GEOTHERMAL RESEARCH AND DEVELOPMENT IN SWITZERLAND: ACHIEVEMENTS AND PROSPECTS

Ladislaus RYBACH

Institute of Geophysics ETH Zurich, Switzerland

Harald L. GORHAN

Elektrowatt Engineering Zurich, Switzerland

ABSTRACT

In Switzerland the R & D efforts in the past years led to significant achievements in direct uses of geothermal energy: areal density of borehole heat exchanger systems for decentral space heating is highest worldwide; novel solutions like combined heat extraction/storage, energy piles, tunnel water use are supported by govermental aid. The risk guarantee system for aquifer drilling >400m which terminates in 1997 led to some success (e.g. the first doublet system in Riehen/BS which will be extended into Germany) but also to a number of failures. After summarizing the present status of utilizing the indigenous resources the Swiss activities on the international geothermal scene are highlighted, including the banking of development projects for electricity generation.

INTRODUCTION

Switzerland is a small country (41'000 km^2, 7 million population) with a remarkably low reliance on fossil fuels for electricity generation (about 60 % hydro, 40 % nuclear). There is no geothermal-based electricity. Most primary energy carriers for heating and transportation must be imported. In this situation the Federal Government initiated significant steps in the energy policy development towards the utilisation of indigenous and environmentally benign forms of energy: i) acceptance of an energy law (popular vote, 23 September 1990), ii) initiation of the action plan ENERGY 2000 (on 14 December 1990; details see below), and iii) issuing of the energy utilisation decree (enacted on 22 January 1992) to encourage, by financial support mechanisms, the development of new solutions. In this context a govenmental risk coverage system for deep (>400m) geothermal drilling must be mentioned (for details see Rybach and Gorhan, 1995) which will terminate in 1997.

A brief summary of geothermal direct use in Switzerland is given below. First, the role of geothermal energy utilisation is positioned within the global and the Swiss energy scene. Thereafter, near-surface thermal water occurrences are treated, followed by deep, stratiform aquifers. Then some of the unique experience with the numerous borehole heat exchangers is highlighted (including some specific applications) and some prospects of tunnel waters are outlined, followed by a summary of Hot Dry Rock activities. Finally the Swiss activities on the international geothermal scene are summarized and an outlook at further domestic developments is presented.

GEOTHERMAL UTILISATION IN THE GLOBAL AND THE SWISS ENERGY SCENE

The achievements of Switzerland in the direct use of geothermal energy are remarkable: with an installed capacity of about 20 W_{th} per capita it ranks number 6 worldwide behind 1) Iceland, 2) New Zealand, 3) Hungary, 4) Macedonia, 5) Slovakia (ranking based on the numbers published by Fridleifsson, 1996).

On the national scene the utilisation is embedded in the above-mentioned action plan EN2000. This ten year program aims, for the year 2000, at

- stabilising CO_2 emmissions at the 1990 level
- additional production of 3'000 GWh heat from renewable sources (3 % of total heat demand)
- additional 300 GWh electricity production from renewable sources (0.5 % of total production)
- efficiency improvement of hydropowar; power uprate (10 %) of nuclear power plants as well as saving and rational use of energy.

In 1995, at mid-way, the EN2000 goals were generally fulfilled to 50 %. Table 1 shows the role of geothermal production in comparison with other sources; Table 2 presents the breakdown of different geothermal sources. It is anticipated that the geothermal production can be incerased to about 350 GWh in 2000.

Table 1 Heat production from different sources in 1995

Source	Production (GWh)
Biomass e.g. wood)	5'120
Environment (e.g. air)	580
Geothermal	265
Solar	180
total	6'145

Table 2 Contributions of different geothermal sources to heat production in 1995

System	Production (GWh)
Foundation piles	1.0
Borehole heat exchangers	240.0
Thermal springs	6.0
Deep aquifers	8.0
Tunnel waters	10.0
total	265.0

THERMAL SPRINGS, NEAR-SURFACE THERMAL WATERS

The occurrence of thermal springs and near-surface thermal waters is strongly corrrelated with the main geologic-tectonic units of Switzerland. These are, from north to south (cf. Fig. 1): the Jura (mainly relatively compact Mesozoic limestones and dolomites arranged in rather simple folded and faulted structures), The Molasse basin (a flat-lying Tertiary sandstone/marl/conglomerate sequence with increasing southeatsward thickness where, near the Alps it is uptilted, "subalpine"), and the Alps (a complicated nappe structure consisting of sedimentary and metamorphic units like the Helvetics and Penninics and of Central Massifs). In the Jura and Alps fracture zones and fractured strata can accomodate thermal springs/near-surface thermal waters while these are absent in the Molasse basin, mainly due to generally low vertical permeability.

The environs of long-known thermal spring occurrences were targets of modern prospecting (including exploration/production drilling). A number of sites like Zurzach, Lavey-les-Bains, Lostorf, Schinznach) benefited from the general interest created by the oil crisis in 1973. Subsequently the thermal power output was increased and most Swiss spa localities take now advantage of the cascaded use of the geothermal fluid. While the primary purpose remains the balneology itself, space heating in the bathing facilities and of nearby buildings like hospitals is established. Heat exchangers and heat pumps are essential components of the utilisations schemes. At Schinznach, cascade use with greenhouses as end user is in construction. Fig. 1 shows the location of spa facilities, along with sites of deep aquifer utilisation (singlet, doublet; see below).

DEEP AQUIFERS

The success of large-scale geothermal heating systems in France led to exporation and drilling activities also in Switzerland. Both the doublet and singlet concept has been followed, encouraged by a Government Risk Guarantee (a total of 15 Msfr to cover activities from 1987 to 1997; Rybach and Gorhan, 1995). In the eighties, several drilling projects were successful (Kloten/ZH, Kreuzlingen/TG, Riehen 1&2/BS). In fact, the first Swiss doublet system is operational in Riehen since 1994 (geothermal capacity 4.7 MW_{th}, total heating power 15.2 MW_{th}), the district heating network will be extended to the neighboring community Lörrach in Germany, thus providing the first example of a trans-boundary geothermal utilisation.

Unfortunately the activities in the nineties were less successful (failure at St. Moritz/GR, Bulle/FR, Thonex/GE, Weissbad/AI („dry holes"); success at Bassersdorf/ZH and Schinznach/AG); The mixed balance of these drilling endeavours directed interest to other options for using geothermal heat: borehole heat exchangers and tunnel waters; in addition, at some of the "failure" localities the establishment of a deep borehole heat exchanger is planned (see below).

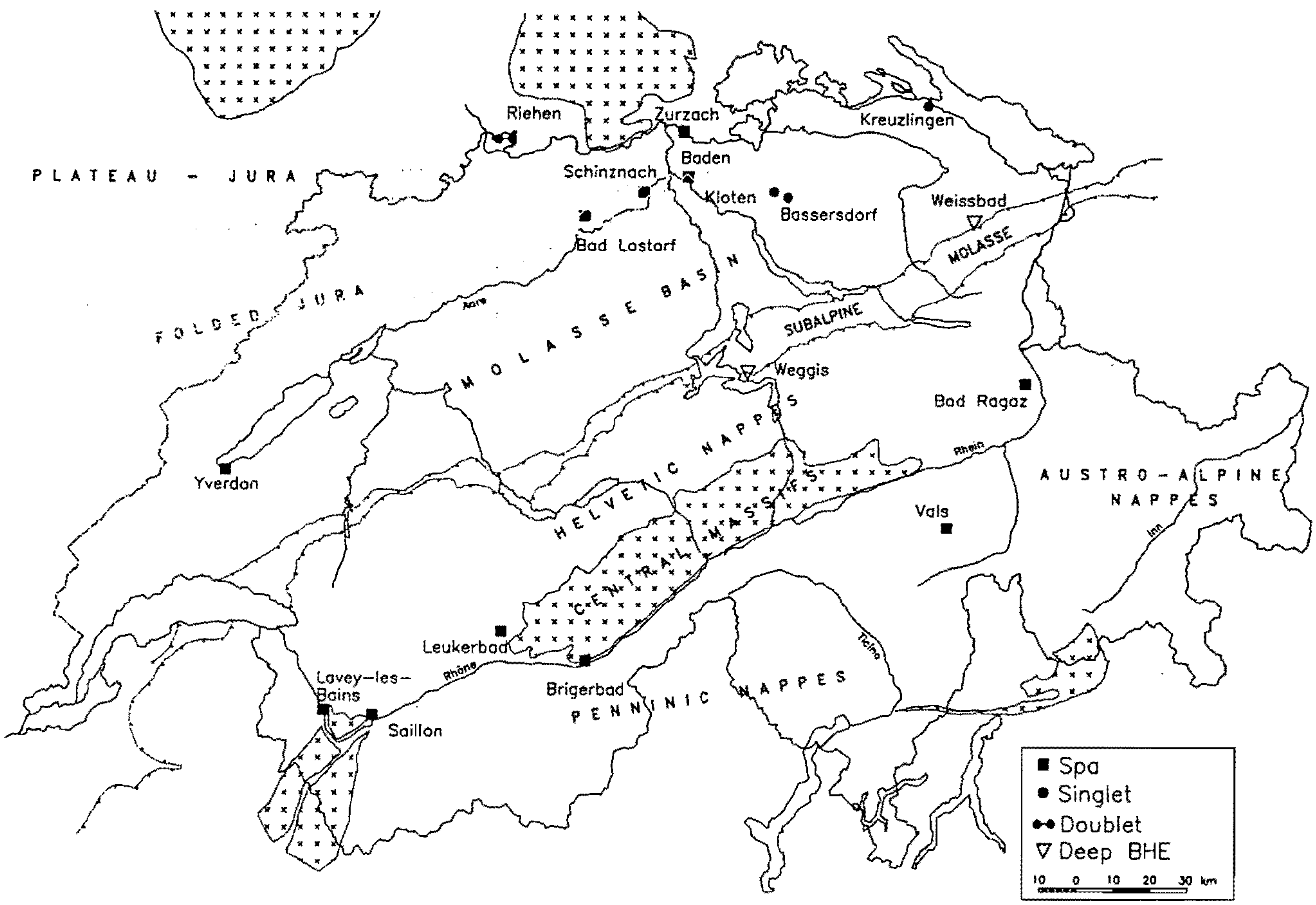
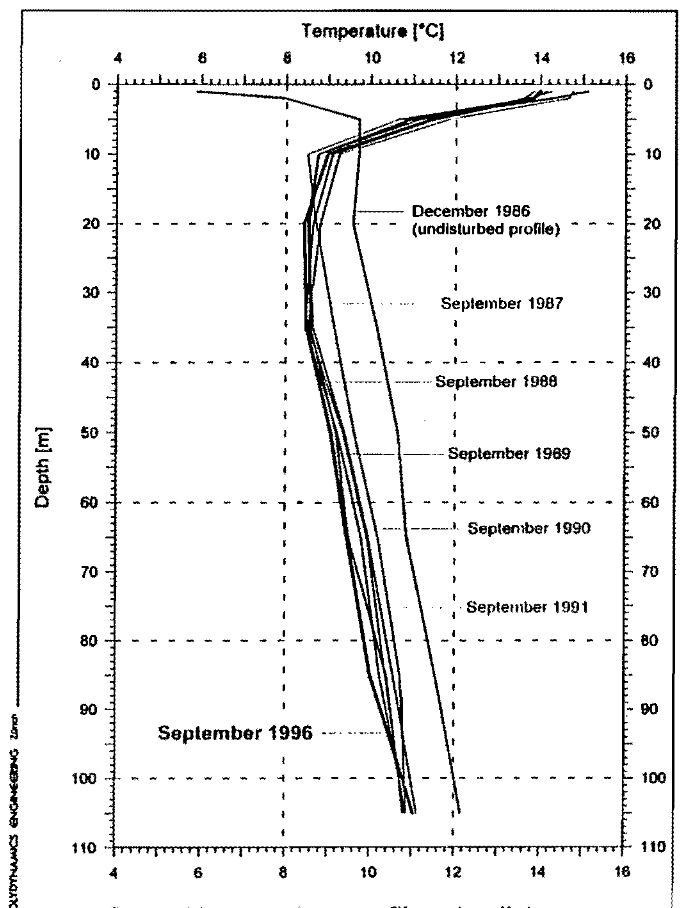


Fig. 1 Sites of geothermal direct use in Switzerland (thermal water production and deep borehole heat exchangers; for shallow BHE's see Fig. 3)

SHALLOW AND DEEP BOREHOLE HEAT EXCHANGERS (BHE)

BHE's are ideal to make use of shallow geothermal resources. The most popular BHE heating system with one or more boreholes typically 50 - 150m deep is a decentral, closed-circuit, heat pump-coupled system, ideally suited to supply heat to smaller objects like single family or multi-family dwellings. The heat exchangers (mostly as double U-tube plastic pipes) can be installed in nearly all kinds of geologic media (except in materials with low thermal conductivity like dry gravel). These systems operate by conduction, i.e. there are no formation fluids produced. Experimental and theoretical invesitigations prove that BHE systems, if properly designed, operate reliably also on the long term without negative environmental effects (Rybach and Hopkirk, 1995). In fact, a new thermal equilibrium is reached in the ground around the BHE after a few years of operation (Fig. 2). To date, over 10'000 such systems are installed, with a total of 1'500 km BHE length; areal density (number of BHE's per country area) in Switzerland is highest worldwide. Fig. 3 shows the areal distribution of shallow BHE installations, delivered by a single company (GRUNDAG, Gossau/SG: 7'500 BHE's with 643 km total length; status in mid 1996).

Deep BHE's can be installed in abandoned drillholes, provided that consumers are nearby. Due to the considerably higher hydrostatic and ground pressures this will require special construction, including materials like thermally isolated tubes and adequate heat extraction strategies. A deep BHE system can provide several hundrers of kW_{th} heating capacity. A first succes has been achieved with the 2.3 km deep BHE at Weggis/LU (a „dry" geothermal borehole; Rybach and Hopkirk, 1995). Another deep BHE is in test operation in Weissbad/AI where a 1.6 km drillhole failed to find formation water in Molasse rocks.



Ground temperature profiles at a distance of 1.0 m from the BHE in Elgg (ZH)

Fig. 2 Ground temperature profiles at 1 m distance from a BHE, before the heating season's start, over 10 years. New thermal equilibrium is approached, at somewhat lower temperatures.

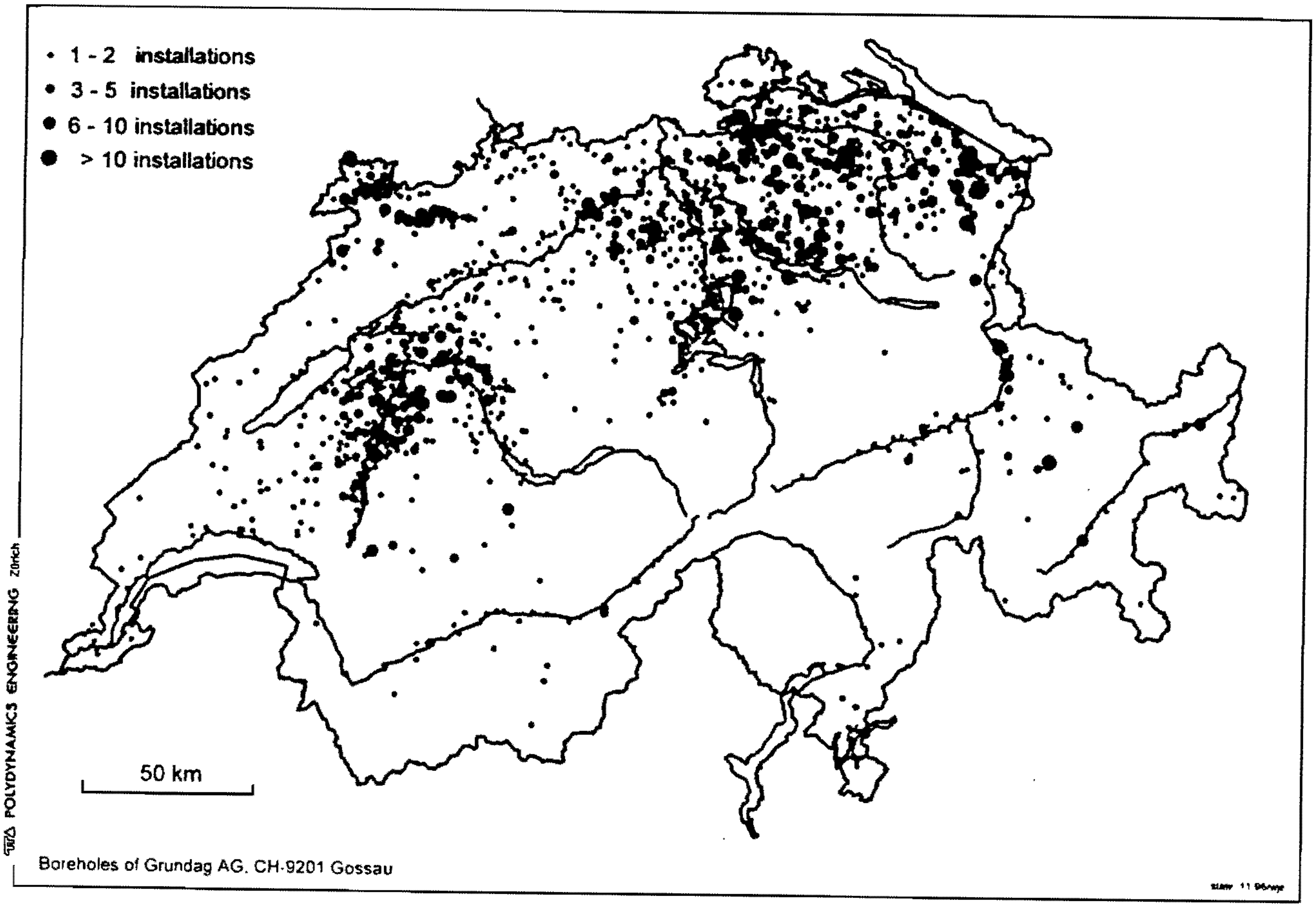


Fig. 3 Distribution of shallow BHE installations in Switzerland (of GRUNDAG company only; status in mid 1996). Distribution corresponds roughly to population density.

SPECIAL BHE APPLICATIONS

This rapidly growing field of research and development can only briefly be summarised here, merely by mentioning the main topics:

- Multiple BHE's: There is a tendency increase the size of geothermal installations by using a multitude of BHE's. Here, extensive studies are being carried out to determine optimum depths and borehole spacings in order to guarantee an economic life span. As an example, the BHE field with 40 150m deep BHE's at the Scuol/GR spa can be mentioned.
- Combined heat extraction/storage: multiple BHE's can also be used to acess a ground storage volume for seasonal storage of waste heat from large buildings or with solar energy (solar collectors, flat building roofs, surfaces of streets or parking areas). In this respect, a well-balanced management of the subsurface stock, taking into account local factors, is essential. The stock (up to several 100'000 m^3) can be installed directly beneath the building compexes; its use for heating in winter and cooling in summer is technically feasible. Several such installations work satisfactorily (Meister jewelery factory Wollerau/SZ with 32 135m deep BHE's, the road bridge de-iceing system SERSO at Därligen/BE with 91 65m deep BHE's, no heat pump).
- Energy (foundation) piles: Piles up to tens of m length are often driven into problematic ground to increase foundation stability. The idea is to equip these piles with heat exchangers. In this context, the influence of load bearing capacity of the temperature reduction around the piles and the effect of cyclic heat extraction over the years need to be carefully addressed. Two installations in Kreuzlingen/TG (Fotocolor: total pile length 1'023m) and Finkernweg (4'200m) can serve here as examples.

- Major airports frequently need piling for sound foundation of runways. By means of energy piles the extracted heat can be used for de-iceing of runways and aircraft parking lots (thus elimininating the use of salt or toxic substances) as well as for heating airport buildings during the winter (or for cooling puproses during the summer). Exactly such a combined utilisation is foreseen for the extension of the airport Zurich-Kloten (Project "Midfield"). Based on this type of Swiss experience, similar plannings are underway for the extension of a runway at the Vienna airport Schwechat, Austria.

TUNNEL WATERS

Being a typical Alpine country, Switzerland has many deep road and railway tunnels. Several deep tunnels crosscut considerable sections of Switzerland in the Jura and the Alps which drain, especially in permeable fracture zones, considerable amounts of warm water. Two tunnels of considerable length and cover are planned for the near future (Gotthard and Lötschberg base tunnels, NEAT project). The warm waters encountered during tunneling can be directed, instead to disposal, to the tunnel portals e.g. for space heating, provided that consumeras are nearby. In fact, this is already done at several sites including a small alpine village which uses water flowing out of the Furka rail tunnel by applying decentralized heat pumps (Rybach and Wilhelm, 1995). Several feasibility studies are presently underway to assess the geothermal potential of the existing and planned tunnels all over Switzerland.

HOT DRY ROCK (HDR), DEEP HEAT MINING (DHM)

Switzerland is actively participating since several years in the European HDR Pilot Project in Soultz/F. The primary goal of the Swiss contribution is a quantitative understanding of the relevant physical processes which may influence the long-term production behavior of HDR reservoirs. In particular, the hydraulic, thermal and rock mechanic processes and their coupling must be addressed. To this end, a mathematical simulation software tool FRACTure (Kohl 1992) is used to evaluate and interpret field test data. Fig. 4 shows a nearly perfect fit between measured and numerically modelled data from flow tests; the results indicate non-Darcyan, non-laminar flow in the and far field of the boreholes (for detailed description see Kohl et al., 1997). These activities are supported by the Swiss Federal Office of Science and Education.

The Swiss Federal Office of Energy has initiated in 1996 a new project, called „Deep Heat Mining". This project aims at the realisation of a first pilot plant in Switzerland, between the years 2005 and 2010, to produce electricity and/or heat by the HRD technology. The current activities of a special team, assembling private companies as well as university institutes, extend over general site evaluation, feasibility studies, public relations and financing considerations; Fig. 5 displays the timetable of the planned actions. It is intended to incorporate some of these activities in an Annex of the new Geothermal Implementing Agreement of IEA.

INTERNATIONAL ACTIVITIES

Swiss scientists are regularly active on the international geothermal R&D scene. The synoptic interpretation of KTB observables (German Continental Deep Drilling Project) must be mentioned here, along with the POLYPROPJECT MARMARA, an interdisciplinary approach to unveil the complex interplay of active tectonics, hydrogeology, geothermics and seismology in W. Turkey. Regardless of its non-member status, Switzerland participates in EU projects like the European Geothermal Atlas and the European HDR Pilot Project in Soultz (see above).

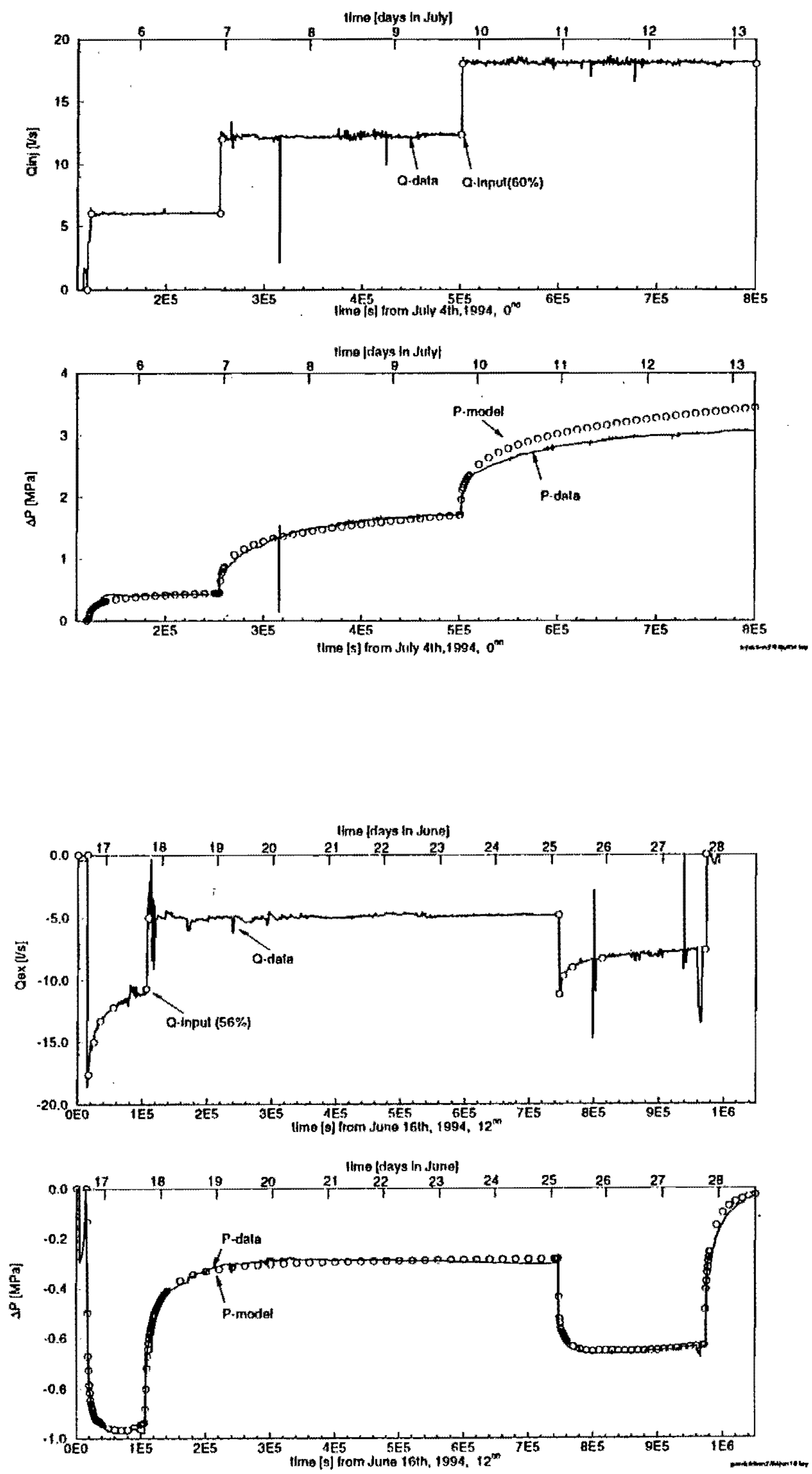


Fig. 4 Measured and modelled test data of the European HDR Pilot Project Soultz/F. Top: injection test 94JUL04; measured flow history and main points of the applied flow-time function (open circles; upper part of the diagram); pressure response (lower diagram). Bottom of figure: production test 94JUN16 (same data plotted as in upper diagram). Δp: difference between measured downhole pressure and natural formation pressure.

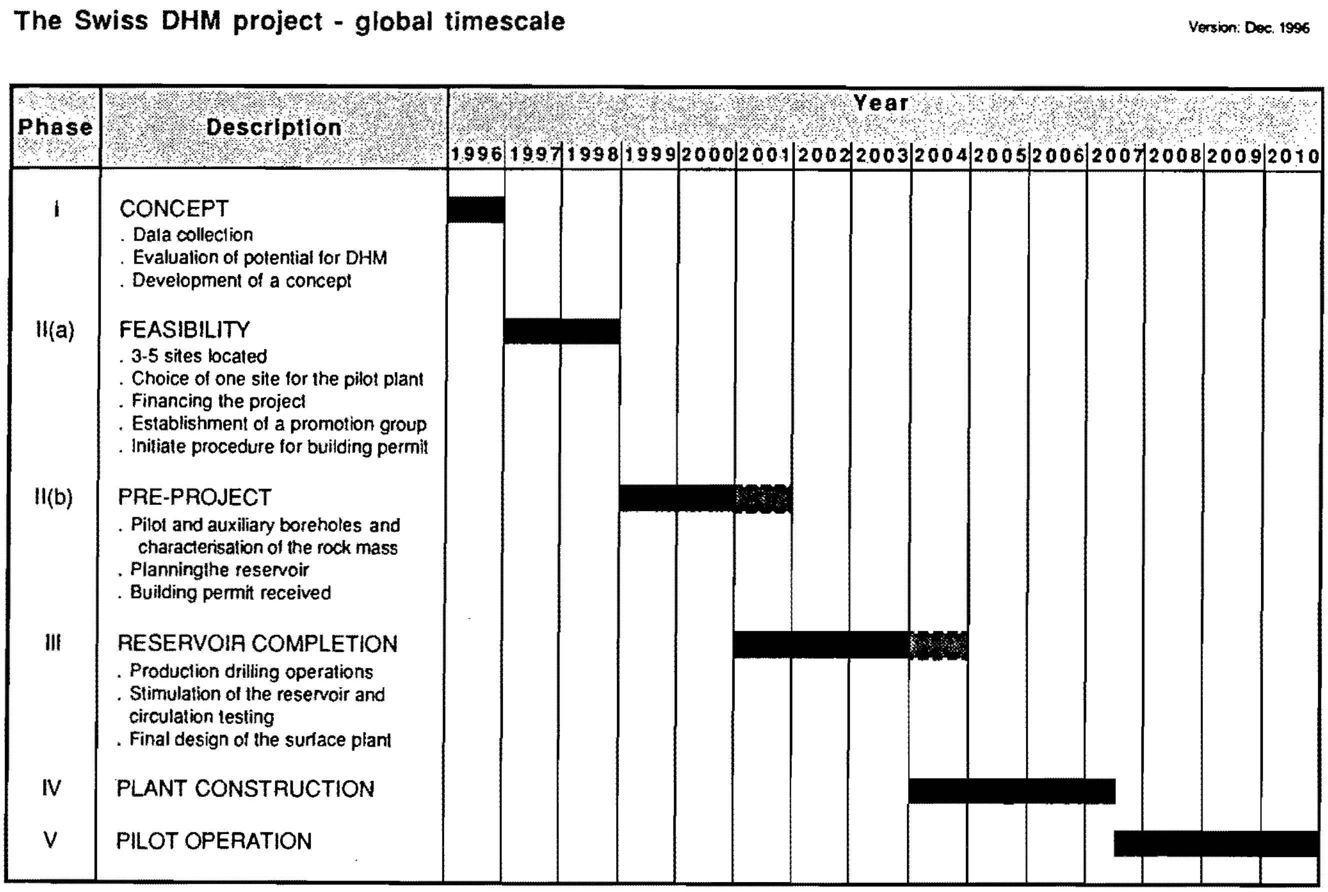


Fig. 5. Timing and plannned activities of the Swiss Deep Heat Mining Project.

According to old tradition, large Swiss companies and banks are internationally active. The lack of indigeous high-enthalpy fields is counterbalanced by the development of this resource type abroad under Swiss control. CALPINE, the second largest producer of geothermal electricity in the USA, is a wholly-owned subsidy of Elektrowatt AG (Zurich). Swiss banks like Union Bank of Switzerland (UBS) or Credit Suisse (CS) are active in project financing in USA and Philippines since 1990 (Table 3 lists current CS activities). Also the involvement of the first author in the International Postgraduate Schools in Geothermics (in Pisa/I, Rejkjavik/IS and Auckland/NZ) is worth to be mentioned.

Table 3 Geothermal project financing by Credit Suisse

Locality	State/Country	Year	MW_e
Puna	Hawaii/USA	1990	25
Salton Sea	California/USA	1994	80
Upper Mahaio	Leyte/Philippines	1994	119
Malitbog	Leyte/Philippines	1994	216
Mahangdong	Leyte/Philippines	1994	180
Dieng I	Java/Indonesia	1996	60

OUTLOOK

New frontiers are already visible: novel techniques and solutions in BHE applications (alternative options like the GEOHIL system with half-open circulation, multiple BHE's, combined heat extraction/storage, energy piles, deep BHE's); utilisation of tunnel waters; further pursuing HDR/DHM work. Concerted PR actions on the private, cantonal and community level are also in planning. The Swiss geothermal activities are favourably supported by Federal Offices (for Energy, for Science and Education) and popularized by the „Schweizerische Vereinigung für Geothermie" (SVG), with presently over 300 members. The present support of the Swiss Federal Office of Energy amounts to a total of 2.1 Msfr per year (about 5 % of its total EN2000 R&D budget). Switzerland intends to continue its involvement in international geothermal cooperation like the IEA Geothermal Implementing Agreement.

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