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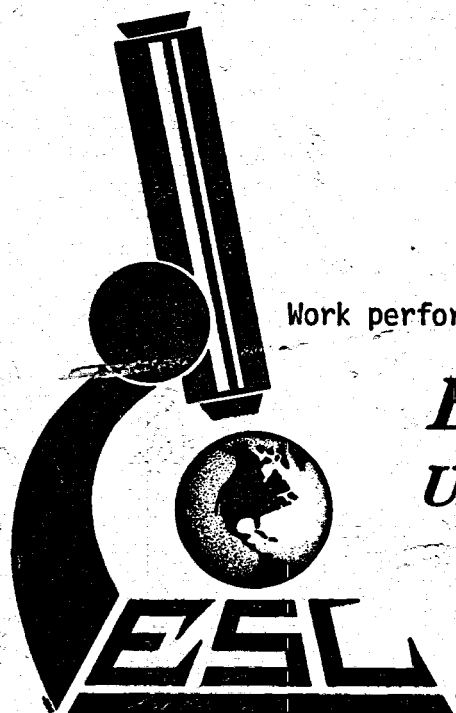
STATE COUPLED GEOTHERMAL RESOURCE

ASSESSMENT PROGRAM

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GEOHERMAL INVESTIGATIONS IN NEBRASKA: METHODS AND RESULTS

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GEOHERMAL INVESTIGATIONS IN NEBRASKA: METHODS AND RESULTS

Introduction.

At the inception of the geothermal resource assessment program in Nebraska there was some skepticism about the existence of any geothermal resources within the state. Now after two years of study and collaboration with other workers in the geothermal field we find that about two-thirds of the state has access to a potential low-temperature resource. The nature of the resource is warm water in laterally extensive aquifers which are overlain by thick (> 1 km) sections of low thermal conductivity sediments. For most of the resource area the high temperatures in the aquifers result from high temperature gradients in the overlying shales. However, in the northcentral and far western parts of the state there is evidence for convective heat flow due to updip water flow in the aquifers. The success of the program has resulted from the synthesis of heat flow and temperature gradient measurements with stratigraphic and lithologic data. This paper describes the methods used and the results obtained during the study.

Methodology.

The general plan of the resource assessment has been to acquire heat flow and subsurface temperature data and to synthesize these data with other geological information. Heat flow sites (Figure 1) were selected on the basis of our interpretation of existing data on the thermal regime of Nebraska. The published literature are summarized by Gosnold(1980 a) and are reproduced here for reference (Figure 2). In addition to published literature

data from temperature logs made in a number of water table observation wells (Figure 1) were also used in the selection of heat flow sites. Thirteen of the heat flow sites are located in areas indicated as having anomalous subsurface temperatures by the AAPG-USGS geothermal gradient map of North America (AAPG-USGS, 1976). Seven sites are on or near the Nemaha Ridge and ten sites are on or near the Chadron-Cambridge Arch. Three sites also include an area suspected of having anomalous subsurface temperatures by inference from a geothermal gradient map of South Dakota (Schoon and McGregor, 1974).

The geological setting of Nebraska is that of a stable continental platform. The relatively flat-lying sedimentary veneer ranges in thickness from about 300 m in the northeast to greater than 3000 m in the west, and the stratigraphy is relatively well known (Condra and Reed, 1959). The known structural features cannot cause widespread convective heat transfer, thus conductive heat flow is considered to be the primary factor in the thermal structure of the upper crust beneath Nebraska.

In a conductive regime subsurface temperatures are determined by the heat flow and the thermal conductivities of the lithologic units present. Thus knowledge of the heat flow, stratigraphy, and thermal conductivities allows calculation of subsurface temperatures and provides a means for estimating the geothermal resource potential. The general scheme is shown in Figure 3 where heat flow determinations at two sites are used to estimate subsurface temperatures in the regions between and below the sites. The practice of projecting temperature gradients beyond measured depths is theoretically valid in conductive regimes if the thermal conductivities of the stratigraphic section are known. Nevertheless it is best to verify temperature gradient projections

with equilibrium temperature measurements in deep wells. An essential component of our investigation is the measurement of deep-well temperature gradients especially those near populated regions where the geothermal resource may be exploited.

Projection of a potential geothermal resource by this method requires using the heat flow, thermal conductivity, and stratigraphic data to produce a subsurface temperature map. Then the temperature contours are superimposed on structure contours of the aquifers, and those regions which satisfy the criteria for a low-temperature resource are defined by the intersecting contour lines.

Results.

A total of 28 wells were completed for heat flow and temperatures were recorded to the nearest 0.01 K at 5 m intervals with a thermistor probe. Bulk conductivities of drill cuttings from nine of the wells were measured at the Southern Methodist University Geothermal Laboratory, and porous rock conductivities were calculated using the method of Sass et al., (1971a). The remainder of the drill cutting samples are being processed for measurement later. Estimates of thermal conductivities in the remaining wells were made on the basis of lithology and known conductivities to allow preliminary heat flow calculations (Table 1) for the resource assessment. Some of the preliminary heat flow values have been reduced from previous estimates (Gosnold, 1980a, 1980b) to conform with new data on the thermal conductivity of shales in the Midcontinent (Blackwell et al., 1981).

Heat flow values for most of the state range from 38 mWm^{-2} to 67 mWm^{-2} and fall within expected values for a stable platform with only conductive heat flow. However large areas of anomalously high heat flow appear to exist

in the north central section and in the panhandle west of the Chadron-Cambridge Arch. These high heat flow areas are interpreted to be due to convective heat flow within deep aquifers. Two separate convective systems are postulated to account for the heat flow anomalies.

One system underlies the north central part of Nebraska and the south central part of South Dakota. The warm water in this system may enter the Dakota Group through a subcrop connection with the Madison aquifer in South Dakota and flow within the Dakota Group through the high heat flow zone. Warm waters are known in numerous wells penetrating the Madison and the Dakota in South Dakota (Schoon and McGregor, 1974) and 12 water wells in Boyd County Nebraska produce warm water from the Dakota Group (Souders, 1976). A flowing well at Lynch Nebraska produces water at 28°C at about 570 l min^{-1} and was formerly used to fill the city swimming pool. Temperature gradients and heat flow increase from east to west in the high heat flow zone suggesting that the source area for the warm water may lie to the west.

A separate convective system is postulated to account for the high heat flow west of the Chadron-Cambridge Arch. Figure 4 is a structure contour map on top of the Dakota from Volk (1972) and shows a configuration that could cause an extensive, convective heat flow anomaly between the arch and the Denver-Julesburg Basin. Structural cross sections (Figures 5 a & b) in western Nebraska from Condra, Reed, and Scherer (1950) indicate that subsurface temperatures should be high due to great thicknesses of low-conductivity shales. The coupled effect of the thick shale units and updip water flow probably account for the subsurface temperature patterns in the area (Figures 6 a, b, & c). The results of a finite-difference heat flow model are shown in Figure 6 d. An updip flow of water in the Dakota at a rate of 1 m yr^{-1} gives heat flow and subsurface temperature profiles that are consistent with

the existing data. The results of the heat flow data do not contradict the predictions of high heat flow by Swanberg and Morgan(1979), in fact the results provide an explanation for the silica geothermometry anomaly.

Both zones which show evidence of convective heat flow will be included in our scheme of projecting subsurface temperatures on the basis of a conductive heat flow model. We can do this because the convecting zones are the aquifers underlying the Cretaceous shales and we see no problem with projecting temperature gradients down to the tops of the aquifers.

The data have been synthesized to produce a temperature contour map for a depth of 1 km (Figure 7). This map is our first attempt to define geothermal resources in Nebraska, and it does delineate regions which overlie potential low temperature thermal waters. A future version of the map will have structure contours for the warm-water-bearing aquifers and temperature contours for the aquifers. We believe that the second version will clearly delineate potential resource areas by showing three pieces of information, i.e., the locality of the resource, the depth to the resource, and the temperature of the resource. We suggest that this approach is a significant improvement over recent attempts to represent geothermal resources in the Midcontinent.

Examples of comparisons between shallow-well temperature gradients and bottom hole temperature data are shown in Figures 8 & 9. The broad scatter in the BHT data is a ubiquitous phenomenon and casts doubt on the usefulness of those data. However, as a large data set, the BHT data are useful for identifying areas which may have anomalous temperatures.

Concluding Remarks.

In a stable continental interior the synthesis of heat flow data with stratigraphic, and thermal conductivity data is highly effective in exploring for low temperature geothermal resources on a regional scale. An effective

method of presentation of the resource in map form is to delineate the resource area with shading, indicate the depth to the resource with contour lines, and indicate the temperature of the resource with another set of contour lines.

Acknowledgements.

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		Locality Name	Latitude North	Longitude West	Gradient (K km ⁻¹)	Depth Interval (m)	Conductivity (Wm ⁻¹ K ⁻¹)	Rock Type	Heat Flow (mWm ⁻²)
Chadron Arch	Southeast & Nemaha Ridge	Bennet	40° 38.4'	96° 30.8'	28	10-150	2.4	Ls	67
		Elk Creek	40° 15.9'	96° 11.0'	32	200-240	3.3	Do	106
		Liberty	40° 3.0'	96° 27.5'	30	120-145	1.7	Ls+Sh	51
		Stella	40° 11.2'	95° 50.0'	30	60-80	1.8	Ls+Sh	54
		Table Rock	40° 9.1'	96° 4.6'	18	140-155	3.0	Gr	54
		Union North	40° 51.4'	95° 48.9'	20	120-125	2.9	Ls	58
		Union South	40° 46.2'	95° 59.6'	23	75-80	2.4	Ls	55
	Northeast	Fremont	41° 29.5'	96° 33.4'	15	60-115	4.2*	Ss	63
		Oakland	41° 49.5'	96° 27.3'	9	75-140	4.2*	Ss	38
		O'Neill	42° 26.2'	98° 39.0'	50	105-150	1.1*	Sh	55
		Wayne	42° 13.8'	97° 2.5'	62	65-115	1.1*	Sh	68
	North Central	Naper	42° 58.8'	99° 1.4'	86	10-155	1.1*	Sh	95
		Springview	42° 57.8'	99° 42.4'	109	10-145	1.1*	Sh	120
		Valentine	42° 54.1'	100° 30.3'	64	25-150	2.2*	Sa+Si	145
	North Platte Area	Box Elder Canyon	40° 57.6'	100° 34.4'	27	45-225	2.2*	Sa+Si	59
		Gothenburg	40° 47.2'	100° 20.5'	30	10-235	2.2*	Sa+Si	66
		Cross Ranch	41° 36.4'	101° 48.2'	54	200-570	1.1*	Sh	59
		Rothwell Ranch	41° 46.7'	101° 40.9'	47	270-570	1.1*	Sh	52
		Milldale Ranch	41° 39.7'	101° 28.7'	49	240-470	1.1*	Sh	54
		Gordon	42° 54.9'	102° 12.3'	48	10-185	1.7*	Si+Cl	82
		Rushville	42° 36.7'	102° 12.3'	38	120-200	1.7*	Si+Cl	65
		White Clay	42° 47.4'	102° 39.4'	48	10-35	1.7	Si+Cl	82
		Hay Springs	42° 34.2'	102° 38.9'	45	10-235	1.7	Si+Cl	77
		Whitney	42° 45.3'	103° 16.4'	66	10-153	1.7*	Si+Cl	112
	Southern Panhandle	Bayard	41° 49.7'	103° 17.0'	60	90-153	2.2*	Sa+Si	132
		Lisco	41° 25.1'	102° 33.5'	47	10-189	2.2*	Sa+Si	103
		Sidney	41° 8.2'	102° 56.1'	52	20-180	2.2*	Sa+Si	114
		Big Springs	41° 4.2'	102° 5.9'	59	10-135	2.2*	Sa+Si	130

Table 1. Preliminary heat flow data in Nebraska. Estimated conductivities are indicated by (*). Rock type key: Ls = limestone, Do = dolomite, Sh = shale, Ss = sandstone, Sa = sand, Si = silt, Cl = clay, Gr = granite.

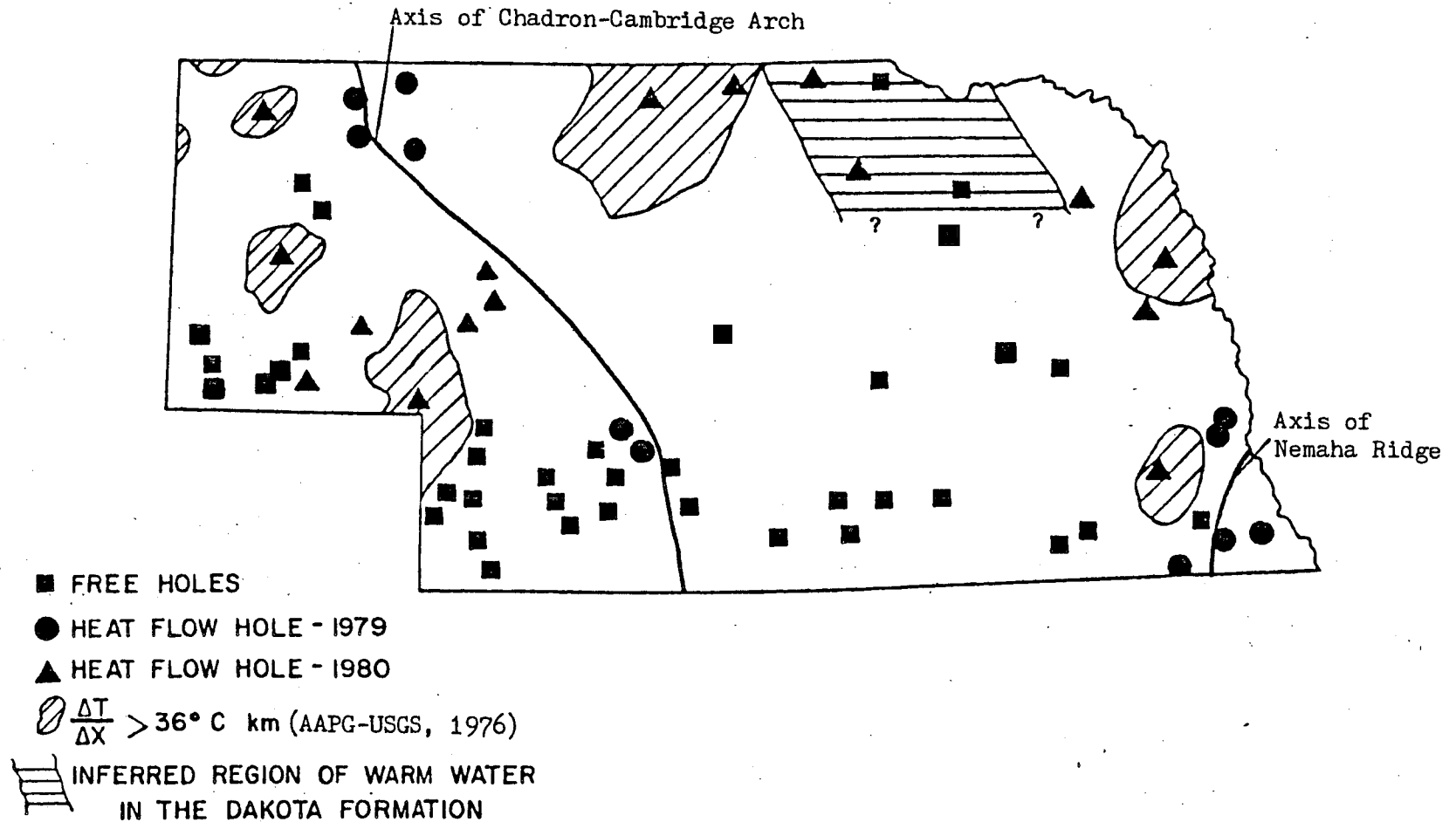
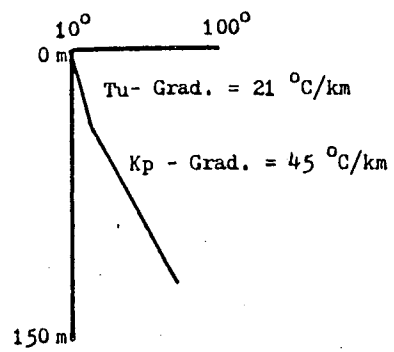
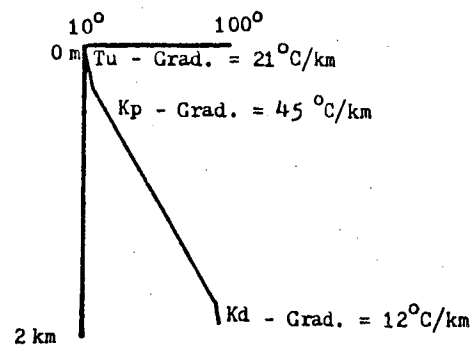


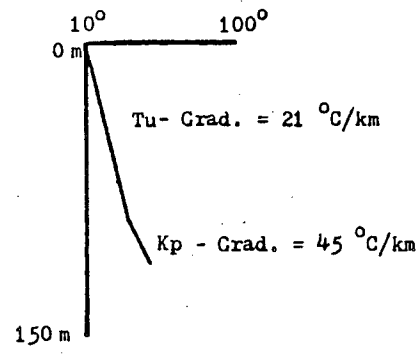
Figure 1. Locations of heat flow sites and other wells where temperature gradients have been measured.



T-D Plot for site #1



T-D Plot for deep well



T-D Plot for site #2

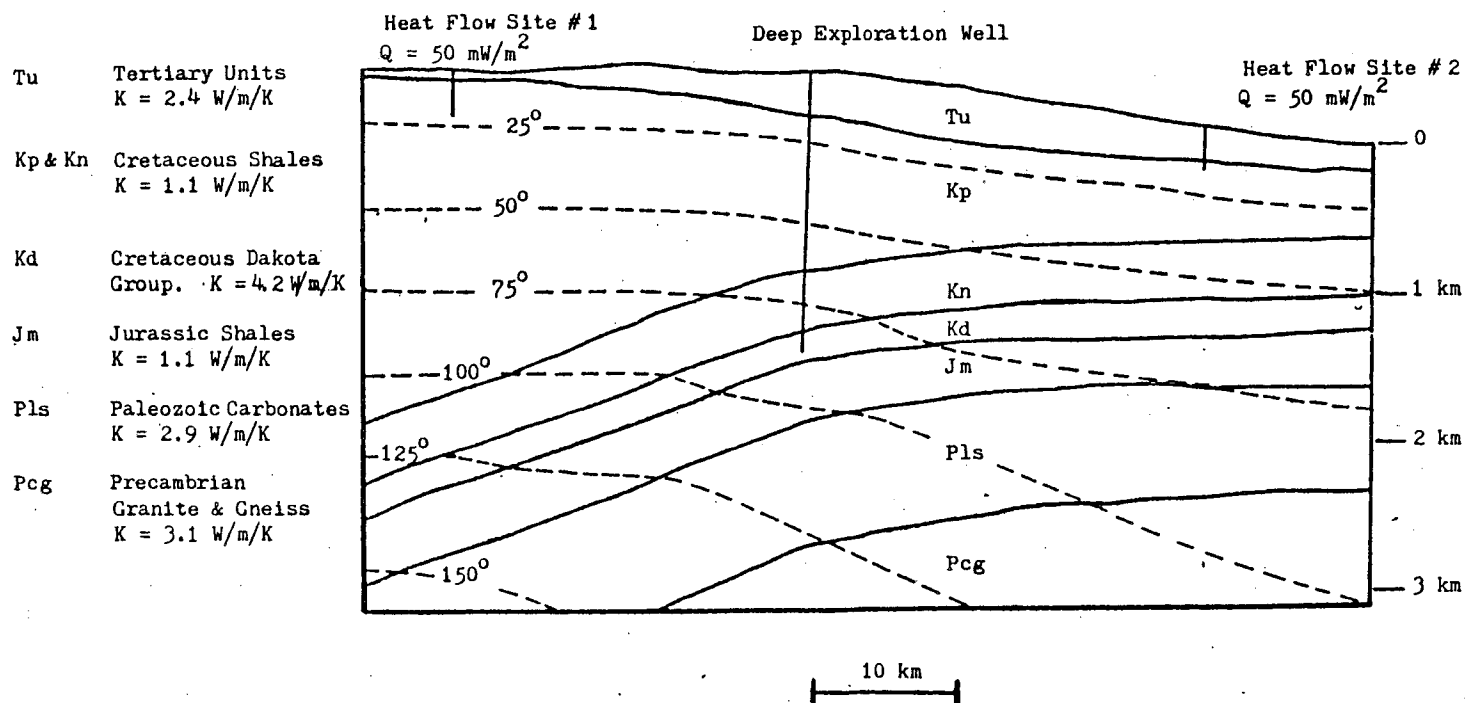


Figure 3. Temperature profile in a conductive thermal regime. Isotherms are contoured on the basis of known heat flow, stratigraphy, and thermal conductivity. The section is typical of western Nebraska where the potential resource is warm water in the sandstone aquifers of the Cretaceous Dakota Group.

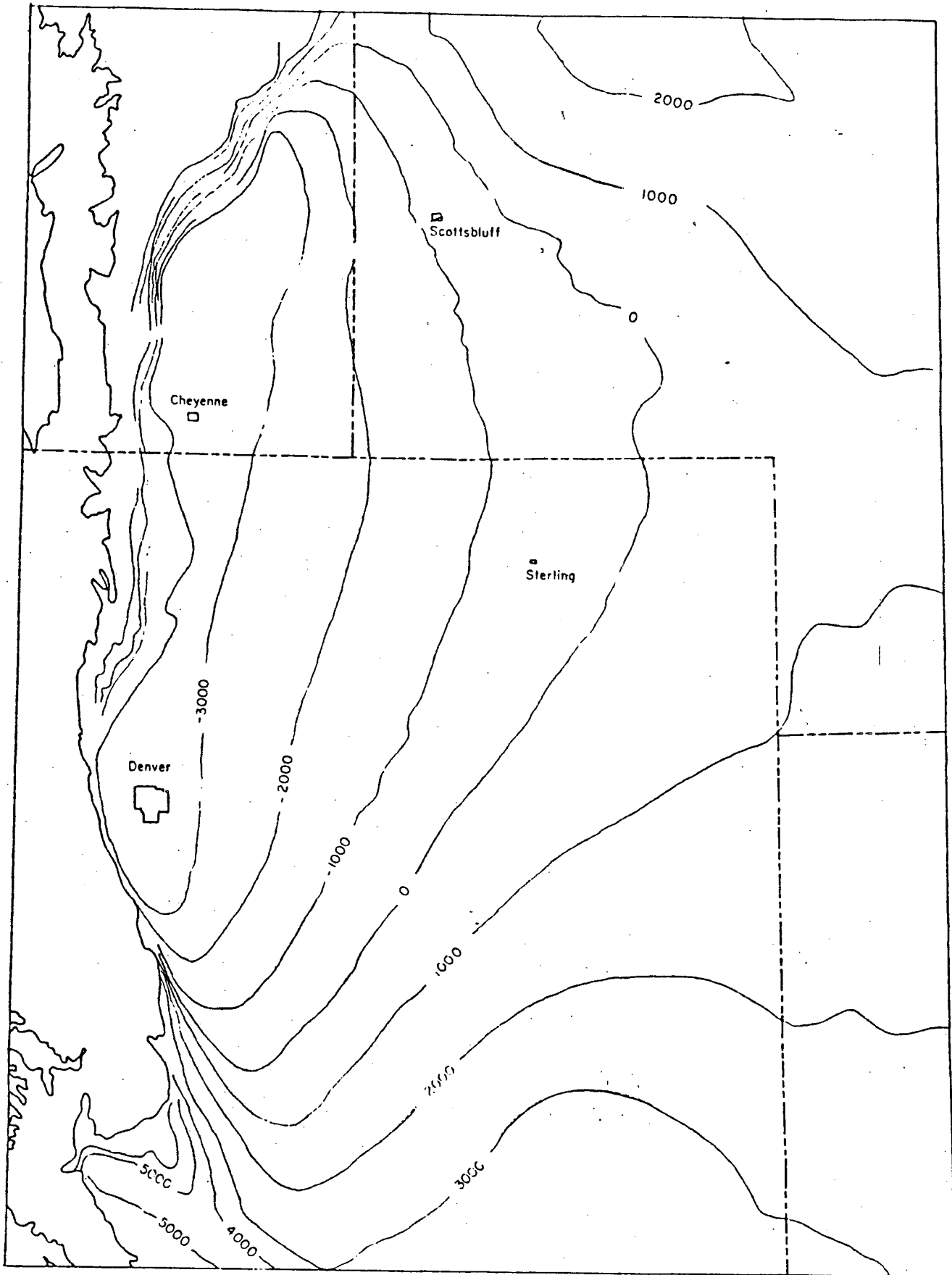


Figure 4. Structure contour map of the Dakota group from Volk,(1972). Datum is sea level.

Figure 5 a.

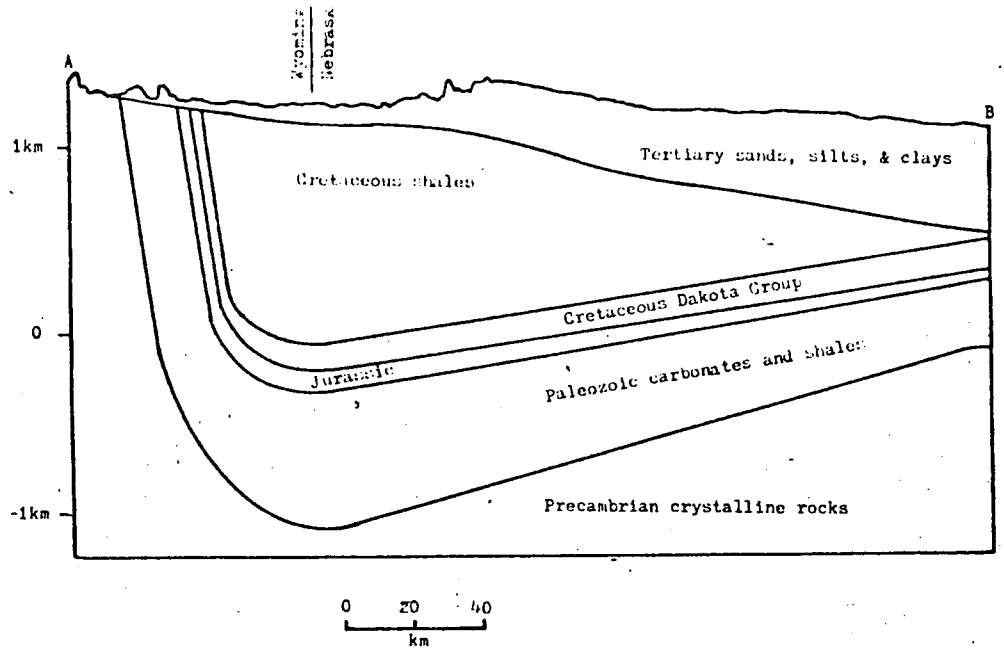


Figure 5 b.

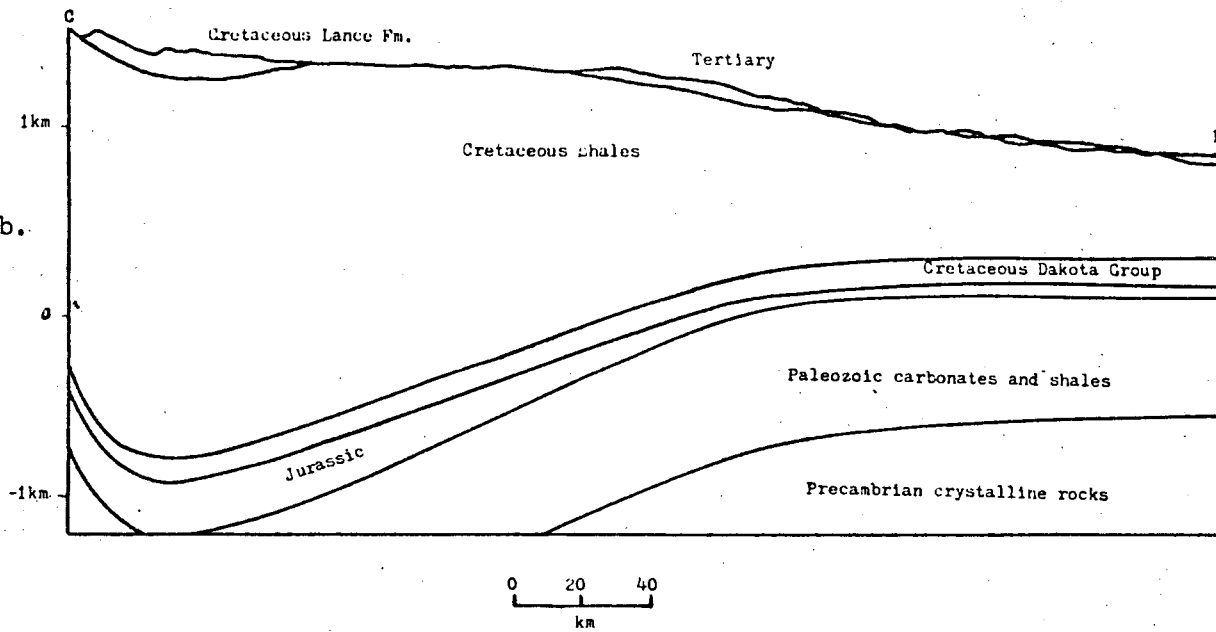
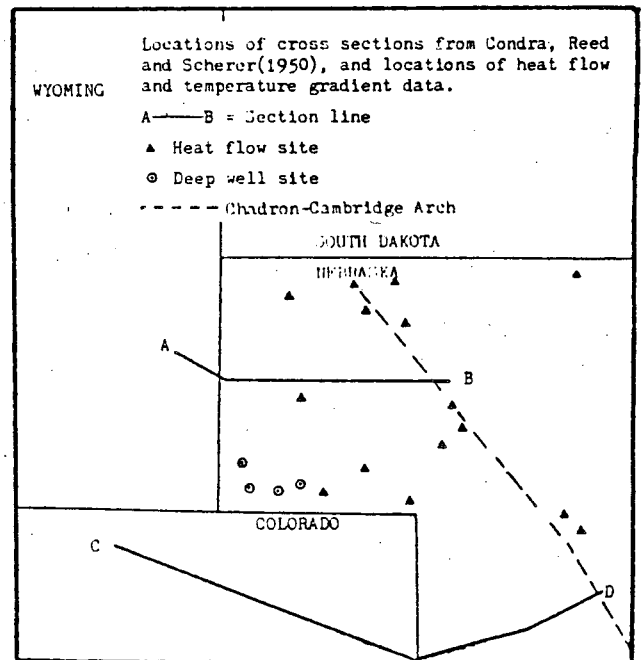


Figure 5. Structural cross sections in western Nebraska from Condra, Reed, and Scherer (1950).



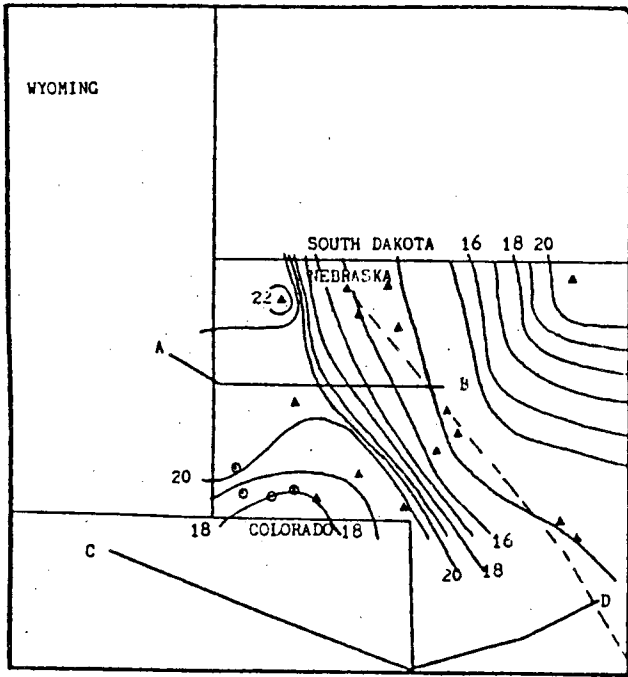


Figure 6 a. Hand contours of temperatures recorded at a depth of 150 m.

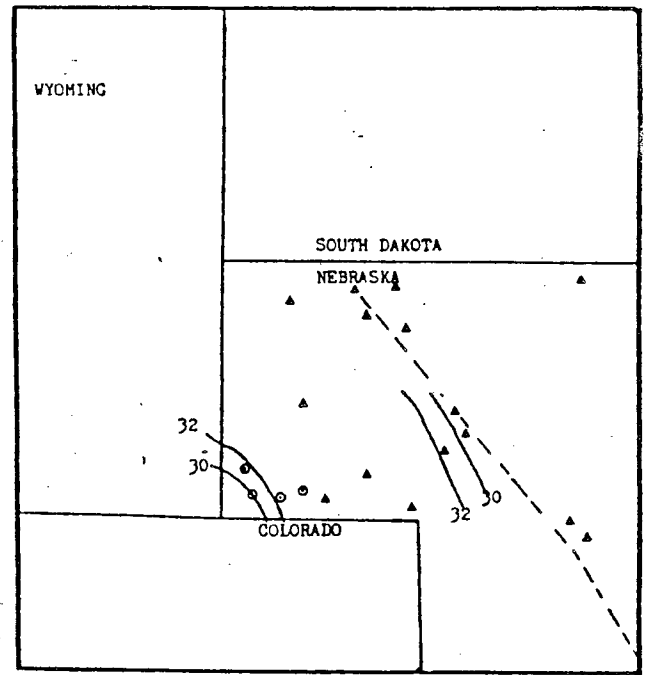


Figure 6 b. Hand contours of temperatures recorded at a depth of 500 m.

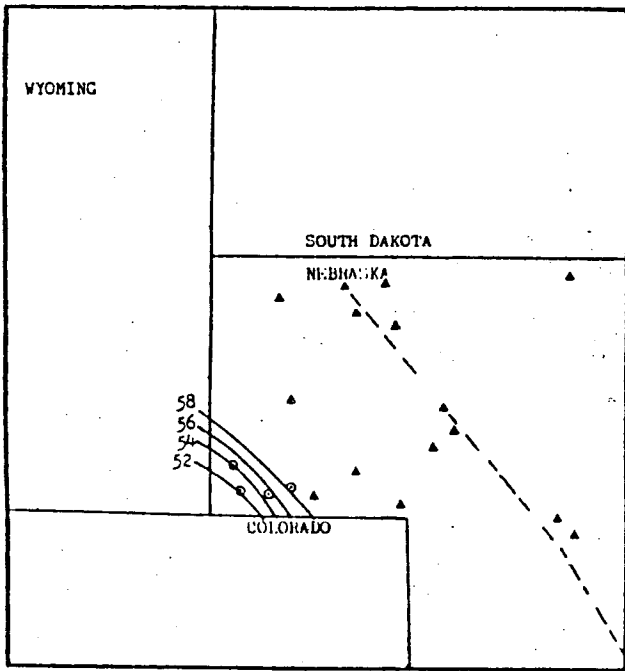


Figure 6 c. Hand contours of temperatures recorded at a depth of 1000 m.

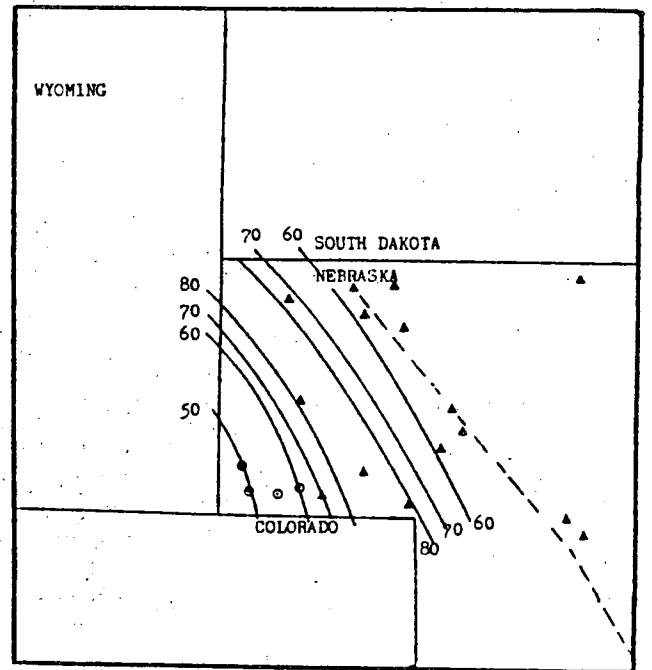


Figure 6 d. Hand contours of temperatures at a depth of 1000 m predicted by a finite difference model of heat flow with updip convection at 1 m yr^{-1} in the Dakota Group.

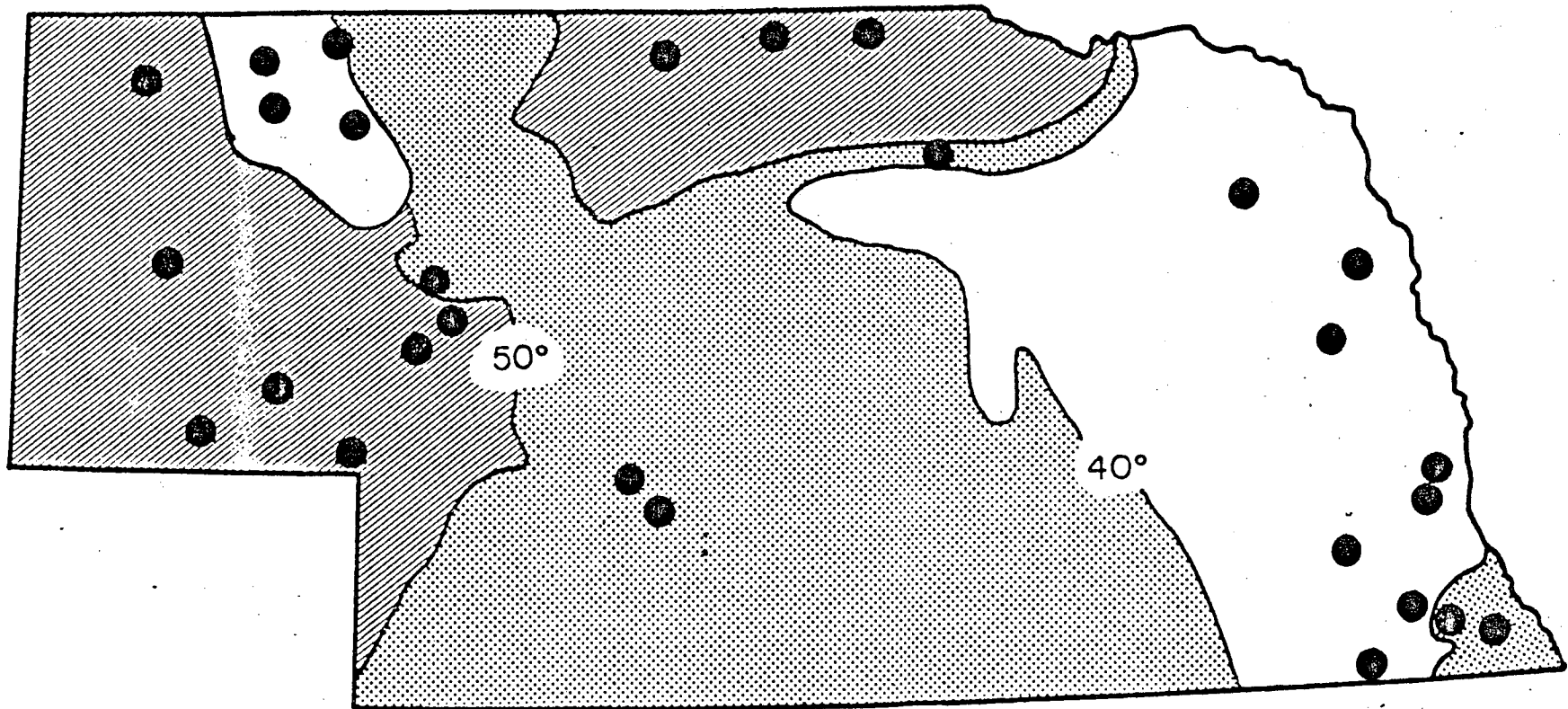


Figure 7. Temperature contours at a depth of 1 km as inferred from a synthesis heat flow data with stratigraphic and thermal conductivity data. The dots are heat flow sites.

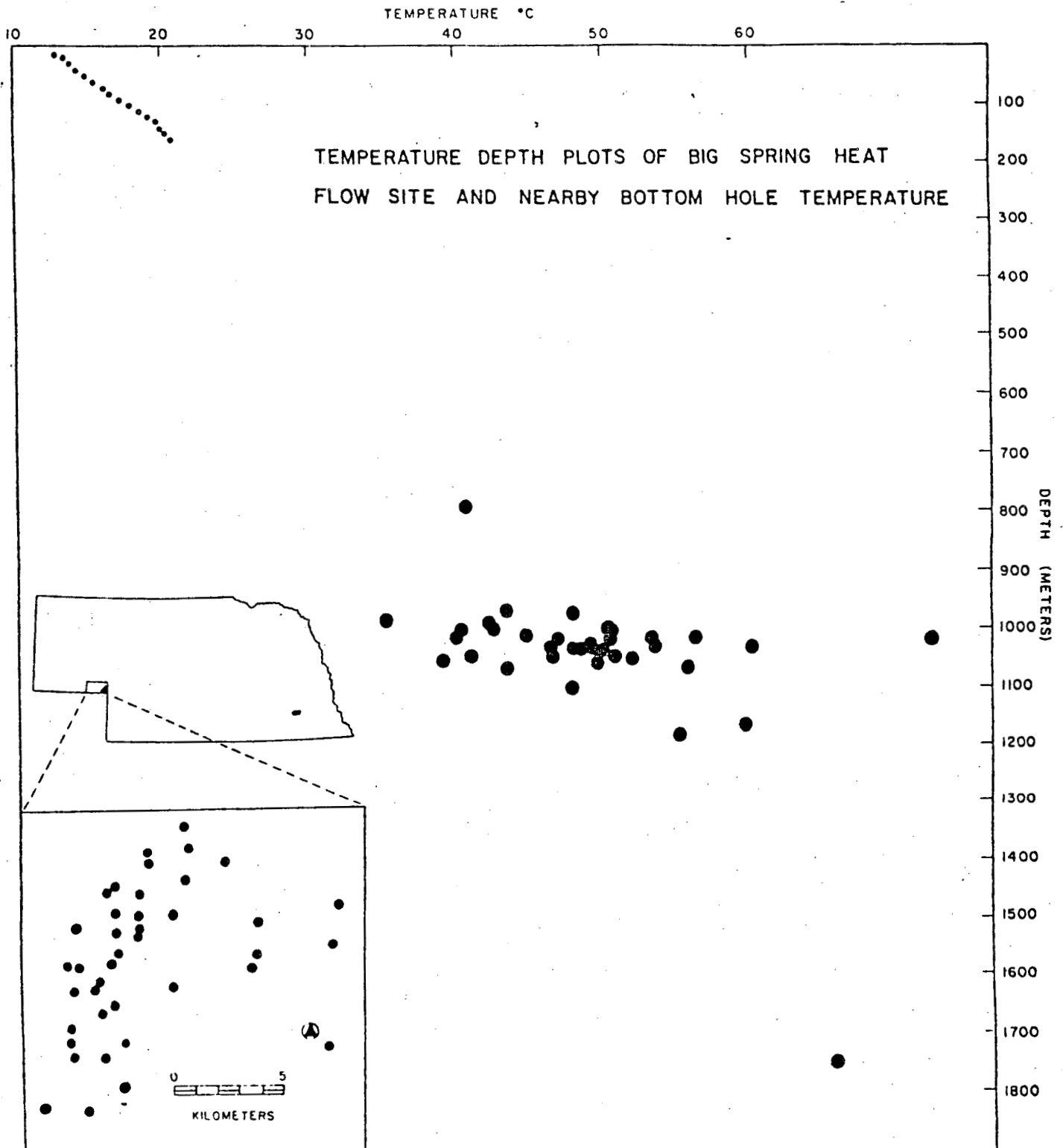


Figure 8. Comparison between the temperature gradient in a heat flow hole and bottom hole temperatures in Deuel County.

TEMPERATURE °C

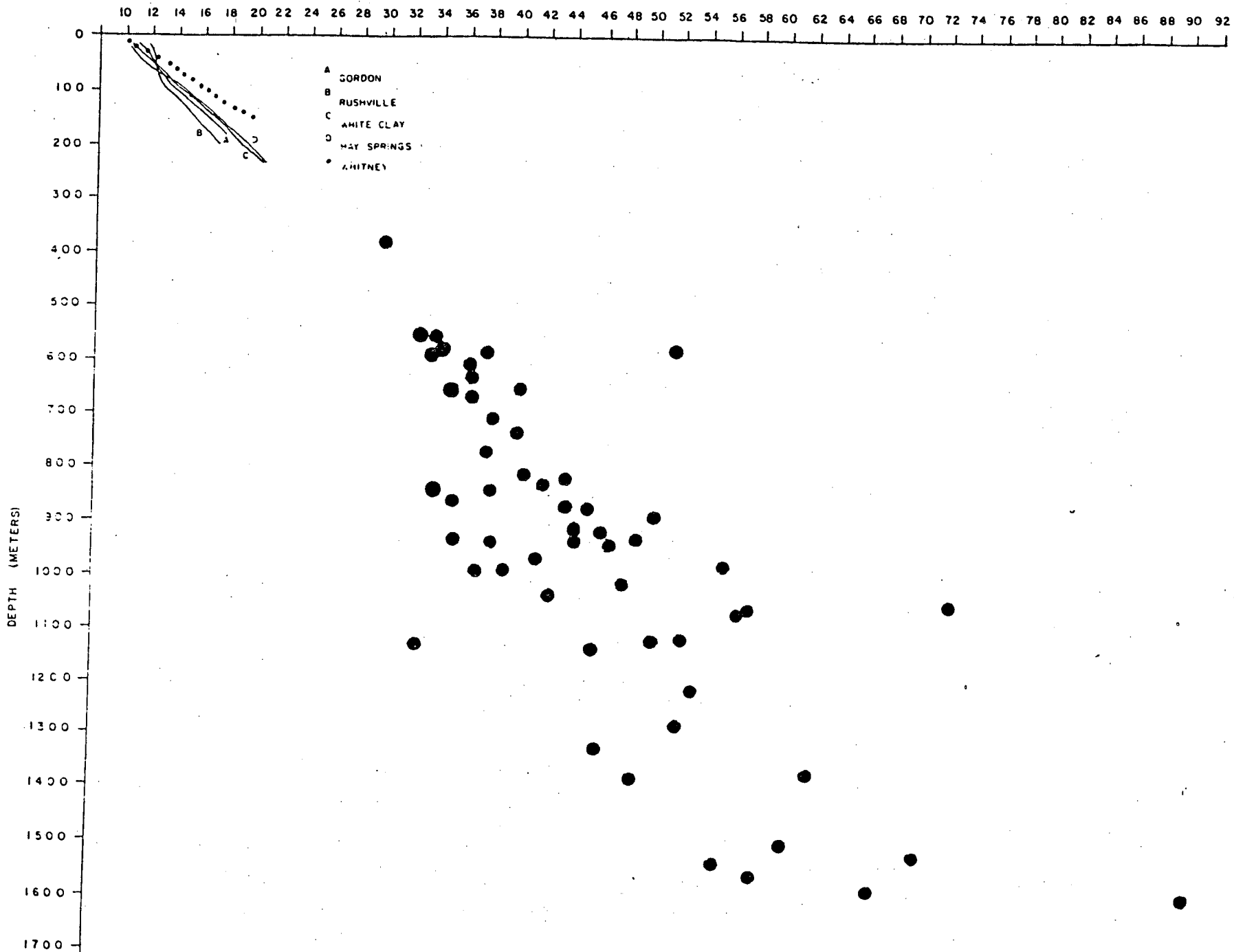


Figure 9 Comparison between multi-point temperature measurements and single-point measurements