SOUTH DAKOTA GEOTHERMAL RESOURCES

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South Dakota is normally not thought of as a geothermal state. However, geothermal direct use is probably one of the best kept secrets outside the state. At present there are two geothermal district heating systems in place and operating successfully, a resort community using the water in a large swimming pool, a hospital being supplied with part of its heat, numerous geothermal heat pumps, and many individual uses by ranchers, especially in the winter months for heating residences, barns and other out building, and for stock watering.

GEOLOGY AND RESOURCE BACKGROUND

The best known and most significant geothermal resource in the state is the Madison Limestone. It is well known as an aquifer and oil producing formation throughout the northern Great Plains and Rocky Mountains. The Madison (also known as the Pahasapa) contains about 179 miles^3 (746 km^3) of recoverable water with temperatures range from about 86°F to 216°F (30°C to 102°C) and a mean resource base is 2.78 x 10^{18} Btu (2,930 x 10^{18} J) (Gosnold, 1987 and revised in 1991). The Madison is one of the two geothermal aquifers that are presently used in direct-heat applications. The other is the Newcastle-Dakota Sandstone. Recent work, including eight potential geothermal aquifers, estimate the accessible geothermal resource base (about 0.001 times the resource base) of South Dakota as 12.52 Exajoules (10^{18}) or 11.88 quads as shown in Table 1 (Gosnold, 1991).

Table 1. Geothermal Accessible Resource Base for South Dakota

Formation	Resource Exajoules	Avg. Thick. m	Avg. Temp. °C	Max. Temp. °C
Dakota	0.42	36.5	18.5	73.4
Jurassic	1.22	81.9	42.5	71.5
Spearfish	0.66	43.8	57.7	82.3
Minnekahta	0.52	36.8	46.4	85.4
Minnelusa	2.02	134.1	47.3	86.5
Madison	2.93	153.7	51.0	90.3
Ord-Dev	2.90	140.2	53.7	97.2
Cambrian	1.85	110.0	56.1	104.8
Total	12.52			

* Temperatures are given for formation tops. Average thickness values are calculated from top to top. All of the formations named aquifers which may produce water. Higher temperatures are typical for the Williston Basin in northwestern South Dakota.

The Madison Limestone formation underlies at modest depths the western half of South Dakota. The recharge water is assumed to come from the Black Hills in South Dakota and the Big Horn Mountains and the Laramie Mountains in Wyoming (Applied Physics Laboratory, 1977). The Madison waters are considered potable in southwestern quarter of the state and are brackish in the northwestern quarter of the state.

The Mississippian age Madison Group is a sequence of carbonate rocks deposited over several western states including part of South Dakota, mainly west of the Missouri River (Figure 1). The sequence in South Dakota thickens from zero on the east edge to 1300 feet (400 m) in the northwest corner of the state (Figure 2) (Gries, 1977 and Martinez, 1981). After recession of the Mississippian seas, erosion and dissolution of the limestone created a karst topography. The Madison Group was then down warped into the Williston Basin to the north, and uplifted and eroded in the Black Hills to the west (Figure 3) (Schoon and McGregor, 1974). The depth to the top of the Madison varies from 1000 feet (300 m) in the east to over 7,000 feet (2,100 m) in the northwest (Figure 4) (Gries, 1977).

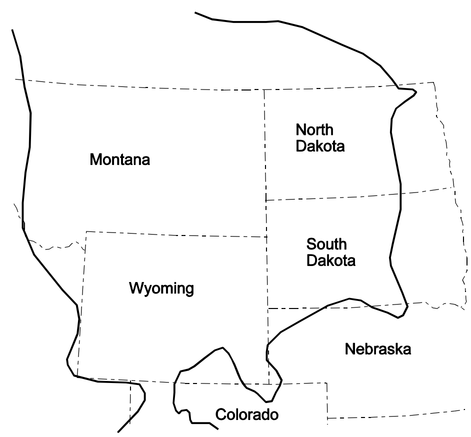

Figure 1. Extent of the Madison Group.

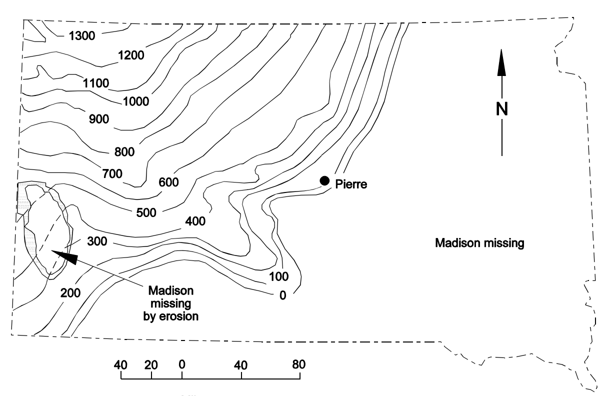

Figure 2. Thickness of the Madison Group.

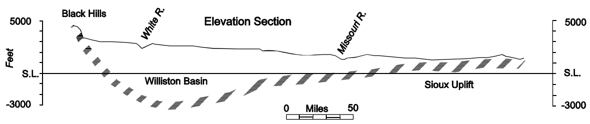

Figure 3. Profile of the state from Rapid City to Sioux Falls.

The average porosity of the Madison Group is 8% (Freeman and Meier, 1978) resulting from normal intergranular porosity, joint and fracture systems, and solution openings. Recharge occurs through infiltration of rain and snowmelt, and from water loss to sinkholes in limestone creekbeds in the Black Hills outcrop area. The average expected discharge for a properly constructed and developed well in the area is 500 gpm (32 L/s), with a range from 80 to 1000 gpm (5 to 63 L/s) (Gries, 1977).

Water temperature in wells in the Madison Groups is a function of depth to the resource - the typical gradient being near normal at 2°F/100 feet (37°C/km). Anomalous high gradients exist in the west central and southwest part of the state (exceeding 5.4°F/100 feet - 100°C/km) as shown in Figure 5 (Gosnold, 1991) and inferred from Figure 6 (Gries, 1977). Heat flow varies between 81 mW/m^2 and 112 mW/m^2 in the Madison (Gosnold, 1988).

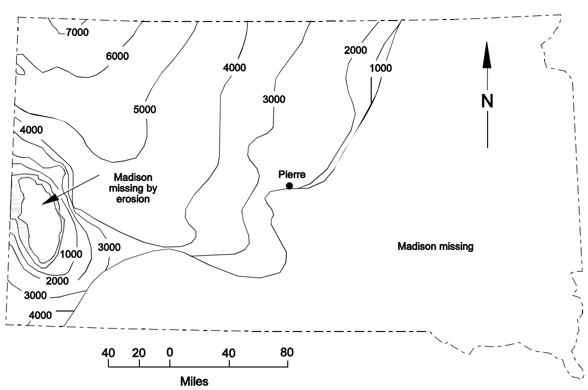

Figure 4. Depth to the top of the Madison Group.

Water quality varies widely, being best near the Black Hills and decreasing in quality radially outward. Disposal is not a major problem, however radium 226 has been detected in wells located in the west central portion of the state, and thus requires special treatment (see the article on Philip). Scaling of pipelines with calcium carbonate, calcium sulfate, silica or iron may occur if the water is allowed to cool and evaporate, but is normally not a problem. A bornite scaling (a black copper-iron-sulfate deposit) was observed by the author in a plate heat exchanger in the Midland School. Similar results were observed from testing using a corrosion test rack (Carda, 1978). Severe corrosion was experienced with "homemade" heat exchangers in the Philip Municipal Water Treatment Plant and in a commercial shell-and-tube heat exchanger in Midland. These has now been replace with plate heat exchangers, showing little corrosion problems.

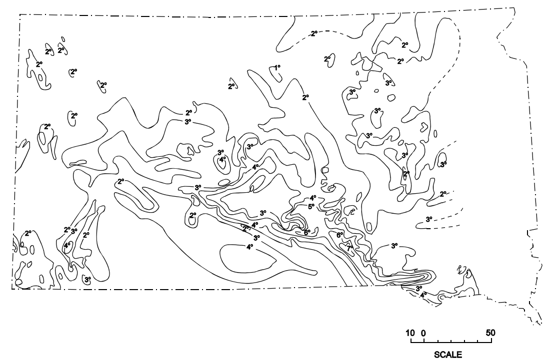

Figure 5. Geothermal gradient map modified from Schoon and McGregor (1974).

Examples of the Madison Group water quality is shown in Table 2 in ppm (mg/L) (Carda, 1978).

Table 2. Madison Group WaterQuality

Name	TDS	Temp	SO_4	Cl	Ca	Na
Edgemont	1140	130°F	280	257	130	180
Philip	1172	153°F	633	21	221	15
Midland	1462	160°F	736	28	272	18
EAFB*	1210	129°F	214	3	73	8

*Ellsworth Air Force Base near Rapid City

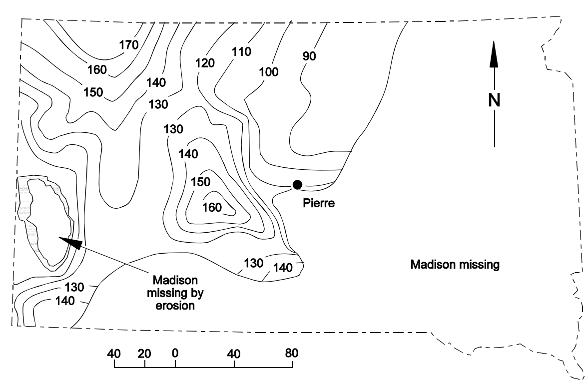

Figure 6. Isothermal map of the Madison Group.

EXAMPLES OF GEOTHERMAL DIRECT UTILIZATION

Early Uses

Warm artesian water from the Madison or Pahasapa Formation were observed as early as the 1880s in eastern South Dakota. The drilling of the first deep water well (2,983 ft) at Edgemont, Fall River County, 1910-13, demonstrated the potential of this formation. The flow of this well attracted attention because of its volume, 515 gallons per minute (32 L/s), its abnormally high temperature (130ºF [54ºC]) and its high shut-in pressure of 94 pounds per square inch (6.5 bar).

Subsequent drilling of a few municipal, military and industrial water wells, and a few hundred deep oil tests in western South Dakota, provided information on the quantity, quality, depth, temperature and pressure head on these artesian flows.

One of the earliest uses of geothermal water in the state was in Pierre, the state capital. A well was drilled on the capitol grounds in the winter of 1909-1910 to a depth of 1350 feet (411 m). This well produced 1,620 gpm (100 L/s) of 92ºF (33ºC) water. In addition, it produces 59 ft^3/min (28 L/s) methane gas. It was reported to have been used to heat the capitol building and provided gas for city street lights (according to the plaque at the well), however, it appears the gas was only used for lights in the capitol building. In the late 1950's the mains rusted out and the well was abandoned. However, the flow from the well stabilized and was run into a three-acre (1 ha) lake on the capitol grounds. In the mid 1960's the idea of a flaming fountain was conceived as a memorial for South Dakota's fallen military personnel. The flame was ignited in August of 1967 and has burned perpetually since that time (see cover photo).

Other early uses include bathing and spa therapy (balneology) in Edgemont, Midland and Hot Springs.

In Edgemont, near the southwest corner of the state, a small sanatorium and both house has been in operation for many years - the Pitman Bath House (Natural Resources Commission, undated) It featured hot sulfur baths from water that has total solids of 1097 ppm (mg/L) of which 317 ppm are sulphates, 250 ppm chlorides and 130 ppm calcium. It has a high concentration of hydrogen sulphide, which makes the water very corrosive. Two wells are used in the city, one drilled in 1910 and the other in 1935, at temperatures of 128ºF and 126ºF (53ºC and 52ºC) respectively. The city allowed the hot water to flow into an open reservoir for cooling before be used in the city system. The older well had its casing corroded sufficiently to allow leakage of the warm water from the Madison (Pahasapa) aquifer to mix with the sulphate water in the aquifer above (Leo sands of the Minnelusa formation) providing the hot sulfurous water used in the hot baths.

The Stroppel Hotel, located in Midland about 60 miles (100 km) west of Pierre uses warm water from a well drilled in 1939. The well, 1784 feet (544 m) deep, produced 33 gpm (2 L/s) of 116ºf (47ºC) water. Location of the well was based on known warm water wells in Capa and Nowlin on either side of Midland, but off the main highway. An addition was built onto the hotel to house three dressing rooms and three 8-ft by 8-ft (2.4-m x 2.4-m) separately enclosed bath tubs, each filled with four feet (1.2 m) of hot mineral water continually flowing through them. The hotel is also heated by the geothermal water (Figure 7). An analysis of the water gave a total dissolved solid content of 2686 ppm (mg/L), of which 1170 ppm is calcium carbonate and 850 ppm chloride (Natural Resources Commission, undated).

Figure 7. Stroppel Hotel in Midland. The baths are located under the sloping roof structure on the right.

Numerous warm springs have been used for swimming and balneology in the Hot Springs area that date back to before the turn of the century. These are discussed in a separate article in this Bulletin.

District Heating Applications

Two geothermal district heating projects have been developed in Philip and Midland.

The Philip district heating project was based on a Program Opportunity Notice (PON) solicitation and the resulting grant of cost shared funds to heat Haakon School and then cascade the geothermal water to heat downtown businesses. The project was completed in 1982 at a cost of $1.21 million. The well is 4,200 feet (1,280 m) deep, and produces 340 gpm (21 L/s) of 157º F (69º C) water. Eight buildings are heated in the downtown area before the water is disposed of in the Bad River. A special design was needed to remove Radium-226 from the spent fluid using barium chloride. A second geothermal well located about 2.5 miles (4 km) north on town, just west of Lake Waggoner supplies geothermal heat to the Haakon County highway equipment maintenance shop, the Water Treatment Plant and an aquaculture project. The details of these projects are discussed in another article is this Bulletin.

The Midland district heating project started in 1964 using a well on the hill behind town, however, today it uses a well drilled in 1969 that supplies 152ºF (67ºC) water. The high school and grade school were the original users of the heat, but over the years four buildings in the downtown area were hooked to the system, along with heating the concrete slab and wash water for a car wash. The water is finally piped uphill to a water treatment plant and then returned to the city as domestic tap water. Waste water is also used in a swimming pool and rancher in the winter will take of load of hot water to their ranch to thaw livestock watering troughs. The details of this system also appears to a separate article in this Bulletin.

St. Mary's Hospital

St. Mary's Hospital in Pierre was also the recipient of a PON grant to drill a geothermal well. The well, heat exchanger and connection to the heating system of the hospital was completed in 1980. The system uses 106ºF (41ºC) water from a 2,200-foot (670-m) artesian well drilled on the hospital property. The well originally produced 375 gpm (24 L/s), but now uses only 80 to 100 gpm (5 to 6 L/s) to heat about 35% of the building (60,000 ft^2 - 5,600 m^2). The savings amount to 25,000 to 30,000 gallons of fuel oil annually (95 to 113 tonnes). The project which cost $718,000, was 75% funded by the USDOE grant. This project is also discussed in more detail in this Bulletin.

Diamond Ring Ranch

This ranch is located about 40 miles (65 km) west of Pierre and had an existing well drilled into the Madison Formation at a depth of 4265 ft (1300 m) (Zeller et al., 1980). It supplied 152ºF (67ºC) domestic water, stock ponds and partial irrigation needs of the ranch for about 20 years. The well had a peak flow of 173 gpm (11 L/s) of highly corrosive water with high concentrations of SO_4 (>1000 ppm), Ca (>375 ppm), Cl (>175 ppm) and total dissolved solids of >2,000 ppm (mg/L). A space heating and grain drying project was proposed in 1980, and was funded by a USDOE PON grant of about $400,000. The space heating portion of the project involved retrofitting four residences, a shop, barn and garage (Figure 8). All were heated with forced air, except for the garage which used a floor slab heating system. The grain drier used a separate heat exchanger and was designed to replace the conventional propane grain drying system used for wheat, oats, barely and corn. Figure 9 is a schematic diagram of the geothermal system (Zeller et all., 1980). The geothermal water is disposed of into a stock pond. Conventional "off-the-shelf" items were used in the system, which included two stainless steel plate heat exchangers and PVC pipe reinforced with a fiberglass wrap. The capacity of the grain drier was 1.4 million Btu/hr (410 kW) and the space heating system 0.55 million Btu/hr (128 kW). Unfortunately, corrosion, fire in the residence and change of ownership, has caused the system to be abandoned.

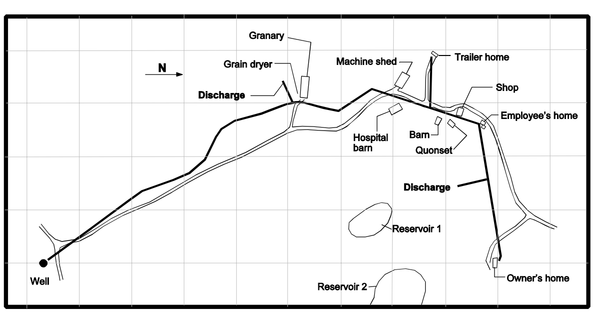

Figure 8. Layout of piping system for the Diamond Ring Ranch.

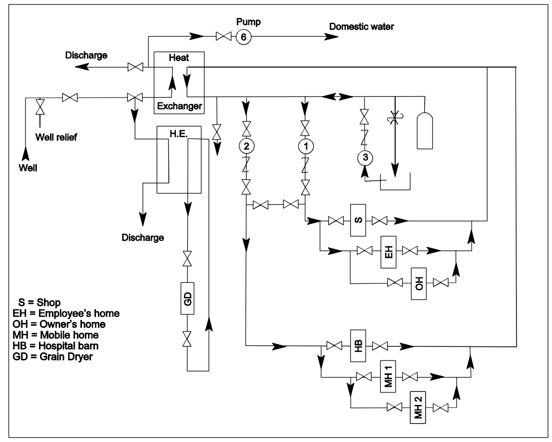

Figure 9. Schematic diagram of the geothermal heating system for the Diamond Ring Ranch.

Heat Pumps

Two major geothermal heat pumps systems have been installed in public buildings in Pierre for heating and cooling. A 45 ton (158 kW) unit has been installed in City Hall using 55ºF (13ºC) water at a maximum flow of 100 gpm (6.3 L/s) to heat 10,000 ft^2 (930 m^2) of floor space. The other system has been installed in the Discovery Center, a converted power station, used as a science museum for school children has a 125 ton unit (438 kW) for heating and cooling. It also uses 55ºF (13ºC) water.

Numerous cities throughout the state have installed heat pumps using the city water as the source for heating and cooling. These cities include Belle Fourche (127.5 tons - 446 kW - in the Community Center), Deadwood (in the City Hall - 60 tons - 210 kW, and the Visitors Information Center - 15 tons - 52.5 kW, Winter, and Hot Springs (described in the Hot Springs article in this Bulletin) (personal communication, Phil Nichols).

SUMMARY OF UTILIZATION

The following is an estimation of the installed capacity and geothermal energy utilization for South Dakota:

Table 3.

Source	Number	Installed Capacity MWt	Annual Energy Use 10^9Btu	GWh
Philip District Heating	1	1.59	11.5	3.37
Midland District Heating	1	0.10	0.8	0.24
Lake Waggoner	1	1.54	13.8	4.04
St. Mary's Hospital	1	1.28	4.1	1.20
Heat Pumps (Pierre)	2	0.45	3.4	0.98
Heat Pumps (cities)	5	1.32	9.8	2.89
Evan's Plunge	1	1.52	36.2	10.61
Swimming/Spa (others)	5	0.73	11.0	3.21
Ranch Heating	1000	10.55	78.8	23.10
TOTAL		19.08	169.4	49.64

This would amount to an annual savings of 30,000 barrels of oil equivalent.

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