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WELLS AND HOT SPRINGS

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

CONTENTS

Cover: Photo 1 - Venting Well, Tongonan Geothermal Field, Leyte Philippines; Photo 2 - Pohutu Geyser Basin, Rotorua, New Zealand and Photo 3 - Hot Springs, Upper Geyser Basin, Yellowstone National Park (Photos by John Lund).

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WESTERN STATES GEOTHERMAL DATABASES CD

Compiled by
Tonya L. Boyd
Geo-Heat Center

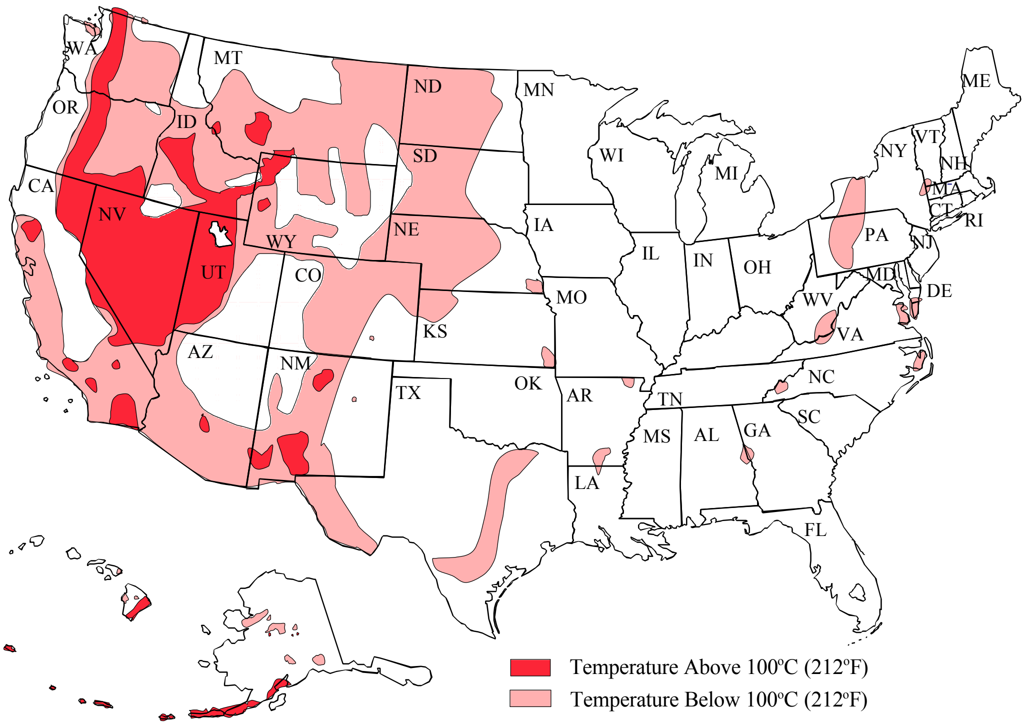

Figure 1. Geothermal Resources Areas of the United States.

INTRODUCTION

Low- and moderate-temperature geothermal resources are widely distributed throughout the western and central U.S. as can be seen in Figure 1. There are also a few low-temperature geothermal resources that occur in the east.

There has been several major efforts in assessing the potential for low-temperature geothermal resources in the U.S. The first major effort in the 1980s included 17 states which resulted in geothermal resource maps, prepared by the National Geophysical Data Center of the National Oceanic and Atmospheric Administration (NOAA), that are still being used today. The latest effort, which included 10 of the 17 original states, was in the early-1990s, and which resulted mainly in individual digital databases of all known geothermal wells and springs for a total of over 9,000 wells and springs. The 10 states were: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, and Washington (Lienau and Ross, 1996).

The state databases that were completed in the 1990s were designed for use on personal computers, and have the capability of being accessed and managed by using readily available commercial spreadsheets. The only problem was the databases were produced in several different formats and no two states were set up in the same format; although, there was a general guideline for the format of the information.

The low-temperature resource assessment completed in 1990s included another task. The task was to complete a statewide study of collocated geothermal resources with the only criteria being a collocated community with a resource temperature above 50ºC (122ºF) and located within 8 km (5 miles) of a community (many of which have <1,000 population). There were 1,723 wells and springs identified with a temperature over 50ºC (122ºF), with 1,469 of them located within 8 km (5 miles) of a community. There were a total of 271 communities identified within the 10 western states.

The oldest, most versatile and most common use of geothermal energy is direct-use applications; although, most people associate geothermal with power generation. Direct-use applications include: greenhouse heating, aquaculture pond and raceway heating, space and district heating, industrial applications such as food processing, and resort and spas. The fastest growing direct-use applications are for greenhouses and aquaculture, which can be seen in Figure 2.

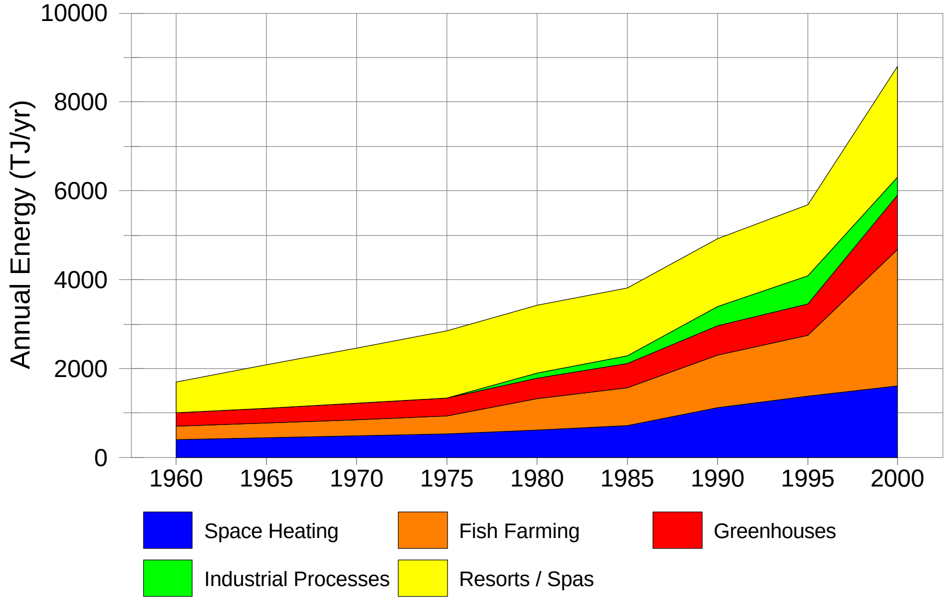

Figure 2. U.S. geothermal direct-use growth.

The Geo-Heat Center was recently tasked through a contract with the Department of Energy to complete a state resource database, including collocated communities, for six more states in the west. These states are: Alaska, Nebraska, North Dakota, South Dakota, Texas and Wyoming. The Geo-Heat Center was further tasked to include the original state databases into a standard format for ease of use. Research for the databases included finding reports and other information on wells and springs for those states, and also to ask knowledgeable people in those states where to obtain additional information.

The reports of the original state teams and the new information from the additional six states documents a total of 11,775 wells and springs in the databases with the new states producing 2,731 more entries. The number of collocated sites increased to 404 from the previous 271 for the 10 states. The total of wells and springs with a temperature over 50°C (122°F) went from 1723 to 2211, which is an increase of 28%. A summary of the numbers by state is shown in Table 1. All of this information is available on a CD, as described below.

WESTERN STATES GEOTHERMAL DATABASES CD

The Geothermal State Resources CD can contain up to five databases for the 16 states as stated above. The five databases are:

1. *Well and Springs* - Which contains all the known wells and spring for that state with a temperature typically > 20°C (68°F);

2. *Chemistry* - This database contains the most common fluid chemistry for the sites listed in the *Wells and Springs* database. There are a couple states where no chemistry information was available (Texas and Nebraska);

3. *Other Information* - This database contains additional information found in the original databases but did not fit in the original two categories;

4. *Direct-Use Sites* - This database contains known locations of existing direct-use sites for each state. The states of Arkansas, Georgia, Hawaii, New York and Virginia are also included since they all have direct-use; and

5. *Collocated Sites* - Contains information on population centers located with 8 km (5 miles) of a known resource with a temperature above 50°C (122°F).

The databases are available in three different formats for use over a wide range of spreadsheets and database programs. The three formats are listed below.

1. QuattroPro 8 extension *.wb3
2. Microsoft Excel 97 extension *.xls
3. Comma delimited Text extension *.csv

Background information on each state database can be found in the "Information" file. This file includes where the information was obtained, summary of each database included for the state (such as how may entries in the wells and springs database), a listing or the column headings for each database, and which of the column headings has no information for that state.

There are two more white paper files that may be available for each state. The first one is the original state team report for the 10 original states. Seven of the original reports are available online at the website DOE Information Bridge

Table 1 Summary of the Western States Geothermal Databases

	Number of Wells and Springs	Number of Chemistry Entries	Number of Collocated Communities	Number of Direct-Use Sites
Original Databases				
Arizona	1,251	2,491	14	12
California	989	683	70	100
Colorado	168	443	15	39
Idaho	1,555	620	51	73
Montana	292	288	18	34
Nevada	455	365	30	330
New Mexico	361	823	12	13
Oregon	2,195	208	32	628
Utah	964	885	23	17
Washington	814	195	6	6
Subtotal	**9,044**	**7,001**	**271**	**1,252**
New Databases				
Alaska	238	242	17	14
Nebraska	87	0	9	0
North Dakota	128	139	1	0
South Dakota	821	4	58	6
Texas	1,101	0	43	3
Wyoming	356	182	5	21
Subtotal	**2,731**	**567**	**133**	**44**
TOTAL	**11,775**	**7,568**	**404**	**1,296**

<http://www.osti.gov/bridge/>. As the other state reports become available they will also be placed on the CD. The second white paper file contains a listing of references that provides more information for each state.

To be able to view these white paper files, you must be able to view an Adobe PDF file. If a person does not have the program Adobe Reader or similar program to read the white papers files, the installation files have been included on the CD in the directory Adobe. The files are available for both Windows and Mac computers.

WHAT EACH STAT DATABASE CONTAINS

The *Wells and Springs* databases are available in both SI (site-a) and US (site-b) units. The column headings for this database are:

a. Site ID - Corresponds to the other databases Chemistry and Other for easy reference between them
b. Site Name - Name given to the well or spring in the original databases
c. Type - well, spring or other (for example, California lists several types of wells)
d. Latitude
e. Longitude
f. County
g. Quad - Some states listed Quadrangle information which represents Township N/S and Range E/W. Some of the states used both references.
h. Township - Part of the legal land description which includes columns h, i, j, k, l
i. North or South - Part of the legal land description which includes columns h, i, j, k, l
j. Range - Part of the legal land description which includes columns h, i, j, k, l
k. East or West - Part of the legal land description which includes columns h, i, j, k, l
l. Section - Part of the legal land description which includes columns h, i, j, k, l
m. Quarter Section - further defines the location of the well or spring.
n. Depth
o. Temperature
p. Flow
q. TDS - Total Dissolved Solids
r. Chemistry - if there is available chemistry in the chemistry database (yes or no).

The *Chemistry* database has information on the more commonly reported chemistry entries in the original databases. The column headings are:

a. Site ID - Corresponds to the other databases Chemistry and Other for easy reference between them
b. Date Sampled - Corresponds to the date the sample was taken as reported in the databases. Some wells and springs have more than one chemistry entry.
c. Sample Name - Some of the chemistry entries were given identifying names
d. Site Name - Name given to the well or spring in the original databases

e. Type - well, spring or other (for example, California lists several types of wells)
f. Latitude
g. Longitude
h. Temperature - reported in Degrees C
i. TDS - Total Dissolved Solids
j. Field pH
k. Lab pH
l. Field Conductivity
m. Na - Sodium (milligrams per liter, mg/L)
n. K - Potassium (milligrams per liter, mg/L)
o. Ca - Calcium (milligrams per liter, mg/L)
p. Mg - Magnesium (milligrams per liter, mg/L)
q. Fe - Iron (milligrams per liter, mg/L)
r. Sr - Strontium (milligrams per liter, mg/L)
s. Li - Lithium (milligrams per liter, mg/L)
t. B - Boron (milligrams per liter, mg/L)
u. SiO_2 - Silica (milligrams per liter, mg/L)
v. HCO_3 - Bicarbonate (milligrams per liter, mg/L)
w. SO_4 - Sulfate (milligrams per liter, mg/L)
x. Cl - Chlorine (milligrams per liter, mg/L)
y. F - Fluoride (milligrams per liter, mg/L)
z. As - Arsenic (milligrams per liter, mg/L)
aa. Calc TDS - Calculated Total Dissolved Solids
bb. Br - Bromide (milligrams per liter, mg/L)
cc. NO_3 - Nitrate
dd. NA + K

The *Other* database contains additional information that was not included in the *Wells and Springs* database or the *Chemistry* database. This information was either not consistently reported in all the state databases or was newly discovered in the development of the newer state databases. Some examples of column headings are drilling date, well status, reference, and SWL (static water level).

The *Collocated* databases were developed using the *Wells and Springs* databases. The criteria for being a collocated community is a geothermal resource with a temperature of at least 50ºC (122ºF) and located within 8 km (5 miles) of a community. The column headings for this database are:

a. State
b. City
c. County
d. Latitude
e. Longitude
f. Resource Temp., ºC
g. Resource Temp., ºF.
h. # of wells listed
i. Typical depth, m - average for the wells listed
j. Typical Depth, ft - average for the wells listed
k. Flow, L/min - total flow for all the wells listed
l. Flow, gpm - total flow for all wells listed
m. TDS (Total Dissolved Solids) - highest value reported
n. Current Use
o. HDD - Heating degree days
p. Design Temp. - used for designing building heating systems
q. Remarks - This sometimes listed the wells associated with the collocated community.

The *Direct-Use* database contains known direct-use applications located in the U.S.; although, we believe there are a significant number of projects utilizing geothermal energy that are not included in this database. The direct-use applications are: district heating, space heating, aquaculture, greenhouses, industrial, snow melting, resorts/pools and agriculture applications. The column headings for this database are:

a. State
b. Site - name of the business
c. Location -
d. Application - which of the direct-use application it is
e. Temp, ºF
f. Temp, ºC
g. Flow, gpm
h. Flow, L/min
i. Capacity, 10^6 Btu/hr
j. Capacity, MWt
k. Energy Use, 10^9 Btu/yr
l. Energy Use, GWh/yr
m. Energy Use, 10^{12} TJ/yr
n. Load Factor, [annual load / (capacity x 860)]
o. Contact
p. Address
q. Zip code
r. Phone number

HOW TO OBTAIN THIS INFORMATION

The databases, which can be obtained in part or as a whole set on a CD, are available through the Geo-Heat Center. The cost for information for one state is $10 and for all 16 of the western states is $25. To obtain a copy of the CD, contact the Geo-Heat Center by phone (541-885-1750), fax (541-885-1754), email (geoheat@oit.edu), or mail (Geo-Heat Center, 3201 Campus Drive, Klamath Falls, OR 97601).

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A TRIBUTE TO CHARLIE LEIB GRANDFATHER OF KLAMATH FALLS GEOTHERMAL DEVELOPMENT

Charles B. "Charlie" Leib, 95, died November 21, 2001 of natural causes in Klamath Falls. He is considered the grandfather of geothermal development in this southern Oregon city, and is especially noted for his work with the downhole heat exchanger (see Vol. 20, No. 3 for more details on this subject).

Mr. Leib was born January 16, 1906, in Olbendorf, Austria and as a teenager, he moved with his parents to the United States. He then lived and worked in Philadelphia, Pennsylvania for a few years before moving west with his parents.

Charlie first moved to Klamath Falls in the winter of 1928. As a former East Coast resident, he found the climate of Klamath Falls and the superb opportunities for hunting and fishing most desirable. He had been apprenticed to an engineering contracting firm in Philadelphia, that did a variety of work including plumbing and heating. He completed his apprenticeship, joined the local plumbers' union, and gained invaluable experience during his stay with that company and with two other Philadelphia firms.

But when his last employer wanted to transfer him to another state to work as a superintendent, Charlie refused the position and came to Oregon. His parents had settled in Ashland, so a visit to Klamath Falls was imminent.

During his first years in Klamath Falls, Charlie spent some of his time employed by Lorenz Company working with local hot water wells. The firm, which is no longer in existence, primarily worked in plumbing. He began work with Sears plumbing department in 1937, but was still not professionally involved with hot water wells. During this time; however, he did some important work on these wells for neighbors and friends. His first professional geothermal project in Klamath Falls was a four-unit apartment complex. It was an innovative effort, taking a year and a half to complete. The system incorporated automatic controls to regulate the pumps and individual heating units for each residence. The apartment complex, located on Eldorado Boulevard and Earle Street in Klamath Falls, still has an operating geothermal well today.

The start of WWII (1939-1941) had an impact on the direction of Charlie's career. A bout of crippling rheumatism made him ineligible to join the Army. The lack of materials for domestic use due to the war, limited the work effort of the Sears heating department and led Charlie into business for himself. This began his full-time interest in the hot water wells of Klamath Falls.

Charlie's earliest accomplishment was the first use of the downhole heat exchanger (DHE) in Klamath Falls for a geothermal heating system some 70 years ago. This first system, installed in 1931, lasted 25 years and probably would have lasted longer if the well had not caved in. He was also instrumental in getting well owners to fully case their wells and provide perforations for circulation--necessary for the DHE to work properly. He determined this to be a better design, not so much by calculation and theory, but more through observation and experience. The first perforations installed in a well in Klamath Falls were in 1945 under Charlie's supervision. A major problem with early wells in the area was the failure of the coil or heat exchanger in the well itself, especially at the air/water interface. Oil was commonly used to prevent corrosion of the pipes, but was harmful to the environment. Charlie convinced homeowners, starting in 1945, to use paraffin instead. The wells in Klamath Falls treated with paraffin have lasted longer, as Charlie anticipated.

Because of Charlie's pioneering work, there are over 500 geothermal wells equipped with the downhole heat exchanger in Klamath Falls. These are used by single homes, shared by several homes, and provide heat to apartments and schools. He was concerned with the efficient use of the resource, obtaining and studying well logs, and attempting to understand the regional reservoir characteristics in order to provide an efficient and workable heating system for the proposed downtown district heating system. This system has since been installed and is working well, heating 20 downtown buildings and providing snow melt for sidewalks.

This article is based on an interview by Ann Fornes, former staff member of the Geo-Heat Center, and published in our *Quarterly Bulletin*, Vol. 6, No. 1, March 1981 as "Charlie Leib - Veteran of Geothermal Development."

THERMAL SPRINGS IN GERMANY AND MIDDLE EUROPE

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HISTORIC INTRODUCTION

When one thinks of mineral springs and thermal springs in middle Europe, names like Carlsbad, Wiesbaden, Baden-Baden, Spa immediately come to mind. Furthermore, this thought is associated with an epoch, during which many spas played an important part in the social and cultural life. This was the 19th century and the first decades of the 20th century, a time when the leading classes not only of Europe gave the spas their unique character. This society felt the need to relax and to take care of their health. They probably were convinced that this could be achieved by curing at a spa and drinking the waters. Those places provided by nature with mineral and thermal springs used their good fortune. Their investments in spa houses, parks, hotels, casinos have probably been profitable.

At first, the visitors came from the nobility, from barons and counts to kings and emperors. The wealthy bourgeoisie soon followed, since they didn't want to miss the opportunity to mix with the noble. Increasingly, artists, writers, thinkers were attracted. For the ladies, it was an excellent opportunity to present their marriageable daughters at balls, concerts, in the theater and parks. The men would do businesses and diplomacy. It was exquisite publicity for the spa when the czar and the czarina with their entire court came for a visit. Very welcome were the regular stays of the Prussian kings and later emperors. Very often came the Austrian emperor with his wife, Napoleon III with Eugenie, Queen Victoria, and innumerable German princes. Maharajas from India brought an oriental atmosphere to the spas. Bismarck was a frequent visitor. Cavour and Disraeli showed up and then there were Beethoven, Dostojewski, Nietzsche, Victor Hugo, Grillparzer, Richard Wagner, and of course, Goethe, conceited and eager to mix with the noble. Several times a year, often for weeks, he enjoyed life at the spas, of which he preferred Carlsbad and Marienbad. Let me remind you of the "Marienbader Elegies." He left his wife at home or sent her to Bad Lauchstädt, a spa for the lower classes. On July 8, 1802, Goethe writes in his diary: "Visited prince Reuß after breakfast, later joined princess Lubomirska and count Polocky." On July 15, 1802, he writes: "Dined with the count of Hesse, later took a stroll with princess Narischkin." Similar entries are found each day. On July 28, he writes to his wife in Bad Lauchstädt: "Enjoy yourself, have yourself a nice day occasionally. You wouldn't like Carlsbad."

The Belle Epoch of the spas lasted until the 20th century. Until the 1950s, oriental potentates visited the spas. Then, there was a change. Now, the visitors were working-class people with financing from the health insurance. This period is coming to an end, too and considering the lack of money from public health insurance, new concepts have to be found.

I could talk about the old times for hours, but I will stop here and talk about the thermal waters.

NATURE OF THERMAL WATERS

The formation of thermal waters requires, that precipitation infiltrates into great depths, that there is a sufficiently long time of contact with the rock, and that there is a possibility for the water to ascend to the earth's surface again. A low geothermal gradient supports the evolution of thermal waters. These conditions can be found in zones of tectonic movement (e.g., along the margins of tectonic graben systems). The result are thermal springs (i.e., groundwater), which flows freely from the earth's surface. Of course, one can help nature by developing the thermal water with deep wells in places where the conditions seem favorable or where thermal springs already exist.

Depending on the type of rock and the time, the infiltrating and ascending heated water is in contact with the rock, the resulting thermal waters will have different chemical compositions. A number of thermal waters in Germany and middle Europe have a low concentration of the major ions Na, Ca, Mg, and Cl, SO_4, HCO_3, which are thermal waters that have been in contact with rocks containing little or no soluble components. These are silicate rocks like granites, diorites, quartz porphyries, quartzites, slates, gneiss's. Table 1 shows some examples of these thermal waters. With concentrations of total dissolved solids (TDS) below 1000 mg/L one speaks of "low concentration."

Among these four thermal waters Bad Gastein is an exception, because of the radon content of the waters. They are termed radioactive thermal waters. The radon comes from uranium bearing gneiss's. Radioactive waters can be found elsewhere, but not all of them are thermal waters. In Heidelberg, there is a mineral water, which is considered a radioactive thermal water (Table 2).

Evidently, the Heidelberg thermal water has a very high concentration of solutes. It originates from Permian quartz porphyries, which give it its radioactivity, and from Tertiary evaporates of the Upper Rhine graben, which contribute to the high concentrations of Na and Cl. Throughout middle Europe, many highly mineralized thermal waters can be found, since halite, gypsum, and carbonate rocks are widespread (e.g., the Tertiary of the Upper Rhine graben, the Triassic middle Muschelkalk and Röt, and the Permian Zechstein of northern and middle Germany). Some examples are listed in Table 3.

Table 1. Examples for Thermal Waters of Low-Ion Concentration in Middle Europe (mg/L)

	T°C	CO_2	Na	Ca	Mg	Cl	SO_4	HCO_3
Wildbad (Black Forest)	39.5	22.5	148	38	2.5	156	35.5	225
Schlangenbad (Taunus)	29	<50	107	14	2	154	7	73
Luxenil-les Bains (Eastern Vosges)	44	10	184	16	2	232	54	96
Bad Gastein (Eastern Alps)	45		86	20	0	31	138	55

Table 2. Examples for Radioactive Thermal Waters (mg/L)

	T°C	CO_2	Na	Ca	Mg	Cl	SO_4	HCO_3
Bad Gastein (Eastern Alps)	45		86	20	0	31	138	55
Heidelberg (Upper Rhine Graben)	24	137	22820	6556	567	50100	0	1124

Table 3. Examples for Highly Mineralized Thermal Waters (mg/L)

	T° C	CO_2	Na	Ca	Mg	Cl	SO_4	HCO_3
Boll	49	1100	1423	645	108	1734	1930	1136
Urach	54	1330	826	723	95	1102	1297	1458
Salzuflen	37		42351	1978	631	65924	50372	2440
Oeynhausen	33.5	1540	18710	1621	379	29020	4271	1437
Aachen	55		1421	63	15	1601	276	1031
Nauheim	33	1126	10416	1412	127	18124	44	2059
Wiesbaden	65	219	2673	351	48	4605	65	619
Baden-Baden	64.5		850	129	2	1437	155	1
Karlsbad	61	510	1726	132	45	624	1713	2319

The thermal waters of the north rim of the Rheinische Schiefergebirge, Carlsbad, the south rim of the Taunus get their salt content from the Permian Zechstein. Some of these waters travel a long distance from the area of recharge and salt dissolution to the area of ascent and discharge. This becomes obvious from the following Figure 1.

Between the recharge and the discharge area, or within the discharge area some waters receive additional CO_2. Those thermal waters like in Bad Oeynhausen and Bad Nauheim are called acidic mineral waters.

Thermal waters of the Schwäbische Alb and its foreland to Stuttgart-Bad Cannstatt and especially Urach, Boll, Überkingen are enriched with NaCl from the Triassic middle Muschelkalk and receive CO_2 from a late phase of the regional Tertiary volcanism.

In the Upper Rhine graben, the thermal waters are influenced by Tertiary evaporates in the graben.

One must not forget to mention the sulphuric thermal waters. They contain dissolved sulphides or hydrogen sulphide. These constituents originate from pyrite bearing bituminous shales, like the Lower Jurassic Posidonia-shale, the Tertiary Pechelbronn series, or the copper-shale of the Zechstein. The thermal waters of Heidelberg, Bad Boll, Oeynhausen, and Füssing belong to this group. Füssing is situated in a zone, which comprises the Alps and the Molasse–foreland. Thermal waters of this zone are Bad Gastein, which I have already mentioned, Ragaz, Baden near Vienna, and Leukerbad. Although they are of different origin, they all have rather low ionic concentrations and show specific features like radon or hydrogen sulphide contents.

CONCLUSIONS

I think, this overview gave an idea of the frequency and diversity of thermal waters in Germany and middle Europe, some of which have been used for a very long time. Many of them show special attributes, like considerable concentrations of carbon dioxide, sodium chloride, sulphate, bicarbonate, hydrogen sulphide, or radon. Often, thermal waters of different composition occur within the same region and sometimes even at the same spa.

The great diversity of the thermal waters and their classification into different regional provinces is shown in the final Figure 2.

ACKNOWLEDGMENTS

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EDITOR'S & AUTHOR'S NOTE

For additional articles on these spas, see Vol. 21, No. 3 (September 2000), which can be viewed on the GHC website: http://geoheat.oit.edu/bulletin/bull21-3/bull21-3.pdf.

In the year 1823, Goethe stayed at the spa Marienbad (today's Czech Republic). There, at the age of 74, he made the acquaintance of young, 19-year-old Ulrike von Levetzow. She declined his proposal of marriage. Goethe was very sad and disappointed about the rejection and wrote the lamentations "Marienbader Elegie." By the way, Miss Levetzow never got married.

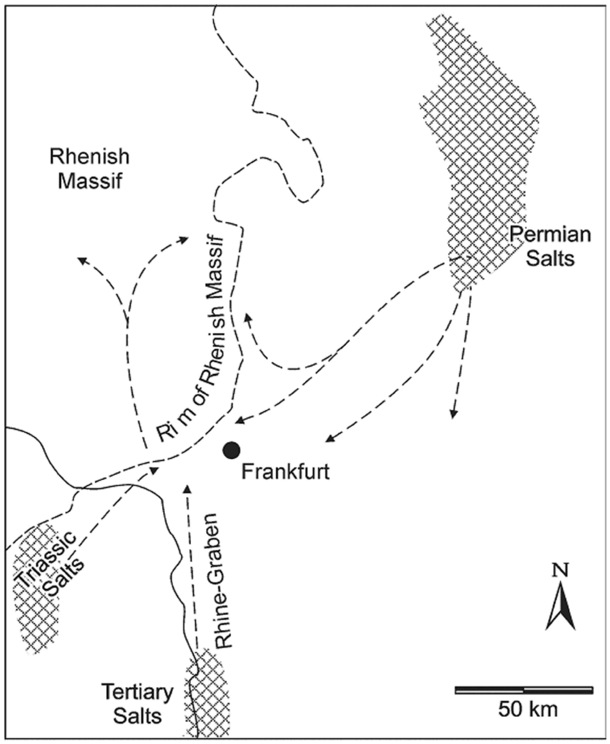

Figure 1. Salt water transport.

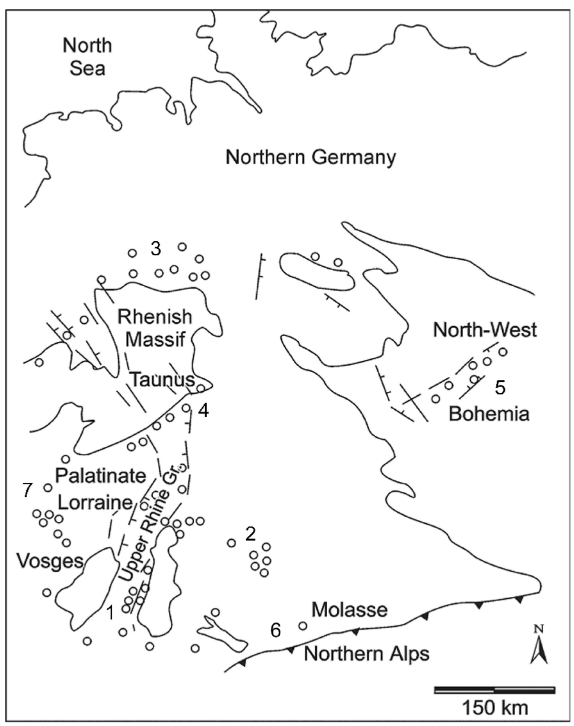

Figure 2. Thermal Water - Provinces

1	***Upper Rhine graben – Black Forest***
2	***Schwäbische Alb and its foreland***
3	***North rim of the Schiefergebirge***
4	***South rim of the Taunus***
5	***Northwest Bohemia***
6	***Northern Alps and Molasse-foreland***
7	***Palatinate – West-Vosges – Lorraine***

THERMAL SPRINGS AND SPAS IN POLAND

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SUMMARY

Geothermal waters from springs and wells are currently used in eight spas and water centers in Poland. These resorts have a long and interesting history, being an important part among all the health spas in the country. The demand for geothermal curative and recreation services offered in spas constantly increases. The paper presents several cases of geothermal resorts and some examples of initiated and planned new projects which will often be executed as a part of complex systems of geothermal energy application both for space heating and curative purposes. In several places, there are proposals to construct new geothermal resorts based on warm waters supplied by wells. Balneo-therapy and bathing using natural warm waters constitute potential sector of geothermal activities and business in Poland.

INTRODUCTION

The tradition of use of geothermal waters for bathing and balneo-therapy has old roots in Poland. The first written records report that since the 12th century warm spring waters have been used for balneo-therapy in some localities. Through the centuries, warm springs were used in the Sudetes and Carpathians mountains. Yet, undergoing up- and down-periods, this practice increased over time, to the point that some locations (Cieplice, Duszniki, Iwonicz) became quite renown spas in Central Europe. With time, several other spas using geothermal waters have been founded which are still in operation (Sokolowski, et al., 1999).

With this background, the country is still at the very beginning of geothermal application for space heating and other agricultural and industrial uses, as such activities only date back to the 1980s. In 2001, three geothermal space-heating plants were online: in the Podhale region, in Pyrzyce town and in Mszczonow town (Kepinska, et al,. 2000). Several other feasibility studies and utilization projects are in progress. Most of the project, already under construction and planned, provide the use of the geothermal waters for the recreation and therapeutics besides their heat application.

In the recent years, the growth of interest in recreation and water centers development, as well as water therapeutics including the geothermal water application have appeared in Poland. It concerns the operational spas as well as – it's worth to notice – the localities, which have never dealt in this field as they plan to develop that activity from the very beginning using the geothermal water discharged by existing or planned wells. This sector of recreation and therapeutics has great prospects for development and economic attraction.

The demand for the geothermal treatment services is great and still growing. The spas carry out the modernization of the facilities and upgrade their service despite the financial and legal difficulties resulting from the change of the ownership and financing rules of the spa enterprises. The fees for lodging and service are being revised as well. Many spas prosper by achieving the proper European standards.

GEOTHERMAL RESOURCES

Poland possesses large low-enthalpy geothermal resources to be found within about 80% of its territory (Sokolowski, 1995). They are connected with extensive geothermal provinces predominantly built of sedimentary basins with numerous geothermal aquifers (Figure 1) which are as follows:

- The Polish Lowland Province. It forms the most extensive and promising unit containing numerous geothermal aquifers (Palaeozoic-Cretaceous). The reservoir temperatures range from 30 to 130°C (1-3 km of depth). The TDS range from 1 to 300 g/L.

- *The Fore-Carpathian Province.* Geothermal aquifers occur in Mesozoic-Tertiary rocks. The reservoir temperatures range from 25 to 50°C; while, the TDS varies from several to about 100 g/L.

- *The Carpathian Province*. Geothermal aquifers are connected with Mesozoic-Tertiary formations. The TDS range from 0.1 to about 100 g/L.

- *The Sudetes Region.* It is characterized by a limited possibility of geothermal aquifers occurring in fractured Precambrian and Palaeozoic crystallinic rocks.

Considering the present prices of traditional fuels, feasible geothermal plants can be built in about 40% of Poland (Kepinska, et al., 2000). The most favorable reservoir conditions exist in the Polish Lowland (Sokolowski, 1993 and 1995; Gorecki, 1995 and 1998; Ney, 1995) and in the Podhale region (Kepinska, 2000).

GEOTHERMAL BALNEO-THERAPHY AND BATHING

General

In Poland, there are 36 spas using underground waters for balneology and bathing. Among them, eight spas use 20 - 62°C geothermal waters (Figure 1) issued by natural springs or discharged by wells. Usually, both cold and warm waters are provided. The main information on localities using geothermal waters for bathing and curing is given in Table 1.

Polish spas (including the geothermal ones) act according to the legal regulation concerning spas and balneology, which was adopted in 1966 and updated in 1990. At present (2001), a new law is expected to be passed. The spa localities hope for prosperous and sustainable economic development resulting from recreation and balneology. This hope is expressed by the establishment of many so called spa boroughs within the entire country. There is a boom in the production of mineral water in many spas and their sale in both the country market and abroad. The development of balneology and spa services in Poland requires supporting state and self-government policy. Among others, the Economic Chamber – Polish Spas was created for this purpose. It is an organization of companies and institutions dealing in spas. Its main task consists of representing spas' interests against home and foreign bodies, acting for the development of the existing spas, and establishing new ones, participation in legislative works, promotion, and the elaboration of the spa standards. The necessity of the adjusting spa service to European standards is being realized. The role of the local self-government in spa management, as well as the other activities serving the sustainable development of such localities should be emphasized.

Geothermal Spas – Selected Cases

The oldest spas in Poland are located in the Sudetes Mountains. (SW-Poland). During the centuries, that region has been famous throughout Central Europe for its landscape and numerous health spas. Abundant mineral springs have been used there for healing purposes. Some of them issue geothermal water that contributed to the flourishing of certain resorts like Cieplice Spa, Ladek Spa and Duszniki Spa. In the Polish Lowland in two localities, Ciechocinek and Konstancin, cold and geothermal waters produced by the wells are used for treatment and recreation. Three resorts using geothermal waters for specific application are situated in the Carpathian Mountains (S-Poland): Iwonicz Spa, Ustron and Zakopane. This region abounds with low-temperature mineral springs, which gave rise to numerous health resorts. The most famous among them are Krynica and Szczawnica. On the contrary, warm springs are very rare there, and were known in Iwonicz and Zakopane only (Figure 1); while at present, geothermal balneo-therapeutical and water centers are based on water supplied by wells.

To give insight into geothermal spas and water centers in Poland, some selected cases are presented in the following.

Cieplice Spa

Having the warmest curative waters in Poland, Cieplice (Figure 1) is one of the most famous and visited spas in Poland. Its convenient location close to the frontier attracts patient and tourists from the neighbouring countries – Czech Republic and Germany. Natural outflows of warm waters were already known there in the 13th century when they started

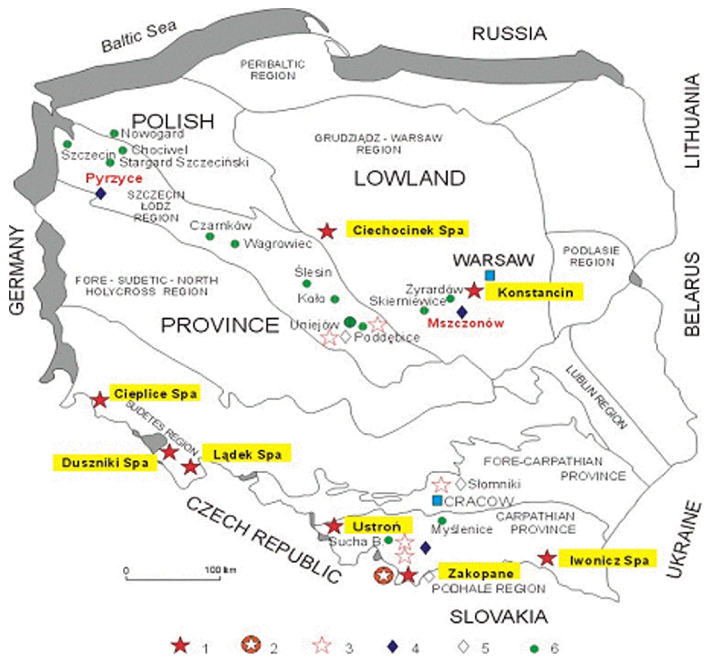

Figure 1. Geothermal spas in Poland (geothermal division based on Sokolowski, 1995).

Geothermal spas and water centers: 1. on-line, 2. under construction, 3 – planned to construct.
Geothermal space heating plants: 4. on-line, 5. under construction, 6. planned to construct

Table 1. Polish spas using geothermal water for bathing and balneo-therapy (based on Kepinska, et al., 2000)

Locality	Type of water intake	Maximum utilization			Annual utilization	
		Flowrate kg/s	Temperature,°C		Average flowrate kg/s	Energy use[b] TJ/yr
			Inlet	Outlet		
Zakopane	w	36	26-36	25	18	14
Cieplice Spa	s + w	7.5	36-39[a]	26	6.0	10
Ladek Spa	s + w	11	20-28 s 44w	20	10.8	16.8
Duszniki Spa	s + w	5.5	19-21	19-21	5.5	0.3
Ciechocinek Spa	s + w	56.8	27-29	20	4.2	2.8
Konstancin	w	2.5	29	12	0.1	0.2
Ustron	w	0.9	28	11	0.4	0.58
Iwonicz Spa	s + w	3	21	10	0.4	0.58

w – well, s – spring, [a] mixture of 20-62°C waters from springs and wells (20-62°C),
[b] energy use (TJ/yr) = Annual average water flowrate (kg/s) x [Inlet temp.(°C) - Outlet temp.(°C)] x 0.1319

to be used for treatment (Sokolowski, et al., 1999). This renown European spa was already operating in the 17-19th centuries.

Geothermal aquifers occur within fractured Carboniferous granites of the Karkonosze Mountains massif.

Currently, water flows out from several natural springs and one well. The springs yield about 10 m^3/h of water with temperatures ranging from about 20 to 44°C. The well (750 m of depth) is capable of discharging 40 m^3/h of water with wellhead temperature of 60-68°C (Dowgiallo, 1976; Dowgiallo & Fistek, 1998). The total dissolved solids (TDS) are about 600 – 700 mg/L (exceptionally up to 1000 g/L), the predominant contributor being SO_4 – HCO_3 – Na - F - Si. The content of H_2SiO_3 amounts to 100 mg/L and is the highest among all geothermal waters in Poland, and is also very high in fluorine (F ion) content – up to 12 mg/L (Dowgiallo, 1976).

Waters are predominantly suitable for therapeutic baths; and they are also used for other treatments, such as orthopaedic-traumatic and neurological diseases, nephropathy and the diseases of the urinary track. The spa offers a wide range of the curative treatment and physical recovery. Mineral waters are also bottled.

The oldest historical record of Cieplice comes from 1281. It was found in a document concerning the donation of "Caldius Fons" (warm springs) to the Silesian monastery of the Knights of St. John of Jerusalem from Strzegom by prince Bernard from Lwowek. In 1288, the first curative house was built and consent was given to erect an inn for the growing number of patients. The Slavonic name *Cieplowod y-* "*Chleplevode*" (warm waters) can be found in records of the papal functionary Gabriele da Rimini who visited the Silesian villages to collect the overdue taxes.

In the past centuries, the most magnificent patient who visited Cieplice was the Polish queen Maria d'Arquien Sobieska, who came there in 1687. The queen was accompanied by her numerous court, some 1500 people. She was the beloved wife of one of the greatest Polish kings Ian III Sobieski whose army stopped the Turkish invasion in Europe in the famous battle of Vienna in 1683. Two of the warm springs in Cieplice were named after king Sobieski and his wife.

In the end of the 1990s, the other existing well in Cieplice was deepened from 661 m to 2002 m. The artesian flow of about 90 m^3/h water with wellhead temperature of 87.9°C; while, the measured bottom temperature (depth of 1870 m) was 97.7°C (Dowgiallo, 2000). Those works were carried out in response to the growing demand for curative water, planning the sport and recreation facilities, and the project of utilizing the water for heating. Currently (2001), the well is being tested. The start of the utilization projects depends on obtaining the proper funds.

Ladek Spa

The first records of warm waters in Ladek come from 1242. The first bathing house was built towards the end of the 15th century; since then, it developed slowly but flourished in the 19th century. Among numerous visitors who stayed at Ladek for curing, was John Quincy Adams, the sixth President of the United States. He declared at the end of his visit in Ladek: "I have never seen a spa, the location and appearance of which would be as much favourable to health preservation and restoring as Ladek."

Geothermal waters occur in the fractured Pre-Cambrian gneisses. The flowrate from several springs amounts 1 - 17 m^3/h, with the temperature ranges from 20 and 30°C. There are also two wells (up to 700 m deep) discharging water with wellhead temperature around 46°C. The TDS is low: 160 – 280 mg/L, but with a high content of fluorine ion (F) (up to 11 mg/L) and H_2SiO_3 (up to 70 mg/L). Radioactive waters harnessed at Ladek Spa are suitable mainly for treating patients with the motor system, vascular, oral and dermatological diseases.

Among Polish resorts, Ladek Spa possesses one of the greatest therapeutic attractions. Wide promotion and advertising of the spa was also addressed to the foreign clients, particularly from Czech Republic and Germany. Cultural performances are organised and sponsored, a system of preferences and rebates was introduced, and some interesting offers for investors were prepared. Ladek is a good example of proper joint utilization of the geothermal water in curing, recreation, and tourism. It is a town, which offers not only curative services, but also a variety of rest, health preventive treatment and physical recovery (Figures 3 and 4).

Duszniki Spa

Duszniki Spa is located about 40 km west from Ladek Spa. The first records of warm springs from Duszniki come from the year 1408.

Geothermal aquifers are connected with the Pre-Cambrian shists formation. Currently, geothermal waters are produced under artesian conditions from several shallow (up to 160 m) wells. The wellhead temperatures are 17 - 18°C. These relatively low temperatures result from the fact that waters are cooled down on the way to the surface due to expansion of the dissolved CO_2. There also exists one spring named *Pieniawa Chopina* (Figure 5). Geothermal waters from Duszniki represent the type HCO_3 – Ca – Na – Mg. They are rich in iron, CO_2 (up to 2 g/L) and H_2SiO_3 (50 – 90 mg/L). The TDS amounts about 2 g/L (Dowgiallo, 1976).

Duszniki Spa is famous thanks to Frederik Chopin - the great Polish composer and pianist (1810 - 1849), who stayed there for a healing treatment in 1826. He was only sixteen when he came to the resort along with his mother and sister. During his stay in Duszniki the young artist gave one of his first public concerts raising the sincere admiration of the audience. This was one of his first performances, which opened the gateway to the world's artistic career for Chopin (Sokolowski, et al., 1999).

In the 19th century, Duszniki, then belonging to Bohemia, was visited by numerous Poles who had founded a monument to Chopin and a theatre bearing his name. To commemorate the artist genius and his stay in Duszniki, the warm spring was given the name *"Pieniawa Chopina*." It is also worth noting that each year the Chopin international music festival is organised in Dusznik –the oldest one in Poland, gathering outstanding musicians and a large international audience.

In Duszniki, there are some medicine research units, which are managed by country universities of medicine. They deal with balneo-therapeutics. The spa makes its development widely known, namely through the expansion and modernization of recreation and tourism infrastructure, sustainable development, Chopin Festival of Music, promotion and advertising, cooperation with other spas in this region, joint promotion of the curing advantages, and offers for investors.

Ciechocinek

Ciechocinek is situated in Central Poland, on the left bank of the Vistula River Valley (Figure 1). As a health resort, it started to develop at the beginning of 19^{th} century on the base of curative brines with the temperatures of 10-13°C flowing from natural springs.

Geothermal aquifers are found in the Jurassic sandstones. Currently the spa is supplied with cold and geothermal water discharging from several wells. Warm waters are tapped by two wells (depths of about 1300 m and 1380 m) which produce 29 - 37°C waters. The TDS is variable: 3 – 72 g/L, depending on the depth of the aquifer. Waters predominantly represent Cl – Na - F - Br - I - B - SO_4 and H_2S type (Krawiec, 1999).

The content of iodine and bromine comes from the Zechstein salt formations. The salt minerals are dissolved by waters of probably paleo-infiltration meteoric origin.

For curative treatment, both warm iodine-bromine brines and cold waters, are used, and peat is used for highly active peat baths. Patients with gynaecological diseases, rheumatism as well as those having problems with circulation, central nervous system and upper airways can be treated in this resort. The cures consists in hospital, sanatorium, or part-time treatment. Along with water used for treatment and bathing, the production of table salt (with iodine content), several kinds of mineral water, lye and crystalline slime have been carried out.

The development of the town and its neighbourhood commenced after the first partition in 1772 when central Poland lost the access to the Wieliczka salt mine. At that time, brine sources for salt extraction were obtained from there (Sokolowski, et al., 1999).

In 1836, the saline springs started to also be used for healing purposes. In the mid-19th century, a specialized therapeutic station was established in the spring area. In 1841-1860, the first shallow wells were drilled. They discharged brines with the temperatures in the range of 18°C. According to the project of S. Staszic – the pioneer of Polish geology and mining - specific wooden cooling towers (2.5 km long were built, used for spraying iodide-bromide brines. In this way, an ocean-like microclimate was created, especially suitable for natural curative inhalations. These installations are still in use (Figure 6).

After Ciechocinek was granted city rights (1919), the therapeutic station was a starting point for the rapid development of the city. Then already about 25,000 person per year were treated at Ciechocinek.

At present, Ciechocinek is one of the main Polish resorts. A number of treated persons exceeds 30,000 per year. After financial problems in the beginning of 1990 were solved, Ciechocinek again came into a development period. The following items make Ciechocinek a successful and renown spa:

- Variety and high quality of treatment service,
- Providing treatment means over a wide range,
- Spa facilities strictly satisfying the requirements of curing people.
- High quality and volume of the accommodation and food base (19 sanatoriums, 8 spa hospitals, numerous lodging houses, restaurants, bars etc.),
- Excellent urban layout of the spa – four spa parks, gardens, nature reserves,
- Wide promotion and advertisement.

Iwonicz Spa

Iwonicz Spa is located in the Outer Flysch Carpathians (Figure 1). Geothermal waters (around 20ºC) occur within the Eocene sandstones and are currently produced by several abandoned oil wells (to 1000 m of depth). The TDS values vary from ca. 8 to 20 g/L. The brines represent the type Cl - HCO_3 – Na - Br - I and (CO_2 + H_2S). Because of their origin, the water reserves are non-renewable; thus, they must be exploited with special care.

Rheumatism, skin diseases, diseases of the motor, alimentary and respiratory systems, and many other illnesses are treated in this resort. Waters are used for drinking and bathing treatments (peat baths including), and also for curative and cosmetic salt extraction.

The first records of the use of warm springs in this locality date back to 1578 and 1630; when, they were recognised and described by the royal physicians. The first bathrooms were built in 1793 and the resort soon started to flourish. At the beginning of the 19th century, outstanding chemists and physicians provided favorable opinions about the great curative value of these waters. It was at the same time that suitable utilities and buildings for curative purposes were built. Some of them have survived to the present. In 1856, Jozef Dietel - professor of the Jagiellonian University, called Iwonicz a "prince of iodine waters." Iwonicz water was bottled and sent around the Europe. The first wells (400 - 600 m deep) supporting the existing springs were drilled at the end of the 19th century. Warm brine discharged by one of them has been used to now. With time, the former springs vanished; thus, the exploitation started from the abandoned oil wells (Sokolowski, et al., 1999).

The interwar period was a real boom for Iwonicz. Also, at present, this is one of the best known and most frequented Polish resorts. At present, over 30,000 patients and tourists per year visit Iwonicz Spa.

FURTHER PROJECTS

Besides the existing structures, there are plans to build new geothermal health and recreation spas. Some projects await development, and several ones are in the process of design. The popularity of so-called water centers, several of which have already been successful, raises the interest to build more such facilities. In general, the centers will be one of the elements of integrated or cascaded geothermal systems. They are designed to use waters from deep and shallow wells, or thermal energy stored in shallow underground horizons, often with additional use of heat pumps and other renewables (i.e., solar). They include, among others, a geothermal station under construction in Zakopane, as well as several others that are planned (i.e., Poddebice).

Zakopane and Podhale Region

Zakopane is located in the southern Poland (Figures 1 and 2) on the slopes of the Tatra Mountains. (the highest part of the Carpathians). The Tatras, Zakopane and the Podhale region, due to their natural characteristics, constitue the main center of tourism and winter sports in Poland. Over three million tourists visit this place each year. In the last years, the construction of a large-scale district heating system and other types of direct geothermal utilization were started here (Kepinska, et al., 2000) including balneo-therapy and bathing, because there is a great demand for water and geothermal centers.

The main geothermal artesian aquifer occurs in the Eocene and Mesozoic carbonates (depths of 1-3.5 km). The reservoir temperatures reach up to 80-100ºC; flowrate from a single well 55-150 L/s; TDS of 0.1-3 g/L; wellhead static pres-sure 27 bar. Over 10 geothermal wells have been drilled with-in this area so far. All of them produce waters which have curative properties suitable in the dermatological, rheumatic, and endocrinological diseases; apart from this, they can be used as an adjunctive treatment for patients with contagious diseases.

The tradition of using warm waters for bathing is connected with Jaszczurowka – a suburb of Zakopane. A 20ºC natural spring existing there was scientifically described in 1844. Hydrogeologically, this was an ascending spring outflowing along the regional fault which delineates the northern border of the Tatra Mountains. The warm spring in Jaszczurowka had been used by the local highlanders long before the middle of the 19th century.

In the interwar period, the 1920s and 1930s, Jaszczurowka flourished. The warm spring, two pools and the subsidiaries existed in Jaszczurowka until the 1960s. There were plans to modify the place and adjust it to balneological and therapeutic treatments. Unfortunately, after drilling a well which was to raise the spring's output, due to the mixing with cold waters from the neighbouring stream, the warm spring disappeared. In the 1970s, a small geothermal bathing center was established in the center of Zakopane. It uses warm (26 - 36ºC) waters from two wells. In the summer, this place is flooded with tourists.

There are exceptionally great possibilities to build water centers in this region. In fact, every locality where there are wells discharging geothermal waters up to 80 – 90ºC, can have its own geothermal center tailored to the needs of both the inhabitants and tourists (Figure 2). These can not only be large but also smaller centers fitted into the local architecture and landscape. There are two finished projects, one of which has just started to be developed in Zakopane (population 30,000)–the main city of the region. It will be one of the most modern geothermal water centers in Poland, and was created on the site of the above mentioned swimming pool, which existed since the 1970s.

The project provides for the construction of a complex for rehabilitation and recreation offering a full range of treatments and services. This will include outdoor and indoor swimming pools. The plans also include the building of a conference center as a integral part of the complex. The facility will serve 1000 people per hour. The investment will be financed from Polish sources, with the municipal administration as one of the shareholders.

This is a long awaited project, indispensable to broaden the tourist offer of the city and to improve the quality of recreation at the main tourist center in Poland.

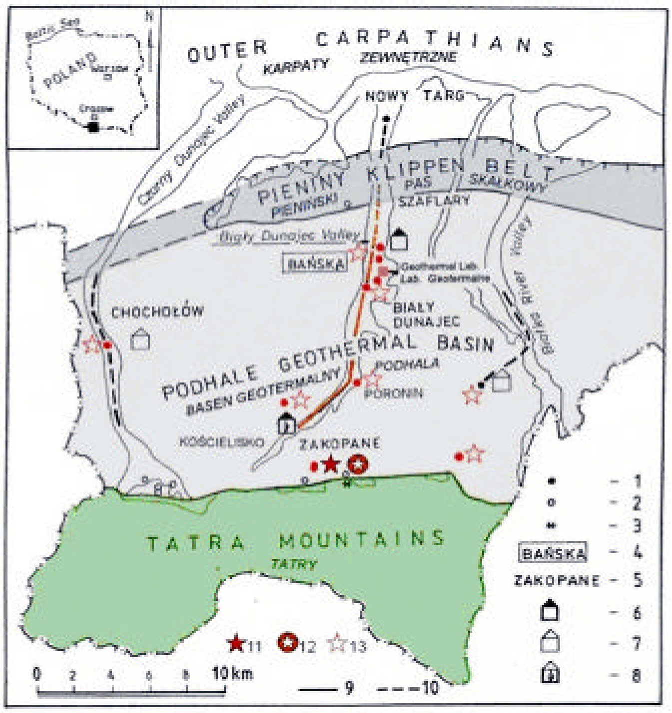

Figure 2. ***The Podhale region, S-Poland: geothermal balneo-therapeutical and bathing centers and geothermal space-heating facilities .***

1. Geothermal wells, 2. other wells, 3. geothermal spring in Jaszczurowka (existing to the 1960s), 4. locality with geothermal space heating system on-line (2001), 5. localities planned to be geothermally heated (2001 – 2001), 6. geothermal base load plant (commissioned in 1998), 7. geothermal heating plants planned, 8. central peak heating station (commissioned in 1998), 9. main transmission pipeline, 10. transmission pipelines planned, 11. geothermal bathing center on-line, 12. geothermal bathing center under construction (2001), 13. possible locations of geothermal balneo-therapeutical and bathing centers Poddebice.

Poddebice

The town is located in the Central Poland (Figure 1). This area constitutes the relaxation and solace base for the inhabitants of Lodz – the second largest, after Warsaw, agglomeration in Poland. In Poddebice and the surrounding areas (just as nearby Uniejow which has geothermal prospects, too) are within the area of the occurrence of the Cretaceous sedimentary formations – one of the most promising geothermal aquifers in the country. In this area, reservoir temperatures amount to 70 - 80ºC, geothermal waters characterise with TDS up to 60 mg/L. (Sokolowski, 1993; Ney, 1995; Gorecki, 1995). The waters have high curative and healing properties.

Poddebice is an example of a medium size town (population around 8,000) and county, which is dynamic and aims at the development of new spheres of balneo-therapy, tourism and recreation in the area with no such traditions in the past. Thanks to a convenient location in Central Poland and the qualities of geothermal waters, Poddebice has the chance of becoming a modern, regional center of balneology and relaxation on the grounds of the warm waters.

The town and county have already developed feasibility studies and technical projects of complex geothermal energy use for heating, curing and recreation purposes. Now they are trying to obtain suitable financial means and find investors. As far as balneology and recreation go, there are plans to establish a large local hydrotherapy center. The project was highly rated by the renown Polish and foreign medical experts. The waters will be delivered from new wells which have to be drilled. At present (2001), the construction of a modern hospital is underway where about 800 treatments will be done every day. A sports and recreation center will also take advantage of the waters. The biological rejuvenation center will complement the medical functions of the balneo-therapeutical hospital.

The existence of the new geothermal center will cause the development of a hotel base, services, agro-tourism and economy infrastucture, as well as - which is very crucial - influencing unemployment by creating new jobs.

In Uniejów - located about 10 km from Poddebice, a geothermal heating network is being built and in the future the construction of bathing and balneology center will take place.

CONCLUSIONS

Although not numerous, geothermal spas offering curative and recreation services are an important element of health resorts in Poland. They have a long and interesting history. There is a growing need for this type of services, as well as an increased interest of potential investors.

In the recent years, together with the projects of a comprehensive usage of geothermal energy in Poland, there occurs opportunities to develop new spas and water centers. They can be created near the largest city agglomerations in the country, which are political, economical, and business centers. Such centers express a great and constantly growing need for recreation, biological rejuvenation and treatment services. These facts are an important stimulus for the creation of new water centers, that should raise the interest among investors and also generate financial benefits.

Geothermal therapy and recreation is a promising line of business with great opportunities for development in Poland; although, they are not fully understood and exploited. One of the limitations of a wide and adequate development is still insufficient promotion and funds.

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Figure 3. Ladek Spa – main balneo-therapeutics station named Wojciech (Source: Internet page www.ladek.pl).

Figure 4. Ladek Spa – one of indoor curative pools using warm water discharged by a spring (Source: Internet page www.ladek.pl).

Figure 5. Duszniki Spa – natural warm spring named Pienawa Chopina (Source: Internet page www.duszniki.pl).

Figure 6. Ciechocinek Spa – wooden cooling tower for spraying brines and creating an ocean-like microclimate (Source: Internet page www.ciechocinek.pl).

THERMAL WATERS AND BALNEOLOGY IN BULGARIA

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INTRODUCTION

Bulgaria has a variety of mineral waters with temperatures up to 100ºC. Thermal waters with high alkalinity and low level of TDS are predominant. The country is situated at the southern part of the Balkan Peninsula and is an heir of ancient civilizations.

There are extremely good bio-climatic resources which combined with the existing ancient Mediterranean traditions in thermal water use, provide a base for the balneological development in the country. A number of large spa resorts have developed in places of old Thracian or Roman residential areas, like: Sandanski, Kjusten-dil, Hisarja, Velingrad, Sapareva Banja, etc. Even the capital city of Bulgaria, Sofia, was established close to thermal springs with temperature interval of 20ºC-50ºC, by Thracian tribes in third century BC.

The most active development of our spa system is in the time period of 1970-1980. Until 1990, about 40 resorts of local and national significance were actively operating in Bulgaria. In these spas, a wide range of diseases are treated using scientific methods and programs, confirmed by a long-term professional experience.

The economical and social changes in our country during the transition period towards the free market economy led to a drastic decrease in the governmental subsidies for balneology, and to a deterioration of some of the resorts and even to a closure of some. The Bulgarian spas are under the Ministry of Health governance, and their sponsoring, management and exploitation will be done according to the new laws and regulations in the country.

In most Bulgarian spas, the thermal waters are not used to their fullest potential. This is especially true in the case of high temperature reservoirs (T>70ºC); where, the water is left in open tanks to cool down to the desired temperature or is mixed with expensive cold tap water. In this way, the water's mineral composition has been changed and its healing agents have been diminished. At the same time, the buildings are heated with conventional fossil fuel boilers, usually coal or oil. This gives a situation of reduced efficiency of the mineral application, wasted energy and locally polluted environment.

Up until the 1980, thermal water was only partially used for health and recreational bathing, washing, swimming pools, greenhouses, bottling of potable water and soft drinks production, derivatives, etc.

After the 1980s, modern systems for space heating, air conditioning and ventilation, indoor and outdoor swimming pools have been constructed. Most of the geothermal stations have been build on reservoirs of low temperature (40ºC-60ºC) which prevail in our country. These systems are indirect ones and are assisted by plate heat exchangers and heat pumps. The total installed capacity of the geothermal systems in Bulgaria is 95.35 MWt.

The construction of new cascaded geothermal systems at these sites will considerably improve the efficiency of the medical treatment, improve the local air quality and significantly reduce the use of fossil fuels.

CONDITIONS FOR SPA DEVELOPMENT IN BULGARIA

Bulgaria covers 111,000 sq km and there is an extraordinary combination of factors providing perfect conditions for tourism, healing and recreation. The abundance of thermal waters, their variety and purity, the moderate to transcontinental climate and the Mediterranean influence as well as the national traditions in thermal water healing in Bulgaria, are prerequisites for effective and complete use of our natural resources.

Thermal Waters

The mineral waters are one of the most precious natural resources in Bulgaria. There are more than 500 hydrothermal sources with a total flow rate of 3000 L/s, having different temperature and mineral composition. Almost all of them are thermal as the temperature varies in a wide range from 20ºC to 100ºC. About 33 % of the total discovered flow rate is of temperature between 20ºC-30ºC, and 43%-between 40ºC-60ºC (Petrov, et al., 1998) (Figure 1).

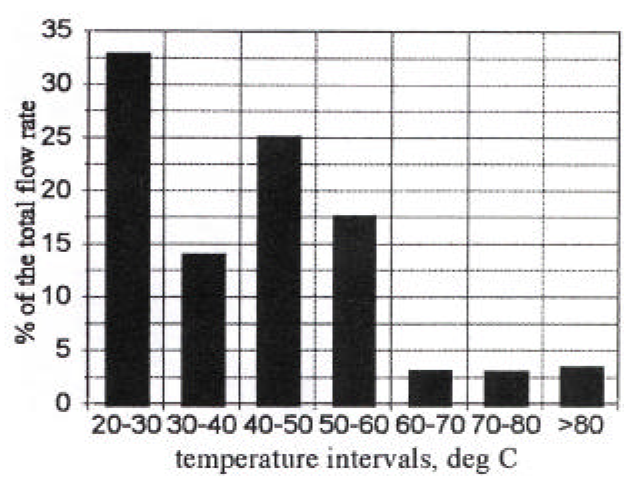

Figure 1. Flow rate distribution (in %) for temperature intervals.

About 70% of the thermal waters are slightly mineralized with fluoride concentration ranging from 0.1 to 17mg/L, various metasilicic acid concentration (up to 230 mg/L) and of mostly low alkalinity. In comparison to most of the European mineral waters, the Bulgarian ones have a lot of advantages: low TDS close to the optimal one typical for potable water, high purity level especially in terms of anthropological pollution, microbiological purity and a variety of water types (Vladeva and Karakolev, 1996).

Mineral waters in spa centers at most of the sites, flow out of taps. This allows a free-of-charge and massive water use for drinking and disease prevention. In the capital city area alone, there are six mineral water springs provided by fountains.

Climate

Considering the small area of the country, its climate is very diverse: from moderate to transcontinental, with Mediterranean influence from the south and local Black Sea influence from the east. The spa centers in Bulgaria are usually placed in mountain tourist resorts and some are at the seaside. The elevation varies over a wide range (from the sea level up to 800 m) and this satisfies the specific needs of the patients and provides good conditions for treatment. In most of the healing centers, there are year-long activities: disease prevention, treatment and rehabilitation.

Balneological Tradition

In our largest spa centers, there are data about using thermal waters both for healing and heating in the Roman baths from the I-IV century AC. These uses continue, and in addition, the literature records show that these baths were also social centers.

Until 1990, all spa centers were included in the health care system and received regular governmental subsidies. At the moment, privatization and reconstruction processes are taking place in all of these centers.

Highly experienced specialists are working in our spas. They offer treatment of a wide range of malfunctions and diseases such as: chronic respiratory malfunctions, locomotory system problems; peripheral nervous system diseases; digestive system, gynecological and kidney diseases; chronic intoxication problems, etc. (Karakolev, 1984). The treatment includes the use of mineral water drinking in prescribed doses depending on its composition. Water is used for healing baths in tubs, showers, pools, as well as for inhalation (mixed with herbs or other medications), irrigation, etc. This treatment is combined with other physiotherapeutic or rehabilitation procedures, such as sun baths, etc.

The wide spread of thermal waters therapy allows using an outpatient treatment that keeps the patients' every day routine unchanged: one goes to work and comes for treatment during suitable day hours. There are a lot of beaches created around indoor and outdoor geothermal pools, and this improves the prevention of many diseases.

SPA CENTERS IN BULGARIA

The spa centers in Bulgaria are of local and national significance and most of them are situated in South Bulgaria, Figure 2.

Seven national resorts are presented in more details. They have been selected for several reasons: well-developed base for treatment, large tourist centers and good prospects for further development under the new free market policy in the country.

Figure 2. Location map of spas of national significance.

Figure 3. Thermal bath (built in 1912).

Figure 4. A sanatorium, heated with geothermal energy.

THE TOWN OF KJUSTENDIL

The town of Kjustendil (50,000 residents) (Figure 2) is built on the place of the famous ancient Roman town of Poutalia. It prospered in the I century during the Roman rule when impressive balneotherapeutic "temples" were built, being the second in size on the Balkan Peninsula. The town is at the foot of the Ossogovo Mountain at an elevation of 530-550 m and there is a good communication system between Kjustendil and Sofia, Greece, and Macedonia in terms of railways and bus transport. In 1910, the water of forty mineral springs was captured in a common shaft. The total flow rate is 33 L/s and its temperature is 71.5º-74.8ºC. The balneological complex is in the center of the town and has been in operation since1966.

Chemical Composition

Most of the thermal waters in the region are slightly mineralized and are of wide temperature range. The TDS values are within 0.276 to 0.920 g/L. The waters are hydrocarbonic-sulphate-sodium or only hydrocarbonic-sodium ones.

The mineral water tests done in Kjustendil region show a constant physical-chemical water composition, and stable characteristics in terms of mineral content. An additional advantage is that this water meets the existing European sanitary and chemical criteria for level of purity.

There is a big curative peat deposit in the vicinity of the spa rich in biologically active substances and humid acids. The combination of different natural factors in the same region creates exclusive opportunities for a versatile, complete and wide application of all of them.

Healing Indicators

The climate in Kjustendil is transcontinental with a Mediterranean influence. The summer there is long and warm, the winter is mild and short, and autumn is long and warm. The mean annual air temperature is +10.9ºC, the mean January one is (-0.6ºC), and the mean July temperature is +21.6ºC.

The presence of hydrogen sulphide, hydro-sulphide and sulphide in the mineral water in Kjustendil and Sapareva Banja make them very useful in bone joints treatment, peripheral nervous system, gynecological malfunctions cure, healing of chronic lead based intoxication, etc. These waters might also be used in prophylactic treatment of osteoporosis, over dose radiation based malfunctions, fluoride based caries prevention, etc.

Thermal Water Application

The existing geothermal station is of 1.250 MWt installed capacity and provides space heating and domestic hot water to one sanatorium (Figure 4). Two outdoor mineral water pools are built in the town.

There are favorable conditions for construction of a new integral system for complex geothermal energy utilization. This system is going to provide space heating, air conditioning, and domestic hot water to the whole balneological complex: the polyclinic, sanatoriums, public baths, etc. The new system capacity has been estimated to be about 5 MWt.

The thermal water from well 2 Nevestino (about 10 km away from Kjustendil) is used for bottling of potable mineral water. There is an optimal fluoride ion concentration (1.0 to 1.2 mg/L) in it and the produced quantities are both for local market and export.

THE TOWN OF SAPAREVA BANJA

Sapareva Banja (9,000 residents) is a mountain resort and it is one of the largest balneological centers in Bulgaria, (Figure 2.) Ancient relics from the Thracian settlement of Djermaneja founded in I-II century BC have been found there. The town is situated in Southwest Bulgaria in a valley between two Alpine mountains – Rila and Pirin, at an elevation of 745 m. There is a bus transport between Sapareva Banja and Sofia (at a distance of only 60 km) as well as to Greece.

The highest temperature for the country thermal water of 101ºC has been recorded here. The local water temperature in the springs varies from 60ºC to 86ºC. At present just one well is producing and is self flowing; with a temperature is 97ºC-98ºC and flow rate of 16 L/s, (Figure 5).

Figure 5. ***Well 4 (The Geysir) in Sapareva Banja town.***

Chemical Composition

In this region, the water chemical composition is similar to the waters in Kjustendil. The TDS is 0.69 g/L and the pH is 9.14. The water purity level meets the existing sanitary and chemical criteria.

Healing Indicators

The climate in Sapareva Banja is transcontinental with some Mediterranean influence. The mean annual air temperature is +10.6ºC. The mean temperature in January is (– 0.7ºC), and in July is +20.2ºC. The existing spa center consists of a sanatorium (Figure 6), having three departments: polyclinic, building of medical surgery and canteen, and outdoor mineral water pool.

Figure 6. ***A sanatorium heated with geothermal energy.***

Locomotory system and gynecological diseases as well as peripheral nervous system disorders and chronic heavy metal poisoning malfunctions are treated there. The center has over 200 beds for extended patients stay and provides for thousands of outpatients.

Thermal Water Application

The balneological center and the geothermal station were both built in the period of 1954 – 1962. The total installed capacity of the geothermal station is 0.250 MWt and it provides space heating and domestic hot water for the balneological center as well as for greenhouses and a public bath. A new installation was set up in 1997 in the building with medical surgeries and a canteen. The building was chosen for a demonstration site as a part of the project: "Technical and Economic Assessment of Bulgarian Renewable Energy Resources," PHARE Project, 1997

A Bulgarian team of experts presented a project for a new modern geothermal district heating system (of about 11 MWt installed capacity) for 14 downtown buildings in Sapareva Banja (Bojadgieva, et al., 1999).

Many international organizations are interested in Sapareva Banja in relation to the development of a complex center of balneology, tourism and thermal water application.

THE TOWN OF SANDANSKI

Figure 7. ***Sandanski spa hotel.***

The town of Sandanski (32,000 residents) is a famous climato-balneological center (Figure 2). It is situated at the foot of the Alpine Pirin Mountain near the river Sandanska Bistritca. There is bus and railway transport between Sandanski and Sofia, Greece and Macedonia.

The waters from the Sandanski area were even used in II millennium BC by the Thracian tribe "Medi." During the Roman and Medieval ages, the spa center prospered as can be seen from the temple-bath remains. There are more than 20 springs in the resort. The waters have a temperature ranging between 35ºC-83ºC and total flow rate of 19 L/s.

Chemical Composition

This region is characterized by a variety of waters of different temperatures and chemical composition. The mineral waters are silicic, mildly fluorine, hydrocarbonic-sulphate-sodium-calcium and have a neutral to mild alkaline reaction with pH of 7.6 -9.0.

From the sanitary point of view the water is unpolluted. The physical-chemical thermal water composition and properties are stable for the region.

Healing Indicators

The climate of Sandanski is Trans-Mediterranean. The mean annual air temperature is +13.9°C; the mean January temperature is +2.4°C and mean July is +24.6°C. Sandanski boasts the mildest climate in Bulgaria, the greatest sunny days per annum (2440 hours of sunshine) and the lowest humidity - 66%. All chronic conditions of respiratory tract and bronchial asthma are successfully treated here. The combined climatic and balneological factors give good results in locomotory system diseases, peripheral nervous system and digestive disorders, some kidney disease, skin or allergic problems, and acute bone-joint rheumatism attack treatments.

The set of treatment and prophylactic methods, used in Sandanski resort, are of great interest. For instance, sun and air baths, climatic influence combined with specially designed walking routes, respiratory directed gymnastics, acupuncture, mineral water mixed with herbs (or medications) for inhalation procedures are often used. Hydro-therapy like underwater gymnastics, swimming in indoor and outdoor mineral water pools, electrical and light healing procedures, healing massages, special food diets, apitherapy using bee products, and sauna give fantastic results.

Thermal Water Application

The existing geothermal station is in use all year. It provides space heating, domestic hot water, air conditioning and ventilation for a vacation complex and is of 2.1 MWt installed capacity. An underfloor heating system is constructed in the building.

THE TOWN OF VELINGRAD

Figure 8. A view from the town of Velingrad.

Figure 9. A sculptural composition of the thermal water image.

Velingrad is well known for its beautiful surroundings and excellent mineral springs, located in Figure 2. Roman baths and water supply system remains are found here.

The town of Velingrad is situated on the west side of the picturesque mountain Rhodopes at 750-780 m elevation. There are over 70 hot mineral water springs on the town territory of 132 L/s total flow rate.

Chemical Composition

The mineral water varies considerably in temperature, mineral content, radon, silicic acid and fluorine content. There are well-defined water temperature and chemical zones in the town of Velingrad. From south (Chepino suburb) to north (Kametitca suburb) the mineral water temperature increases (from 20°C to 95°C), the quantity of the dissolved salts increases (from 0.21 to 0.75 g/L), as well as the quantity of fluoride (from 3.6 to 10 mg/L), and silicic acid (from 36 to 129 mg/L). The water in Chepino and Kamenitca suburbs is of a higher radioactivity. The presence of radon (1.8 nC/l) and hydrogen sulphide (1.2 mg/L) improves the healing properties of the mineral water in Kamenitca suburb.

The mineral water in Velingrad is sulphate-hydrocarbonic-sodium-fluoride-silicic type. It is unpolluted according to the sanitary and chemical criteria.

Healing Indicators

The extremely favorable climate of Velingrad combined with the Mediterranean influence provides good opportunity of applying the climatic- and balneotherapeutic programs all year. The mean annual air temperature is +9°C; the mean temperature in January is (- 1.8°C), and in July is +18.8°C. The sunny period is significant, over 2000 hours in a year. The summer is mildly warm and the winter is mildly cold, the autumn is warmer than the spring.

The combined climatic and balneological treatment is recommended for patients having chronic respiratory system disorders. There are very good results in the treatment of patients with locomotory system and neurological diseases. The gynecological malfunctions are of a special priority in the balneo-therapeutic list of this region. Velingrad spa serves as a prophylactic center as well. There is a well-developed balneological center with modern sanatoriums and hotels, operating all year.

Thermal Water Application

Geothermal energy is used for space heating of two buildings – a Youth Club and a school (Chepino suburb). The installed capacity is 0.150 MWt and 0.900 MWt, respectively. Mineral water is widely used in outdoor and indoor pools, greenhouses and public water taps. Since 1999, the mineral water from Chepino suburb has been bottled for sale in the country and abroad.

THE TOWN OF DEVIN

Figure 10. ***A view from the town of Devin***.

Figure 11. ***The rehabilitation hall***.

The town of Devin (7000 residents) is located on the East Rhodopes at 710-780 m elevation, located in Figure 2. The clear Devin River passes through the town. Besides its picturesque placement, the Devin region is well known for its mineral waters that were discovered by drilling deep wells. Their temperature varies from 37ºC to 44 ºC and the total flow rate is 18 L/s.

Chemical Composition

The TDS values are low (from 0.29 to 0.37 g/L), hydrocarbonic and sodium ions prevail, along with limited quantities of chlorides and sulfides. The fluoride ions (from 1.8 to 7.7mg/L) are also found in the composition. The hydrogen sulphide presence is very useful for external balneotherapy.

Healing Indicators

The climate in Devin is transcontinental and upland. Its main characteristic is a warm but not hot summer and a warm, sunny autumn. The mean annual air temperature is +10.5ºC, the mean January one is (-1.5ºC), and the mean July is +16ºC. This creates suitable conditions for both summer and winter tourism as well as for climatic treatment and prophylactic. The main diseases recommended for treatment by this mineral water are as follows: degenerative joint diseases of the locomotory system; nervous system functional disorders as well as mental ones; overweight problems, etc. This mineral water is suitable for prophylactics and recreation procedures in cases of physical and mental overstrain; post operational rehabilitation; for advanced aging prevention; for fluoride caries prevention; for radioactive overdose exposure healing and osteoporosis treatment.

Thermal Water Application

A new modern mineral water bottling factory of 5,000,000 liters monthly has been recently opened in Devin. In addition to local sale, these mineral water bottles are exported to Kosovo and are going to be exported to Germany and some Arabs countries.

THE TOWN OF HISARJA

The town of Hisarja (15,000 residents) is one of the largest spa known since ancient times, located in Figure 2. It is situated in South Bulgaria at the foot of the Sredna Gora Mountain at 364 m of elevation, close to the Valley of Roses. There are 22 mineral water sources with a total flow rate of 35 L/s and temperature of 27ºC - 52ºC in this area.

Chemical Composition

There are a unique variety of mineral waters of high content of some chemical elements such as calcium (from 3 to 21 mg/L) and sulphate (from 17 to 45 mg/L). The mineral water in Hisarja is famous for its radon content. Its highest concentration has been measured in the spring "Momina banja"-180 emans (666 Bq/L) and the lowest - in "Chuludja"- 30 emans (111 Bq/L).

This composition is combined with very low TDS of 0.256 g/L in a wide temperature range. The mineral water in this region is of hydrocarbonic- sulphate- sodium - silicic type, of high alkaline reaction (pH from 8.3 to 9.02) and is extremely pure.

Figure 12. ***Ruins of an ancient Roman fortress (Hisarja town).***

Figure 13 ***Thermal water fountain (Hisarja town).***

Healing Indicators

The spa climate is both sub-mountain and plain one with Mediterranean influence. The mean annual air temperature is +11.9 ^{o}C, the mean July temperature is +23^{o}C, and the mean January one is +0.4 ^{o}C. The summer is very warm to hot, the winter is mild, the spring comes early, and the autumn is long and sunny.

This water is excellent for people suffering from kidney, liver, gall bladder and digestive systems problems. Hisarja is also very suitable resort for prophylactic of osteoporosis through the complex balneophysical therapy leading to general body fitness.

Thermal Water Application

A geothermal station of 0.260 MWt installed capacity has been built in Hisarja. It provides space heating and domestic hot water for a sanatorium. There is an underfloor heating system constructed in the building.

Water from several sources (wells number 3 and 7, "Choban Cheshma," etc.) is used for bottling and sale to the local market.

BLACK SEA RESORTS

In the North Black Sea region, there is a unique combination of sea resorts and spa centers for healing and prophylactic. The thermal sources (wells) are located very close to the seashore and there are mineral water seeps on the beach. The geothermal pools (outdoor and indoor) are also placed close to the beach. Some modern international resorts are located here, for example: Varna city, The Golden Sands, Riviera, St. Constantine and Elena, and Albena (Figure 2). The attractive combination of sea water baths with mud baths and mineral water baths, as well as the geothermal energy application, makes the resorts operation very effective all year.

Figure 14. ***Center of balneo-therapy (Albena resort).***

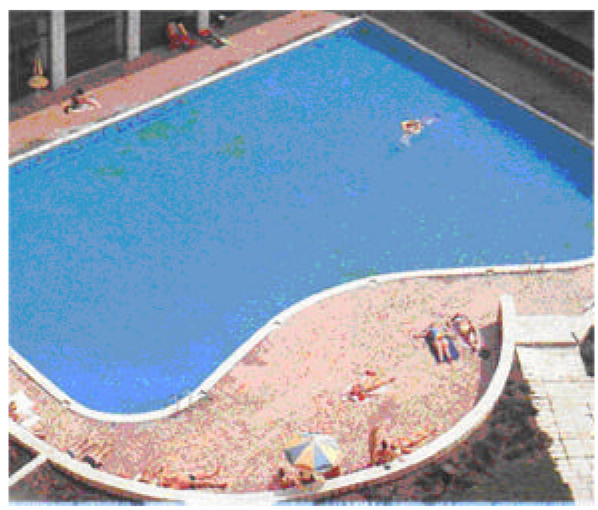

Figure 15. ***Outdoor geothermal pool (Albena resort).***

The thermal water temperature decreases within the region from south to north as in Varna city it is 52^{o}C (of 22 L/s flow rate), in "St. Constantine and Elena" - 48^{o}C (of 43 L/s flow rate), and to the north in Albena it becomes 30^{o}C (of 6 L/s flow rate).

Chemical Composition

The TDS is very low in these resorts and varies within a small range from 0.611 to 0.673 g/L. Inorganic nitric compounds as nitrates and nitrides have not been detected. The sanitary and chemical tests prove the water to be naturally pure. The low fluoride concentration defines the water as drinkable and acceptable for all age groups of customers. The water is hydrocarbonic-sodium-calcium-magnesium; hydroarbonic-chloridic and suphatic-sodium magnesium.

Healing Indicators

These mineral waters can be used in the treatment of: respiratory system diseases as well as cardiovascular and nervous system functional disorders; blood circulation diseases, second rate allergies; locomotory malfunctions, gynecological disorders, etc.

Healing and prophylactic centers are developed in Varna city and Pomorie town, and in "St. Constantine and Elena," Riviera and Albena resorts. Seawater and climatic procedures as well as balneo-therapeutic treatment is offered in these centers making use of outdoor and indoor mineral water and sea water pools, thermal water baths, lye treatment, manual therapy, herbal treatment, etc.

Thermal Water Application

Up-to-date geothermal stations that operate all year have been built in the north Black Sea region after 1980. They provide space heating, air conditioning and ventilation, domestic hot water for hotels and spa centers. The geothermal stations are located in Varna city (2.5 MWt and 3.5 MWt), Chaika resort (2.0 MWt), "St Constantine and Elena" resort (15 MWt) and "Golden sands" resort (0.35 MWt).

CONCLUSIONS

The wide variety and the high quality of pure thermal waters in Bulgaria combined with the extremely favorable natural and climatic conditions, a good spa base plus mineral water healing traditions justify a long-term investment policy for the development and improvement of the existing resorts.

In parallel to that, there are conditions favoring small local centers in the spirit of today's tendencies in the so called "countryside tourism" and traditional healing as well as to widely use the renewable energy sources in our every day life.

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LOW-ENTHALPY POWER GENERATION WITH ORC-TURBOGENERATOR THE ALTHEIM PROJECT, UPPER AUSTRIA

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INTRODUCTION

Altheim is a municipality in the Upper Austrian "Inn-region" with 5000 inhabitants and encloses an area of about 22 km^2. The budget on a yearly base is about 6,300,000 Euro (5,670,000 US$). The decision to construct a geothermal heat supply, for environmental reasons, was made by the municipal council in January 1989.

The district heating system is fed by 106°C geothermal fluid flowing from an aquifer about 2300 m deep. Since 1989, efforts were undertaken by the municipality to supply 10 MWe of thermal heat to a district heating network. In order to keep the water balance in the Malm aquifer, a injection drill hole was required. The new idea was to use the income from power production to finance the injection drill hole. A binary cycle or Organic Rankine Cycle (ORC) turbo-generator was proposed.

The main contractor and operator for the installation is the Marktgemeinde of Altheim. The Altheim project is challenging from the ORC point of view, both because of the low temperature of the heat source and the fact that the well head and the turbogenerator are placed within the town, near the town hall. Hence, very efficient silencing is required and the use of a flammable working fluid was excluded for safety reasons. As a working fluid, a harmless fluorocarbon was selected instead. A total power of 1000 kWe was generated during the test run, and it is presently operating at about 500 kWe.

The ORC is cooled by the water from a nearby canal. After use, the geothermal water is pumped back at a temperature of 70°C to the deep geothermal Malm-aquifer, allowing a sustained exploitation of the system. As a result, the balance of the water in the Malm reservoir is maintained.

HEAT SUPPLY/PRODUCTION DRILL HOLE/SUPPLY NETWORK

The production borehole was drilled in 1989. After two months, the water bearing Malm was encountered at 2300 m depth. The artesian flow rate was finally 46 L/s, at a temperature of 104°C. Thus, the desired heat distribution of 2500 kWe was possible. The expenses for the first drill hole amounted to 1,450,00 Euro (1,305,000 US$).

Presently, about 650 consumers are connected to the heat supply, with a thermal power load of 10,000 kWt. About 40 % of the inhabitants of Altheim live in buildings that are connected to the heat supply. The supply network has a length of about 14.5 km. The biggest single consumer are municipal facilities with about 1000 kWt thermal power (school, gymnasium). The majority of the supplied buildings are one- and two-family houses.

The fee for the heat supply is 39.39 Euro (35.45 US$) per MWh. To create a demand for the consumer to be connected to the heat supply, the contract conditions in 1989 were made consumer friendly; since, almost exclusively a fix temperature difference of 30°C was charged. The real temperature difference is greater, thus the consumers pay less per MWh. Meanwhile the community is in a better position, as the increasing demand made it possible to create more favorable conditions for them (the new consumers are charged for the actual supplied energy). The calculated 1500 operating hours per year in 1989 could not be obtained, as the actual number is about 1200.

The use of geothermal energy for heat supply led to a significant reduction of air pollution and greenhouse gas in the community area as well as an immense saving of fossil fuels, as shown below.

Comparison of 1989 and Present State			
	1989	Present State	Reduction
CO_2	11,150,000 kg	3,094,000 kg	72%
NO_2	8,000 kg	2,600 kg	67%
SO_2	32,200 kg	11,200 kg	65%
CO	411,000 kg	173,000 kg	58%
Fossil Fuel Savings: 2,500 t/year			

REINJECTION DRILL HOLE/CONSTRUCTION OF THE POWER PLANT

In order to keep the water balance in the water bearing limestone of the Malm, authorities were ordered to inject the geothermal water. The question was how to finance this second drill hole. Since incomes for the district heating were not sufficient, new possibilities had to be found.

Then in 1994, a project of geothermal power generation was developed. The power output from the very first design was calculated at 240 kWe–not enough to finance a drill hole; thus, a new concept had to be developed.

A minimum production rate of 100 L/s had to be achieved to produce electrical power of 1 MWe.

As the costs per MWh without fundings were calculated to 140 Euro (126 US$), a proposal for additional financial support by the Commission of the European Communities was combined with three other project partners.

A funding level of 35% was granted by the Commission. With additional funds from the local government of Upper Austria and the federal government of Austria, the project was completely financed. Negotiations with the local energy supplier "Energie AG - Oberösterreich" followed. Liberalization of the energy market leads to a decreasing reimbursement of the generating costs--but nevertheless an appropriate financial contribution of the energy utility also helped in this case. With that, an economic operation of the power plant by the municipality was then ensured. In 1998, the drill bit went downward once more--40 m away from the first drill hole.

In order to reach the geothermal water bearing layer at a horizontal distance of 1700 m, the drill hole had to be deviated from the vertical. This technically ticklish operation started at a depth of 460 m. The drill bit had to be guided several times into the right direction. The deviation operation was performed by Becfield Drilling Services.

After eight months of drilling, the final depth was reached. With a total length of almost 3100 m, the drill hole reached the target at 2200 m depth--the white treasure in the Malm karst of the Molasse Basin. The horizontal distance between starting and ending point of the drill hole is 1700 m.

Hydraulic tests showed that hot water with 100 L/s at a temperature of 93ºC could be produced. The same rate can also be injected.

According to the planning, the first well was used for production and the second drill hole as the injection well. The geothermal water is produced by a high temperature downhole pump which is installed at a depth of 290 m.

A Rankine turbogenerator was constructed by Turboden in Brescia, Italy. To obtain a high efficiency of the binary cycle, the working parameter of the turbogenerator had to be well adapted to the flow rate and temperature of the produced water. The working fluid had to be non toxic, as there must be no danger of explosion and it should also not affect the ozone layer in any way. A suitable fluid was found by Turboden, a harmless "Fluorocarbon." The thermal water heats up the working fluid in a heat exchanger. The fluid evaporates at relatively low temperatures of 28-30ºC. As steam, it drives the turbine. The vaporized medium is cooled down, condensed and then once again, continues its way through the closed turbine cycle.

After using the heat of the geothermal water, it is injected into the underground at a temperature of 70ºC. By this measures, the balance of water in the Malm reservoir is maintained.

The ORC plant was installed in spring/summer 2000, and first tests started in September 2000. Due to insufficient purification of the cooling water (taken out of a creek), the

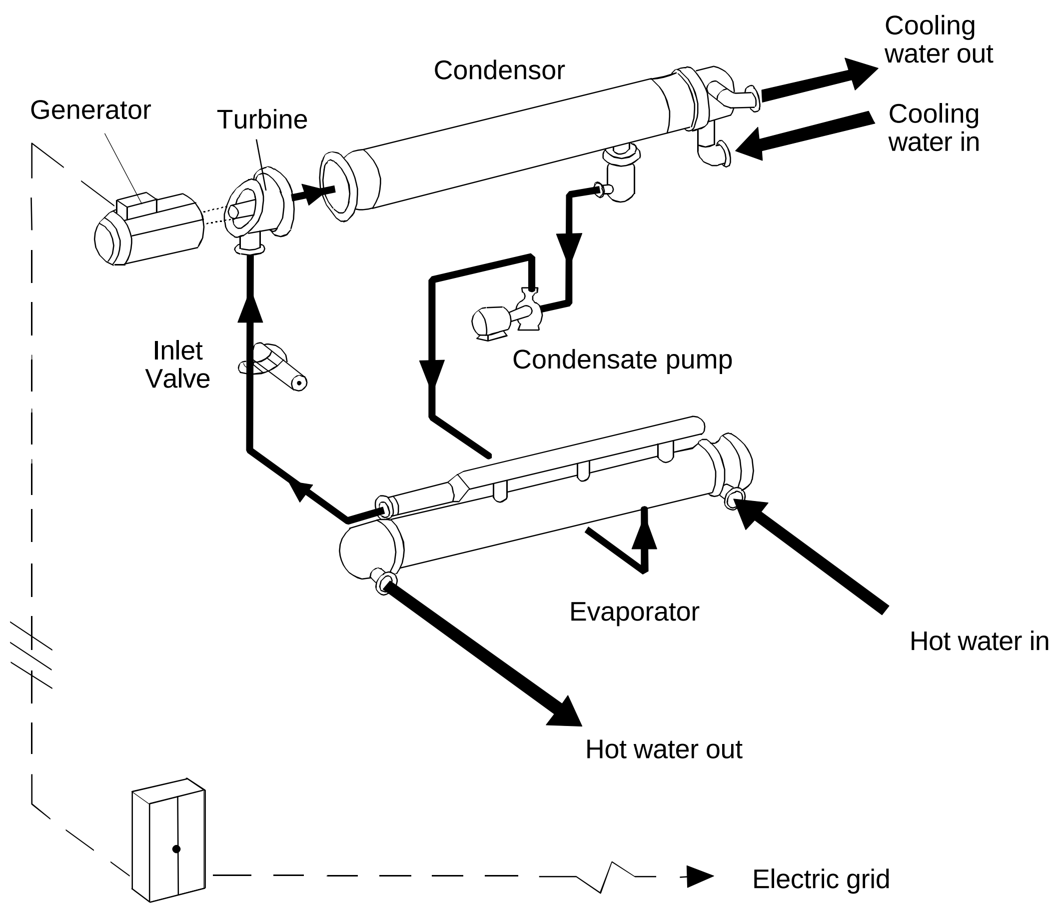

Figure 1. Schematic of the ORC turbogenerator.

Table 1. Altheim ORC Turbogenerator Performance Data Sheet

Geothermal water inlet temperature:	106 ºC (223 ºF)
Geothermal water outlet temperature	70 ºC (158ºF)
Geothermal water flow rate:	81.7 kg/s (1,295 gpm)
Cooling water flow rate (about):	340 kg/s (5,389 gpm)
Cooling water inlet temperature:	10 ºC (50ºF)
Cooling water outlet temperature:	18 ºC (64ºF)
Electric generator:	synchronous,.low voltage
Net electric power output:	1,000 kW

Table 2. Expenses for the Project

Electricity power plant	1,580,000 EURO (1,422,00 US$)
Reinject. drillh. / Completion prod. drillh.	2,117,000 EURO (1,905,000 US$)
Underwater product.- / Inject.- installation	378,000 EURO (340,000 US$)
Further expenses	436,000 EURO (392,000 US$)
Total expenses	4,511,000 EURO (4,060,000 US$)

Table 3. Yearly/Production Costs (Due to the funding of the European Commission, the continuous expenses could be reduced to the following numbers)

Yearly costs	349,861 EURO (315,000 US$)
Production costs per MWh	91.47 EURO (82.32 US$)

Table 4. Input Tariff per kWh (fixed price guaranteed for 15 years)

		ATS*	EURO**	US$
Winter -	High rate	0.72	0.0523	0.0445
Winter -	Low rate	0.607	0.0441	0.0397
Summer -	High rate	0.473	0.0344	0.0310
Summer-	Low rate	0.421	0.0306	0.0275

* ATS = Austrian Schilling (1US$ = 15.4 ATS)

** 1 EURO = 0.90 US$

plant was shut down after a short time. After installation of additional filters in the cooling water system, the plant started operation again in January 2001. At this time, the highest capacity of the plant was 1027 kWe.

Unfortunately, after a few days the plant had to be shut down again. The reason was damage to some of the turbine blades. After changing of all turbine blades, the plant was restarted at the beginning of March 2001.

During the following period, the plant had good performance–the capacity to the public grid was more than 500 kWe (peak 564 kWe).

In April and May, problems emerged again–both in the condenser and the turbine. The aproximately 5,000 copper pipes in the condenser were changed and the turbine was fitted with new blades (a reduced number with a modified shape).

Since December 2001, the plant has been in operation again. The highest capacity to the grid was 414 kWe. The current thermal water flow rate is about 85 L/s–up to half of it goes to the district heating. After winter when the demand of the district heating systems is decreased, the capacity to the grid can be increased up to 500 kWe.

To improve the clarification of the cooling water, an automatic flushing filter system will be installed in the next months.

Since January 2001, the following quantities of power have been supplied to the grid.

Period	kWh_e	Max. Capacity in kWe
January 2001	40,907	545
March 2001	132,694	545
April 2001	115,103	564
May 2001	99,67	530
December 2001	64,818	360
January 2002	171	414

About 63% of the gross power production of the plant is supplied to the grid of the electricity company Energie AG Oberösterreich. The remaining power is used for the submersible pump, the pump to increase the pressure in the injection borehole, the cooling water pumps and other auxiliaries. The submersible pump is also necessary to maintain a stable operation of the district heating; otherwise, other pumps in the central station have to be used.

The floor space requirement is very low. The heating plant with a thermal capacity of 10 MWe needs only 70 m³. Both well heads of the two drill holes require 50 m² each, and the power house requires some 230 m³.

The general planning of the integration of the turbogenerator system into the district heating grid was carried out by Geotec Consult from Markt Schwaben in Bavaria. The staff of Geotec Consult was also responsible for the design and supervision of the drill hole.

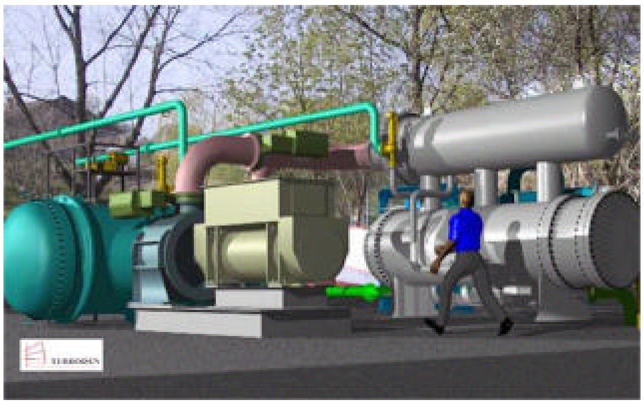

Figure 2. ***ORC Turbo Generator Without Housing Nearby the Townhall of Altheim.***

The first geothermal power generation from low enthalpy resources in Middle Europe is complete. Only geothermal energy is the one which is independent from climate and can be used all year and is capable of supplying base load energy.

With this contract and tariff concept it will be possible to run the geothermal station for heat and power in the municipality of Altheim economically.

ACKNOWLEDGMENTS

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Figure 4. ***Well 1A with pump house.***

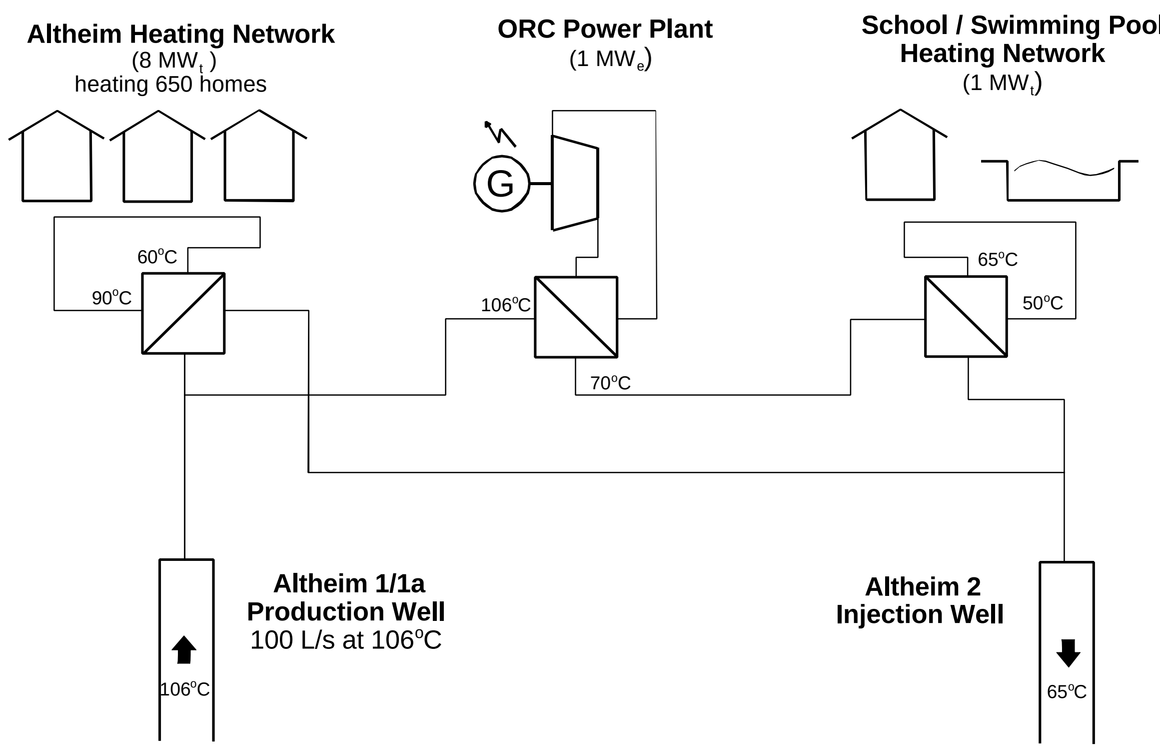


Figure 3. Schematic of the power plant and district heating system.

Figure 5. *ORC turbine.*

Figure 6. *ORC generator.*

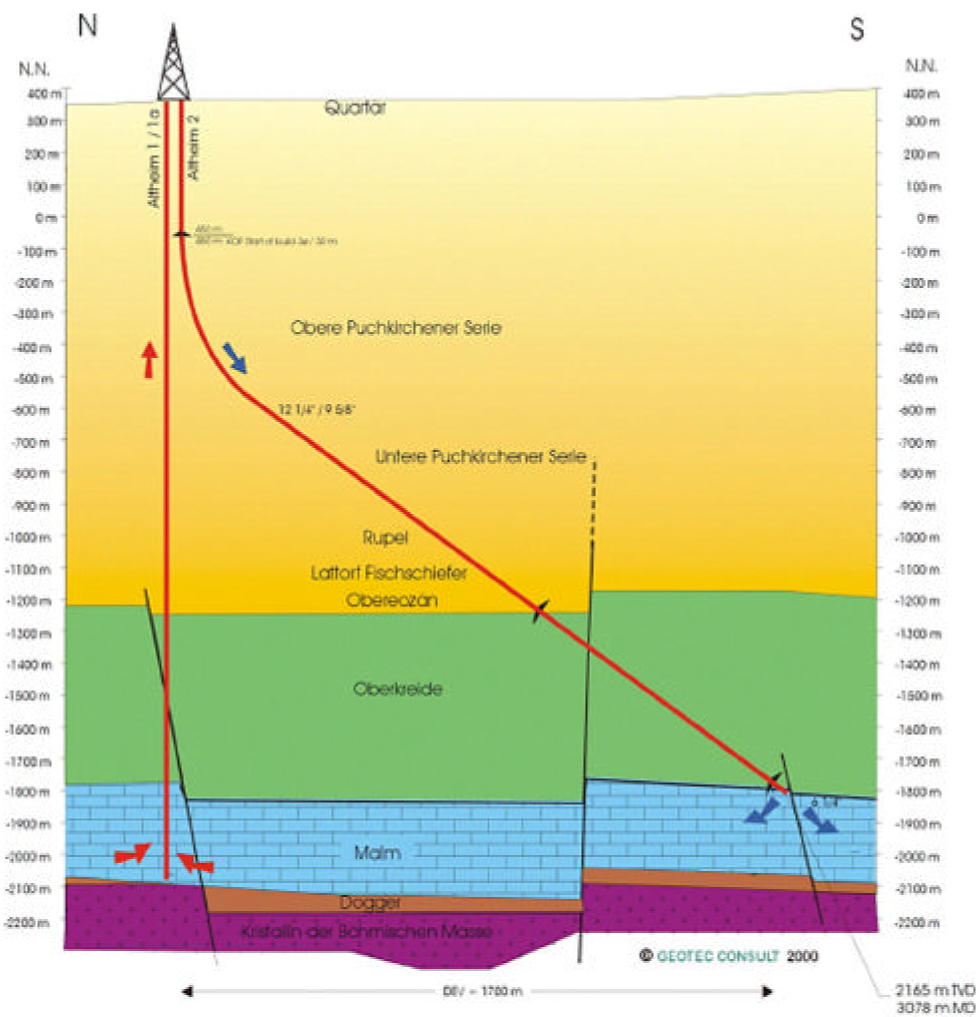


Figure 7. *Geological Cross Section with Production and Injection Well.*

THE SWISS DEEP HEAT MINING PROJECT - THE BASEL EXPLORATION DRILLING -

Markus Häring, Geoprojects, Steinmaur, Switzerland
Robert Hopkirk, Polydynamics, Männedorf, Switzerland

A DEEP HEAT MINING PLANT IS FEASIBLE IN SWITZERLAND

The conditions for the construction and successful operation of such a plant are particularly attractive in northern Switzerland, because of the significant potential of heat consumption and of the known geological and geothermal conditions. The two main requirements for site selection are a temperature of 200°C at a depth of about 5 km and local heat consumers connected to a large heat distribution network.

Building a Deep Heat Mining (DHM) plant does not require the development of essentially new technologies. For decades, electric power has been generated economically from geothermal fields all over the world. The deep drilling technology (5-6 km) into hot and hard rock is available, representing a combination of experiences gained in the oil and mining industries, with specific high temperature tools and knowhow from the geothermal industry.

A selection of ten potential sites in Switzerland have been evaluated. On the basis of logistics, heat distribution and geological criteria, two sites are under detailed appraisal in Basel and in Geneva.

The areas of responsibility of the DHM consortium is the identification and scientific evaluation of potential DHM sites, the creation and promotion of new projects, their scientific supervision and their quality control. The different steps of the Deep Heat Mining project are closely related to the development of the European Hot Dry Rock program in Soultz-sous-Forets, Alsace, France.

DEEP HEAT MINING: FRIENDLY ENERGY FROM THE EARTH'S INTERIOR

Deep Heat Mining is power and heat generation from deep enhanced geothermal systems and is a new energy project in Switzerland.

Geothermal energy is the only renewable source of energy which can be tapped continuously with no need of storage facilities.

The Deep Heat Mining project was initiated and is partly financed by the Federal Office of Energy (OFEN) since 1996. Private and public institutions also support the activities of the project.

Specifications for the Deep Heat Mining Pilot Plant

Parameters	Characteristics
Underground system	1 injection well and 2 production wells connected to the reservoir Reservoir: stimulated volume of fractured crystalline rock
Surface installation	Circulation pumps Heat exchanger (binary cycle system) Steam turbine Electricity generator Cooling system Connection to the power grid Connection to the district heating network
Depth of the wells	About 5000 m
Temperatures	200°C in the fractured reservoir 170°C at the production wellhead 70°C at the injection wellhead
Flow rate	70 kg/sec
Output power	3 MW electric and 20 MW thermal
Energy production	Power: 20,000 MWh/year Heat: 80,000 MWh/year
Milestones	1996: beginning of the DHM project, concept 1997-98: preliminary studies, site selection
Future potential	Creation of new DHM sites in Switzerland

After the selection of a first adequate site in the city of Basel and the drilling of the necessary boreholes, the objective was to create a deep fractured reservoir and to build a pilot plant delivering electricity and heat.

The modular concept of a Deep Heat Mining pilot plant is composed of one injection well and two production wells. The cold water is pumped down and circulates through the fractured reservoir. This natural heat exchanger delivers hot and pressurized water to the production wells. The energy is converted into power by means of a turbine-generator unit. The excess heat is used for space heating. The cooled water is then injected at depth. This closed-loop system provides CO_2-free energy.

MAIN DHM PROJECT IN BASEL

For a number of practical, economic, political and geothermal reasons, the first Enhanced Geothermal System pilot plant in Switzerland will be situated in the Basel area of NW Switzerland at the border with France and Germany. The city of Basel is a highly developed urban area, with numerous heat consumers, existing heat distribution networks and a strong policy towards renewable energies. Basel is located at the southeastern end of the Rhinegraben, a failed rift system. The sedimentary sequence filling the rift is relatively well known, but no drill hole has penetrated the crystalline basement, foreseen at a depth of 2.2 ± 0.2 km. The geothermal gradient is estimated to reach 40ºC/km.

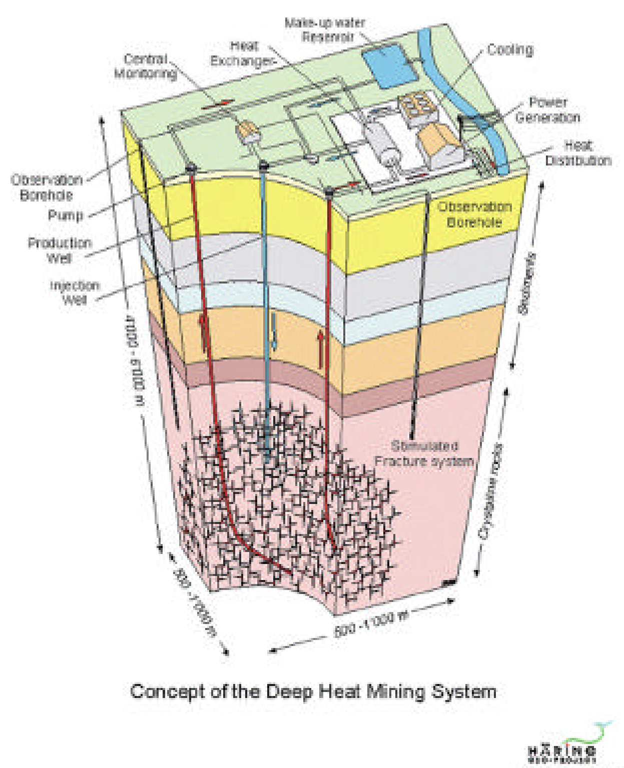
DRILLING OF DHM-1 WELL IN OTTERBACH, BASEL

A first exploration borehole (DHM-1) has been spotted in Otterbach and drilling operations started in June 1999. Unfortunately, successive drilling problems stopped the penetration at 1537 m. After numerous fishing attempts to retrieve a broken casing string, the well DHM-1 was abandoned. In January 2001, a temperature log from surface down to 537 m has revealed a geothermal gradient of 4.2EC/100 m, which is slightly above that forecasted. Later, DHM-1 borehole will be equipped as a seismic station by the Swiss Seismological Service.

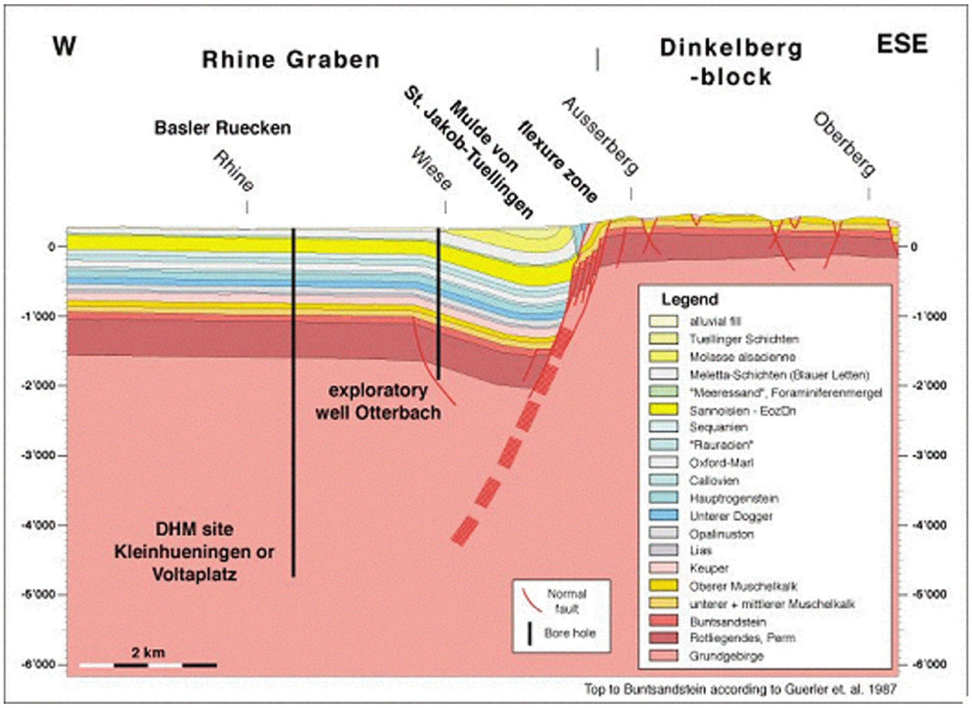
DRILLING OF DHM-2 WELL IN OTTERBACH, BASEL

A new drilling program has been set up, including a more powerful drilling rig as well as larger borehole and casing diameters. The well DHM-2 is situated on the same location in Otterbach, by UGS Co. from Germany. The rig, a IRI Franks 900 with a regular hook load of 138 tons, arrived on the site March 7 and drilling operations started March 15, 2001.

Status at: June 17, 2001
Days since spudding: 94
Depth: 2755 m ——> Total Depth
Formation: crystalline basement
Current action: demobilization works
Last drilling diameter: 5 7/8" (149 mm)
Cased down to: 2030 m.
1st casing: at 25 m, 22" (500 mm)
2nd casing: at 845 m, 13 3/8" (340 mm)
3rd casing: at 1540 m, 9 5/8" (244 mm)
4th casing: at 2030 m, 7" (178 mm)
Open hole section: 2030 to 2755 m, 5 7/8" (149 mm).



Concept of the Deep Heat Mining System



Cross Section Across the Rhine Graben Margin at Basel (Häering, 1999).

PRELIMINARY RESULTS

Drilling, coring and logging operations of borehole DHM-2 in Otterbach can already be regarded as a success:

1. Preliminary temperature logs show a geothermal gradient of at least 38ºC/km,
2. Cores recovered from unweathered crystalline basement display tight and fractured granite,
3. Remarkable geological findings will represent new and important references for the understanding of the southern Rhine graben.
4. Fracture system was mapped by newly developed borehole logging tools / a combination of acoustic and electrical measurements.

NEXT OPERATIONS

Additional temperature logs and tests to follow after demobilization of drilling rig.

* Core analysis of the granite and petrographical investigations,
* Hydraulic tests, and stress measurements,
* Fluid and gas sampling and analyses,
* Obtaining enough information for the site selection of a first deep well at 5 km

Later, this borehole will be completed as the first of three seismic monitoring wells located around and above the future deep fractured reservoir.

ACKNOWLEDGMENTS

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GEOTHERMAL PIPELINE

Progress and Development Update
Geothermal Progress Monitor

MEETINGS

Geothermal Resources Council 2002 Annual Meeting

The GRC Annual Meeting will be held at the Reno Hilton Hotel, Reno, NV from September 22 to 25. The theme of this years meeting is *Geothermal Energy - The Baseload Renewable Resources* which recognizes the solid and reliable contribution that geothermal resources make to economic growth and the environment. The meeting will feature distinguished keynote speakers at its Opening Session, Technical and Poster sessions on a broad range of timely geothermal resource and development topics, technical workshops, field trips, the popular Annual Golf Tournament and GRC Banquet, and the GEA Geothermal Energy Trade Show. The deadline for submitting technical papers is April 26th. Information on the meeting can be obtained from the GRC office in Davis, CA (PO Box 1350, Davis, CA 95616), by phone (530-758-2360) or from their website: www.geothermal.org.

Geothermal Resources Council Introductory Short Course

An Introductory Short Course on all aspects of geothermal energy, along with field trips of power generation and direct-use sites in the Reno area, will be held by the GRC on the University of Nevada, Reno campus on April 18-19. This is a course for people who have no or little background in geothermal energy, but, who would like a basic understanding of what geothermal is and what goes into a project. It will cover, world-wide development and use, geology, exploration, drilling, production, power generation, direct-use, economics and financing, legal and regulatory issues, and environmental concerns. Contact the GRC office for details.

International Summer School of the International Geothermal Association Conference

The ISS will hold their Annual Conference: "International Geothermal Days GREECE 2002" in Thessaloniki, Greece from September 1 to 11, 2002. The conference will consist of (1) International Course on District Heating, Agricultural and Agro-Industrial Uses of Geothermal Energy (September 1-4 in Thessaloniki), (2) International Workshop on Possibilities of Geothermal Development of the Aegean Islands Regions (September 5-7 on Milos), and (3) Guided tour of Santorini island with round table discussions on the possibilities of geothermal development (September 9-11 on Santorini). Details on the conference can be obtained through the organizer, Dr. Kiril Popovski of Skopje, Macedonia, at the conference website: http://www.heliotopos.net/conf/geotherm2002/ and photos can be viewed at the following website: http://homepage.mac.com/kpopovski/PhotoAlbum5.html.