PILGRIM SPRINGS KGRA, SEWARD PENINSULA, ALASKA: ASSESSMENT OF FLUID GEOCHEMISTRY

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ABSTRACT

The Pilgrim Springs geothermal system is hosted by a fault-block sedimentary basin and consists of a shallow 90°C aquifer fed from deeper reservoirs with temperatures of at least 150°C. The deep aquifers are likely recharged by surface meteoric waters migrating along graben faults while river water infiltrating through creek bottoms appears to be diluting waters in the shallow reservoir. Thermal waters are slightly saline with chlorides and other constituents in part derived from interaction of heated meteoric waters with marine sediments that comprise the basin fill. Gas chemistry, dominated by CH_4 and N_2, is consistent with sedimentary source for dissolved constituents. Geochemical and temperature gradients measured in drill holes indicates conduits feeding the shallow aquifer lie closest to Well PS1 and the hot springs. Flowing wells have captured and diverted much of the ascending thermal water away from nearby springs, which have dropped dramatically in temperature and discharge.

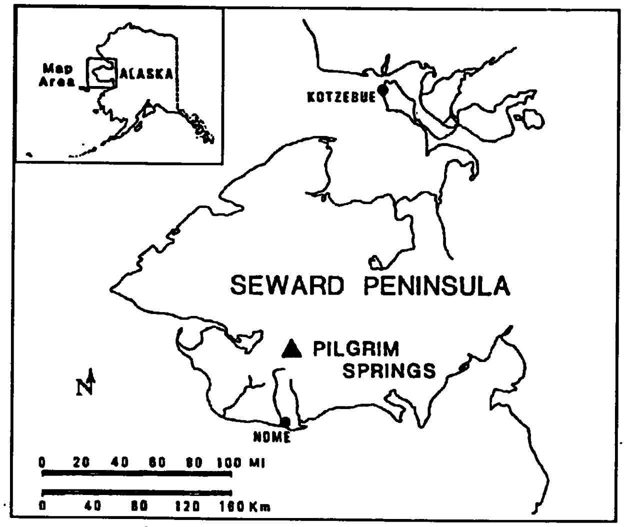

Figure 1. Location of Pilgrim Springs.

INTRODUCTION

Finding a reliable and relatively inexpensive source of energy remains a chronic problem for rural Alaska and the town of Nome, located on the Seward peninsula is no exception. The Pilgrim Springs Known Geothermal Resource Area (KGRA), located 75 km north of Nome, has the potential of providing a geothermal energy alternative to fossil-fuels now used by Seward Peninsula communities for electric power and heating. Known to the Inupiats as "Kruzagampah", Pilgrim Springs was used by early indigenous peoples for its curative powers. The springs have been intermittently used by later settlers ever since the Nome gold rush in the late 19th century, serving first as a resort for miners and later as a site for an orphanage run by the Roman Catholic Church. The orphanage helped support itself by growing vegetables for sale in Nome. Geothermal waters heated the buildings.

In 1968, a Nome group - Pilgrim Hot Springs Ltd. - acquired a 99 year lease from the Church and the Mary's Igloo Village Corp. acquired the adjacent lands under terms of the Alaska Native Claims Settlement Act (ANCSA). The State of Alaska and U. S. Department of Energy funded exploration programs in 1979-1982 to investigate the geothermal potential of the site. A broad, oval-shaped shallow aquifer of thermal water was delineated by geophysical investigations and later confirmed by exploratory drilling. Temperatures in the shallow aquifer reached 90°C while geothermometry indicates deeper reservoir waters at ~ 150°C or higher. Attempts at finding the conduits feeding the aquifer have so far been unsuccessful. The current lease holder has requested additional assessment work be done to help determine the viability of using Pilgrim Springs as a source of power for Nome. A DOE-sponsored reconnaissance of the site was conducted July, 1993 to help evaluate future exploration strategies. We took this opportunity to revisit and re-sample waters from the springs and wells. We report here the results of this work and also the results of geochemical analyses performed in 1979 and 1982, work which had not been previously published.

REGIONAL SETTING

The Pilgrim Springs lie in the Imuruk Basin, a structural fault-block basin containing at least 350 m of sediments consisting of sandstones, silts, and clays. The E-W trending

Kigluaik Fault delineates the southern boundary of this graben which has an estimated 425 m of downward displacement to the north (Lockhart and Kienle, 1980). An en-echelon system of three fault segments are poorly exposed in the vicinity of Pilgrim (Hudson and Plafker, 1978). Bedrock both north and south of the springs consists of upper amphibolite facies Precambrian gneiss and biotite quartz schist intruded by Cretaceous granitic plutons (Forbes and others, 1975; Hudson and Plafker, 1978). The normal faulting and nearby Quaternary volcanism prompted Turner, Swanson, and Wescott (1981) to propose a rift model for this part of the Seward Peninsula. They suggested that a depression extending from the Imuruk Basin on the west through the Pilgrim and Kuzitrin valleys and eastward to the Imuruk Lava flows, is a result of tensional tectonics associated with the beginnings of continental rifting. Surficial mapping by Kline (1981) shows evidence of rapid subsidence in the vicinity of Pilgrim springs. Basaltic late Cenozoic volcanism is common in western Arctic Alaska and includes the Imuruk basalt 65 km NW of Pilgrim Springs (1650 BP to 5 MA) and the ~3 MA Teller basalt 70 km W of the springs (Hopkins, 1968). While these fields are too distant to be directly responsible for the Pilgrim Springs, intrusive magmatism, similar in composition, may provide the underlying heat source.

BACKGROUND

A large wooded area in an otherwise treeless landscape marks the location of the Pilgrim Known Geothermal Resource Area (KGRA). Two hot springs emerge near the center of the 1 1/2 km^2 oval of thawed ground along an abandoned channel of the Pilgrim River. Permafrost is over 100 m thick outside the geothermal area. Kline (1981) indicates four additional springs downstream along the same abandoned meander channel. Six geothermal gradient wells were drilled during 1979 and 1982; all are artesian. Since 1984 it has been possible to drive to the springs via an 12 km spur off the "summer-only" Nome-Taylor highway. There also are two runway's at the springs, one at least 400 m long.

Geophysical reconnaissance studies including seismic refraction, geomagnetic profiling, electrical resistivity surveys, hydrologic studies, and He and Hg soil surveys delineated a shallow geothermal reservoir, subsequently confirmed by drilling, but did not find bedrock or the feeders to the shallow reservoir (Turner and Forbes, 1980). Two shallow (~35 m) exploratory wells, PS1 and PS2 were drilled in 1979; four deeper exploratory wells, PS3, PS4, PS5, and MI1 were drilled in 1982 (Fig. 2) (Kunze and Lofgren, 1983; Woodward and Clyde Consultants, 1983). The objective of intercepting a feeder to the shallow aquifer proved unsuccessful. The deepest well, PS5, was drilled to ~ 300 m. Bedrock was not encountered. Well-logs based on drill cuttings show wells were drilled through "sandstones, sands and silts, and clays". All wells encountered a shallow ~90°C aquifer, located between 15 m and 35 m below the surface

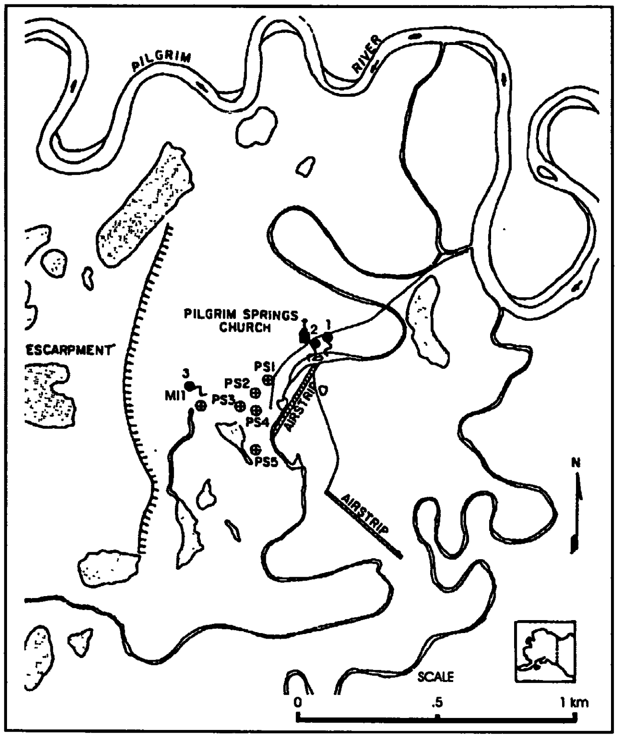

Figure 2. Spring (●~) and well (⊕) sites in the Pilgrim Springs KGRA (modified from Woodward and Clyde Consultant, 1983).

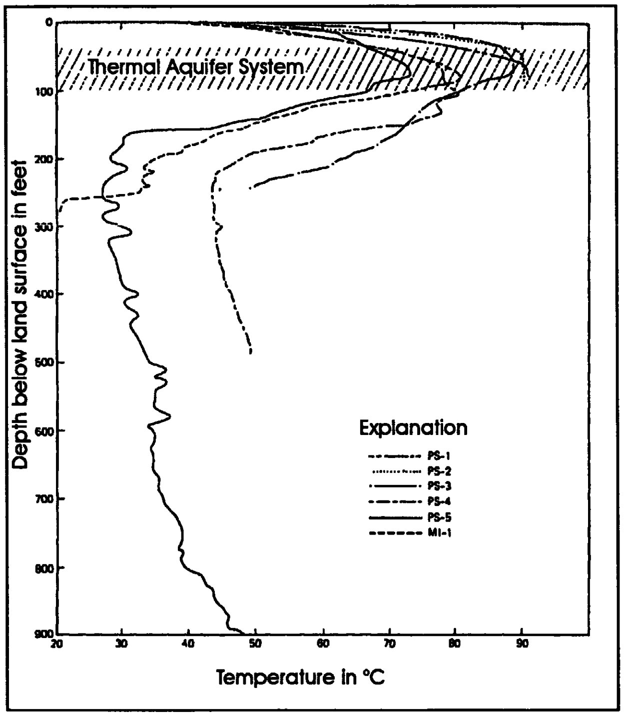

Figure 3. Temperature (°C) versus depth (ft) profiles of six geothermal wells (Woodward and Clyde Consultants, 1983).

Table 1. Water Chemistry from springs and wells in the Pilgrim Springs KGRA.[a]

Site Name	Date	T° C	pH	Na	K	Ca	Mg	Li	Sr	HCO_3	SO_4	F	Cl	Br	SiO_2	H_2S	B	Al	Fe
Springs:																			
Pilgrim 1[b]	8-04-72	82	6.8	1450	61.	530.	1.4	4.0	na	30	24	4.7	3350.	na	100	smell	2.4	.04	na
Pilgrim 1	6-22-79	81	7.1	1410	55.	381.	1.2	3.1	9.9	32	13	3.8	2680.	9.	75	2.20	2.0	.04	0.27
Pilgrim 1	7-27-93	42	6.5	1580	65.	569.	1.5	4.0	16.	19	18	4.7	3530.	na	86	smell	2.7	na	0.04
Pilgrim 2[c]	9-02-15	70	na	1590	61.	545.	7.4	na	na	21	25	na	3450.	na	87	smell	na	4.1	0.70
Pilgrim 2	7-27-93	28	6.9	1560	60.	522.	1.1	4.0	15.	23	19	4.9	3350.	na	74	smell	2.1	na	0.06
Mary's Igloo	7-12-82	55	6.8	1660	59.	542.	1.0	4.5	12.	36	15	4.3	3360.	na	91	2.15	2.2	na	na
Wells:																			
PS1	11-07-79	90	6.4	1830	75.	518.	0.9	3.9	na	16	16	4.8	3590.	14.	95	na	2.5	na	0.40
PS1	7-10-82	92	7.5	1720	60.	511.	0.9	4.7	13.	30	19	4.4	3420.	na	94	4.38	2.3	na	na
PS1	7-26-93	82	7.1	1560	65.	545.	0.6	4.2	15.	20	7	5.3	3460.	na	90	na	2.4	na	na
PS2	11-19-79	90	6.4	1820	75.	516.	0.9	3.9	na	19	15	4.8	3540.	17.	101	na	2.3	na	0.28
PS2	7-09-82	96	7.3	1510	57.	516.	0.9	4.7	13.	26	19	4.5	3420.	11.	92	3.32	2.3	na	na
PS3	7-11-82	75	8.0	592	25.	260.	0.4	2.0	6.0	36	15	1.3	1430.	na	60	3.39	1.0	na	na
PS3	7-27-93	65	6.8	1100	43.	441.	0.6	3.2	14.	27	6	2.9	2450.	na	67	na	1.5	na	na
PS4	7-27-82	48	8.6	115	4.8	23.	0.0	.3	.4	80	11	.5	284.	na	35	na	.5	na	na
PS4	7-27-93	45	8.6	146	7.8	97.6	0.2	0.2	2.5	48	1	0.3	386.	na	27	na	0.22	na	na
PS5	7-27-93	32	9.6	36	1.1	1.5	0.2	0.1	0.0	81	5	0.5	6.0	na	21	na	0.55	na	0.22
MI1	7-22-82	22	9.7	16	0.5	5.0	0.0	0.1	0.0	37	9	0.2	4.7	na	21	na	na	na	na
MI1	7-27-93	31	8.3	29	1.5	23.3	0.6	0.2	0.3	32	10	0.2	66.0	na	20	na	0.07	na	na
Lake:	7-11-82	24	8.1	1660	68.	561.	1.0	5.0	14.	27	10	4.6	3730.	na	4	na	2.4	na	na

a. All 1979 and 1982 samples analyzed by Mary A. Moorman, Alaska Division of Geological & Geophysical Surveys, all 1993 samples analyzed by the University of Utah Research Institute, others as indicated, na = not analyzed.
b. From Miller (1973)
c. From Waring (1917).

(Fig. 3). Kline (1981) reported a zone of pyritization in the capping layer above the thermal aquifer. All 1982 wells experienced steep temperature gradient inversions below 35 m. Well PS5 registered the coolest shallow aquifer temperature (73°C), suggesting it was furthest from the zone of up-welling. The well had a temperature of 48°C at 272 m below the surface.

In July, 1993, when the site was revisited, wells PS1, PS3, PS4, and MI1 were found open and running and had been for over a year. The caretakers reported that water did not flow from the wells until after breakup of the Pilgrim River in May.

WATER CHEMISTRY

All known chemical analysis of Pilgrim Springs and wells are listed in Table 1. These include the original analysis of the spring waters by Waring (1917) in 1915 and our previously unpublished analyses from 1979, 1982, and 1993. For well samples obtained at the time of drilling, several hours of flushing by the natural artesian flow preceded sampling. In 1993, wells PS1, PS3, PS4, and MI1 had been flowing for several months. Well 5 was flushed for over an hour before sampling was started. Well 2 could not be sampled due to subsidence of the well head. The 1979 and 1982 samples were analyzed by the Alaska Division of Geological and Geophysical Surveys (ADGGS), and the 1993 samples by the University of Utah Research Institute (UURI).

Waters produced from PS1 and PS2 in November, 1979 are nearly identical and are a more concentrated version of spring waters (Fig. 4). These waters are relatively thermally "mature" (criteria of Giggenbach, 1988; Giggenbach and Goguel, 1989), are slightly saline, Cl ~ 3,400 ppm, and low in HCO_3 and SO_4. The Cl/Br ratio is about 210 to 265 suggesting a sea water component, perhaps from Tertiary-Quaternary marine sediments that underlie the thermal area. However, the stable isotope composition of the thermal water is nearly the same as Pilgrim River (Fig. 5) indicating the river is the major source of recharge to the thermal aquifer. Dissolved H_2S is relatively high, 4 ppm; B is moderate, 2.3 ppm.

Wells PS3 and PS4 drilled in 1982 produced diluted versions of the more concentrated PS1 well waters (Table 1; Fig. 4). Water from PS1 had become slightly more dilute and PS2 significantly more dilute between 1979 and 1982. Re-sampling of wells in July, 1993 revealed two trends: water from PS1 continued to become more dilute while PS3, PS4, and MI1 waters became more concentrated, with constituent concentrations nearly doubling at PS3 and MI1. Wells PS5 and MI1 are highly diluted versions of PS1 and spring waters (Table 1; Fig. 4).

While water temperatures at the wells declined slightly between 1982 and 1993, the Pilgrim Spring waters cooled substantially, from 81° in 1979 to 42°C by 1993. In 1993 there was almost no outflow from a cribbed hot pool

Table 2. Stable isotope analyses from Pilgrim Springs KGRA.[a]

Site Name	Date	$\delta^{18}O$	δD
Springs:			
Pilgrim 1[b]	8-04-72	-14.9	-122
Pilgrim 1	6-22-79	-15.7	-111
Pilgrim 1	7-27-93	-11.8	-119
Pilgrim 2	7-27-93	-14.1	-117
Wells:			
PS1	7-26-93	-15.6	-121
PS3	7-27-93	-15.4	-120
PS4	7-22-82	-13.9	-114
PS4	7-27-93	-15.5	-115
PS5	7-22-82	-15.8	-114
PS5	7-27-93	-15.5	-115
MI1	7-22-82	-16.3	-115
MI1	7-27-93	-15.2	-114
Lake:	7-27-93	-12.2	-103
River:	7- -82	-15.7	-110
River:	7-28-93	-14.5	-110
Rain:	7- -82	-9.1	-78

a. Analyses in per mil with respect to Standard Mean Ocean Water (SMOW). 1979 and 1982 samples analyzed by Stable Isotope Laboratory, Southern Methodist University. 1993 samples analyzed by the U.S.G.S.
b. From Miller, 1973.

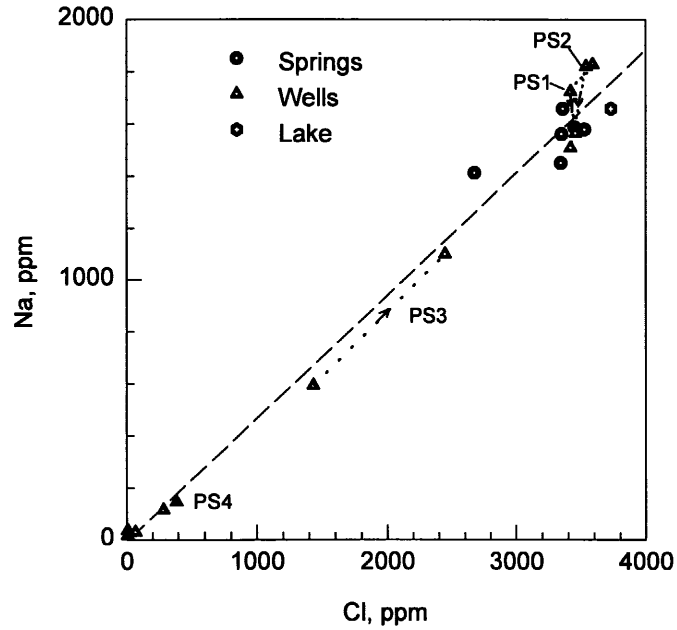

Figure 4. Sodium versus chloride for Pilgrim Springs KGRA waters. Dotted lines and arrows delineate temporal trends in composition for individual wells.

to the stream channel while in 1979 it measured 255 l/min. The low 1993 temperatures and flow measured at the spring sites is probably the result of interception and diversion of ascending thermal waters by the flowing wells, away from the conduits to the springs. The remaining thermal water reaching the spring probably cooled conductively and not by dilution. A comparison of the chemical analysis of the Pilgrim Spring waters shows that the 1979 results are anomalously low. In that year abnormally high precipitation occurred in the Pilgrim Springs area just prior to sampling and may have contributed to diluting the thermal waters. In 1993, sampling was preceded by 2 week of sunny and warm weather.

GAS CHEMISTRY

Gas samples were obtained from wells PS1, PS2, and PS3 in 1982 with both regular and NaOH charged flasks (Table 2). Analyses were performed at U. S. Geological Survey, Menlo Park. The gases are composed mostly of CH_4 and N_2 with minor amounts of CO_2, H_2, H_2S, Ar, He, and C_2H_6. The O_2 and Ar peaks were not separated in the NaOH analyses and are reported jointly although the low N_2/Ar ratio indicates the NaOH samples were slightly air contaminated. The N2/Ar ratio for regular flask samples indicates that N_2 and Ar are derived from dissolved air. The methane and ethane indicate the remaining gases are largely thermogenically derived from breakdown of organic

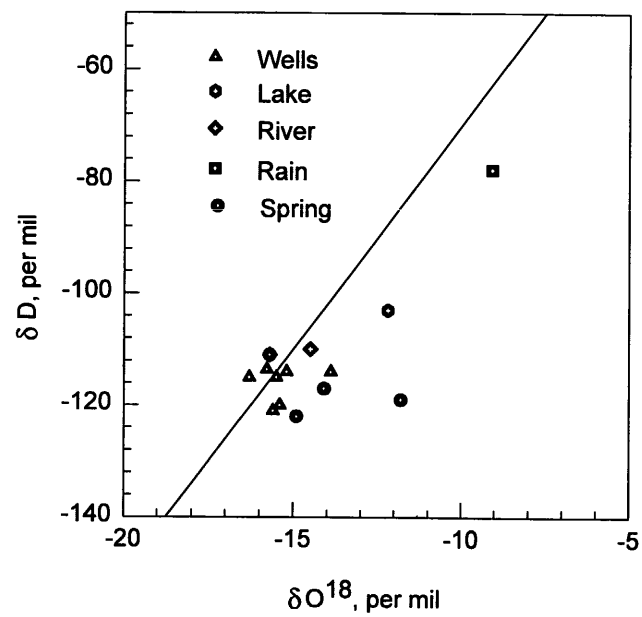

Figure 5. Stable isotope compositions of waters in the Pilgrim Springs KGRA.

Table 3. Gas chemistry from wells in the Pilgrim Springs KGRA.[a]

Site Name	Date	He	H_2	Ar	O_2	N_2	CH_4	CO_2	C_2H_6	H_2S	N_2/Ar
Regular flask:											
PS1	7-10-82	0.13	2.29	0.69	b.d.	44.6	51.9	0.20	0.40	b.d.	65
PS2	7-09-82	0.15	0.56	0.75	b.d.	41.8	56.2	0.60	0.42	0.18	56
PS3	7-11-82	0.12	0.15	1.04	0.002	68.6	30.5	0.01	0.22	b.d.	66
NaOH flask:											
PS1	7-10-82	0.02	3.32	2.67	in Ar	41.8	36.8	11.0	n.a.	2.20	16
PS3	7-11-82	0.02	0.03	3.97	in Ar	58.7	20.7	13.9	n.a.	0.28	15

a. Samples analyzed by Roman Motyka, Alaska Division of Geological and Geophysical Surveys, and Bill Evans and Cathy Janik, U.S. Geological Survey. b.d. = below detection, n.a. = not analyzed.

sediments. The $\delta\ ^{13}C\text{-}CO_2$ of -23 per mil PDB is additional evidence of a sedimentary origin for the carbon. Gases from Well PS1 are of particular interest because of their relatively high H_2 content of ~2.3 % compared to either PS2 or PS3 which have H_2 contents of less than 0.5 %. The higher H_2 suggests PS1 may be closer to the hot water conduit than either PS2 or PS3. Hydrogen outgases quickly as pressure on ascending fluids decreases as they come to the surface. Samples acquired closer to the conduit may therefore be expected to have higher concentrations of H_2.

The helium 3/4 isotope ratio is about 0.9, well-below values found for most geothermal systems that are directly related to volcanism, but substantially higher than a simple crustal source would allow. The high value suggests that there is a mantle component in the helium gases. Helium makes up about 0.14 % of the exsolved gases at Pilgrim.

GEOTHERMOMETRY

Silica (quartz conductive) geothermometers give temperature estimates of about 135°C while cation geothermometers (Na/K, Na-K-Ca) are generally ~ 150°C. Giggenbach's (1988) K-Mg gives ~ 160°C while Kharaka and Mariner's (1989) Mg-Li gives estimated temperatures as high as 190°C. The latter geothermometer was specifically developed for sedimentary basins. The difference between cation and silica values suggests that dilution of hotter geothermal water occurs to produce the waters in the 90° aquifer.

We applied D'Amore and Panichi's (1980) gas geothermometer to the well gas samples. As expected PS1, the well with highest H_2 content gave the highest temperature estimate: 230°C. Applying this gas geothermometer to the other well samples gave temperatures around 113°C. We also applied Giggenbach's and Goguel's (1989) H_2/Ar geothermometer to the well gases. Again, PS1 is the highest at 215°C; the other wells are at 160° and 130°C. Gas geothermometers are not as yet generally accepted and must therefore be treated with caution.

DISCUSSION

Geothermometry indicates the existence of a deep reservoir at 150°C to perhaps 190°C. Gas geothermometry suggests even higher reservoir temperatures. The conduit from this deeper reservoir was not found by drilling or geophysical surveys but water and gas chemistry, and drill hole temperatures suggests it lies nearer to PS1 than to either PS2 or PS3. Upflow of thermal fluids is likely to be fault-controlled, possibly along the Kigluaik Fault. Rate of upflow is unknown but could be considerable given the size of the shallow aquifer (~1.5 km^2). Woodward-Clyde Consultants (1983) estimated a continuing supply of at least 24 MW of geothermal energy is fed into the shallow aquifer. The size and location of any deep reservoir remains unknown. Projection of the thermal gradients measured in the drill holes suggests reservoir depths at up to 1.5 km.

Judging from isotopic chemistry (Table 2; Fig. 5), the deep aquifers are likely recharged by surface meteoric waters migrating along graben faults. Fluids from PS1 are the most concentrated and most representative of the deep, undiluted thermal water. Given the thick permafrost in the surrounding regions, river water infiltrating through creek bottoms is the likely source of waters diluting the shallow reservoir. There is little or no evidence in the fluid geochemistry that magmatic volatiles are directly contributing constituents to the hydrothermal system. However, the helium 3/4 ratio does suggest magmatic input to the system. Basaltic lavas have erupted in the area during the Holocene. Perhaps a deep-seated magma is supplying heat to the hydrothermal system by conduction. Alternately, meteoric waters descending to deep levels along graben faults are being heated by natural geothermal gradients.

The Pilgrim geothermal system bears geologic and tectonic similarities to Basin and Range geothermal systems such as Dixie Valley. Work performed on these Basin and Range systems could serve as models to guide future exploration strategies at Pilgrim.

Table 4. Geothermometers applied to Pilgrim Springs KGRA waters. Where multiple analyses are available, average of the geothermometers is quoted. Temperatures in °C.

	Silica[a]		Cation			
Site Name	Qtz. Cond.	Chal	Na-K[b]	Na-K-Ca[c]	K-Mg[d]	Mg-Li[e]
Springs:						
Pilgrim 1	129	101	151	145	146	169
Pilgrim 2	126	98	147	143	134	177
Mary's Igloo	132	105	142	140	151	184
Wells:						
PS1	133	106	148	145	159	187
PS2	136	108	149	145	156	184
PS3	114	84	150	115	144	176
PS4	76	44	168	61	109	106
PS5	65	32	136	73	61	82
MI1	64	32	150	25	64	103

a. Fournier and Potter (1982).
b. Fournier's equation, Fournier (1981).
c. Fournier and Truesdell's equation, Fournier(1981).
d. Giggenbach (1988)
e. Kharaka and Mariner (1989).

FURTHER WORK

Further work needs to be centered around additional exploration and gaining a better understanding of the resource. Deep resistivity techniques, capable of penetrating down to 1.5 km should be used in an effort to locate zones of upwelling and deep reservoirs before any further drilling is done. Deep seismic profiling should also be done to determine the depth of the sedimentary basin. The results of the geophysical work can then help guide locating optimum drill sites for investigating reservoir characteristics.

We suggest obtaining $\delta^{18}O$ H_2O-SO_4 geothermometer temperatures as another indicator of deep temperatures. Additional gas and water investigations are also warranted, particularly isotope studies ($\delta^{13}C$-CO_2, δ ^{13}C-CH_4, helium 3/4) to help delineate origins of constituents. Waters should be analyzed for Rb, Cs, and As in addition to other constituents and gas samples should be obtained from Wells PS4 and PS5.

SUMMARY

We believe sufficient evidence exists to indicate that a hydrothermal system with temperatures high enough to produce electricity, at least using a binary flash process, underlies Pilgrim Springs. We therefore believe that the potential for future development can be viewed with "cautious optimism". However, there are very important parameters that remain unknown and need to be addressed: 1) the location and geometry of the upwelling zone or zones, and 2) reservoir characteristics such as temperature, porosity, permeability, and transmissivity. Without knowledge of these parameters it is impossible to estimate the power potential of the resource.

ACKNOWLEDGMENTS

This work was funded in part by a grant from the U. S. Department of Energy. The views expressed in this paper are solely those of the authors. We thank Marshall Reed (DOE) and Joe Moore (UURI) for analyzing the 1993 water samples and Bill Evans and Cathy Janik (USGS) for their help in analyzing gas samples.

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