	993	1.007 049	3 119.602	774 441.1
944	1.059 322	2 965.663	699 896.6	994	1.006 036	3 122.743	776 001.7
945	1.058 201	2 968.805	701 380.2	995	1.005 025	3 125.885	777 563.8
946	1.057 082	2 971.947	702 865.4	996	1.004 016	3 129.026	779 127.5
947	1.055 966	2 975.088	704 352.1	997	1.003 009	3 132.168	780 692.8
948	1.054 852	2 978.230	705 840.5	998	1.002 004	3 135.309	782 259.7
949	1.053 741	2 981.371	707 330.4	999	1.001 001	3 138.451	783 828.2

Table XIV

NATURAL LOGARITHMS OF NUMBERS—0.00 to 5.99

(Base e = 2.718 · · ·)

N	0	1	2	3	4	5	6	7	8	9
0.0	Take tabular value −10	5.395	6.088	6.493	6.781	7.004	7.187	7.341	7.474	7.592
0.1	7.697	7.793	7.880	7.960	8.034	8.103	8.167	8.228	8.285	8.339
0.2	8.391	8.439	8.486	8.530	8.573	8.614	8.653	8.691	8.727	8.762
0.3	8.796	8.829	8.861	8.891	8.921	8.950	8.978	9.006	9.032	9.058
0.4	9.084	9.108	9.132	9.156	9.179	9.201	9.223	9.245	9.266	9.287
0.5	9.307	9.327	9.346	9.365	9.384	9.402	9.420	9.438	9.455	9.472
0.6	9.489	9.506	9.522	9.538	9.554	9.569	9.584	9.600	9.614	9.629
0.7	9.643	9.658	9.671	9.685	9.699	9.712	9.726	9.739	9.752	9.764
0.8	9.777	9.789	9.802	9.814	9.826	9.837	9.849	9.861	9.872	9.883
0.9	9.895	9.906	9.917	9.927	9.938	9.949	9.959	9.970	9.980	9.990
1.0	0.0 0000	0995	1980	2956	3922	4879	5827	6766	7696	8618
1.1	9531	*0436	*1333	*2222	*3103	*3976	*4842	*5700	*6551	*7395
1.2	0.1 8232	9062	9885	*0701	*1511	*2314	*3111	*3902	*4686	*5464
1.3	0.2 6236	7003	7763	8518	9267	*0010	*0748	*1481	*2208	*2930
1.4	0.3 3647	4359	5066	5767	6464	7156	7844	8526	9204	9878
1.5	0.4 0547	1211	1871	2527	3178	3825	4469	5108	5742	6373
1.6	7000	7623	8243	8858	9470	*0078	*0682	*1282	*1879	*2473
1.7	0.5 3063	3649	4232	4812	5389	5962	6531	7098	7661	8222
1.8	8779	9333	9884	*0432	*0977	*1519	*2058	*2594	*3127	*3658
1.9	0.6 4185	4710	5233	5752	6269	6783	7294	7803	8310	8813
2.0	9315	9813	*0310	*0804	*1295	*1784	*2271	*2755	*3237	*3716
2.1	0.7 4194	4669	5142	5612	6081	6547	7011	7473	7932	8390
2.2	8846	9299	9751	*0200	*0648	*1093	*1536	*1978	*2418	*2855
2.3	0.8 3291	3725	4157	4587	5015	5442	5866	6289	6710	7129
2.4	7547	7963	8377	8789	9200	9609	*0016	*0422	*0826	*1228
2.5	0.9 1629	2028	2426	2822	3216	3609	4001	4391	4779	5166
2.6	5551	5935	6317	6698	7078	7456	7833	8208	8582	8954
2.7	9325	9695	*0063	*0430	*0796	*1160	*1523	*1885	*2245	*2604
2.8	1.0 2962	3318	3674	4028	4380	4732	5082	5431	5779	6126
2.9	6471	6815	7158	7500	7841	8181	8519	8856	9192	9527
3.0	9861	*0194	*0526	*0856	*1186	*1514	*1841	*2168	*2493	*2817
3.1	1.1 3140	3462	3783	4103	4422	4740	5057	5373	5688	6002
3.2	6315	6627	6938	7248	7557	7865	8173	8479	8784	9089
3.3	9392	9695	9996	*0297	*0597	*0896	*1194	*1491	*1788	*2083
3.4	1.2 2378	2671	2964	3256	3547	3837	4127	4415	4703	4990
3.5	5276	5562	5846	6130	6413	6695	6976	7257	7536	7815
3.6	8093	8371	8647	8923	9198	9473	9746	*0019	*0291	*0563
3.7	1.3 0833	1103	1372	1641	1909	2176	2442	2708	2972	3237
3.8	3500	3763	4025	4286	4547	4807	5067	5325	5584	5841
3.9	6098	6354	6609	6864	7118	7372	7624	7877	8128	8379
4.0	8629	8879	9128	9377	9624	9872	*0118	*0364	*0610	*0854
4.1	1.4 1099	1342	1585	1828	2070	2311	2552	2792	3031	3270
4.2	3508	3746	3984	4220	4456	4692	4927	5161	5395	5629
4.3	5862	6094	6326	6557	6787	7018	7247	7476	7705	7933
4.4	8160	8387	8614	8840	9065	9290	9515	9739	9962	*0185
4.5	1.5 0408	0630	0851	1072	1293	1513	1732	1951	2170	2388
4.6	2606	2823	3039	3256	3471	3687	3902	4116	4330	4543
4.7	4756	4969	5181	5393	5604	5814	6025	6235	6444	6653
4.8	6862	7070	7277	7485	7691	7898	8104	8309	8515	8719
4.9	8924	9127	9331	9534	9737	9939	*0141	*0342	*0543	*0744
5.0	1.6 0944	1144	1343	1542	1741	1939	2137	2334	2531	2728
5.1	2924	3120	3315	3511	3705	3900	4094	4287	4481	4673
5.2	4866	5058	5250	5441	5632	5823	6013	6203	6393	6582
5.3	6771	6959	7147	7335	7523	7710	7896	8083	8269	8455
5.4	8640	8825	9010	9194	9378	9562	9745	9928	*0111	*0293
5.5	1.7 0475	0656	0838	1019	1199	1380	1560	1740	1919	2098
5.6	2277	2455	2633	2811	2988	3166	3342	3519	3695	3871
5.7	4047	4222	4397	4572	4746	4920	5094	5267	5440	5613
5.8	5786	5958	6130	6302	6473	6644	6815	6985	7156	7326
5.9	7495	7665	7834	8002	8171	8339	8507	8675	8842	9009
N	0	1	2	3	4	5	6	7	8	9

$\log_e 0.10 = 7.69741\ 49070 - 10$

AMAX EXPLORATION, INC.
Geothermal Group

TIME-TEMPERATURE OBSERVATION FORM

(For use with the Crosby method)

Date 10/23/78
Field NAPA
Well AMAX #1, Livermore
Observer WMD - JD
State CA
Analysis
County NAPA
Depth 7931'

Comments: Agnew + Sweet, 3 Kuster instruments, 2 bimetal, 1 gas (AMAX's), Logged open hole 7000' to 7930' @ 20'/min, 3 hrs @ 7930', Log 7930' to 7000' @ 20'/min, Log 10 mins @ ea. 500', 7000' to 2500'

1492 on bottom @1730

true time		t	event	temp. °C	temp. °F	$\frac{tn}{tn-s}$	Ln $\frac{tn}{tn-s}$	
0144	t_o	0	bit arrival					
0644	s	5	circulation ceases					
1509	t_1	13.41	observation		241.65	1.594	.465	.466
1539	t_2	13.91	"		244.19	1.561	.445	.445
1609	t_3	14.41	"		245.43	1.531	.424	.426
1639	t_4	14.91	"		247.32	1.504	.408	.408
1709	t_5	15.41	"		249.04	1.480	.390	.392
1739	t_6	15.91	"		250.45	1.458	.368	.377
1744½	t_7		"		250.86	1.		

These data taken by Kuster tool rented by AMAX (gas principle)

AMAX EXPLORATION, INC.
Geothermal Group

TIME-TEMPERATURE OBSERVATION FORM

(For use with the Crosby method)

Date 10/23/78

Field

Well AMAX #1 Livermore

Observer

State CA

Analysis

County Napa

Depth 7521'

Comments: A+S Bimetal Tool #1

true time		t	event	temp. °C	temp. °F	$\frac{tn}{tn-s}$	Ln $\frac{tn}{tn-s}$	
0030	t_o	0	bit arrival					
0644	s	6.24	circulation ceases					✓
1447	t_1	14.28	observation		240.6	1.776	.575	.574
1517	t_2	14.78	"		242.3	1.731	.550	.549
1547	t_3	15.28	"		243.8	1.690	.524	.525
16 17	t_4	15.78	9.54 "		245.4	1.654	.502	.503
1647	t_5	16.28	"		246.4	1.622	.482	.484
1717	t_6	16.78	"		247.3	1.592	.465	.465
1747	t_7	17.28	"		248.2	1.565	.448	.448

AMAX EXPLORATION, INC.
Geothermal Group

TIME-TEMPERATURE OBSERVATION FORM

(For use with the Crosby method)

Date 10/23/78

Well AMAX #1, Livermore

State CA

County NAPA

Comments: A+S Bimetal tool #2

Field

Observer

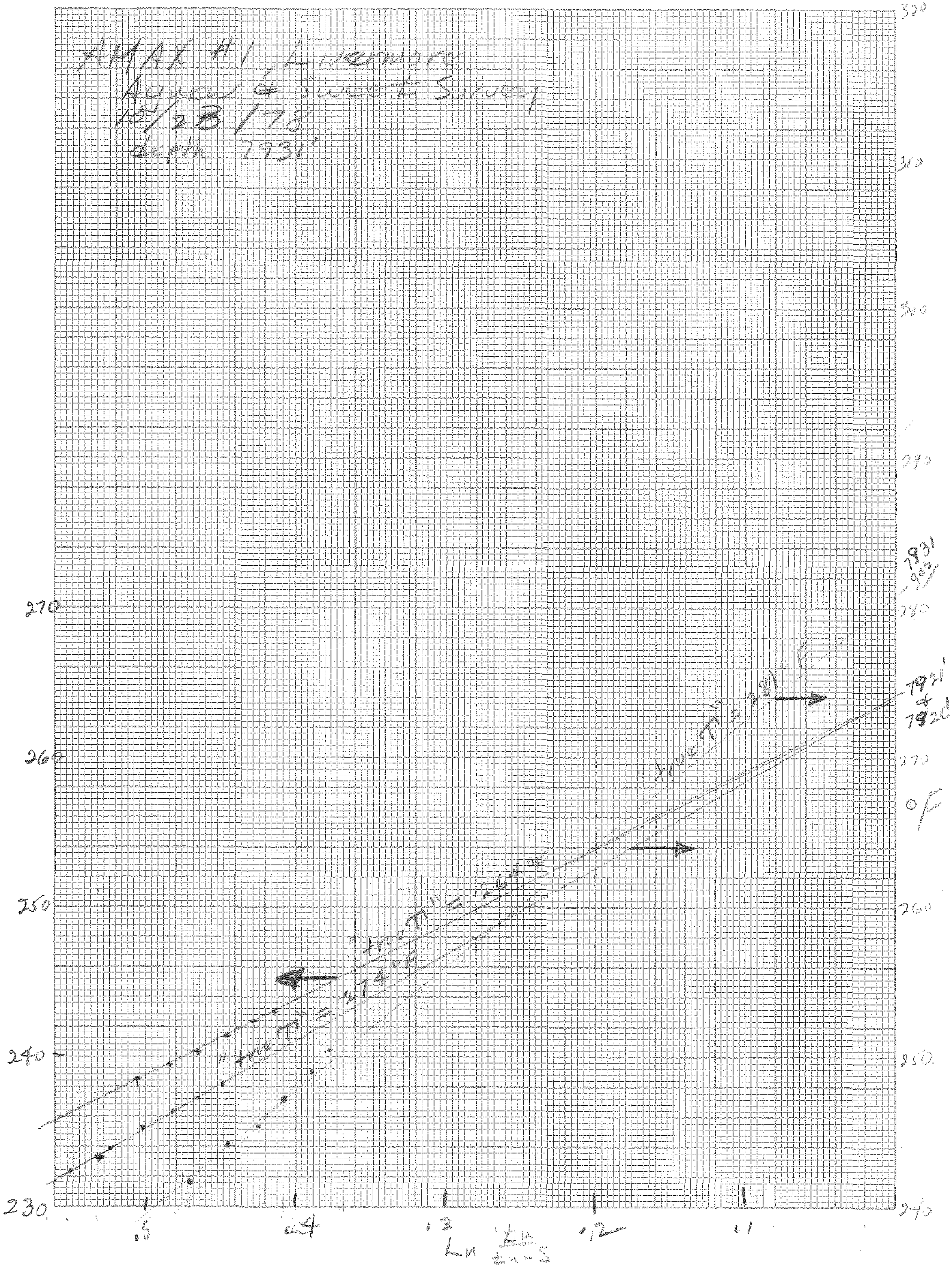
Analysis

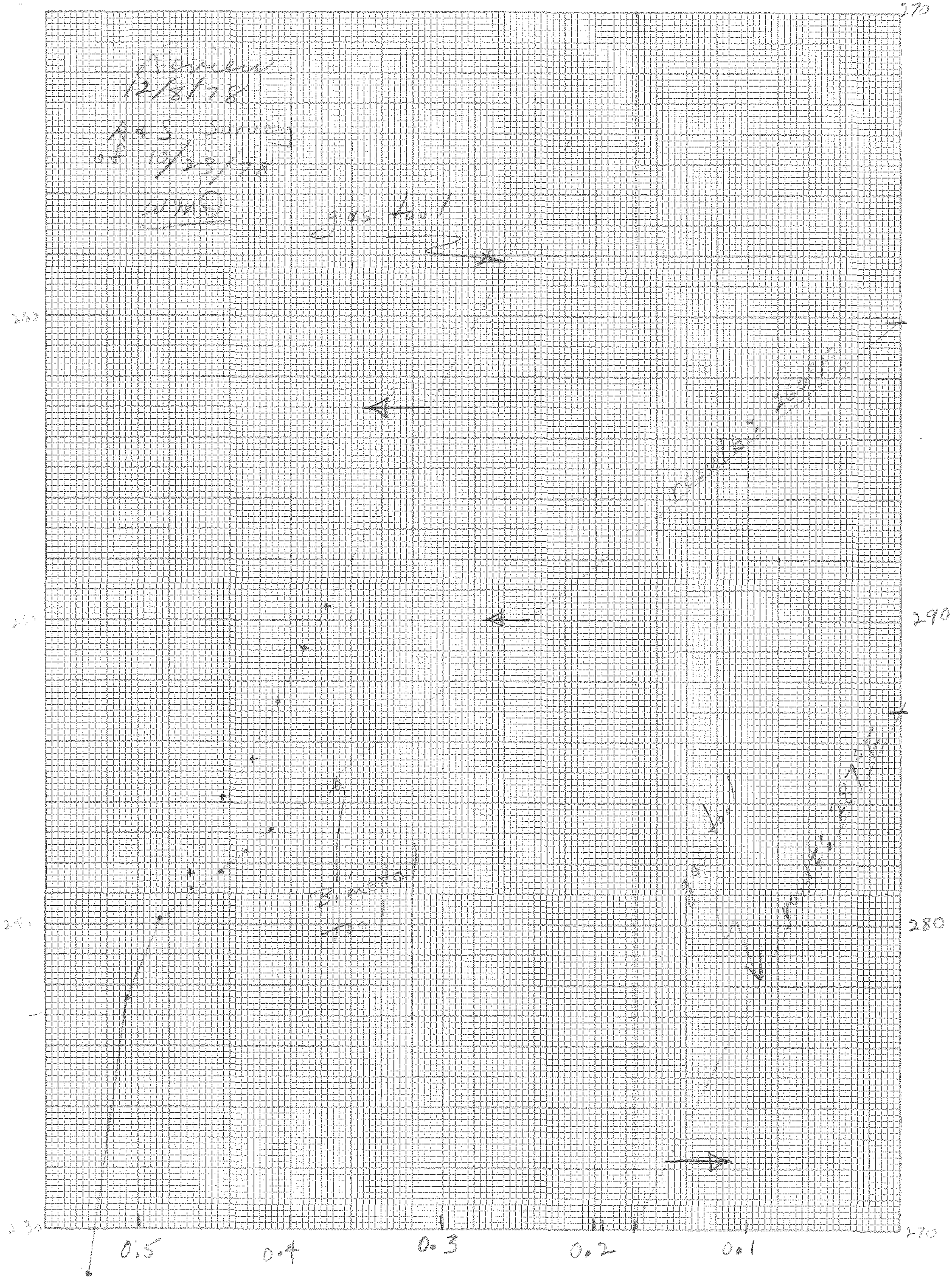
Depth 7926'

true time		t	event	temp. °C	temp. °F	$\frac{tn}{tn-s}$	Ln $\frac{tn}{tn-s}$	
0105	t_o	0	bit arrival					
0647	s	5.65	circulation ceases					
1447	t_1	13.7	observation		233.3	1.702	.531	.532
1517	t_2	14.2	"		238.6	1.661	.506	.507
1547	t_3	14.7	"		239.6	1.624	.484	.485
1617	t_4	15.2	"		240.3	1.592	.466	.465
1647	t_5	15.7	"		241.5	1.562	.446	.446
1717	t_6	16.2	"		242.4	1.536	.428	.429
1747	t_7	16.7	"		243.0	1.511	.413	.413

0030

AMAX #1 Livermore
Agnew & Sweet Survey
10/23/78
depth 7931'




12/8/78
A-5
10/23/78
270
290
280
270
0.5
0.4
0.3
0.2
0.1