ACIDIZATION OF A DIRECT HEAT HYDROTHERMAL WELL AND ITS POTENTIAL IN DEVELOPING ADDITIONAL DIRECT HEAT PROJECTS

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ABSTRACT

A matrix acid treatment on a limestone formation in a low temperature hydrothermal production well in South Dakota has resulted in a 40% increase in heat (BTU) available for use in space heating a hospital. The results of this experimental treatment on the Madison Limestone suggest a significant potential may exist for similar applications, particularly throughout the western United States.

This paper presents the results of the acid treatment, suggests other possible areas for similar application, and analyzes the economics for successful treatments.

DISCLAIMER

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INTRODUCTION

The Madison Formation (or Madison Group, as it should be called) has been identified as a major source of low temperature hydrothermal waters found in the sedimentary carbonate rocks of the Northern Great Plains. As a source of water for direct heat uses, it appears this rock unit may provide one of the more widely available energy sources for direct heat exploitation.

The Department of Energy (DOE), through its Division of Geothermal Energy, has been providing support to a number of direct heat applications projects throughout the country designed to encourage the near-term commercialization by the private sector of hydrothermal resources. Specifically, DGE has funded three projects in South Dakota to evaluate the energy resource potential of the Madison for space heating. These projects have been supported through the issuance of Program Opportunity Notices (PON's) issued by DOE, and technically supported by EG&G Idaho, Inc.

MADISON GROUP (FORMATION) WELLS

The Madison Group is a sequence of Mississippian carbonates deposited across Montana, Wyoming, western North Dakota, western South Dakota and the extreme northwest corner of Nebraska (see Figure 1). The Group is divided into three formations; the Lodgepole Formation (oldest), the Mission Canyon Formation, and the Charles Formation. In South Dakota, the Madison is often referred to as the Pahasapa Limestone. Similarly, many people use the collective term Madison Formation for the entire sequence of carbonates. In this paper the terminology used will be that of the Madison Group or Madison Limestone, which is intended to correctly classify this rock type.

Three distinct lithologic units exist in the Madison Group. The Lodgepole Formation is a thin-bedded argillaceous and dolomitic limestone, with the dolomite being confined to the upper section. The Mission Canyon Formation is thick-bedded with dense crystalline limestone and dolomite, and minor amounts of evaporite. The Charles Formation consists of anhydrite and halite, with interbedded limestone and dolomite. The entire Madison Group thickens and becomes shalier eastward into the Williston Basin of Montana and North Dakota.

Since a petroleum potential exists within this Group, and the water potential is significant, numerous data points are available to assess the potential of this Group. In addition, the geothermal direct heat potential was recognized as early as 1910-13 in a well near Edgemont, South Dakota [1], so temperature has become a relevant data point in evaluating the Madison.

From the Hanny and Lunis report [2], over 300 Madison Group wells in South Dakota, which were drilled for either water, oil or gas, encountered temperatures greater than 100°F. The same editors [3] report somewhat similar data from oil and gas tests in North Dakota. However, the Madison Group aquifer in North Dakota is deeper (and warmer) and has poor water quality. Therefore, none of the hydrothermal water in this Madison Group is currently being used in North Dakota.

In the Powder River Basin of Wyoming and Montana, where significant coal development is planned, the Madison is being evaluated to assess its potential as a major water resource for potential synfuel development [4,5,6,7]. These two states also have significant oil and gas development data on temperatures and depths to the Madison.

As a result of the above work, a significant data base has been gathered to assess the geothermal resource of this geologic strata. Circular 790 [8] has assessed the low-temperature value of this resource and of overlying formations. It appears that not only the Madison, but the overlying Dakota Sandstone may serve as sources of hot water for direct heat use. Specifically, as one moves southeastward into Nebraska, the Dakota is a major resource for direct heat use [9]. Nevertheless, this paper will stress the potential of the Madison Group as the major heat source of the region.

THE RESOURCE AND ITS ACCESSIBILITY

South Dakota

Based upon the resource data base that has been acquired through oil and gas drilling, water well development and geothermal well activity in South Dakota, J. P. Gries [1] has presented a series of figures in evaluating the use of geothermal resources in that state for direct heat use. Based on his prior work (Figures 2 and 3,) it is apparent that a shallow heat source can be exploited in South Dakota.

Figure 2 presents the temperature data collected on the Madison in South Dakota. Anomalous highs occur in the center of the state (over Haakon County) and toward the northwest corner of South Dakota. Except for the north-central portion of the state (or the most northeastern extent of Madison Group deposition), virtually the entire western half of South Dakota has temperatures above 100°F in the Madison.

However, to truly assess the availability of this resource on an economic basis, the data must be reviewed to determine the depth at which the Madison can be encountered. These data are presented in Figure 3. As can be seen, the Madison limestones are found, at depths less than 4000 feet, adjacent to the Black Hills and along the eastern extreme of Madison deposition in the central part of South Dakota. In northwest corner of South Dakota, the Madison Group is buried by over 7000 feet of sediment, as it dips into the trough of the Williston Basin.

Figure 4 was constructed using both temperature and depth information. This map also presents a third variable: areas where favorable porosity exists in the Madison, suggesting that a producible water zone may be present. Figure 4 also contains three Madison PON projects that have been drilled in South Dakota. It should be noted that these wells fall within the parameters of less than 4000 feet and greater than 100°F, suggesting these parameters are critical to economic space heating and district heating projects. Table I summarizes some of the key parameters of these wells, as taken from Childs, et al [10].

Another option, based upon the data presented in Figure 4, is to investigate the porous zones noted in the Madison that may have higher flow rates (and greater temperatures, as presented in Figure 2). Even though drilling costs are higher, larger projects which cascade the fluid use, may be feasible.

Should other projects be planned (outside the porous zones), consideration should be given to including acid treatment in the plans for well completion, and to comparing the results of the well to the requirements necessary to meet the heat load design.

THE ACID TREATMENT

In researching the results from Madison water well completions in South Dakota, Dr. J. P. Gries [1] acknowledges the fact that Madison Group wells respond favorably to acid stimulation. Gries [11] specifically identified well flow increases that doubled or tripled after acid treatment, suggesting acidizing as a routine completion tool on such wells.

DOE's PON Program has funded three space heating projects in South Dakota that were drilled into the Madison. These projects included the Haakon School District project, the Diamond Ring Ranch project and the St. Mary's Hospital project. Neither of the former projects employed an acid treatment, although serious consideration was given to using an acid fracture treatment on the Haakon well.

The third project under DOE's PON program involved drilling into the Mississippian Madison Formation within the city limits of Pierre, South Dakota. The well was drilled on the property of the St. Mary's Hospital in that city, with the intent of producing 100°F water for space heating and domestic hot water. The Madison Group as found here is a porous and permeable limestone-to-dolomitic rock.

The results of the acid treatment have been reported previously [12], but are summarized in this paper to demonstrate the technique employed. The well was drilled to a depth of 2176 ft. in April 1979, using mud as the drilling fluid. Casing and liner were set to total depth, as shown in Figure 5. The seven-inch liner was perforated across the porous zones of the Madison shown on well logs, using four shots per foot (a total of 232 perforations) over a net interval of 58 ft. During a two-hour artesian flow test, the well flowed at a rate of 250 gpm. The lower-most intervals of the liner were reperforated, exposing the limestone interval from 2043 to 2172 ft. A subsequent twelve-hour artesian flow test resulted in a flow rate of 283 gpm of 107°F water.

Because these results were below design requirements, a matrix acid treatment was conducted to stimulate production from the well. The treatment consisted of 8000 gallons of 20% Hydrochloric Acid being injected at pressures of 1500 psi down 2-7/8 inch tubing at a rate of 9 barrels per minute. The acid contained 20 gallons of corrosion inhibitor and 800 gallons of an additive to prevent scale on the casing. Six hundred ball sealers were injected near the end of the treatment, and a fresh water flush was employed at the end of the pumping.

After the acidizing, a twelve-hour flow test showed an average artesian flow rate of 400 gpm. These results increased the heat available by 2.05 x 10^6 Btu/hr, at a cost of $31,700. This is a 42% increase in heat available for use in space heating the hospital. Total system payback (including capital costs, plus $30,000 of annual expenses) will be decreased from 14.4 years (before acidizing) to 8.9 years (after acidizing). Since the system design requires only 350 gpm, the above figures are based upon the well capability (after acidizing) and not on the system design.

Evaluated in another manner, the total cost of the well (before acidizing) was $288,300. The resultant heat available (before acidizing) was 4.9 X 10^6 Btu/hr. Had these initial results been used in the system design, either a second well would have been necessary or an alternate design, and greater dependence on the backup heating system (#2 Fuel Oil) would have been required. Either approach would have been undesirable. However, employing the acid treatment resulted in a 11% increase in cost to obtain a 42% increase in flow capability.

The acid treatment, in iteself, was not unique. Both oil and gas developers and water well developers have employed acid treatments since 1932 on limestones and dolomites to enhance flows. This was, however, one of the first known acid treatments on a direct heat geothermal well in the U.S., and is highlighted as a technique that merits further consideration as a completion tool for such wells.

THE ECONOMICS OF THE MADISON RESOURCE

For space heating and district heating projects, numerous parameters including competitive energy costs, system load factor, capital investment requirements, annual operating requirements, energy conversion efficiencies, well head flow rate and temperature and heat exchanger input and output temperatures must be evaluated before one can properly assess the economic viability of a project. However, in many cases, assuming favorable resource conditions, well costs, which are often 25 to 50% of total project costs, become the critical element upon which economic decisions are made. From information obtained from Childs, et al [10], on well costs versus well depths, wells drilled beyond approximately 4000 feet may preclude economic district or space heating projects, unless increased temperatures and flow rates can be found and unless the end-use has a high heat load with a high load factor, such as an industrial process.

In addition to well depth, resource temperature greatly affects the economic success of a geothermal project. As noted in GRC Special Report No. 9, space heating requires a minimum wellhead temperature of 100°F, although 120°F is usually quoted [13]. However, as shown in Figure 2, temperatures in the Madison Group generally exceed the 100°F minimum requirement.

Finally, reservoir flow rate greatly affects project economics. As shown in Figure 4, the Madison Group has widespread porous zones. From Table I, wells drilled in the Madison encounter high porosities and flow rates in the 170 to 400 gpm range.

In summary, depending on the area, the Madison Group has high probabilities of encountering acceptable temperatures and flow rates, The economic success of the projects then is primarily determined by the depth to the resource. Since the Madison Group is found at depths as shallow as 2000 feet, with temperatures exceeding 100°F and flow rates in excess of 300 gpm, with as much as a 40% flow increase due to acidization, a geothermal project that utilizes a Madison Group resource has a high probability of encountering an adequate resource and has high probability of giving a good economic return on investment.

Other Madison Group Areas

As noted earlier, and shown in Figure 1, the Madison Limestone was deposited across a broad belt of Rocky Mountain states, including Wyoming, Montana, North Dakota and South Dakota. Due to the wealth of data on the Madison in the state, South Dakota has served as our principal area for discussion since three PON projects have demonstrated the concept of using the Madison for direct heat projects. However, although the Madison lies at greater depths in the other three states, it can be encountered at relatively shallow depths on geologic highs and adjacent to outcrops in those states.

In Wyoming, for example, Decker, et al [14] highlight Madison aquifer systems near Thermopolis, Cody, Casper and Douglas, all associated with structural highs (arches and anticlines). Head, et al [4] shows a structural contour map and an isothermal map on the Madison Limestone of the Powder River Basin of northeast Wyoming and southeast Montana. Although the center of basin shows the Madison at depths in excess of 15,000 feet, the Madison limestone along the flanks of the Big Horn Mountains, the Laramie Mountains, and the Black Hills, are economically accessible.

In Montana, where data on the Madison is sparse, the best areas appear to be in the extreme southeast corner [15] and along geologic highs [16]. Projects and prospective areas are continuing to be evaluated in this state.

The Madison in North Dakota lies fairly deep, particularly along the western edge of the state [17]. Along the eastern fringe of Madison deposition in the state, a potential exists for economic direct heat applications employing fluids from the Madison.

SUMMARY AND CONCLUSIONS

The Mississippian Madison carbonates of the Northern Great Plains states are presently being monitored by three PON demonstration projects in South Dakota as a major area where district heating and space heating concepts can economically be employed using low-to-moderate temperature geothermal fluids. Specifically, the application of a matrix acid treatment on one of the projects has demonstrated the successful economic application of a known oil and gas technique to a geothermal production well.

The investigation of specific areas of relatively shallow (less than 4000 feet) 100°F+ resources in South Dakota is highlighted, suggesting areas that could be exploited by using acid treatments. Where deeper zones of porous Madison rock are drilled, it is suggested that multiple use or cascaded use projects be designed to achieve an economic return on investment.

For geothermal projects to be developed in the Madison Limestones in adjacent states, one should look on geologic highs, in areas near the edges of the Powder River Basin, or in the fringe Madison deposition areas of the Williston Basin. These areas should be closely investigated for economic feasibility of direct heat geothermal use.

REFERENCES

[1]J. P. Gries, Geothermal Applications on the Madison (Pahasapa) Aquifer System in South Dakota - Final Report, IDO/1625-2 (Rapid City, SD: South Dakota School of Mines and Technology, September 1977).

[2]J. A. Hanny and B. C. Lunis, editors, South Dakota Hydrothermal Commercialization Baseline, (Idaho Falls: EG&G Idaho, Inc., August 1979).

[3]J. A. Hanny and B. C. Lunis, editors, North Dakota Hydrothermal Commercialization Baseline, (Idaho Falls: EG&G Idaho, Inc., August 1979).

[4]W. J. Head, K. T. Kilty, and R. K. Knottek, "Maps Showing Formation Temperatures and Configurations of the Tops of the Minnelusa Formation and the Madison Limestone, Powder River Basin, Wyoming, Montana, and Adjacent Areas," U.S. Geological Survey Open-File Report 78-905, (Cheyenne, Wyo.: November 1978).

[5]R. K. Blankennagel, W. R. Miller, D. L. Brown, and E. M. Cushing "Report on Preliminary Data for Madison Limestone Test Well No. 1, Crook County, Wyoming," U.S. Geological Survey Open-File Report 77-164 (Denver, Colo.: February 1977).

[6]D. L. Brown, R. K. Blankennagel, J. F. Busby, and R. W. Lee, "Preliminary Data For Madison Limestone Test Well 2, Custer County, Montana," U.S. Geological Survey Open-File Report 77-863 (Denver, Colo.: December 1977).

[7]R. K. Blankennagel, L. W. Howells, W. R. Miller, and C. V. Hansen, "Preliminary Data for Madison Limestone Test Well 3, Yellowstone County, Montana," U.S. Geological Survey Open-File Report 79-745 (Denver, Colo.: June 1979).

[8]L. J. P. Muffler, Editor, "Assessment of Geothermal Resources of the United States--1978, U.S. Geological Survey Circular 790. (Arlington, VA. 1979).

[9]William D. Gosnold, "Preliminary Report on the Geothermal Resource Potential of Nebraska," Transactions, Volume 4 (Geothermal Resources Council, September 1980) pp 45-48.

[10]F. W. Childs, K. W. Jones, L. B. Nelson, J. A. Strawn, M. K. Tucker, "Progress in Direct Heat Applications Projects," Transactions, Volume 4 (Geothermal Resources Council, September 1980) pp 549-552.

[11] J. P. Gries, Personal Communication, 1979.

[12] Jon A. Strawn, "Results of Acid Treatments in Hydrothermal Direct Heat Experiment Wells," Transactions, Volume 4 (Geothermal Resources Council, September 1980) pp 427-430.

[13] Jay F. Kunze and Ray W. Gould, "The Economics of Drilling For Direct Heat," Commercial Uses of Geothermal Heat, Special Report No. 9 (Geothermal Resources Council, June 1980) pp 71-73.

[14] Edward R. Decker, Henry P. Heasler, and Jon K. King, "Hydrothermal Resources in Wyoming: A Preliminary Report on the University of Wyoming's Research in 1979," Resource Assessment/ Commercialization Planning Meeting, (U.S. Department of Energy, January 1980) pp 67-78.

[15] Jeff Birkby, Keith Brown, and Michael Chapman, "Montana Geothermal Commercialization Planning Semi-Annual Progress Report," DOE/ID/12014-1 (Helena, Montana: Montana Department of Natural Resources and Conservation).

[16] J. H. Birman, Jane Cohen and Glenn J. Spencer "Geothermal Space Heating Applications for the Fort Peck Indian Reservation in the Vicinity of Poplar, Montana," DOE/ID/12046-4 (Orange, CA: PRC Toups, October 1980).

[17] Kenneth L. Harris, Laramie M. Winczewski, Howard R. Umphrey and Sidney B. Anderson, "An Evaluation of the Hydrothermal Resources of North Dakota," Resource Assessment/Commercialization Planning Meeting, (U.S. Department of Energy, January 1980) pp 129-135.

TABLE I

PON PROJECTS
DRILLED INTO THE MADISON GROUP

Parameter	Project		
	Diamond Ring	Haakon School	St. Mary's Hospital
Well Total Depth	4000'	4266'	2176'
Wellhead Temperature (°F)	152°	157°	107°
Design Flowrate (GPM)	170	300	350
Maximum Flowrate	170	300	400**
Productive Interval	N/A	3898-4266'	2043-2172'
Project Cost ($\$10^3$)	$392*	$1,147	$718

*Does not include cost of old well that was used.
**After acidizing.

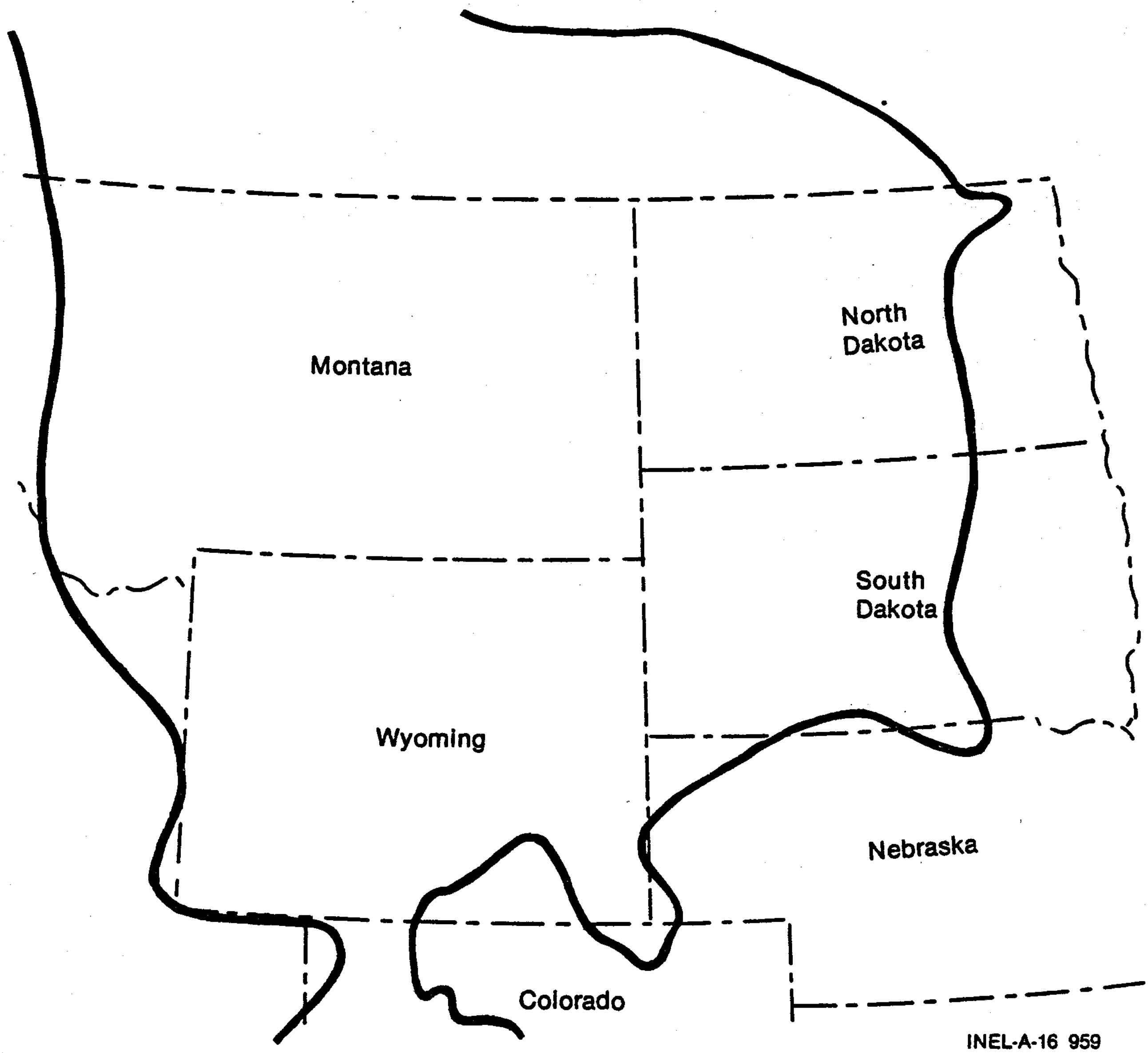

Figure 1. Areal Distribution Of Madison Group

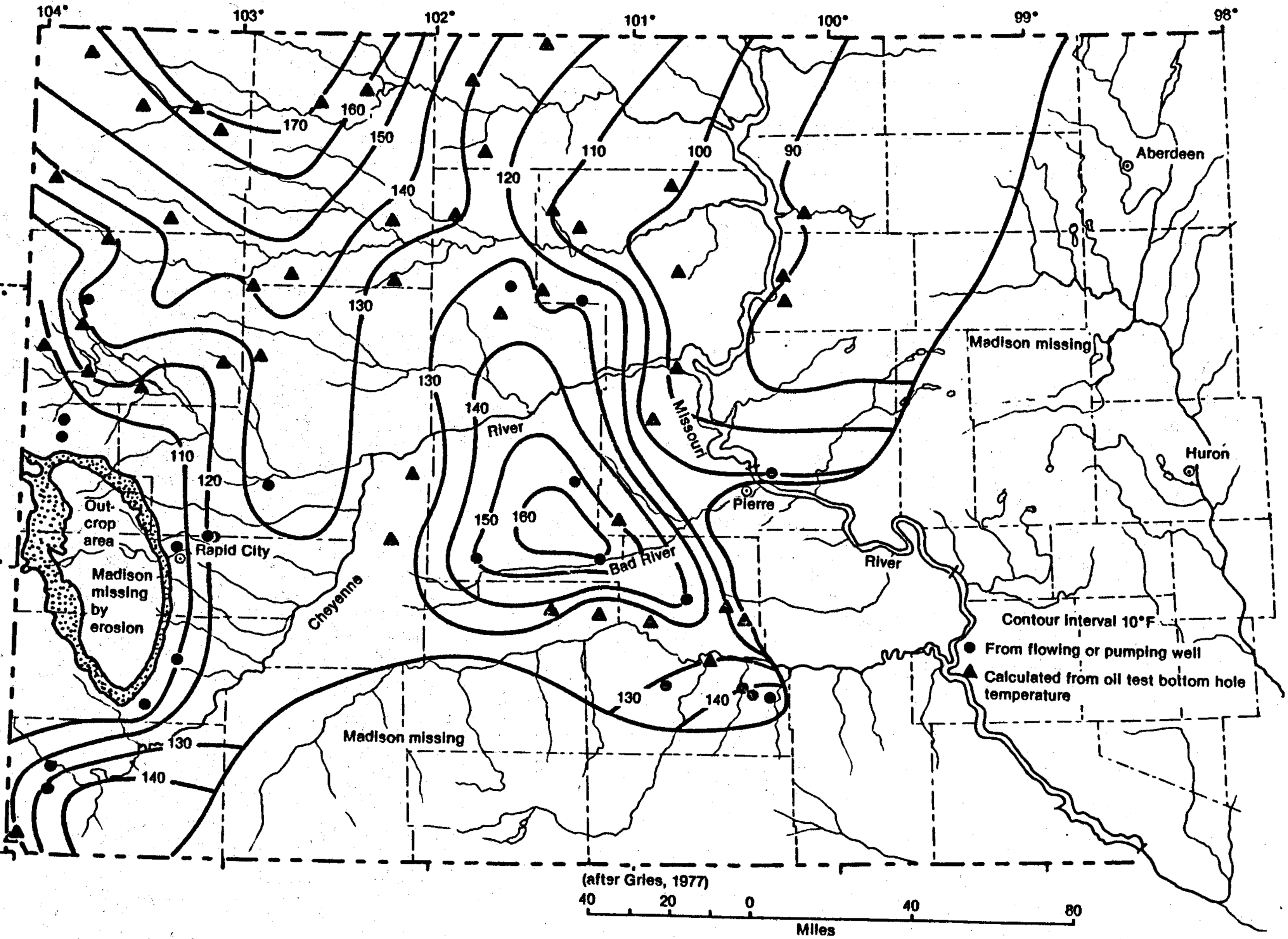

Figure 2. Isothermal Map Of Madison Group In South Dakota

INEL-A-16 954

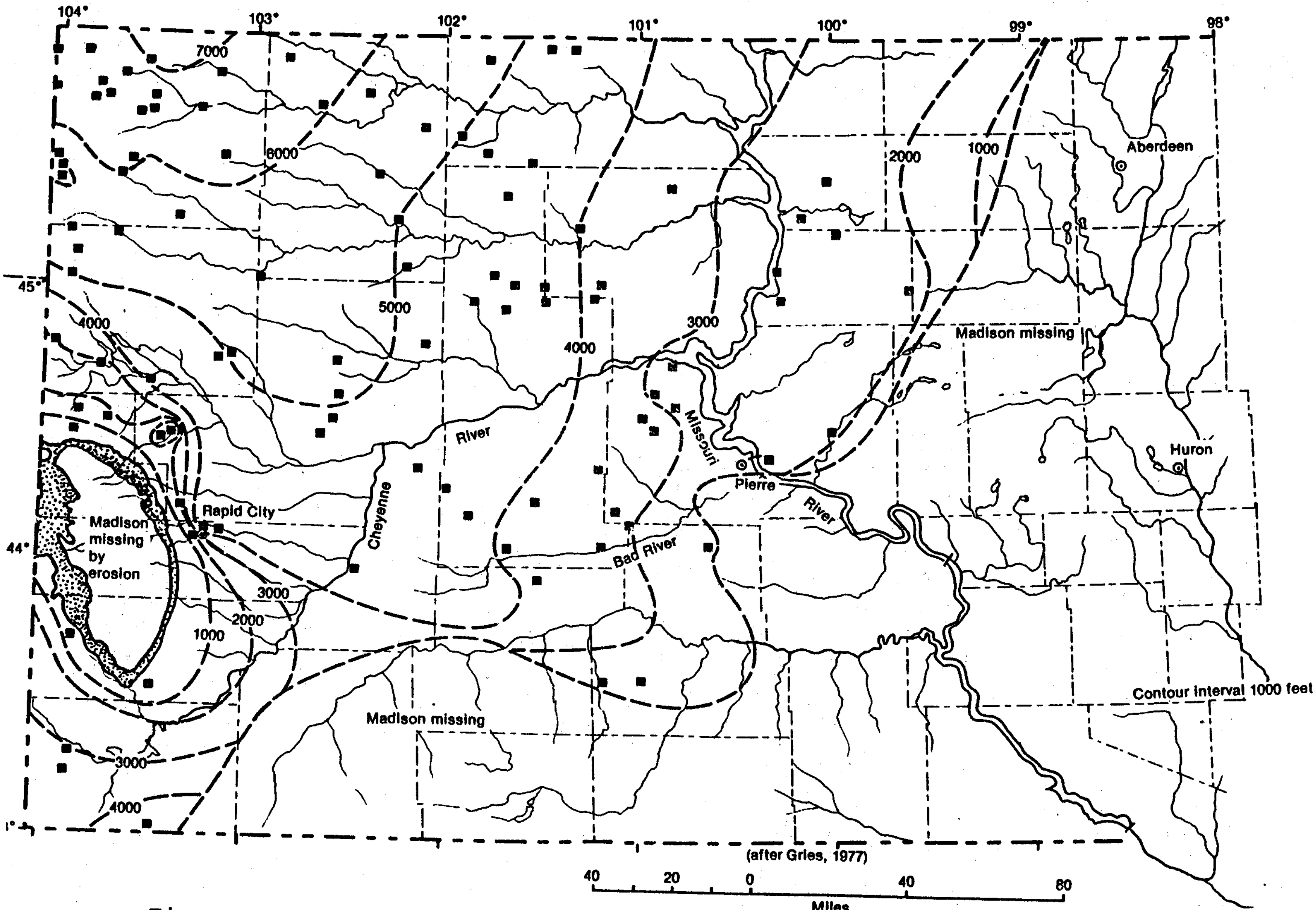

Figure 3. Depth To The Top Of The Madison Group In South Dakota INEL-A-16 958

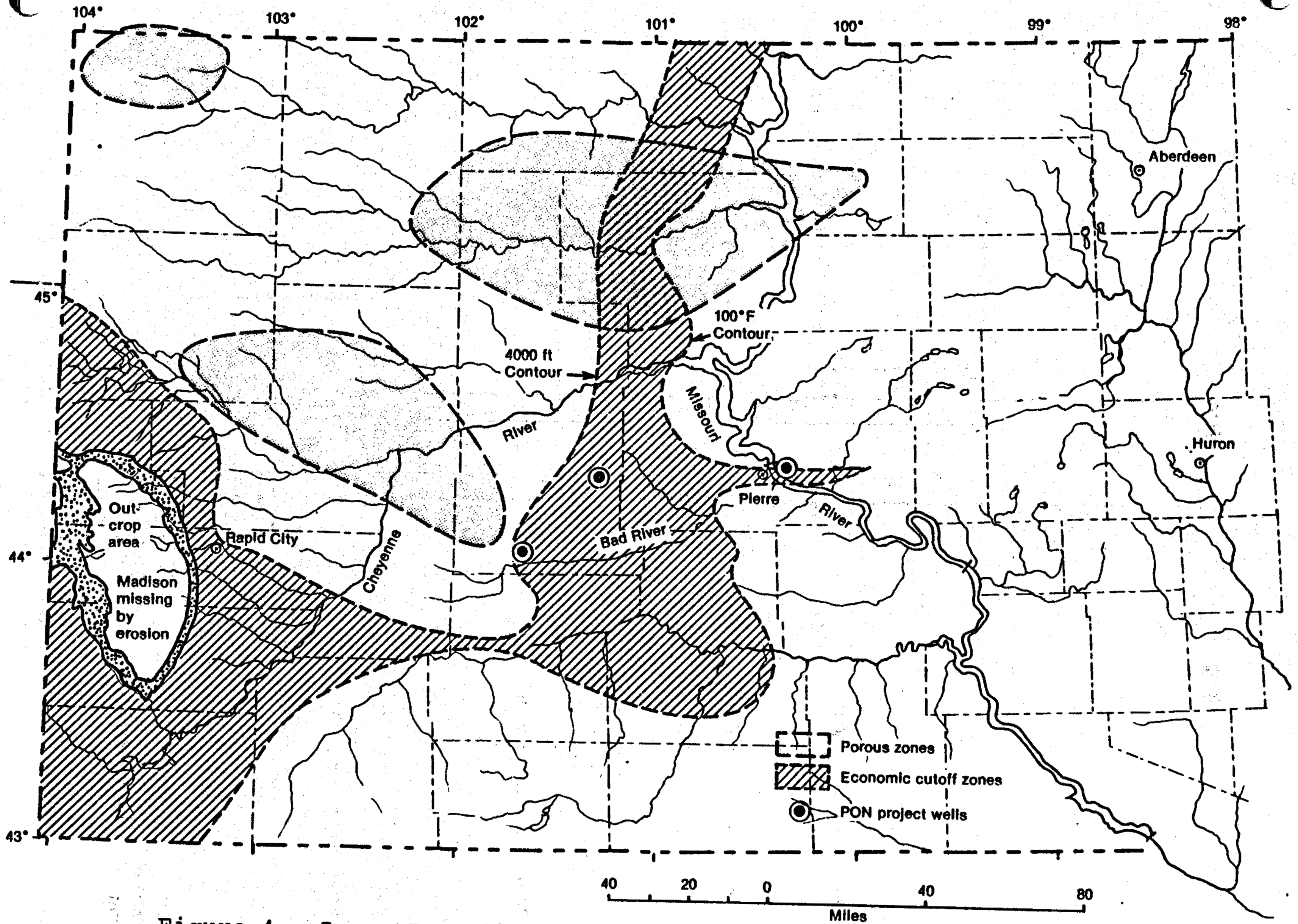

Figure 4. Zones In Madison Group Of South Dakota Most Likely To Prove Economical For Direct Heat Use.

INEL-A-16 953

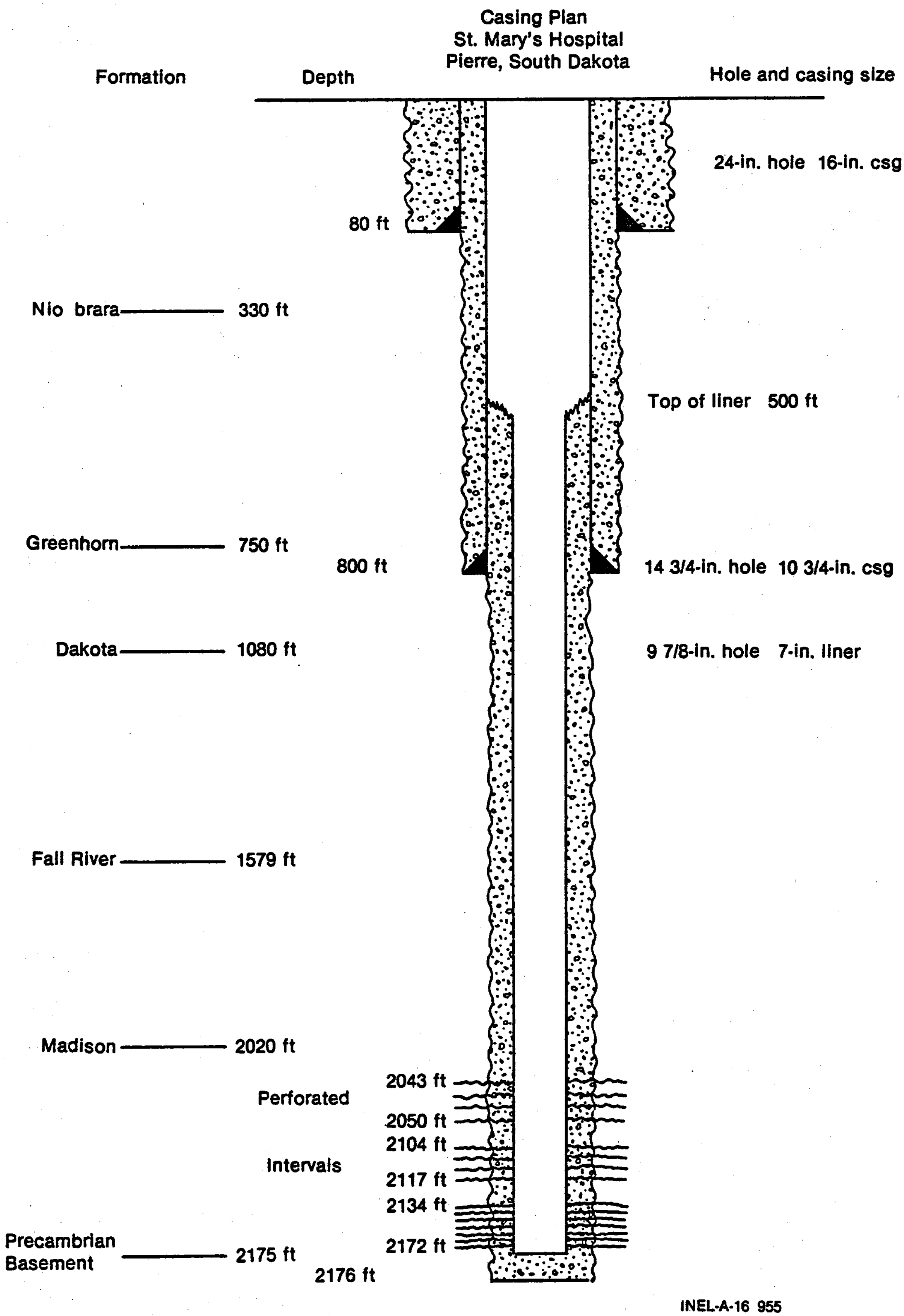

Figure 5. Casing Plan Of St. Mary's Well