System Specific Geothermal Gradient/Heat Flow Data Base for the Western United States

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ABSTRACT

A data base of geothermal site-specific thermal gradient and heat flow results from individual exploration wells in the western US has been assembled. We have collected, compiled, and are synthesizing as much of the previously unavailable company temperature gradient and heat flow exploration data collected during the active geothermal system exploration of the 1970's and 1980's as we can locate and obtain. At the present time there are over 5000 well sites in the data base. The locations of 133 geothermal areas with multiple well sites are given. Examples of the use and applications of the data are briefly described. The results will be available on the World Wide Web.

Introduction

Background – The project described in this paper is focused on area specific geothermal gradient and heat flow data sets in geothermal systems in the western United States. The detailed focus is due to the more site specific nature of the geothermal resource in the high heat flow areas of the western US. We have previously (Blackwell *et al.*, 1996) expanded and updated the extensive regional geothermal data base developed for the Geological Society of America Decade of North American Geology (DNAG) *Geothermal Map of North America* (Blackwell and Steele, 1992; Blackwell *et al.*, 1989, 1991). That project extended the early geothermal resource evaluations of Muffler (1979), and Reed (1983). The results of that project are described by Blackwell *et al.* (1994, 1995, 1996) and the complete data set of thermal information for 2191 sites can be downloaded in spreadsheet format from www.smu.edu/~geothermal. The entry for each site includes location, thermal gradient, heat flow, maximum temperature, maximum depth, geology, and other pertinent data as described in the reports cited above.

Project Objective–The technical objective of this project is to characterize individual geothermal systems in the western United States both with respect to their local and their regional settings based on thermal gradient and heat flow data that are in the public domain. This objective is being met by first developing a data base of site specific heat flow, geothermal gradient, and thermal conductivity information for geothermal systems in the western United States. Secondly we are making the data readily available for use by developers and other researchers involved in the process of resource evaluation. The third step is to implement the second step by developing and operating an Internet home page with results of the project available in the form of downloadable data and map summaries of results. Fourth, we will add to the usefulness of the data sets by supplementing the information where there are data gaps. Fifth, and finally, we will use the results of compilations to develop generalized models for the site specific evaluation of resource potential. The results of the first three steps are described in this paper.

Approach

This project is in the middle of a multi-year effort to map and evaluate the geothermal conditions at depths of several km in the United States. By expanding the focus of the project from regional conditions for the eastern US, the emphasis in the previous study (Blackwell *et al.*, 1994, 1995, 1996), to the more complex geothermal conditions in the western Cordillera, the amount of well information on geothermal conditions both needed and available is greatly increased. The thermal data from the western US for this study are being collected from a variety of published and unpublished sources. During the active geothermal system exploration of the 1970's and 1980's thousands of holes were drilled for geothermal gradient and heat flow studies. We are collecting, compiling, and synthesizing as much of the company temperature gradient and heat flow exploration data as can be located. In addition, public domain data available in publications and open-file reports are being compiled in the same format for completeness and easy access to all well information for a particular geothermal area.

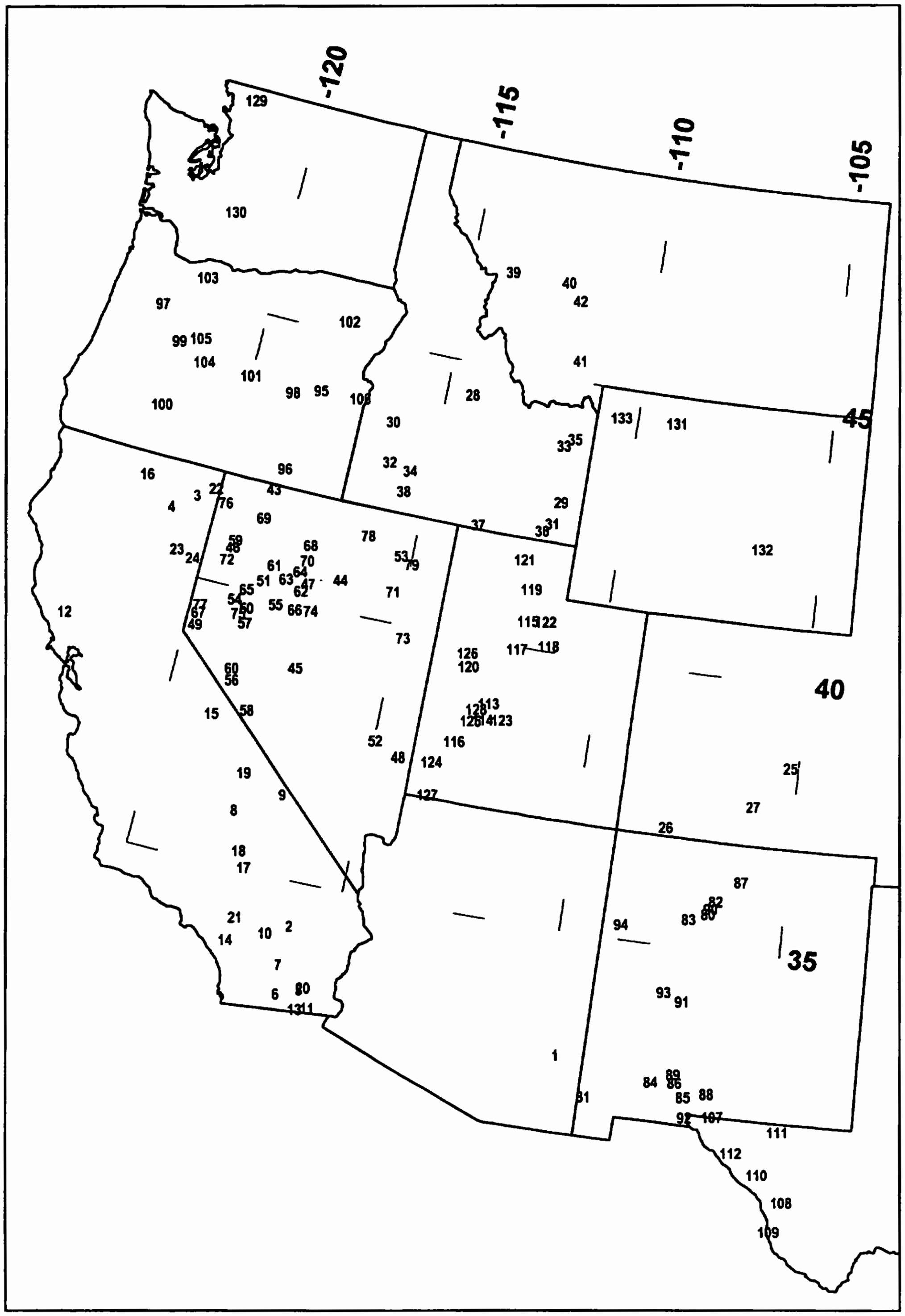

Figure 1. Geothermal areas listed in Table 1. Areas shown have multiple sites within them. Not shown in figure are single well locations.

Research Results

Geothermal System Heat flow and Thermal Properties Data Base

One of the main results of this project is development of a well data base similar to the regional data base, but geothermal system specific. The ideal set of information for each geothermal gradient/heat flow exploration well site is similar to the regional data set and includes, for each well, maximum and bottom hole temperature, location (by latitude /longitude and township/ range), thermal gradient(s) and depth ranges, thermal conductivity, heat flow, lithology, and a reference (or references) to any publication of the results and/or the source of the original thermal information. Other information is included as available. Where the temperature-depth data are available in detailed form multiple intervals of gradient are included in the data tables if the temperature depth curves are nonlinear.

The locations of 133 geothermal areas with data that are available to us at the present time are shown keyed by number on Figure 1 to a corresponding name and location listed in Table 1. To compile Table 1 we have included sites as areas when there are multiple well locations and a geothermal anomaly. There are many additional single well sites with anomalous gradients that are not included in Table 1 and many areas of wells that have essentially regional geothermal gradients. Finally one large data set was not included in the production of the map shown in Figure 1 because of the structure of the data. These sites will be included in the future. A number of producing areas are represented by only a small number of sites in the data base.

Table 1. Western United States geothermal area locations, as shown in Figure 1.

Geothermal Locations	LAT	LONG	Map #	Geothermal Locations	LAT	LONG	Map #
Safford Basin, Arizona	32.75	-109.67	1	Paradise Valley, Nevada	41.07	-117.51	68
29 Palms, California	34.18	-116.01	2	Pinto Mountain, Nevada	41.36	-118.79	69
Alturas Basin, California	41.47	-120.53	3	Pumpernickel Valley, Nevada	40.77	-117.49	70
Beiber, California	41.15	-121.06	4	Ruby, Nevada	40.55	-115.28	71
Brawley, California	33.08	-115.50	5	San Emidio, Nevada	40.45	-119.41	72
Cactus, California	32.92	-115.98	6	Shellbourne, Nevada	39.76	-114.81	73
Coachella Valley, California	33.45	-116.06	7	Shoshone, Nevada	39.89	-117.15	74
Coso Hot Spring, California	36.04	-117.82	8	Soda Lake - Stillwater, Nevada	39.54	-118.83	75
Death Valley, California	36.51	-116.82	9	Soldier Meadows, Nevada	41.46	-119.79	76
Desert Hot Springs, California	33.96	-116.50	10	Truckee Meadows, Nevada	39.53	-119.76	77
East Mesa, California	32.79	-115.23	11	Tuscarora, Nevada	41.47	-116.17	78
Geyers-Clearlake, California	38.75	-122.83	12	Wells, Nevada	41.11	-114.97	79
Heber, California	32.72	-115.50	13	Albuquerque, New Mexico	35.65	-106.70	80
Lake Elsinore, California	33.68	-117.33	14	Animas, New Mexico	32.07	-108.93	81
Long Valley, California	37.65	-118.86	15	Baca - Valles Area, New Mexico	35.89	-106.57	82
Medicine Lake-Glass Mtn., CA	41.61	-121.85	16	Cabezon, New Mexico	35.52	-107.13	83
Mojave Desert, California	35.05	-117.30	17	Florida, New Mexico	32.50	-107.52	84
Randsburg, California	35.33	-117.50	18	Las Alturas, New Mexico	32.29	-106.78	85
Saline Valley, California	36.75	-117.80	19	Las Cruces, New Mexico	32.53	-107.00	86
Salton Sea, California	33.13	-115.41	20	Ojo Caliente Warm Springs, NM	36.30	-106.04	87
San Bernardino-Harlem HS, CA	34.12	-117.23	21	Otero County, New Mexico	32.39	-106.28	88
Surprise, California	41.67	-120.12	22	Rio Grande Rift, New Mexico	32.68	-107.05	89
Susanville, California	40.41	-120.65	23	San Diego Grant, New Mexico	35.75	-106.66	90
Wendel-Amedee- Honey Lake, CA	40.32	-120.23	24	Socorro, New Mexico	34.02	-107.04	91
Canon City, Colorado	38.48	-105.19	25	Strauss, New Mexico	31.92	-106.70	92
Durango, Colorado	37.15	-107.92	26	Tres Montosas, New Mexico	34.15	-107.48	93
San Luis Valley, Colorado	37.70	-105.96	27	Zuni , New Mexico	35.27	-108.63	94
Bayhorse, Idaho	44.40	-114.32	28	Beulah, Oregon	43.88	-118.17	95
Blackfoot, Idaho	42.75	-111.60	29	Borax Lake - Alvord Valley, Oregon	42.33	-118.58	96
Boise, Idaho	43.62	-116.18	30	Breitenbush, Oregon	44.67	-122.67	97
Franklin County - Maple Grove, Idaho	42.33	-111.73	31	Burns, Oregon	43.72	-118.86	98
Grandview, Idaho	42.88	-116.06	32	Cascades, Oregon	44.10	-122.00	99
Madison County, Idaho	43.79	-111.78	33	Crater Lake, Oregon	42.90	-121.99	100
Magic Reservoir - Snake Rv. Plains, ID	42.80	-115.50	34	Glass Butte, Oregon	43.83	-120.00	101
Newdale, Idaho	43.94	-111.53	35	La Grande, Oregon	45.22	-117.87	102
Preston - Bear River Prospect, Idaho	42.17	-111.95	36	Mount Hood, Oregon	45.35	-121.75	103
Raft River, Idaho	42.08	-113.55	37	Newberry , Oregon	43.85	-121.25	104
Twin Falls and Jerome Counties, Idaho	42.41	-115.55	38	Santiam Pass, Oregon	44.25	-121.50	105
Deer Lodge, Montana	46.75	-113.90	39	Vale, Oregon	43.90	-117.14	106
Marysville, Montana	46.75	-112.37	40	Hueco Tanks, Trans-Pecos, Texas	31.99	-106.10	107
Texton - Ennis Geothermal Area, MT	45.37	-111.73	41	Marfa, Texas	30.54	-104.44	108
White Sulfur Springs, Montana	46.45	-111.99	42	Presidio Bolsum, Texas	29.97	-104.65	109
Baltazor and McGee, Nevada	41.92	-118.73	43	Rio Grande Valley, Texas	31.00	-105.02	110
Beowawe, Nevada	40.56	-116.60	44	Salt Basin, Texas	31.83	-104.66	111
Big Smokey Valley Area, Nevada	38.81	-117.19	45	Van Horn, Texas	31.36	-105.62	112
Black Rock Desert, Nevada	40.70	-119.35	46	Best, Utah	38.88	-112.49	113
Buena Vista Valley, Nevada	40.36	-117.35	47	Cove Fort Sulphurdale, Utah	38.57	-112.57	114
Caliente, Nevada	37.62	-114.37	48	Crystal Hot Springs, Utah	40.49	-111.91	115
Carson - Eagle Valley, Nevada	39.16	-119.77	49	Escalante Desert, Utah	38.09	-113.14	116
Carson Sink, Nevada	39.67	-118.67	50	Eureka, Utah	39.95	-112.05	117
Colado, Nevada	40.24	-118.43	51	Fifth Water, Utah	40.10	-111.31	118
Coyote Springs, Nevada	37.83	-114.97	52	Hill Air Force Base, Utah	41.08	-111.96	119
Deeth, Nevada	41.23	-115.27	53	Little Drum - Keg Mountains, Utah	39.48	-113.13	120
Desert Peak-Brady Hot Springs, Nevada	39.78	-119.00	54	Little Mountain, Utah	41.59	-112.25	121
Dixie Valley, Nevada	39.86	-118.01	55	Midway, Utah	40.53	-111.47	122
Excelsior, Nevada	38.33	-118.59	56	Monroe-Red Hill, Utah	38.63	-112.11	123
Fallon NAS - Carson Lake, Nevada	39.41	-118.62	57	Newcastle, Utah	37.66	-113.57	124
Fish Lake -Alum - Emigrant, Nevada	37.86	-118.08	58	Roosevelt Hot Springs, Utah	38.51	-112.84	125
Fly Ranch, Hualapai Flat, Gerlach, NV	40.83	-119.33	59	Spor Mountain, Utah	39.72	-113.22	126
Hawthorne, Nevada	38.54	-118.66	60	St. George Basin, Utah	37.05	-113.53	127
Humboldt House - Rye Patch, Nevada	40.55	-118.25	61	Twin Peaks, Utah	38.74	-112.75	128
Jersey Valley, Nevada	40.20	-117.48	62	Baker Mountain, Washington	48.76	-121.81	129
Kyle Hot Springs - Granite Mountain, NV	40.36	-117.90	63	Ohanapecosh, Washington	46.66	-121.51	130
Leach Hot Springs-Grass Valley, NV	40.55	-117.61	64	Cody, Wyoming	44.50	-109.00	131
MacFarland Hot Springs, Nevada	40.01	-118.77	65	Laramie, Hanna & Shirley Basins, WY	42.40	-106.45	132
McCoy, Nevada	39.85	-117.53	66	Yellowstone National Park, Wyoming	44.46	-110.44	133
Moana -Steamboat Springs, Nevada	39.39	-119.76	67				

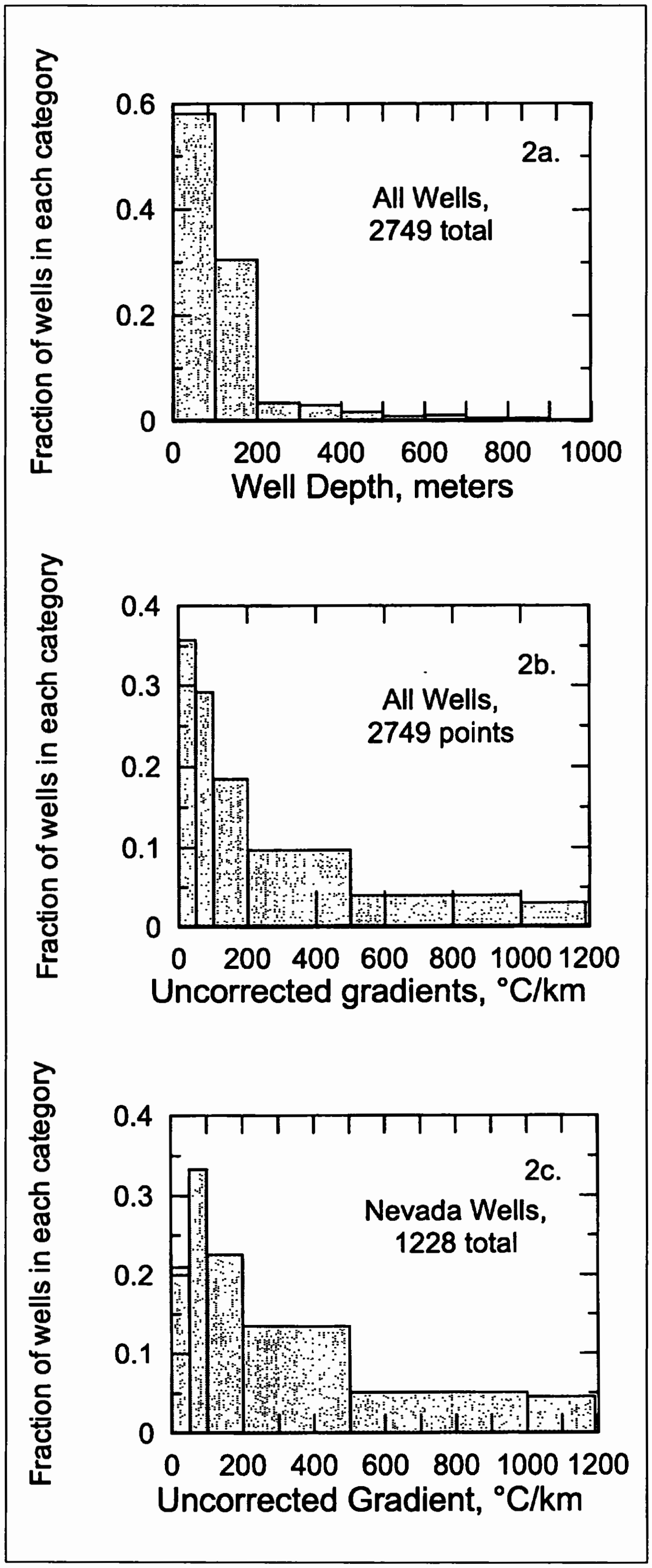

Figure 2. Histograms of well depth and "uncorrected" gradient.

The emphasis in this compilation has been on data from areas where exploration and/or evaluation activity might occur in future development of geothermal resources.

There are a total of 5040 sites in 10 western states in the data base at the present time. The data available for each well ranges from extensive to only a location and a geothermal gradient, so complete comparisons of the results are difficult. A histogram of the well depths from a subset of 2749 of the wells with the most complete data is shown in Figure 2a. Most of the wells are less than 200 m (700 ft) in depth as exploration wells have been the focus of the compilation. However, 113 wells are greater than 1000 m in depth. A histogram of the "uncorrected" geothermal gradients for the 2749 wells is shown in Figure 2b. The median value for geothermal gradient is 71 °C/km while the average is 185 °C/km. A similar histogram for the state of Nevada alone for 1228 wells is shown in Figure 2c. The median and averages for this subset are 93 and 245 °C/km, slightly higher than the total data set. Of the 2749 well subset a total of 195 have reported temperatures above 100 °C and 114 have temperatures above 150°C.

Tables of the thermal data will be available on our web site at smu.edu/~geothermal as the data are checked and verified and converted into spreadsheet format. The site can be consulted for the status of individual data sets and requests for status information on specific areas can be directed to the web site or the authors of this paper.

Resource Analysis

Data sets from individual geothermal areas will be described by maps and other graphical information to allow easier access to the data by interested parties (see the web page discussion below). An example is shown in Figure 3 for the McCoy geothermal area in Churchill County, Nevada (Olson *et al.*, 1979, Pilkington, 1982, AMAX, 1980, 1981a, 1981b, 1981c). The thermal gradient contours from the compiled data set are overlaid on a scanned version of the county geologic maps (Willden and Speed, 1974; Stewart and McKee, 1977). Overlays with topography are also possible due to the availability of digital data sets at 1:250,000 and 1:24,000 scales from the US Geological Survey.

In addition to compiling the thermal data a resource analysis is being done. Preliminary results of the analysis of the database were described by Wisian *et al.* (1999). They found that 95% of the geothermal systems with temperatures over 150°C occur in areas where the regional heat flow is greater than 80 mWm^{-2}. This result can be attributed to two factors. Young magma chambers will be found in areas with high regional heat flow as high temperature conditions are required at depth to generate magmas. Secondly, for geothermal systems related to deep circulation of water rather than localized magma systems, there seems to be a "maximum" depth of circulation of about 6 km. Thus the higher the heat flow in an area, the higher will be the temperature experienced by the deeply circulating water. Clearly background heat flow is one factor in evaluating regional potential for high temperature geothermal systems.

Web Page Data

A major part of the dissemination of the results is the availability of the data in spread sheet form and downloadable from our home page on the World Wide Web at smu.edu/~geothermal. The web site is designed for user friendly open dialog between the SMU Geothermal Laboratory and interested persons in the geothermal field. At the present time this site contains the regional heat flow/geothermal gradient database, a regional data reference list, a geothermal system specific reference list, and US maps of various kinds in downloadable form, and examples of temperature-depth curves and their interpretations. The individual geothermal system data sets and analysis results will be available on the web site as well. Data for areas not presently on the web site due to incompleteness or lack of error checking, but listed in Table 1, are available upon request. Additional examples of maps similar to those shown in Figure 3 are included on the web site as well as a tutorial in the interpretation of temperature-depth curves.

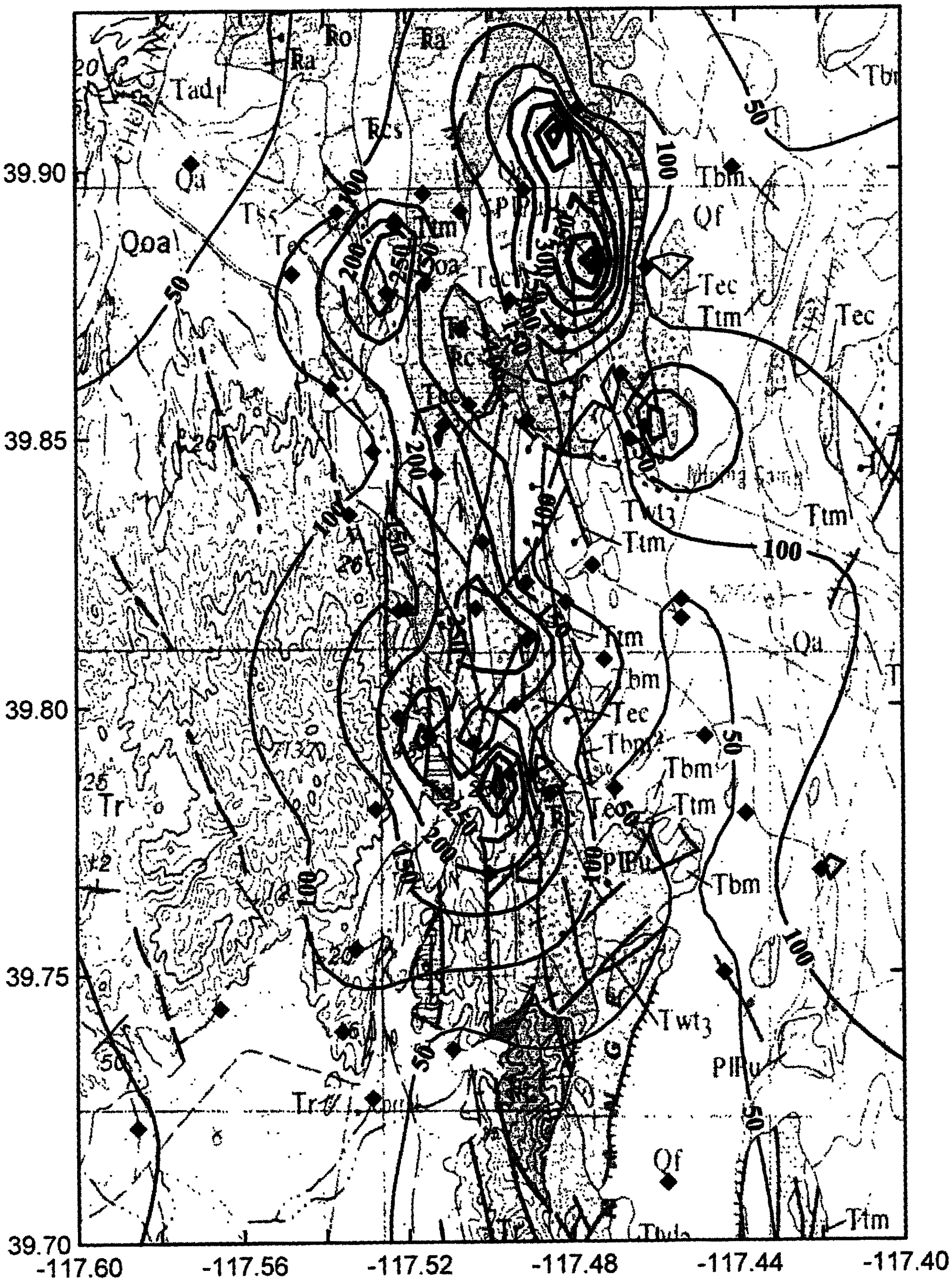

Figure 3. McCoy Geothermal Area, NV. Well locations are shown with diamond symbol. Gradient contours are overlayed on the geologic map. Contour values increase with increasing line thickness.

Future Plans

In the future there are plans to add additional data to the regional thermal properties data base and to keep updated results available by operating the home page on the Internet with the up-to-date information on line. The database of exploration heat flow wells in the western US will be developed and expanded. The regional resource evaluation and exploration methodology used in the earlier studies, with appropriate modifications, will be applied to the western US. Local system evaluations will be made using the data compilations.

Acknowledgments

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