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PRELIMINARY SCIENTIFIC RESULTS OF THE CREEDE CALDERA CONTINENTAL SCIENTIFIC DRILLING PROGRAM

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THERMAL DATA FOR CREEDE CALDERA MOAT PROJECT COREHOLES

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ABSTRACT

Basic thermal data are available for coreholes CCM-1 and CCM-2 in the Creede Caldera Moat. Thermal conductivity values (31) are in the range 1.06-2.05 W/mK, and average 1.39±0.05 W/mK; bulk density values for these samples range from 1.87 to 2.41 gm/cm^3, and average 2.13±0.03 gm/cm^3. The best near-surface heat flow value for the Creede Caldera Moat is estimated to be 78-92 mW/m^2, and that for the Creede Mining District is 95-105 mW/m^2.

INTRODUCTION

Studies of temperature, thermal conductivity, and terrestrial heat flow are important elements of the results from "scientific" drilling of coreholes CCM-1 and CCM-2 in the Creede Caldera Moat. Such research also could have important regional hydrologic implications, and provide valuable data on the thermal budget of the San Juan Mountains-Northern Rio Grande rift system. This report focuses on the thermal data that are currently available for these holes, and tabulates the first-order results for future and general use.

PROCEDURES

Temperatures were measured at discrete depths in the holes using well-calibrated thermistor probes, together with 4-lead cables, digital multimeters, and hand written or computer generated output data. Personnel from the U.S. Geological Survey made the first measurements of temperature in late 1991. More detailed measurements of temperatures in the holes were made by personnel from the University of Maine in June and August of 1992. The available temperature data provide reliable estimates for "equilibrium" gradients and perhaps "equilibrium" temperatures in the holes.

Thermal conductivities were measured using a divided-bar system at the University of Maine. The apparatus was calibrated using quartz and dynasil (precipitated silica glass). Ratcliffe's (1959) curves for the conductivities of quartz (heat flow perpendicular to the optic-axis) and silica glass were used for calibrations. Thermal conductivity samples were prepared in the form of right-circular cylinders of full-diameter core from the holes. The first measurements of conductivity were made using samples that were prepared from core that was wrapped and waxed immediately after collection in the field. Each "surviving" thermal conductivity sample was then remeasured after saturation with tap water using the methods described by Walsh and Decker (1966).

A bulk density value was determined for every right-circular cylinder of core that did not crumble or break during the first set of thermal conductivity measurements. Each density value was calculated as the quotient of the weight of the sample in air divided by the volume of that cylindrical sample. The thicknesses of the right-circular density samples were in the range 0.702-0.740 inches. The average diameters of the cylinders ranged from 2.38-2.50 inches.

Holes CCM-1 and CCM-2 are in relatively flat Moat area terrane that is bordered by much higher and more rugged parts of the San Juan Mountains. Therefore, "steady-state" topographic corrections were applied to the temperature-depth data for each hole. Topographic corrections were made assuming two-dimensional topography near each drill hole using the theory and procedures developed by Birch (1950).

Heat flow values were calculated using well-established least-squares gradient and mean conductivity procedures like those described by Roy and others (1968) and Sass and others (1971). Future research could employ other calculation procedures. In particular, thermal conductivity measurements of closely-spaced core samples could utilize resistivity integral or interval heat flow calculations to check internal consistency of vertical components of flux at each locale, data that may be "smoothed out" during the reduction procedures used herein.

RESULTS

Lithology, Temperatures and Interval Gradients

Generalized lithology (after Hulen and Campbell, 1992) for the holes is shown in Figure 1, and Figures 2 and 3 depict lithology and representative temperature-depth data. The nearly isothermal temperature profile over depths below about 1715 feet in CCM-2 is consistent with a major deep hydrologic disturbance at this locale. Otherwise, the deeper (>50-100 feet) temperature profiles that are plotted at the scales shown in Figures 2 and 3 imply extensive vertical zones with significant conductive heat transfer. The shallower temperature-depth profiles for both holes provide evidence for low thermal conductivities of the Rio Grande sands and gravels, and for seasonal ground surface temperature changes at these Moat locales.

Interval gradients as functions of depth in the holes are plotted in Figures 4 and 5. The very low gradients below about 1715 feet in CCM-2 provide more evidence for hydrologic flow in the deeper units at the site. Relatively lower interval and average gradients between 1207 and 1345 feet in CCM-1 are evident in Figure 5, perhaps partly reflecting a relative increase of borehole conductivity in that depth interval of this hole. The other gradient-depth data show that there are significantly different non-zero interval gradients throughout the shallower portions of both holes. One explanation of such juxtaposed, contrasting interval gradients at both locales is that the conductivity of the penetrated rock units changes rapidly as a function of vertically changing lithology. For example, thin layers of rocks with high conductivity could correspond to lower interval gradient values, and conversely. Alternatively, markedly different gradients in adjacent short-depth intervals in both holes may indicate important fine structure in the subsurface hydrologic flow at these locales. More specific explanations of the contrasting, significantly different interval gradients in the upper parts of CCM-1 and CCM-2 will require closely-spaced determinations of the thermal conductivity in many of the indicated depth intervals.

Thermal Conductivity Data

Presently available thermal conductivity and bulk density data for both holes are summarized in Table 1. The positive correlations between measured conductivity and bulk density of the samples suggest that the respective measurements of these small samples are reliable (see Figure 6).

Heat Flow

Table 2 is a summary of basic thermal data and calculated heat flow values for each station. The observed and terrain-corrected heat flow values (87-103 mW/m^2, 78-92 mW/m^2) for CCM-1 suggest that the vertical component of conductive heat flow near this locale is reasonably uniform. From the data for CCM-2, it may be conjectured that the major hydrologic disturbance(?) below 1715 feet accounts for the lower near-surface heat flux (45-80 mW/m^2) near this station, and perhaps at nearby locales in the Moat.

The observed and terrain-corrected heat flow values for CCM-1 are in the ranges 87-103 mW/m^2 and 78-92 mW/m^2, respectively (Table 2). Because the Moat area units near this hole probably are characterized by a thermal conductivity (about 1.4 W/mK) that is significantly lower than the conductivity (2.2-3.0 W/mK) of the volcanic units in the bordering mountains (after Table 2 herein and Decker and others, 1988, Table 1), it may be speculated that the calculated flux values for CCM-1 are lower than the "undisturbed" regional heat flow for the Creede Mining District. Thus, the "best" regional heat flow value for the District is considered to be in the range 95-105 mW/m^2, bounding values that Decker and others (1988) reported for locales in volcanic rocks in the mountains to the north.

CONCLUDING REMARKS

Available data for hole CCM-1 and non-Moat drill holes suggest that the undisturbed regional heat flow in the Creede Mining District is high (95-105 mW/m^2). The significantly lower conductive heat flow values that are calculated for hole CCM-2 imply that a major hydrologic disturbance occurs at depth (≥1715 feet) in more easterly portions of the Moat. Quantification of this important regional disturbance could be accomplished with additional thermal conductivity and interval gradient studies in both holes. Another important future project would be to clear the blockage that occurs below the nearly isothermal zone in CCM-2. Temperature and thermal gradient studies at greater depths at this locale could resolve the issue of whether a major high-yield aquifer is controlling the deep and near-surface thermal regimes in this and nearby parts of the Moat structure.

ACKNOWLEDGMENTS

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TABLE 1. SUMMARY OF CONDUCTIVITY AND DENSITY DATA FOR CCM-1 AND CCM-2.

Number of Samples	Mean Conductivity* W/m°K	Conductivity Range W/m°k
31	1.39 .05	1.06-2.05

Number of Samples	Mean Density* gm/cm^3	Density Range gm/cm^3
31	2.13 .03	1.87-2.41

* Standard errors shown below mean values.

TABLE 2. SUMMARY OF BASIC THERMAL DATA FOR DRILL HOLES CCM-1 AND CCM-2.

CCM-1:

				Heat Flow, mW/m^2	
Interval, meters	Grad, °C/km	r*	K,W/m°K	Obs+	Cor+
43.8 - 410.5	62.95	0.9994	1.50	94.4	85.4
242.2 - 410.5	58.28	0.9993	1.76	102.6	92.3
368.4 - 410.5	49.13	0.9993	1.76	86.5	77.9

CCM-2:

				Heat Flow, mW/m^2	
Interval, meters	Grad, °C/km	r*	K,W/m°K	Obs+	Cor+
74.7 - 498.7	60.45	0.9995	1.30	78.6	73.1
498.7 - 522.7	38.41	0.9997	1.30	49.9	46.4
522.7 - 604.7	5.5	0.9383	n/a	n/a	n/a

Best CCM-1 Heat Flow Values 85 - 92 mW/m^2

Best Regional Heat Flow Values 95-105 mW/m^2

*r is the correlation coefficient of the least-squares gradients for the indicated depth intervals

+Obs and Cor refer to observed and terrain-corrected heat flow values, respectively

FIGURE CAPTIONS

Figure 1. Generalized lithology for holes CCM-1 and CCM-2 in the Creede Caldera Moat (after Hulen, 1992).

Figure 2. Temperature vs depth for hole CCM-1. Lithology after Figure 1.

Figure 3. Temperature vs depth for hole CCM-2. Lithology after Figure 1.

Figure 4. Interval gradients vs depth for hole CCM-1. Lithology after Figure 1.

Figure 5. Interval gradients vs depth for hole CCM-2. Lithology after Figure 1.

Figure 6. Bulk density vs thermal conductivity for samples from holes CCM-1 and CCM-2.

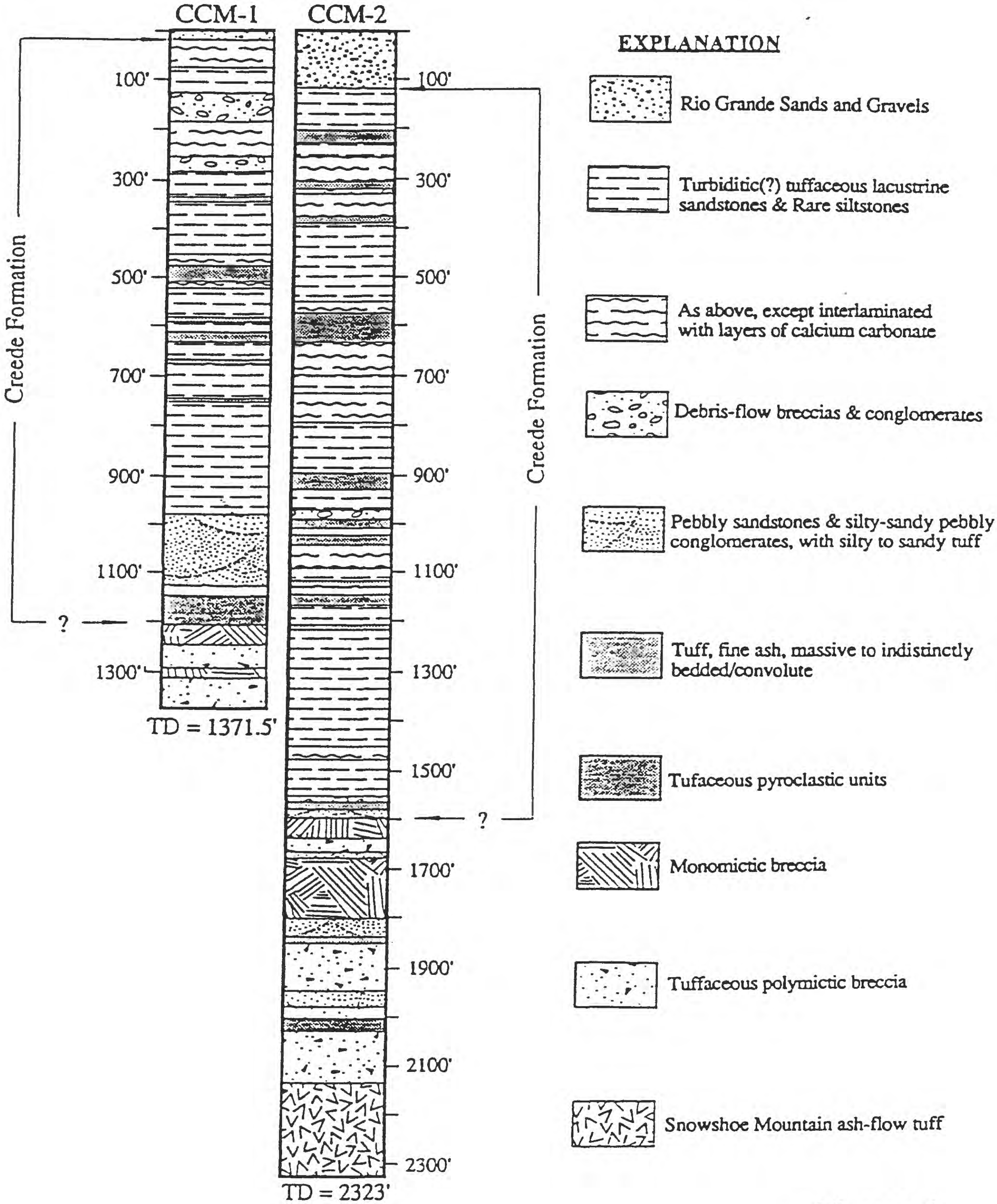
CCM-1
CCM-2
Creede Formation
100'
300'
500'
700'
900'
1100'
1300'
1500'
1700'
1900'
2100'
2300'
?
TD = 1371.5'
TD = 2323'
EXPLANATION
Rio Grande Sands and Gravels
Turbiditic(?) tuffaceous lacustrine sandstones & Rare siltstones
As above, except interlaminated with layers of calcium carbonate
Debris-flow breccias & conglomerates
Pebbly sandstones & silty-sandy pebbly conglomerates, with silty to sandy tuff
Tuff, fine ash, massive to indistinctly bedded/convolute
Tufaceous pyroclastic units
Monomictic breccia
Tuffaceous polymictic breccia
Snowshoe Mountain ash-flow tuff

Figure 1

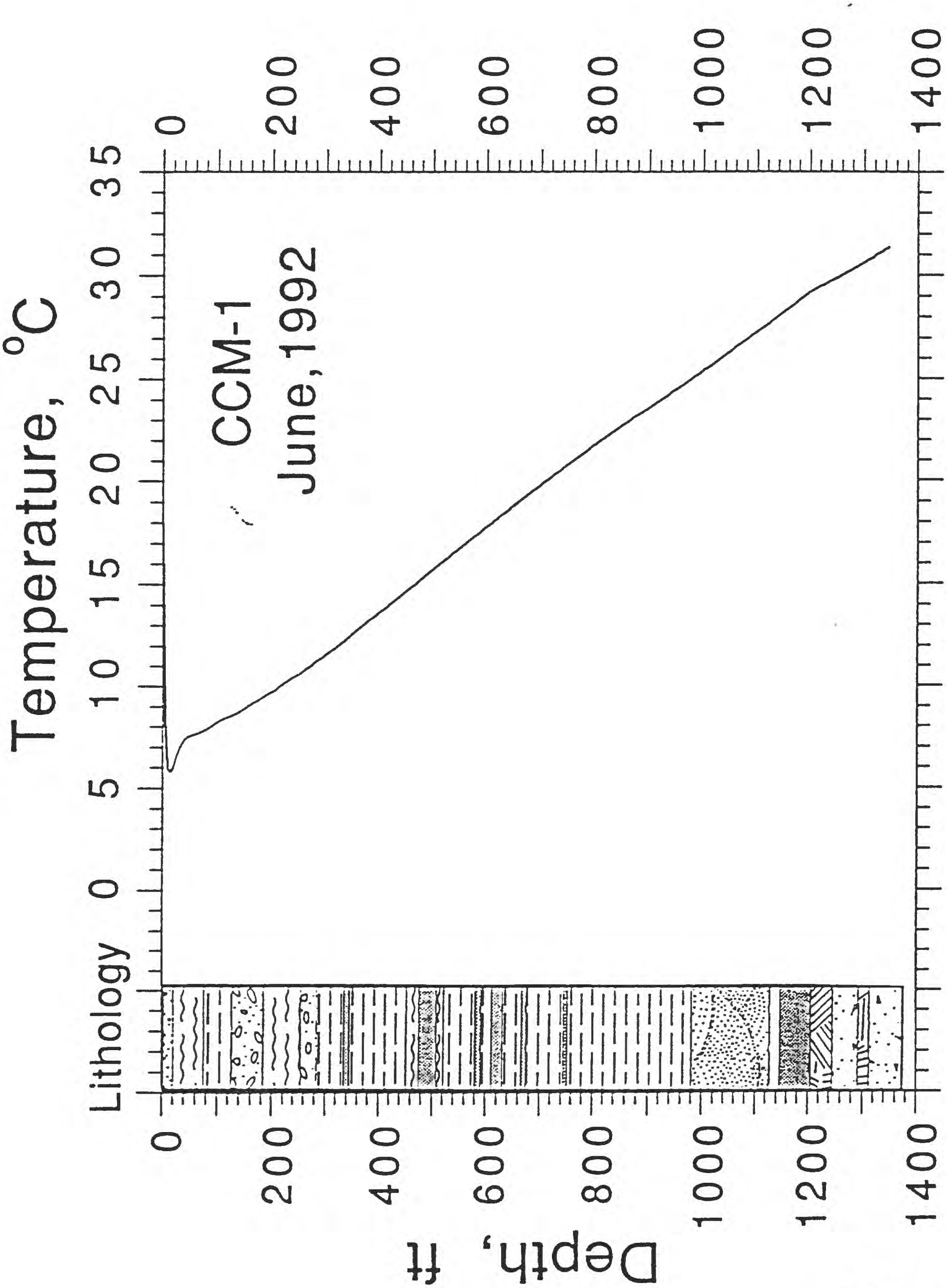
Temperature, °C
0 5 10 15 20 25 30 35
CCM-1
June, 1992
Lithology
0 200 400 600 800 1000 1200 1400
Depth, ft

Figure 2

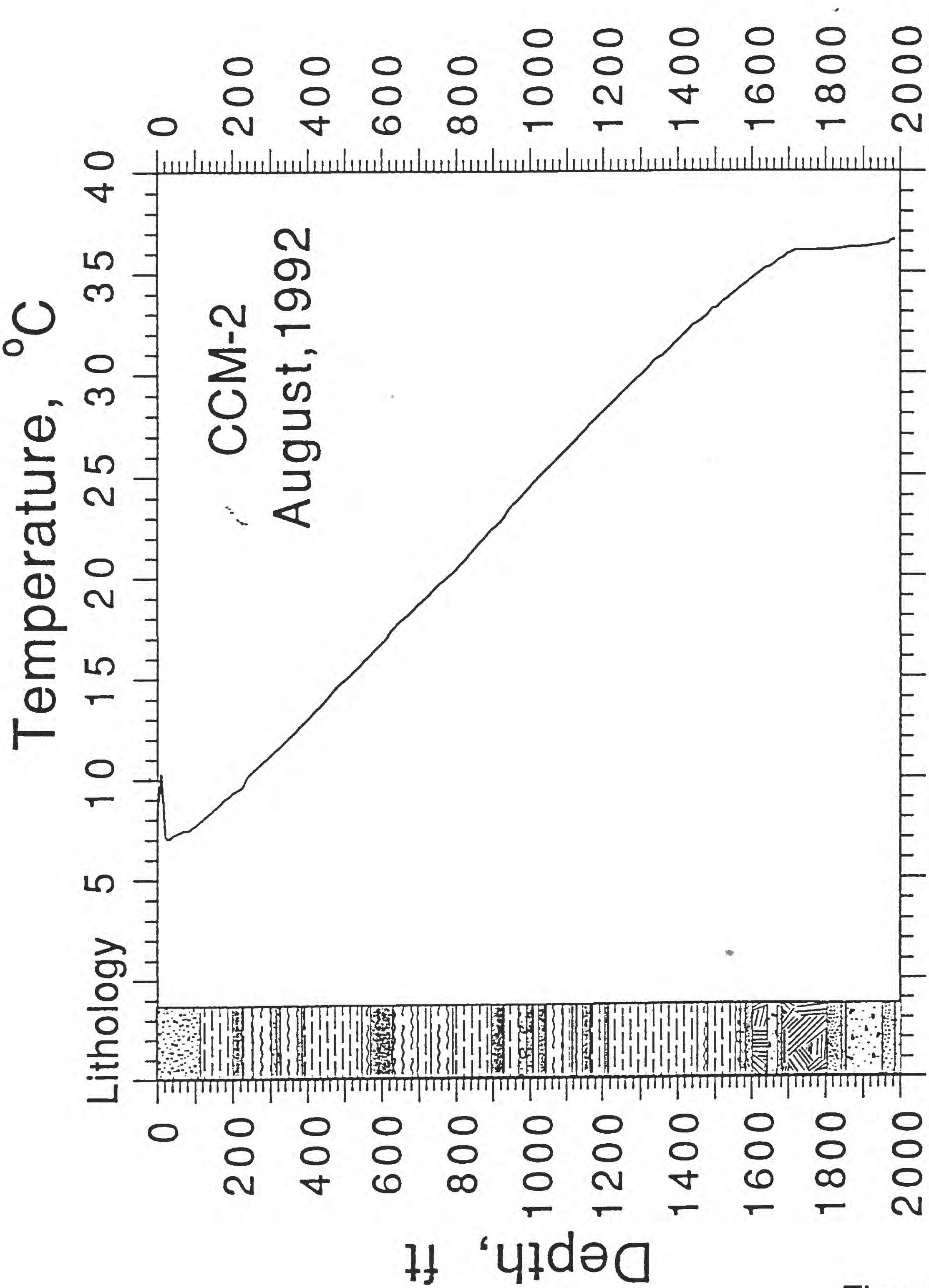

Figure 3

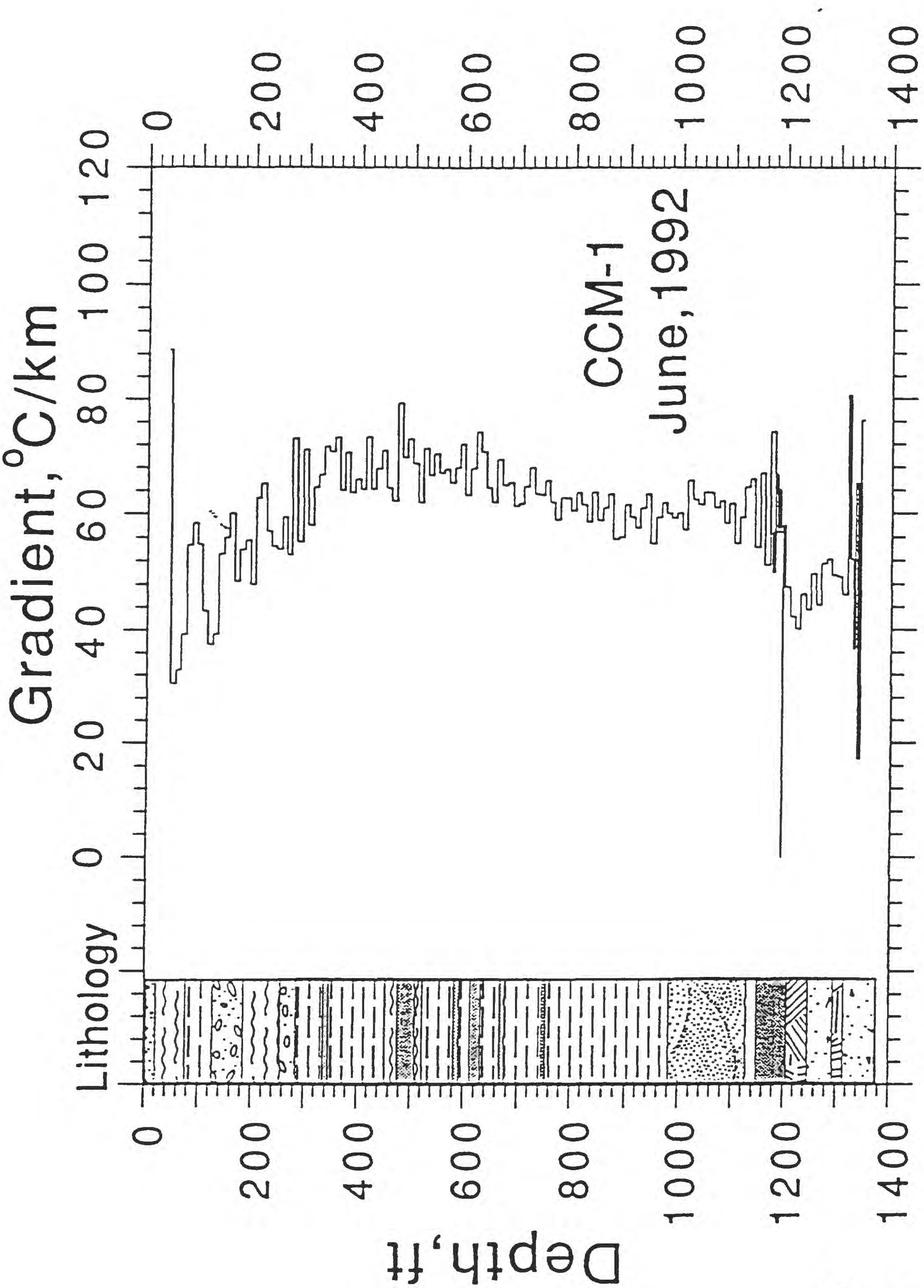
Gradient, °C/km
CCM-1
June,1992
Lithology
Depth, ft
0
20
40
60
80
100
120
0
200
400
600
800
1000
1200
1400

Figure 4

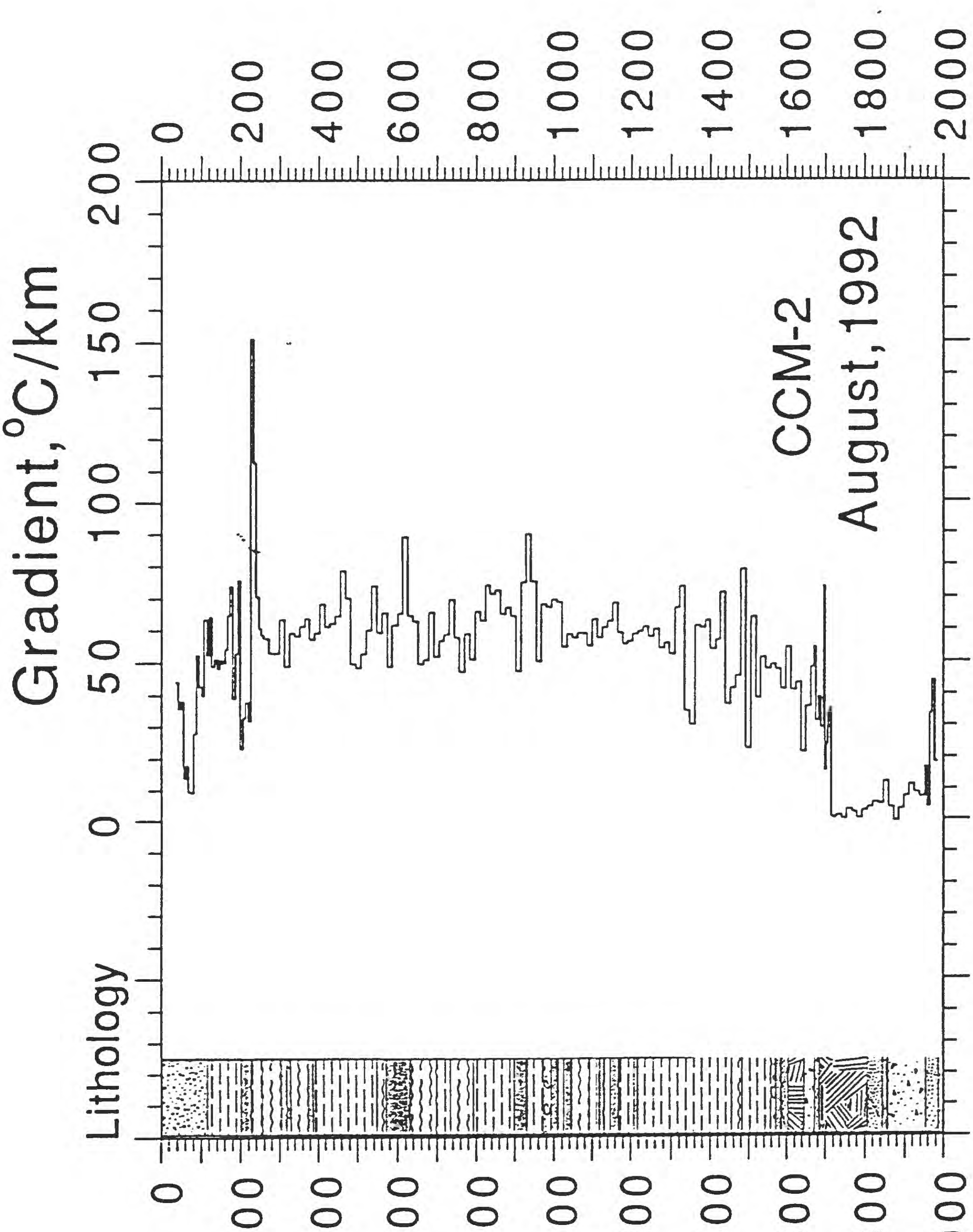
Gradient, °C/km
0
50
100
150
200
Lithology
CCM-2
August, 1992
Depth, ft
0
200
400
600
800
1000
1200
1400
1600
1800
2000

Figure5

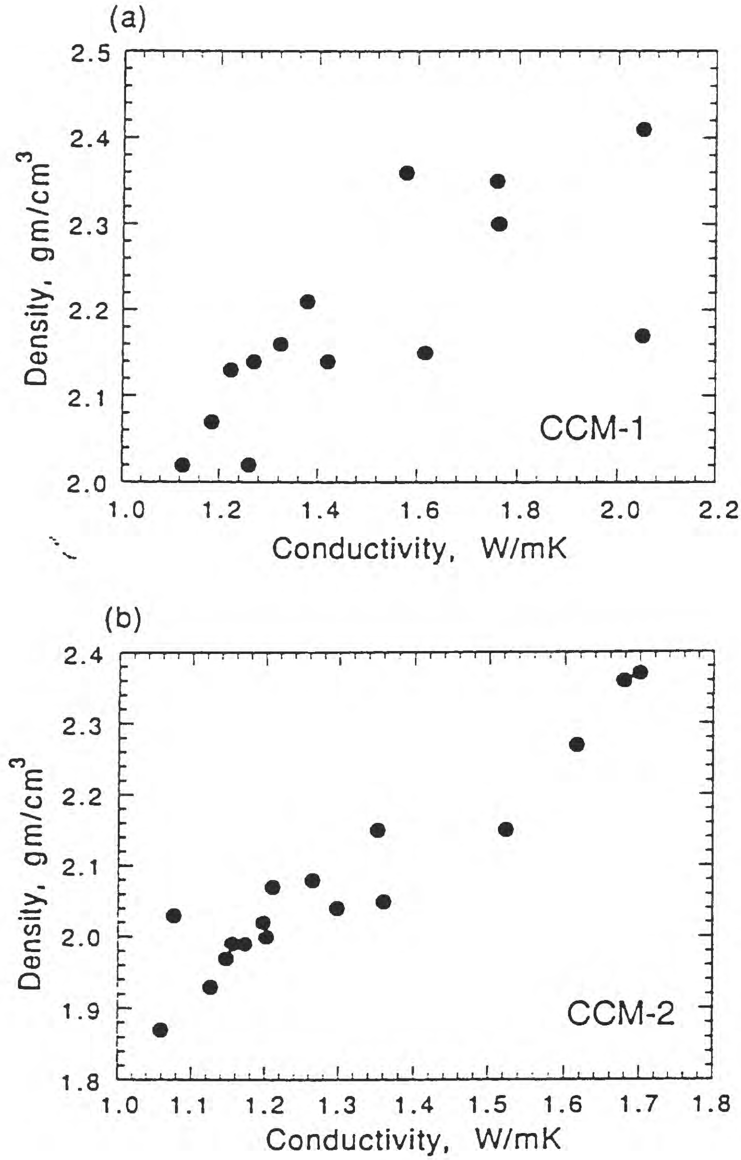
(a)
2.5
2.4
2.3
2.2
2.1
2.0
Density, gm/cm3
1.0
1.2
1.4
1.6
1.8
2.0
2.2
CCM-1
Conductivity, W/mK
(b)
2.4
2.3
2.2
2.1
2.0
1.9
1.8
Density, gm/cm3
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
CCM-2
Conductivity, W/mK

Figure 6