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ASSESSMENT OF THE GEOTHERMAL RESOURCES OF KANSAS

VOLUME II - APPENDICES
FINAL REPORT

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CHAPTER 2.
APPENDIX I.

TECHNICAL DATA ON THERMAL LOGGING APPARATUS

The thermal logging apparatus used in this study consists of a DR-789 digital temperature meter and well probe, or thermistor, manufactured by GISCO (Geophysical Instrument and Supply Company - 4665 Joliet Street; Denver, Colorado 80239).

The thermistor (thermo-resistor) technique involves comparison between a temperature varying resistor (temperature dependent) and a control resistor (temperature independent). The difference, in resistance, between the temperature dependent resistor and the control, as measured in the well probe, is converted to absolute temperature by the digital temperature meter at the surface and displayed numerically in degrees Celcius or Fahrenheit to the nearest tenth. The thermistor is contained in an aluminium sheath which is a GISCO design.

Company specifications maintain a total response time for the probe and meter of 10 to 15 seconds and instrument accuracy to greater than ± 0.2 degrees for both temperature scales. This relationship between actual temperature and time of response of the instrument is a logarithmic one. In other words, the final temperature reached varies logarithmically with total time of measurement. The temperature scales range from 0.0 to 100.0 °C and -22.0 to 212.0 °F.

During operation, the well probe is attached to a 183 meter (600 foot; marked off in feet) reel of 1/4 inch cable. This cable is steel armored (breaking strength of 320 pounds), four conductor, elec-

trical cable with a neoprene outer coating that is resistant to water and oil. A second reel of cable was provided so that wells could be logged to a total depth of 366 meters. The apparatus was designed to operate from an internal 12 volt DC source. However, because the current requirement (1400 milliamps) exceeded company specifications of 400 milliamps, it was necessary to use an external source (e.g., car battery) in the field.

BASIC OPERATION

The well probe and cable were lowered by hand into a well and temperature measurements were taken at the predetermined depth intervals. A pulley system was designed to guide the probe into the exact center of the well (Figure I-1). The digital meter was turned off between temperature readings (i.e., as the probe was lowered to the next interval) to prevent overheating. In air-filled holes at depths less than 30 meters the meter was often in continuous operation for as much as 30 minutes at each depth interval before a stabilized temperature reading could be taken (a response time of 10 to 15 seconds does not apply to air-filled holes). Due to extreme surface temperatures of the 1980 summer field season, we discovered that our instrument overheated after approximately three hours of continuous use (i.e., the integrated circuits used in the meter reached temperatures exceeding their range of reliable operation which was 32 to 95 °F). Because we began to have trouble with the meter overheating in air filled holes, we modified our technique, exploiting the logarithmic relationship between temperature and response time.

We took five temperature readings at two minute intervals for each depth (usually 4.6 meters (15 feet)) and estimated the actual temperature graphically. At depths greater than 30 meters, in air-filled holes temperature readings were taken directly and a stabilized reading was usually obtained in three to six minutes.

APPENDIX II.

LOGGING METHOD: TOP-DOWN VERSUS BOTTOM-UP

Misener and Beck (1960, p.13) suggest that logging from the top-down is preferable to logging from the bottom-up to "avoid stirring up the fluid at the point of measurement".

In the following simplified situation (Figure II-1) the disturbance caused by logging a hole from the top-down versus the bottom-up is analyzed (data in Table II-1). In all cases it is assumed that:

- 1) the effect of the cable is negligible
- 2) the probe is lowered into position in the well instantaneously
- 3) in the mass transfer situation (Case 3; Figure II-2) the volume of water displaced by the probe is transferred to the new position instantaneously
- 4) specific heat of bakelite and density of resin are used for the insulated portion of the probe
- 5) casing diameter of the well equals four inches
- 6) temperatures based on a geothermal gradient of $35^{\circ}\text{C}/\text{Km}$
- 7) surface temperature of 35°C (95°F) (extreme condition)
- 8) water level is 15 meters below surface at a temperature of 13.3°C .

In each case the effect of the probe on the water column will be examined for:

- a) a volume of water equivalent to the volume displaced by the probe (greatest disturbance)

- b) a volume of water equivalent to the entire volume of water in the well (least disturbance)
- c) a volume equivalent to a one meter column of water surrounding the probe (best approximation to real situation, in my opinion).

In Cases 1 and 2 the steady state situation is analyzed using Equation II-1 (Sears and Zemansky, 1967) below. Mass transfer is analyzed in Case 3 with Equations II-1 and II-2 (Sears and Zemansky, 1967). In the following formulation a dot is used to denote scalar multiplication:

$$m_p \cdot c_p \cdot (T_1 - T_{2p'}) = m_w \cdot c_w \cdot (T_{2w'} - T_2) \quad (\text{Eqn. II-1})$$

$$m_{w2} \cdot c_{w2} \cdot (T_2 - T_{1w2'}) = m_{w1} \cdot c_{w1} \cdot (T_{1w1'} - T_1) \quad (\text{Eqn. II-2})$$

where, m_p and c_p are the mass and specific heat of the probe

m_w and c_w are the mass and specific heat of the water

m_{w2} and c_{w2} are the mass of water displaced by the probe at z_2 and the specific heat of the water displaced

m_{w1} and c_{w1} are the mass computed from a volume specified by 'a, b or c, above minus the volume equivalent to the probe's volume in its initial position, and the specific heat of the water

T_1 and T_2 are the initial and final temperatures of the probe, respectively

$T_{2p'}$ and $T_{2w'}$ are the final temperatures of the probe and water specified by a, b or c, above

$T_{1w1'}$ and $T_{1w2'}$ are the final temperatures of the water at depth z_1 surrounding the volume initially occupied by the probe (as specified by a, b or c, above) and the temperature of the water occupying the initial position of the probe.

Equation II-1 relates the probe to the water being heated by the probe after it is lowered to some depth z_2 . Equation II-2 relates the mass of water displaced by the probe at z_2 to the mass of water at z_1 (Figure II-2).

Case 1: TOP-DOWN - probe is lowered from surface ($T_1 = 35^\circ\text{C}$, $z_1 = 0\text{m}$) to depth 2 ($T_2 = 13.8^\circ\text{C}$, $z_2 = 30\text{m}$), instantaneously.

$$\text{a. } 58.4 \cdot 0.341 \cdot (35 - T_{2p'}) = 49.2 \cdot 1.000 \cdot (T_{2w'} - 13.8) \quad (\text{Eqn. II-1})$$

$$1376.0 = 19.9T_{2p'} + 49.2T_{2w'}$$

$$\text{let } T_{2p'} = T_{2w'} = T_{eq} = 19.9^\circ\text{C}.$$

$$\text{b. } 58.4 \cdot 0.341 \cdot (35 - T_{2p'}) = 1197937.6 \cdot 1.000 \cdot (T_{2w'} - 13.8) \quad (\text{Eqn. II-1})$$

$$16532235.9 = 19.9T_{2p'} + 1197937.6T_{2w'}$$

$$\text{let } T_{2p'} = T_{2w'} = T_{eq} = 13.8^\circ\text{C}.$$

$$\text{c. } 58.4 \cdot 0.341 \cdot (35 - T_{2p'}) = 8107.3 \cdot 1.000 \cdot (T_{2w'} - 13.8) \quad (\text{Eqn. II-1})$$

$$112577.7 = 19.9T_{2p'} + 8107.3T_{2w'}$$

$$\text{let } T_{2p'} = T_{2w'} = T_{eq} = 13.9^\circ\text{C}.$$

Case 2: BOTTOM-UP - probe is lowered from surface ($T_1 = 35^\circ\text{C}$, $z_1 = 0\text{m}$) to bottom of hole ($T_2 = 18.5^\circ\text{C}$, $z_2 = 163\text{m}$), instantaneously.

$$\text{a. } 1607.2 = 19.9T_{2p'} + 49.2T_{2w'} \quad (\text{Eqn. II-1})$$

$$\text{let } T_{2p'} = T_{2w'} = T_{eq} = 23.3^\circ\text{C}.$$

$$b. \quad 22162542.6 = 19.9T_{2p'} + 1197937.6T_{2w'} \quad (\text{Eqn. II-1})$$

$$\text{let } T_{2p'} = T_{2w'} = T_{eq} = 18.5^\circ\text{C}$$

$$c. \quad 150682.1 = 19.9T_{2p'} + 8107.3T_{2w'} \quad (\text{Eqn. II-1})$$

$$\text{let } T_{2p'} = T_{2w'} = T_{eq} = 18.5^\circ\text{C}$$

Case 3: Probe is lowered from depth 1 ($T_1 = 13.6^\circ\text{C}$, $z_1 = 25\text{m}$) to depth 2 ($T_2 = 13.8^\circ\text{C}$, $z_2 = 30\text{m}$) and mass of water displaced by probe is transferred to initial position of the probe, instantaneously (Figure II-2).

$$a. \quad 949.8 = 19.9T_{2p'} + 49.2T_{2w'} \quad (\text{Eqn. II-1})$$

$$\text{let } T_{2p'} = T_{2w'} = T_{eq} = 13.7^\circ\text{C}$$

$$49.2 \cdot 1.000 \cdot (13.8 - T_{1w2'}) = 49.2 \cdot 1.000 \cdot (T_{1w1'} - 13.6) \quad (\text{Eqn. II-2})$$

$$1348.1 = 49.2T_{1w2'} + 49.2T_{1w1'}$$

$$\text{let } T_{1w1'} = T_{1w2'} = T_{eq} = 13.7^\circ\text{C}$$

$$b. \quad 16531809.7 = 19.9T_{2p'} + 1197937.6T_{2w'} \quad (\text{Eqn. II-1})$$

$$\text{let } T_{2p'} = T_{2w'} = T_{eq} = 13.8^\circ\text{C}$$

$$49.2 \cdot 1.000 \cdot (13.8 - T_{1w2'}) = 1197888.4 \cdot 1.000 \cdot (T_{1w1'} - 13.6) \quad (\text{Eqn. 5})$$

$$16291961.2 = 49.2T_{1w2'} + 1197888.4T_{1w1'}$$

$$\text{where, } 1197888.4 = 1197937.6 - 49.2$$

$$\text{let } T_{1w1'} = T_{1w2'} = T_{eq} = 13.6^\circ\text{C}$$

$$c. \quad 112151.6 = 19.9T_{2p'} + 8107.3T_{2w'} \quad (\text{Eqn. II-1})$$

$$\text{let } T_{2p'} = T_{2w'} = T_{eq} = 13.8^\circ\text{C}$$

$$49.2 \cdot 1.000 \cdot (13.8 - T_{1w2'}) = 8058.1 \cdot 1.000 \cdot (T_{1w1'} - 13.6) \quad (\text{Eqn. II-2})$$

$$110269.1 = 49.2T_{1w2'} + 8058.1T_{1w1'}$$

$$\text{where, } 8058.1 = 8107.3 - 49.2$$

$$\text{let } T_{1w1'} = T_{1w2'} = T_{eq} = 13.6^\circ\text{C}$$

All of the holes were logged from the top down, as suggested by Misener and Beck (1960). The effect of taking measurements from the bottom-up was examined in the Rush County hole: 1RH2 - NWNWNE 6, T17S, R17E. Measurements were restricted to the water-filled interval (15 meters to 163 meters).

Three logs of the well were acquired over a one and one-half hour time period. The first two logs were obtained from the top of the water column to the bottom of the hole; the third log was obtained from bottom to the top of the water column (Figure II-3). In each case the measurement interval was 1.5 meters. Comparison of the regression coefficients using the t-test method (Appendix IV., p.223) indicates that there is no significant difference between the geothermal gradient computed for each log.

Cases 1c, 2c and 3c, from the hypothetical analysis of the logging method, are the most acceptable in my opinion, and are compatible with the field results. Therefore, the logging method (that is: top-down verses bottom-up), in holes that are water-filled, does not significantly effect the thermal logging data obtained.

FIGURE CAPTIONS

- FIGURE I-1: Schematic diagram of the basic operation of the thermal logging apparatus.
- FIGURE II-1: Schematic diagram of thermal logging situation as it applies to Cases 1 and 2 in text. Insert shows dimensions and physical characteristics used in analysis of logging method.
- FIGURE II-2: Schematic diagram of mass transfer situation (Case 3, in text), where z_1 and z_2 are the initial and final positions of the probe, respectively and m_{w1} is the volume specified by a, b or c (in text) minus the volume equivalent to the probe.
- FIGURE II-3: Temperature profiles of thermal logging data for hole 1RH2, obtained over 1.5 hours.
RUSH COUNTY 1 and 2 represent data obtained from logging top - down.
RUSH COUNTY 3 represents data obtained from logging bottom - up.

TABLE CAPTION

- TABLE II-1: Data for analysis of thermal logging method.

TEMPERATURE (DEG-C)

TABLE II-1

DATA FOR ANALYSIS OF THERMAL LOGGING METHOD

Specific Heat (gcal/g)	Density (g/cm ³)	Volume (cm ³)	Mass (g)
$c_{\text{bakelite}} = 0.350$	$\rho_{\text{resin}} = 1.07$	$V_{\text{bakelite}} = 45.7$	$m_{\text{bakelite}} = 48.9$
$c_{\text{Aluminium}} = 0.266$	$\rho_{\text{Al}} = 2.70$	$V_{\text{Al}} = 3.5$	$m_{\text{Al}} = 9.5$
$c_{\text{probe}} = 0.341$		$V_{\text{probe}} = 49.2$	$m_{\text{probe}} = 58.4$
$c_{\text{water}} = 1.000$	$\rho_{\text{water}} = 1.00$	$V_{\text{water(a)}} = 49.2$	$m_{\text{water(a)}} = 49.2$
		$V_{\text{water(b)}} = 1197937.6$	$m_{\text{water(b)}} = 1197937.6$
		$V_{\text{water(c)}} = 8107.3$	$m_{\text{water(c)}} = 8107.3$

Values for specific heat and density obtained from Eschbach, 1936, p.1-124, 1-128, 1-129 and 11-59.

APPENDIX III.

TEMPERATURE PROFILES OF THERMAL LOGGING DATA

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The following references were used to construct stratigraphic columns that are presented with some of the temperature profiles:

1AL1-(Miller, 1969)	1AL2-(Miller, 1969)
1BT1-(Latta, 1950)	1BU1-(Adkinson, 1963; Zeller, 1968)
1BU2-(Adkinson, 1963; Zeller, 1968)	1CQ2-(Moore, 1937)
1CN1-(Keene <u>et al</u> , 1969)	1CD1-(Bayne and Walters, 1959)
1CD2-(Bayne and Walters, 1959)	1CR1-(Abernathy, 1941; Pierce, 1938)
1CR2-(Abernathy, 1941; Pierce, 1938)	1DC1-(Hodson, 1969; Keene <u>et al</u> , 1969)
1DC2-(Hodson, 1969; Keene <u>et al</u> , 1969)	1DC3-(Hodson, 1969; Keene <u>et al</u> , 1969)
1DC4-(Hodson, 1969; Keene <u>et al</u> , 1969)	1ED1-(McLaughlin, 1949)
1ED2-(McLaughlin, 1949)	1EL2-(Leonard and Berry, 1961)
1EK1-(Bayne, 1958)	1EW1-(Bayne <u>et al</u> , 1971)
1GO1-(Hodson and Wahl, 1960; Keene and Pabst, 1971)	1GO2-(Hodson and Wahl, 1960; Keene and Pabst, 1971)
1GH1-(Prescott, 1955)	1GH2-(Prescott, 1955)
1GH3-(Prescott, 1955)	1HV1-(Lohman, 1940)
1HV2-(Lohman, 1940)	1JW1-(Fishel, 1955)
1LB3-(Abernathy, 1941)	1LC1-(Berry, 1952)
1LG1-(Johnson, 1958; Keene and Pabst, 1971)	1LG2-(Johnson, 1958; Keene and Pabst, 1971)

1MP1-(Lohman, 1940; Zeller, 1968)
 1NT1-(Frye and Leonard, 1949)
 1NT3-(Frye and Leonard, 1949)
 1OB1-(Landes, 1930; Leonard, 1952)
 1PN1-(McLaughlin, 1949)
 1RA2-(Walters, 1956; Keene et al, 1969)
 1RN1-(Cobb, 1980, pers. comm.)
 1RP1-(Wing, 1930; Zeller, 1968)
 1RH3-(McNellis, 1973)
 1SA2-(Lee, 1949; Zeller, 1968)
 1SD1-(Bayne, 1956; Keene et al, 1969)
 1SH1-(Prescott, 1953;
 Keene et al, 1969)
 1SH3-(Prescott, 1953;
 Keene et al, 1969)
 1SF1-(Cobb, 1980, pers. comm.)
 1SF3-(Cobb, 1980, pers. comm.)
 1TH1-(Frye and Stoltenberg, 1945;
 Keene et al, 1969)
 1TR1-(Hodson, 1965)
 1WA1-(Hodson, 1963;
 Keene and Pabst, 1971)
 1CL1-(Bayne, 1962)
 1NO1-(Jungman, 1966)
 1WL1-(Wagner, 1954; Zeller, 1968)
 1BA1-(Lee, 1949)
 1BB1-(Abernathy, 1941)
 1CQ1-(Moore, 1937)
 1EL1-(Leonard and Berry, 1961)
 1GW2-(Haworth and Piatt, 1894;
 Zeller, 1968)
 1LB1-(Abernathy, 1941)
 1NT5-(Frye and Leonard, 1949)
 1RH2-(McNellis, 1973)
 1WO2-(Bennett, 1896; Zeller, 1968)
 1MC1-(Hodson, 1959)
 1NT2-(Frye and Leonard, 1949)
 1NT4-(Frye and Leonard, 1949)
 1OT1-(Mack, 1962)
 1RA1-(Walters, 1956; Keene et al, 1969)
 1RA3-(Walters, 1956; Keene et al, 1969)
 1RN2-(Cobb, 1980, pers. comm.)
 1RH1-(McNellis, 1973)
 1SA1-(Lee, 1949; Zeller, 1968)
 1SG1-(Lane, 1965)
 1SD2-(Bayne, 1956; Keene et al, 1969)
 1SH2-(Prescott, 1953;
 Keene et al, 1969)
 1SM1-(Leonard, 1952)
 1SF2-(Cobb, 1980, pers. comm.)
 1SF4-(Cobb, 1980, pers. comm.)
 1TH2-(Frye and Stoltenberg, 1945;
 Keene et al, 1969)
 1TR2-(Hodson, 1965)
 1WA2-(Hodson, 1963;
 Keene and Pabst, 1971)
 1MG1-(O'Connor, 1974)
 1RO1-(Byrne et al, 1949; Zeller, 1968)
 1WO1-(Bennett, 1896; Zeller, 1968)
 1BT2-(Latta, 1950)
 1BU3-(Adkinson, 1963; Zeller, 1968)
 1CL1-(Bayne, 1962)
 1GW1-(Haworth and Piatt, 1894;
 Zeller, 1968)
 1HP1-(Bayne, 1960)
 1LB2-(Abernathy, 1941)
 1RC1-(Bayne and Ward, 1974)
 1RS1-(Bass, 1925; Zeller, 1968)

EXPLANATION

STRATIGRAPHIC SYMBOLS

Qu - Quaternary undifferentiated
To - Tertiary Ogallala Formation

CRETACEOUS
Kp - Pierre Shale
Kn - Niobrara Formation
Kc - Carlisle Shale
Kgh - Greenhorn Limestone
Kg - Graneros Shale
Kd - Dakota Formation
Kk - Kiowa Formation
Kcn - Cheyenne Sandstone
lKu - lower Cretaceous undiff.

PERMIAN
uPu - upper Permian undiff.
Pn - Nipewalla Group
Ps - Sumner Group
Pw - Wellington Formation
Pc - Chase Group
Pcg - Council Grove Group
Pa - Admire Group

PENNSYLVANIAN
IPw - Wabaunsee Group
IPs - Shawnee Group
IPd - Douglas Group
IPl - Lansing Group
IPkc - Kansas City Group
IPp - Pleasanton Group
IPm - Marmaton Group
IPc - Cherokee Group

LITHOLOGIC SYMBOLS

sandstone

shale

limestone

dolomite

chalk

cross-bedded sandstone

siltstone

gravel

sandy shale

calcareous shale

coal

chert

salt

unconformity

possible contact

TEMPERATURE (DEG-C)

TEMPERATURE (DEG-C)

TEMPERATURE (DEG-C)

TEMPERATURE (DEG-C)

TEMPERATURE (DEG-C)

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