Proceedings Eighth Workshop Geothermal Reservoir Engineering
Stanford University, Stanford, California, December 1982
SGP-TR-60

# A FIELDWIDE RESERVOIR ENGINEERING ANALYSIS OF THE PILGRIM SPRINGS, ALASKA, GEOTHERMAL RESERVOIR

Michael J. Economides[1], Christine A. Ehlig Economides[1]
Jay F. Kunze[2], Ben Lofgren[3]

[1]University of Alaska, [2]Energy Services Inc., [3]Woodward-Clyde Consultants

## INTRODUCTION

In an attempt to identify the geothermal potential of the Pilgrim Springs area in the Seward Peninsula, Alaska, exploratory drilling was undertaken in the Summer of 1982. A total of four wells were drilled through a State appropriation. The Division of Energy and Power Development acted as the Project Manager while Woodward-Clyde Consultants were selected as the principal contractor. Two other shallow wells were drilled in 1979. The six wells were completed at various depths ranging from approximately 70 ft to 1000 ft.

The drilling activity followed an extensive geological and geophysical assessment done by Forbes et al. (1979), Turner and Forbes (1980) and Wescott and Turner (1981). Their work indicated the existence of an extensive, liquid dominated, shallow geothermal reservoir in the area. The shallow reservoir, confirmed by the 1979 drilling, was delineated within a 1 to 1.5 $km^2$ area, bounded by permafrost at least 350 ft thick.

The results of the 1979 drilling were presented by Kline (1981). Table 1 is a summary of the well completion data. Figure 1 shows the well locations. Wells PS1 and PS2 were drilled to 150 ft. Air-lifted flowrate was estimated at 200 GPM and 350 GPM, respectively, with a flowing wellhead temperature of 91°C. The wells were then filled with mud and cemented until 1982 when they were reopened. The mud settled at 105 ft in both wells, making them inaccessible below that depth. They were perforated using shape charges at the interval 70-100 ft (PS1) and 60-90 ft (PS2). The unaided flowrate never exceeded 30 GPM in PS1 and 65 GPM in PS2.

The first well, drilled in 1982 was PS3 at a total depth of 260 ft. A 3-inch slotted liner was installed between 155 and 255 ft. The completed interval produced 60 GPM at over 65°C.

Wells PS4 and PS5 were attempts towards an intermediate depth. They were drilled to 881 ft and 1001 ft respectively. Well PS4 is an open hole completion from 186 ft and below. A flowrate of 100 GPM and a wellhead temperature of 46°C were recorded. Well PS5 was completed below 540 ft with a 3" slotted liner. This interval presented siginificant problems during drilling. The formations encountered were often very hard materials. The total flowrate in Well PS5 was only 10 GPM, with a temperature of 35°C.

A sixth well, MI1, was drilled in land owned by Mary's Igloo. It was completed between 227 and 307 ft using 3" slotted liner. The flowrate was 120 GPM at 25°C.

The successively lower flowing temperatures observed in the deeper completions were later explained by the data from temperature versus depth surveys. Interpretation of the temperature surveys will be discussed in detail in this article.

## REGIONAL GEOLOGY

The thermal activity at Pilgrim Springs is located in the Pilgrim River Valley, a tectonic depression (graben) bounded by Precambrian amphibolites and Mesozoic plutons. In some areas it is overlain and overthrust by Paleozoic carbonates. Potassium-Argon dating done by Turner and Swanson (1981) indicated a cooling age of 84 m.y. suggesting igneous intrusive activity in mid-Cretaceous time.

Gravity surveys conducted in the region by Kienle and Lockhart (1980) suggest that Pilgrim Springs is near the intersection of two possible fault zones which form the corner of a

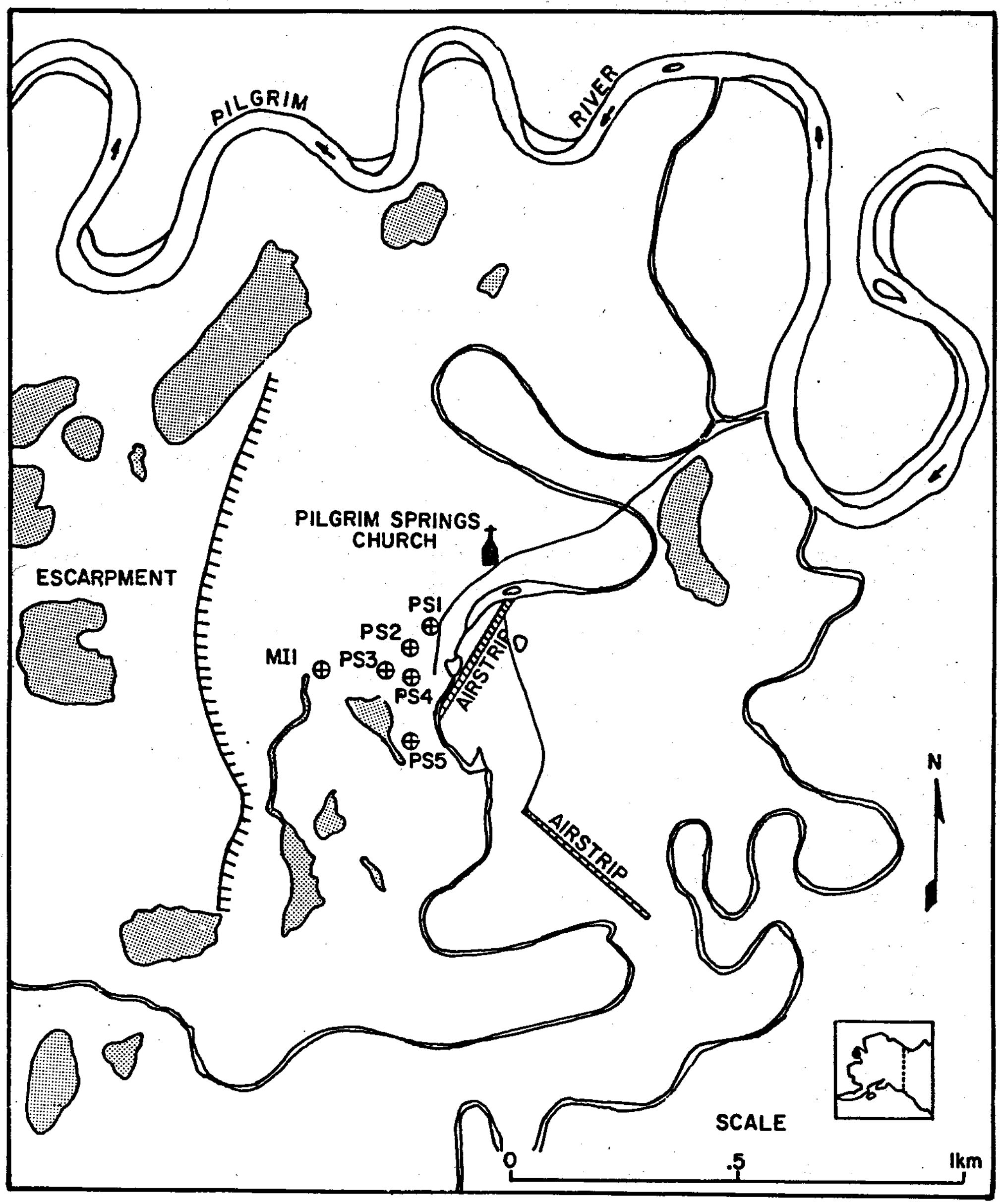


Figure 1. Drill Sites in the Pilgrim Springs Geothermal Reservoir

downdropped basement block. Other faults in the area have been verified by seismic data and geologic mapping, and one or more of these faults could provide a deep conduit for the geothermal anomaly.

The possible existance of a major rift system is of significance for the regional geothermal potential. A helium survey was conducted to test this rift model, and nine out of eleven helium anomalies occur near the proposed rift segments and suggest abnormally high heat flow in these areas. Furthermore, extensive basaltic fields north of Pilgrim Springs area have been interpreted as resulting from eruption in a zone of crustal weakness produced by the general north-south extension (Turner and Swanson, 1981).

The amount of separation along this proposed rift is less than the widths of the Quaternary depressions which have probably been enlarged by normal faulting and marginal subsidence, along with rifting. Potassium-argon dating indicates that volcanism which

## Table 1

### WELL-COMPLETION SUMMARY, PILGRIM SPRINGS, ALASKA

| Well | Drilling Date | Drilled Depth | Remarks |
|---|---|---|---|
| PS-1 1982 | Fall'79 | 150 | Cemented from 1979-1982. Perforated in 1982 between 60-90 ft. |
| PS-2 | Fall'79 | 150 | Cemented from 1979-1982. Perforated in 1982 between 70-100 ft. |
| PS-3 | Sum.'82 | 260 | Static head 12 ft. above land surface. Artesian flow- 60 GPM |
| PS-4 | Sum.'82 | 881 | 76 feet of drill stem stuck in bottom. Static Head -12 ft. Latest artesian flow- 250 GPM at 114°F. |
| PS-5 | Sum.'82 | 1001 | Latest artesian flow-10 GPM at 98oF |
| MI-1 | Sum.'82 | 307 | Static head - 11 ft. above land surface. Latest artesian flow--100 GPM at 78°F very soft, sweet |

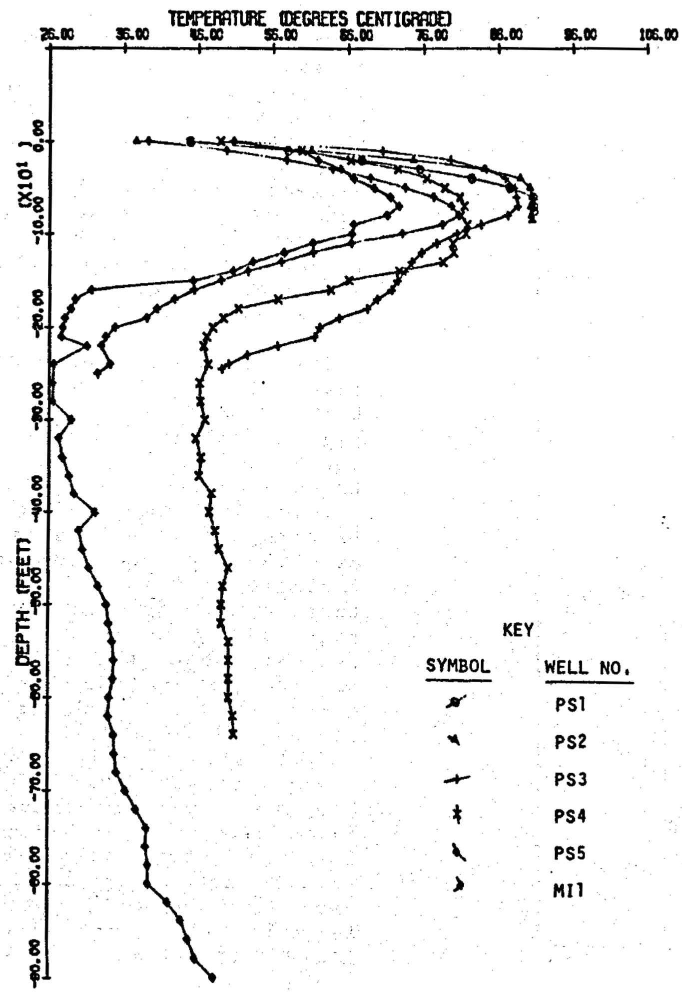


Figure 2. Temperature Versus Depth Profiles of the Pilgrim Springs Wells

was associated with rifting began in the Upper Miocene (Turner and Swanson, 1981).

Finally, a permafrost boundary, enclosing a 1 to 1.5 $km^2$ area has been identified. The thickness of the permafrost is over 350 ft.

TEMPERATURE DATA INTERPRETATION

Previous temperature data were limited to shallow depth, (4.5 meters) by Wescott and Turner (1981), soil Helium surveys by Turner and Forbes (1980), and geothermometry by Motyka et al. (1980) Motyka's estimate for the source water temperature using Na-K-Ca as the temperature indicator was 150°C ± 10°C. The data of Wescott and Turner indicated a regional geothermal anomaly and suggested that the well sites chosen for PS3, PS4 and PS5 were likely locations for the source fluid.

The temperature data for this study were taken from temperature versus depth data recorded in the wells drilled in the Pilgrims Springs region.

Two months after completion of the last well, temperature surveys were run in all six wells. The temperature versus depth profiles for all wells were identical in shape, as shown in

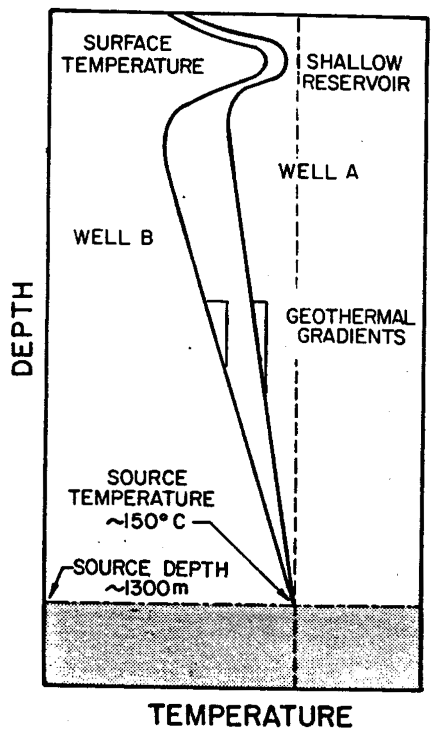


Figure 3. Conceptual Representation of the Shallow and Deep Reservoirs at Pilgrim Springs.

Fig. 2. All showed a trend toward a maximum temperature at depths from 40 to 100 feet, followed by a sharp decrease in temperature with depth from 100 to 250 ft, followed by a constant geothermal gradient ranging from 1.8°C to 2.1°C per 100 ft that was recorded down to 900 ft in the deepest well. The two wells, drilled deep enough to determine the geothermal gradient at depth (PS4 and PS5) show temperature trends that would intersect at about 155°C at a depth of 4875 ft. Hence, the geothermometer temperature estimate of 150°C is corroborated by the latest findings. In addition, and more importantly, the data suggest that all of the wells overlay the source reservoir at the 4875 ft depth.

Figure 3 is a schematic representation of the temperature versus depth profile that would be expected at a well (A) near the source from depth of the hot water flowing in the shallow zone. Well B, further away from the source, shows a lower maximum temperature in the shallow zone which grades to a lower temperature at the base of the shallow temperature anomaly and results in a higher geothermal gradient to reach the source temperature at depth.

The shallow temperature anomaly observed in all the wells suggests that somewhere in the immediate region, water from the hot source at depth is flowing upwards through a fissure or fault which extends vertically from a depth of about 50 feet to the 4875 foot depth identified as the source depth. Aerial variations in the maximum recorded temperature for the six wells are contoured in Figure 4. These data suggest that the hot source fluid enters the shallow formation at some point to the north of the six well sites. The fluid then flows radially and laterally away from the fissure source towards springs such as the Pilgrim Springs or perhaps in the surrounding stream beds, thus creating a steady state flow pattern for the shallow hot water zone. Locating the hot water source for the shallow zone is relatively unimportant, since the fluid at depth provides a high temperature source formation extending aerially at least as far as the total area drilled. The temperature data provide a most compelling justification for deeper drilling in the area.

## SHALLOW FORMATION PROPERTIES

Core samples were taken from the 87 to 95 foot depth interval in Well PS4. Three plugs were taken and analyzed for porosity and permeability. The uppermost sample was a large-grained, poorly cemented, primarily quartz sandstone with a porosity of 40% and air permeability in excess of 4 Darcys. This sample is believed to be representative of the shallow hot water zone. The middle sample was a fine grained, well cemented, quartz sandstone with a porosity of 28% and exceptionally low permeability. The deepest sample was a loose conglomerate with a porosity of 24%. The permeability of this sample could not be determined. The middle sample could represent the impermeable base for the shallow hot water zone.

Data from an interference well test are shown in Table 2. Shut-in pressures were recorded in PS2 while PS1 was flowing at a rate of 30-35 GPM. A log-log graph of the drawdown pressures in Well PS2 versus time was analyzed by type curve matching with the line source solution, as shown in Fig. 5. From the pressure match, the permeability is estimated at 4.5 Darcys. The time match gives a porosity compressibility product of $5.4 \times 10^{-6}$ $psi^{-1}$, which results in an estimate of $14 \times 10^{-6}$ $psi^{-1}$ for the compressibility, if the porosity is assumed to be 40%. The results of the interference test agree with the core analysis data from Well PS4 and suggest that the shallow hot water zone has similar properties throughout the region of the six wells.

## CONCLUSIONS

The wells drilled in the region of the geothermal anomaly near Pilgrim Springs provide considerable insight into the general characteristics of the geotherml system. Previous work, including resistivity studies and geothermometry are corroborated by the temperature profiles observed in the six wells. The existence of a hot

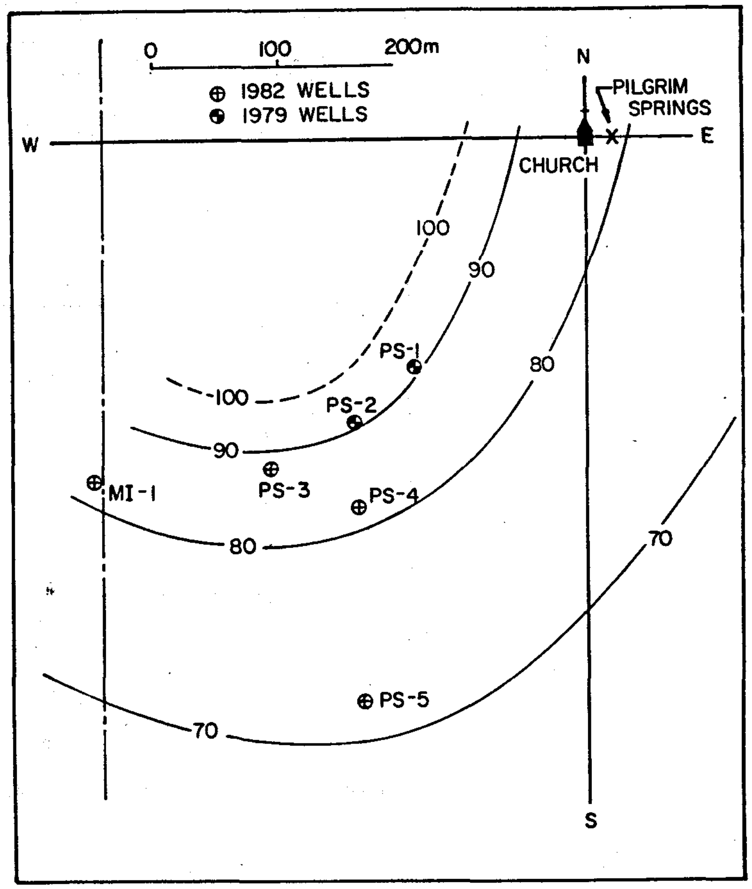


Figure 4. Temperature Contours in the Shallow Reservoir.

**Table 2**

Pressure Interference Data Between Wells PS1 and PS2

PS1 (flowing), q = 30-35 GPM

PS2 (wellhead pressures recorded)

| Time(min) | p(psig) | Time(min) | p(psig) |
|---|---|---|---|
| 0 | 3.5 | 20 | 1.6 |
| 8 | 2.9 | 22 | 1.5 |
| 12 | 2.4 | 24 | 1.3 |
| 14 | 2.3 | 27 | 1.1 |
| 16 | 2.1 | 29 | 1.0 |
| 17 | 2.0 | 30 | 0.9 |
| 18 | 1.9 | 31 | 0.8 |

Distance between wells = 269 ft
Water viscosity = 1 cp
Reservoir porosity = 40%
Reservoir thickness = 60 ft

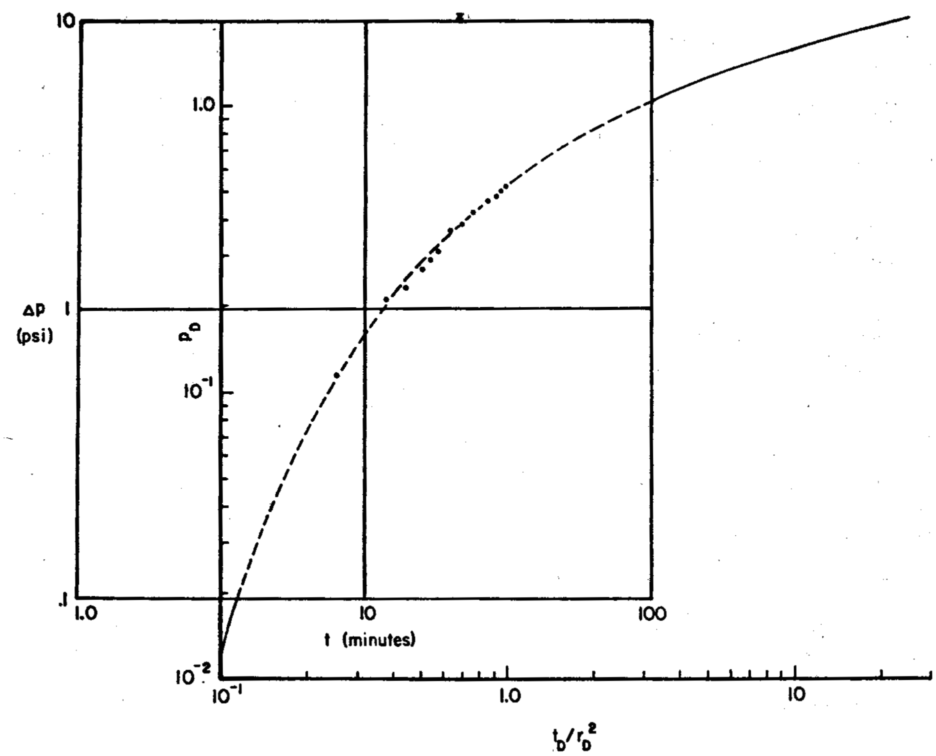


Figure 5. Type-Curve Matching of the Pressure Interference Data Between Wells PS1 and PS2.

water zone of about 150°C and at a depth of around 5000 ft is now virtually certain.

Acknowledgements

The authors wish to thank the State of Alaska through its Department of Energy and Power Development for funding to do this study and to present our findings. We also wish to acknowledge the effects of Mr. Paul Chamberlin to keep an accurate record of all the tests run and the data taken during drilling and completion of the new wells.

## REFERENCES

Forbes, R.B., Wescott, E.M., Turner, D.L., Kienle, J., Ostercamp, T., Hawkins, D.B.,Kline, J.T., Swanson, S., Reger, R.D. and Harrison, W.: "A Geological and Geophysical Assessment of the Geothermal Potential of Pilgrim Springs, Alaska", Geophysical Institute, UAF and Alaska D.G.G.S. Preliminary Rept., 39 pp., 1979.

Kienle, J. and Lockhart, A. in Turner, D.L. and Forbes, R.B. (Eds), 1980.

Kline, J.T.: "Surficial Geology of the Lower Pilgrim Valley and Vicinity, Western Seward Peninsula, Alaska", Alaska D.G.G.S., AOF-140, 1981.

Motyka, R., Moorman, M. and Forbes, R.B. in Turner, D.L. and Forbes, R.B. (Eds), 1980.

Turner, D.L. and Forbes, R.B. (Eds): "A Geological and Geophysical Study of the Geothermal Energy Potential of Pilgrim Springs, Alaska", Geophysical Institute, UAF, Report UAG R-271, 166 pp., 1980.

Turner, D.L. and Swanson, S.E. in Wescott, E.M. and Turner, D.L. (Eds), 1981.

Turner, D.L. (and 13 other authors): "Summary of Results of a Geological and Geophysical Investigation of the Geothermal Energy Potential of the Pilgrim Springs KGRA, Alaska," Geothermal Resources Council, Trans. v.4, pp. 93-95, 1980.

Wescott, E.M. and Turner, D.L. (Eds): "Geothermal Reconnaissance Survey of the Central Seward Peninsula, Alaska", Geophysical Institute, UAF, Report UAG. R-284, 123 pp., 1981.