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GEOTHERMAL DIRECT HEAT PROGRAM ROUNDUP TECHNICAL CONFERENCE PROCEEDINGS

VOLUME I

PAPERS PRESENTED

STATE COUPLED RESOURCE ASSESSMENT PROGRAM

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THREE YEARS OF GEOTHERMAL RESEARCH IN NEBRASKA

Report to the U.S. Department of Energy
State-Coupled Resource Assessment Meeting
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SUMMARY

The results of the first three years of geothermal research in Nebraska are encouraging in their promise for the discovery and development of low-temperature geothermal resources and from the standpoint of scientific value. We have developed a sucessful method for geothermal exploration and we have discovered extensive low-temperature geothermal deposits in Cretaceous age rocks that underlie a total area of about 107,000 km^2 and contain about 1000 X 10^{18} J of stored energy. Our heat flow data indicate zones of large-scale, slow flow in deep aquifers. This discovery of deep aquifer flow patterns by surface heat flow has important implications for both geothermics and hydrology. The heat flow data also indicate some areas of high heat flow that may be due to high radioactive heat generation in the Precambrian crystalline rocks. If our preliminary interpretations of these data are verified it will have a significant impact on geothermal exploration in the continental platform.

One of the original tasks of our program is evaluation of the bottom hole temperatures (BHT) for more than 14,000 oil and gas exploration wells. Our preliminary interpretations of the BHT data are that the gradient patterns indicated by the BHT data do not coincide with the known thermal regime, and that the validity of the data are questionable.

The geothermal resource map of Nebraska is in press and will be available for general distribution in late May, 1982. Public awareness of the state's geothermal resources has been enhanced through newspaper coverage of our project and through television coverage on the Nebraska Educational Television Network.

The state legislature has passed geothermal legislation (LB 708) that defines and provides for the regulation of geothermal resources and, (LB 799) to provide $100,000 in state funds to the Nebraska Energy Office for development of the state's geothermal resources.

OUTLINE OF THE GEOTHERMAL RESOURCE ASSESSMENT PROGRAM

The Department of Energy (DOE) State Coupled Program with Nebraska commenced in 1979 with the following three tasks: (1) Compile and evaluate the BHT data on file at the Conservation and Survey Division. (2) Drill about 30 shallow (150 m) heat flow holes. (3) Produce a 1:500,000 scale map showing the geothermal resource areas of the state. In 1981 the project was modified and extended for two years and a total of seven research tasks were defined including the three original tasks. The additional tasks are: (4) Analyse the BHT data heat flow data, deep well temperature data, and produce computer software to aid in the intepretation of the BHT data. (5) Produce a 1:500,000 scale map of the residual Bouguer gravity field of Nebraska. (6) Prepare reports for four substate regions based on geothermal potential and population density. (7) Disseminate information within the state and to other DOE contractors. An eighth task that deals with reporting to DOE is also included in the present contract.

CURRENT PROJECT STATUS

Task 1: More that 14,000 data sets are recorded on disk in the Conservation and Survey Division's mini-computer and on magnetic tape in the University's main computer network. The data stored include: Well location, drilling date, well elevation, elevation of Kelley Bushing, total depth, bottom hole temperature, mud temperature, time elapsed between circulation and logging, and information on formation tops. Based on the current rate of exploration and field-development drilling about 400 new data points are being added per year. These new data are added to the data file as they arrive from the Nebraska Oil and Gas Commission and a computer program designed to identify erroneous data is routinely run on the data set. Various analyses of the BHT data are in progress and we expect to complete a geothermal gradient map derived from the BHT data this summer.

Task 2: Twenty-nine wells have been completed specifically for heat flow and interpretations of the data have been reported by Gosnold and Eversoll(1981) and Gosnold, Becker, and Eversoll (1981). Heat flow estimates have been made for eight additional wells in western Nebraska which penetrate up to 1800 m of Cretaceous shales. Heat flow for most of Nebraska ranges from 40 mW m^{-2} to 60 mW m^{-2} and appears to be consistent with previous heat flow studies that included the Great Plains (see Roy, et. al., 1972; Combs and Simmons, 1973; Lachenbruch and Sass, 1977). However two laterally extensive areas with heat flow as high as 120 mW m^{-2} (Figure 1) are anomalous and were not anticipated by previous conventional heat flow studies. The high heat flow in the Nebraska panhandle is attributed to updip flow in deep aquifers in the Denver-Julesburg Basin (Gosnold and Eversoll, 1981). Temperature-depth plots for the eight deep wells in the panhandle show a systematic increase in temperature gradient along lines perpendicular to the structure contours of the Cretaceous age Dakota Group (Figure 2), and data on the potentiometric surface of the Dakota Group indicate a northeastward gradient in the panhandle area (D. Jorgenson, U.S.G.S. Lawrence, KS, personal communication). This discovery of probable flow in a deep aquifer by surface heat flow measurements is significant for both heat flow and hydrologic studies. Previous heat flow studies have identified anomalously low heat flow zones such as the Eureka Low (Lachenbruch and Sass, 1977) and the Snake River Plain (Brott, *et. al.*, 1981) that are due to hydrologic phenomena. This case appears to be similar to that of the Snake River Plain in that lateral water flow is causing the heat flow anomaly. However in the case of western Nebraska an updip component to the flow causes a heat flow high.

The high heat flow in north central Nebraska was also attributed to updip water flow in the Dakota on the eastern side of the Kennedy Basin. However a temperature profile obtained in a 500 m section of a 750 m oil exploration well drilled in November, 1981 shows no break in temperature gradient below the Dakota Group. Two possible explanations for the high heat flow that remain are that updip flow is occurring in one or more of the Paleozoic units below the logged interval or that the basement rocks have high amounts of radioactive heat generation. This question may be answered when the well is logged to total depth during the summer of 1982.

Task 3: The geothermal resources map of Nebraska is in press and will be available for distribution on May 24, 1982. The geothermal resources map is a synthesis of bottom-hole temperatures, temperature gradients, heat flow, thermal conductivity data, and stratigraphy. Most of these data were collected specifically for assessing Nebraska's geothermal resources. Additional information was acquired from open-file and published reports of the Conservation and Survey Division, University of Nebraska-Lincoln.

A major premise of this synthesis is that in a conductive thermal regime subsurface temperatures are determined by the heat flow and the thermal conductivities of the lithologic units present. Thus, where stratigraphy, thermal conductivities, and heat flow are known the subsurface temperature can be calculated for a specified depth.

The conditions necessary for applying this methodology in Nebraska were as follows. Heat flows determined at 29 strategic sites and more than 100 temperature gradient measurements defined the thermal regime of the state. The subsurface geology is relatively well known (Condra and Reed, 1959) and is not structurally complicated (Carlson, 1969). The thermal conductivities of all major lithologic units were determined by direct measurement or by calculation from heat flow and temperature gradient data. Bottom-hole temperatures measured under equilibrium conditions and temperature gradients measured in deep wells provided both input data and critical tests of the method of interpretation. Three types of control points were used for temperature calculations. First-order points are equilibrium temperatures measured in deep wells. Second-order points are deep well sites where stratigraphic data were taken from well logs and temperatures were calculated. Third-order points were selected where no deep-well data exist and stratigraphy was inferred from the closest data. Control point locations are shown in Figure 3. Subsurface temperatures were calculated for the sandstones of the Dakota Group (Cretaceous) which constitute a widespread aquifer system in much of the Great Plains. The region within which the aquifer satisfies the U.S. Geological Survey requirements for a low-temperature geothermal resource (Reed and Sorey, 1981) lie west of the dashed line in Figure 4. Another potential resource is the Madison Group (Mississippian) which is a geothermal aquifer in South Dakota (Schoon and McGregor, 1974; Martinez, 1981) and underlies a small section of northwestern Nebraska. Predicted temperatures on top of the Madison Group in Nebraska are on the order of 60 to 70 Deg. C. This region is represented by cross hatching in Figure 4. The total area included in the identified resource area is 107,000 km^2. The amount of stored energy in the Dakota group is estimated to be on the order of 1000 X 10^{18} J. The estimate is based on an assumed thickness of 100 m and a temperature drop of 15 Deg. C. for the waters extracted from the formation.

Task 4: The gravity map is in preparation by Carlos Aiken at the University of Texas at Dallas. The Bouguer correction to the gravity data will be made using the best available data on the densities of the rocks in Nebraska that lie between the land surface and the geoid. This correction should give a more accurate representation of the gravity field than the standard approach of assuming a uniform density of 2.67 g cm^{-3} for two reasons. First there are no rocks in the correction zone which have densities as high as 2.67 g cm^{-3}; second there are lateral density changes in eastern Nebraska where the Cretaceous and Paleozoic rocks crop out.

Task 5: Acquistion of equilibrium temperature data in eight deep exploration wells in western Nebraska has significantly influenced our approach to analyses of the BHT data. Comparisons between the equilibrium temperature logs and the reported BHT data are shown in Figure 5. In general the BHT data seriously underestimate the formation temperatures and the degree of underestimation increases with depth. The wide range of temperatures found in the BHT data for a small geographical area were first believed to be due to seasonal differences in mud temperatures; but a comparison of mud temperatures to BHT's shows no correlation (Figure 6). We plan to aquire many more equilibrium temperatures from shut-in deep wells during the upcoming field season and we will continue to pursue the plan of finding an acceptable correction for the BHT data.

Task 6: The exploration methodology described in Task 3 is being used on all potential aquifers in four substate regions that roughly divide the state into four parts. The potential uses of the identified resources are being analysed by personnel in the Economic Geography group at the University of Nebraska at Omaha.

Task 7: Considerable input from the Nebraska research team has been provided to to the Nebraska State Energy Office and to the state legislature during the current legislative session. The state legislature has passed two bills pertaining to geothermal energy. LB 708 defines the geothermal resource as a mineral and provides for its regulation. LB 799 is a more general energy bill that provides $100,000 in state funds to the Nebraska Energy Office for development of the geothermal resource. A number of newspaper reports on the research project have appeared during the past three years; and the Nebraska Educational Television Network has produced two programs on the project. The state team has also provided a considerable amount of information for a possible geothermal installation at Western Nebraska College in Scottsbluff.

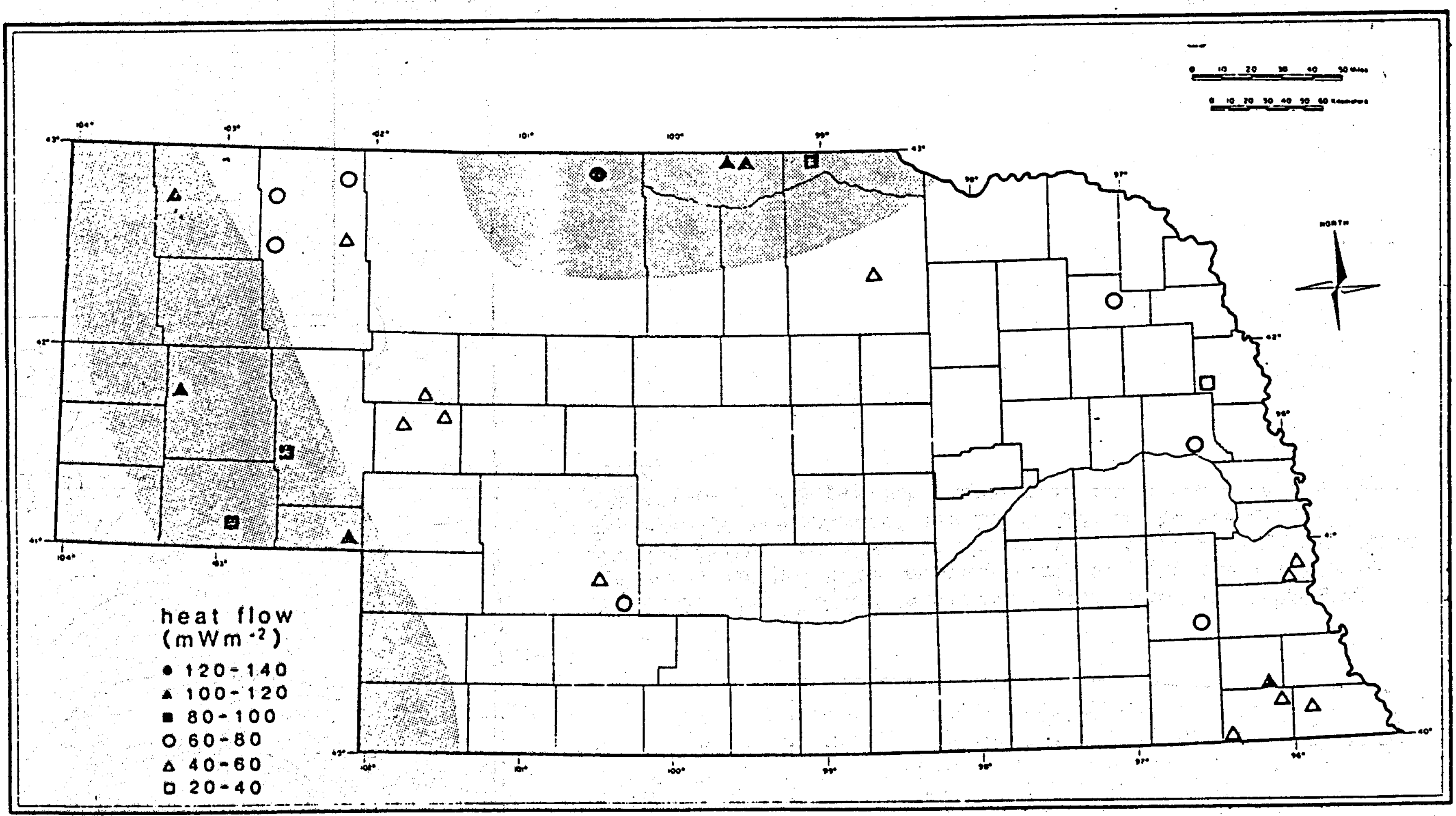
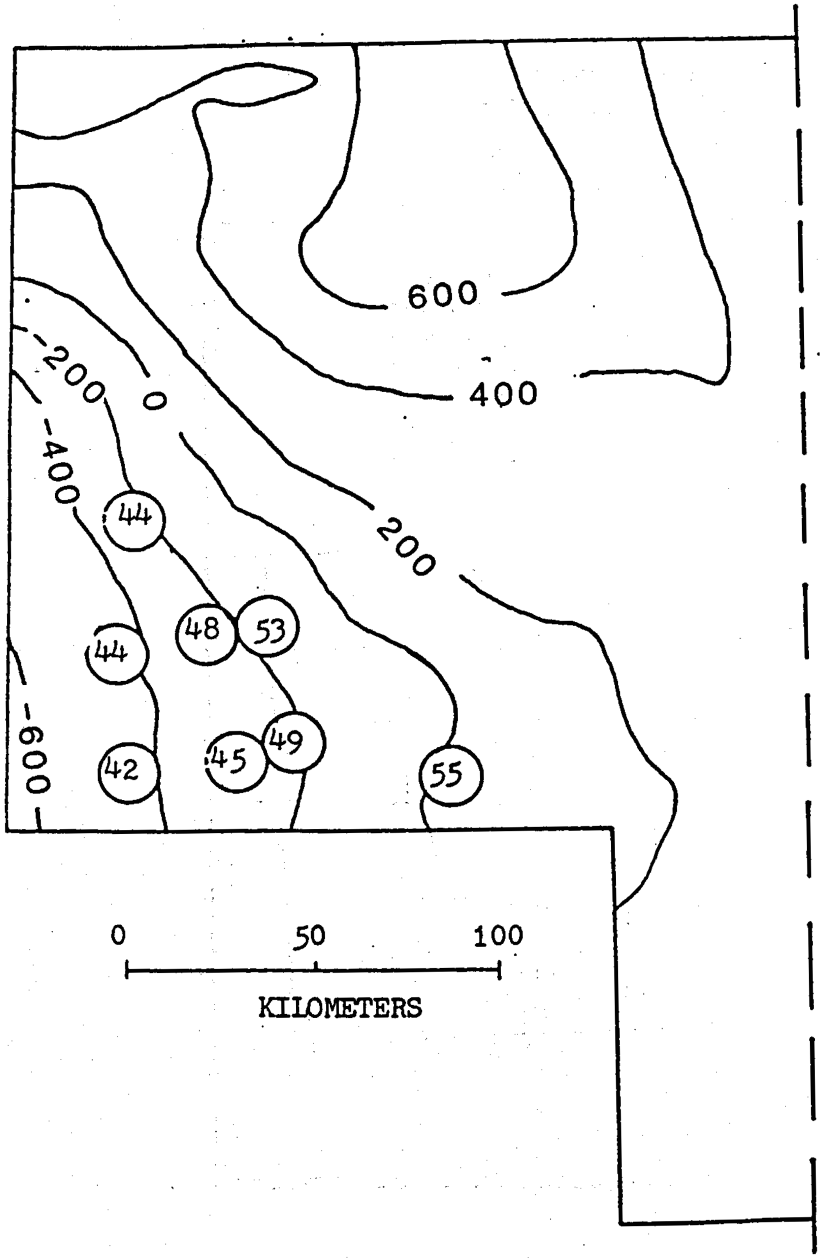


Figure 1. Nebraska Heat Flow Data. High heat flow zones are shaded but the limits of the zones are inferred and are not certain. The high heat flow zone in western Nebraska may be due to updip flow toward the north east from the Denver basin. The origin of the high heat flow zone in north central Nebraska is discussed in the text.



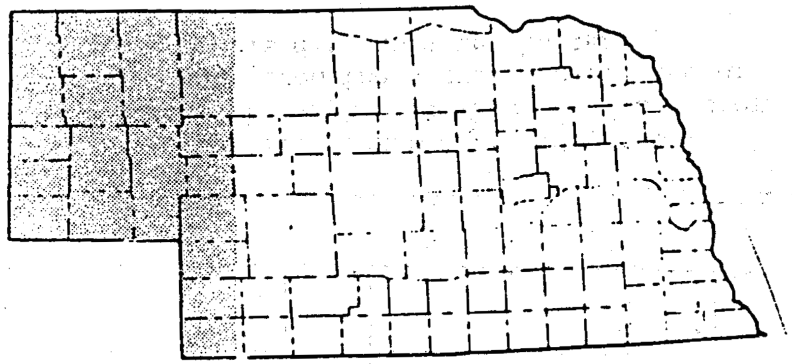


Figure 2. Equilibrium temperature gradients for eight deep wells are given in the locating circles. Structure contours for the Dakota are given in meters with datum as mean sea level. The area of the enlarged map is shaded in the map above. See Figure 5 for partial temperature-depth plots of the eight wells.

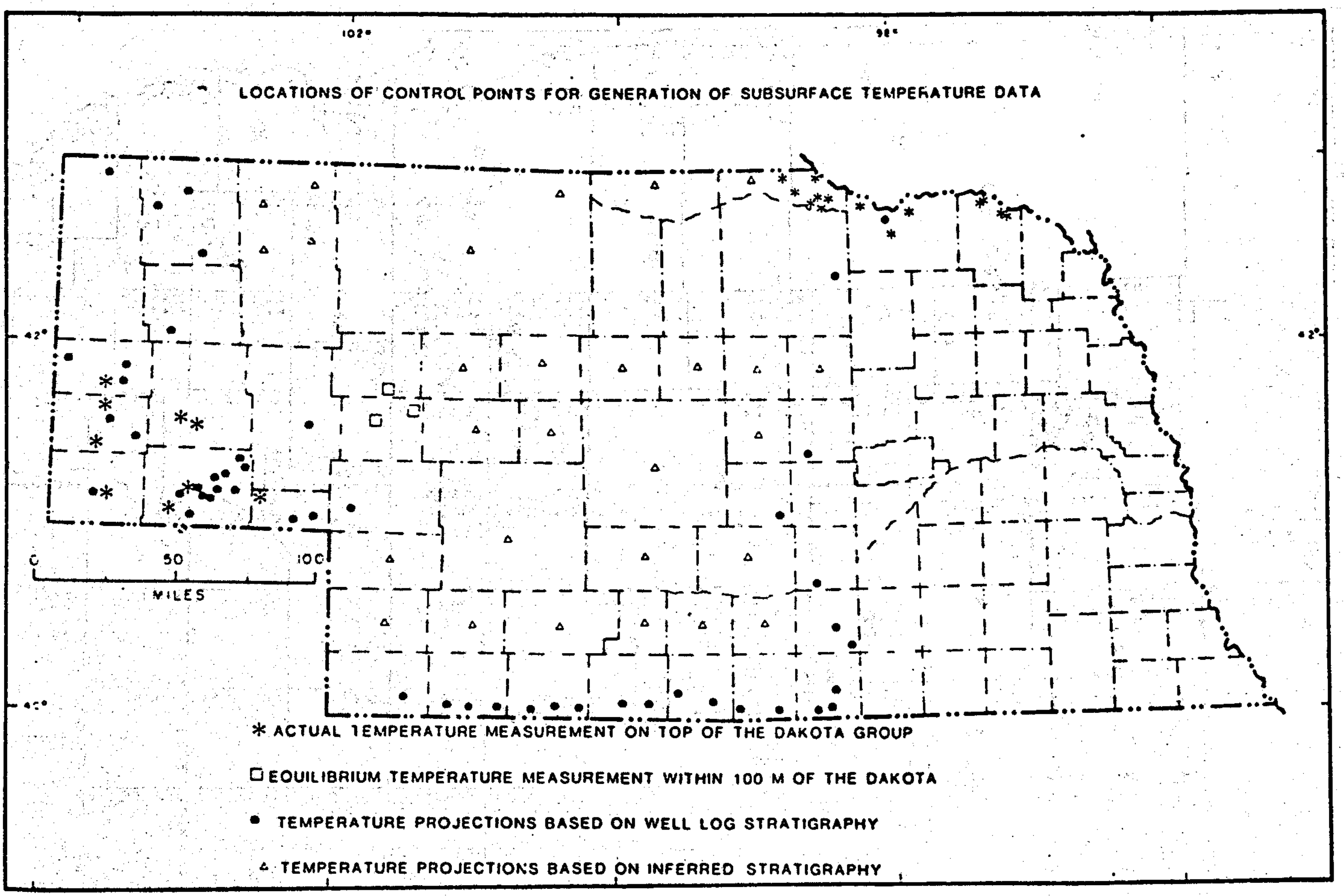


Figure 3. Control points for determination of temperatures on top of the Dakota Aquifer.

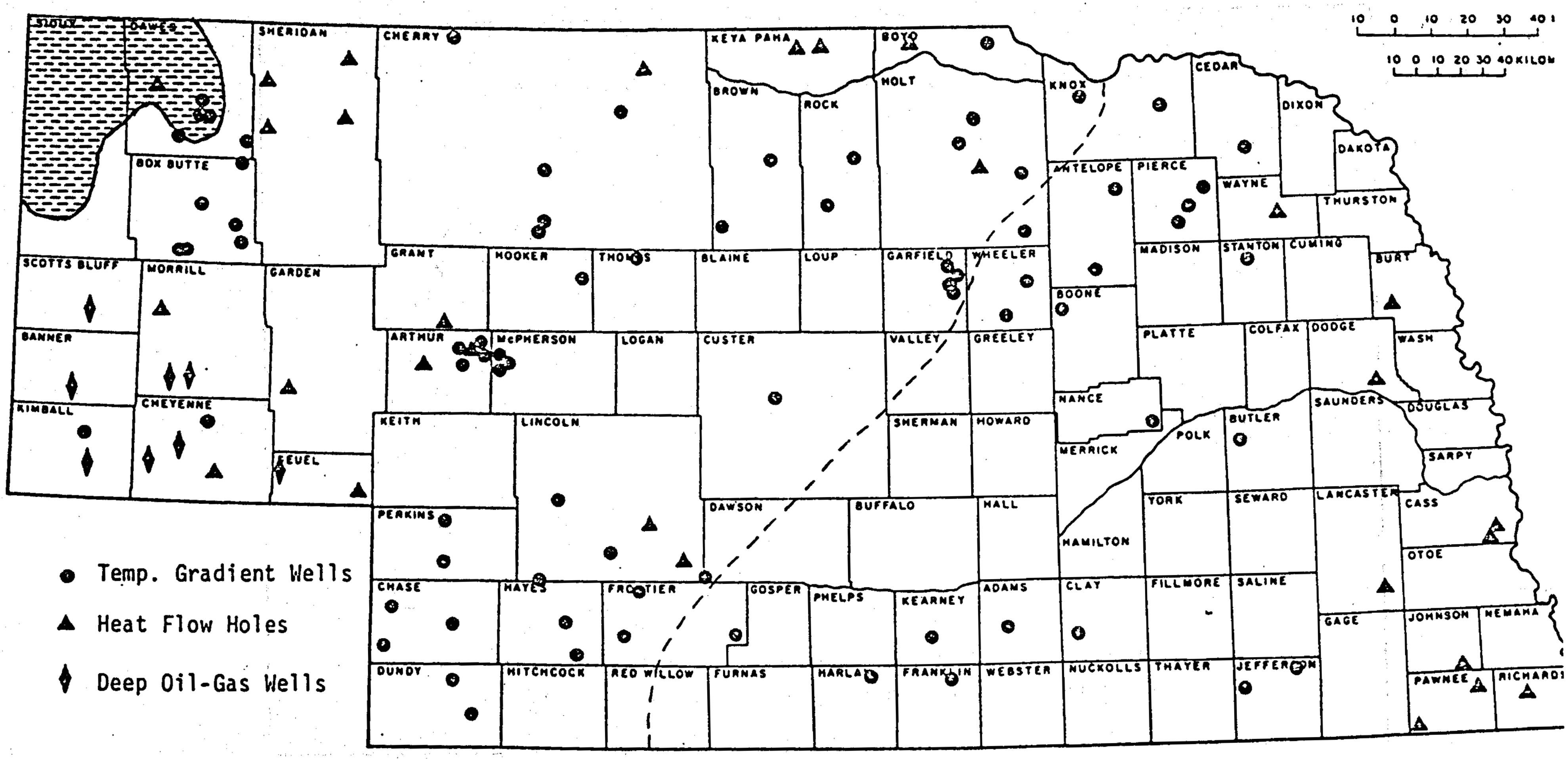


Figure 4. Geothermal data on Nebraska. The region west of the dashed line comprises the identified geothermal resource area for the Dakota Aquifer. The cross-hatched region comprises the resource area for the Madison Aquifer.

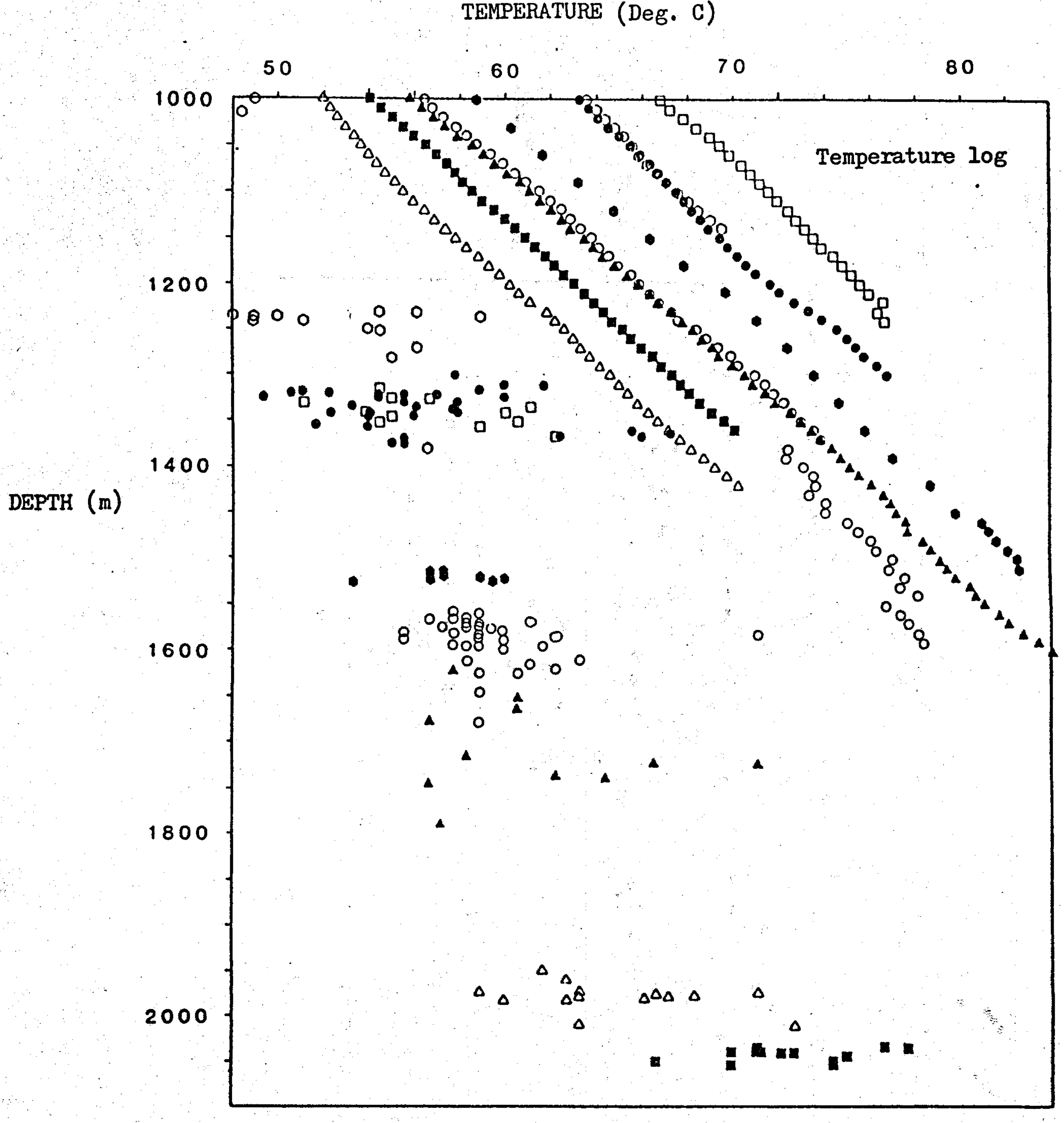


Figure 5. Comparison of temperature gradients measured in eight deep wells in the Nebraska Panhandle to bottom hole temperatures measured in oil wells within a 10 km radius of the deep well. The symbols are explained below.

Location	Least Squares Equilibrium Grad.	Projected Two-Point Gradient
○ 14N 46W sec. 9	55 Deg. C/km	37 Deg. C/km
⬢ 14N 50W sec. 4	49 Deg. C/km	32 Deg. C/km
▲ 14N 52W sec. 27	45 Deg. C/km	32 Deg. C/km
△ 14N 55W sec. 19	42 Deg. C/km	28 Deg. C/km
■ 17N 56W sec. 10	44 Deg. C/km	32 Deg. C/km
□ 18N 50W sec. 17	53 Deg. C/km	37 Deg. C/km
● 18N 51W sec. 12	48 Deg. C/km	36 Deg. C/km
○ 21N 55W sec. 28	44 Deg. C/km	32 Deg. C/km

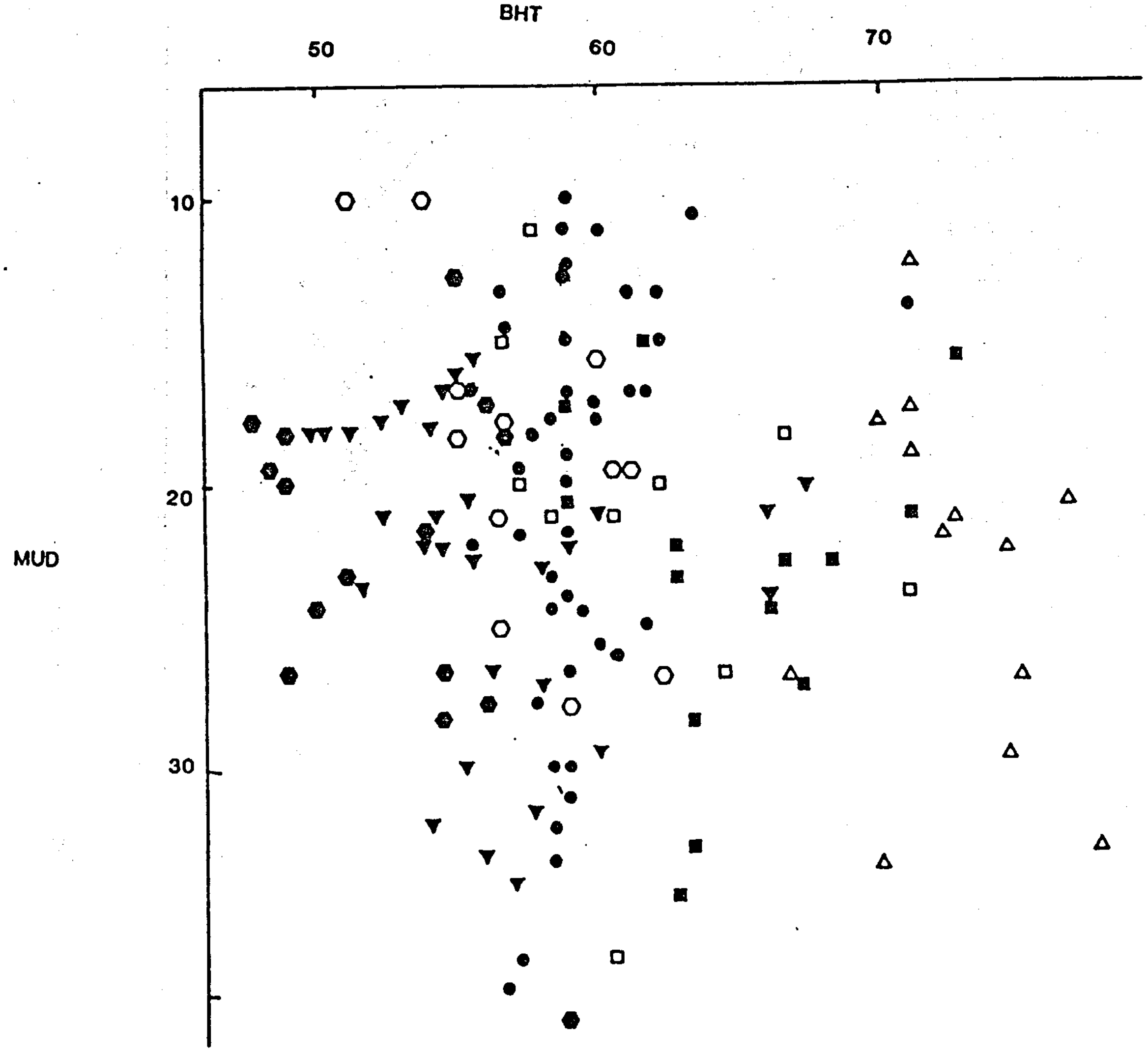


Figure 6. Comparison of Bottom Hole temperatures to MUD temperatures. Symbols are the same as Figure 5.

REFERENCES

Brott, C.A., D.D. Blackwell, and J.P. Ziagos, Thermal and tectonic implications of heat flow in the Eastern Snake River Plain, Idaho, Jour. Geophys. Res., 86, 11,709-11734.

Carlson, M.P., 1970, Distribution and subdivision of Precambrian and Lower and Middle Paleozoic rocks in the subsurface of Nebraska, Conservation and Survey Division, Univerisity of Nebraska-Lincoln, Report of Investigations No. 3, 27 p.

Combs, J., and G. Simmons, 1973, Terrestrial heat flow determinations in the North Central United States: Jour. Geophys. Res.,78, 441-461.

Condra, G.E., and E.C. Reed, 1959, The geological section of Nebraska, Nebraska Geological Survey Bulletin No. 14-A, 82 p.

Gosnold, W.D., Jr., and D.A. Eversoll, 1981, Usefulness of heat flow data in regional assessment of low-temperature geothermal resources with special reference to Nebraska, Geothermal Resources Council Transactions, v. 5, pp.79-82.

Gosnold, W.D., Jr., D.J. Becker, and D.A. Eversoll, 1981, New heat flow data from Nebraska, EOS, 62,1054.

Martinez, J.A., 1981, Geothermal Development of the Madison Group Aquifer - A case study, Geothermal Resources Council Transactions, v. 5, pp. 541-544.

Reed, M.J., and M. A. Sorey, 1981, Low-temperature geothermal resource assessment of the United States: A Progress Report, Geothermal Resources Council Bulletin, v. 10, pp. 11-14.

Roy, R.F., D.D. Blackwell, and E.R. Decker, 1972, Continental heat flow, in Nature of the Solid Earth, E.C. Robertson (ed.),McGraw-Hill, pp. 506-554.

Schoon, R.A., and D.J. McGregor, 1974, Geothermal potentials in South Dakota, Report of Investigations No. 110, South Dakota Geol. Survey, 76 p.