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SWISS GEOTHERMAL ENERGY UPDATE 1985 – 1990

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ABSTRACT

Since 1985, geothermal R&D has evolved steadily in Switzerland. Regional low-enthalphy exploration and resource assessment are largely complete; emphasis is now on drilling and development. Vertical earth-heat exchangers (small-scale, decentralized, heat pump-coupled heating facilities) increase rapidly in number; the governmental system of risk coverage for geothermal drilling, established in 1987, gives rise to several drilling projects. Of these, a single well and a doublet have been successfully completed so far. Numerical modelling of coupled thermohydraulic processes in fracture-dominate Hot Dry Rock systems, including rock-mechanics aspects, is in progress. Some further efforts such as contributions to general geothermics, exploration and resource assessment activities in Switzerland, and financing of geothermal development abroad by Swiss banks are described.

INTRODUCTION

The status of geothermal energy utilization in Switzerland as of 1985 was described in Griesser and Rybach (1985). In particular, the geologic background was presented, the efforts in exploration and resource characterization were discussed, and references containing more detailed information were given.

Since 1985 some factors and boundary conditions have remained unchanged whereas others underwent considerable changes. Within the over-all energy situation in Switzerland public opinion became quite critical towards nuclear energy. But regardless of saving efforts, electricity consumption is still increasing, with an average of 3 percent per year. General environmental concern is also growing, especially with respect to the CO_2 problem.

The low price of oil is still a major obstacle to the development of alternative energy sources, especially for space heating. However, the growing environmental concern is often helpful in surmounting purely economic thinking. This is the basis of the increasing preparedness of public authorities to undertake not only desk (feasibility) studies but also field work (drilling) for geothermal energy utilization.

Two developments are definitely encouraging and worth reporting on the international level: (1) the rapidly increasing number of vertical earth heat exchangers (VHE; small-scale, decentralized heating facilities), and (2) the governmental system of risk coverage for geothermal drilling.

Besides these two developments which will be discussed in more detail below, there are some other positive results and trends: (a) basic contributions to general geothermics (Chapman and Rybach, 1985; Haenel and others, 1988; Rybach, 1989); (b) assessment of geothermal potential and of development and utilization costs in the whole country (Rybach, 1988; EGES, 1988), and in specific regions (Gorhan and Griesser, 1988); and (c) financing of geothermal development abroad by Swiss banks (Heierli and Rybach, 1988).

A substantial geothermal exploration program, 'GEOTHERMOVAL," is currently in progress in and around the Valais area (see Figure 1) rich in thermal springs, aiming at the location and characterization of geothermal resources in fracture systems. The investigations include hydrogeological, geochemical, and geophysical field work (airborne IR measurements and, especially, high-resolution reflection seismics).

The growing general interest in geothermal energy as a domestic source manifests itself in the formation of the promoting organization "Swiss Association for Geothermal Energy" in April 1990.

VERTICAL EARTH HEAT EXCHANGERS (VHE)

These are small, decentral, closed-circuit, heat pump-coupled systems, ideally suited to supply heat to smaller objects such as single family or multifamily dwellings. They can be installed in nearly all kinds of geologic media (except in materials with low thermal conductivity like dry gravel). Over 4,000 such systems operate now successfully in Switzerland, some of them 700-800 m deep but mainly with probe lengths of 50-100 m. In this depth range the virgin temperature field is governed by the thermal conductivity structure of the ground and by the geothermal heat flow. The latter can be influenced by flowing groundwater.

Theoretical and experimental investigations have been performed in order to answer a number of questions concerning VHE systems:

- What are the dominant physical processes involved in the operation of a VHE?
- What are the typical limits of performance to be expected?
- Are there any measurable or observable effects upon the environment which could cause legal imposition of performance limits on ecological or social grounds?

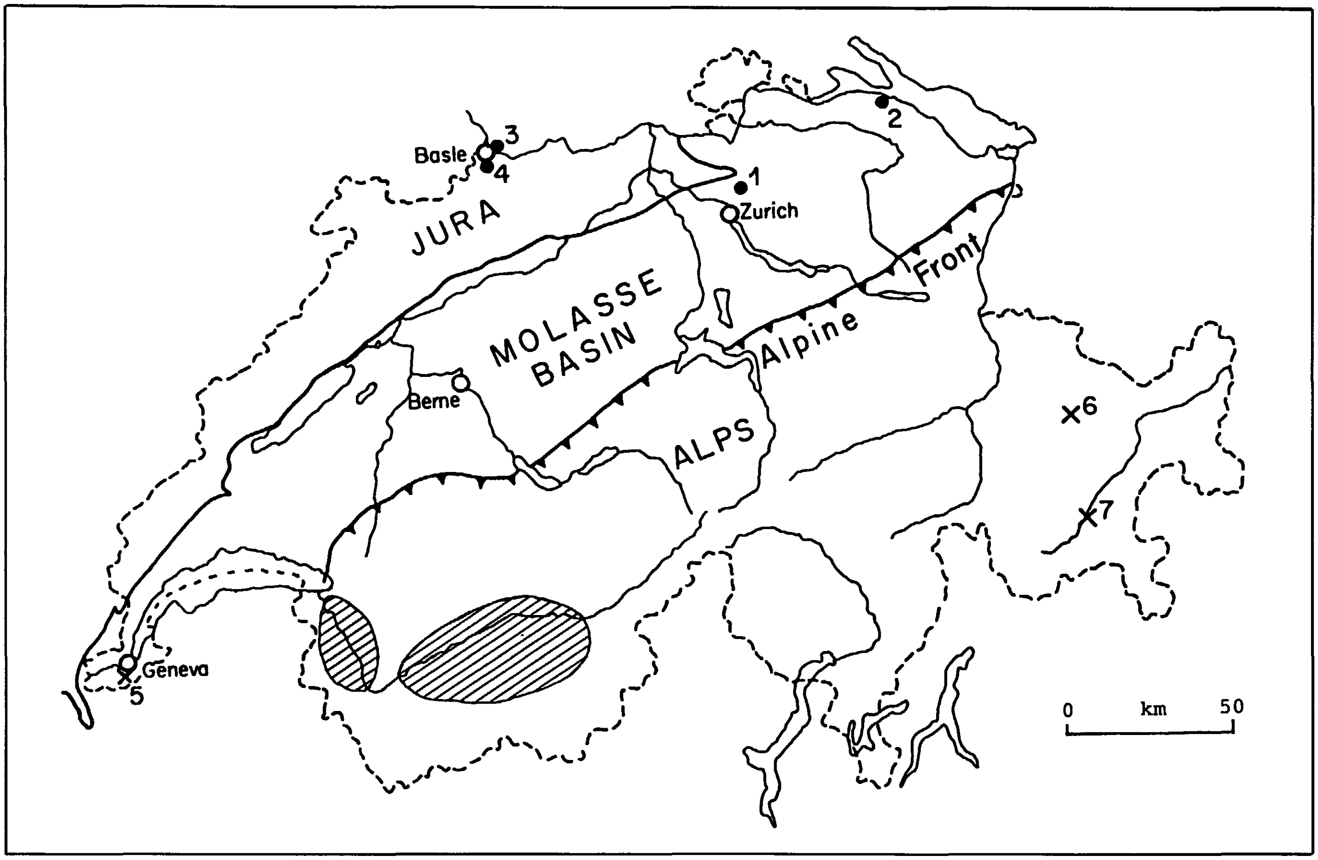

Figure 1. The three main geologic units of Switzerland: Jura, Molasse basin and Alps. The sites of low enthalpy geothermal utilization and (or) drilling since 1985 are shown by dots and numbers: 1 = Kloten, 2 = Kreuzlingen, 3 = Riehen, 4 = Reinach. Crosses mark projected drillsites: 5 = Geneva, 6 = Davos, 7 = St. Moritz. Hatched area: Exploration and resource assessment study "GEOTHERMOVAL" (see text).

> Does the heating system based upon the VHE, heat pump and underfloor heating offer an economically viable alternative, not only for the owners but particularly on the global economics scale?

The answers to these questions are sought by means of numerical model calculations. The models must be validated on the basis of field measurements. These are performed at instrumented, fully operating VHE systems, and include the temperature distribution in the ground, VHE inlet and outlet temperature, operational data of the heat pump along with the relevant meteorological data and inside room temperature.

The results show that during the heating season (October to May) the ground around the VHE cools down significantly in the first month of operation. Towards the end of the heating season, when the energy demand is reduced, the ground temperatures start to recover. The process continues during the summer until by the start of the next heating season a very small temperature deficit remains (it can even be compensated during a warmer winter). The radius of measurable thermal influence of the VHE is restricted to a radius of about 5 m (Rybach, 1987), with no resulting effects.

With a properly designed VHE (probe length/diameter, specific energy output in the order of 50 W/m, proper heat pump dimension) an average performance coefficient (heating energy/electrical energy) of 3.0 or better can be achieved over the whole heating season. Seasonal performance factors of this kind are essential in the overall energy economy of Switzerland (Hopkirk and others. 1988).

The performance of VHE systems can be expected, also on the long term, to be fully satisfactory. In specific cases (low thermal conductivity of the local earth materials, close neighbors) summer recharge of the VHE system by means of a simple solar collector can be applied (Hopkirk and others, 1985a).

THE GOVERNMENTAL SYSTEM OF RISK COVERAGE FOR GEOTHERMAL DRILLING

In March 1987 the Swiss government allocated 15 million Swiss francs for the coverage of drilling risks involved with geothermal development in the following 10 years, in order to promote geothermal energy in general and to help cover the financial consequences of a failure in particular (Rybach and others, 1988). By these means, public authorities and/or private promoters are encouraged to undertake risky drilling.

The risk lies in finding an aquifer with thermal power (proportional to yield x temperature, MW) below expectations. The risk coverage applies to projects with drilling depths greater than 400 m and amounts usually to 50 percent (exceptionally up to 80 percent) of the total drilling costs, including production as well as reinjection tests but excluding liability.

Applications for risk coverage are to be submitted in a prescribed format to the Swiss Federal Office of

Energy (BEW). The applications have to describe the local geological conditions, the drilling and testing program, to include a feasibility study, and to specify the conditions of success/failure. In particular, the numerical values of success (Q_s) and failure (Q_f) are defined in MW.

The cost distribution between applicant and the BEW is determined, prior to drilling, on the basis of the numerical values of the thermal power for success (Q_s) and failure (Q_f). By defining Q_{eff} as the thermal power effectively obtained by the geothermal drilling, the project is considered to be a success if $Q_{eff} \geq Q_s$, a partial success if $Q_f \leq Q_{eff} \leq Q_s$, and a failure if $Q_{eff} \geq Q_f$. In case of a success the BEW has no financial obligations.

The BEW covers only a certain portion (p) of the risk of geothermal drilling (up to 80 percent). The financial contribution of the BEW applies to a partial success as well; in this case a proportional amount will be paid to the applicant. Three coefficients are introduced to determine the cost distribution key:

$$\alpha = Q_f / Q_s$$
$$\beta = Q_{eff} / Q_s$$
$$\alpha \leq \beta \leq 1.0$$
$$\gamma = (1-\beta)/(1-\alpha)$$

In case of a partial success ($\beta \leq 1.0$) and with the BEW participation of p percent the following cost distribution results:

$p(1 - \beta)/(1 - \alpha)$% of the total sum is to be paid by the BEW

$100 - p(1 - \beta)/(1 - \alpha)$% of the total sum is to be paid by the applicant.

For example, suppose that the BEW has agreed to cover 60 percent of the total costs in the case of a complete failure of a particular drilling project (p = 60%). The numerical values of thermal power for success and failure have been fixed and give $\alpha = 0.5$. The drilling tests showed that only 65 percent of the expected thermal power can be maintained ($\beta = 0.65$). In this case, the governmental risk coverage amounts to:

$60(1 - 0.65)/(1 - 0.5) = 42\%$ of the total costs.

For the case of partial success, the financial risk coverage could improve the economy of a geothermal project to an extent that, after design adjustments to cope with less thermal power, the economical conditions would still be close to the initial ones. Thus, the project could be saved. To illustrate this, for $Q_{eff} = 0.5\ Q_s$ calculations indicate that specific heat costs would increase by only 10-15 percent with risk coverage, and by 35-45 percent without risk coverage.

The system of governmental risk coverage for geothermal drilling promises to be an effective and powerful instrument to promote geothermal development in Switzerland. Several projects are underway at present (see below); all aim at the production of warm water for space heating.

NEW DRILLING AND DEVELOPMENT

The governmental risk coverage gave impetus to numerous geothermal drilling and development projects in Switzerland. They will be described briefly below. The first one became operational before the establishment of the risk coverage scheme.

Kloten

At this locality, only a few kilometers north of Zurich, a far-sighted private enterprise installed a geothermal heating system for 130 apartments. The fluid is pumped at a rate of 10 l/s with a temperature of 20°C from a Miocene sandstone aquifer ("Obere Maeresmolasse") at 400 m depth. No reinjection is necessary thanks to the low salinity (0.91 g/l). The fluid passes a heat exchanger and feeds the cold (evaporator) side of a heat pump. The installation's operation since 1986 has been fully satisfactory.

Kreuzlingen

As in the Kloten installation, the drilling target here is also the basal sandstone complex of the Obere Meeresmolasse. The 655 m deep drillhole was completed in 1988. Water is pumped, after two stimulations with 10 percent and 20 percent HCl, at a rate of 4.5 l/s with a salinity of 0.87 g/l from the bottom 200 m of the hole with a temperature of 30°C. Long-term pumping tests with observation of the hydraulic potentials in existing wells surrounding the production well at various distances are still underway. The tests, along with geochemical and isotopic analyses and thermo-hydraulic modelling, shall help to clarify the origin of the produced fluid, provide information about the hydraulic system of the area, and assist in reservoir management.

Riehen

The Basel region in northwest Switzerland extends into the Rhinegraben, a regional rift valley underlain by a relatively thin crust and lithophere and consequently characterized by a comparatively high geothermal gradient. In view of this geothermal potential, the Canton of Basel-Stadt, jointly with the Community of Riehen, decided to explore the possibility of its practical exploitation for a heating system by deep drilling. From the very beginning a two-well program for a doublet has been set up, due to the fact that the Rhinegraben shows highly mineralized thermal waters which need to be reinjected for environmental reasons.

In 1988 the two wells were drilled. Riehen-1 reached the upper part of middle Triassic fracturated limestones and dolomites (= Upper Muschelkalk), which proved to be an aquifer, at a depth of 1444-1547 m, whereas Riehen-2, 1 km north of it, drilled through the same aquifer from 1123 to 1223 m (for the geology, see Gurler and others, 1987 and Hauber, 1989; for technical data see Hauber and others, 1989).

In well #1 a longtime test was carried out from 30 Oct. to 21 Nov. 1988. Continuous production of 20 l/s of water at 64.7°C was obtained. During this test the water level in well #2 was lowered by about 45 m, which indicates a hydraulic connection between the two wells. In both wells water is under artisan pressure, is highly mineralized (18.3 g/l dissolved matter in Riehen-1, 14.2 g/l in Riehen-2, according to preliminary chemical analysis), and contains carbon dioxide as well as hydrogen sulfide.

A long-duration test in well #2 also yielded a good 24 l/s after application of diluted hydrochloric acid. Temperature was somewhat lower ([illegible]), corresponding to the shallower depth of the aquifer.

In 1989 a short-time reinjection test was run with a positive result. A long-time test should follow within a short period of time.

The whole operation of the pilot project has so far been highly successful. Two problems, however, still remain to be solved; Gas content and mineralization require an analysis of p-T dependence in order to define conditions for doublet operation. Corresponding efforts are planned for 1990.

Reinach

In 1989 another well was drilled a mere 10 km south of Riehen, in a comparable geological situation at the border of the Rhinegraben, aimed again at the Upper Muschelkalk as aquifer, which was met at 1697 -1770 m. Bottomhole temperature was 72°C, corresponding to an average gradient of 35°C/km. Unfortunately, the Upper Muschelkalk proved rather tight: even after application of acid and hydrofrac the yield could not be made to exceed 5 l/min, and the well is to be considered a failure.

The question arises as to the cause of the widely different results in these rather closely spaced and closely related cases. An answer will only be forthcoming after close analysis of the nature of the possible porous/fractured systems providing flow paths. The main possibilities at present seem to be (1) open fissures connected with the tectonics of the border of the Rhinegraben, and (2) karst systems, which in view of the present lack of circulation at depth would have to be fossil (paleokarst), or (3) a combination of (1) and (2).

Besides these geothermal drillings already performed, three further projects are at an advanced stage. One of them is in Geneva, the target being Jurassic and Cretaceous aquifers, the other two are in the Alpine area of Switzerland. The effort to keep the air locally clean at the well-established tourist resorts of Davos and St. Moritz was the basic incentive for these projects. Highly complicated tectonic and hydrogeologic conditions are expected to prevail at both localities. Data about the subsurface temperature and permeability distribution is very limited. The exploration program included structural geology and reflection seismics. Fractured Triassic limestones/dolomites are the drilling targets in Davos and St. Moritz.

EFFORTS IN HOT DRY ROCK (HDR)

Although Switzerland has no field facilities for HDR research there are substantial modelling efforts to contribute internationally to this fascinating research field (MAGES, 1979; Hopkirk and others, 1985b). The aim of these studies is to understand the long-term behavior of HDR systems, especially the processes linked with prolonged heat extraction and fluid circulation. The numerical modelling (2-D and 3-D) utilizes finite difference as well as finite element schemes to treat coupled thermo-hydraulic processes in a fractured medium. As a new element, aspects of rock mechanics are now integrated (shear displacements, dependence of fracture width on the changing stress distribution in the HDR system). The modelling is carried out on data from the field projects in Cornwall, UK and Soultz, F (Hopkirk and Rybach, 1989).

CONCLUSIONS, PROSPECTS

The growing interest in geothermal energy utilization in Switzerland is mainly the result of increasing environment concern. The use of an indigenous energy source is also motivation, in view of the high degree of dependence on imported fuel for space heating. In spite of the currently low oil price there are far-sighted decision makers who accept the challenge of developing a domestic, environmentally favorable, alternative energy source in Switzerland.

Whereas regional exploration and resources assessment are more or less completed, the emphasis is now on drilling and development. On one hand, the installation of small, individual VHE systems exhibits a rapidly growing trend. On the other hand, the governmental risk guarantee will certainly stimulate further development (in addition to those described above) in the years to come. Finally, further efforts in HDR research might lead to the establishment of a Swiss field facility, preferably in the Alps where strong uplift/erosion causes elevated subsurface temperatures. The research funding atmosphere is favorable at present.

In short, Switzerland will do its share in geothermal research and development.

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TABLE 1 - PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

		Geothermal		Fossil Fuels		Hydroelectric		Nuclear	
		Capacity MW_e	Utilization GWh/yr	Capacity MW_e	Utilization GWh/yr	Capacity MW_e	Utilization GWh/yr	Capacity MW_e	Utilization GWh/yr
In operation	January 1990	-	-	200	1'100	11'500	30'000	3'000	21'500
Under construction	January 1990								
Funds committed, but not yet under construction	January 1990								
Total projected use	by 1995								

TABLE 2B - UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT -- DECEMBER 1989

*Type of Use

I = Industrial process heat	D = District heating
C = Airconditioning	B = Bathing and swimming
A = Agricultural drying	G = Greenhouses
F = Fish and other animal farming	O = Other (please specify by footnote)

**Enthalpy information should be given only if there is steam or two-phase flow.

Locality (Footnote for comments)	Type*	Maxiumum Utilization						Average Annual Utilization				
		Flow Rate kg/s	Temperature °C		Enthalpy** kJ/kg		Flow Rate kg/s	Temperature °C		Enthalpy** kJ/kg	
			Inlet	Outlet	Inlet	Outlet		Inlet	Outlet	Inlet	Outlet
Kloten (with heat pump)	D						10	20	9		

TABLE 3 - INFORMATION ABOUT GEOTHERMAL LOCALITIES

Rock[1] = Main type of reservoir rock.

Water[2] = Total dissolved solids, in mg/kg, before flashing. Put v for vapor dominated.

Status[3]
- N = Identified geothermal locality, but no assessment information available
- R = Regional assessment
- P = Pre-feasability studies
- F = Feasability studies (reservoir evaluation and engineering studies)
- U = Commercial utilization

Locality	Location To Nearest 0.5 Degree		Reservoir		Status[3] in January 1990	Reservoir Temp. °C	
	Latitude	Longitude	Rock[1]	Water[2]		Estimated	Measured
Collonge-St. Maurice } GEOTHERMOVAL	46.0 N	7.0 E	fractured crystalline	ca. 2'000	R	100	
Brigerbad-Simplon } GEOTHERMOVAL	46.0 N	8.0 E					

TABLE 5 - WELLS DRILLED FOR DIRECT HEAT UTILIZATION OF GEOTHERMAL RESOURCES FROM JANUARY 1, 1985 TO JANUARY 1, 1990
(Do not include thermal gradient wells less than 100 m deep)

*Type or purpose of well and manner of production
(Use one symbol from column (1) and one from column (2)

(1) T = Thermal gradient or other scientific purpose
E = Exploration
P = Production
I = Injection
C = Combined electrical and direct use

(2) A = Artesian
P = Pumped
F = Flashing

**For wellhead temperatures less than 100°C, multiply the temperature in °C by 4.1868 to obtain the enthalpy.

Locality (Footnote for comments)	Year Drilled	Well Number	Type of* Well (1)	(2)	Total Depth (meters)	Maximum Temp. °C	Flowing Enthalpy** kJ/kg	Flow Rate kg/s
Kloten	1986	1	P	P	400	20	84	10
Kreuzlingen	1988	1	P	P	655	30	126	5
Riehen-1	1988	1	P	P	1550	65	260	20
Riehen-2	1988	1	I	P	1250	51	214	(20)
Reinach	1989	1	P	-	1800	-	-	-

TABLE 6 - ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES
(Restricted To Personnel With A University Degree)

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Aid Programs
(6) Private Industry

Year	(Professional Man Years of Effort)					
	(1)	(2)	(3)	(4)	(5)	(6)
1985	1		2			2
1986	1		1			2
1987	1		1			2
1988	2		1			2
1989	2		2			2