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Properties of geothermal fluids in Switzerland: A new interactive database

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Abstract

A database on geothermal fluids in Switzerland, called BDFGeotherm, has been compiled. It consists of nine related tables with fields describing the geographical, geological, hydrogeological and geothermal conditions of each sampling location. In all, 203 springs and boreholes from 82 geothermal sites in Switzerland and neighboring regions are listed in this new interactive Microsoft Access database. BDFGeotherm is a functional tool for various phases of a geothermal project such as exploration, production or fluid reinjection. Many types of queries can be run, using any fields from the database, and the results can be put into tables and printed or exported and saved in other files. In addition to describing the database structure, this paper also gives a summary of the reservoir formations, the geographical distribution of hydraulic parameters, the geochemical types of thermal waters and the potential geothermal resources associated with the sites.

Keywords: Geothermal potential; Switzerland; Geothermal fluids; Geochemistry; Thermal springs; Deep boreholes; Database; MS Access; BDFGeotherm

1. Introduction

Many data are available on geothermal fluids in Switzerland. They were obtained from deep boreholes drilled for geological evaluations, oil exploration, geothermal prospecting, thermal spas, thermal springs and fluid outflows from tunnel-drainage systems. These data are contained

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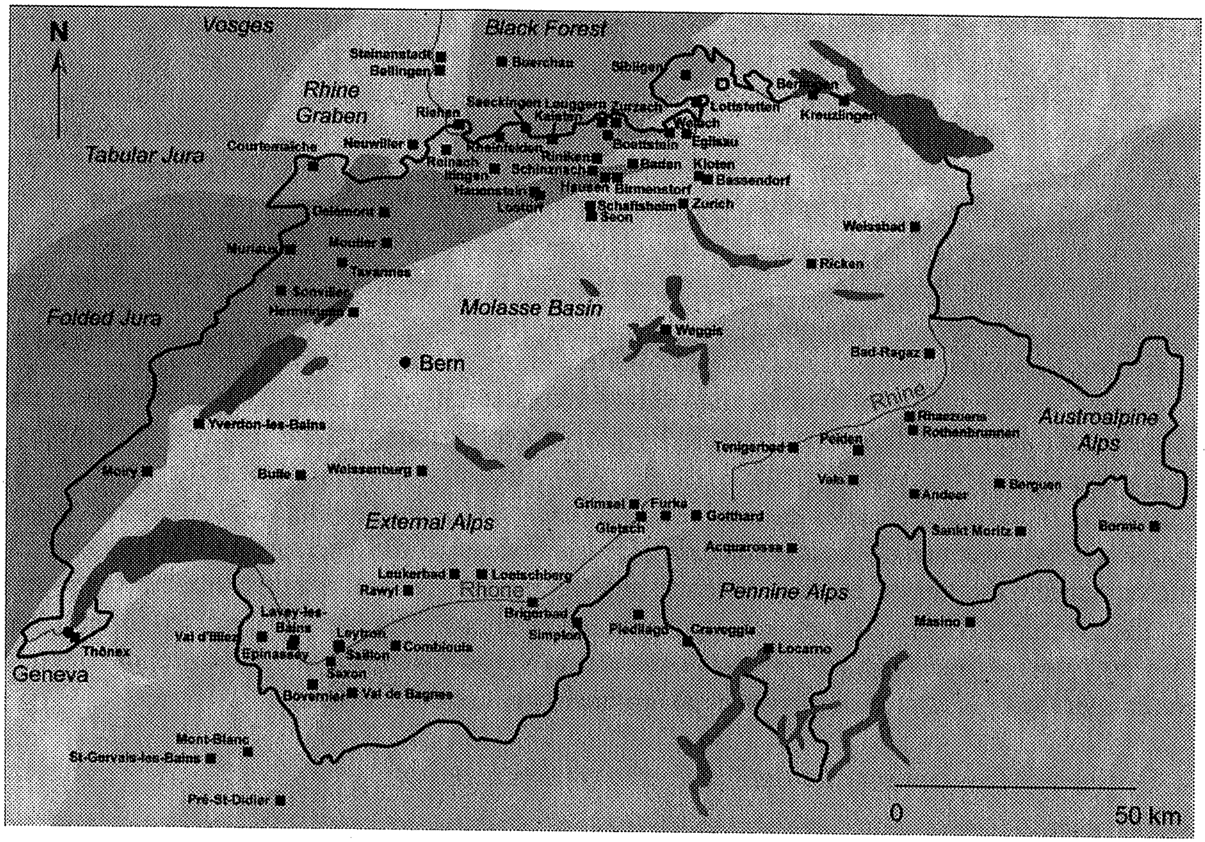

Fig. 1. Locations of geothermal sites included in BDFGeotherm. The shaded areas correspond to the main tectonic units of Switzerland.

in a variety of reports and papers, often not published and not easily accessible to potential users of the information (Sonney and Vuataz, 2007).

The objective of this work was to gather the maximum amount of data on deep fluids and to integrate them in a relational database. This database can be useful to all geothermal projects dealing with the exploration, production, and injection of geothermal fluids. The projects may involve permeable geological reservoirs or may be based on the technology of enhanced geothermal systems (EGS). The tool may also be used to estimate and forecast the chemical composition of geothermal fluids. The database is also of interest for studies related to the risks of mineral deposition or corrosion in boreholes and in surface installations, and also for studies on interactions between rocks and thermal waters.

Geographically, all Switzerland is covered, although the distribution of data is quite heterogeneous (Fig. 1). Additional sites outside the country were selected because they are located near the border, have hot springs, deep boreholes or geological features similar to those in Switzerland and are of geothermal interest. Geologically, each formation presenting groundwater aquifers, from the crystalline basement to Tertiary sediments, was taken into account. Moreover, all thermal and sub-thermal springs with a temperature greater than or equal to 15 °C, or between 10 and 15 °C if the mass production is high, were included in this database.

The selected parameters concern the following fields: geography, geology, hydrogeology, hydraulics, hydrochemistry and geothermal parameters. The interactive and multiparameter BDF-Geotherm database was built using Microsoft Access.

2. Geographical description of sites

In Switzerland, geothermal direct use in 2006 is estimated to have reached an installed capacity of about 650 MW_{th}, with 5500 TJ/year of heat production, mostly in installations coupled to geothermal heat pumps (GHP). This corresponds to an annual saving of 130,000 tons of fossil fuel, and reduces the emission of CO_2 by about 400,000 tons per year (Rybach and Minder, 2007). There is also some use of deep aquifers and hot spring resources, respectively in small district heating networks and for the heating of several spas. So far there is no electricity generation using geothermal fluids in Switzerland.

In total, 82 geothermal sites, and 203 springs and boreholes are documented in BDFGeotherm. Their location on the Swiss tectonic map shows a concentration of sites in the northeastern part of the Jura range, which is characterized by a high geothermal gradient and a significant heat flow anomaly (>150 mW/m^2) (Rybach et al., 1987), and to a lesser extent in the upper Rhone valley (Fig. 1). The Alpine sites are primarily thermal springs, discharging from deep vertical flow systems in the presence of vertical fractures. On the Plateau (Molasse Basin), extending NE–SW and containing the largest lakes of Switzerland, the number of sites is much smaller because of the thick Tertiary Molasse cover. Finally, a number of sites in Germany (5), France (3) and Italy (6) were selected either because they are located near Swiss hot springs or deep boreholes, exhibit similar geological features or represent a significant geothermal potential.

3. Geological description of potential geothermal reservoirs

This section, based on the publication by Trümpy (1980), summarizes the geological description of potential geothermal reservoirs. Geologically, Switzerland can be divided into three parts: 12.5% of its surface lies in the Jura, 30.5% in the Molasse Basin and 57% in the External and Pennine Alps (Fig. 1). The term 'External Alps' refers to a pre-Triassic basement complex, affected by the Variscan (Hercynian) and older orogenies, with Triassic to Lower Oligocene sediments that were deformed only by the Alpine movements (middle-Cretaceous to Pliocene). The Pennine Alps consists of a nappe series with recumbent folds in which the basement and its sedimentary cover have the same tectonic behavior.

The Jura Mountains are not very high (1679 m, Mont Tendre). The range extends from Geneva to Basel and consists of a succession of SW–NE folded chains with valleys about 700–1000 m above sea level. The altitude and breadth of the Jura decrease towards the northeast. The Folded Jura becomes the Tabular Jura in the northwestern part of Switzerland. The Tabular Jura consists of subhorizontal Mesozoic cover rocks affected by Oligocene faulting south of the Rhine Graben. The Jura Mesozoic and Cenozoic reservoirs correspond to karstified limestones of the Dogger and Malm formations (Fig. 2), with a variable thickness in the range of 200–500 m.

The Plateau or Molasse Basin has a hilly landscape, studded with lakes and with a few large plains. Valley bottoms lie at 350–600 m, the intervening hills a few hundred metres higher, except towards the southern margin, where the morphological transition to the Alps is gradual. The Tertiary deposits, which stratigraphically overlie the Cenozoic and Mesozoic formations that are found in the Jura, consist of three units: Lower Marine Molasse, Lower Fresh-water Molasse and Upper Marine Molasse (Trümpy, 1980) (Fig. 2). Groundwater flow is often absent in the Lower Fresh-water Molasse; it is therefore regarded as an aquiclude. Groundwater flow through the Upper Marine Molasse sandstone is common but dependent on local conditions. The geological formations of the Muschelkalk, Dogger and Malm beneath the Tertiary deposits represent the aquifers, and can contain great quantities of hot water in permeable fractures (Balderer, 1990).

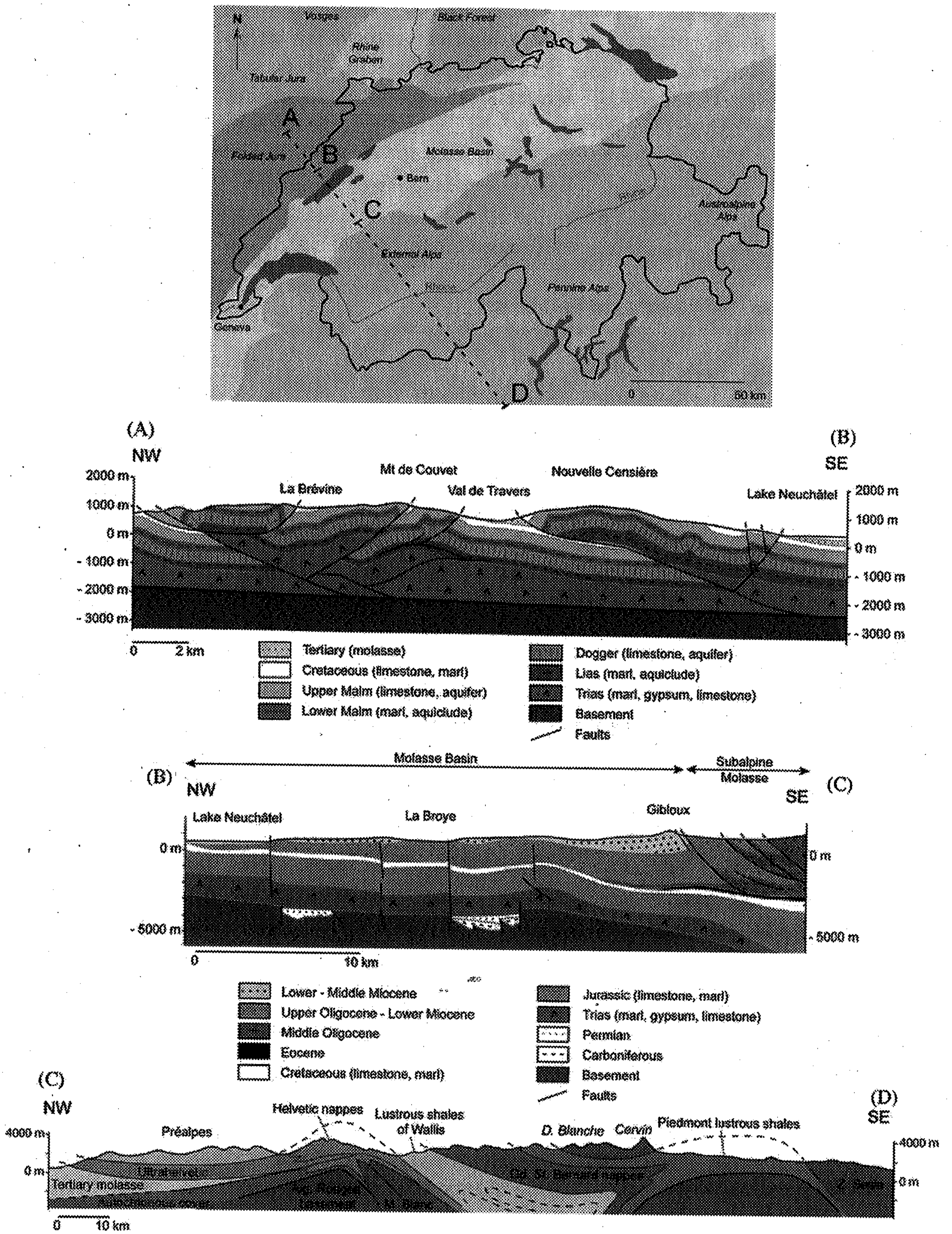

Fig. 2. Geological cross sections through Switzerland. AB represents the Folded Jura structures with two major deep aquifers in the Dogger and Upper Malm limestones (modified after Sommaruga, 1997). BC is a section across the Molasse basin; CD is a simplified view of the great Alpine structures (modified after Debelmas and Kerkhove, 1980). Elevations (in meters above sea level) are given on the vertical axes.

The Alps are divided into two parts by the large longitudinal valleys of the Rhone and Rhine Rivers. The northern mountains comprise a high chain to the south and lower ranges to the north. South of the Rhone-Rhine depression, the high Pennine Alps occupy the southernmost part of eastern Switzerland. In general, Alpine rocks fall into two categories: a pre-Triassic basement complex affected by the Variscan and older orogenies, and Triassic to Lower Oligocene sediments which were deformed only by the Alpine movements. Reservoirs in the Alps can be encountered in all the major geological units. These aquifers may be fractured (granite, gneiss), karstified (limestone) or porous (sandstone, fluvio-alluvial deposits). The locations and limits of the aquifers are not easily definable at this scale, however, and are highly dependent on local tectonic features.

4. Structure of the BDFGeotherm database

The database on geothermal fluids in Switzerland consists of 9 tables numbered from 1 to 6 and from 7.1 to 7.3, with 77 fields and 203 records corresponding to all groundwater points indexed in BDFGeotherm (see Table 1). The first two tables in the structure of the database are used to describe the geographic and geologic conditions of the sites where fluid samples have been acquired. The third to sixth tables in BDFGeotherm include quantitative data on thermal fluids, whereas Table 1(7.1)–(7.3) of the database contain the list of authors and bibliographical references related to the sites.

To avoid problems of the non-recognition of character strings during queries, all field names and all values are written without accents or special characters. In order to permit a search of data contained across several tables, they are related with the fields "Code", "No.author" and "No.bibliography", representing primary keys of the BDFGeotherm database. A unique code is used to identify each water sampling point. For example, the borehole P600 in Lavey-les-Bains will be defined by "LAVEY-P600".

5. Hydraulic parameters of thermal waters

The 203 sample points recorded in BDFGeotherm have temperatures ranging from 10 °C in the Malm limestone of the Jura (Tavannes borehole; Ziegler, 1992) to 112 °C in the deep crystalline basement below the Molasse Basin (Weiach borehole; Pearson et al., 1989). Measured temperatures in thermal springs, boreholes and thermal outflows in tunnels are illustrated on the simplified Swiss tectonic map in Fig. 3 and show that the warmer waters (>60 °C) are found in deeper boreholes (>1 km), the exception being Lavey-les-Bains in the External Alps where water at 68 °C inflows at a depth of 200–400 m (Bianchetti, 1994). This high temperature is not due to the existence of a heat flow anomaly (Rybach et al., 1987) but results from deep flow systems through permeable faults or subvertical strata in the Alps (Vuataz, 1982; Bianchetti et al., 1992). This process also gives rise to many thermal springs present in the Alps. The warmest springs exceed 40 °C, examples being Brigerbad (52 °C) and Leukerbad (51 °C) in Switzerland, Saint-Gervais-les-Bains (41 °C) in France and Bormio (42 °C) in Italy (Vuataz, 1982; Muralt and Vuataz, 1993). The measured temperatures of thermal outflows in tunnels do not exceed 40 °C. The maximum values are associated with water from the Mont Blanc (34 °C in Lebdioui, 1985; Dubois, 1991) and Simplon tunnels in the Alps (38.6 °C in Bianchetti et al., 1993; Vuataz et al., 1993). Nevertheless, these tunnels drain large quantities of water (>10 L/s), which enables them to be considered potential geothermal resources. In the Eastern Swiss Alps, in the Upper Rhine watershed, thermal springs have low temperatures and discharge rates are often rich in carbon dioxide (Hartmann, 1998).

Table 1
Description of fields of each table in the BDFGeotherm database

Fields	Field description
(1) Description	
Code	Simplified name of sample point, primary key
Location, country, canton, elevation, *X* and *Y* coordinates	Geographical general information
Type, name, number, depth and year of realization of sample point	Sample point general information
Primary and secondary exploitation	General information about sample point exploitation: none, building heating, drinking water, electricity, heating network, thermal usage
(2) Geology	
Code	Primary key
Type and age of surface formation and deep reservoir	General information about type of rock and geological age
Regional and local tectonic context	General information about geological context of infiltration of geothermal fluid and the presence of local geological structure such as fractures, faults, folds
Sample point log	Picture of geological log of boreholes
(3) Hydraulics	
Code	Primary key
Discharge/flow	Sample point discharge/flow in L/s. Because of the great variability of this parameter, we selected one of the three following types: annual average value, measured value associated with analyses or value of production yield
Surface temperature	Measured temperature at the wellhead and in the springs
Permeability	Permeability of geological reservoir in m/s
Exploitation procedure	None/Artesian/free flow/pumping/reinjection/borehole heat exchanger (BHE)
Static and dynamic water level	Elevation of water table (in meters above sea level) with and without pumping exploitation
(4) Hydrochemistry	
Code	Primary key
Sampling name and date	General information about the sampling
Geochemical types	Simplified and detailed geochemical type of analysed water
Temperature, conductivity and pH	Value of analysed physical parameters
Ca, Mg, Na, K, Li, Sr, HCO_3, SO_4, Cl, F, SiO_2, TDS	Value of analysed chemical parameters in mg/L (TDS = total dissolved solids)
Ionic balance	Calculated ionic balance in %
Variability of TDS	Variability of TDS calculated from several chemical analyses
Comments	Comments on the chemical analysis described above
(5) Isotope	
Code	Primary key
Sampling name and date	General information about the sampling
Water stable isotopes	Value of ^{18}O and ^{2}H in ‰
Radioactive isotopes	Value of ^{3}H in tritium units (TU) and ^{14}C in percent modern carbon (pmc)
Residence time	Estimation of groundwater residence time given in years or with symbols ">" and "<"
Infiltration elevation	Mean elevation of the basin in m.a.s.l. calculated from stable water isotope data

Table 1 (*Continued*)

Fields	Field description
Comments	Comments on the isotopic analysis described above
(6) Geothermal parameters	
Code	Primary key
Surface temperature	Measured temperature at the wellhead and in the springs
Reservoir temperature	Min and max temperatures of the deep reservoir calculated from geothermometry, mixing models or modelling of chemical equilibrium
Depth of reservoir	Depth to top of geothermal reservoir in m.a.s.l.
Geothermal gradient	Average geothermal gradient in °C/km calculated from the depth of boreholes or derived from literature
Potential geothermal energy	Potential geothermal energy in kW_{th} calculated from sample point hydraulic data
(7.1) Author	
Number of author	Code number allotted to each author, primary key
Author	List of author(s) and co-author(s) classified alphabetically
(7.2) Table-links	
Code	Primary key
Number of author	Code number allotted to each author, primary key
Number of bibliography	Code number allotted to each reference, primary key
(7.3) Bibliography	
Number of bibliography	Code number allotted to each reference, primary key
Bibliography	List of references classified alphabetically

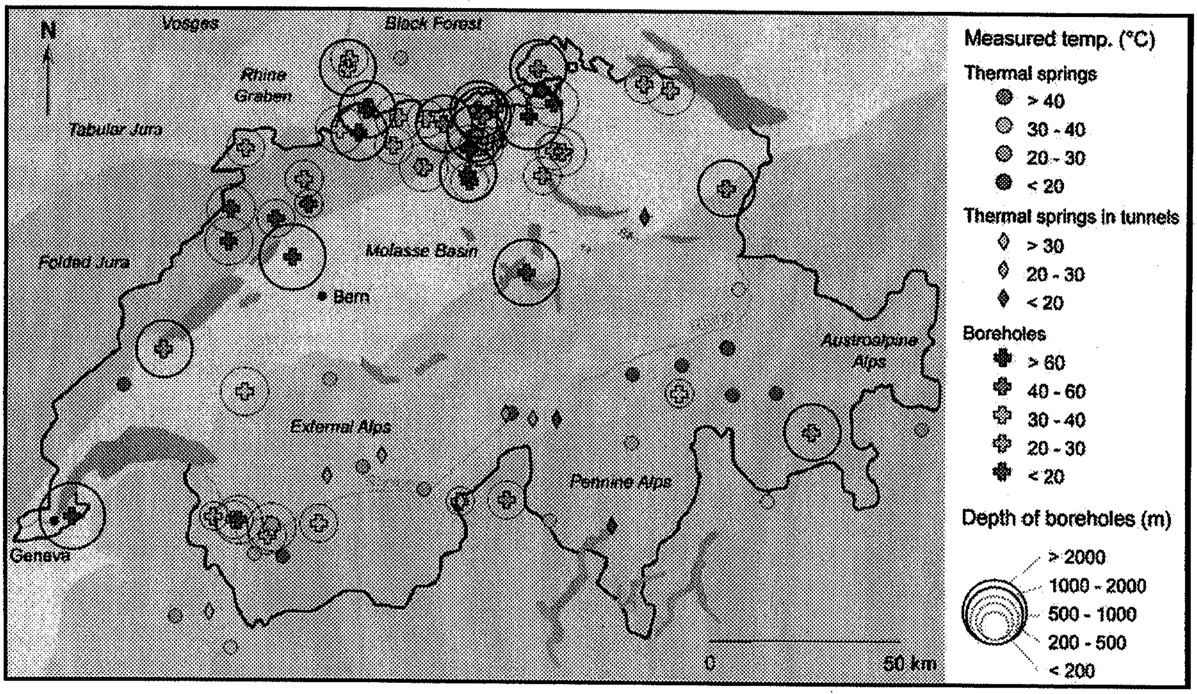

Fig. 3. Location and temperature of the thermal sample points after data included in BDFGeotherm.

In the Molasse Basin, measured water temperatures in the Tertiary deposits do not exceed 30 °C (29 °C in the Zürich borehole; Högl, 1980), although temperatures are higher in the Muschelkalk, Dogger and Malm formations because of their depth (Pearson et al., 1989; Gorhan and Griesser, 1998). When developing a geothermal project, temperature forecasting is rather easy; however, it is a difficult task is to estimate borehole production rate. For example, the Thônex deep borehole near Geneva (88 °C in the Malm) was not sufficiently productive (3.1 L/s at 39 °C) and is still unused (Jenny et al., 1995; Muralt, 1999).

In the Tabular Jura, in northern Switzerland, thermal waters (>40 °C) occur at relatively shallow depth due to the presence of high heat flow (>150 mW/m^2; Rybach et al., 1987). For example, the Riniken borehole presents warm (50 °C) water inflows at a depth of 800 m in subhorizontal Triassic sandstones (Pearson et al., 1989).

In the Folded Jura, the warmest waters are located at the northeastern end of the Jura Massif in Baden (47 °C in Högl, 1980; Vuataz, 1982). As in the Alps, this is due to the upflow of deep hot water into the Muschelkalk. Elsewhere, thermal waters are found in shallow boreholes (<650 m) in the fractured and karstified limestones of the Dogger and Malm, but the measured temperatures do not exceed 25 °C (Muralt, 1999).

6. Water chemistry

Many reports and publications concern the chemistry of thermal waters in Switzerland. Regional studies can be found in Carlé (1975), Högl (1980) and Vuataz (1982), while more local or specialized works are available in Pearson et al. (1989), Hartmann (1998), Kullin and Schmassmann (1991) and Pastorelli (1999). Chemical data of selected sites that are potentially interesting from a geothermal point of view, either because of temperature or production rate, and have been included in BDFGeotherm are given in Table 2 and are shown on the simplified Swiss tectonic map (Fig. 4). In the following paragraphs, the different types of geothermal fluids are described in terms of geochemistry. The geochemical type is defined by the most important cations and anions.

6.1. Ca-SO$_4$ waters

The selected thermal sites having a Ca-SO$_4$ type water have total dissolved solids (TDS) ranging between 800 and 2700 mg/L, an exception being the lightly mineralized water of Mont-Blanc (Table 2). These waters are influenced by the dissolution of sulfate minerals (mainly gypsum and anhydrite) contained in the Triassic sediments. Gypsum and anhydrite are much more soluble and dissolve faster than Al-silicates; the Ca-SO$_4$ fingerprint is easily acquired by shallow or deep groundwaters upon interaction with these rocks (Pastorelli et al., 2001). This lithotype is found in the Alps due to the occurrence of Triassic rocks, which played a central role in the position of the Alpine nappes. They are often found in the overthrust faults and in the northeastern part of the Jura where these formations are at shallow depth. Acquarossa thermal waters in the Pennine Alps are a good example of circulation in the contact zone between the crystalline basement and pinched Triassic layers (Vuataz, 1982). The water circulation starts with infiltrated rain water descending progressively, being heated at depth and locally rising quickly to the surface, preserving the physical and chemical Triassic characteristics (TDS = 2663 mg/L, with SO$_4$ = 1300 mg/L) (Pastorelli et al., 1999).

Some Ca-SO$_4$ waters do not contact the Triassic rocks. These waters generally have a low TDS (<300 mg/L) and come from interactions with granitic or gneissic rocks. An example is the

Table 2
Chemical data of selected sites recorded in BDFGeotherm

No.	Location	Sample point type	Discharge temperature (°C)	Flow rate (L/s)	Reservoir geology	pH	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	Cl (mg/L)	SiO_2 (mg/L)	TDS (mg/L)	Power (kW_{th})
Ca-SO_4 waters																
1	Leukerbad-SANLO	Spring	51	15.2	Triassic evaporite	6.7	447	56	19	1.8	99	1248	6.2	24.6	1,904	2608
2	Schinznach-Bad-S3	Borehole	44.5	8.3	Triassic limestone	7.1	237	57	170	12.1	300	600	194	35.4	1,610	1185
3	Simplon-F1	Borehole in tunnel	44.2	3.3	Triassic evaporite	7.24	302	26.2	4.4	1.3	84	778	0.2	14.2	1,217	480
4	Bormio-SANMA	Spring	42	3.3	Triassic evaporite	7.65	233	60.9	18.7	2.9	164	675	9.5	28.6	1,265	442
5	Val d'Illiez-F3	Borehole	30	22	Triassic evaporite	6.5	398	81	27.6	1.8	122	1191	3.6	13.2	1,827	1840
6	Vals-NB	Borehole	29.6	10	Triassic evaporite	6.7	446	57.5	11.4	1.8	403	1020	2.5	22.5	1,975	820
7	Mont-Blanc-S138	Spring in tunnel	27	2.5	Hercynian granite	5.6	21.5	0.7	14.9	2.2	28.7	50.3	1.9	7.6	1,29	178
8	Weissenburg-STH	Spring	25.9	0.9	Triassic evaporite	7.38	341	76.8	16.8	4.1	150	1025	10	22.9	1,657	56
9	Acquarossa-ALB	Spring	24.9	2	Triassic evaporite	6.7	549	85.5	18.5	18.3	621	1300	7	47.1	2,663	125
10	Lostorf-F3	Borehole	24.4	10	Triassic limestone	7.65	152	55.4	3.6	2.1	250	330	7.5	9.8	817	603
11	Andeer-STH	Spring	18	3.3	Triassic evaporite	7	545	55	12	2.7	162	1430	4.5	17.7	2,245	110
Na-SO_4 waters																
12	Lavey-les-Bains-P600	Borehole	64	20	Hercynian gneiss	7.7	56.7	1.5	376	11.5	87.4	577	242	65.7	1,435	4600
13	Brigerbad-TQBId	Gallery	50.2	12	Hercynian gneiss	7.46	136	2.6	275	29.3	91.5	664	117	67	1,386	2020
14	Baden-LIMMAT	Spring	47.2	2.3	Triassic limestone	6.55	557	114	804	69.4	505	1450	1175	53.5	4,740	366
15	Saint-Gervais-les-Bains-G1	Spring	39.6	0.5	Hercynian gneiss	7.15	281	28.3	1258	41.6	264	1800	952	48.6	4,700	62
16	Combioula-C3	Borehole	28.5	20	Triassic evaporite	6.78	621	137	670	49.5	271	2062	876	31.4	4,950	1550
Ca-HCO_3 waters																
17	Bad-Ragaz-PFA	Spring	36.5	39.7	Triassic limestone	7.34	60.8	15	30	2.7	223	27	38	15.6	416	4402
18	Yverdon-les-Bains-F4	Borehole	27.3	28	Jurassic limestone	7.53	50	22.8	12.7	1	253	15.1	15.5	11.8	384	2109
19	Delémont-S3	Borehole	21.7	28	Jurassic limestone	7.5	50.8	24.1	7.3	1.4	270	9.9	3.6	11.7	379	1370
20	Rothenbrunnen-SSTH	Spring	17.2	4.2	Jurassic schist	6.64	154	48	79	5.3	783	96	10	32.6	1,213	126
Na-HCO_3 waters																
21	Zurzach-Bad-T1	Borehole	38.2	28.7	Hercynian gneiss	8	13.7	0.71	282	7.4	254	220	135	25.3	950	3387
22	Berlingen-B3	Borehole	29	2	Tertiary molasses	8.5	2.6	1.2	298	1.8	500	161	48	13.1	1,030	159
23	Sankt-Moritz-PSG	Borehole	29	1.3	Hercynian granite	7.33	442	370	2760	17	7050	1900	760		13,299	103
24	Zurich-B2	Borehole	23.5	5	Tertiary molasses	8.9	2.4	0.8	318	1.7	395	129	144	8.5	1,027	282
25	Furka-S8737	Spring in tunnel	21.7	0.3	Hercynian granite	8.84	18.3	0.1	18.6	0.7	49	48.7	1.1	16.7	153	15
Na-Cl waters																
26	Riehen-F1	Borehole	61.2	20	Triassic limestone	6.42	786	192	4850	151	1100	2810	7150	39.2	17,099	4283
27	Steinenstadt-GEORG	Borehole	33.4	31	Jurassic limestone		386	104	668	22	815	231	1408	17.7	3,100	3035
28	Saeckingen-BAD	Spring	29	5	Hercynian granite	6.82	140	17.5	975	60	296	124	1613	34.9	3,265	410

The geothermal fluids are arranged by their geochemical type and by decreasing temperature. The field "Location" gives the site and sample point names. The sample number is the same as that shown in Fig. 4.

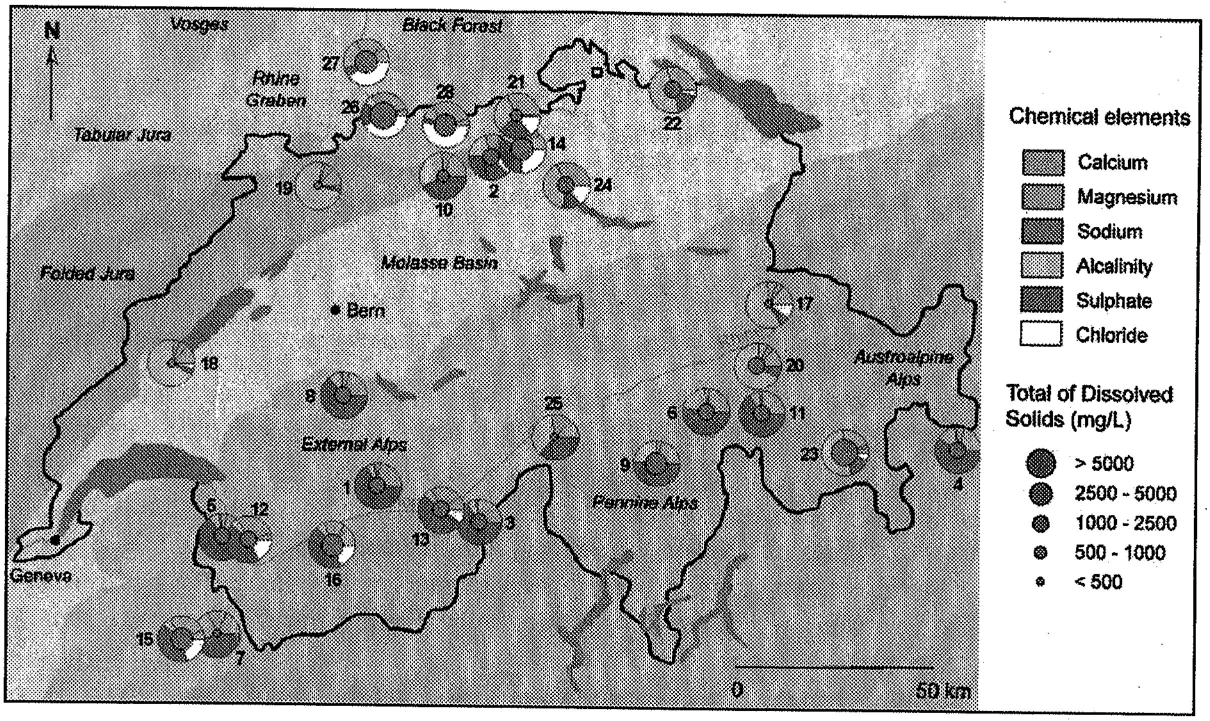

Fig. 4. Location and geochemical type of selected thermal water samples from data included in BDFGeotherm. The colors in the pie-charts represent the major chemical elements, and the size of the gray circles illustrates the amount of total dissolved solids (TDS). The numbers near the pie-charts relate to the site number indicated in Table 2.

thermal springs in the Mont Blanc tunnel with the chemical type Ca-Na-SO_4-HCO_3. In this case, the sulfate comes from dissolution and oxidation of sulfide minerals from hydrothermal veins in crystalline rocks (Bianchetti, 1994).

6.2. Na-SO_4 and Na-HCO_3 waters

Selected thermal waters rich in sodium often have a TDS over 1000 mg/L except for the lightly mineralized waters of the Furka tunnel (TDS = 153 mg/L). These waters mainly circulate in crystalline rocks. Their sulfate concentration is due to the dissolution of sulfide minerals. Sodium comes mainly from reactions with feldspars in crystalline rocks (Pastorelli et al., 2001). These geochemical types are found in the Alps and, more precisely, in the peripheral regions of the external crystalline massifs (Brigerbad, Lavey-les-Bains and Saint-Gervais-les-Bains). Na-HCO_3 waters are those that penetrated the basement under the Tabular Jura (Zurzach-Bad). In the Molasse Basin, there are also Na-HCO_3 waters in the Lower Marine Molasse with TDS close to 1000 mg/L (Berlingen and Zürich).

Some waters with rich in calcium (Na-Ca-SO_4) have an intermediate composition type between those from crystalline rocks and those contacting Triassic gypsum and anhydrite. For example, the thermal springs of Combioula emerge from Triassic formations but circulate partly in crystalline rocks found below these sediments. The deep borehole of St-Moritz contains strongly mineralized thermal water (TDS > 13 g/L), which is believed to be due to high levels of CO_2 favoring rock dissolution (Aemissegger, 1993; Bissig et al., 2006).

6.3. Ca-HCO_3 waters

Thermal Ca-HCO_3 waters are generally lightly mineralized, with a TDS often below 500 mg/L, except for the Rothenbrunnen thermal spring (TDS = 1213 mg/L) in the Pennine Alps which belongs to the family of "carbogaseous" springs (Hartmann, 1998). This fingerprint is typical of a calcareous environment as observed for the Malm thermal waters in the Jura (Yverdon-les-Bains and Delémont) and for the waters of Bad-Ragaz in the External Alps (Fig. 4).

6.4. Na-Cl waters

Thermal Na-Cl waters have generally a high mineralization (TDS > 3 g/L) with concentrations sometimes exceeding 10 g/L, as in Riehen (17 g/L). The origin of this fingerprint is twofold: it could be due either to the mixing of old, deep, strongly mineralized seawater and fresh water at shallow depth, or to the dissolution of halite deposits. Na-Cl water is found throughout the geological column, from the Tertiary deposits to the crystalline basement. For example, the boreholes of Riehen and Steinenstadt contain saltwater that originates in the Muschelkalk and Jurassic limestones, while the saltwater thermal springs of Saeckingen arise from the Hercynian granites of the Black Forest (Table 2).

Stober and Bucher (1999) studied deep groundwaters in the crystalline basement of the Black Forest. They concluded that saline thermal water used in spas has its origin in 3–4 km deep crystalline reservoirs and has developed its composition by a mixing of surface freshwater with saltwater (of ultimately marine origin), and water-rock reactions with an increasing mineral dissolution due to the presence of CO_2.

7. Potential geothermal resources

The geothermal resources in Switzerland are found in most parts of the country (Fig. 5). Well-known resources are located in the northern part of Switzerland and the upper Rhone valley. Deep fluids are used in small district heating networks and for the heating of spas. Some areas are not endowed with obvious geothermal resources, for example the southern part of the Folded Jura and the high Alpine relief, but Alpine valleys drain large amounts of water coming from the mountain slopes and may contain thermal waters at depth. However, the identification of hidden deep sources remains difficult because of the fluvio-glacial sedimentary cover. In some cases, it is possible to observe temperature anomalies in the shallow groundwater.

The estimated thermal energy potential of the springs and wells shown in Fig. 5 varies because of differences in temperatures and discharges. Potential geothermal energy was calculated using the following equation (Modified from Signorelli, 2004),

$$P = 1000\frac{Q(T-t)}{239} \tag{1}$$

where P is the potential geothermal energy (in kW_{th}), Q is the discharge (in L/s), T is the initial temperature (in °C) and t is the final temperature after cooling (in °C), arbitrarily fixed at 10 °C.

8. Information about the use of BDFGeotherm

A CD-ROM containing BDFGeotherm database is available on request at the Centre for Geothermal Research (CREGE, contact@crege.ch). Due to its size, the database cannot be trans-

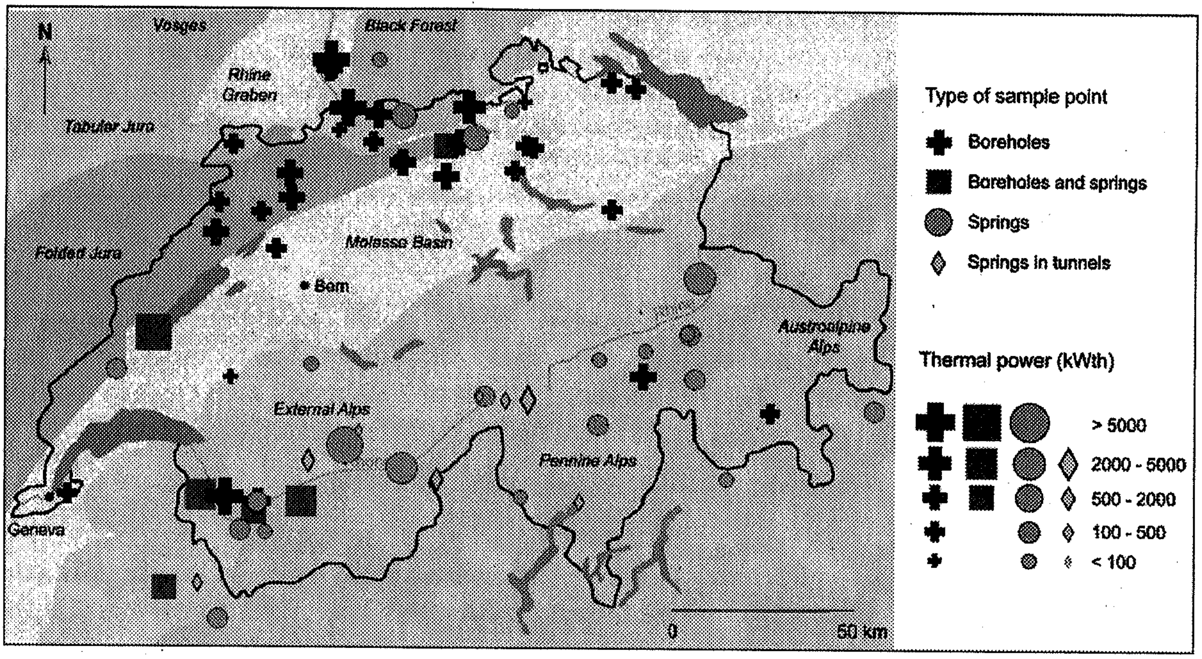

Fig. 5. Location and thermal power of geothermal resources included in BDFGeotherm. The thermal power of a given site corresponds to the sum of all the sample points. Some sites are not represented due to lack of discharge data.

mitted by e-mail (BDFGeotherm.mdb; 408 MB) but it is possible to download it from a ftp address. This CD-ROM also contains the users' manual (BDFGeotherm-Notice-explicative.pdf, for the time being in French only) allowing the users to introduce new information into the database. This users' manual describes all steps to be followed for an optimum use of this database, i.e. search, addition, export and use of data.

8.1. Search of data contained in tables of BDFGeotherm

The simplest search of data consists of selecting the information contained in several fields of a single table. For example, we can run a query on all the springs and boreholes included in BDFGeotherm. The result of this search will give a new table with the selected fields for the entire set of records. This table can be kept in BDFGeotherm or exported to another database. It is possible to limit the number of records by inserting selection criteria into the query. For example, data for of boreholes deeper than 500 m and located in a specific area of Switzerland can be extracted.

8.2. Adding data in BDFGeotherm

The literature consulted for the development of BDFGeotherm is certainly not exhaustive and there exist other reports and papers on deep fluids of Switzerland that were not examined. Users having other bibliographical references can add data to their version of BDFGeotherm.

First, adding data for a sample point already indexed for a given geothermal site involves entering new data in the chosen cells and then saving the table. Second, to add data for a new sample point on an existing site, enter into each 'Code' field the first five letters of the site name followed by a new number, and then enter the new data in the appropriate tables. Third, adding data for a new geothermal site requires inserting a new record with a new site name.

Finally, the structure of the database is not limited to geothermal fluids of Switzerland but can be customized or modified, in case users would like to handle data sets from other regions. In the table “Description”, it is possible to add countries in the drop-down list of the field “Country” and to generate a new site. For each field, the user has the choice to select the type of data: text format, numerical data, date, figures, hypertext links, etc.

8.3. Exporting and using data from BDFGeotherm

Exporting data from an Access database is possible from a table or a query. The exported file type can be preserved or modified from a drop-down list in the standard “File type” menu. Data contained in BDFGeotherm is useful for various types of geothermal projects: exploration, production and injection of geothermal fluids into all potentially permeable formations.

9. Conclusions

The geothermal map of Switzerland shows an important concentration of geothermal sites in the northern part of the Jura range, where they are related to a heat flow anomaly, and in the upper Rhone Valley, where they originate in deep upflow systems. In Switzerland there exist many thermal fluid occurrences with temperatures between 20 and 65 °C. Their various geochemical water types are linked to the geological formations, and the length and mode of fluid circulations.

The BDFGeotherm database was built under Microsoft Access because it is widely available. Its structure allows many types of queries to be run and integrated easily into various geothermal projects. Moreover, other records on geothermal fluids or sites can be added and new physical or chemical parameters can be easily included.

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