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GEA/GRC GEOTHERMAL EXCELLENCE AWARDS

Vol. 21, No. 4 **December 2000**

GEO-HEAT CENTER QUARTERLY BULLETIN

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A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources

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Cover: ***Top:*** Glass Geothermal Excellence Award. ***Bottom Left:*** Klamath Falls City Hall, geothermally-heated. ***Bottom Right:*** CalEnergy's V.P. of Operations, Jim Turner discussing the zinc recovery plant with the 49-MWe Unit 5 geothermal plant under construction in the background (photo courtesy of Ted Clutter).

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FIRST GEA/GRC GEOTHERMAL EXCELLENCE AWARD

John W. Lund
Geo-Heat Center

On September 26 at the GRC Annual Meeting in Burlingame, two Geothermal Excellence Awards were presented for the first time jointly by the Geothermal Energy Association and the Geothermal Resources Council (GEA/GRC). These were presented live by Karl Gawell, Executive Director of GEA, over the Internet at the Town Hall meeting in the GEA Trade Show Hall at the Annual Meeting. The two awards, one for a Facility Excellence Award to the CalEnergy Minerals Recovery Plant in the Imperial Valley, CA, and the other for a Community Excellence Award to the city of Klamath Falls for their Community Geothermal Project, were announced at the Town Hall meeting. The CalEnergy award was accepted by Jim Turner, General Manager of the Minerals Recovery Plant and the Klamath Falls award was accepted by Todd Kellstrom, Mayor of Klamath Falls--both live over the Internet, since neither person could be present at the Town Hall meeting. The award is of curved glass with the appropriate etched lettering as shown below (Figure 1). The presentation can be viewed over the Internet at: <www.ishow.com/doe/>.

Figure 1. ***Geothermal Excellence Award.***

Klamath Falls is located in southern Oregon on the east flanks of the volcanic Cascades. *Big Springs* and *Devils Teakettle*, hot springs that originally existed within the present city limits, were used by the Native Americans for over 10,000 years. They were then used by the early European settlers and more recently for space heating of homes for the past 75 years. There are over 500 geothermal wells in use for heating individual residences by means of a closed loop of pipe or downhole heat exchangers–thus conserving the water resource. The heat has also been used for pasteurizing milk and ice cream, in a laundry; for swimming pools and pavement snow melting systems; for heating city, county, state, federal government buildings, a hospital, churches, schools, a performing arts center and the Oregon Institute of Technology (OIT) campus buildings. A geothermal district heating system using over 200ºF water is used to heat 20 downtown buildings and melt snow on the sidewalks (Figure 2). One of the side benefits to the geothermal industry in the U.S. and internationally, is the collocation of the Geo-Heat Center (GHC) on the OIT campus. The local experience has been observed and documented by the GHC staff and has become a show-place for visitors from all over the world (the city's sister city is Rotorua, New Zealand--also a geothermally-heated city). This living laboratory, along with the information dissemination and technical assistance provided by the GHC, has promoted the direct use of geothermal energy worldwide. Two international geothermal conferences have been held on the OIT campus, and international engineers have worked at the Center to gain added experience. The various geothermal uses in the community results in a savings of about 85 GWh/yr (300 billion Btu/yr), which is equivalent to saving $2 million in equivalent fossil fuel use annually. Additional information on the uses in Klamath Falls can be found in the *GHC Quarterly Bulletin*, Vol. 20, No. 1 (March 1999).

Figure 2. ***Klamath Falls Mayor Todd Kellstrom frying an egg on a geothermally-heated sidewalk (photo courtesy of Lou Sennick).***

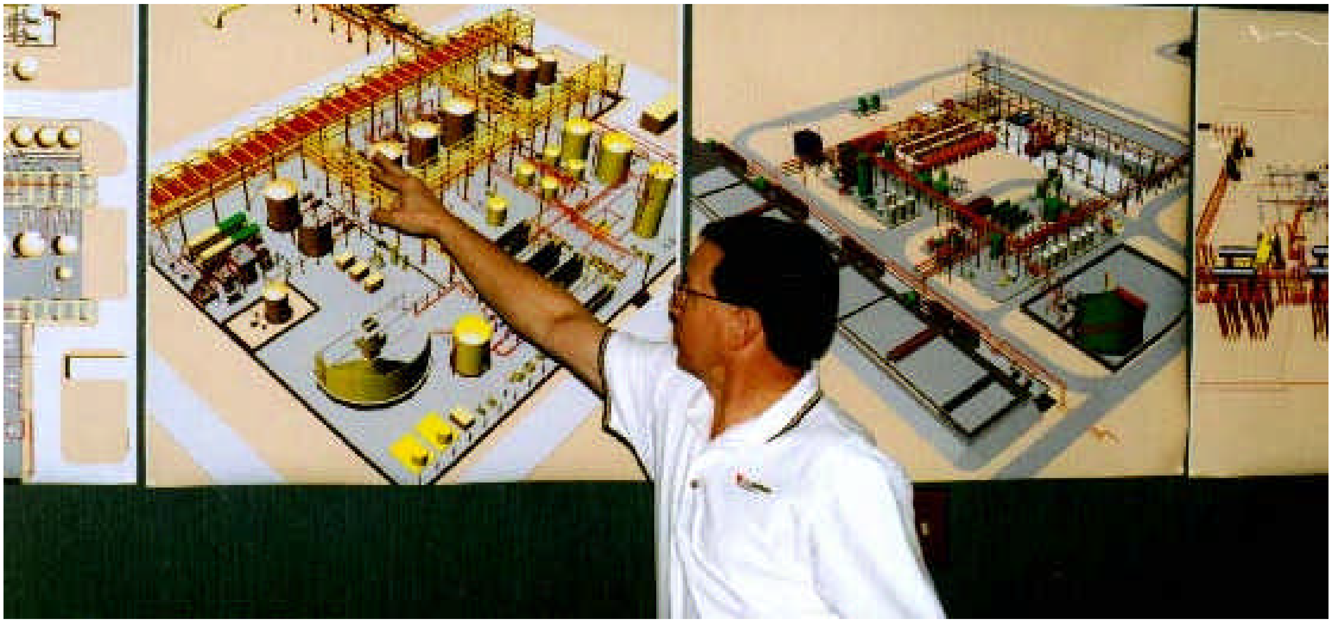

Figure 3. CalEnergy Vice President of Operations Jim Turner describing the minerals recovery facility (photo courtesy of Ted Clutter).

The CalEnergy Operating Corporation's Minerals Recovery Plant is part of a $400-million expansion of their geothermal power complex on the shores of the Salton Sea in southern California's Imperial Valley. The new construction includes nearly 60 MWe of new geothermal electric capacity, and a plant to recover commercial-grade zinc from the geothermal brine produced for power generation. Unit 5, a 49-MWe facility, utilizes high-temperature spent brine from four other units to produce electricity for the minerals recovery operation. Only 20 MWe will be used for the zinc production, with the excess power sold into the California deregulated electricity market. The $280-million mineral recovery facility (Figure 3) uses a combination of already existing technologies that were modified for this project. Besides ion exchange, the facility employs solvent extraction and "electro-winning" to extract zinc from the spent brine that is supplied at a flow rate of 20 million lbs/hr. The brine contains 550 to 600 ppm of zinc, but high grade silica and manganese may also be extracted. The result is nearly pure zinc (99.99% pure) deposited on large cathodes; where, it is then removed and melted into 2,400 lb ingots. The project will recover an estimated 30,000 metric tons (66 million lbs) of zinc per year. Additional details on this unique "green energy" project combining geothermal electric power and an industry can be found in an article by Ted Clutter in Vol. 21, No. 2 (June, 2000) of the *GHC Quarterly Bulletin* or from the *GRC Bulletin*, Vol. 29, No. 1 (Jan./Feb. 2000).

TAWAU HILL PARK SPRINGS, SABAH, MALAYSIA

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Tawau Hill Park (N04º14'42.7'', E117º53' 03.3'') is located 20 km north of Tawau town. This 280 km^2 virgin lowland dipterocarp forest has been advertized as a state park since 1979 and it houses many interesting species such as *Phalaenopsis gigantea*, *Presbytis rubicunda*, *Tarsius bancanus*, *Otus lempiji* and the rhinoceros hornbill. Within a few kilometres of the park headquarters itself, two waterfalls and 11 warm sulphurous springs are found.

The natural setting of this park, made up of this beautiful combination, has lured tourists regularly, especially the local people of Tawau. Throughout the year of 1999, 17,624 tourists arrival had been recorded. This figure is expected to rise further once the road-upgrading project is completed.

One of the tourist attractions is the warm sulphurous springs situated 3.2 km from the Bombalai Hostel. An hour walking along the jungle track will lead you to the first spring (labeled 2A). As seen in Figure 1, eleven warm sulphurous springs (25-33.7ºC) occur along the 250 m stretch of the Upper Tawau River. The temperature distribution of the springs is noteworthy; as the spring water got hotter to the south. The elevation of this site is approximately 370 m above sea level. The springs outlets are on the riverbed or by the bank just below the water level. According to Lim *et. al.* (1990), the northeasterly alignment of the springs indicates structural control. The close proximity of these springs to major northeasterly trenching lineaments observed on LANDSAT imagery had been noted by Lim (1988).

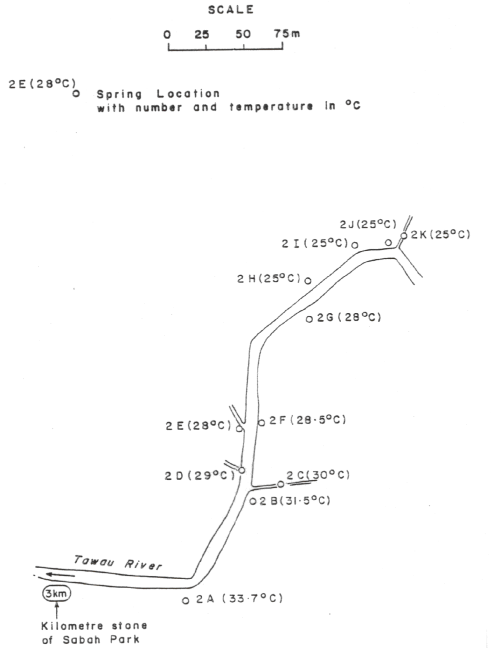

Figure 1. ***Distribution of warm sulphurous springs in Tawau Hill Park.***

The spring waters are acidic (pH 3.68-4.10). A strong hydrogen sulphide smell can be detected at 150 m range before reaching the first spring (2A). The waters of Spring 2A emerge from among boulders of rhyolitic rocks (Figure 2). The boulders surrounding the springs are characteristically sulphur coated (Figure 3).

Figure 2. ***Spring water emerging from boulders of rhyolitic rocks.***

It is not possible to obtain a total flow discharge of this area; however, Spring 2B has a flow discharge of 0.15 L/s, a pH of 4.04 and a temperature of 31.5ºC. The chemistry of Spring 2B is summarized in Table 1. The temperature was 23.6ºC and the pH 6.50 at 10 m downstream from this spring. At 10 m upstream, the temperature was 23.1ºC and the pH

Figure 3. The sulphur-coated boulders downstream of the spring.

7.51. The Tawau River flow rate here is approximately 1,600 L/s. The temperature downstream of all the springs was 24.3°C and the pH 6.35. Upstream of all the springs, the stream temperature was 23.1°C and the pH 7.51.

From the data available on these springs, they indicate that there are heat transfer processes at deeper level to a hydrothermal reservoir in the nearby region (Lim *et. al.*, 1991). We do notice that the geothermal water is not hot enough for any direct use in this region; however, we strongly believe that these springs have an important role to play in the nature tourism industry of Tawau Hill Park. According to the local people, the spring water has its own medicinal properties for skin treatment. Bathing in these springs is popular here.

Table 1. Chemistry Characteristic of Spring 2B (Lim, et al., 1991)

Sample	T2B
Site temp. °C	31.5
pH at 25°C	3.7
Dissolved SiO_2	Not analyzed
Total SiO_2	32 ppm
Ca	138.66 ppm
Mg	14.91 ppm
K	3.55 ppm
Na	14 ppm
Li	Not detected
HCO_3	7.32 ppm
SO_4	500 ppm
Cl	6 ppm
F	0.23 ppm
B	Not detected
As	5 ppm
Fe	1.4 ppm
Mn	0.4 ppm
Total solids	64 mg/L
Turbidity	Not analyzed
Conductivity	835 Fmhos

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Lim, P. S.; Intang, F. and F. O. Chan, 1990. "Geothermal Prospecting in the Semporna Peninsula with Emphasis on the Tawau Area." *Presented at GSM Annual Geological Conference 1990.*

OPERATIONAL CHARACTERISTICS OF THE GAIA SNOW-MELTING SYSTEM IN NINOHE, IWATE, JAPAN

DEVELOPMENT OF A SNOW-MELTING SYSTEM WHICH UTILIZES THERMAL FUNCTIONS OF THE GROUND

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ABSTRACT

The authors have developed the Gaia Snow-Melting System, which utilizes the ground as a heat source and heat storage body. Another characteristic of the Gaia Snow-Melting System is the utilization of the Downhole Coaxial Heat Exchangers (DCHEs) proposed by the authors. In this system, solar heat absorbed in a pavement is recovered and stored in the ground over summertime. Hence, both geothermal heat and solar heat are used for melting snow in winter.

The first Gaia Snow-Melting System was installed in December 1995 in Ninohe, Iwate Prefecture. The system covers an area of 266 m^2. Three DCHEs, each 8.9 cm in outer diameter and 150.2 m long, and a heat pump driven by a 15-kW electric motor were used. Adjustments of the setting parameters of the operation control system were performed during the first winter and first summer of operation. Modifications of the control system were carried out before the second winter.

In winters (not including the first winter), the average coefficients of performance (COP) for the heat pump have been 4.2 to 4.3 and the average specific heat extraction rates 80 to 83 W/m. The Gaia system's annual electric power consumption per unit area has been less than 20% that of the electric heating cable systems used in the same city.

The cumulative heat charged into the ground from the onset of operation until the end of November 1998 was greater than that extracted from the ground during the same period. Temperature profiles measured at an observation DCHE have changed year by year. However, the average temperature in the DCHE before the winter of 1998 was almost the same as that of the initial temperature profile in the DCHE. A more appropriate design and higher performance will be realized in the next system.

INTRODUCTION

The Japan Sea side of Japan from central Honshu through Hokkaido is subject to heavy snowfall. Many snow-melting apparatuses have been used over the past several decades and have been increasing in number. The oldest and most utilized method for melting snow is the sprinkling of groundwater over roads. However, the associated problems of ground subsidence and the dropping of groundwater levels have emerged. Apparatuses using electric heating cables and boilers burning oil or gas have been increasing in number especially in northern Japan, where the sprinkling of groundwater is not applicable. This can lead to an increase in the consumption of fossil fuels, and thereby, the emission of carbon dioxide.

The authors have developed the Gaia Snow-Melting System, which utilizes the ground as a heat source and a heat storage body. This system's main heat source is the geothermal heat contained in the shallow ground and its auxiliary source is summertime solar heat. Another characteristic of the system is the utilization of the Downhole Coaxial Heat Exchangers (DCHEs) proposed by the authors (Morita, et al.,1985; Morita and Tago, 1995). The DCHE utilizes thermally insulated inner pipe and reverse circulation (i.e., cold fluid flows down the annulus and warmer fluid flows up through the inner pipe) for efficient heat extraction.

The first Gaia Snow-Melting System was installed in Ninohe, Iwate Prefecture and has been in operation since December 1995. So far, this Gaia system has functioned effectively and has eliminated accidents due to snow or ice.

THE GAIA SNOW-MELTING SYSTEM

The Gaia Snow-Melting System consists of DCHEs, a heat pump and heating pipes embedded in the pavement (Fig. 1).

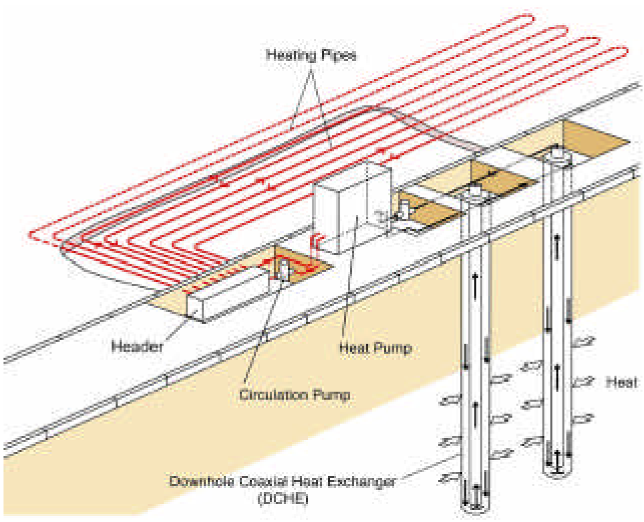

Figure 1. Conceptual drawing of the Gaia Snow-Melting System.

In winter, heat extracted from the ground with the DCHEs is transferred to the heat pump. After the heat pump increases the temperature, the thermal energy is transmitted to a heating medium circulating through a network of heating pipes for melting snow. Antifreeze is used as both a heat extraction medium and a heating medium.

In summer, solar heat raises the temperature of the pavement, in which the heating pipes are embedded, up to between 30 to 50EC. The solar heat is recovered from the pavement and charged into the ground by directly connecting the DCHEs and heating pipes, and by circulating antifreeze in this loop. Forward circulation is employed for efficient heat charging.

Thus, geothermal heat and summertime solar heat are used for melting snow in winter.

A newly developed control system operates the Gaia system automatically when road conditions meet specified criteria for melting snow or charging heat.

A numerical simulation code has been developed for predicting the operational behavior and performance of the system including DCHEs and a heat pump. This code was used for designing the Gaia system in Ninohe and for predicting its performance. Another code for analyzing temperature behavior in the pavement and the roadbed surrounding the heating pipes has been developed after the installation of the first Gaia Snow-Melting System. These two codes make it possible to design the system appropriately, meeting specific site conditions, and to predict the performance of the system.

THE GAIA IN NINOHE

Ninohe City is located about 500 km north of Tokyo. The Gaia system was installed at the downhill section of a curved road with a 9% gradient in order to prevent accidents caused by skidding and sliding vehicles in winter. The area covered by the snow-melting system is 4 m wide and 65 m long, covering a total area of 266 m^2.

The formation consists of Tertiary sandy tuff. Preliminary numerical simulations for the first winter's operation indicated the effective thermal conductivity of the formation to be 1.3 W/m•K. The temperature at the bottom of one of the DCHEs, 150.8 m in depth, was 22.5EC before the initial operation of the system, at one month after the completion of the DCHE.

Three DCHEs (Fig. 2), each 8.9 cm in outer diameter and 150.2 m long, a heat pump driven by a 15-kW electric motor and two 0.75-kW circulation pumps are used. Polybutene pipes of 16 mm in inner diameter are used as heating pipes and were embedded in the asphalt concrete pavement at 20 cm intervals. The depth of the top of the heating pipes is 10 cm from the surface of the pavement. The thermal capacity of the Gaia System is approximately 50 kW$_t$.

Snow-Melting Operation

In the current control system, the operation of the Snow-Melting System in the snow-melting mode is controlled utilizing information from a road surface temperature sensor and two road surface water detectors, one water detector with a heater inside and another without a heater. The heater is for melting snow or ice on the surface of the detector, and thus, snow or ice can be detected as water. The system begins its operation when the road surface temperature becomes lower than a specified value and one or both water detectors detect water. When the road surface temperature is higher than the specified value or when neither water detectors detect water, the system doesn't operate or its operation is stopped. The sensitivity of these water detectors is so high that the operation of the system begins immediately after the onset of snowfall.

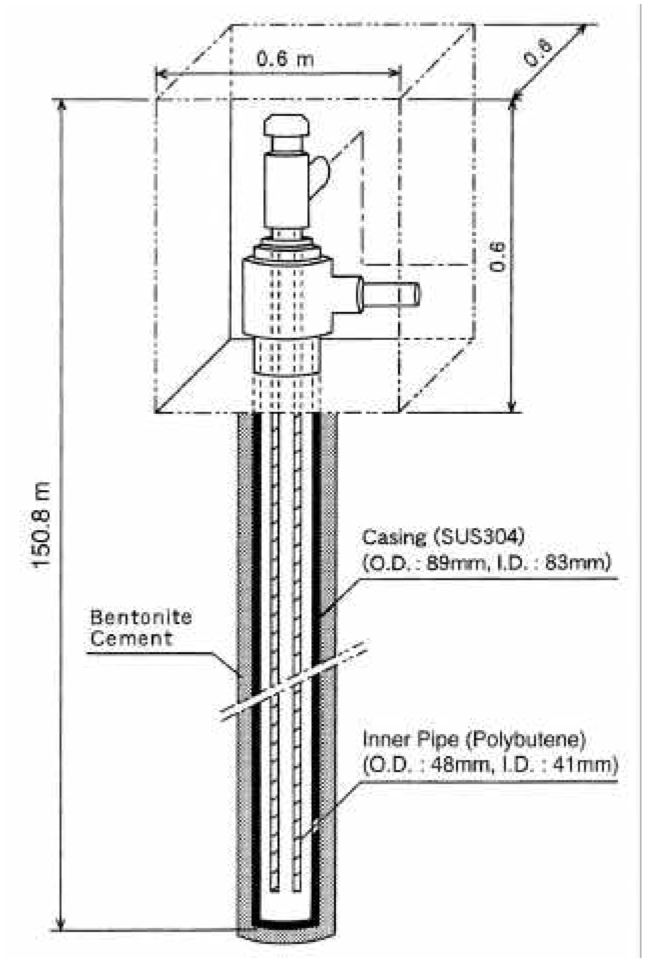

Figure 2. Structure of the DCHE.

It has been demonstrated that the Gaia system is an effective method to melt snow on roads. Figures 3 and 4 show the snow-melting conditions on February 13, 1996. So far, four snow-melting seasons have passed since the installation of this system. The operational characteristics of the system in the snow-melting mode are introduced here mainly using data from the winter of 1997. The average low temperature for the month of January was –8.3EC in that winter in the city.

Figure 5 shows the daily snowdepth differences in the winter of 1997 measured by a weather station of the AMeDAS (Automated Meteorological Data Acquisition System) located in Ninohe City. This station is located about 10 km east of the Gaia system. The daily snowdepth difference is a positive difference between the snowdepth of a certain day and that of the previous day. Hence, the number of actual snowfall days is greater than the snowfall days shown in Figure 5.

In Ninohe City, snow-melting operations begin at the beginning of December and end at the end of March (hereinafter, this period shall be called the snow-melting season). The total snowdepth difference for the 1997 snow-melting season was 223 cm.

Figure 3. ***Snow-melting condition at the upper section of the road on February 13, 1996.***

Figure 4. ***Snow-melting conditin at the lower section of the road on February 13, 1996.***

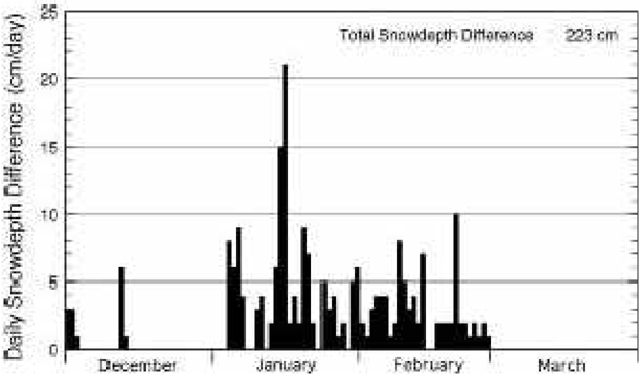

Figure 5. ***Daily snowdepth differences at the weather station in the 1997 snow-melting season.***

Figure 6 shows the changes in the daily operation times over the 1997 snow-melting season. The number of operation days in Figure 6 is greater than the snowfall days shown in Figure 5. This is because of the nature of the daily snowdepth difference and limitations in the resolution of the AMeDAS, which is 1 cm. Also, the system sometimes goes into operation because of rain or condensation of water in the air on the road surface. The total operation time of the system over the 1997 snow-melting season was 491.9 hours.

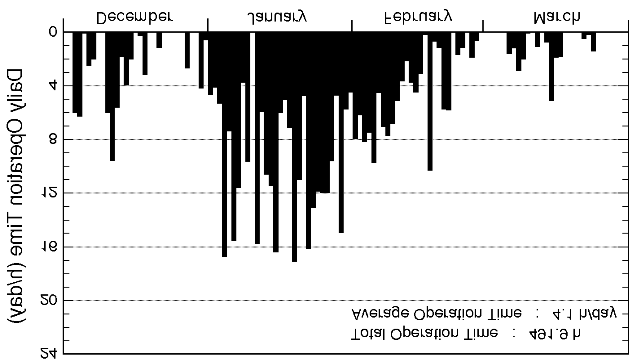

Figure 6. ***Daily operation time of the system in the 1997 snow-melting season.***

Figure 7 shows the changes in the antifreeze temperature at the outlet of the observation DCHE and in the ambient temperature at the weather station. The Gaia snow-melting system normally works in an ambient temperature range between the average and the low temperatures. Hence, the ambient temperature ranges shown in Figure 7 are ranges between the average and low temperatures. It can be seen that the outlet temperatures of the DCHE are higher than the ambient temperatures by 1.4 to 20.4EC.

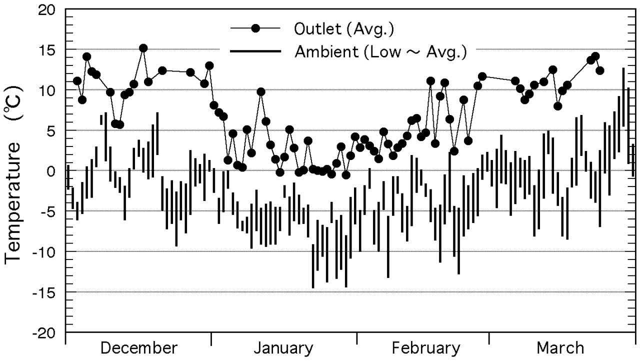

Figure 7. ***Daily average outlet temperatures of DCHE and ambient temperatures in the 1997 snow-melting season.***

Figure 8 shows the changes in the delivery temperatures of the heating medium from the heat pump to the heating pipes. Except in the case of short daily operation times, daily high temperatures of delivery temperatures roughly ranged from 28 to 36EC and daily average temperatures 25 to 30EC.

Figure 9 shows the changes in the extracted heat with DCHEs and delivered heat from the heat pump to the heating pipes in the 1997 snow-melting season. The total supplied heat with this system was 21.8 MW_th and extracted heat with the DCHEs was 16.6 MW_th (about 76% of the total supplied heat of the system).

Figure 10 shows the changes in the thermal output rate of the system and the heat extraction rate of the DCHEs. Normally, both rates decrease after the onset of operation with the progress of the season and recover after late January or early February. This tendency is associated with the decrease and recovery in the outlet temperature of the DCHEs. Therefore, this figure indicates that the heat pump is mostly

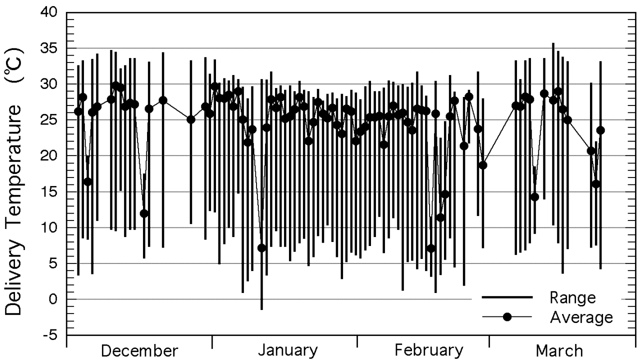

Figure 8. ***Change in delivery temperatures in the 1997 snow-melting season.***

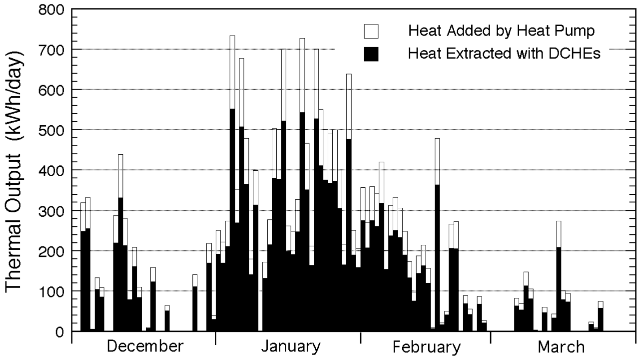

Figure 9. ***Thermal output of the system in the 1997 snow-melting season.***

at full load in January and February, and thus, the selected heat pump for the Gaia system was appropriate from the view point of capacity.

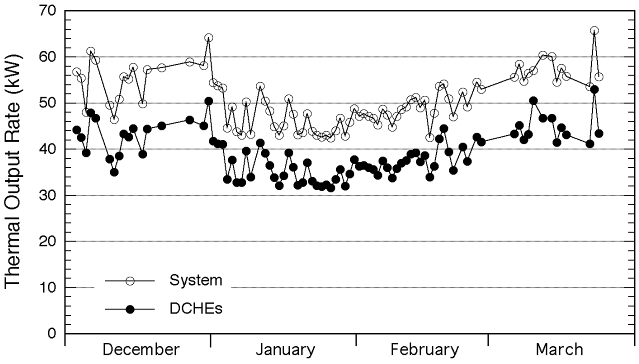

Figure 10. ***Changes in thermal output rate of the system and DCHEs in the 1997 snow-melting season.***

Table 1 summarizes the major characteristic values of the system in snow-melting operations for four winters. Despite a smaller total daily snowdepth difference, the supplied heat in the 1996 snow-melting season was greater than that of the previous season. This is because of a modification in the temperature control unit and an increase in the heat supply rate with this modification.

In winters (except for the first winter), the average supplied heat to the heating pipes per unit area of the snow-melting area over a snow-melting season ranged from 178 to 185 W/m^2, and the average specific heat extraction rates of the DCHEs ranged from 80 to 83 W/m. These high specific heat extraction rates at a low effective thermal conductivity of the formation is mainly due to the small operation rate of the system. Coefficients of performance (COP) ranged from 4.2 to 4.3 for the heat pump and 3.4 to 3.6 for the whole system.

Table 1. **Major Characteristic Values for Snow-Melting Seasons**

Snow-Melting Season	**1995**	**1996**	**1997**	**1998**
Total Snowdepth Difference (cm)	234	149	223	323
Avg. Low Temp. for January (°C)	-7.1	-4.6	-8.3	-6.2
Operation Time of System (h)	460.0	417.7	491.9	597.2
Operation time of HP (h)	381.5	393.4	460.7	507.3
Avg. Inlet Temp. of DCHE (°C)	1.7	2.1	0.2	1.1
Avg. Outlet Temp. of DCHE (°C)	4.8	5.3	3.4	4.3
Avg. Delivery Temp. of HP (°C)	26.2	26.6	26.2	25.4
Avg. Return Temp. to HP (°C)	19.3	19.4	19.2	18.5
Extracted Heat (kW_th)	12,330	14,740	16,600	18,870
Supplied Heat (kW_th)	16,230	19,360	21,810	24,650
Avg. Outlet of HP (kW_t)	42.5	49.2	47.3	48.6
Heat Supply Rate per Unit Area (W_t/m^2)	160	185	178	183
Specific Heat Extraction Rate (W_t/m^w)	71.8	83.2	80.0	82.5
Electric Power Consumption (kW_eh)	5,164	5,939	6,641	7,363
Power Consumption of HP (kW_eh)	3,899	4,617	5,211	5,779
Avg. COP of HP (-)	4.16	4.19	4.19	4.27
Avg. COP of Total System (-)	3.42	3.59	3.57	3.60
Seasonal Performance Factor (-)	3.14	3.26	3.28	3.33

Note: Data for each winter are for a period from the first of December to the end of March except for the 1995 snow-melting season. Data for 1995 are for a period from December 27, 1995 to March 31, 1996.

Heat-Charging Operation

In heat-charging mode, the system kicks into operation when the difference between the pavement temperature and a bottom-hole temperature of the observation DCHE becomes greater than a specified value. The heat-charging operation is stopped when the difference between the inlet temperature and the outlet temperature of the DCHE becomes smaller than a specified value.

Here, the operational characteristics over the 1998 heat-charging season, the season after the 1997 snow-melting season, are introduced.

Figure 11 shows changes in operation time at Japanese Standard Time. As shown in Figure 13, the daily average heat charging rates were almost constant over most of the heat charging period. Hence, the daily charged heat was essentially proportional to the daily operation times. The length of daily operation time was closely related to the total daily insolation, and most non-operation days in the period from May to the middle of October coincided with the days when no sunshine were observed at the weather station.

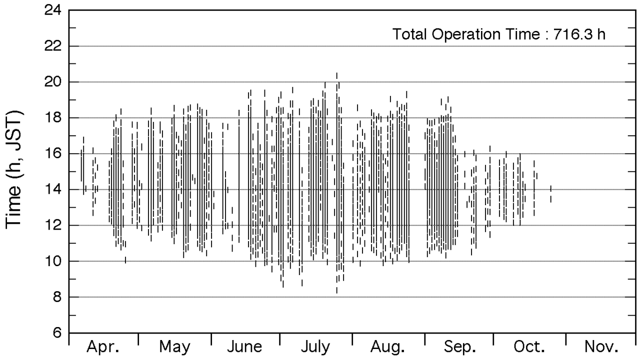

Figure 11. ***Operation time of the system at Japanese Standard Time in the 1998 heat-charging season.***

Figure 12 shows changes in inlet temperature of the observation DCHE and its bottom-hole temperature at 9 a.m. The bottom-hole temperature changed in a similar manner to that of the inlet temperature. Gradual decrease in the bottom-hole temperature after the last heat-charging operation might have been due to self-circulation of the working fluid in the DCHEs.

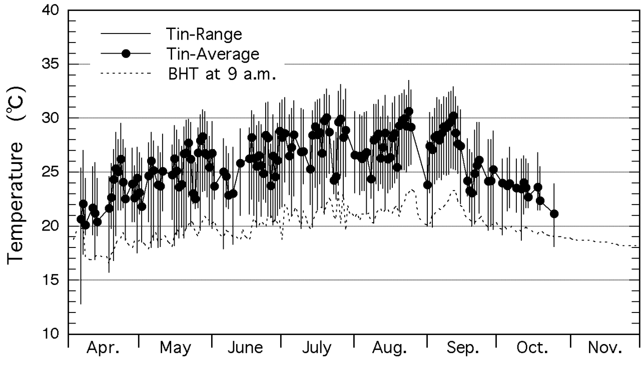

Figure 12. ***Changes in inlet temperature of the observation DCHE and its bottom-hole temperature in the 1998 heat-charging season.***

Figure 13 shows changes in the heat charging rate. The reason for the high heat charging rate in April, despite the low inlet temperature of the DCHE, was mainly due to the low formation temperature caused by heat extraction in the preceding winter. An increase in the formation temperature follows that of the inlet temperature, and the temperature difference between the working fluid in the DCHEs and the surrounding formation is limited in a narrow range. Therefore, the increase in the heat charging rate was very small from April to August.

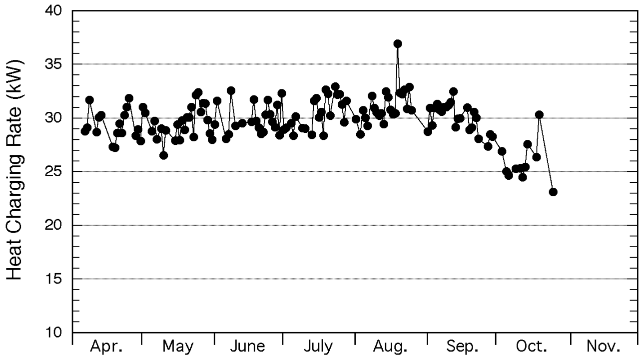

Figure 13. ***Changes in heat charging rate in the 1998 heat-charging season.***

Table 2 summarizes the major characteristic values of the system over three heat-charging seasons. Because adjustment of setting parameters of the operation control system was performed, values for the first season did not fully reflect weather conditions. The average heat recovery rate per unit area of the snow-melting area was 92 to 113 W/m^2. The average specific heat charging rates of the DCHEs ranged from 54 to 67 W/m. Heat charging rates per unit electric power consumption over a heat-charging season were 13.4 to 23.8 kW_th/kW_eh.

System's Behavior and Performance

Heat Balance

Figure 14 shows the seasonal extracted and charged heat since the onset of the operation of the system.

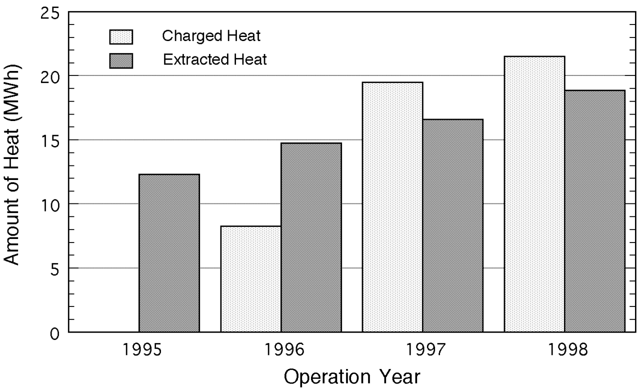

Figure 14. ***Charged heat and extracted heat up to March 31, 1999. Operation year is from the first of April to the end of March in the next year.***

Table 2. Major Characteristic Values for Heat-Charging Seasons

Heat-Charging Season	1996	1997	1998
Total Insolation (kW_th/m^2)	892	925	870
Operation time of the System (h)	339.2	691.6	716.3
Avg. Inlet Temp. of DCHE (°C)	26.7	28.4	27.1
Avg. Outlet Temp. of DCHE (°C)	22.3	23.4	21.8
Charged Heat (kW_th)	8,270	19,490	21,510
Recovered Heat per Unit Area (kW_th/m^2)	31.1	73.3	80.9
Heat Recovering Rate (W_t/m^2)	92	106	113
Heat Charging Rate (kW_t)	24.4	28.2	30.0
Specific Heat Charging Rate (W_t/m)	54.1	62.5	66.6
Electric Power Consumption (kW_eh)	619	872	903
Seasonal Performance Factor (-)	13.4	22.4	23.8

The cumulative charged heat into the ground up to the end of November 1998 was greater than the cumulative extracted heat over the same period. It seems that the greater the extracted heat in preceding season, the greater the charged heat in the successive season.

Changes in Temperature Profiles in a DCHE

Figure 15 shows measured temperature profiles in the observation DCHE at the beginning of the snow-melting season. As can be seen in this figure, temperature profiles have changed year by year. However, average temperatures in the DCHE over a section from 10 m in depth to the bottom-hole have remained almost the same. The average temperatures for 1995, 1996, 1997 and 1998 were 17.04, 16.95, 16.88 and 17.07EC, respectively. It is clear that the heat charging operation has been effective in preventing deterioration of the ground's function as a heat source.

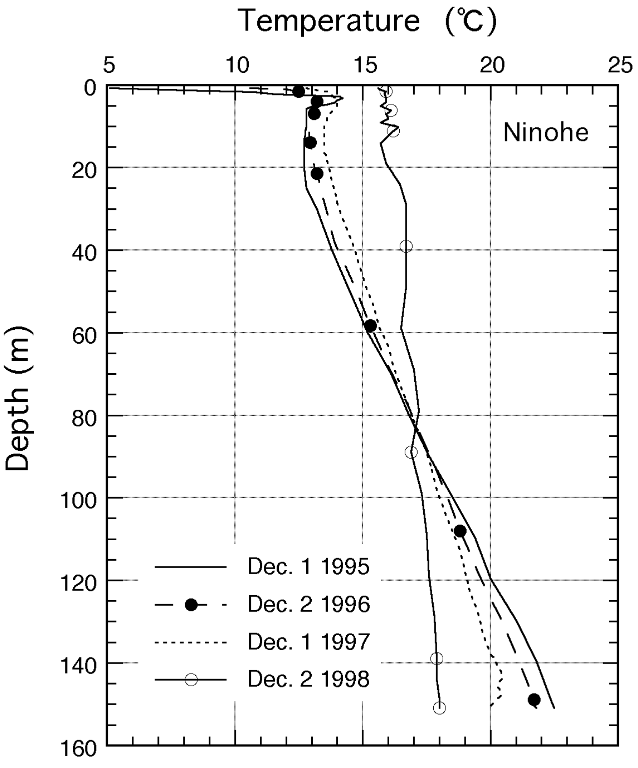

Figure 15. Change in temperature profiles in the observation DCHE.

The temperature profiles are becoming more vertical year by year. This is mainly due to self-circulation in the DCHE and vertical redistribution of heat in it and in the surrounding formation. Collected data from a flow meter in the snow melting seasons indicate that self-circulation occurs after the end of each operation of the system.

Power Consumption and Electric Power Costs

Table 3 shows the annual power consumption of the Gaia System per unit area of the snow-melting area for the operation years of 1996 to 1998, and the coinciding electric power costs. Values for electric heating cable systems in the city installed by the Iwate prefectural government are also shown in the table.

Table 3. Annual Power Consumption and Power Cost of the Gaia Snow-Melting System along with Those of Electric Heating Cable Systems in Ninohe City (operation year is from the first of April to the end of March in the next year).

	Power Consumption ($kWh/m^2/y$)		Power Cost (Vm^2/y)	
Operation Year	Electric Heating Cable	Gaia	Electric Heating Cable	Gaia
1996	145.4	24.7 (17.0%)	4,1082.4	771.6 (18.9%)
1997	154.7	28.3 (18.3%)	4,259.5	809.8 (19.1%)
1998	168.9	31.2 (18.5%)	4,201.0	792.3 (18.9%)

The power consumptions of the Gaia System were 17 to 19% those of the electric heating cable systems. This means that more than an 80% decrease in fossil fuel consumption or carbon dioxide emission can be obtained by replacing electric cable systems with the Gaia System. Annual electric power costs, including those for electric capacity and for power consumption, were about 19% those of the electric cable systems.

Modifications of the Control System

Based on the experiences of the first snow-melting season, modifications of the control system were made before the second winter.

Modification of the Operation Control Unit

In the initial control system, the operation of the Gaia system was controlled using information from one road surface temperature sensor and one road surface water detector with a heater inside. In the first winter, it was observed several times that the system stopped before the road surface completely dried up and the surface froze instantly. This occurred on very cold days. The cause of this phenomenon was that the water detector's surface dried up earlier than the road surface, because of the heater installed in the detector. Hence, another water detector without a heater was added to prevent the above phenomenon.

Modification in the Manner of Adjusting the Capacity of the Heater in the Water Detector

The capacity of the heater inside the water detector used to be manually adjustable at three degrees. In the first winter, the capacity was fixed at the medium degree. The major problem associated with this system was the freezing of the water detector's surface at very low ambient temperatures. In the modified control system, the degree of the capacity is adjusted automatically referring to the ambient temperature.

Modification of the temperature control unit

Initially, it was designed so that the heat pump operates to keep the return temperature of the antifreeze, from the heating pipes to the heat pump, at a specified temperature. In the modified control system, the heat pump is operated so that the temperature of the pavement is kept at another specified temperature. The major purposes of this modification were:

- To increase the temperature of the pavement up to a sufficient temperature level for melting snow as fast as the system's capacity allows, and
- To avoid intermittent operation of the heat pump. In actuality, frequent and intermittent operation of the heat pump was observed in the first snow-melting season.

FUTURE IMPROVEMENTS

In order to achieve higher performance than that attained with the first system, the following modifications will be made in the next Gaia Snow-Melting System.

- Plastic pipes more thermally conductive than polybutene pipes will be used as heating pipes.
- The interval between heating pipes will be shortened from 20 cm in the first system to 15 cm.

These two modifications will enable the supply of required heat flux for melting snow at lower heating medium temperatures by several degrees. This will result in a higher heat pump performance.

Also, a more efficient heat pump than that used in the first system will be employed, because the authors have learnt that is available on the commercial market.

CONCLUSIONS

Through several years of operation, it has been demonstrated that the Gaia Snow-Melting System is an effective system for melting snow and is environmentally benign. Also, an economic analysis, which was carried out separately, indicated that the Gaia System is economical.

The high load factor of the heat pump and a high specific heat extraction rate attained with this system indicated that the design of the system was adequate. A more appropriate design and higher performance will be realized in the next system.

The authors' primary purpose is to promote the utilization of the thermal functions of the ground in Japan. Currently, the authors are carrying out the design and economic evaluation of systems. These systems are applied for melting snow, space heating and cooling, and for indoor swimming pools. Some of them will be realized within the next several years.

ACKNOWLEDGMENT

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DRILLING GEOTHERMAL WELL ISO

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by
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INTRODUCTION

This report was prepared for Mr. Dale Merrick of I'SOT, Inc. to document the process that led to drilling and completion of their geothermal well ISO-1, located in Canby, Modoc County, California. The drilling project was completed during the months of April, May and June 2000. Construction of the well was partially funded by USDOE, and partially by I'SOT, Inc. This report does not include analysis of well testing data.

The report was prepared from the author's notes taken while being on site, and notes taken from phone reports by Dale Merrick and daily driller's reports. The purpose of this report is to document and analyze the data and document what has been learned from this project.

DRILL SITE LOCATION AND FEASIBILITY ANALYSIS

As is typical in such projects, the drilling site had to be selected based on practical considerations dictated by the infrastructure of the I'SOT property. An empty lot was selected, large enough to accommodate all drilling equipment, and close to the facilities that would eventually be served by the well. Subsequent aerial photo analysis hinted at the presence of a lineament in close proximity to the well site, thereby verifying the suitability of the selected site.

Feasibility of the drilling project was based on an earlier analysis by the Geo-Heat Center, assuming a depth to reservoir of 1,600 ft, based on the data obtained in the 1970s from the Kelley Hot Springs Area (KHS), located less than two miles to the east.

For the purpose of permitting and bidding, a synopsis of geologic and hydrogeologic information pertinent for this drilling project was prepared. Pertinent reports and drillers logs were reviewed to determine if:

- Water quality expected would be suitable for disposal either in a wetland or the nearby Pit River,
- The desired temperatures can be found within the proposed target depth of 1,600 ft, and
- That depth can be reached with the proposed drilling budget.

A number of reports were reviewed, copies of which were obtained in 1990 from the State Division of Oil, Gas and Geothermal (CDOGG). Most of the data were drawn from a report prepared by GeothermEx for Thermal Power Company, dated March 1977. Other information included a report prepared by Eliot Allen (1986), local driller's logs, and a number of chemical analysis data sets. Much of this effort also benefitted from what had been learned in the late-80s and early-90s in the Alturas and Bieber drilling projects (PGH, 1992, GJ&A, 1987 and others).

Given the limited budget, no additional field work was conducted to gather additional data.

Based on data from the Kelley Hot Springs wells and the Alturas, California city wells, the proposed well was anticipated to be flowing artesian, producing out of fractured lithified tuffs. Although the initially proposed target depth was 1,600 ft, it was recommended to plan for a minimum target depth of 2,000 ft, to assure flexibility to accommodate unforeseen cold water zones above 1,600 ft, and the uncertainty of finding a water bearing zone at 1,600 ft. More so it would have provided for sufficient resources to drill to an aquifer that was at a temperature similar to the minimum observed in the KHS wells.

GEOLOGIC CONDITIONS AT DEPTH

Based on geophysical, geochemical and drilling data, previous investigators concluded that the Kelly Hot Springs area, including Canby is underlain by an extensive geothermal aquifer below 1,600 ft, reaching down to more than 3,000 ft (GeothermEx, 1977). For example resistivity data suggest a low resistivity area extending several miles across Warm Springs Valley from east to west.

In the 1970s, at least two deep wells were drilled near Kelley Hot Springs to depths exceeding 3,000 ft. The wells were drilled in the 1960s and 1970s, by GRI and GPC. These bore holes penetrated clays, silts, sands and gravels and their lithified equivalents, plus intermittent basaltic lava flows. Apparently the lithology extending east from KHS is relatively consistent, and was assumed to be similar at the proposed drilling location to the west.

The temperatures encountered by the KHS exploration wells were measured at 239ºF maximum. This temperature prevails below 1,600 ft down to more than 3,000 ft. Temperature gradients in several shallow temperature gradient holes near KHS were more than 30ºF per 100 ft.

The area where drilling was proposed as part of this project has higher resistivity at depth, which could be indicative of geothermal water diluted by river water, or a lower permeability zone. This may have affected the success of this well, symptomized in somewhat lower temperatures and greater depth to a production zone.

In previous years, a number of wells were drilled near the I'SOT geothermal well location, but these wells do not exceed 900 ft. Geologic conditions below that (i.e., down to the proposed target depth of 1,600 ft, or deeper) were extrapolated from the deep wells drilled near the Kelley Hot Springs (KHS), and from the two temperature logs prepared by Eliott Allen and Associates in 1984.

Gradients observed in the nearby Canby School Well No. 1 were up to 7°F per 100 ft, similar as in the nearby I'SOT test well drilled in 1985 (Eliot Allen, 1986). Assuming a surface temperature of 58°F and a gradient of 7°F per 100 ft, the proposed well was expected to reach a temperature of 170°F at 1,600 ft, assuming no major shallow aquifer(s) had to be penetrated before target depth.

The temperatures encountered by the KHS exploration wells were measured at 239°F maximum. This temperature prevails below 1,600 ft down to more than 3,000 ft. Temperature gradients in several shallow temperature gradient holes near KHS were more than 30°F per 100 ft. However, given the data from Eliot Allen & Associates (1986, p. 75) from the I'SOT well, the temperature is more likely to be about 150°F.

DRILLING HISTORY

The drilling history is summarized in the Table 1. The well was spudded on April 3, 2000. The contractor was Story Drilling Services (SDS) of Klamath Falls (selected by bidding).

Although initial drilling progress was reasonably good below about 400 ft, drilling progress slowed down significantly due to the sticky clay (fine-grained tuffs) formations, eventually forcing the driller to drill with a blade auger bit. This problem, from the start, severely affected the course of the drilling project, and added to the project's continuing budgetary problems.

On May 4, when the hole had reached a depth of 900 ft, a temperature log was conducted. The results were encouraging, suggesting a gradient of about 7°F per 100 ft, as predicted. Although the gradient observed in this log was still affected by previous drilling mud circulation, the observed temperature of 110°F at 850 ft reasonably well matched the expected temperature of 150°F at 1,600 ft (assuming a gradient of 7.14°F per 100 ft). In other words, up to that depth, the temperature gradient was as expected. Assuming a desired resource temperature of 160°F, it was expected the target depth would still be 1,600 ft to obtain such a resource (assuming there would be a water bearing zone at that depth). By May 11, a depth of 1,599 ft was reached. Although the original target depth had been reached, no water bearing formation was encountered and a decision had to be made whether to drill deeper. At this time, another temperature log was run. The results of this log were disappointing. However, given the fact that the lithology had not changed significantly since 850 ft, it was assumed that these results were affected by inadequate temperature equilibration following mud circulation. However, given the financial commitment made so far, the operator felt uncomfortable stopping short of a major resource. For that reason, it was decided to allocate more financial resources and to continue drilling until a resource was found. Under the given gradient, assuming a minimum reservoir temperature of 125° F, the operator felt it was worth continuing drilling until a resource was found, presumably above 2,300 ft.

Given continuing concerns about potential sloughing problems after more than five weeks of drilling, it was decided to set and cement 6 5/8- inch casing (0.250" wall strength) to 1,600 ft before continuing with drilling. The casing string included a 10-inch diameter pump chamber (10 ¾-inch OD, 0.280" wall) from surface to 251 ft, connected to the 6-inch casing with a bell reducer.

Drilling continued with a 5 7/8-inch bit. By May 31, a depth of 1,952 ft had been reached. Although still no significant change in lithology was encountered, increasing occurrence of partially lithified tuffs below 1830 ft. An important observation was a red zone of lithified fine-grained tuff at about 1,950 ft, suggesting maybe a fault zone.

On June 5, another temperature log was conducted. A bottom hole temperature of 208°F was measured at 1,908 ft with a maximum mercury thermometer. The decrease of the temperature gradient below 1,830 ft (obtained by Wellenco), was encouraging, suggesting a change in formation characteristics, maybe associated with some fracturing.

By June 8, the hole had reached 2,100 ft--the maximum depth the contractor could drill to (due to limited drill pipe availability). At 2,048 ft, the hole began to lose mud circulation, requiring addition of about 20 to 25 gpm of water (plus bentonite) for more than six hours (i.e., the total amount of drilling fluid lost was about 7,500 gallons or more). Caliper and electrical logs run to 2,100 ft were encouraging, suggesting a significant water bearing zone below 2,075 ft. After the hole was cleaned out, a 4-inch liner was set from 1,531 to 2,100 ft, with perforations from 1,900 to 2,100 ft (3/16 in. by 2.5 ft, eight slots per foot).

Subsequent well development showed disappointing results, and was hampered by the drill rig's inability to airlift more than 500 ft of water column to flush out the perforations and/or fracture. Several options were considered, including sounding the well to determine if cuttings had filled the hole, and then clean out the well with a cable tool rig with a 2,100 ft sand line or a larger air compressor and small diameter tubing.

Given the unobstructed installation of the liner, liner perforations being obstructed by cuttings was deemed unlikely by the driller. Instead it was assumed that the fracture was plugged by drilling mud and/or cuttings. On June 15, under directives of Ed Granados of Geothermex, Inc. (the consultant working for SDS), the driller started to inject cold water into the well, to flush out and dilute any remaining mud deposits that would inhibit production of the well.

Unfortunately, after more than four days of injecting between 250 and 350 gpm at about 230 psi pressure, the hope for decrease in injection pressure never occurred. Consequently a sinker bar was lowered to the bottom of the well, which suggested that the well had filled up below 1,973 ft.

To clean out the fill SDS leased a high yield compressor and 2,100 ft of small diameter tubing, attached to the drill string (small enough to fit inside the 4-inch liner

Table 1 - Geothermal Well ISO-1, Drilling History

4/3/00	Start drilling project: drill 12 1/4" pilot hole to 275'.
4/4 - 4/5	Ream to 18" diameter to 260'. Run 14" casing to 257'.
4/6/00	Pump cement, cement surface casing.
4/10-4/12	Rig up BOPE.
4/12/00	Pressure test BOPE. Tag cement at 220'. Drill out cement to 256'.
4/13-4/17	Drill with 9 7/8" bit to 495'. Drilling progress slowed due to clay rich formations.
4/17-4/23	Change to long tooth soft formation bit for clay formations. Drill to 709'.
4/24-5/2	Due to repeated problems with clay plugging long tooth tricone, changed 9 7/8" drag bit. Changed out drill bit at 895', due to problems with changing formation from clay to lava. Then back to blade bit.
5/3	Pull drill string, lay down. Ready the hole for temperature log.
5/4/	Run temperature and caliper logs to 895' by Geo-Hydrodata. Then trip back in.
5/5	Drill to 1411' then change to mill tooth bit.
5/11	Drilled to 1599'. Temperature and caliper logging by Geo-Hydrodata.
5/12	Decision made to continue drilling.
5/14-5/25	Run 6" casing to 1599', and cement casing, with Haliburton Co.
5/26-5/31	Tag cement at 1500'. Drill out of casing, drill to 1952'. Below 1830 ft increasingly partially fine-grained lithified tuffs are observed.
6/5/00	Down hole geophysical logging, temperature, caliper logs. A bottom hole temperature of 208F was measured 1908 ft. Temperature gradient approximately 7.5F/100ft.
6/2 - 6/8	Continue drilling to 2100 ft.
6/13 - 6/15	Run 4 inch liner from 1600' to 2100', with perforations from 1900 to 2100 ft.
6/15 - 6/30	Attempt to clean out fracture zone by injecting cold water. Subsequently clean out obstruction (drill cuttings) from below 1973 ft, and develop the well.
6/30	Drill rig released.

below 1600 ft). On June 28, the driller started airlifting the well, slowly lowering the open end of the tubing to the depth of the obstruction. By June 30, the well had been cleared, producing about 75 gpm at 140 to 158°F by airlift. The material lifted to the surface turned out to be angular and sub angular chips of lithified tuff (i.e., drill cuttings) presumably washed in from the fracture and/or the annulus between formation and blank liner.

The drill rig was released on June 30.

GEOLOGIC SECTION

The geologic section is made up almost entirely of unconsolidated fine-grained tuffs. One exception was a "lava flow" between 890 and 900 ft depth. The lithologic log is summarized in the Table 2.

Table 2 - Geothermal Well ISO-1, Canby, Modoc County, CA. Geologic profile:
(sample depths indicated in left column)

10 to 40 ft:	Soil and alluvial deposits.
50 to 70 ft	Fine-grained tuff
80 to 180 ft	Lacustrine gravels, mixed with fine-grained tuffs.
190 to 590 ft	Volcanic mud flow
600 to 660 ft	Fine-grained tuff, partially lacustrine deposits.
670 to 780 ft	Volcanic mud flow, probably lacustrine deposit.
790 ft	Lithified fine-grained tuff.
800 to 880 ft	Volcanic mud flow. Rock fragments, embedded in greenish-grey clay often rounded, coated with white non-carbonaceous mineral deposits (alteration)
890 ft	Lava, probably andesitic (less than 10 ft thick)
900 to 1380 ft	Volcanic mud flow: greenish gray clay with subrounded and angular rock fragments. Slightly altered.
1390 ft	Fine-grained tuff, partially lithified.
1400 to 1600 ft	Volcanic mud flow.
1610 to 1620 ft	No samples
1630 to 1680 ft	Lacustrine sand: fine to very fine sand, angular zeolite crystals, and rounded rock fragments.
1690 to 1870 ft	Fine-grained tuff (maybe occasionally lithified?)
1880 1930 ft	Lithified tuff. Angular chips, of indurated (cemented) fine-grained tuff.
1940 ft	Red tuff, fine-grained. Poor sample recovery. Sample recovered from drill bit, suggests fine-grained tuff.
1950 to 2040 ft	Angular chips of fine-grained lithified tuff, embedded in reddish brown clay (tuff).
2050 to 2100	Chips, angular and sub angular, of fine-grained tuff embedded in dark gray clay. Sample from 2090 almost purely chips, no clay. Chips show evidence of fractures, lined with pyrite and reddish-brown material, and white to greenish white deposits. Sample from 2100 has again reddish brown clay matrix.

Figure 1. ***Drilling rig setup.***

Figure 2. ***Blowout preventor being installed.***

Figure 3. ***Cementing operation.***

Figure 4. ***Drilling bit with clay.***

Figure 5. ***Compressor for blowing out the well.***

Figure 6. ***During air stimulation.***

To summarize, several general observations can be made.

Lithology

The sequence of geologic formations consists almost entirely of fine-grained tuffs (volcanic ash) and lahars (volcanic mud flows). The monotonous clay rich profile is broken up only in two cases:

- A thin lava flow (less than 10 ft thick) between 890 and 900 ft, which is probably andesitic, and
- A lacustrine sand layer (probably of volcanic origin) between 630 and 1,680 ft.

The fine-grained nature of the tuffs and lahars is symptomized by the predominance of sticky gray-green clays, which made drilling rather difficult and added to cost overruns.

The entire section is believed to have penetrated the lacustrine and volcanic sequences of the Alturas Formation. As was the case in both Alturas wells (AL-1 and AL-2) and the Bieber well, production in the ISO-1 well is from fractures within lithified tuffs below 1,950 ft.

Alteration

Alteration (changes in mineral composition due to elevated temperatures) is evident throughout the entire profile below 500 ft (if not 200 ft), as symptomized by occasional silicic coatings on rock fragments, mineral deposits on vugs lined with mineral deposits, and frequent greenish staining of light colored rock fragments. In general, the "clays" (fine-grained tuffs) appear to be greenish in many sections, suggesting chloritization, which is an indication of alteration.

Production from Lithified Sections

In Alturas and Bieber the fractured lithified sections tended to produce hot water instead of fractured lava flows. Above 1,830 ft, the almost continuous sequence of fine-grained tuffs (symptomized as clays) in the ISO-1 borehole is characterized almost completely by the absence of what could be clearly interpreted as lithified sections that could produce water. However, the section below 1,830 ft contains increasing evidence of lithification, and the section below 1880 ft is even more lithified. Below 1,950, the fine grained tuffs are probably entirely lithified. Though only very rarely, these lithified sections show occasional evidence of hairline fractures filled with mineral deposits.

Below 1,940 ft, the cuttings are characterized by fine-grained red tuff (a sample recovered from drill bit, suggests fine-grained tuff). Below 1,950 ft, the predominance of angular chips, and reddish brown clay (tuff) suggests an almost completely lithified fine-grained tuff. Chips from this section were typically angular and sub angular. Occasionally the chips show evidence of fractures, lined with pyrite and reddish-brown material, and white to greenish white deposits.

For clarification, the term "lithification" suggests grains being cemented together by mineral deposits in the microscopic pore spaces. These mineral deposits originate probably from water trapped in the sediment for extend periods of time at elevated temperatures. Evidently lithification occurs to a higher degree below 1,950 ft.

The increasing lithification in the lower ISO-1 borehole is encouraging from a standpoint of producing water. It is possible that below 2,100 ft, the degree of lithification may increase; gradually, leading to harder formations that are even more promising for holding open water producing fractures.

Comparison with Kelley Hot Springs Geologic Logs

This geologic profile matches only to an extent with the one described for the Kelley Hot Springs wells. Both the KHS and ISO-1 wells are similar in that they both intercepted a very thick sequence of fine-grained tuffs, which are in part lithified.

But, there are also some major differences. For example, while ISO-1 encountered only one thin lava flow at 890 ft, at Kelley Hot Springs at least five "basaltic lava flows" were logged between 364 and 1980 ft, ranging in thickness between 10 and 260 ft.

One lava flow logged at KHS as "granodiorite" between 1,088 and 1,148 maybe equivalent to the lava flow logged between 890 and 900 ft in the I'SOT well (which in our opinion is probably andesitic, considering that granodioritic intrusives are absent in this part of the Modoc Plateau).

The KHS geologic logs also show several inconsistencies. For example it repeatedly mentions what is commonly referred to as "shale" by many drillers. These are probably lithified fine-grained tuff, the kind of formation that was also encountered below 1950 ft at ISO-1. Interestingly the KHS records indicate that production is commonly associated with these lithified tuffs, as was observed in ISO-1.

SYNOPSIS

A number of conclusions can be drawn based on the results of this project. This brief discussion will address three subject matters: geologic model, budget and project management.

Geologic Model

Evidently, ISO-1 barely penetrated only by about 200 ft into a much larger geothermal resource at depth. Although the lithified tuff sections were encountered at a depth similar as in Alturas, it is certainly deeper than at Kelley Hot Springs. This may very well explain the increasing resistivity around the ISO-1 site, as mapped in the 1970s. Although the final temperature estimate at bottom hole is still not determined, it is clear that the temperature is at least close to the minimum temperatures observed at KHS. It is likely that if ISO-1 had been drill only a few hundred feet deeper a much better well would have been completed.

All three intermediate temperature geothermal drilling efforts in the eastern Modoc Plateau (Bieber, Alturas and Canby) suggest a number of common features:

- Production zones are associated with lithified tuffs. These seem to occur at depths not shallower than about 1,800 ft,
- Temperature gradients above the lithified zones are about 7°F per 100 ft, suggesting formations with very similar thermal properties (confirmed by the geologic logs), and
- Given the similarity in depth and gradients, the reservoir temperatures must be similar in all three areas.

These observations may lead a number of conclusions that should be considered in future drilling efforts in the deep sedimentary basins of the Modoc Plateau:

- When planning a drilling project one should assume that the target depth is about 2000 ft or deeper.
- At that depth the resource temperature is probably greater than 185°F, if not more than 200°F.
- Assuming a conveniently lower resource temperature to accommodate a lower drilling budget is probably not warranted.

Project Management and Budget

The project budget clearly affected the outcome of this project. Although the Alturas drilling experience had clearly suggested that it is best to use a large rig, instead of a common water well rig, the budget realities for this project led to using a much smaller (water well) drilling rig.

Unfortunately, not having enough information at hand the initial proponent of this project was not able to develop a realistic budget. The initial bidding process had made it clear that, among other items, mobilization costs would lead to significant cost overruns. The larger drilling companies are located in Reno and the Sacramento area, if not southern California, which significantly increases mobilization fees. Preliminary cost estimates from qualified drilling consultants suggested that the cost for this well would be more than $200,000, using a rig comparable to the one used at AL-2 in Alturas. During the bidding process this estimate was confirmed by the bigger drilling companies, although at least one local small water well drilling company was able to bid within the desired price range.

Unfortunately, contracting with a smaller rig turned out to be as costly if not more costly than using a large rig, due to slow drilling progress in the clay rich formations. Slow drilling also eventually resulted in the hole becoming unstable, forcing the driller to run casing too early, thereby limiting further drilling options at greater depth. Clearly this affected the ability to drill to sufficient depth (and eventually well productivity). For example, instead of the anticipated three weeks, it took almost three months to drill ISO-1 (and AL-1 in 1987); while, it took only 11 days to drill AL-2 (in 1991) to almost the same depth. Evidently, being able to generate higher mud pressures, a larger rig is more capable of dealing with these difficult drilling conditions in the clay rich formations, than a small one.

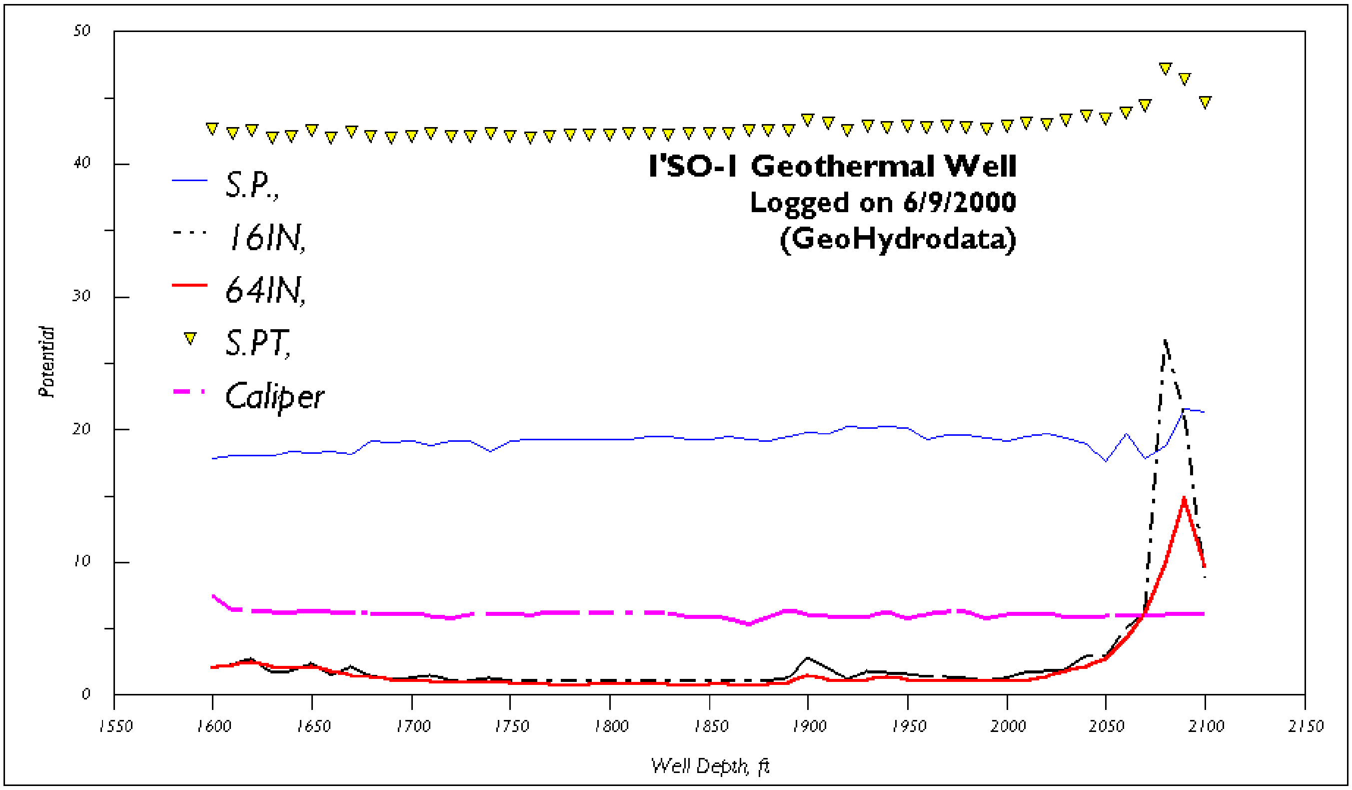
The trouble is that these problems are only symptomatic of a much larger problem that is related to the initial project budget planning. In the case of ISO-1 an insufficient budget (funded by a federal grant) forced the operator into making adjustments in the drilling program, overly optimistic assumptions and greater financial commitments than originally intended. To worsen matters, due to a policy decision at the state level, the operator was forced to quickly come to a drilling decision, or otherwise jeopardize California State (CEC) funds made available for retrofitting the heating system above ground. Not having more time, the operator was not able to secure further funds for the project before the drilling started. Fortunately for this project, the operator was determined enough to pull through to the end and borrow money against equity to bring the project to fruition. Our common experience is that drilling usually takes more money than most people think, and if not enough money is committed to begin with all money spent maybe wasted. Worst of all is when operators and drillers are forced into risky "cost-saving" measures which usually in the end come to haunt us by leading to even greater costs.

Once drilling started the commitment was made, and the operator was forced to pull through, or otherwise lose not only the funding for the retrofit, but also having wasted their matching funds already provided out of pocket. Sadly, any drilling project that falls short of the minimum drilling target based on technical analysis, leads to a waste of significant amounts of government and private money.

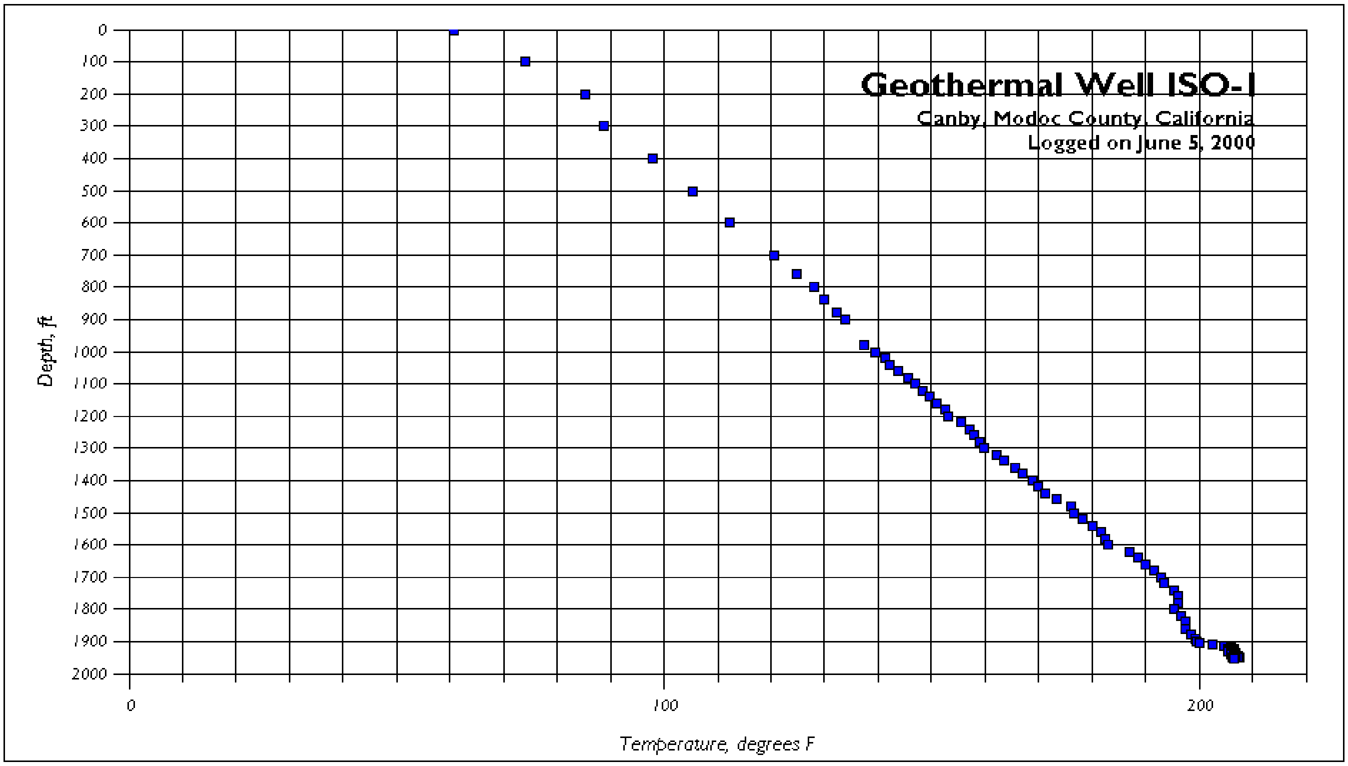
These observations symptomize what has been said before. In the 1980s, the author of this report was involved in several geothermal drilling projects in northern California. It was observed already then that the funding agencies funded too conservatively. It led several drilling projects to be conducted only to find that they had to stop short of reaching a good resource. Often, this occurred when being within reach of only several hundred feet of the target depth. This was the case in the Bieber drilling project (Lassen County), the Clio and Indian Valley Hospital drilling projects (both in Plumas County), and it almost happened in Alturas. In the latter a reasonable drilling budget was put together by merging two separate drilling projects (each one under budgeted) thereby eventually leading to one successful well, AL-1.

Sadly, in at least one project (Clio) the failed drilling effort led to the probably unwarranted conclusion that there is no resource, although the geophysical and geochemical data analysis came to rather optimistic prediction.

The lessons learned should be heeded for future funding of geothermal drilling projects in the Modoc Plateau. It maybe advisable that funding agencies base their funding allocations on an independent and in-depth geologic and budgetary analysis of the proposed project. It is important that project management and well testing receive sufficient contingencies (in our experience drilling decisions should not be left entirely to a drilling contractor, but to a well balanced, constructive decision making process shared by driller and geologist). After all, too many promising drilling projects have turned into failures not because of a poor resource, but



Caliper Log and Electric Logs



Temperature Log

because of budget troubles. Not enough money spent on a promising project without fruition, is money spent without benefit, whereas when an adequate amount of money results in a successful project, it can be easily justified by its own success story.

RECOMMENDATIONS

The immediate recommendations made for this project are:

- The well should be tested to determine long term production capacity. This would be best accomplished with a constant discharge test, following a short step drawdown test. The constant discharge test should be long enough until the data convincingly plot as a straight line on a Cooper-Jacob plot (which may take up to a week or more).
- Water quality testing should be done during the latter half of this test. We also recommend to have a sample analyzed for stable isotopes to be able to compare this well with other geothermal waters in the Modoc Plateau (including Kelley Hot Springs).

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ENERGY DEPARTMENT ADVANCING GEOTHERMAL POWER IN THE WEST

Geothermal Energy Association
GEA Washington Update
Washington, DC

August 9, 2000, Secretary of Energy Bill Richardson joined Senator Harry Reid (D-NV) in Las Vegas to announce the creation of 21 partnerships between the Department of Energy (DOE) and private industry to support the development and use of geothermal energy throughout the western United States. The projects will expand production and use of energy generated from the earth's heat to bring electricity and geothermal heat to millions of homes and businesses in California, New Mexico, Nevada and Utah. DOE and industry will share funding the projects over a three-to-five year period.

"Today's projects move us one step closer toward our goal of providing 10 percent of the electricity needs of the western states with geothermal resources by 2020," said Secretary Richardson. "Clean, reliable and renewable energy sources such as geothermal energy can become a significant contributor to the energy mix in the west, at a time when parts of the region are experiencing power supply shortages."

The Energy Department will provide first-year funding of $3.5 million to 21 companies to expand their geothermal activities. The research and development work will be conducted in three areas:

- **Small-Scale Geothermal Electric Power Plants** will demonstrate the capabilities of small generating stations in a variety of settings. Each plant will produce between 300 kilowatts and one megawatt of power.
- **Enhanced Geothermal Systems Technology** to improve the electricity generating potential of geothermal systems at existing sites by increasing production and extending their operating life.
- **Geothermal Resources Exploration and Definition** to support the exploration and development of new or previously undiscovered geothermal resources. Activities will focus on surface exploration, exploratory well drilling, and well testing.

In January, Secretary Richardson launched ***GeoPowering the West***, to expand the production of geothermal energy activities in 19 western states. The goals of the initiative include:

- Supplying at least 10 percent of the electricity needs of the west by 2020 with 20,000 megawatts of geothermal energy installed;
- Supplying the electric power of heating needs of at least seven million homes through geopower by 2010; and
- Doubling the number of states with geothermal electric power facilities to eight by 2006.

A complete list of the DOE awards announced on August 9 appears below.

DOE GEOTHERMAL POWER CONTRACTS ANNOUNCED AUGUST 9, 2000

Project Area	Private Sector Partners	Project Location	FY 2000 DOE Funding	Total DOE Funding	Private Funding
Small-Scale Geothermal Power Plants	Empire Energy LLC Empire, NV	Empire, NV	$150,000 prior year money	$1,600,000/4 years	$600,000
	Exergy Inc. Hayward, CA	Cotton City, NM	$150,000 prior year money	$1,700.000/4 years	$1,600,000
	Milgro Newcastle Inc. Newcastle, UT	Newcastle, UT	$150,000 prior year money	$1,100,000/4 years	$1,400,000
	ORMAT International Inc. Sparks, NV	Lordsburg, NM	$150,000 prior year money	$1,596,000/4 years	$1,604,000
	Vulcan Power Company Bend, OR	Radium Springs, NM	$150,000 prior year money	$500,000/4 years	$1,900,000

Enhanced Geothermal System Technology	Americulture Inc. Los Alamos, NM	Animas Valley, NM	$177,000	Funding being awarded through evaluation **	
	Drilling Observation and Sampling of Earth's Continental Crust, Inc., Salt Lake City, UT	The Geysers, Santa Rosa, CA	$199,917	Funding being awarded through evaluation **	
	Maurer Engineering, Inc. Houston, TX	The Geysers, Santa Rosa, CA	$194,554	Funding being awarded through evaluation **	
	Northern California Power Agency, Middleton, CA	The Geysers, Santa Rosa, CA	$174,584	Funding being awarded through evaluation **	
	ORMAT International, Inc. Sparks, NV	Animas Valley, NM	$200,000	Funding being awarded through evaluation **	
	Power Engineering, Inc., Hailey, ID	Roosevelt Hot Springs, UT	$191,615	Funding being awarded through evaluation **	
	Steamboat Envirosystems, LLC, West Palm Beach, FL	Reno, NV	$199,805	Funding being awarded through evaluation **	
	ThermaSource, Inc., and RES Company, Santa Rosa, CA	The Geysers, Santa Rosa, CA	$198,630	Funding being awarded through evaluation	
	University of Utah, Salt Lake City, UT	The Geysers, Santa Rosa, CA	$199,973	Funding being awarded through evaluation **	
Geothermal Resource Exploration and Definition	Calpine Siskiyou Geothermal Partners Limited Partnership, Middletown, CA	Glass Mountain, CA	$202,371	$1,102,371 / 3 years	$275,593
	Coso Operating Company of Caithness Resources, Inc., Ridgecrest, CA	U-boat, NV	$300,00	$1,875,000 / 3 years	$500,000
	Mount Wheeler Power Company, Ely, NV	Rye Patch, NV	$20,000	$1,620,000 / 3 years	$405,000
	Noramex Corporation, Carson City, NV	Blue Mountain, NV	$21,600	$656,736 / 3 years	$164,184
	ORMAT International, Inc., Sparks, NV, and Lighting Dock Geothermal Inc., Las Cruces, NM	Animas Valley, NM	$245,000	$913,000 / 3 years	$245,500
	SB Geo. Inc., Reno, NV	Steamboat Springs, NV	$14,792	$269,792 / 3 years	$67,448
	Utah Municipal Power Agency, Spanish Forks, UT	Cove Fort-Sulphurdale, UT	$23,057	$366,057 / 3 years	$91,514

BOOK REVIEW

STORIES FROM A HEATED EARTH OUR GEOTHERMAL HERITAGE

Pegamon
and
Ronald DiPippo
University of Massachusetts
Dartmouth, MA

Fact or fiction? People in several Korean communities got so fed up with lepers and other diseased folks over-running their villages to bathe in their hot springs that they poisoned the springs with dead dogs and even buried the springs so they could no longer be used.

Fact or fiction? Icelanders complained about the nuisance of hot springs on their farms to convince the tax assessor to set a low value on their properties.

Fact or fiction? The French Revolution nearly lead to the destruction of the geothermal district heating system at Chaudes-Aigues that had been operating smoothly since the 1300s.

All of those are true and represent but a few of the fascinating items to be found in *Stories from a Heated Earth - Our Geothermal Heritage*. This handsome volume is a collection of articles skillfully assembled into 34 chapters by three editors well-known in the geothermal community: R. Cataldi from Italy, S. F. Hodgson from California, and J. W. Lund from Oregon. There are stories from at least 41 countries, written by 47 individual authors, within its 588 pages. The book is jointly published by the Geothermal Resources Council and the International Geothermal Association.

This is indeed a weighty tome; the sewn paper-bound volume measures 8.5 x 11 x 1.5 inches and weighs about 3.5 pounds. The book is most pleasing to the eye, beginning with the handsome cover designed by J. Spriggs, a wood-block print–*Boy and Mount Fuji* by Hokusai, depicting a lad seated on a leaning tree branch, contemplating the majestic mountain–set on a red background with elegant white lettering. There are some 215 illustrations–photographs, line drawings, paintings and sketches. These are mainly black and white, but there are six in full color counting the cover.

The table of contents is well organized; the chapters are arranged by region of the globe. The volume begins and ends at Easter Island, and the stories travel around the planet stopping at nearly all countries or areas that have geothermal resources of any kind. Although the editors say that not all countries are included, they have done a fine job of selecting a most representative set to tell the tale of geothermal energy around the world and through time.

The writers generally come from the countries or regions described in each chapter, leading authenticity to the stories. The job of organizing and editing such a collection must have been formidable, given the fact that for most of the authors, English is not their first language. M. Sekoka, the author of the chapter on Japan, expressed his feelings in his concluding section: "As the author is not an historian and English is not his Mother Language, the author has gone through all sorts of hardship." To his and the editors' credit, the final product is well worth the hardship.

The format for each chapter is consistent and effective. Each chapter begins with the title page on the recto and a frontispiece on the verso. The frontispiece may be a photograph, painting, piece of sculpture or other work of art. While these are all arresting and valuable contributions, my favorites are the photograph by William Henry Jackson of "Bella, a Maori guide, sitting at the edge of the Rotorua geysers" (p. 434) and the painting by Paul Kane entitled "Mount St. Helens" showing a canoe carrying eight American Indians watching a spectacular eruption of this famous volcano (p. 6). Honorable mention goes to two others: "Madam Pele" by Herb Kawainui Kane (p. 450) and the aerial photograph of Mount Mayon by B. J. Barker (p. 406).

The title page carries an abstract and an introduction together with a small map at the top of the page (Mercator projection) outlining the continents of the world. The map highlights in black the country or area covered in the chapter. This helps orient the reader as the stories progress around the globe. Each chapter is amply illustrated with numerous figures. The illustrations in nearly all chapters, however, are not numbered which makes it awkward to refer to them, particularly since there are cases of cross-references between chapters. Most chapters include detailed maps to show the specific sites discussed, but I still found myself often referring to my atlas for more information.

Several chapters incorporate informative side-bars and excerpts from other literature that add significantly to the enjoyment and edification of the reader. Here we find quotations from many well-known authors, including Homer, Seneca, Strabo, Shakespeare, Poe, Twain, John L. Stephens, Frances Calderón de la Barca, and Garcilaso de la Vega.

Each chapter concludes with a summary and an extensive list of references. It must be said, however, that the references tend to be in the native language of the author, as one would expect. Furthermore, many are in the so-called "gray literature" and are probably inaccessible for the average reader. For readers wishing to delve further into the material, they may reach the authors directly since there is a complete set of information on each author at the end of each chapter, including telephone and facsimile numbers, and in most cases, e-mail addresses. The lack of an index in a book of this size and scope is disappointing.

Many of the chapters are reprints or re-writes of previously published articles (18 out of 34) that have been adapted for the present book. Most of the reprinted articles first appeared in either the *Proceedings of the World Geothermal Congress*, v. 1, sect. 2, 1995 or *Geotermia, Revista Mexicana de Geoenergia*, v. 8, n. 3, 1992.

The material is aimed at a general audience. One need not be an archaeologist, anthropologist, geologist, geochemist or engineer to understand the material. There is, however, use of specialized terminology for a wide range of fields for which a glossary would have been helpful. Since the stories go back to prehistoric times, reference is often made to various geologic periods. There are three helpful charts in chapter 2 that relate the Lower Paleolithic, Upper Paleolithic, Neolithic, the Stone Age, Metal Age, etc., to years B.C., but since reference is made to these ages throughout the texts, I found myself thumbing back to chapter 2 to get the timing straight in my mind. While the language is generally accessible, there does appear the odd sesquipedalian here and there, such as a word "autochthonous" that sent me running to my unabridged dictionary–it means "indigenous" if you did not know.

While there is not enough space in this review to comment on every chapter of the volume, I will try to convey the sense of the work and offer a few comments. The general theme is the interaction between humans and geothermal phenomena from the beginning of time, with emphasis on how geothermal energy influenced the development of civilization. This required the study of tales, legends and myths, gleaned from ancient writings, official documents, pictorial representations, and oral histories. In such matters, the distinction between fact and fiction is often blurred, and the key to understanding is interpretation.

While there is no shortage of myths and beliefs surrounding "The Creation," the first chapter offers yet a new mythological version. Cataldi presents a geothermal-centered explanation of the beginning of it all. He continues in this vein in the next chapter by speculating on the nature of humans' first encounters with geothermal manifestations.

Chapter 3 on the African Rift, written by Oregonian Lund (breaking the pattern mentioned earlier) unites the first humans with the forces of geothermal energy. I believe it is significant that the scientifically accepted cradle of life as we know it corresponds to an active geothermal zone. We humans may owe a lot more to geothermal than we think.

This is followed by several excellent chapters on the Middle East, Turkey, Greece and Macedonia. The reader is treated to the oldest known depiction of a geothermal event–a Turkish wall painting dating from 6200 B.C. that shows the eruption of Çatal Höyük. The mural appears twice in the volume, first in chapter 2 (p. 16) where a photo of the actual mural is juxtaposed against a reconstruction and a modern interpretation, and again in chapter 5 (p. 53) where only the reconstruction is presented.

The book then focuses for the next seven chapters on the Mediterranean region and specifically on Italy. The attention given to Italy and in particular to Larderello (or, as it was known in the early days, the Boraciferous Region) is justified by the important advances that were made there in the areas of chemical production (mainly boric acid), space heating using geothermal fluids, integrated use of geothermal energy for industrial processes, and the first commercial generation of electricity from geothermal energy. Starting from the time of the Etruscans in 800 B.C. to the present, Italy has been at the center of geothermal development. It is an interesting and important story. Since six of the chapters on Italy are reprinted from other sources, there is considerably overlapping and repetition. In my view, the bulk of the story can be found in the excellent chapters 13 and 14 by P.D. Burgassi and Burgassi, Cataldi and C. Donati, respectively.

The low-temperature resources of the Caucasus region, Poland and France are described in the next several chapters. The story of the French village of Chaudes-Aigues, written by J. P. Gibert and F. Jaudin, is intriguing. Blessed with one of the hottest springs in all of Europe (82°C), the villagers have long put these waters to good use. Back in the 14th century, they built a district heating system that was similar in principle to the ones in operation today at many places. Water from their spring was channeled through the village. Individual houses were connected to the main channel by side channels controlled by sluice gates. Hot water flowed through ducts under the floors of the houses, into and out of a large pit dug under the house, eventually returning to the main channel. When the house reached a comfortable temperature, the gate could be closed. This system served quite well until the French Revolution in 1789, after which everyone (and no one) became responsible for its operation. Residents began filing lawsuits against one another as the system fell into disrepair. The villagers soon realized that they were about to lose a very valuable asset and this led them to establish rules and regulations for the operation and use of the waters. Most importantly, they placed an individual in charge of running the system. The spring remains in use today, and the town is the site of the Museum of Geothermics and Water Cures established in 1993.

I. B. Fridleifsson relates Iceland's history of geothermal use in chapter 19. The island settlements got started around the year 900 A.D. Unlike in other parts of the world, early settlements were not sited close to hot springs. Since the main livelihood of the Icelanders was fishing, they preferred to live close to the ocean. The hot springs were used primarily for washing clothes, a task done by the women. The convenience of the fishermen was paramount. The Icelandic farmers disparaged the existence of hot springs on their land, exaggerating their disadvantages, to lower the value of their property in the eye of the assessor and thus, reduce their taxes. This information comes from tax documents dating from

1709, but the strategy is easily recognizable and timeless. The first attempt to capture the heat of the energy of the hot springs for heating houses was in the 1200s, but it failed. No further attempts were made for the next 700 years, a surprisingly long time given Iceland's cold climate. Of course, today Iceland leads the world in the use of geothermal energy for space heating.

A recurring story throughout the book is the therapeutic benefits of thermal-mineral waters. Everywhere the story is the same: soak your tired, weary, diseased body in geothermal waters and be refreshed, rejuvenated, and cured. There seems no end to the list of afflictions and diseases that can allegedly be cured in this way: arthritis, rheumatism, gout, syphilis, leprosy, goiter, paralysis including polio, dyspepsia, leucoderma, rashes, burns, psoriasis, fibrous tissue syndrome, eye infections, liver disease, dysentery, sexual dysfunction, gynecological disorders, et cetera. Some cultures believed that hot springs could restore virginity. Some myths would have us believe that springs could even restore life to the dead. In a remarkable passage in chapter 24, we learn that Korean villagers poisoned their own hot springs to put an end to lepers trying to cure themselves. B. W. Yum tells us that they would throw dead dogs in the pools to discourage their use, and that they even filled in and buried springs to save their villages from being overrun by these diseased outsiders who were viewed as a health threat.

A story from Japan told by Sekioka in chapter 25 deals with the export and sale of hot spring water. Entrepreneurs would scoop up and barrel water from the springs for shipment to localities lacking hot springs. This obviously was a rather inconvenient way to spread the benefits of the waters, so an innovative fellow hit on the idea of making artificial hot spring water. Following a carefully devised formula of chemicals, he was able to reproduce the alleged healing properties of natural waters. Unfortunately, the product turned out to be too expensive for the average consumer. Undeterred, he simplified the formula–by dissolving geyserite in salt water, he created his new, improved artificial spring water. Presumably, his clients did not notice any difference in the quality or effectiveness of the product.

The holistic view of natural geothermal resources held by indigenous peoples is another recurring theme. It is exemplified by the Maoris of New Zealand (chapter 28 by C. M. Severne) and Native Americans (chapter 29 by Lund), to mention only two. Recurring themes in the oral histories of diverse cultures serve to unite all the people of the world in coping with mysterious and powerful natural forces. The notion of stewardship of a divine gift to preserve it for future generations is a commonly held principle. The conflict between this belief and modern development has created a number of adversarial situations. Several chapters deal with this issue and point out ways of reconciling the opposing positions.

The impact of geothermal energy on the early settlers of Mesoamerica and South America is told vividly in chapters 31, 32 and 34. Although these regions were isolated from Europe, Asia and Africa at the time, the similarity of the developments is striking. Again, we see that there was a common way of thinking about the great forces of nature that permeated all early peoples, regardless of where or when they lived.

Chapter 33 by Hodgson converts some current oral history from Mexicans into the written record. The stories related by A. G. Salazar are especially moving and poignant for anyone who has ever worked, traveled or lived in active geothermal areas.

The belief in animism is another of the common features of the stories of many peoples. Physical features of the landscape are thought to be alive. While hardly anyone would doubt that a tree is alive, many would question whether a mountain is alive. We plant seedlings and watch tree grow; we did not actually see how a mountain was born and grew–we can only glimpse this through our intellect. It comes down to a question of time-scale relative to our own lives. It is easy to understand how indigenous peoples with a long tradition of oral history can believe in the life of mountains because the oral history lengthens the effective life of an individual to that of all their ancestors. Thus, the eruption of Mount Mazama and the creation of Crater Lake in Oregon–witnessed by Native Americans some 7,700 years ago–can be a part of the personal experience of a Native American today.

Hodgson captures this idea in the last paragraph of chapter 33: "Birth and death. Like us, geothermal features begin and end, moving through cycles of their own. We draw towards them, lured by change, beauty and an unusual cast of the familiar–water, rocks and heat. We search them for answers to mysteries in our own lives, like birth and death. We have done this through time, and geothermal stories are the archives of our quest."

The authors have succeeded in their objective, namely, to show how "applications of geothermal resources stand not alone but on an historical continuum." Their unique volume is a valuable addition to the historical literature of our geothermal world.

GEOTHERMAL PIPELINE

Progress and Development Update
from the Geothermal Progress Monitor

OREGON

BPA, Calpine in 49.9-MW Geothermal Power Deal

Bonneville Power Administration recently signed an agreement to buy 49.9 MW of electric power from Calpine Corporation. The power will be produced at the Fourmile Hill Geothermal Development Project at Medicine Lake (Glass Mountain) in northern California. There has been strong opposition by environmental groups, summer home owners and Indian tribes, with a recent appeal to the agreement made by the Pit River Tribe. Exploratory drilling has already been approved and the plant is expected to being operation in late 2004. Exploratory drilling will probably begin next spring. Calpine has received a $20.8 million award from the California Energy Commission under its new renewable account to assist the project. BPA will pay about $57 a MW-hr for 20 years. (Source: Reuters, Dec. 1, 2000).

CHINA

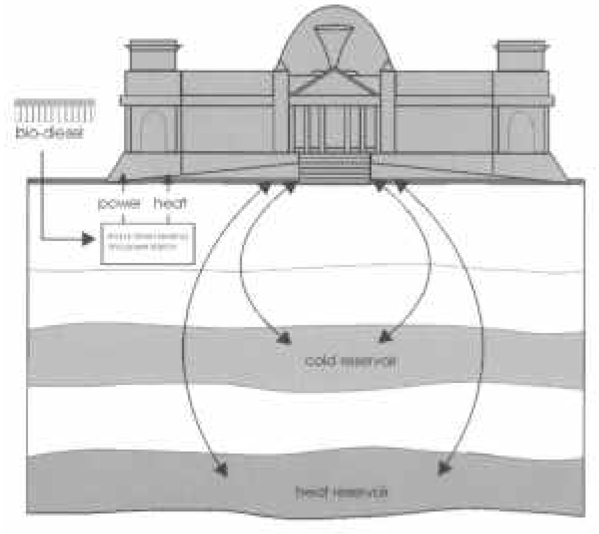
Beijing Will Explore New Energy Resources

Beijing is exploring the use of new energy sources to improve its energy efficiency and to reduce pollution of coal, gas and oil in the this major metropolis. This will include geothermal power , solar energy, bio-energy and wind power. This will also benefits their goal to win the bid for the 2008 Olympic games. Beijing has about 150 geothermal wells, capable of producing 8.8 million cubic meters (2.3 billion gal) of hot water annually, of which about 400,000 cubic meters (106 million gal) is being used for space heating. If the city explores for additional geothermal resources, the new energy will heat an additional 20 to 30 million square meters (24 to 36 million square yards) of floor space, equivalent to the consumption of 3 million tonnes (3.3 million tons) of coal annually. (Source: Xinhau News Agency, Dec. 1, 2000).

GERMANY

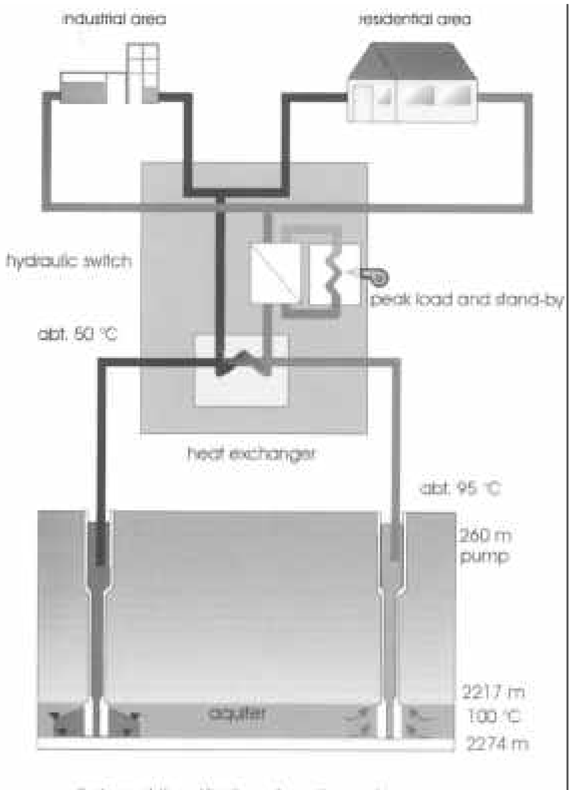
Energy Supply of the Reichstag Building in Berlin

The reconstruction of the Reichstag building (destroyed in 1933), as the seat of the German Parliament, was completed in 1999. This building has an innovative heat generation and cold storage system developed and planned by GTN - Geothermie Neubrandenburg, Ltd of Germany. A bio-diesel fired 1,600 kWe motor-driven heating and power station forms the heart of the system and provides the co-generation of power and heat. In summer, excessive heat of the motor-driven heating and power station is fed at a temperature of 70ºC (158ºF) into a subsoil heat reservoir located 300 m (1,000 ft) beneath the Reichstag building. In periods of peak demand in winter this heat can be directly recovered for the supply of special low-temperature heating systems. A second reservoir, about 50-m (165-ft) deep, is used for cold storage. Groundwater cooled down to 5ºC (41ºF) by ambient cold in winter is stored here and is supplied in summer, without any additional driving energy, to the cooling system of the building. (source: Engineer and Geologist, 1999).



Neustadt-Glewe Geothermal Heating Station

Since 1995, the natural heat potential of the subsoil has been utilized by the Erdwärme Neustadt-Glewe Ltd. for the supply of heat to more than 1,100 households and



System of the utilisation of geothermal energy numerous industrial consumers at Neustadt-Glewe located in western Germany near Mannheim. The geothermal loops of the station was planned by GTN - Geothermie Neubrandenburg Ltd. By utilizing geothermal heat, which is used exclusively in direct heat exchange, the emission of 6,500 tonnes (7,200 tons) of CO_2 is avoided from a conventional gas-fired heating station of the same capacity. The thermal water loops production depth is 2,250 m (7,400 ft) and provides a flow rate of 125 m^3/h (33,000 gal/h) from two wells. The station has an installed capacity of 10.7 MWt of which 6.5 MWt is geothermal and provides 23,700 MWh annually of which 22,200 MWh is provided by geothermal energy. The reservoir temperature is 100°C (212°F) and the temperature at the heat exchangers is 95°C (203°F). (Source: *Engineer and Geologist*, date unknown)