Heat Flow and Geothermal Assessment
of the Escalante Desert, Southwestern Utah,
With Emphasis on the Newcastle KGRA

by

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February, 1981

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Prepared for the Department of Energy/Division of Geothermal Energy
under contract number DE-AC07-80ID12079

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ABSTRACT

Twenty-five new regional heat flow measurements are presented for the Escalante Desert region within the Great Basin of the western U.S. Heat flow excluding geothermal areas ranges from 42 to 350 mW m^{-2} but much of the variability may be caused by deeply circulating groundwater redistributing the regional flux. A subset of 10 sites drilled specifically to characterize the heat flow of the region yielded a mean of 100 mW m^{-2} with a standard deviation of 22 mW m^{-2} . An analysis of thermal conductivities of solid cylindrical discs and rock chips of rhyolite to andesite tuffs emphasized the importance of porosity corrections to thermal conductivity measurements.

A "blind" geothermal system southwest of Newcastle, Utah, situated within the Escalante Desert has also been studied. Heat flow results from 11 local drillholes yield values between 163 and 3065 mW m^{-2} . The 500 mW m^{-2} contour encloses an area of 9.4 km^2 . By integrating the anomalous flux above background over the thermal anomaly, a thermal power loss of 12.8 MW and corresponding subsurface mass discharge of 32 kg s^{-1} are calculated for this geothermal system.

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ACKNOWLEDGMENTS

We would like to acknowledge Dr. William Sill, Dr. John Bowman, Dr. Rick Allis, and Chuck Mase for their critical reviews of this report. Dr. Sill, Chuck Mase, and John Bodell assisted with the regional heat flow measurements, and Eugene Rush kindly gave permission to use his Newcastle temperature data prior to its release as a USGS Professional Paper. Reed Mower provided a list of drill-hole locations which was particularly valuable.

A special thanks is extended to Dr. Myron Best and Eric Struhsäcker for their time given in the interest of hand sample description and nomenclature. Thanks also to Roger Stoker who provided the Newcastle chip samples.

This work was supported under DOE/DGE Grant No. DE-AC07-80ID12079.

INTRODUCTION

The Escalante Desert, Utah, is an elliptical (70 x 45 km) valley situated within the southeastern Great Basin about 50 km west of Cedar City, Utah (See Figure 1). The valley is surrounded and underlain by Tertiary ash-flow tuff sequences erupted between 29 and 12 m.y. before present. These tuffs are characteristic of one phase of widespread Cenozoic volcanic activity, forming a belt of volcanic rocks covering southwestern Utah and extending west-northwest into Nevada (Figure 1).

Within this geologic setting are found many of the geothermal areas of the state of Utah: Roosevelt Hot Springs KGRA (Known Geothermal Resource Area), Monroe-Redhill Hot Springs KGRA, Joseph Hot Springs, Cove Fort-Sulphurdale KGRA, Thermo-Lund KGRA, and Newcastle KGRA (Figure 1). The object of this paper is to make an assessment of the thermal regime of the Escalante Desert. New heat flow values are presented which define the magnitude of the regional heat flow, and this value in turn is used to delineate anomalous areas, and as a background for more detailed analyses of the Newcastle KGRA.

Figure 1. Index map showing the location of the Escalante Desert (E.D.) in southwestern Utah, and its relationship to the volcanic belt (igneous rocks younger than 34 m.y. old) in Utah and Nevada. Open squares and site designations locate the KGRA's (Known Geothermal Resource Areas). Open circles and letter designations are cities: D, Delta; R, Richfield; M, Milford; CC, Cedar City; SG, St. George. ISD locates the Iron Springs Mining District. (after Stewart and Carlson, 1976).

I. GEOLOGICAL SETTING

The geology of the Escalante Desert region is dominated by sequences of thin ash-flow tuff sheets of rhyolitic to andesitic composition (Rowley et al., 1978; Hausel and Nash, 1977), the stratigraphy of which is given in Figure 2. These rocks form the topographically high boundary ranges surrounding the Quarternary alluvial, colluvial, and lacustrine deposits of the valley floor (Hintze, 1963). Sedimentary rocks of Paleozoic and Mesozoic age are found in the northeastern part of the Escalante Desert, and Cretaceous sediments (Iron Springs Fm., Figure 2) crop out in the southeastern section in the Iron Springs District (ISD, Figure 1) (Mackin, 1947, 1960; Hintze, 1963). These rocks were subjected to regional and local thrust faulting with the Sevier Orogeny, and broad regional folding during the Laramide event (Mackin, 1947, 1960). The early Tertiary Claron Formation (equivalent to the Wasatch Formation of the Colorado Plateau) was deposited on the nearly flat erosional surface of the pre-Cenozoic rocks (Mackin, 1960; Rowley et al., 1979). The earliest of the ash-flow tuff units were deposited directly on the Claron Formation (Figure 2) and sometimes interfinger with it (Mackin, 1947). Volcanic evolution along the entire belt shown in Figure 1 was episodic, with a major mid-Miocene hiatus in activity apparent, possibly due to an abrupt change in the plate tectonic regime (Noble, 1972). It

AGE	SEQUENCE	EASTERN BASIN and RANGE	THERMAL CONDUCT- TIVITY Mean $\pm$ Sd. (W/m-K)	NUMBER OF SAMPLES			
Holocene	Quaternary and Upper Tertiary	BASALT and RHYOLITE Sevier River Fm. and correlative rocks MY 0-20					
Pleistocene or Holocene					Page Ranch Fm. (Cook, 1957) 19		
					Rencher Formation (Cook, 1957)		
					Harmony Hills Tuff Member 21	1.57 $\pm$.08	2
Miocene		Middle Tertiary
			Quichapa Group Condor Can. Fm.	Bauers Tuff Member 22	1.72 $\pm$.14	3	
				Swett Tuff Member 23			
			Bear Valley Fm.				
			Quichapa Gp. Leach Can. Fm.	Table Butte Tuff Member	1.85 $\pm$.28	8	
				Narrows Tuff Member 24			
	Isom. Fm.		Hole-in-the-wall Tuff Mbr.	1.99	1		
			Baldhills Tuff Members 25-26				
	Oligocene and/or Oligocene		Lower Tertiary	Wallaces Peak Tuff Member			
				Lund Tuff Member	2.02 $\pm$.31	18	
Wah Wah Springs Tuff Member		1.93 $\pm$.27		4			
Cottonwood Wash Tuff Member 30							
Claron Formation

Iron Springs Fm.							
Eocene	Upper Mesozoic						
Cretaceous							

Figure 2. Volcanic stratigraphy of the Escalante Desert region, southwestern Utah (modified from Rowley et al., 1978).

is generally believed that the volcanic rocks are Great Basin derived, although exact source areas are not known (Rowley et al., 1978). The volcanic sequences probably predate major episodes of Basin and Range rifting in this area (Rowley et al., 1978).

Tertiary (20 m.y., Rowley et al., 1978) quartz monzonite intrusive rocks occur in an arcuate pattern on the southeastern border of the Escalante Desert in the Iron Springs Mining District (Figure 1; Mackin, 1947, 1960; Cook and Hardman, 1967; Rowley et al., 1979). Although the intrusive outcrop is spatially restricted, the occurrence of a much larger body at depth is not precluded (Mackin, 1947, 1960; Cook and Hardman, 1967; Schmoker, 1972). To date there is no strong geological or geophysical evidence to support the hypothesis (Crosby, 1973) of a caldera origin for the valley (Best, pers. comm.; Win Pe, 1980). Except in localized areas (i.e. Roosevelt Hot Springs KGRA, Figure 1) the rocks of this Tertiary volcanic belt are too old to attribute a magmatic source of heat for the geothermal systems in the region (Ward et al., 1978; Wilson and Chapman, 1981). This is specifically true for the Lund and Newcastle KGRA's which lie within the Escalante Desert.

Geophysical studies in the Escalante Desert have been restricted to regional gravity and magnetic surveys (Cook and Hardman, 1967; Win Pe, 1980), reconnaissance AMT surveys at the Lund and Newcastle KGRA's (Gardner et al. 1976), and isolated heat flow determinations (Wright, 1966; Rush, 1977).

II. HEAT FLOW

Temperature Measurements

Temperatures in drillholes were measured with a thermistor probe connected by lightweight cable using three or four wire configurations to a Wheatstone Bridge or digital ohm meter respectively (details are similar to those described in Roy et al., 1968; Sass et al., 1976, and Appendix I of Chapman, 1976). Fenwal K212E thermistor probes are used, which have a nominal resistance of 10,000 ohms at 20°C, power dissipation of 50 mW K⁻¹ in still water, and response time of 5 seconds. The probes were calibrated against a platinum thermometer by determining resistance R and temperature T pairs over the range 0 to 60°C and fitting them to a single curve of the form

$$R = \exp \left(A + \frac{B}{T + C} \right).$$

Residuals from these curves at calibration points did not exceed 0.05°C over the entire range, indicating that more complicated curve fitting over limited segments of the temperature range (Sass et al., 1971-b) is unwarranted for these probes. For a thermistor temperature coefficient of -4% K⁻¹ typical of these probes, a ±1 ohm uncertainty in the resistance measurement at 20°C is equivalent to a temperature sensitivity of ±0.004°C. The accuracy of a field temperature measurement, however, is limited by accumulation of

calibration errors, stability of the resistance meter, and stability of the medium being measured, and may amount to ± 0.1 K. Field measurements are normally made at discrete intervals in drillholes after waiting at least one minute for the probe to equilibrate with its surroundings.

Temperature-depth profiles for 25 sites in and around the Escalante Desert (Figure 3) are shown in Figures 4 through 8. The drillholes vary in depth from 30 to 118 m, somewhat shallower than desired for purposes of regional heat flow determinations. However, depth of drillhole alone is no guarantee of reliability; it is important to display the new temperature-depth data and to judge the reliability of a conductive heat flow assumption in the context of the data and the local geological conditions surrounding the site. For this region, five subsets of new data will be discussed separately. More complete details of each site, including location and elevation, borehole drilling and logging history, temperature-depth table and lithology can be found in Table 1 and Appendix A.

Temperature-depth profiles shown in Figure 4 are from 10 boreholes drilled in the ash-flow tuffs around the periphery of the Escalante Desert (see Figure 3) specifically for heat flow determinations. Profiles from ED-9, 10, 7, 4, 6, and 8 do not depart significantly from a constant gradient and can be interpreted as resulting from purely conductive vertical heat flux. ED-11 exhibits a disturbance at 35 m as do ED-2, between 35 and 60 m, and ED-1 intermittently throughout the entire hole. These disturbances, discussed in more detail in Appendix A, likely arise from minor

Figure 3. Geologic map of the Escalante Desert region, southwestern Utah (after Hintze, 1963), showing location of regional heat flow sites. Site designations match those in Table 1. The rectangular area near 37°40' N, 113°30' E encompasses the Newcastle geothermal system, discussed in the text. Circles denote sites where thermal conductivity values are available, squares where they are not. Sites designated with a "+" are isothermal wells. Geologic key: Qal, Quaternary alluvium and colluvium; Qb, Quaternary basalt; Tb, Tertiary basalt; Tc, Tertiary Claron Formation; Tsu, Tertiary sediments, undifferentiated; PTu, pre-Tertiary rocks, undifferentiated; Tv, Tertiary silicic volcanic rocks; Ti, Tertiary intrusive rocks; Mis, Mesozoic Iron Springs Formation.

TABLE 1 BASIC HEAT FLOW DATA -- ESCALANTE DESERT

Locality	Site	N. Lat.	W. Long.	Elev. (m)	Depth Range (m)	Gradient (°C/km)	N	k (W/m·K)	q (mW/m ²)
Regional heat flow sites.									
Escalante Desert	ED-1	37°36'23"	113°48'52"	1747 ± 5	30-92	74 ± 7	11	1.5 ± 0.1	111 ± 13 (87 ± 11)
	ED-2	37°44'20"	113°44'56"	1602 ± 2	12-70	51 ± 5	10	2.3 ± 0.1	115 ± 11
	ED-3	37°44'20"	114°02'19"	1750 ± 3	12-100	82 ± 4	16	1.8 ± 0.1	143 ± 10
	ED-4	37°36'53"	113°01'06"	1735 ± 3	20-100	51 ± 3	14	2.0 ± 0.1	102 ± 8 (83 ± 6)
	ED-6	37°59'05"	113°39'20"	1743 ± 3	22-100	56 ± 3	14	1.7 ± 0.1	97 ± 5
	ED-7	38°07'11"	113°37'41"	1862 ± 3	12-100	51 ± 2	16	2.4 ± 0.1	122 ± 7 (102 ± 5)
	ED-8	37°59'59"	113°31'13"	1643 ± 2	20-88	57 ± 3	11	2.2 ± 0.1	125 ± 9
	ED-9	37°53'00"	113°26'12"	1600 ± 2	12-100	46 ± 1	16	1.4 ± 0.1	67 ± 3
	ED-10	37°47'41"	113°22'43"	1655 ± 3	10-92	46 ± 2	15	1.9 ± 0.1	87 ± 6
	ED-11	37°52'51"	113°11'56"	1692 ± 3	12-100	50 ± 6	16	1.9 ± 0.1	93 ± 12
Escalante Desert, Central	EDC-1	37°50'20"	113°32'41"	1560 ± 1	20-30	41 ± 1	1	1.4 ± 0.2	58 ± 8
	EDC-2	37°52'28"	113°37'04"	1563 ± 1	10-59	31 ± 2	A	1.4 ± 0.2	43 ± 7
	EDC-3	37°50'20"	113°41'14"	1566 ± 1	35-64	68 ± 10	A	1.4 ± 0.2	96 ± 20
	EDC-4	37°50'08"	113°37'53"	1563 ± 1	20-60	66 ± 2	A	1.4 ± 0.2	92 ± 13
Escalante Desert, East	EDE-1	37°53'09"	113°19'56"	1585 ± 2	25-70	30 ± 4	A	1.4 ± 0.2	42 ± 9

TABLE 1 (continued)

Locality	Site	N. Lat.	W. Long.	Elev. (m)	Depth Range (m)	Gradient (°C/km)	N	k (W/m·K)	q (mW/m ²)
Hamblin Valley	HV-1	37°59'05"	113°57'02"	2021 ± 3	16-60	49 ± 2	B	1.6 ± 0.2	78 ± 10
Lund	LD-1	38°03'29"	113°26'22"	1579 ± 2	11-31	132 ± 10	C	1.7 ± 0.2	224 ± 31
	LD-2	38°02'37"	113°24'03"	1548 ± 1	14-93	40 ± 1	B	1.6 ± 0.2	64 ± 8
Black Mountain	BM-1	38°06'43"	113°07'30"	1762 ± 3	25 -75	49 ± 2	9	1.5 ± 0.1	74 ± 3
	BM-2	38°05'18"	113°08'12"	1865 ± 3	15-45	78 ± 8	E	1.5 ± 0.2	116 ± 17
	BM-3	38°07'26"	113°06'02"	1737 ± 3	10-65	178 ± 5	F	2.0 ± 0.1	350 ± 11
	BM-4	38°08'57"	113°08'34"	1612 ± 1	20-65	163 ± 5	G	1.6 ± 0.2	255 ± 33
	BM-7	38°04'40"	113°12'53"	1632 ± 2	20-68	84 ± 6	E	1.5 ± 0.2	125 ± 15
Iron Mountain	IM-1	37°38'12"	113°24'43"	1904 ± 3	35-80	28 ± 1	H	3.7 ± 0.4	101 ± 11
	IM-2	37°37'31"	113°24'30"	1912 ± 3	15-55	24 ± 3	II	3.7 ± 0.4	87 ± 13
Newcastle geothermal system heat flow sites									
Newcastle	NC-2	37°38'05"	113°33'18"	1774 ± 12	46-89	89 ± 3	D	1.8 ± 0.2	163 ± 15
	NC-3	37°38'18"	113°34'06"	1643 ± 6	46-89	116 ± 4	D	1.8 ± 0.2	212 ± 20
	NC-4	37°38'26"	113°33'59"	1658 ± 6	8-91	199 ± 12	D	1.8 ± 0.1	349 ± 27
	NC-5	37°39'08"	113°33'34"	1631 ± 3	8-36	1869 ± 78	D	1.6 ± 0.1	3065 ± 275
	NC-6	37°38'56"	113°33'50"	1634 ± 3	5-38	1065 ± 102	D	1.6 ± 0.1	1747 ± 218
	NC-7	37°39'37"	113°33'03"	1619 ± 3	11-91	309 ± 24	D	1.8 ± 0.1	541 ± 49
	NC-8	37°39'51"	113°33'02"	1617 ± 3	17-41	1028 ± 30	D	1.8 ± 0.1	1871 ± 69
	NC-9	37°40'00"	113°32'52"	1618 ± 1	23-84	475 ± 58	D	1.8 ± 0.1	874 ± 116

TABLE 1 (continued)

Locality	Site	N. Lat.	W. Long.	Elev. (m)	Depth Range (m)	Gradient (°C/km)	N	k (W/m·K)	q (mW/m ²)
Newcastle (cont.)	NC-10	37°39'34"	113°33'51"	1603 ± 2	0-40	1833	D	1.6 ± 0.1	3006 ± 238
	NC-11	37°39'18"	113°34'15"	1600 ± 3	15-46	1292 ± 45	D	1.8 ± 0.1	2351 ± 97
	NC-12	37°41'21"	113°31'26"	1619 ± 3	49-118	21 ± 3	D	1.6 ± 0.2	35 ± 6

Thermal conductivity code:

- A - alluvium sample from EDC-1 35% porosity ±10%
 B - alluv. from EDC-1 25% porosity ±10%
 C - alluv. from EDC-1 20% porosity ±10%
 D - based on 8 downhole chip measurements from a well
 100 feet N.W. of NC-10. Porosity-corrected ±10%

- E - from BM-1 ±10%
 F - mean ED 7,8 hand sample data ±10%
 G - mean ED 7,8 hand sample; 20% porosity ±10%
 H - mean Iron Springs Fm; Sass and Munroe (1974) ±10%

Figure 4. Temperature-depth profiles for the ED series sites in tuffs surrounding the Escalante Desert (see Figure 3 for site locations). An arbitrary temperature scale is used to avoid overlap, but inclusion of the actual temperature T_1 of the shallowest point plotted permits the reconstruction of actual temperature profiles. Thermal gradient values for the straight line segments are given.

groundwater flow in fractures or in the formation; but again the overall profile is indicative of a predominantly conductive flux. ED-3 has a gradient break at 50 m not entirely explicable by thermal conductivity contrasts and it too may indicate minor groundwater flow. The thermal gradients attached to these data are indicated in Figure 4 by solid lines, and listed in Table 1. The average gradient from the 10 drillholes is $56.4^{\circ}\text{C km}^{-1}$ and will henceforth be referred to as the "background" gradient for the Escalante Desert.

Another set of regular temperature-depth profiles found in sites on the northern margin of the Escalante Desert is shown in Figure 5. Sites HV-1, LD-1 and LD-2 all exhibit conductive behaviour on the scale of the borehole although the high gradient of $132^{\circ}\text{C km}^{-1}$ in LD-1, and the contrast with results in LD-2 suggests a convective heat transfer enhancement at a deeper level. Profiles at sites ED-6, ED-7, and ED-8 are repeated from Figure 4 for comparison purposes.

In contrast to the consistent and regular gradients in the ED series holes, measurements made in four shallow water wells in the central Escalante Desert (Figures 5 and 6) show greater irregularities and much less consistency. EDC-3 and EDC-4 (Figure 6) are water wells adjacent to two deep geothermal test wells. Goode (1978) reports 149°C water produced from 2.1 km depth in the westernmost test well (total depth = 3.0 km) near EDC-3. Assuming a 12°C surface intercept temperature, a thermal gradient of $64^{\circ}\text{C km}^{-1}$ is

Figure 5. Temperature-depth profiles for sites on the northern margin of the Escalante Desert (see Figure 3 for site locations).

Figure 6. Temperature-depth profiles for water wells within the central Escalante Desert (see Figure 3 for site locations).

obtained for the geothermal well. Gradients calculated for EDC-3 and EDC-4 are 68 and $66^{\circ}\text{C km}^{-1}$ respectively. Because the gradients in these two wells are very similar to that in the 3.0 km deep well, EDC-3 and EDC-4 are taken as the more representative gradients. EDC-1, EDC-2 (Figure 6), and EDE-1 (Figure 5) also have consistent gradients of 41 , 31 , and $30^{\circ}\text{C km}^{-1}$ respectively, but they differ significantly from EDC-3 and 4, and the deep test well. These differences over lateral distances of a few kilometers are not uncommon among sites in Basin and Range alluvial valleys and suggest that all shallow gradients should be regarded with suspicion until checked against other and preferably deeper results.

Two profiles from boreholes separated by 1.3 km in the Iron Springs District vicinity are shown in Figure 7. While both profiles exhibit some irregularities, the consistent gradients of 24 and $28^{\circ}\text{C km}^{-1}$, and extrapolated surface intercept temperatures lend weight to their reliability. Heat flow values determined for these holes are also consistent with values published previously in the same District (Sass and Munroe, 1974).

A final example can be made from a composite temperature-depth plot (Figure 8) from sites located within a 144 km^2 area in the Black Mountains in the northeastern Escalante Desert. Average site separation is 4 km. Thermal gradients vary from $49^{\circ}\text{C km}^{-1}$ in BM-1 to $178^{\circ}\text{C km}^{-1}$ in BM-3. None of these holes exhibits strong irregularities which are symptomatic of convective heat transport on the scale of the borehole depth, yet the contrasting gradients

Figure 7. Temperature-depth profiles for sites in the Iron Springs District (see Figure 3 for site locations).

Figure 8. Temperature-depth profiles for sites in the Black Mountains (see Figure 3 for site locations).

in similar rock types imply heat flow sources within the upper crust. Unless a case can be made for sufficiently recent upper crustal intrusions (i.e. in the last 500,000 years) which are still losing heat, the most plausible explanation for such gradient contrasts is a redistribution of heat flow patterns caused by deeply circulating groundwater moving over scales of several kilometers. These flow patterns can be revealed by heat flow surveys, but conclusive identification will not be possible until the spatial density of measurements is equivalent to several sites per flow scale length and not several flow scale lengths per measurements, as is now most often the case.

Thermal Conductivity

All thermal conductivity values were determined using the modified divided bar designed by Blackwell (pers. comm.) and similar in operation to that described by Roy et al. (1968) and Sass et al. (1971-b). The bar was calibrated with standards of fused silica and crystalline quartz using temperature dependent conductivity given by Ratcliffe (1959) and a procedure given by Chapman (1976), which accounts for lateral heat losses and sample contact resistance. Reproducibility of thermal conductivity determinations is typically better than 2%; interlaboratory agreement between measurements on identical samples has been shown to be about 3% (Chapman, 1976).

Thermal conductivities were determined for each site by measurement on drill core or chips, measurements on discs cut from hand sampled equivalent lithology, or by assigning values based on

previous measurements (Table 1, Appendix B). In the case of the drillholes ED-1 through ED-11, between 11 and 16 composite drill chip samples from each hole were measured using the cell technique of Sass et al. (1971-a). Thermal conductivity values for the remaining sites were assigned on the basis of measurements made on samples of alluvium and on solid discs cored from hand samples of outcrops. The solid disc samples form the basis of a laboratory experiment designed to determine appropriate formation porosities and to demonstrate the importance of porosity corrections to the measured chip conductivities of these rhyolite to andesite tuffs.

The thermal conductivity value determined for drill chips using the cell technique corresponds to the conductivity k_s of the solid component only. For rocks with a natural porosity ϕ_0 , the water saturated rock conductivity k_r , appropriate for in situ conditions, will be given by

$$k_r = k_w \phi_0 + k_s (1 - \phi_0)$$

where k_w is the thermal conductivity of water. Figure 9 (top) illustrates this effect of rock porosity for the appropriate range of solid conductivities encountered in this study, and emphasizes the importance of porosity in heat flow determinations. For example, although porosities determined by simple vacuum saturation methods reveal that 77% of the samples have a porosity of 10% or less (Figure 9, bottom), for a conductivity range of 1.5 to 3.5

Figure 9. (top). Relationship between thermal conductivity k_r of a porous rock saturated with water and the thermal conductivity k_s of the solid component for a range of rock porosities ϕ_0 . Water conductivity used in the calculation is $0.6 \text{ W m}^{-1} \text{ K}^{-1}$,
(bottom). Histogram of rock porosities for the Escalante Desert tuffs.

$\text{Wm}^{-1}\text{K}^{-1}$, even a 10% porosity adjusts the measured chip conductivity and consequently the resulting heat flow downward between 9 and 16%.

The porosity-thermal conductivity test involved drilling sixty-nine cylindrical cores from forty-one hand samples of outcrops near sites ED-2 through ED-11. Porosities were determined by weighing dry and vacuum saturated discs. After the saturated disc conductivities k_r were determined, the discs were crushed and the solid chip conductivities k_s were measured using the cell technique. Measured disc porosities ϕ_d were applied to determine a porosity corrected conductivity k_{pc}

$$k_{pc} = k_w^{\phi_d} k_s (1 - \phi_d)$$

for comparison with the disc value. Details for each sample are given in Appendix B and results of the test are shown in Figure 10. Whereas the uncorrected chip values (solid component k_s) fall systematically 10% or more above the disc values k_r , the porosity corrected values k_{pc} and disc conductivities agree much better (regression results: $k_{pc} = 1.06k_r - 0.01$; correlation coefficient 0.93). The 6% deviation from a one-to-one correspondence could be caused by incomplete saturation of discs which would have two effects: a measurement of k_r less than the true fully saturated k_r ; also an underestimate of porosity and hence of the porosity correction. Alternatively, the crushing and cell loading process may lead to a loss of the powder (low conductivity clay) fraction and inadvertent enhancement of a resistant (high conductivity

Figure 10. Thermal conductivity comparison of measurements on rock discs and identical rock crushed into chips (a) uncorrected for rock porosity - open circles and (b) corrected for rock porosity - solid circles. Solid line shows one to one correspondence; dashed lines show $\pm 10\%$ deviation from solid line.

quartz) fraction. A further possibility is that the aggregate chip-water mix in the cells is not adequately described by the mixing of law chosen. In view of the uncertainty in downhole porosity and of inherent variability in rock conductivity, such deviations are quite tolerable. Hence all chip thermal conductivity values subsequently cited have been corrected for formation porosity.

Heat Flow - Escalante Desert

Heat flow values computed as the product of least squares temperature gradients over a specified depth interval and the harmonic mean thermal conductivity of samples from the same interval are given in Table 1 and shown in Figure 11 for 25 regional sites (excluding NC sites, Table 1) in and around the Escalante Desert. Site locations, elevations, depth intervals over which heat flow is computed, and the number and nature of conductivity samples is also given. Further details, including new temperature-depth, conductivity-depth and lithology-depth data are given in Appendix A. Topographic corrections to heat flow have been calculated following the technique of Birch (1950) and have been applied to sites where the correction is 5% or greater. Heat flow values in parentheses (See Table 1) are corrected values for such sites.

Heat flow at the twenty-five regional sites in Table 1 (excluding NC sites) ranges from 42 to 350 mW m^{-2} with a mean and standard deviation of 112 and 69 mW m^{-2} respectively. It has long been held in heat flow studies that linearity in temperature-depth profiles is the principle criteria for evaluating whether heat is

Figure 11. Geologic map of the Escalante Desert region (ibid. Figure 3) showing heat flow values in mW m^{-2} . Circles and squares explained for Figure 3. Heat flow values for the Newcastle geothermal system are shown in Figure 13.

being transferred conductively or by convection. Those sites with reasonable linear temperature-depth behaviour, or patterns that can be explained by the thermal conductivity structure, are thought to be characterized by conductive flux and have traditionally been used to compute geotherms for the entire crust. However, results from this study and others (see Sass et al., 1971-b; Sass et al., 1976; Sass and Sammel, 1976) indicate that heat flow at these pseudo-conductive sites has a higher degree of variability and changes more rapidly over short lateral distances than would be expected for an entirely conductive thermal regime. One obvious explanation for this variability is the deep circulation of groundwater to depths of kilometers, and redistribution of part of the regional heat flux over distances of tens of kilometers. The unfortunate consequence of this realization for heat flow studies is the necessity either to be very selective in the geologic environment of heat flow sites so that deep groundwater effects can be avoided, or to increase the density of measurement to the point where groundwater flow patterns are delineated and evaluated.

The simple mean heat flow of 112 mW m^{-2} probably does not characterize the regional heat flux for the Escalante Desert for the following reasons: (1) results from EDC-1 and EDC-2 are inconsistent with EDC-3 and EDC-4 and more importantly, inconsistent with the 3.0 km deep test well only 8 km away; (2) the high heat flow at the Black Mountains, in particular BM-3 cannot be sustained to great depths in the crust; (3) the two Lund values differ by almost a

factor of four although they are obtained at sites only 4 km apart. However, simply eliminating inconsistent data lacks some objectivity. In the case of this study, a subset of sites does exist which were drilled specifically for regional heat flow purposes in locations chosen so as to minimize topographic and hydrologic disturbances. These sites (ED-1 through ED-11, Table 1 and Figure 9) exhibit a narrower heat flow range and less scatter than the entire regional set. Therefore, the mean heat flow of 100 mW m^{-2} (standard deviation 22 mW m^{-2}) is taken to be representative of the Escalante Desert regional flow.

Heat flow in the east-central Escalante Desert is lower than normal, but is consistent with data taken in the vicinity of the Thermo Hot Springs in the Escalante Valley (Figure 3) to the north (Rush, 1977). Subnormal heat flow in the center of a basin has also been observed by Sass and Sammel (1976) in the Lower Klamath Lake Valley. Abnormally high heat flow is observed in the Black Mountains at sites BM-3 and BM-4. These sites may have some high temperature geothermal potential, although a more likely explanation for their enhanced heat flow is the existence of a warm water aquifer at a depth of a few hundred meters. The new heat flow values in the Iron Springs District (Figure 11) are consistent with earlier measurements in the region (Sass and Munroe, 1974).

Heat Flow - Newcastle KGRA

The Newcastle region in the southeastern Escalante Desert (Figures 3 and 11), is of interest because it can properly be

Figure 12. Temperature-depth profiles for the Newcastle geothermal system. Numbers on profiles correspond to the NC site designation in Table 1. Location of sites is shown in Figure 13.

called a "blind" geothermal system. There are no surface hot springs or deposits here, and it was not until 1975, when boiling water (108°C) was encountered at about 70 m during the drilling of an irrigation well, that active geothermal interest was spurred.

Temperature-depth profiles for the Newcastle area shown in Figure 12 are based on data from Rush (1977). The profiles exhibit many features such as abnormal gradients, downward curvature, isothermal sections and temperature reversals that are now recognized to be characteristic of many geothermal systems (Lachenbruch et al., 1976; Sass and Sammel, 1976; Sorey et al., 1978; Mase et al., 1978; Mase et al., 1979).

These features are caused by fluid motion in recharge, discharge, and lateral flux regions, respectively, where a substantial quantity of heat is being transferred by moving water. Only one site, NC-12, 3 km northeast of Newcastle (Figure 13) has a subnormal gradient ($21^{\circ}\text{C km}^{-1}$) indicative of a hydrologic recharge zone. The remaining ten sites have elevated near-surface gradients between 89 and $1870^{\circ}\text{C km}^{-1}$. Whereas NC-2, 3, and 4 exhibit constant gradients, the temperature patterns at NC-6, 8, 9, and 11 become isothermal or reverse between 75 and 100 m suggesting a thermal leakage aquifer at that interval. This depth range also corresponds to a "coarse to pebbly" lithologic section (R. Stoker, written comm.) and it is not unreasonable to postulate hot water moving laterally through this more permeable zone and losing heat conductively through the overlying material.

Thermal conductivity determinations were made on eight down-hole composite drill chip samples obtained from a 152-m deep well near NC-10. The entire section is alluvial; volcanic silts and sands with quartzite chips from the Iron Springs or Claron Formations (Figure 3) and varying degrees of carbonate cement. A mean value of $1.76 \text{ Wm}^{-1}\text{K}^{-1}$ was assigned for this material based on porosity corrected conductivities.

Heat flow values for the 11 NC sites were computed using this average thermal conductivity and a geothermal gradient calculated for the upper section of each hole. Because of the magnitude of the gradients, the annual temperature wave is overwhelmed within 5 m of the surface, meaning that extremely shallow data may be used. Furthermore, the observation that most of the temperature-depth profiles have an upper linear section and extrapolate to about 15°C (the mean annual soil temperature for the Escalante Desert) supports the assumption of a conductive heat flux over this geothermal system, although deeper heat transfer is obviously convective. The resulting heat flow values in such a case will be of little regional significance but will be useful in determining the nature and magnitude of heat loss from the convective system.

Heat flow results for the Newcastle geothermal system are given in Table 1 and are shown as a contoured map in Figure 13. The thermal anomaly is constrained to the southwest by sites NC-2, 3, and 4, and to the northeast by site NC-9, but lack of heat flow sites to the north, northwest, and southeast leave the anomaly

Figure 13. Heat flow map for the Newcastle geothermal system. Heat flow values and contour values are given in mW m^{-2} . Solid circles indicate sites where heat flow is computed from actual temperature-depth and conductivity measurements. Open circles represent estimates based on temperatures in irrigation wells. Heat loss from this system is compiled in Table 2.

unconstrained in those directions. Some additional constraint is provided by estimating thermal gradients in irrigation wells (open circles, Figure 13) under the assumption that observed water temperatures represent temperatures at the bottom of the well, and converting those gradients to lower limit heat flow values. The resulting shape of the heat flow contours (Figure 13) considered together with the temperature-depth profiles (Figure 12) suggest a vertical upwelling zone which includes at least sites NC-5 and NC-10, and a broad lateral leakage zone to the north.

An estimate of the heat loss for the Newcastle geothermal system may be made by integrating the anomalous flux over the heat flow map shown in Figure 13. Details of the integration are given in Table 2. The anomalous heat loss within the 9.4 km^2 enclosed by the 500 mW m^{-2} contour above a background flux of 100 mW m^{-2} is about 13 MW. Other heat losses, namely in the region outside the 500 mW m^{-2} contour, yet still above background, are unaccounted for in this method. Also, the temperature reversal site NC-11 suggests that a cool region exists below the hot leakage zone and this region may also absorb a fraction of the heat loss; that is then unaccounted for also. However, no data exists to constrain the magnitude of these latter effects and therefore the calculated value of 13 MW will be used as a minimum for the system. The age of volcanism in the region (29-12 m.y. before present) precludes the volcanics being related directly to a heat source for the geothermal system, and suggests that the system is supported by circulating groundwater which is heated by a regional heat flow. The area over which

TABLE 2

HEAT LOSS FOR THE NEWCASTLE GEOTHERMAL SYSTEM

Contour Interval (W m^{-2})	Area (10^6 m^2)	Average Heat Flow (W m^{-2})	Heat Loss (MW)
0.5-1.0	3.2	0.75	2.4
1.0-1.5	2.2	1.25	2.7
1.5-2.0	1.5	1.75	2.5
2.0-2.5	1.3	2.25	2.9
2.5	1.2	2.75	3.2
TOTAL	9.4		13.7
Background heat loss (0.1 W m^{-2}) $\times$ ($9.4 \times 10^6 \text{ m}^2$) =			0.9
Anomalous heat loss			12.8

some fraction of normal heat flow is extracted (i.e.: if heat discharge is balanced by recharge in other parts of the system) in order to heat water circulating through the Newcastle system is equivalent to the background flux over an area of 130 km^2 . It remains an important problem to substantiate this model of deep circulation and regional heating by mapping the subnormal heat flow area in such systems.

Knowing the thermal power loss of a system such as this, one can compute several related quantities. Assuming that the anomalous heat discharge rate is supported by mass flow, minimum mass discharge m_D and volume v_D rates are given by

$$m_D = \frac{P}{c_f(T_R - T_0)} \quad \text{and} \quad v_D = \frac{P}{\rho_f c_f(T_R - T_0)}$$

where P is the observed thermal power loss, c_f the specific heat of the fluid, ρ_f the density of the fluid, and T_R and T_0 the reservoir and surface temperatures, respectively.

Using the following:

$$P = 12.8 \times 10^6 \text{ watts}$$

$$c_f = 4.18 \times 10^3 \text{ J kg}^{-1} \text{ } ^\circ\text{C}^{-1}$$

$$\rho_f = 10^3 \text{ kg m}^{-3}$$

$$T_R = 110^\circ\text{C}$$

$$T_0 = 15^\circ\text{C}$$

the minimum mass discharge and volume discharge rates are calculated:

$m_D = 32 \text{ kg s}^{-1}$ and $v_D = .032 \text{ m}^3 \text{ s}^{-1}$. If the reservoir of lateral discharge below the thermal anomaly is considered to have an area

of 9.4 km^2 (Table 2), to extend from 75 to 100 m on the basis of temperature-depth profiles (Figure 12), and have a 15% porosity, the mass of water in the reservoir is $3.5 \times 10^{10} \text{ kg}$. The replacement time for this water is 1.1×10^9 seconds, or 35 years.

In terms of utilizing this geothermal system, the total useful heat will be that at depth in the upflow region. However, the minimum useful heat will be that measured in this study, about 13 MW thermal produced by 32 kg s^{-1} mass flow. Permeability factors will determine how much extra fluid can be economically extracted.

The Newcastle geothermal system may also be evaluated using the formalism of Brook et al. (1978), although some qualifications must be placed on the appropriateness of such an analysis for this type of a geothermal system. In particular, as opposed to low permeability high temperature reservoirs, where resupply of heat may be a small fraction of energy producible from storage alone, the Newcastle system is likely in a steady state condition whose lifetime is limited only by the natural sealing of the system. In spite of this, it is still useful for comparison purposes to compute the reservoir thermal energy Q_R given by (Equation 1, Brook et al., 1978):

$$Q_R = (\rho c) \cdot A \cdot D \cdot (T_R - T_0)$$

where ρc is the volumetric specific heat of rock plus water assuming a 15% reservoir porosity, A the reservoir area, D the reservoir

thickness, and T_R and T_O the reservoir and surface temperatures respectively. The following values are used:

$$(\rho c) = 2.7 \text{ J cm}^{-3} \text{ } ^\circ\text{C}^{-1}$$

$$A = 9.4 \text{ km}^2$$

$$D = 25 \text{ m}$$

$$T_R = 110^\circ\text{C} \quad (\text{see Figure 12})$$

$$T_O = 15^\circ\text{C} \quad (\text{see Figure 12})$$

to obtain a value $Q_R = 6.0 \times 10^{16} \text{ J}$. The least certain parameter here is the reservoir thickness D . The estimate above is based on the model that most of the thermal anomaly is caused by lateral flow in a thermal aquifer from 75 to 100 m below the surface. An alternative approach would be to try to estimate the value $(A \cdot D)$ of a reservoir defined by the upflow region. The appropriate depth D might now be construed as the interval from 75 m to a depth 2 km, the approximate depth at which the background gradient produces the reservoir temperature, and A to be 1.2 km^2 , the area enclosed by the highest heat flow contour. Reservoir thermal energy Q_R in this case is $5.9 \times 10^{17} \text{ J}$. Other uncertainties involve reservoir temperature, estimated to be 137°C and 196°C from quartz conductive and Na/K/Ca geothermometers, respectively, but again, a conservative value of actual measured temperature has been used, consistent with a minimum estimate procedure. The estimates of reservoir thermal energy given here for Newcastle are somewhat less than the value of $1.9 \pm 0.9 \times 10^{18} \text{ J}$ given by Brook et al. (1978), and reflects principally the differing viewpoints of what constitutes the "reservoir" in this type of geothermal system.

III. CONCLUSIONS

Twenty-five new regional heat flow values for the Escalante Desert region of southwestern Utah confirm a pattern of high but variable heat flow for this part of the Basin and Range Province. The variability is probably caused by deep groundwater flow causing a redistribution of the regional heat flux. The best estimate of a background thermal regime comes from 10 sites in tuffs surrounding the Escalante Desert drilled specifically for heat flow measurements. Here the average geothermal gradient is $56.4^{\circ}\text{C km}^{-1}$ (s.d. 12.1), and the mean heat flow is 100 mW m^{-2} (s.d. 22). Localized heat flow anomalies in the Black Mountains and near Newcastle may indicate promising geothermal prospects.

A "blind" geothermal system southwest of Newcastle, Utah has been analyzed, utilizing detailed temperature-depth profiles from 11 drillholes and other geologic and hydrologic information. Heat flow determinations for the 11 wells reveal an area of about 10 km^2 where heat flow is 500 mW m^{-2} or greater. Heat flow maxima exceeding 3 W m^{-2} were measured at two sites. The anomalous thermal power loss at Newcastle is about 13 MW corresponding to a mass discharge of 32 kg s^{-1} for the system. Conventional estimates of the reservoir thermal energy have also been made; the values are between $6.0 \times 10^{16} \text{ J}$ and $5.9 \times 10^{17} \text{ J}$, but it is argued that the 13 MW thermal power loss is a more useful number for the classification of such systems.

APPENDIX A

PRINCIPLE FACTS FOR HEAT FLOW DATA

Included here are data summary sheets for all sites located in Figure 3 of the text. Separate temperature-depth profiles, with lithologic and thermal conductivity data are shown separately for each site for which these data are available (ED-1 through ED-11, and BM-1). The remaining thermal profiles can be found in the text. A lithology/thermal conductivity summary sheet is included for the borehole near NC-10, at Newcastle, Utah, where no temperature measurements were made.

The vertical component of heat flow was computed as the product of the harmonic mean of the thermal conductivity and the least-squares gradient. The standard error in heat flow values was estimated by propagations of errors and the standard errors computed for the gradient and mean conductivity.

Thermal Conductivity

Downhole thermal conductivity values were obtained for chip samples collected at 6 m intervals in the ED series holes using the techniques described in the text. The same method was used in determining thermal conductivity values for eight downhole chip samples from a borehole in the Newcastle area (near NC-10). Porosity values applied as corrections to the measured composite

conductivity value were estimated from measurements made on hand samples taken from the vicinity of ED-2 through ED-11 (see Appendix B). Where downhole samples were not available, mean conductivity values were estimated using data from other sites, and a standard error of $\pm 10\%$ was assigned (see Table 1, text).

Temperature

Most ED series holes, drilled between September 20 and October 4, 1978, were sited in the ash-flow tuffs that surround the Escalante Desert, where it was expected that groundwater disturbance would be minimal, and nonexistent at best. The holes were completed with 1 inch pvc pipe, backfilled, and cemented at the top. The temperature of water in the pipe was measured at least twice after completion on a 2 m interval from surface to bottom (generally 100 m). Precision of the standard thermistor used is covered in the text.

ED-1 exhibits at least 3 zones of disturbance, suggesting a well fractured or layered media of changing permeabilities through which fluids flow. The borehole is collared in a formation of reworked volcanic rocks. The affected zones are small-amplitude deviations from the preferred least-squares gradient. ED-2 shows two distinct gradients which cannot be explained by a corresponding change in lithology/conductivity. Drill logs suggest, rather, that the break is attributable to intersection with the water table. Active water migration proved troublesome enough to complete this well early.. The gradient is taken from 12-70 m, and the break in

slope appears as a local perturbation to the calculated straight line gradient. The temperature profile from ED-3 is slightly convex up in shape, probably due to an upward component in water flow. Hand samples from this location are poorly welded ash-flow tuffs with extremely high porosities in most cases (see Appendix B). Most were not competent enough to form discs suitable for conductivity measurement. A pronounced short-wave temperature increase is shown at 35 m by the ED-11 profile. This phenomenon has been modelled by Bodvarsson (1973) as a line source of hot water running perpendicular to the borehole. The remaining ED profiles show consistent conductive heat flux with no appreciable disturbances.

EDC-3, EDC-4, and EDE-1 are shallow water wells drilled for use at geothermal test well sites. The wells are open 6 or 8 inch casing. Logging procedures are as described for the ED series holes, but on a 5 m interval from water level to 50 m and then every 10 m. Wells were logged in July, 1979.

EDC-3 and EDC-4, separated by 1.6 km have been discussed in the text. The pronounced temperature drop in the top 30 m of EDC-3 is difficult to interpret, and may be related to well completion techniques unknown to the author. The same may be true for the decrease in gradient at about 60 m in both wells. EDE-1 is slightly disturbed, but generally shows a conductive character.

Temperature data for the Hamblin Valley hole (HV-1), Lund series (LD-1, LD-2), and the Newcastle series (NC-2 through 12) were taken from Rush (1977). Details of temperature measurements are not known to the author.

The Black Mountain series (BM-1 through BM-4, and BM-7) and the Iron Mountain series (IM-1 and IM-2) are taken from Chapman et al. (1978) and are discussed in the text.

LITHOLOGY

VOLCANIC

ALTERED VOLCANIC

SAND & GRAVEL

SILT & CLAY

CONGLOMERATE,
SANDSTONE

CONGLOMERATE

Figure 14. Legend for lithologies shown in Figures 15 through 25.

Figure 15. Lithology, thermal conductivity, and temperature data, versus depth, for site ED-1.

Area: Escalante Desert Iron Co., Utah

Locality: T37S/R18W/S36 ccd

Borehole: ED-1 (Hebron)

Site Latitude: 37°36'23" N Depth Range (H.F. Calc.): 30-92 m

Site Longitude: 113°48'52" W No. Cond. Samples: 16

Site Elevation: 1747 ± 5 m Conductivity: 1.61 ± .04 W/m·K
1.45 ± .04 W/m·K
(10% porosity)

Completed by: 9/20/78

Logged On: 10/16/78

Gradient: 59.99 ± 7.37 °C/km

Dip Angle: 90°

Heat Flow: 86.99 ± 10.95 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
2.00	16.19	12.2	1.899	100.6	rhyolitic tuff
4.00	14.48	18.3	1.504		
6.00	12.93	24.4	1.770		
8.00	12.18	30.5	1.617		
10.00	12.25	36.6	2.118		
12.00	12.48	42.7	1.489		
14.00	12.67	48.8	1.765		
16.00	13.00	54.9	1.499		
18.00	13.03	61.0	1.543		
20.00	13.10	67.1	1.441		
22.00	13.19	73.2	1.691		
24.00	13.27	79.2	1.568		
26.00	13.33	85.3	1.454		
28.00	13.47	91.4	1.594		
30.00	13.77	97.5	1.758		
32.00	13.79	100.6	1.382		
34.00	14.06				
36.00	14.19				
38.00	14.33				
40.00	14.47				
42.00	14.62				
44.00	14.81				
46.00	14.84				
48.00	15.02				
50.00	15.35				
52.00	15.47				

Area: Escalante Desert Iron Co., Utah

Locality: T37S/R18W/S36 ccd

Borehole: ED-1 (Hebron) - continued

Site Latitude: Depth Range (H.F. Calc.):

Site Longitude: No. Cond. Samples:

Site Elevation: Conductivity:

Completed by:

Logged On: Gradient:

Dip Angle: Heat Flow:

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
54.00	15.56				
56.00	15.66				
58.00	15.76				
60.00	15.86				
62.00	15.96				
64.00	16.04				
66.00	16.11				
68.00	16.52				
70.00	16.68				
72.00	16.83				
74.00	16.97				
76.00	17.12				
78.00	17.27				
80.00	17.43				
82.00	17.59				
84.00	17.75				
86.00	17.91				
88.00	18.19				
90.00	18.26				
92.00	18.35				
94.00	18.47				
96.00	18.58				
98.00	18.65				
100.00	18.74				
101.00	18.76

Figure 16. Lithology, thermal conductivity, and temperature data, versus depth, for site ED-2.

Area: Escalante Desert Iron Co., Utah

Locality: T35S/R17W/S21 dd

Borehole: ED-2 (Beryl Junction)

Site Latitude: 37°44'20" N

Depth Range (H.F. Calc.): 12-70 m

Site Longitude: 113°44'56" W

No. Cond. Samples: 11

Site Elevation: 1602 ± 2 m

Conductivity: 2.68 ± .06 W/m·K
2.26 ± .05 W/m·K)
(12% porosity)

Completed by: 9/21/78

Logged On: 10/17/78

Gradient: 51.05 ± 4.63 °C/km

Dip Angle: 90°

Heat Flow: 115.37 ± 10.77 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
2.00	17.68	12.2	2.592		
4.00	15.75	18.3	2.432		
6.00	14.41	24.4	2.894		
8.00	13.35	30.5	2.522		
10.00	13.12	36.6	2.714		
12.00	13.19	42.7	2.621		
14.00	13.34	48.8	3.112		
16.00	13.48	54.9	2.762	55	rhyolite/dacite
18.00	13.60	61.0	2.946		
20.00	13.71	67.1	2.580		
22.00	13.83	73.2	2.465	73.2	altered rhyolite/ dacite
24.00	13.96				
26.00	14.07				
28.00	14.18				
30.00	14.31				
32.00	14.43				
34.00	14.57				
36.00	14.70				
38.00	14.84				
40.00	14.98				
42.00	15.14				
44.00	15.30				
46.00	15.48				
48.00	15.52				
50.00	15.56				
52.00	15.63				

Area: Escalante Desert Iron Co., Utah

Locality: T35S/R17W/S21 dd

Borehole: ED-2 (Beryl Junction) - continued

Site Latitude: Depth Range (H.F. Calc.):

Site Longitude: No. Cond. Samples:

Site Elevation: Conductivity:

Completed by:

Logged On: Gradient:

Dip Angle: Heat Flow:

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
54.00	15.67				
56.00	15.67				
58.00	15.73				
60.00	15.78				
62.00	15.81				
64.00	15.88				
66.00	15.95				
68.00	15.99				
70.00	16.01

Figure 17. Lithology, thermal conductivity, and temperature data, versus depth, for site ED-3.

Area: Escalante Desert Iron Co., Utah

Locality: T35S/R20W/S24 cc

Borehole: ED-3 (Uvada)

Site Latitude: 37°44'20" N

Depth Range (H.F. Calc.): 12-100 m

Site Longitude: 114°02'19" W

No. Cond. Samples: 16

Site Elevation: 1750 ± 3

Conductivity: 2.10 ± .11 W/m·K
1.75 ± .08 W/m·K
(15% porosity)

Completed by: 9/22/78

Logged On: 10/16/78

Gradient: 81.63 ± 4.36 °C/km

Dip Angle: 90°

Heat Flow: 142.85 ± 10.04 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
2.00	16.07	12.2	1.965		
4.00	14.81	18.3	1.523		
6.00	13.80	24.4	2.067		
8.00	12.73	30.5	1.728		
10.00	12.14	36.6	2.012		
12.00	12.28	42.7	1.714		
14.00	12.46	48.8	1.814		
16.00	12.64	54.9	2.290		
18.00	12.79	61.0	2.104	61	rhyolite/quartz
20.00	12.93	67.1	1.849		latite
22.00	13.14	73.2	2.025	73.2	As above; alteration
24.00	13.35	79.2	2.242		
26.00	13.55	85.3	2.927		
28.00	13.72	91.4	2.889		
30.00	13.92	97.5	3.261		
32.00	14.11	100.6	2.592	100.6	rhyolite/quartz
34.00	14.30				latite
36.00	14.49				
38.00	14.68				
40.00	14.86				
42.00	15.06				
44.00	15.26				
46.00	15.45				
48.00	15.64				
50.00	15.83				
52.00	16.00				

Area: Escalante Desert Iron Co., Utah

Locality: T35S/R20W/S24 cc

Borehole: ED-3 (Uvada) - continued

Site Latitude: Depth Range (H.F. Calc.):

Site Longitude: No. Cond. Samples:

Site Elevation: Conductivity:

Completed by:

Logged On: Gradient:

Dip Angle: Heat Flow:

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
54.00	16.39				
56.00	16.46				
58.00	16.59				
60.00	16.72				
62.00	16.87				
64.00	17.04				
66.00	17.19				
68.00	17.35				
70.00	17.49				
72.00	17.64				
74.00	17.79				
76.00	17.92				
78.00	18.04				
80.00	18.15				
82.00	18.28				
84.00	18.37				
86.00	18.41				
88.00	18.64				
90.00	18.75				
92.00	18.85				
94.00	18.94				
96.00	19.02				
98.00	19.09				
100.00	19.18				
101.70	19.27

Figure 18. Lithology, thermal conductivity, and temperature data, versus depth, for site ED-4.

Area: Escalante Desert Iron Co., Utah

Locality: T37S/R15W/S3 aca

Borehole: ED-4 (Pinto)

Site Latitude: 37°36'53" N

Depth Range (H.F. Calc.): 20-100 m

Site Longitude: 113°01'06" W

No. Cond. Samples: 16

Site Elevation: 1735 ± 3 m

Conductivity: 2.01 ± .06 W/m·K

Completed by: 9/23/78

Logged On: 10/16/78

Gradient: 42.07 ± 2.56 °C/km

Dip Angle: 90°

Heat Flow: 82.88 ± 5.64 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
2.00	17.30	12.2	2.185		
4.00	15.86	18.3	2.352		
6.00	14.18	24.4	2.359		
8.00	13.64	30.5	2.068		
10.00	13.64	36.6	2.143	36.6	alluvium/rhyolitic sand and gravel
12.00	13.67	42.7	1.485		
14.00	13.73	48.8	1.986		
16.00	13.78	54.9	2.026	54.9	rhyolitic silts/ clays
18.00	13.92	61.0	1.943		
20.00	13.99	67.1	1.839		
22.00	14.07	73.2	1.975		
24.00	14.16	79.2	1.941		
26.00	14.24	85.3	2.148		
28.00	14.34	91.4	1.986		
30.00	14.43	97.5	2.072		
32.00	14.53	100.6	1.938	100.6	rhyolite/latite
34.00	14.62				
36.00	14.72				
38.00	14.82				
40.00	14.92				
42.00	15.01				
44.00	15.10				
46.00	15.20				
48.00	15.40				
50.00	15.58				
52.00	15.62				

Area: Escalante Desert Iron Co., Utah

Locality: T37S/R15W/S3 aca

Borehole: ED-4 (Pinto) - Continued

Site Latitude: Depth Range (H.F. Calc.):

Site Longitude: No. Cond. Samples:

Site Elevation: Conductivity:

Completed by:

Logged On: Gradient:

Dip Angle: Heat Flow:

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
54.00	15.68				
56.00	15.85				
58.00	15.95				
60.00	16.04				
62.00	16.14				
64.00	16.29				
66.00	16.40				
68.00	16.48				
70.00	16.56				
72.00	16.64				
74.00	16.71				
76.00	16.80				
78.00	16.91				
80.00	16.97				
82.00	17.03				
84.00	17.19				
86.00	17.31				
88.00	17.41				
90.00	17.51				
92.00	17.61				
94.00	17.73				
96.00	17.84				
98.00	17.95				
100.00	18.07				
100.40	18.09

Figure 19. Lithology, thermal conductivity, and temperature data, versus depth, for site ED-6.

Area: Escalante Desert Iron Co., Utah

Locality: T32S/R16W/S28 ccc

Borehole: ED-6 (Beryl)

Site Latitude: 37°59'05" N Depth Range (H.F. Calc.): 22-100 m

Site Longitude: 113°39'20" W No. Cond. Samples: 16

Site Elevation: 1743 ± 3 m Conductivity: 1.87 ± .05 W/m·K

Completed by: 10/2/78

1.74 ± .05 W/m·K
6% porosity

Logged On: 10/17/78

Gradient: 56.02 ± 2.60 °C/km

Dip Angle: 90°

Heat Flow: 97.47 ± 5.32 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
2.00	18.01	12.2	1.980		
4.00	16.81	18.3	1.852		
6.00	15.33	24.4	2.087		
8.00	14.69	30.5	1.938		
10.00	14.62	36.6	2.040		
12.00	14.62	42.7	2.067		
14.00	14.68	48.8	1.908		
16.00	14.73	54.9	2.151		
18.00	14.78	61.0	1.857		
20.00	14.89	67.1	1.879		
22.00	15.01	73.2	1.956		
24.00	15.14	79.2	1.814		
26.00	15.28	85.3	1.678		
28.00	15.41	91.4	1.399		
30.00	15.63	97.5	1.884		
32.00	15.71	100.6	1.683	100.6	rhyolitic/quartz
34.00	15.77				latite tuff
36.00	15.86				(volcanic sand?)
38.00	15.96				
40.00	16.08				
42.00	16.18				
44.00	16.30				
46.00	16.40				
48.00	16.51				
50.00	16.61				
52.00	16.72				

Area: Escalante Desert Iron Co., Utah

Locality: T32S/R16W/S28 ccc

Borehole: ED-6 (Beryl) - continued

Site Latitude:

Depth Range (H.F. Calc.):

Site Longitude:

No. Cond. Samples:

Site Elevation:

Conductivity:

Completed by:

Logged On:

Gradient:

Dip Angle:

Heat Flow:

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
54.00	16.85				
56.00	16.93				
58.00	17.04				
60.00	17.15				
62.00	17.28				
64.00	17.40				
66.00	17.48				
68.00	17.57				
70.00	17.69				
72.00	17.81				
74.00	17.89				
76.00	17.98				
78.00	18.02				
80.00	18.21				
82.00	18.37				
84.00	18.50				
86.00	18.63				
88.00	18.76				
90.00	18.91				
92.00	19.05				
94.00	19.17				
96.00	19.29				
98.00	19.41				
100.00	19.53

Figure 20. Lithology, thermal conductivity, and temperature data, versus depth, for site ED-7.

Area: Escalante Desert Iron Co., Utah

Locality: T31S/R16W/S10 db

Borehole: ED-7 (Bible Spring)

Site Latitude: 38°07'11" N Depth Range (H.F. Calc.): 12-100 m

Site Longitude: 113°37'41" W No. Cond. Samples: 16

Site Elevation: 1862 ± 3 m Conductivity: 2.55 ± .05 W/m.K
2.40 ± .04 W/m.K
4% porosity

Completed by: 10/2/78

Logged On: 10/18/78

Gradient: 42.30 ± 1.80 °C/km

Dip Angle: 90°

Heat Flow: 101.52 ± 4.64 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
2.00	15.82	12.2	2.640		
4.00	14.80	18.3	2.534		
6.00	12.81	24.4	2.455		
8.00	12.19	30.5	2.801	36	Alluvium; welded
10.00	12.18	36.6	2.773		tuff (?) sand
12.00	12.29	42.7	2.593		and gravel
14.00	12.41	48.8	2.603		
16.00	12.53	54.9	2.351		
18.00	12.61	61.0	3.011		
20.00	12.71	67.1	2.438		
22.00	12.82	73.2	2.719		
24.00	12.92	79.2	2.345		
26.00	13.03	85.3	2.459		
28.00	13.13	91.4	2.263		
30.00	13.25	97.5	2.497		
32.00	13.36	100.6	2.474	100.6	Welded tuff;
34.00	13.44				alteration at
36.00	13.60				bottom of hole.
38.00	13.64				
40.00	13.72				
42.00	13.80				
44.00	13.87				
46.00	13.94				
48.00	14.07				
50.00	14.15				
52.00	14.21				

Area: Escalante Desert Iron Co., Utah

Locality: T31S/R16W/S10 db

Borehole: ED-7 (Bible Spring) - continued

Site Latitude:

Depth Range (H.F. Calc.):

Site Longitude:

No. Cond. Samples:

Site Elevation:

Conductivity:

Completed by:

Logged On:

Gradient:

Dip Angle:

Heat Flow:

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
54.00	14.29				
56.00	14.36				
58.00	14.50				
60.00	14.63				
62.00	14.74				
64.00	14.84				
66.00	14.94				
68.00	15.04				
70.00	15.15				
72.00	15.27				
74.00	15.38				
76.00	15.49				
78.00	15.60				
80.00	15.70				
82.00	15.82				
84.00	15.93				
86.00	16.04				
88.00	16.17				
90.00	16.27				
92.00	16.40				
94.00	16.51				
96.00	16.63				
98.00	16.76				
100.00	16.87

Figure 21. Lithology, thermal conductivity, and temperature data, versus depth, for site ED-8.

Area: Escalante Desert Iron Co., Utah

Locality: T32S/R15W/S22 cd

Borehole: ED-8 (Zane)

Site Latitude: 37°59'59" N

Depth Range (H.F. Calc.): 20-88 m

Site Longitude: 113°31'13" W

No. Cond. Samples: 16

Site Elevation: 1643 ± 2 m

Conductivity: 2.16 ± .03 W/m·K

Completed by: 10/4/78

Logged On: 10/18/78

Gradient: 57.44 ± 2.67 °C/km

Dip Angle: 90°

Heat Flow: 125.22 ± 6.26 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
2.00	19.70	12.2	2.148		
4.00	18.06	18.3	2.195		
6.00	16.31	24.4	2.213		
8.00	15.20	30.5	2.270		
10.00	14.74	36.6	2.155		
12.00	14.68	42.7	2.543		
14.00	14.80	48.8	2.084		
16.00	14.96	54.9	2.108		
18.00	15.10	61.0	2.070		
20.00	15.26	67.1	2.135		
22.00	15.38	73.2	2.166		
24.00	15.48	79.2	2.236		
26.00	15.58	85.3	2.059		
28.00	15.71	91.4	2.118		
30.00	15.83	97.5	2.143		
32.00	15.94	100.6	2.022	100.6	rhyolitic
34.00	16.07				tuff.
36.00	16.20				
38.00	16.32				
40.00	16.43				
42.00	16.56				
44.00	16.68				
46.00	16.79				
48.00	16.92				
50.00	17.04				
52.00	17.17				

Area: Escalante Desert Iron Co., Utah

Locality: T32S/R15W/S22 cd

Borehole: ED-8 (Zane) - continued

Site Latitude:

Depth Range (H.F. Calc.):

Site Longitude:

No. Cond. Samples:

Site Elevation:

Conductivity:

Completed by:

Logged On:

Gradient:

Dip Angle:

Heat Flow:

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
54.00	17.38				
56.00	17.46				
58.00	17.51				
60.00	17.62				
62.00	17.71				
64.00	17.84				
66.00	17.95				
68.00	18.02				
70.00	18.11				
72.00	18.18				
74.00	18.37				
76.00	18.49				
78.00	18.61				
80.00	18.69				
82.00	18.81				
84.00	18.92				
86.00	19.04				
88.00	19.21				
90.00	19.28				
92.00	19.33				
94.00	19.40				
96.00	19.50				
98.00	19.68				
100.00	19.80

Figure 22. Lithology, thermal conductivity, and temperature data, versus depth, for site ED-9.

Area: Escalante Desert Iron Co., Utah

Locality: T33S/R14W/S32 dd

Borehole: ED-9 (Avon NW)

Site Latitude: 37°53'00" N

Depth Range (H.F. Calc.): 12-100 m

Site Longitude: 113°26'12" W

No. Cond. Samples: 16

Site Elevation: 1600 ± 2 m

Conductivity: 1.65 ± .07 W/m·K
1.44 ± .05 W/m·K
(14% porosity)

Completed by: 9/27/78

Logged On: 10/19/78

Gradient: 46.44 ± 1.21 °C/km

Dip Angle: 90°

Heat Flow: 66.87 ± 2.90 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
2.00	18.50	12.2	1.783		
4.00	16.36	18.3	1.806		
6.00	14.65	24.4	1.948		
8.00	14.26	30.5	2.090		
10.00	14.30	36.6	2.109		
12.00	14.44	42.7	1.873		
14.00	14.54	48.8	1.466		
16.00	14.64	54.9	1.207		
18.00	14.71	61.0	1.354		
20.00	14.80	67.1	1.374	67.1	rhyolitic tuff
22.00	14.90	73.2	1.586		
24.00	14.98	79.2	1.570		
26.00	15.07	85.3	1.735		
28.00	15.15	91.4	1.663		
30.00	15.24	97.5	1.864		
32.00	15.33	100.6	1.632	100.6	Lapilli tuff? black/green
34.00	15.41				
36.00	15.49				
38.00	15.57				
40.00	15.67				
42.00	15.74				
44.00	15.84				
46.00	15.93				
48.00	16.02				
50.00	16.12				
52.00	16.23				

Area: Escalante Desert Iron Co., Utah

Locality: T33S/R14W/S32 dd

Borehole: ED-9 (Avon NW) - continued

Site Latitude: Depth Range (H.F. Calc.):

Site Longitude: No. Cond. Samples:

Site Elevation: Conductivity:

Completed by:

Logged On: Gradient:

Dip Angle: Heat Flow:

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
54.00	16.34				
56.00	16.42				
58.00	16.53				
60.00	16.63				
62.00	16.72				
64.00	16.82				
66.00	16.90				
68.00	16.99				
70.00	17.09				
72.00	17.17				
74.00	17.27				
76.00	17.37				
78.00	17.46				
80.00	17.55				
82.00	17.65				
84.00	17.78				
86.00	17.89				
88.00	17.94				
90.00	17.99				
92.00	18.12				
94.00	18.23				
96.00	18.33				
98.00	18.43				
100.00	18.53

Figure 23. Lithology, thermal conductivity, and temperature data, versus depth, for site ED-10.

Area: Escalante Desert Iron Co., Utah

Locality: T34S/R14W/S36 cc

Borehole: ED-10 (Antelope Peak)

Site Latitude: 37°47'41" N

Depth Range (H.F. Calc.): 10-92 m

Site Longitude: 113°22'43" W

No. Cond. Samples: 16

Site Elevation: 1655 ± 3 m

Conductivity: 1.91 ± .06 W/m·K

Completed by: 9/25/78

Logged On: 10/19/78

Gradient: 45.62 ± 1.86 °C/km

Dip Angle: 90°

Heat Flow: 87.13 ± 4.48 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
2.00	17.19	12.2	1.613		
4.00	15.79	18.3	1.505		
6.00	14.35	24.4	1.775	24.4	Alluvium; rhyolitic gravel, sand, silt, and clay.
8.00	13.94	30.5	1.737		
10.00	14.06	36.6	1.819		
12.00	14.22	42.7	1.848		
14.00	14.36	48.8	1.922		
16.00	14.49	54.9	1.829		
18.00	14.60	61.0	2.334		
20.00	14.70	67.1	2.009		
22.00	14.82	73.2	2.116		
24.00	14.92	79.2	1.931		
26.00	15.06	85.3	2.263		
28.00	15.15	91.4	2.112		
30.00	15.24	97.5	2.336		
32.00	15.33	100.6	1.852	100.6	rhyolite
34.00	15.42				
36.00	15.52				
38.00	15.61				
40.00	15.71				
42.00	15.80				
44.00	15.88				
46.00	15.97				
48.00	16.06				
50.00	16.15				
52.00	16.25				

Area: Escalante Desert Iron Co., Utah

Locality: T34S/R14W/S36 cc

Borehole: ED-10 (Antelope Peak) - continued

Site Latitude: Depth Range (H.F. Calc.):

Site Longitude: No. Cond. Samples:

Site Elevation: Conductivity:

Completed by:

Logged On: Gradient:

Dip Angle: Heat Flow:

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
54.00	16.34				
56.00	16.41				
58.00	16.50				
60.00	16.59				
62.00	16.68				
64.00	16.77				
66.00	16.86				
68.00	16.95				
70.00	17.04				
72.00	17.12				
74.00	17.20				
76.00	17.28				
78.00	17.35				
80.00	17.44				
82.00	17.53				
84.00	17.65				
86.00	17.72				
88.00	17.78				
90.00	17.81				
92.00	17.85

Figure 24. Lithology, thermal conductivity, and temperature data, versus depth, for site ED-11.

Area: Escalante Desert Iron Co., Utah

Locality: T34S/R12W/S4 aa

Borehole: ED-11 (Enoch NW)

Site Latitude: 37°52'51" N

Depth Range (H.F. Calc.): 12-100 m

Site Longitude: 113°11'56" W

No. Cond. Samples: 16

Site Elevation: 1692 ± 3 m

Conductivity: 2.12 ± .06 W/m·K
1.87 ± .05 W/m·K
(10% porosity)

Completed by: 10/4/78

Logged On: 10/22/78

Gradient: 49.91 ± 6.16 °C/km

Dip Angle: 90°

Heat Flow: 93.33 ± 11.79 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
2.00	18.30	12.2	1.821		
4.00	17.35	18.3	2.176		
6.00	15.30	24.4	1.969		
8.00	14.15	30.5	1.920		
10.00	13.95	36.6	2.341	35	Alluvium; rhyolitic
12.00	14.11	42.7	2.031		tuff. Sand and
14.00	14.25	48.8	1.712		gravel.
16.00	14.45	54.9	1.976		
18.00	14.63	61.0	2.236		
20.00	14.79	67.1	2.269		
22.00	14.94	73.2	2.110		
24.00	15.09	79.2	2.591		
26.00	15.24	85.3	2.179		
28.00	15.38	91.4	2.582		
30.00	15.53	97.5	2.208		
32.00	15.81	100.6	2.194	100.6	rhyolite/quartz
34.00	16.16				latite tuff
36.00	15.95				
38.00	15.82				
40.00	15.91				
42.00	16.02				
44.00	16.13				
46.00	16.26				
48.00	16.39				
50.00	16.52				
52.00	16.64				

Area: Escalante Desert Iron Co., Utah

Locality: T34S/R12W/S4 aa

Borehole: ED-11 (Enoch NW) - continued

Site Latitude:	Depth Range (H.F. Calc.):
Site Longitude:	No. Cond. Samples:
Site Elevation:	Conductivity:
Completed by:	
Logged On:	Gradient:
Dip Angle:	Heat Flow:

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
54.00	16.74				
56.00	16.86				
58.00	16.93				
60.00	17.02				
62.00	17.11				
64.00	17.20				
66.00	17.28				
68.00	17.37				
70.00	17.46				
72.00	17.54				
74.00	17.64				
76.00	17.72				
78.00	17.81				
80.00	17.90				
82.00	17.99				
84.00	18.07				
86.00	18.16				
88.00	18.25				
90.00	18.35				
92.00	18.41				
94.00	18.51				
96.00	18.59				
98.00	18.67				
100.00	18.76				

Area: Escalante Desert, Central Iron Co., Utah

Locality: T34S/R16W/S2 cbb

Borehole: EDC-2 (Clark Farm)

Site Latitude: 37°52'28" N Depth Range (H.F. Calc.): 10-59 m

Site Longitude: 113°37'04" W No. Cond. Samples: 0

Site Elevation: 1563 ± 1 m Conductivity: 1.41 ± .20 W/m·K (est.)

Completed by:

Logged On: 7/22/79

Gradient: 30.68 ± 2.07 °C/km

Dip Angle: 90°

Heat Flow: 43.26 ± 6.79 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
5	(air)				
10	13.411				
15	13.575				
20	13.767				
25	13.938				
30	14.130				
35	14.256				
40	14.355				
45	14.497				
50	14.644				
59	14.956			59	Alluvium

Area: Escalante Desert, Central Iron Co., Utah

Locality: T34S/R16W/S18 cdc

Borehole: EDC-3 (Yale Crossing)

Site Latitude: 37°50'20" N

Depth Range (H.F. Calc.): 35-64 m

Site Longitude: 113°41'14" W

No. Cond. Samples: 0

Site Elevation: 1566 ± 1 m

Conductivity: 1.41 ± .20 W/m·K (est.)

Completed by:

Logged On: 7/17/79

Gradient: 68.42 ± 9.95 °C/km

Dip Angle: 90°

Heat Flow: 96.47 ± 19.60 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
5	(air)				
10	18.186				
15	17.311				
20	15.567				
25	14.320				
30	14.169				
35	14.319				
40	14.667				
45	15.035				
50	15.413				
60	16.134				
64	16.234			64	Alluvium

Area: Escalante Desert, Central Iron Co., Utah

Locality: T34S/R16W/S22 bad

Borehole: EDC-4 (Yale Crossing)

Site Latitude: 37°50'08" N

Depth Range (H.F. Calc.): 20-60 m

Site Longitude: 113°37'53" W

No. Cond. Samples: 0

Site Elevation: 1563 $\pm$ 1 m

Conductivity: 1.41 $\pm$.20 W/m·K (est.)

Completed by:

Logged On: 7/22/79

Gradient: 65.58 $\pm$ 2.18 °C/km

Dip Angle: 90°

Heat Flow: 92.47 $\pm$ 13.47 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
5	(air)				
10	11.744				
15	11.917				
20	12.208				
25	12.503				
30	12.788				
35	13.114				
40	13.483				
45	13.822				
50	14.160				
60	14.792				
66.5	14.937			66.5	Alluvium

Area: Escalante Desert, East Iron Co., Utah

Locality: T34S/R13W/S8 abd

Borehole: EDE-1 (Avon SE)

Site Latitude: 37°53'09"

Depth Range (H.F. Calc.): 25-70 m

Site Longitude: 113°19'56" W

No. Cond. Samples: 0

Site Elevation: 1585 $\pm$ 2

Conductivity: 1.41 $\pm$.20 W/m·K (est.)

Completed by:

Logged On: 7/11/79

Gradient: 30.10 $\pm$ 4.36 °C/km

Dip Angle: 90°

Heat Flow: 42.44 $\pm$ 8.60 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
5	(air)				
10	"				
15	"				
20	"				
25	12.808				
30	12.900				
35	13.034				
40	13.300				
45	13.406				
50	13.530				
60	13.847				
70	14.125				
76	14.250			76	Alluvium

Area: Hamblin Valley Iron Co., Utah

Locality: T32S/R19W/S26 ccc

Borehole: HV-1 (Eightmile Spring)

Site Latitude: 37°59'05" N

Depth Range (H.F. Calc.): 16-60 m

Site Longitude: 113°57'02" W

No. Cond. Samples: 0

Site Elevation: 2021 ± 3 m

Conductivity: 1.60 ± .20 W/m·K (est.)

Completed by:

Logged On: 10/21/78

Gradient: 48.59 ± 2.38 °C/km

Dip Angle: 90°

Heat Flow: 77.74 ± 10.44 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
8.00	10.83				
10.00	10.75				
12.00	10.87				
14.00	11.01				
16.00	11.14				
18.00	11.23				
20.00	11.30				
22.00	11.38				
24.00	11.47				
26.00	11.57				
28.00	11.66				
30.00	11.75				
32.00	11.85				
34.00	11.95				
36.00	12.04				
38.00	12.11				
40.00	12.20				
42.00	12.35				
44.00	12.42				
46.00	12.51				
48.00	12.64				
50.00	12.74				
52.00	12.81				
54.00	12.94				
56.00	13.08				
58.00	13.17				
60.00	13.27			60	Alluvium

Area: Lund Iron Co., Utah

Locality: T31S/R14W/S32 dd

Borehole: LD-1 (Lund)

Site Latitude: 38°03'29" N

Depth Range (H.F. Calc.): 11-31 m

Site Longitude: 113°26'22" W

No. Cond. Samples: 0

Site Elevation: 1579 $\pm$ 2 m

Conductivity: 1.70 $\pm$.20 W/m·K (est.)

Completed by:

Logged On: 90°

Gradient: 132.11 $\pm$ 9.58 °C/km

Dip Angle:

Heat Flow: 224.59 $\pm$ 31.04 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
6.10	14.90				
7.62	15.02				
9.15	15.37				
10.67	15.83				
12.20	16.16				
13.72	16.46				
15.24	16.60				
16.77	16.76				
18.29	16.97				
19.82	17.19				
21.34	17.37				
22.87	17.57				
24.39	17.76				
25.91	17.97				
27.44	18.17				
28.96	18.37				
30.49	18.55				
31.65	18.68			31.7	Alluvium

Area: Lund Iron Co., Utah

Locality: T32S/R14W/S3 dd

Borehole: LD-2 (Lund)

Site Latitude: 38°02'37" N

Depth Range (H.F. Calc.): 14-93 m

Site Longitude: 113°24'03" W

No. Cond. Samples: 0

Site Elevation: 1548 ± 1 m

Conductivity: 1.60 ± .20 W/m·K (est.)

Completed by:

Logged On:

Gradient: 39.90 ± 1.36 °C/km

Dip Angle: 90°

Heat Flow: 63.84 ± 8.27 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
4.6	12.82				
9.1	11.30				
13.7	11.54				
18.3	11.76				
22.9	11.90				
27.4	12.09				
32.1	12.26				
36.7	12.43				
41.2	12.63				
45.7	12.82				
50.2	12.97				
54.9	13.16				
59.5	13.34				
64.0	13.50				
68.6	13.70				
73.2	13.88				
77.8	14.06				
82.3	14.29				
86.9	14.46				
91.4	14.66				
93.3	14.76			93.3	Alluvium

Figure 25. Lithology, thermal conductivity, and temperature data, versus depth, for site BM-1.

Area: Black Mountain Iron Co., Utah

Locality: T31S/R11W/S18 adb

Borehole: BM-1 (Thermo)

Site Latitude: 38°06'43" N

Depth Range (H.F. Calc.): 25-75 m

Site Longitude: 113°07'30" W

No. Cond. Samples: 9

Site Elevation: 1762 $\pm$ 3 m

Conductivity: 1.49 $\pm$ 0.03 W/m·K

Completed by: 10/7/76

Logged On: 3/27/77

Gradient: 49.31 $\pm$ 1.46 °C/km

Dip Angle: 90°

Heat Flow: 73.47 $\pm$ 2.63 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
5	13.04	8	1.34	58.4	angular lithic
10	14.01	18	1.15		fragment con-
15	14.20	23	1.55		glomerate w/
20	14.55	28	1.57		interbedded
25	14.85	33	1.49		thin sandstones
30	15.13	40	1.50		
35	15.42	43	1.49	79.0	angular lithic
40	15.65	52	1.63		fragment con-
45	15.90	62	1.63		glomerate
50	16.13				
55	16.38				
60	16.62				
65	16.88				
70	17.11				
75	17.33				

Area: Black Mountain Iron Co., Utah

Locality: T31S/R11W/S19 c

Borehole: BM-2 (Thermo)

Site Latitude: 38°05'18" N

Depth Range (H.F. Calc.): 15-45 m

Site Longitude: 113°08'12" W

No. Cond. Samples: 0

Site Elevation: 1865 ± 3 m

Conductivity: 1.49 ± 0.15 W/m·K (est.)

Completed by: 6/76

Logged On: 7/21/76

Gradient: 77.79 ± 8.20 °C/km

Dip Angle: 90°

Heat Flow: 115.91 ± 16.89 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
5	11.34			3.7	alluvium
10	11.91				
15	12.39			45.0	conglomerate
20	12.69				consisting of
25	13.18				volcanic
30	13.67				fragments
35	13.95				
40	14.36				
45	14.65				

Area: Black Mountain Iron Co., Utah

Locality: T31S/R11W/S9 bcd

Borehole: BM-3 (Thermo)

Site Latitude: 38°07'26" N

Depth Range (H.F. Calc.): 10-65 m

Site Longitude: 113°06'02" W

No. Cond. Samples: 0

Site Elevation: 1737 $\pm$ 3 m

Conductivity: 1.97 $\pm$.03 W/m·K (est.)

Completed by: 1976

Logged On: 8/2/77

Gradient: 177.56 $\pm$ 5.02 °C/km

Dip Angle: 90°

Heat Flow: 349.79 $\pm$ 11.23 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
10	15.03			66.0	quartz latite
15	16.03				volcanic flow
20	16.99				
25	17.94				
30	18.90				
35	19.85				
40	20.66				
45	21.53				
50	22.34				
55	23.15				
60	23.94				
65	24.93				

Area: Black Mountain Beaver Co., Utah

Locality: T30S/R12W/S36 ddc

Borehole: BM-4 (Thermo)

Site Latitude: 38°08'57" N

Depth Range (H.F. Calc.): 20-65 m

Site Longitude: 113°08'34" W

No. Cond. Samples: 0

Site Elevation: 1612 ± 1 m

Conductivity: 1.56 ± .20 W/m·K (est.)

Completed by: 6/77

Logged On: 7/30/77

Gradient: 163.12 ± 4.54 °C/km

Dip Angle: 90°

Heat Flow: 254.47 ± 33.38 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
10	15.84			70.0	alluvium and colluvium consisting of quartz latite volcanics
15	17.04				
20	18.45				
25	19.30				
30	20.15				
35	21.01				
40	21.79				
45	22.57				
50	23.38				
55	24.19				
60	25.10				
65	25.77				

Area: Black Mountain Iron Co., Utah

Locality: T31S/R12W/S29 da

Borehole: BM-7 (Thermo)

Site Latitude: 38°04'40" N

Depth Range (H.F. Calc.): 20-68 m

Site Longitude: 113°12'53" W

No. Cond. Samples: 0

Site Elevation: 1632 $\pm$ 2 m

Conductivity: 1.49 $\pm$.15 W/m·K (est.)

Completed by: 6/76

Logged On: 8/19/76

Gradient: 84.17 $\pm$ 5.80 °C/km

Dip Angle: 90°

Heat Flow: 125.41 $\pm$ 15.30 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
10	13.07			11.0	alluvium
20	14.40			71.1	conglomerate
30	15.38				
40	16.29				
50	17.09				
60	17.92				
68	18.43				

Area: Iron Mountain Iron Co., Utah

Locality: T36S/R14W/S27 cdb

Borehole: IM-1 (Silver Peak)

Site Latitude: 37°38'12" N

Depth Range (H.F. Calc.): 35-80 m

Site Longitude: 113°24'43" W

No. Cond. Samples: 0

Site Elevation: 1904 $\pm$ 3 m

Conductivity: 3.66 $\pm$.37 W/m·K (est.)

Completed by: 3/6/59

Logged On: 8/6/77

Gradient: 27.47 $\pm$ 1.06 °C/km

Dip Angle: 90°

Heat Flow: 100.54 $\pm$ 10.88 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
10	11.15	surface	3.66	2.4	alluvium alternating sandstones and siltstones
15	11.48			213.3	
20	11.78				
25	11.97				
30	12.12				
35	12.33				
40	12.49				
45	12.62				
50	12.76				
55	12.90				
60	13.03				
65	13.18				
70	13.33				
75	13.44				
80	13.56				

Area: Iron Mountain Iron Co., Utah

Locality: T36S/R14W/S34 caa

Borehole: IM-2 (Silver Peak)

Site Latitude: 37°37'31" N

Depth Range (H.F. Calc.): 15-55 m

Site Longitude: 113°24'30" W

No. Cond. Samples: 0

Site Elevation: 1912 ± 3 m

Conductivity: 3.66 ± 0.37 W/m·K (est.)

Completed by: 6/1/60

Logged On: 8/6/77

Gradient: 23.80 ± 2.60 °C/km

Dip Angle: 90°

Heat Flow: 87.11 ± 12.97 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
10	11.91			3.2	alluvium
15	12.13			213.4	sandstone and
20	12.27				interbedded
25	12.34				siltstone
30	12.43				
35	12.57				
40	12.75				
45	12.87				
50	12.95				
55	13.06				

Area: NewCastle Iron Co., Utah

Locality: T36S/R15W/S29 dc

Borehole: NC-2 (NewCastle)

Site Latitude: 37°38'05" N

Depth Range (H.F. Calc.): 46-89 m

Site Longitude: 113°33'18" W

No. Cond. Samples: 0

Site Elevation: 1774 ± 12 m

Conductivity: 1.83 ± .16 W/m·K (est.)

Completed by:

Logged On:

Gradient: 89.00 ± 2.86 °C/km

Dip Angle: 90°

Heat Flow: 162.87 ± 15.17 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
3.1	20.26				
7.6	18.70				
15.2	17.74				
22.9	17.45				
30.5	17.30				
38.1	18.35				
45.7	19.30				
53.3	20.00				
61.0	20.73				
68.6	21.45				
76.2	22.07				
83.8	22.73				
89.0	23.14			89	Alluvium

Area: NewCastle Iron Co., Utah

Locality: T36S/R15W/S30 da

Borehole: NC-3 (NewCastle)

Site Latitude: 37°38'18" N

Depth Range (H.F. Calc.): 46-89 m

Site Longitude: 113°34'06" W

No. Cond. Samples: 0

Site Elevation: 1643 ± 6 m

Conductivity: 1.83 ± .16 W/m·K (est.)

Completed by:

Logged On:

Gradient: 115.89 ± 3.84 °C/km

Dip Angle: 90°

Heat Flow: 212.08 ± 19.83 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
3.1	16.15				
7.6	14.95				
15.2	-				
22.9	16.55				
30.5	17.70				
38.1	18.73				
45.7	20.56				
53.3	21.46				
61.0	22.37				
68.6	23.28				
76.2	24.05				
83.8	24.96				
89.0	25.63			89	Alluvium

Area: NewCastle Iron Co., Utah

Locality: T36S/R15W/S29 bb

Borehole: NC-4 (NewCastle)

Site Latitude: 37°38'26" N

Depth Range (H.F. Calc.): 8-91 m

Site Longitude: 113°33'59" W

No. Cond. Samples: 0

Site Elevation: 1658 ± 6 m

Conductivity: 1.75 ± .08 W/m·K (est.)

Completed by:

Logged On:

Gradient: 199.44 ± 12.37 °C/km

Dip Angle: 90°

Heat Flow: 349.02 ± 26.89 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
7.6	16.72				
15.2	17.90				
22.9	19.77				
30.5	21.63				
38.1	23.26				
45.7	24.82				
61.0	27.86				
64.0	28.54				
67.1	28.84				
73.2	29.87				
79.2	31.04				
85.3	32.20				
91.3	33.13			91	Alluvium

Area: NewCastle Iron Co., Utah

Locality: T36S/R15W/S20 ca

Borehole: NC-5 (NewCastle)

Site Latitude: 37°39'08" N

Depth Range (H.F. Calc.): 8-36 m

Site Longitude: 113°33'34" W

No. Cond. Samples: 0

Site Elevation: 1631 ± 3 m

Conductivity: 1.64 ± .13 W/m.K (est.)

Completed by:

Logged On:

Gradient: 1869.09 ± 78.08 °C/km

Dip Angle: 90°

Heat Flow: 3065.31 ± 274.66 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m.K)	to depth (m)	Lithology
3.05	22.77				
7.62	33.85				
12.19	43.44				
16.76	52.80				
21.34	61.20				
25.91	69.80				
30.48	77.80				
35.05	85.70				
35.45	86.30			35.5	Alluvium

Area: NewCastle Iron Co., Utah

Locality: T36S/R15W/S20 cc

Borehole: NC-6 (NewCastle)

Site Latitude: 37°38'56" N

Depth Range (H.F. Calc.): 5-38 m

Site Longitude: 113°33'50" W

No. Cond. Samples: 0

Site Elevation: 1634 ± 3 m

Conductivity: 1.64 ± .13 W/m·K (est.)

Completed by:

Logged On:

Gradient: 1065.10 ± 102.36 °C/km

Dip Angle: 90°

Heat Flow: 1746.76 ± 217.61 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
4.57	22.96				
7.62	27.53				
15.24	35.94				
22.87	44.25				
30.49	51.70				
38.11	59.00				
45.73	65.70				
53.35	72.00				
60.98	77.60				
68.60	82.70				
76.22	86.00				
83.84	88.20				
91.46	89.70				
99.09	90.90				
106.71	91.20				
114.33	91.80				
121.95	92.40				
126.52	92.50			126.5	Alluvium

Area: NewCastle Iron Co., Utah

Locality: T36S/R15W/S20 aa

Borehole: NC-7 (NewCastle)

Site Latitude: 37°39'37" N

Depth Range (H.F. Calc.): 11-91 m

Site Longitude: 113°33'03" W

No. Cond. Samples: 0

Site Elevation: 1619 ± 3 m

Conductivity: 1.75 ± .08 W/m·K (est.)

Completed by:

Logged On:

Gradient: 309.10 ± 24.02 °C/km

Dip Angle: 90°

Heat Flow: 540.93 ± 48.77 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
7.62	18.83				
10.67	19.06				
13.72	20.36				
16.76	21.16				
19.81	21.93				
22.86	24.30				
25.91	24.87				
28.96	26.06				
32.00	27.39				
35.05	28.64				
38.10	29.56				
41.15	30.60				
44.20	31.69				
47.24	32.80				
50.29	33.71				
53.34	34.67				
56.39	35.56				
59.44	36.37				
62.48	37.16				
65.53	38.10				
68.58	38.95				
71.63	39.63				
74.68	40.36				
77.72	41.00				
80.77	41.67				
83.82	42.50				
86.87	43.07				
89.92	43.50				
91.14	43.66			91.1	Alluvium

Area: NewCastle Iron Co., Utah

Locality: T36S/R15W/S17 dd

Borehole: NC-8 (NewCastle)

Site Latitude: 37°39'51" N

Depth Range (H.F. Calc.): 17-41 m

Site Longitude: 113°33'02" W

No. Cond. Samples: 0

Site Elevation: 1617 ± 3 m

Conductivity: 1.82 ± .04 W/m·K (est.)

Completed by:

Logged On:

Gradient: 1028.22 ± 30.44 °C/km

Dip Angle: 90°

Heat Flow: 1871.36 ± 69.00 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
4.57	20.11				
7.62	22.13				
10.67	25.87				
16.76	32.20				
22.86	37.88				
28.96	44.28				
35.05	50.76				
41.15	57.10				
47.24	63.41				
50.29	66.57				
53.34	69.80				
56.39	73.15				
59.44	76.20				
62.48	78.70				
65.53	81.50				
68.58	83.90				
71.63	85.70				
74.68	87.10				
77.72	88.00				
78.30	88.40			78.3	Alluvium

Area: NewCastle Iron Co., Utah

Locality: T36S/R15W/S16 cb

Borehole: NC-9 (NewCastle)

Site Latitude: 37°40'00" N

Depth Range (H.F. Calc.): 23-84 m

Site Longitude: 113°32'52" W

No. Cond. Samples: 0

Site Elevation: 1618 ± 1 m

Conductivity: 1.84 ± .10 W/m·K (est.)

Completed by:

Logged On:

Gradient: 474.98 ± 57.68 °C/km

Dip Angle: 90°

Heat Flow: 873.96 ± 116.28 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
7.62	19.12				
10.67	20.30				
13.72	23.10				
16.76	25.30				
19.81	27.20				
22.86	29.40				
25.91	31.50				
28.96	33.87				
32.00	36.37				
35.05	38.66				
38.10	41.00				
41.15	43.04				
44.20	45.14				
47.24	47.20				
50.29	49.15				
53.34	50.87				
56.39	52.47				
59.44	53.75				
62.48	54.60				
65.53	54.75				
68.58	55.00				
71.63	55.25				
74.68	55.60				
77.72	56.68				
80.77	58.00				
83.82	59.20				
86.87	59.96				
89.92	60.40				
91.17	60.60				
			91.2		Alluvium

Area: NewCastle Iron Co., Utah

Locality: T36S/R15W/S20 bb

Borehole: NC-10 (NewCastle)

Site Latitude: 37°39'34" N Depth Range (H.F. Calc.): 0-40

Site Longitude: 113°33'51" W No. Cond. Samples: 0

Site Elevation: 1603 ± 2 m Conductivity: 1.64 ± .13 W/m·K (est.)

Completed by:

Logged On: Gradient: 1833 °C/km

Dip Angle: 90° Heat Flow: 3006.12 ± 238.29 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
0.00	54.40				
3.05	77.80				
9.14	91.80				
18.29	95.30				
30.48	95.50				
39.62	95.60				
41.15	95.60				
42.67	96.70				
44.20	97.30				
45.72	98.30				
47.24	98.80				
48.77	99.20				
50.29	100.00				
51.82	100.20				
54.86	101.30				
57.91	102.70				
60.96	103.20				
64.01	103.30				
67.06	103.50				
70.10	106.60				
73.15	107.60				
76.20	107.60				
79.25	107.60				
82.30	107.60				
85.34	107.80				
88.39	107.80				

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Alluvium; volcanic
silt, sand, gravel.
Some CO₃ cementing.

Area: NewCastle Iron Co., Utah

Locality: T36S/R15W/S20 bb

Borehole: NC-10 (NewCastle) - continued

Site Latitude: Depth Range (H.F. Calc.):

Site Longitude: No. Cond. Samples:

Site Elevation: Conductivity:

Completed by:

Logged On: Gradient:

Dip Angle: Heat Flow:

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
91.44	107.80				
94.49	107.80				
97.54	107.60				
100.58	106.70				
103.63	106.00				
106.68	106.00				
109.73	106.00				
112.78	105.00				
115.82	105.00				
118.87	105.00				
121.92	105.00				
124.97	105.00				
128.02	104.90				
131.06	104.90				
134.11	104.90				
137.16	104.80				
140.21	104.50				
143.26	103.90				
146.30	103.70				
149.35	103.70				
152.40	103.70				

Area: NewCastle Iron Co., Utah

Locality: T36S/R15W/S19 ad

Borehole: NC-11 (NewCastle)

Site Latitude: 37°39'18" N

Depth Range (H.F. Calc.): 15-46 m

Site Longitude: 113°34'15"W

No. Cond. Samples: 0

Site Elevation: 1600 ± 3 m

Conductivity: 1.82 ± .04 W/m·K (est.)

Completed by:

Logged On:

Gradient: 1291.80 ± 45.07 °C/km

Dip Angle: 90°

Heat Flow: 2351.08 ± 96.95 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
6.10	20.70				
15.27	32.24				
24.38	45.25				
27.43	49.50				
30.48	53.20				
33.53	57.00				
38.10	62.20				
45.72	72.00				
53.34	77.50				
60.96	83.70				
68.58	87.30				
76.20	89.50				
83.82	91.10				
91.44	92.50				
99.06	93.90				
106.68	93.90				
114.30	91.90				
121.92	89.60				
129.54	88.20				
137.16	87.10				
144.78	85.80				
152.40	84.90			152	Alluvium

Area: NewCastle Iron Co., Utah

Locality: T36S/R15W/S10 ba

Borehole: NC-12 (NewCastle)

Site Latitude: 37°41'21" N

Depth Range (H.F. Calc.): 49-118 m

Site Longitude: 113°31'26" W

No. Cond. Samples: 0

Site Elevation: 1619 ± 3 m

Conductivity: 1.63 ± .20 W/m·K (est.)

Completed by:

Logged On:

Gradient: 21.44 ± 2.47 °C/km

Dip Angle: 90°

Heat Flow: 34.95 ± 5.88 mW/m²

depth (m)	T (°C)	depth (m)	K (W/m·K)	to depth (m)	Lithology
6.1	24.72				
12.2	20.95				
18.3	19.25				
24.4	18.02				
30.5	17.16				
36.6	16.87				
42.7	16.77				
48.8	16.77				
54.9	16.86				
61.0	16.96				
67.1	17.05				
73.2	17.17				
79.2	17.38				
85.3	17.45				
91.4	17.54				
97.5	17.67				
103.6	17.79				
109.7	18.01				
115.8	18.21				
118.4	18.28				
				118	Alluvium

Thermal Studies Laboratory
Thermal Conductivity Results
Summary Sheet

Site Name: NewCastle (Christensen Bros. production well)

Site Location: Ts 36S Ra 15W Sec. 20 bbb

Lat. 37°39'35" N Long. 113°33'51" W

Number of Samples: 8

Surface Downhole X

Depth (m)	Rock Type	Conductivity (W/m·K)	Comments (Chips/Core)
5-11	Alluvium; rhyolitic tuff; some Qtzite silt to sand size	2.06	chips to 140 m (Alluvium to T.D.)
26-30	As above; fine to coarse. CO ₃ cementing	2.32	
41-44	As above	2.45	
46-53	As above	2.71	
75-84	As above; coarse to pebbly. Beige tuff; altered. CO ₃ cementing	2.10	
92-96	As above	2.01	
126-127	dark volcanic sand; some CO ₃ cementing. Coarse	2.38	
131-140	beige tuff sand. Some CO ₃ cementing	2.30	

APPENDIX B

ESCALANTE DESERT HAND SAMPLE DATA

Basic data for hand samples collected near heat flow holes ED-2 through ED-11 are given in the following Table. The procedure for sample collection was to take at least five samples from outcrops within two kilometers of each of the ten heat flow sites (access problems made sampling at ED-1 difficult, so that no samples are available). These were cored at the University of Utah with a 5.1 cm outer-diameter diamond bit producing core with an average diameter of 4.8 cm. Many samples were highly fractured and brittle, making core recovery impossible. Surviving core were sliced, producing more than one disc from some of the core (hence the A,B, C,D notation). These discs range in thickness from 1.0 to 2.3 cm. Sixty-nine discs from forty-one hand samples were then polished so that parallelism of the faces was within 20 thousandths of a centimeter, reducing surface resistance uncertainties in the measuring process.

Volume estimates of the core samples (used in porosity determinations) were made both algebraically:

$$V = \pi r^2 h$$

and by the immersion technique:

$$V = \text{weight of dry sample} - \text{immersed weight}$$

In general, the computed volumes were within 5% of each other. Highly porous or fractured samples showed as much as a 20% difference, however, and for these samples the immersion technique volume estimate was used in the porosity determination.

The discs were next vacuum saturated and measured in the modified divided bar apparatus as discussed in the text. Each disc was then crushed and re-measured in the conventional manner for chips (Sass et al., 1971-a). Details of the computations done in order to obtain porosity-corrected thermal conductivity values are given in the text. The following Table presents the raw data used in the construction of Figure 10 (text).

Borehole ED-5, although not used for heat flow purposes, was included in the hand sample thermal conductivity experiment. Therefore, it should be noted that these data have been used in the construction of Figures 2 and 10 in the text.

TABLE 3
ESCALANTE DESERT HAND SAMPLE DATA

Location and sample no.	Formation	Sample description	k_s (W/m·K) <u>1/</u>	ϕ_d (%) <u>2/</u>	k_{pc} (W/m·K) <u>3/</u>	k_r (W/m·K) <u>4/</u>	% Diff. <u>5/</u>
ED-2	1A Quichapa Group	rhyolitic-lithic	2.71	17.5	2.09	1.77	18.1
	Leach Canyon Fm.	ash flow tuff					
	1B equiv.		2.01	6.8	1.85	1.78	3.9
	2A	rhyolite/lathite lithic	2.84	20.4	2.08	1.75	18.9
	2B	ash flow tuff	2.44	17.2	1.93	2.05	-5.8
	4A	rhyolitic ash flow tuff	4.21	11.7	3.36	3.25	3.4
	4B	(argillized)	4.54	11.6	3.60	3.25	10.8
	5A	rhyolitic ash flow tuff	3.58	5.4	3.25	2.75	18.2
	5B		3.24	4.1	3.03	2.63	15.2

1/ Solid component conductivity

2/ Measured disc conductivity

3/ Porosity corrected conductivity

4/ Solid disc conductivity

Mathematical expressions appear at end of table

TABLE 3 (continued)

Location and sample no.	Formation	Sample description	k_s (W/m·K) 1/	ϕ_d (%) 2/	k_{pc} (W/m·K) 3/	k_r (W/m·K) 4/	% Diff. 5/
ED-3 1	Needles Range Fm. probably Lund Tuff Member	pumaceous rhyolitic-lithic tuff (not completely welded)	1.79	37.0	1.21	1.19	1.7
3	?	rhyolitic/lithic ash flow tuff; moderately welded	2.44	6.2	2.24	1.91	17.2
ED-4 2A	?	latite tuff biotite, llb	1.91	1.2	1.88	1.91	- 1.6
2B			1.84	1.3	1.81	1.68	7.7
3A	Needles Range Fm.	latite tuff	2.01	1.5	1.97	1.75	12.6
3B	Wah Wah Springs Member	biotite, llb	1.96	1.8	1.92	1.65	16.4
4	Quichapa Group Condor Canyon Fm.	rhyolite/latite welded tuff	2.05	16.0	1.69	1.84	-8.1
ED-5 1A	Quichapa Group	rhyolite	2.83	10.9	2.40	2.01	19.4
1B	Leach Canyon Fm. equiv.		2.58	13.8	2.12	1.77	19.8

1/, 2/, 3/, and 4/ refer to page 1 of table.

TABLE 3 (continued)

Location and sample no.	Formation	Sample description	k_s (W/m·K) 1/	ϕ_d (%) 2/	k_{pc} (W/m·K) 3/	k_r (W/m·K) 4/	% Diff. 5/
ED-5	Quichapa Group						
3	Leach Canyon Fm. equiv.	rhyolite	2.66	3.2	2.54	2.38	6.7
4	Quichapa Group Leach Canyon Fm. equiv.	rhyolite	2.45	1.1	2.41	2.04	18.1
5A	?	quartz latite tuff	1.85	6.9	1.72	1.65	4.2
5B		Hb, bio., magnetite	1.76	5.2	1.67	1.58	5.7
6A	not a local tuff	latite/dacite	1.87	12.2	1.63	1.70	- 4.1
6B		lava flow	1.97	8.9	1.78	1.76	1.1
ED-6	Needles Range Fm.	quartz latite welded					
1	Lund Tuff Member	tuff; magnetite	1.99	5.3	1.87	2.04	-8.3
2	Needles Range Fm. Lund Tuff Member	quartz latite welded tuff; magnetite	2.47	2.8	2.38	2.85	-16.5
3A	Needles Range Fm. Lund Tuff Member	quartz latite welded tuff; magnetite	2.19	3.4	2.10	2.16	- 2.8
3B			2.69	3.7	2.55	2.25	25.2

1/, 2/, 3/, and 4/ refer to page 1 of table.

TABLE 3 (continued)

Location and sample no.	Formation	Sample description	k_s (W/m·K) 1/	ϕ_d (%) 2/	k_{pc} (W/m·K) 3/	k_r (W/m·K)	% Diff. 5/
ED-6 4	Needles Range Fm. Lund Tuff Member	quartz latite welded tuff; magnetite	2.39	1.4	2.34	2.26	3.5
5	?	volcanic sand	1.86	1.4	1.83	1.96	- 6.6
6A	Quichapa Group	volcanic sand	1.97	16.8	1.62	1.52	6.6
6B	Leach Canyon Fm. equiv.		1.90	17.4	1.56	1.55	0.6
ED-7 1A			2.30	4.8	2.16	2.02	6.9
1B	Needles Range Fm. Lund Tuff Member	biotite quartz latite	2.09	5.3	1.96	1.93	1.6
1C			2.20	4.6	2.08	2.04	2.0
1D			2.30	4.4	2.17	2.07	4.8
2A	Needles Range Fm. Lund Tuff Member	biotite quartz latite	2.32	5.1	2.17	2.01	8.0
2B			2.20	5.7	2.04	1.90	7.4
3A			2.35	3.2	2.25	1.95	15.4
3B	Needles Range Fm. Lund Tuff Member	biotite quartz latite	2.01	4.7	1.90	1.95	- 2.6
3C			2.07	3.4	1.99	1.87	6.4

1/, 2/, 3/, and 4/ refer to page 1 of table.

TABLE 3 (continued)

Location and sample no.	Formation	Sample description	k_s (W/m·K) 1/	ϕ_d (%) 2/	k_{pc} (W/m·K) 3/	k_r (W/m·K) 4/	% Diff. 5/
ED-7 4	?	biotite quartz latite	1.97	2.7	1.91	1.67	14.4
5A	?	biotite quartz latite	2.30	1.5	2.26	2.01	12.4
5B			2.00	1.0	1.98	1.99	- 0.5
6A	Needles Range Fm. Lund Tuff Member	biotite quartz latite	2.01	2.4	1.95	2.01	- 3.0
6B			2.14	4.1	2.03	2.06	- 1.5
ED-8 1A	Needles Range Fm. Wah Wah Springs Member	biotite quartz latite	2.38	0.9	2.35	2.13	10.3
1B			2.30	1.1	2.27	2.19	3.7
4	Isom Formation (?)	hornblende latite lava flow	2.18	1.1	2.15	1.99	8.0
5	?	hornblende latite lava flow	2.16	4.1	2.05	1.77	15.8
7	Needles Range Fm. Lund Tuff Member	biotite quartz latite	2.12	2.6	2.05	1.85	10.8
ED-9 1A	Quichapa Group Condor Canyon Fm.	rhyolite/quartz latite pumaceous lithic tuff	2.07	14.0	1.75	1.56	12.2
1B			2.00	14.3	1.69	1.76	- 4.0

1/, 2/, 3/, and 4/ refer to page 1 of table.

TABLE 3 (continued)

Location and sample no.	Formation	Sample description	k_s (W/m ² K) 1/	ϕ_d (%) 2/	k_{pc} (W/m ² K) 3/	k_r (W/m ² K) 4/	% Diff. 5/
ED-10 1A	?	rhyolite/quartz latite	1.98	9.5	1.77	1.42	24.6
1B		lithic tuff	2.06	8.8	1.85	1.65	12.1
3A	?	hornblende latite	1.44	2.6	1.41	1.42	- 0.7
3B		biotite and Hb phenocrysts	1.32	2.4	1.30	1.42	- 8.4
4A	Quichapa Group Harmony Hills	biotite/hornblende quartz latite	1.67	4.4	1.60	1.63	- 1.8
4B		Tuff Member >50% phenocrysts	1.67	2.7	1.63	1.51	7.9
5	?	biotite/hornblende quartz latite >50% phenocrysts	1.89	5.4	1.78	1.55	14.8
6	?	biotite/hornblende quartz latite >50% phenocrysts	1.73	4.6	1.65	1.59	3.8
7A	?	hornblende	1.73	1.4	1.71	1.69	1.8
7B		biotite latite	1.83	1.9	1.79	1.79	0.0
7C		low % pheno.; fine-grained	1.81	3.1	1.75	1.66	5.4

1/, 2/, 3/, and 4/ refer to page 1 of table.

TABLE 3 (continued)

Location and sample no.	Formation	Sample description	k_s (W/m·K) 1/	ϕ_d (%) 2/	k_{pc} (W/m·K) 3/	k_r (W/m·K) 4/	% Diff. 5/
ED-10 8A	?	hornblende latite	1.49	0.9	1.48	1.44	2.8
8B			1.48	0.1	1.48	1.52	- 2.6
8C			1.60	1.4	1.58	1.49	6.0
ED-11 1A	?	rhyolite tuff (partly welded)	1.74	22.6	1.38	1.47	- 6.8
1B			1.80	21.8	1.42	1.46	- 2.7
5	?	biotite quartz latite lithic tuff; moderately welded	2.19	3.4	2.10	2.01	4.5

1/ $k_s = (k_c k_w^{-\phi})^{1/(1-\phi)}$ k_c : thermal conductivity of cell contents
 k_w : thermal conductivity of water
 ϕ : volume fraction of water in cell

3/ $k_{pc} = k_w \phi_d k_s (1-\phi_d)$ ϕ_d : measured disc porosity

5/ % Difference is defined as $(k_{pc} - k_r)/k_r \times 100$

Formation names from Dr. Myron Best

Sample descriptions from Eric Struhsacker and Dr. Myron Best

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