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**GEOHERMAL MAP OF SWITZERLAND 1995
(HEAT FLOW DENSITY)**

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Editor's preface

The present publication entitled "Geothermal Map of Switzerland 1995 (Heat Flow Density)" is Report N° 30 of the "Contributions to the Geology of Switzerland - Geophysical Series" published by the Swiss Geophysical Commission.

It contains a short description of the data acquisition and processing used by the authors, a description of the measuring technique for the determination of rock thermal conductivity, the applied temperature corrections and finally the adopted mapping technique.

Several maps at large scale are also included in this booklet, which show for example temperatures at 500, 1000 and 2000 m depth.

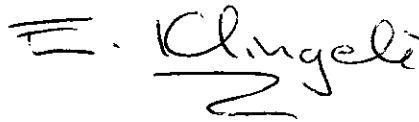
Finally seven pages (Appendix I and II) present the heat flow data base of the available sites outside and inside Switzerland.

The Swiss Geophysical Commission is very grateful to Prof. Dr. Ladislaus Rybach and Dr. Fausto Medici for having taken the initiative in realizing this publication.

Special thanks are due to the Swiss Academy of Natural Sciences for its financial support of this publication.

Zürich, December 1995

In the Name of the
Swiss Geophysical Commission
The President:

A handwritten signature in black ink, appearing to read "E. Klingelé". The signature is written in a cursive style with a large, stylized 'K' and a long horizontal stroke at the end.

Prof. E. Klingelé

Preface

The geothermal map of Switzerland is No. 10 of a series of geophysical maps on the scale 1: 500'000. These maps aim at the representation of the main geophysical parameters and are being prepared and produced by the Swiss Geophysical Commission. The geothermal conditions in the subsurface of Switzerland are represented in the form of a heat flow density map. The terrestrial heat flow density at the surface is in fact closely related to the temperature field at depth.

The temperature distribution in the subsurface is, besides its scientific interest, of great importance for various fields of practical applications:

- for the construction of underground facilities (e.g. for storage or transportation)
- for the utilisation of groundwater resources
- for the exploration of hydrocarbons
- for the development and exploitation of geothermal energy
- for the disposal of radioactive and/or toxic wastes in geological formations

More than ten years have passed since the first edition of the Geothermal Map of Switzerland was published. In the meantime, numerous new heat flow density (HFD) determinations have approximately doubled the available database. The need of a revised edition of the geothermal map thus became evident.

The HFD map of Switzerland reflects the status of knowledge at the end of 1995. HFD determinations of neighbouring countries, incorporated now in the EGT catalogue, were also available. Nevertheless, in areas with few data points, new values that diverge from the local trends could change the isoline patterns considerably.

The HFD data density in Switzerland is among the highest in the world. Nevertheless, more HFD determinations, especially in the Alps, are needed to delineate more precisely the terrestrial heat flow pattern.

Most HFD determinations have been performed in objects available for measurements ("opportunity boreholes", tunnels or shafts). In this regard the co-operation of numerous builders, oil exploration companies, consulting bureaux and various cantonal and communal authorities must be mentioned.

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1. Introduction

The geothermal conditions in the subsurface of Switzerland are represented in the form of a map of the terrestrial heat flow density on the scale 1 : 500'000. The map displays the lateral variation of the terrestrial heat flow density (HFD) near the earth's surface. The HFD [mW m^{-2}] is the amount of heat flowing per unit time and area through the earth's surface from its interior. The HFD is closely related through the rock thermal conductivity to the subsurface temperature field. Reliable information about the subsurface temperature distribution is of growing importance today for a variety of tasks including the planning and construction of subsurface facilities for either storage or transportation (e.g. alpine transversal), the development and exploitation of geothermal energy, the utilisation of groundwater resources and the disposal of radioactive waste in geological formations. In addition to the HFD map, subsurface temperatures at 500, 1000 and 2000 m depth are represented by isoline maps.

The representation of HFD by isolines on a map requires a certain minimum of data density. The necessary database has become available in Switzerland only in the early eighties, despite of several pioneering achievements in geothermics made in this country a long time ago. Among these were the first reliable measurements of the geothermal gradient, performed in 1832 in a 220 m deep borehole at Pregny near Geneva. A value of $0.034\text{ }^{\circ}\text{C m}^{-1}$ (recalculated from Réaumur temperatures and "pieds royaux français" depths) was found (De la Rue and Marcet, 1834). Later the construction of the Gotthard railroad tunnel (1872-1882), a pioneering engineering venture at that time, gave impetus to a number of basic contributions in geothermics:

- systematic measurements of rock temperatures (Stapff, 1887)
- the first HFD estimate for continental Europe (77 mW m^{-2} , Stapff, 1883)
- the first method for topographic correction to the temperature gradient (Königsberger and Thoma, 1906)
- the first reported correlation of heat flow with local rock radioactivity (Joly, 1909).

Modern HFD determinations in Switzerland began with the investigations of Clark and Niblett (1956), who evaluated the data from the railroad tunnels in the Swiss Alps (Gotthard, Simplon, Lötschberg). Further heat flow determinations have been carried out more recently in boreholes, shafts and in lake bottom sediments. The effect of uplift/erosion on surface heat flow in the Alps was recognised and discussed by Clark and Jäger (1969). An attempt to obtain characteristic thermal properties of Swiss rocks was made by Wenk and Wenk (1969). In 1979 only nine HFD values had been reported in Switzerland. In the early eighties concentrated efforts of both the Swiss Geophysical Commission and the Swiss Federal Commission for the Utilisation of Geothermal Energy and Underground Heat Storage resulted in numerous new HFD determinations. At that time about 150 HFD values were available for the drawing up of a Swiss geothermal map. Since then more data are become available. The database consists nowadays of about 340 HFD determination; 150 in Switzerland and 190 in the surroundings.

The HFD has been calculated as the product of the geothermal gradient (dT/dz) and the rock thermal conductivity K . In doing so, steady state, one dimensional conductive heat transfer was assumed. Measurements sites were omitted if the gradient was highly disturbed by moving groundwater. Both K and dT/dz can vary with locality. K depends on the mineralogical composition and on the petrophysical properties of the rocks. Because in most cases no rock cores from the boreholes were available, a thermal conductivity catalogue of the main Swiss rock types was established on the basis of laboratory measurements. At present about 550 samples have undergone a K determination. For most of the boreholes the thermal conductivity profile was obtained using this catalogue and their lithological profiles. The Bullard-plot technique was then used to calculate the HFD.

However, before calculating the HFD, corrections were applied to the temperature data. In addition to corrections for thermal disturbance caused by drilling fluid circulating within the borehole, several other corrections related to conditions at the earth's surface were performed. These included corrections for paleoclimatic temperature fluctuations and for the topographic relief. Computer codes have been developed to perform all the necessary calculations. For the HFD map at 1 : 500'000 only the topographic correction was applied according to common practice. The Swiss HFD map is therefore compatible with the HFD maps of other European countries.

The contouring of isolines at 10 mW m^{-2} intervals was done by computer with some final manual corrections. The geographical distribution of the data points used for contouring is highly uneven, being

largely based on opportunity objects such as exploratory or commercial boreholes available for dT/dz determinations. Since many original data from boreholes are not more directly available and since from most foreign data very little is known, is not possible to check the quality and the uncertainty of every HFD determination. In general the quality of HFD determinations from shallow boreholes (< 200 m depth) is quite poor.

The surface HFD is a complex signal comprising long and short wavelength components. The first ones are due to regional variations of deep HFD (crustal and lithospheric), the second ones to shallower local HFD changes. In Switzerland the mean regional HFD decreases towards the south, from the Jura to the Central Alps and increases slightly south of the Central Alps. Several superimposed local anomalies can be attributed to deep groundwater circulating systems.

Although the density of HFD determinations in Switzerland is one of the highest in Europe, periodic updating on the basis of new data will be indispensable.

2. Zusammenfassung

Die geothermischen Verhältnisse im Untergrund der Schweiz werden in Form einer Wärmestromdichtekarte im Massstab 1 : 500'000 dargestellt. Diese Karte zeigt die lateralen Änderungen der terrestrischen Wärmestromdichte in der Nähe der Erdoberfläche. Die Wärmestromdichte, "heat flow density" (HFD [mW m^{-2}]), ist die aus dem Erdinnern stammende Wärmemenge, welche pro Zeit- und Flächeneinheit die Erdoberfläche durchströmt. Die HFD wird von der Gesteinswärmeleitfähigkeit und vom Temperaturfeld des Untergrundes bestimmt. Zuverlässige Angaben über die Temperaturverhältnisse im Untergrund sind heutzutage für mehrere Projekte von wachsender Bedeutung. Dabei sind gemeint: die Planung und Herstellung von Untergrundeinrichtungen für Lagerung oder Transport (z.B. NEAT-Projekt), die Entwicklung und Nutzung von geothermischer Energie, die Nutzung von Grundwasserressourcen und die Endlagerung von radioaktiven Abfällen in geologischen Formationen. Zusätzlich zur HFD-Karte sind die Temperaturen im Untergrund in 500, 1000 und 2000 m auf Karten gegeben.

Die Darstellung von HFD-Werten mittels einer Isolinienkarte erfordert ein Minimum an Datendichte. Die dafür notwendige Datenmenge stand erst Anfang der achtziger Jahren zur Verfügung; dies trotz einiger Pionierarbeiten in der Geothermik, welche in der Schweiz vor vielen Jahren geleistet wurden. Unter diesen sind zu erwähnen die ersten zuverlässigen Messungen des geothermalen Gradienten, durchgeführt 1832 in einem 220 m tiefen Bohrloch in Pregny bei Genf. Es wurde ein Wert von $0.034\text{ }^{\circ}\text{C m}^{-1}$ (nachgerechnet aus Temperaturen in Réaumur und Tiefen in "pieds royaux français") gefunden (De la Rue and Marcet, 1834). Später führte der Bau des Gotthardeisenbahntunnels, zu dieser Zeit eine Pionierunternehmung des Ingenieurwesens, zu zahlreichen grundlegenden Beiträgen in der Geothermik:

- systematische Messungen von Felstemperaturen (Stapff, 1887)
- die erste Schätzung der HFD für das kontinentale Europa (77 mW m^{-2} , Stapff, 1883)
- die erste Methode zur topographischen Korrektur des geothermischen Gradienten (Königsberger and Thoma, 1906)
- die ersten publizierten Zusammenhänge zwischen Wärmefluss und lokaler Gesteinsradioaktivität (Joly, 1909).

Moderne HFD-Bestimmungen begannen in der Schweiz mit den Untersuchungen von Clark und Niblett (1956), welche die Daten aus den Eisenbahntunnels in den Schweizer Alpen (Gotthard, Simplon, Lötschberg) bewerteten. Zusätzliche HFD-Bestimmungen wurden aus Bohrlöchern, Stollen und in Sedimenten am Seegrund gewonnen. Der Effekt von Hebung/Erosion auf dem Wärmefluss in den Alpen wurde von Clark and Jäger (1969) erkannt und diskutiert. Ein Versuch, thermische Eigenschaften von Schweizer Gesteinen zu bestimmen, wurde von Wenk and Wenk (1969) durchgeführt. 1979 waren in der Schweiz nur neun HFD-Werte bekannt. Anfang der achtziger Jahre führten gemeinsame Bemühungen der Schweizerischen Geophysikalischen Kommission und der Eidgenössischen Fachkommission für die Nutzung geothermischer Energie und die unterirdische Wärmespeicherung zur Bestimmung zahlreicher neuer HFD-Daten. Zu dieser Zeit standen etwa 150 HFD-Werte für die Erstellung der geothermischen Karte der Schweiz zur Verfügung. Seither sind mehrere neue HFD-Daten errechnet worden. Die aktuelle Datenbank enthält etwa 340 HFD-Bestimmungen, davon 150 in der Schweiz und 190 im angrenzenden Ausland.

Die HFD wurde als Produkt des geothermischen Gradienten (dT/dz) und der Gesteinswärmeleitfähigkeit K berechnet, d.h. unter Annahme von stationärem und eindimensionalem konduktivem Wärmetransport. In Fällen, wo der geothermische Gradient sehr stark von fliessendem Grundwasser beeinflusst war, wurden die Messdaten nicht berücksichtigt. Beide, K und dT/dz , können je nach Lokalität variieren. K ist von der mineralogischen Zusammensetzung und von den petrophysikalischen Eigenschaften der Gesteine abhängig. Da in den meisten Fällen keine Bohrkerne von den Bohrungen, in welchen die Temperatur gemessen wurde, zur Verfügung standen, wurde ein Wärmeleitfähigkeitskatalog von schweizerischen Gesteinen anhand von Labormessungen erstellt. Zur Zeit enthält dieser Katalog K -Werte von etwa 550 Gesteinsproben. Bei den meisten Bohrlöchern wurden die Wärmeleitfähigkeitsprofile anhand dieses Kataloges und des lithologischen Bohrlochprofils erstellt. Für die Berechnung der HFD-Werte wurde die Bullard-plot Methode benutzt.

Bevor die HFD-Werte berechnet wurden, mussten die Temperaturdaten jedoch korrigiert werden. Zusätzlich zu den Korrekturen für die thermische Störung, verursacht durch die Spühlflüssigkeit im Bohrloch, wurden andere Anpassungen der Temperaturdaten betreffend die Bedingungen an der

Erdoberfläche wurden durchgeführt. Diese beinhalten Korrekturen für die paläoklimatischen Temperaturschwankungen und für das topographische Relief. Computerprogramme wurden für die Durchführung aller notwendigen Berechnungen entwickelt. Für die HFD-Karte 1:500'000 wurden üblicherweise nur die topographischkorrigierten HFD-Werte benutzt. Die schweizerische HFD-Karte ist somit mit denjenigen anderer Länder völlig kompatibel.

Die Isoliniendarstellung der Karte in Intervallen von 10 mW m^{-2} wurde vom Computer errechnet. Kleine Abänderungen wurden anschliessend manuell durchgeführt. Die geographische Verteilung der Datenpunkten ist sehr unregelmässig, weil diese an "Gelegenheitsobjekte", wie Explorations- oder Nutzbohrungen, verfügbar für dT/dz -Bestimmungen, gebunden sind. Da die meisten Originaldaten von den Bohrungen nicht mehr direkt verfügbar sind und da über ausländische Daten sehr wenig bekannt ist, war es nicht möglich die Qualität und die Genauigkeit der HFD-Werte zu berücksichtigen. Generell ist die Qualität der HFD-Werte aus untiefen Bohrungen ($<200 \text{ m}$) ziemlich schlecht.

Das an der Erdoberfläche beobachtete HFD-Signal ist die Summe lang- und kurzweiliger Komponenten. Die ersten werden von regionalen Änderungen der HFD tief in der Erdkruste und in der Lithosphäre verursacht, die zweiten von lokalen untiefen Variationen der HFD. In der Schweiz nimmt die mittlere regionale HFD südwärts ab, vom Jura bis zu den Zentralalpen, und nimmt südlich der Zentralalpen wieder leicht zu. Einige überlagerte lokale Anomalien werden wahrscheinlich von tiefen Grundwasserzirkulationssystemen verursacht. Obwohl die Dichte der HFD-Bestimmungen in der Schweiz eine der grössten in Europa ist, sind periodische Neubearbeitungen der geothermischen Karte anhand neuerer Daten unerlässlich.

3. Geological background

A brief overview of the main geologic-tectonic units in Switzerland is given below. For more detailed information see e.g. Trümpy (1980), Müller et al. (1984), Diebold et al. (1991).

The area of Switzerland can be geologically subdivided from north to south into the following main units: Rhine Graben, Tabular (Plateau) Jura, Folded Jura, Molasse Basin and the Alps. The latter is further subdivided into: Helvetic belt, Alpine massifs and their autochthonous and parautochthonous sedimentary covers, Penninic units, Austroalpine nappes and, south to the Insubric line, the Southern Alps, reaching into the Tertiary Molasse of the Po plain. These simplified and integrative units are indicated (in German) on the geothermal Map of Switzerland. A more detailed geological map is shown on Fig. 2 (simplified from Trümpy, 1980); the following short description of its main geological units is based on Trümpy (1980) and Bodmer and Rybach (1984).

2.1 Rhine Graben (RG)

In the northern foreland of the Alps, the Variscan crystalline basement rocks ("Moldanubian"), visible at the surface in the Black Forest (SC) and Vosges (VO) massifs, dip gently southwards where they are overlain by an autochthonous sedimentary cover. The massifs are separated by the Rhine Graben, a continental rift structure which has its southern end, at least at the surface, near the Swiss border in the area of Basel. Although the main rifting phase dates back to the late Eocene, different parts of the Graben area have been active since then. Shear movements are predominant in recent times. Due to its high degree of fracturing at depth and the corresponding possibilities for vertical water circulation, the Rhine Graben area and especially its rim zones are of considerable geothermal interest (Rybach, 1981; Gürler et al., 1987; Hauber, 1993). The graben fill consists of Tertiary (Molasse) and some Quaternary sediments.

2.2 Tabular Jura (TJ)

The subhorizontal Mesozoic cover rocks lying unconformably on the buried southern extension of the Vosges/Black Forest crystalline basement consist, except for some Tertiary remnants, of a more or less continuous sedimentary sequence of age between the Lower Trias and the Upper Malm. Below this cover, older sediments are embedded at places into the basement in trough and graben structures. In the Permocarboniferous trough of northern Switzerland beneath the Tabular Jura, two superimposed troughs exist (in total 5 km thick, Diebold et al., 1991): an older, lower trough filled with Stephanian to Lower Permian sediments with coal measures, and an upper, younger trough filled with Upper Permian redbeds.

Especially near the Rhine Graben the Tabular Jura is cross-cut by a dense and complex fault system with a preferred N-S orientation. Most of these faults are of Oligocene age, although there is evidence for movements in both the Trias (NEFF, 1980) and in the Quaternary (Herzog, 1956).

2.3 Folded Jura (FJ)

South of a major thrust zone lies the Folded Jura, consisting of the same cover as the Tabular Jura rocks (in Western Switzerland also of Cretaceous age), but decoupled from the basement and transported northwards for about 2 km in its eastern part and for 25 to 30 km in its western part. This thin-skinned detachment tectonics led to the formation of Jura-type thrust-and-fold structures. The thrust horizon is located within a relatively soft evaporite sequence of Middle Trias age ("Anhydrit Gruppe"). The sediments below the thrust are supposed to be directly connected to the Tabular Jura and are considered autochthonous. The crustal shortening has most probably also affected the crystalline basement. The foreland basement with its Tabular Jura-type cover (plus further Permocarboniferous troughs) dips gently (2°- 3°) in SSE direction beneath the Molasse basin, forming the fundament of that structural unit, and extending well below the northward thrust external crystalline massifs of the Alps.

2.4 Molasse basin (MO)

The Molasse basin is a deep (up to 6 km), elongated, asymmetric trough between the Jura and the Alps filled with Oligocene and Neogene detrital sediments of Alpine origin. Lithologies vary from calcareous shales and sandstones to coarse conglomerates with marked coarsening and thickening from north to south, i.e. from the distal to the proximal parts of the basin.

The southern part of the basin shows complex relationships between sedimentation and tectonics. Northward thrusting folded and deformed this part of the Molasse basin. The coarse synorogenic clastic sediments were subsequently overridden by nappes from the south and transformed into a deformed wedge (Subalpine Molasse, SM).

2.5 The Alps

The Alps form the complex collision zone between the European and African plates. The numerous tectonic units of the Alps can only very briefly be mentioned here:

- the *Prealpes* (PR), décollements nappes of Mesozoic and Paleogene terranes, derived from the Ultrahelvetetic zone and from various parts of the Penninic belt, found near the outer margin of the Alps between Lake Annecy and the Linth valley. They overlay Helvetic nappes or come to rest directly upon the Subalpine Molasse.
- the *Helvetic belt* (HE), the autochthonous and parautochthonous zones, and further the northwards thrust Helvetic and Ultrahelvetetic nappes, dominated by Cretaceous limestones, originally located between the southern rim of the Aar massif and the north Penninic domain (Masson, in Trümpy, 1980)
- the *Alpine (Central) massifs*, comprising the "external" massifs, Aiguilles Rouges (AG), Mont Blanc (MM) and Aar (AM), and the "inner" massifs, Gotthard (GM) and Tavetsch. They mainly consist of granites, gneisses and schists, and were deformed, metamorphosed and partly also thrust during the Hercynian orogeny and again during the Alpine event.
- the *lower* (PB) and *upper* (PM) *Penninic*, the *lower* (AS) and *upper* (AB) *Austroalpine units*, a complicated sequence of different rock types of Permian to Mesozoic age: sedimentary, volcanic (ophiolites) and metamorphic rocks also of basement type. They show imbricated structures and they were thrust northward during the Alpine orogeny. The degree of metamorphism in these units generally increases from north to south, where they dip into a steep zone, which is now interpreted as backfold (Pfiffner, 1992).
- the *Southern Alps*, clearly separated from the rest of the Alps by a major tectonic lineament, the Insubric line (IL), including the Ivrea zone with ultrabasites and granulite facies metamorphic rocks of possibly Variscan lower crust/upper mantle origin. In the north, crystalline basement units (BS) show a considerably lower degree of metamorphism, from greenschist to amphibolite facies, than immediately north of the Insubric line. Further to the south, Mesozoic and Paleozoic sediments (SA) and thick Permian volcanic rocks lie on this "Adriatic" basement. The sedimentary units are derived from the same facies belt as the Austroalpine nappes.

Directly adjacent to the Insubric line lie the Bergell (BE) and the Adamello (AD), both granitoid intrusions of Tertiary age. The southernmost tip of Switzerland reaches into the Tertiary basin of the Po plain (Molasse of Como).

Legend of the tectonic map of Switzerland (Figure 1).

AD = Adamello, granitoid intrusion	MM = Mont Blanc massif
AB = Austroalpine basement rocks	MO = Molasse basin
AG = Aiguille Rouge massif	PB = Penninic basement rocks
AM = Aar massif	PM = Penninic Mesozoic-Paleogene sediments and ophiolites
AS = Austroalpine Mesozoic	PR = Prealpes
BE = Bergell intrusion	RG = Rhine Graben
BS = Basement rocks of Southern Alps	SA = Southern Alps (Permian, Mesozoic and Paleogene)
FJ = Folded Jura	SC = Schwarzwald massif
GM = Gotthard massif	SM = Subalpine Molasse
HE = Helvetic and Ultrahelvetetic nappes	TJ = Tabular Jura
IL = Insubric line	VO = Vosges

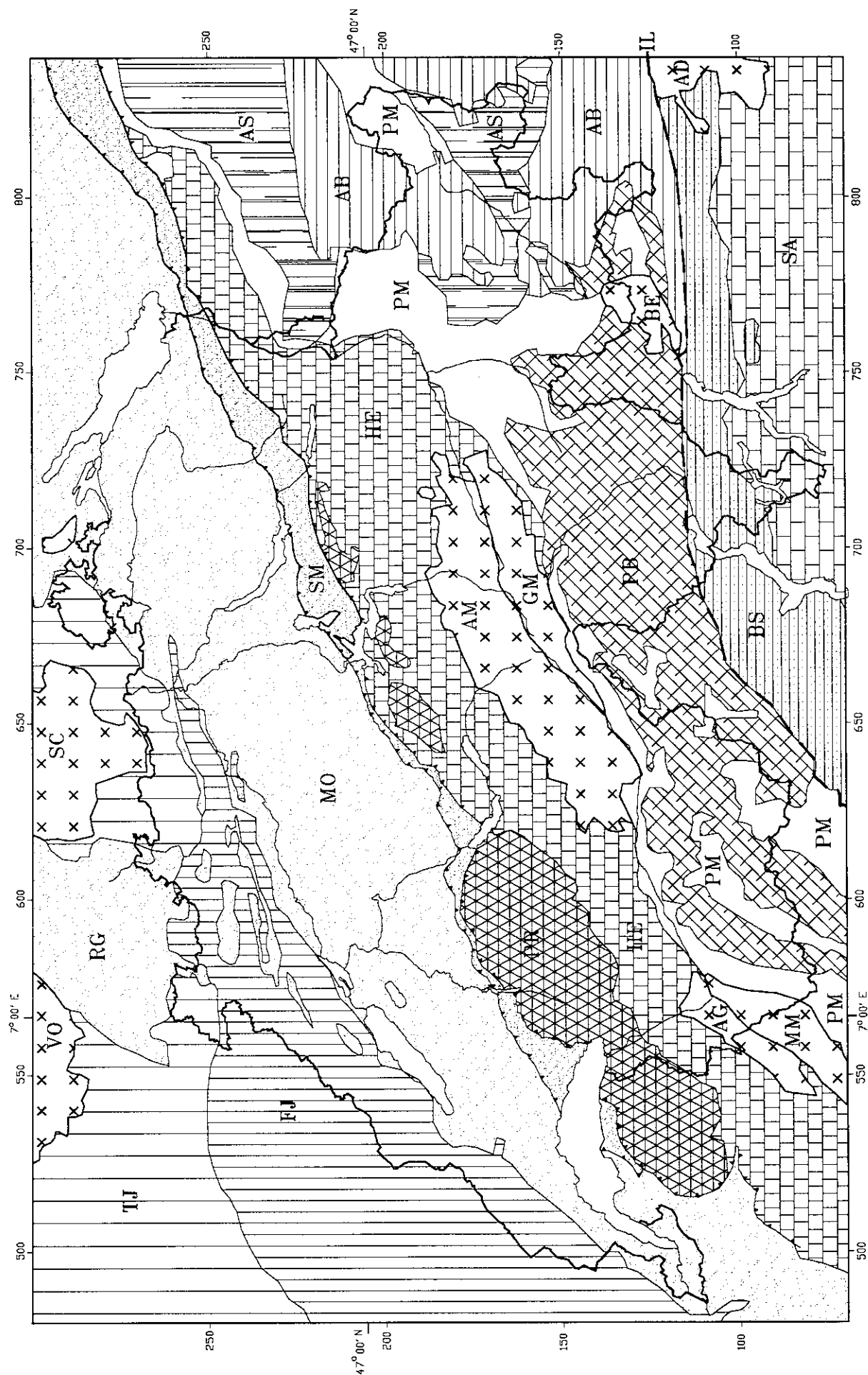


Figure 1 Tectonic map of Switzerland (simplified from Trümpy, 1980)

4. Database

Since the first edition of the Geothermal Map of Switzerland (Bodmer and Rybach), 1984 many more temperature data from borehole and tunnels have been acquired both in Switzerland and in the neighbouring countries. Therefore the necessity for reviewing this map became necessary. Several authors have contributed to increase and improve the HFD database for Switzerland since 1983: Trabattoni (1986), Schärli (1989), Kälén and Rybach (1990) and Eugster (1993). In addition to these works a HFD data compilation in the context of the EGT project was prepared by Cermák (EGT catalogue). Since the reference sources for the HFD values are various, in many cases it was not possible to infer exactly about the correction procedures used. Therefore the knowledge, especially for foreign data, about the quality and the uncertainty of the HFD determination is quite poor. Sometimes data for a particular site differed between compilations and source references. This fact can be explained in some cases by a misinterpretation of the correction methods used in compiling a data set. The data of few sites in Switzerland were elaborated more than once; either for particular studies or because of numerical technique improvements. This led now and then to different HFD values for the same site. Usually the more recent data were retained, but the choice was not always based on well defined criteria. The database used for the compilation of the Geothermal Map of Switzerland is given in Appendix I and II. Appendix II contains more detailed information only because of the availability of more complete data from boreholes. For HFD determinations outside Switzerland only the sites situated up to a distance of ca. 50 km from each Swiss border extremities were used (i.e. inside Swiss co-ordinates 430.000/10.000 and 890.000/350.000, see Figure 2).

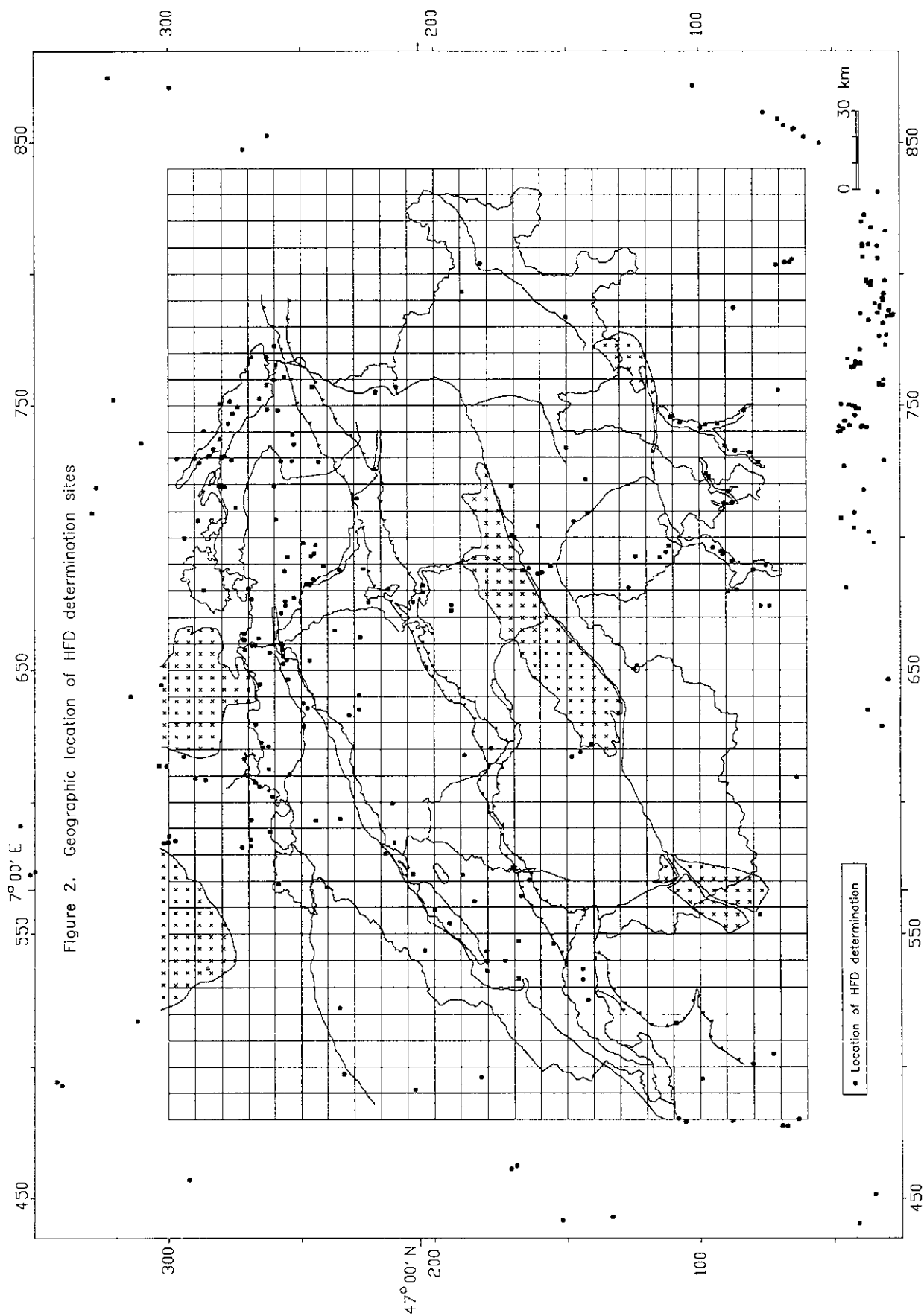
In the EGT catalogue only the co-ordinates of the sites and the values of Q_0 (HFD determination without temperature correction, see chapter 5) and Q_c (HFD determination with temperature correction) are listed. Most probably the Q_c values in this catalogue are based on topographic corrected temperature data.

The HFD database consists nowadays of about 340 HFD determinations; 150 in Switzerland and 190 in the surroundings. Table 1 characterizes the HFD sites in Switzerland according to their category.

Table 1 HFD site categories in Switzerland.

Category of HFD determination	Number of HFD determinations
Borehole	108
Lake (11 different lakes)	40+2 *
Tunnel or shaft	14

* Also datapoints in foreign countries if the lake is partly situated in Switzerland. In the Lake of Constance in two locations two different temperature profile were measured



5. Data acquisition and processing

5.1 Heat flow density determination

The heat production within the earth is largely due to the radioactive decay of unstable natural isotopes, mainly ^{238}U , ^{235}U and ^{40}K . The increase of temperature with depth gives rise to a steady terrestrial heat flow which has a world-wide average value of 87 mW m^{-2} at the earth's surface (Pollack et al., 1993). The temperature increase with depth, called the geothermal gradient, reaches on the continents a value of approximately $0.03 \text{ }^{\circ}\text{C m}^{-1}$ in the upper few kilometres of the earth's crust. The radioactive isotopes, responsible for most of heat generation within the earth, are mainly concentrated in the upper continental crust. In consequence, both the geothermal gradient and the terrestrial heat flow decrease continuously with depth.

The most significant heat transfer mechanisms in the subsurface are conduction and convection. The convection within the upper crust is very often related to water circulation through rock pores or fractures. In general, due to the poor knowledge of the hydrogeological conditions of the subsurface, is not possible to calculate the part of heat transferred by convection.

The heat flow density q (HFD), due to the conductive process, is defined as the heat flow per unit area [W m^{-2}] and is determined as follows:

$$q = K \nabla T \equiv K \frac{dT}{dz} \quad \text{where} \quad K = \text{rock thermal conductivity } [\text{W m}^{-1} \text{ }^{\circ}\text{K}^{-1}]$$
$$\frac{dT}{dz} = \text{geothermal gradient } [^{\circ}\text{K m}^{-1}]$$

This formula can be derived from the general heat transport equation under simplified conditions (e.g. one dimensional flow, stationary conditions, etc.). When the HFD proves to be constant by the measurements, the assumption of pure conductive heat transfer is justified.

Since in many cases the convective heat transfer is much more effective than the conductive one, the detection of water circulation systems is possible. In fact they create strong local, horizontal and/or vertical variation of the temperature field and of the HFD, especially in and near discharge or recharge areas.

The terrestrial heat flow density cannot be measured directly at a specific point. It has to be determined, as the above formula suggests, using a temperature profile over a relatively large distance (i.e. deep boreholes). The temperature gradient in conjunction with the rock thermal conductivity along the measured distance will provide a value for the average HFD across the section investigated. For the computation of HFD only conductive heat transfer along the measured section (boreholes, tunnels, etc.) is assumed.

If important radioactive heat production occurs within the measured profile, this effect has to be taken in consideration as well.

The numerical processing of the above mentioned formula for calculating the HFD can be performed in different ways (see Rybach and Bodmer, 1983). The choice of the most suitable technique depends on the quality and sampling rate of both the temperature and the thermal conductivity data.

For HFD determinations in Switzerland, the "Bullard plot" technique (Bullard, 1939) was selected as the most reliable and useful one. Each temperature value is plotted versus the thermal resistance between the earth's surface and the depth of the temperature measurement (see Figure 3). The slope of the regression line is proportional to the HFD. This method provides good results, especially in deep boreholes where the data quality usually decreases with depth. Furthermore, this calculation method can be applied to all data categories.

Experience in interpreting heat flow data in specific areas has shown that in many cases the changes in temperature gradient with depth are not only due to variations in thermal conductivity, but are the result of various effects like water circulation, thermal disequilibrium during the measurements,

incomplete corrections, measurements errors, etc. A statistical approach to evaluate the heat flow density is therefore considered to be much more realistic than conventional techniques. Furthermore much useful information can be derived from the regression technique; e.g. the correlation coefficient for the evaluation of the input data quality and the statistical error of the regression slope, which gives a measure of the quality of the HFD determination. Also the results of regressions of higher orders can give information about possible water circulation.

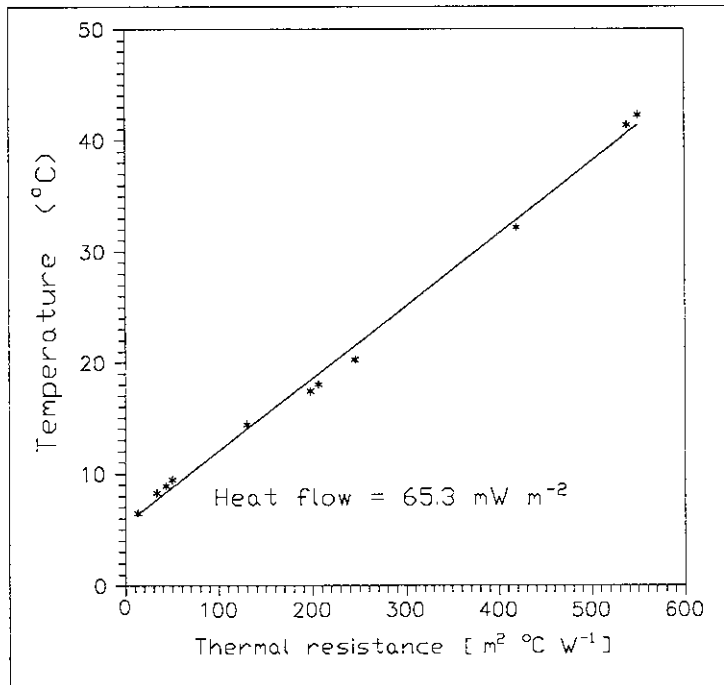


Figure 3.
Bullard plot with topography corrected temperature data. Borehole St. Moritz.

5.2 Rock thermal conductivity

5.2.1 Measuring technique

The thermal conductivity measurements were carried out with a QTM™ apparatus. With this instrument, based on a transient measuring technique, a line heat source in a probe is gently pressed against a planar surface of the sample and is heated at a constant rate. The increase of temperature at the centre of this source is measured by a thermocouple and allows the direct determination of the thermal conductivity of the rock sample. The accuracy of the thermal conductivity measurement is approx. $\pm 5\%$, the reproducibility $\pm 2\%$, depending also on the homogeneity of the sample. It is also possible to carry out measurements on water saturated samples. The thermal conductivity data obtained with this technique is representative only for a small rock volume around the thermo-element. In order to avoid systematic errors due to the effect of rock inhomogeneities the measurement has to be repeated at many different locations on the sample. Both the measuring device and the technique are described in detail in Schärli (1980).

For the determination of the thermal conductivity anisotropy the measuring plane of the rock sample has to be cut perpendicularly to the layering or to the schistosity. The thermal conductivity parallel to the layering (K_p) can be determined directly by positioning the line heat source on the sample perpendicularly to this direction. With a second measurement, holding the line heat source parallel to the layering, the component K_g is obtained. The component perpendicular to the layers (K_v) can then be calculated as follows:

$$K_v = (K_g)^2 / K_p \quad (\text{see also Grubbe et al., 1983}).$$

In case of horizontal layering the information concerning K_v is in general more important than of K_p , because it corresponds to the vertical component of the thermal conductivity, which determines the terrestrial heat flow. The conductivity anisotropy A is defined as the ratio K_p/K_v .

The thermal conductivity is also a function of temperature and pressure, which means that the values obtained at laboratory condition are slightly different from the real ones. Even if this is not a common practice sometimes this effect is taken in account for deeper boreholes (see e.g. Kälén and Rybach, 1990).

5.2.2 K determination on rocks: Results

From most boreholes selected for HFD determinations no core samples were available for thermal conductivity measurements. For this reason, appropriate surface rocks were sampled in order to obtain a representative conductivity profile across the geological sections found in the boreholes and also to establish a comprehensive thermal conductivity catalogue of Swiss rocks (Schärli, 1980; Bodmer and Schärli, 1983; Schärli, 1989). The actual catalogue consists of about 550 thermal conductivity determinations (status at the end of 1995). Most of the rock samples investigated have undergone also measurements to determine other physical properties such as porosity, density, radioactivity, etc. (Schärli, 1989).

Since the collected rock samples were not stored with special precautions their pore fluid evaporated almost totally. Therefore the samples had to be water saturated prior measuring. Except for rocks with very high porosity and permeability, it is recommended to evacuate the pore volume before the samples are watered. The other possibility is to put the samples in water for several days before measuring. Each rock sample had undergone 5 to 30 single measurements and from these an average value was calculated. The number of measurements taken was dependent on the degree of homogeneity of the rock material investigated.

The thermal conductivity of a rock is strongly dependent on its porosity, on the shape of its pores and the pore filling. In many cases these effects are even more important than the mineralogical composition of the sample. In fact the thermal conductivity of water is approximately twenty times larger than that of air. For this reason the thermal conductivity of water saturated samples is higher than that of the same dry samples, even at very small porosities (Schärli and Rybach, 1984). A general dependency of thermal conductivity on the porosity was proposed by Walsh and Decker (1966). Even at rock porosities below one percent, such as in crystalline rocks, this dependency is not negligible. Hanshin and Shtrikmann (1962) proposed theoretical relations for rocks with low porosities according to the shape of their pores.

For only a few HFD sites the vertical distribution of the thermal conductivity was measured in conjunction with the temperature log. In most cases the thermal conductivity information was extrapolated from other boreholes or from corresponding rock material sampled at the surface. Using the thermal conductivity catalogue the thermal conductivities were averaged by formation and attributed to the geological sections covered by the temperature measurements.

The knowledge of the anisotropy permits the selection of the thermal conductivity component parallel to the heat flow. In most HFD sites no exact information about the dip of the layering was available, such that horizontal layering had to be assumed. The error due to this assumption is negligible in most areas in the northern foreland of Switzerland. However in the Alps and in the Folded Jura this assumption is not valid and the dip of the layering has to be estimated from direct measurements in the field or at least from general trends in geological maps.

5.3 Temperature data categories

Numerous temperature data are available in Switzerland, mainly from boreholes in the northern foreland or from tunnels and shafts in the Alps. The quality of these data varies considerably. It is therefore necessary to eliminate unreliable data before further processing is possible. The different categories of temperature data used for HFD determinations are discussed below.

5.3.1 Temperature logs

The temperature logs are often the most reliable data due to the density of measuring points, to the knowledge of the borehole conditions and to the usually well calibrated measuring tools. Many temperature logs were performed by the Institute of Geophysics (ETH-Zürich).

If the measurements take place long enough after the last borehole disturbance, the fluid within it reaches an equilibrium temperature with its surroundings. The measured temperature will then correspond to the true rock formation temperature.

The shape of both temperature and differential temperature-depth profiles give information about the occurrence of water circulation in the vicinity of the borehole. An example is given in Figure 4: between 500 m and 750 m several water inflow zones are evident. The disturbance effect of inflowing water can be seen much more clearly in the gradient profile than in the temperature log. Especially where water movement is not parallel to the isotherms, heat transport due to convection is usually much more efficient than pure heat conduction. The identification of such convection zones is of primary interest in geothermal exploration.

Except for the Quaternary layers and a few local disturbances the temperature-depth profiles in the Tertiary sediments of the Molasse basin are nearly linear. However many local and regional temperature disturbances due to water or gas movement can be detected within the Mesozoic sediments in the Molasse basin and along the Jura.

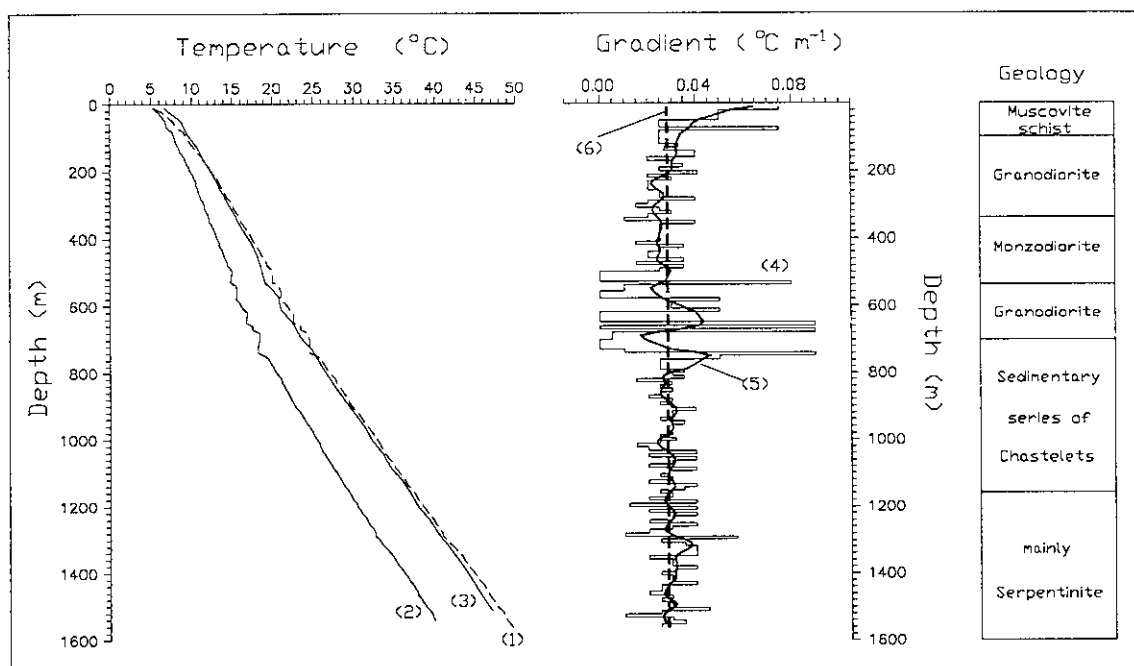


Figure 4. Temperature log and Gradient plot of borehole St. Moritz. 1) unprocessed data. 2) for topography effect corrected temperature, 3) for topography and paleoclimate effects corrected temperature data. 4) unsmoothed gradient. 5) moving average over 5 intervals 6) average along the whole profile ($0.0271\text{ }^{\circ}\text{C m}^{-1}$). For the gradient plot the unprocessed temperature data were used. 1 Interval = 5 m.

5.3.2 Individual temperature values

Many individual temperature values from boreholes, tunnels and shafts have been published or documented in internal reports. A few data from formation tests are also available. The quality of the data varies according to the measuring technique used. In tunnels and shafts it is important to obtain data shortly after the construction operations since air circulation due to ventilation affects strongly the rock temperature. Compared to the temperature logs this category of data is much less reliable because of instrumental inprecisions (e.g. calibration) and hydrogeological or other unknown disturbances. Many doubtful measurements have been eliminated, nonetheless this category of data should be considered with caution.

Usually the general trend of the temperature-depth curves is non linear due to variations in thermal conductivity with depth, to water convection and to the thermal history of the subsurface. Temperature

estimates between widely spaced measurement points should therefore not be evaluated by linear interpolation. A reasonable estimate of temperatures within lacking sections can be found by the use of master curves (Stegena, 1976). These curves are constructed on the basis of the best measured data within the area and are supposed to be representative for the regional geothermal field. For a typical set of curves for Switzerland see Synthese (1982). Such estimations should not be used for detailed calculations, because they do not take in account temperature gradient changes due to local conductivity variations or water movement.

5.3.3 Bottom hole temperatures (BHT)

During borehole logging operations in deep boreholes maximum thermometers are usually carried along with the different logging tools. The maximum temperature obtained is generally considered to be the "bottom hole temperature" (BHT), since in most cases the temperature increases with depth. Because the measurements are usually performed a short time after the end of mud circulation in the borehole, these BHT values do not represent the true formation temperature. In fact, due to the high rig costs or to borehole exploitation, is quite uncommon to perform BHT measurements after thermal equilibrium has been attained in the borehole. A correction method for disturbed BHT values was proposed by Lachenbruch and Brewer (1959). This method has been applied successfully in many cases, especially because the input parameters for the correction can usually be reconstructed from the drilling reports.

When the following two conditions take place the BHT temperature correction mentioned above is not anymore appropriate:

- the measured temperatures do not plot along a straight line after short equilibrium times
- using powerful drilling equipment, the mud temperature is often increased due to frictional effects. At shallow depths (< 500 m), the measured mud temperature is often higher than the formation temperature. Since the location of the maximum temperature measured in the borehole is no longer a function of the geothermal conditions, but of the drilling history, the quality of the corrected data is strongly affected.

In both cases more sophisticated correction methods are required for the evaluation of the true formation temperature.

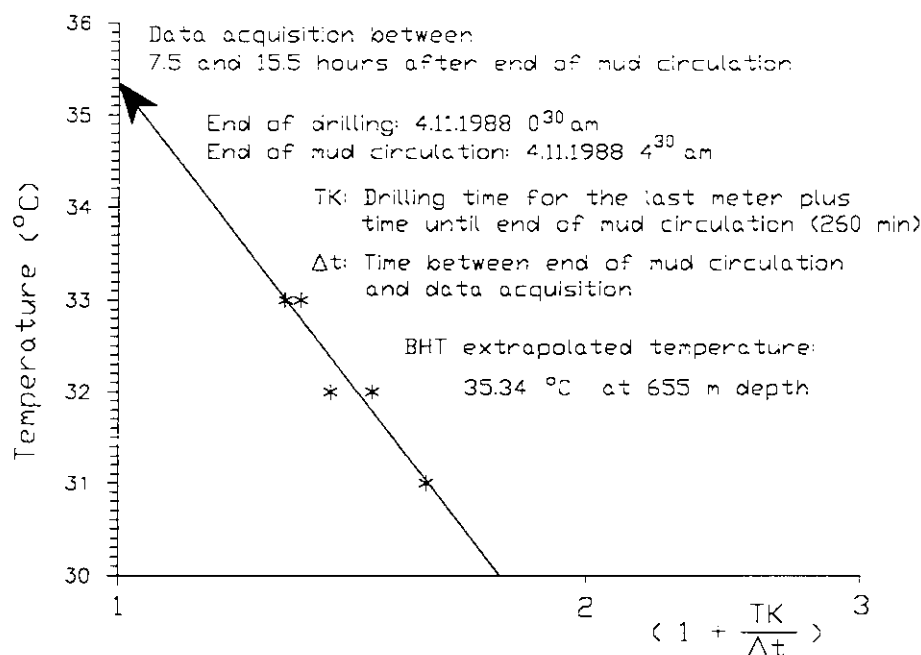


Figure 5.
BHT correction method.
Borehole Kreuzlingen 2.

5.4 Temperature corrections

Depending on the purpose of geothermal mapping, different temperature corrections have to be applied to the measured data prior to the HFD determination. The corrections are of special importance in cases where the geothermal information has to be extrapolated in horizontal or vertical direction. The most common corrections are the ones eliminating the effects of topography, paleoclimatic variations, uplift/erosion and subsidence/sedimentation. The topographic correction is a static correction which

should be applied in any case, the other corrections however are only required for special applications of geothermal data.

Many different correction procedures have been published in the last decades. The desire to apply the most suitable correction technique to the given regional geothermal conditions is often in contradiction with a standardised format which enables the construction of maps on a continental or on a world-wide scale. First attempts to establish standard procedures in geothermics have been made by the International Heat Flow Commission and by the Commission of the European Communities (Haenel, Rybach and Stegena, 1988; Balling et al., 1981).

The different corrections to the geothermal gradient or to the temperature data are usually performed sequentially, correcting first for the most recent perturbation (Bodmer and Rybach, 1983). This procedure is inaccurate since the different disturbances, for which correction is necessary, took place during overlapping episodes; they should therefore be treated simultaneously. A combined simultaneous calculation of the corrections is extremely arduous and the improvement of the results is in no relation to the increase of work. Furthermore it is generally impossible to obtain the requested parameters for detailed models.

The unknown proportion of conductive to convective heat transport represents a critical uncertainty in the correction of temperature data. Due to the lack of sufficient hydrogeological data, the convective heat flux can be only inaccurately estimated. In many cases the procedure is even inverted: the importance and the extent of water circulation systems is usually estimated by comparing the measured data after corrections (assuming pure conduction) with the expected temperature field. Large local anomalies in conjunction with pronounced variations in terrain altitude (i.e. strong relief of water table) suggest the occurrence of important convective processes. In attempt to account for the topographic, erosion and paleoclimatic effects on the temperature field, the corrections have been applied to the subsurface temperatures rather than to the geothermal gradients. The main reason for this lies in the HFD determination technique, the Bullard plot, which uses temperature values. Nowadays all calculations are performed by computers, even on PC's, using software developed for these purposes.

5.4.1 Topographic correction

The topographic correction takes into account the distortion of the subsurface temperatures due to a relief surface. Most methods assume a constant temperature or a given temperature distribution at the earth's surface and a constant heat flow at a lower boundary of the model configuration. The distorted isotherms are corrected assuming an idealised planar earth's surface (reference plane). This reference plane intersects the actual topography at a location of the site investigated. It is important to note here that the topographic correction does not account for denudation but only for the change of shape of the earth's surface departing from an initially planar topography.

The topographic corrections in Switzerland were performed according to the method of Birch (1950). This method, which accounts for a 3-dimensional, time-dependent topography was chosen because it can treat the terrain with a maximum degree of precision at a sufficient radius around the site investigated. Correction techniques using stationary topography (i.e. Jeffreys, 1938) or 2-dimensional calculations are not accurate enough in areas such as the Alps. The numerical calculations, using the Birch's method, is performed by the computer code TOPO. This software is a strongly modified version of the one described by England (1976).

Digitizing the topography was unnecessary because of the prior existence of a digitised topography of Switzerland called RIMINI. RIMINI was compiled by the Swiss Military Department and contains in sequential order 331 segments, each covering a sheet of the official 1:25'000 topographic map of Switzerland. Each segment contains altitude data corresponding to a quadratic grid with a mesh width of 250 m (Züst 1977; Bodmer et al. 1979). More details about the use of TOPO, its input parameters, RIMINI and its features can be found in Bodmer (1982).

5.4.2 Paleoclimatic correction

Temperature fluctuations at the earth's surface can penetrate to different depths, depending on their wavelength (i.e. duration). Daily temperature variations affect only the uppermost few tens of centimetres; seasonal variations penetrate up to a few tens of meters. Paleoclimatic changes, like glaciation periods, have affected the temperature field up to some thousands of meters depth so that

their effects are still disturbing a steady thermal "equilibrium". In order to correct for this paleoclimatic thermal disturbance a step model of temperature changes is chosen. The paleoclimatic temperature correction dT_{paleo} at a specified depth for a sequence of climatic events in the past can be obtained using the method after Birch (1948). To correct the temperature data properly also knowledge about present and past climatic parameters are needed. At particular the annual mean temperature at each site and the atmospheric lapse rate should be known and used according to Kappelmeyer and Haenel (1974). Further a paleoclimatic model for the site (i.e. for Switzerland) should be established. An attempt for this purpose have been made by Rellstab (1981, 1982). For applications of such paleoclimatic model in geothermics see Bodmer (1982), Schärli (1989), Kälin and Rybach (1990). Figure 4 shows the effect of temperature correction in the borehole St. Moritz, Figure 6 in that of Thun 1.

5.4.3 Erosion correction

The topographic correction accounts only for the shape of the relief and its changes with time, but not for the removal of material. Erosion correction can be made using the methods developed by Carslaw and Jaeger (1959) and Von Herzen and Uyeda (1963). Some parameters utilised in order to compute this correction are usually not known or guessed in an inaccurate way. Especially the erosion history is full of uncertainties (erosion rate, glacial erosion, uplift or subsidence). This temperature data correction should be used only when all parameters needed are available and only for specific purposes. For the general use this correction is not advisable because it will introduce more uncertainty than correcting the data.

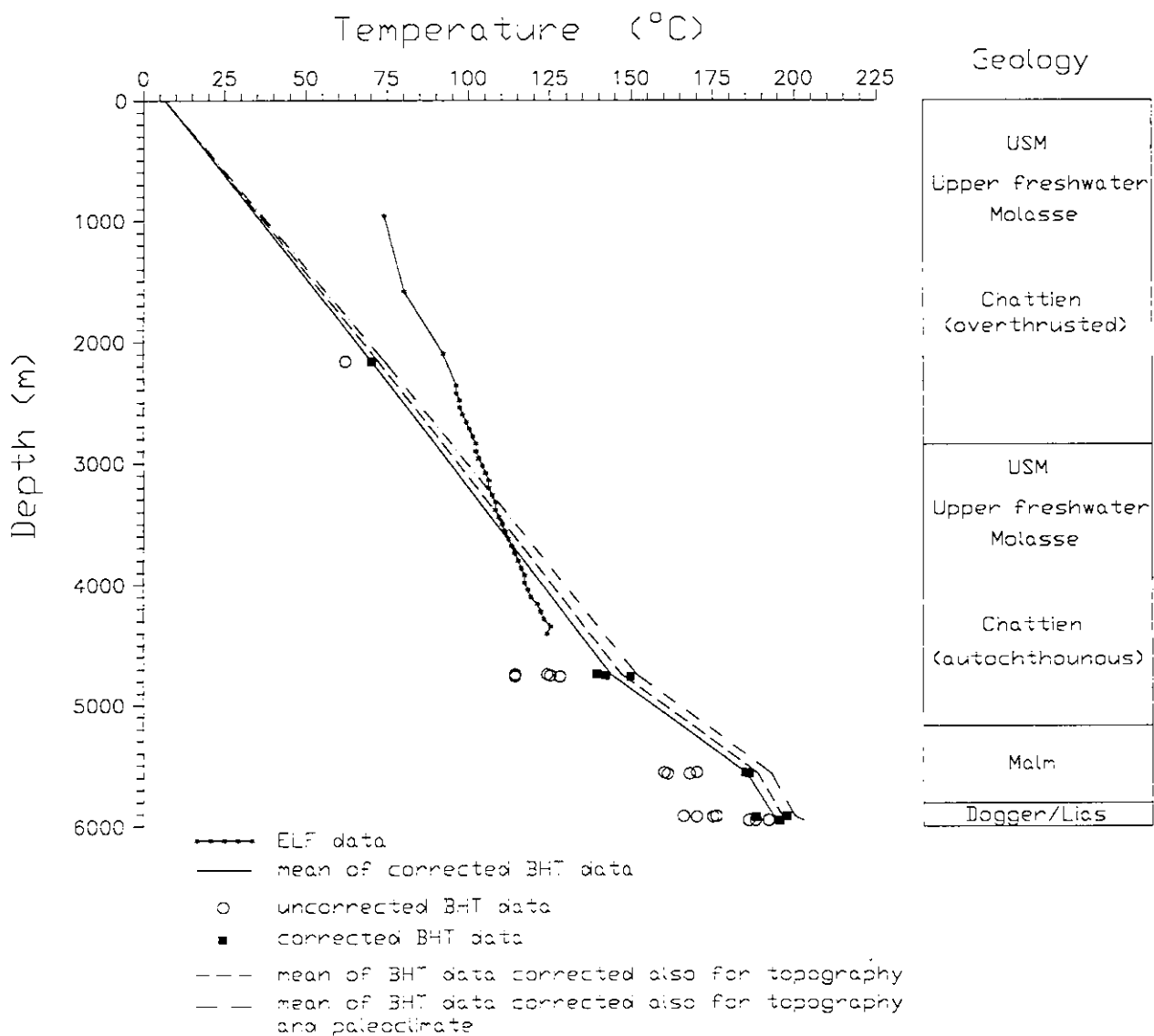


Figure 6. Temperature log with uncorrected and corrected BHT data from borehole Thun-1.

6. Geothermal Map of Switzerland

6.1 Mapping methods

The HFD determinations in Switzerland are unevenly distributed. Many interpolation methods are available to plot HFD contour lines on a map. Manual interpolations would introduce bias of unknown extent since the interpreter is usually influenced by physiographic units, geological boundaries, etc. A completely automatic map generation is, due the very unevenly scattered data points, not the best method either. Therefore a two-stage map contouring method was applied. In the first step an automatic contouring at intervals of 10 mW m^{-2} and a subsequent smoothing of the generated isolines were performed by computer. In the second step some the isolines produced only by numerical computations (i.e. where no data points are present) or that presented an "unrealistic" pattern were corrected or eliminated manually.

The Kriging method, which works on a statistical principle, is a widely used technique to interpolate geophysical data. However the HFD data points available are so unevenly distributed that in some regions computations led to numerical inconsistencies. For this reason a quadratic Inverse-Distance algorithm was chosen, where the weighting factor of a data point is inversely proportional to the distance of the other. For the interpolation also the choice of the appropriate mesh size is quite important. A wide mesh size, although appropriate in some areas with no data points, would lead to a loss of details in other regions. On the other hand a too fine mesh will produce much more details, due to the numerical computations, than what the existing data points should produce. For the Geothermal Map of Switzerland a mesh size of $10 \times 10 \text{ km}$ was chosen. The interpolated region lies inside the Swiss co-ordinates 480.000/60.000 and 840.000/300.000, and consequently is composed of 36×24 squares. The data points outside the mesh, until a distance of ca. 50 km from each country border extremities (i.e. inside Swiss co-ordinates 430.000/10.000 and 890.000/350.000, see Figure 2), were also taken in account for the interpolation. Most of the computation for contouring the HFD was done using a commercial available software called Tecplot™ (Amtec Eng., USA). All maps and figures were designed and plotted using AutoCAD® (Autodesk, USA).

As mentioned in Chapter 4 the reference sources for the HFD values used to construct the geothermal map of Switzerland are various. From many of them no exact information about the calculation procedures used is given or is possible to evaluate. Therefore in many cases very little is known about the quality and the uncertainty of the HFD determination. So it was not possible to introduce weighting factors for each data point according to its quality or presumed uncertainty.

The Geothermal Map of Switzerland 1 : 500'000 has been constructed on the basis of the complete data set given in Appendix I and II. In order to make this Swiss map compatible with other European HFD maps, only the topographic correction has been applied to the temperature data.

6.2 Results and Interpretation

The isolines of the Swiss HFD map cover the whole country. However in some region (e.g. in Valais, the south-western edge of the country and in Grisons, Eastern Alps) the isolines are dashed because their pattern is derived from very few and distant data points only (see Figure 8). New data points here could change their pattern in a very significant way. As illustrated in Figure 7, nearly half of the heat flow sites reach depths less than 500 m.

In Switzerland the mean regional HFD field decreases towards the south, from the Jura to the Central Alps and increases slightly again south of the Central Alps. The minimum lies approximately in the Central massifs where the earth's crust reaches its maximum thickness. Otherwise there is no or very little correlation with the surface geological features. However this can also be the result of the insufficient amount of data points which could outline geological or tectonic units. Several local anomalies can be attributed to deep groundwater circulating systems, in particular the pronounced positive anomaly in the northern part of Switzerland. The presence of the Permocarboniferous trough and intense fissuration allow deep warm waters to reach the surface or near surface formation (Schärli

and Rybach, 1991). The hot springs in the area of Schinznach, Baden and Zurzach are testimonies of these deep water circulation systems.

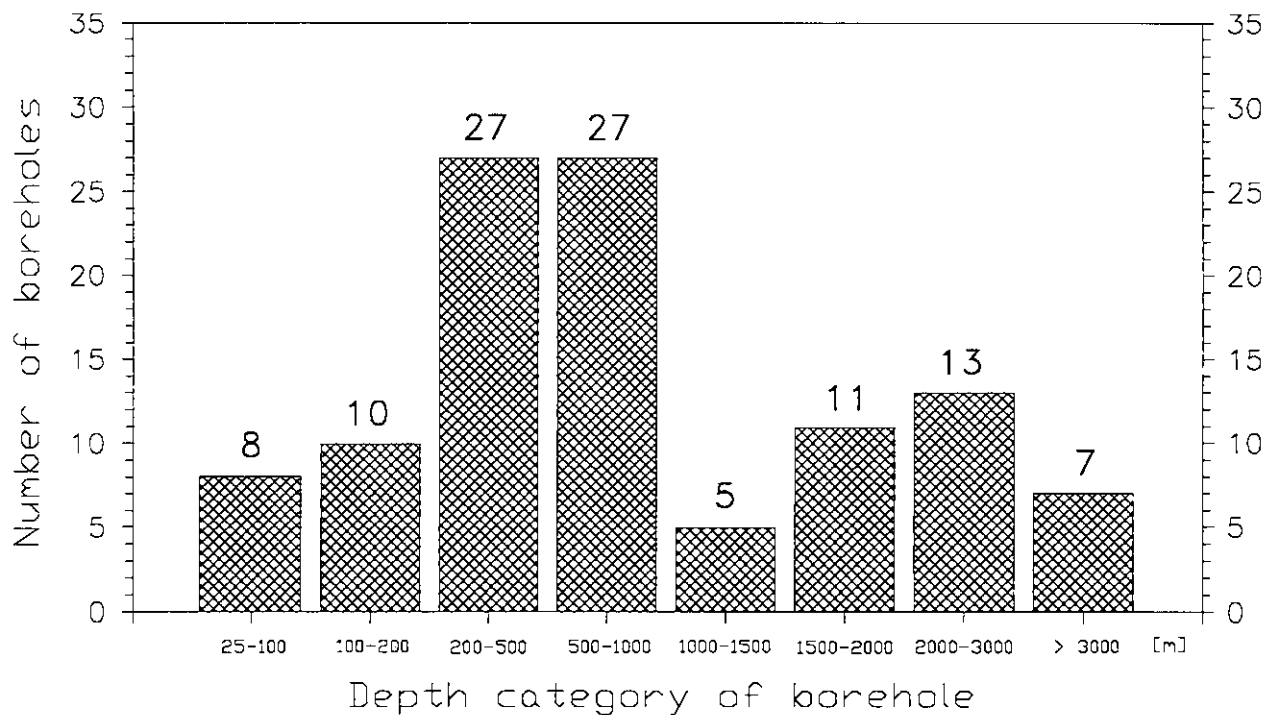


Figure 7. Depth distribution of Swiss boreholes used for HFD determinations.

In the 1985 edition of this geothermal map at the north-eastern edge of Switzerland a "dipole" like feature could be observed. This behaviour of the HFD field was due to bad quality data and inattentive line contouring. In fact this feature is created only by two data points; both HFD determinations there were calculated from very shallow boreholes: Brunnadern (60 m) and Gossau Silthang (31 m). For this new edition of the geothermic map it seemed reasonable not to include these data points for contouring the HFD field.

In addition to the HFD map three more maps are presented. They show the temperature field at 500 m, 1000 m and 2000 m depth. Due to the depth distribution of the boreholes and to the availability of data, these maps are not as complete as the HFD map. The sparsely distributed data points made the temperature values contouring by computer senseless. A manual attempt was made where the data allowed a "reasonable" interpolation.

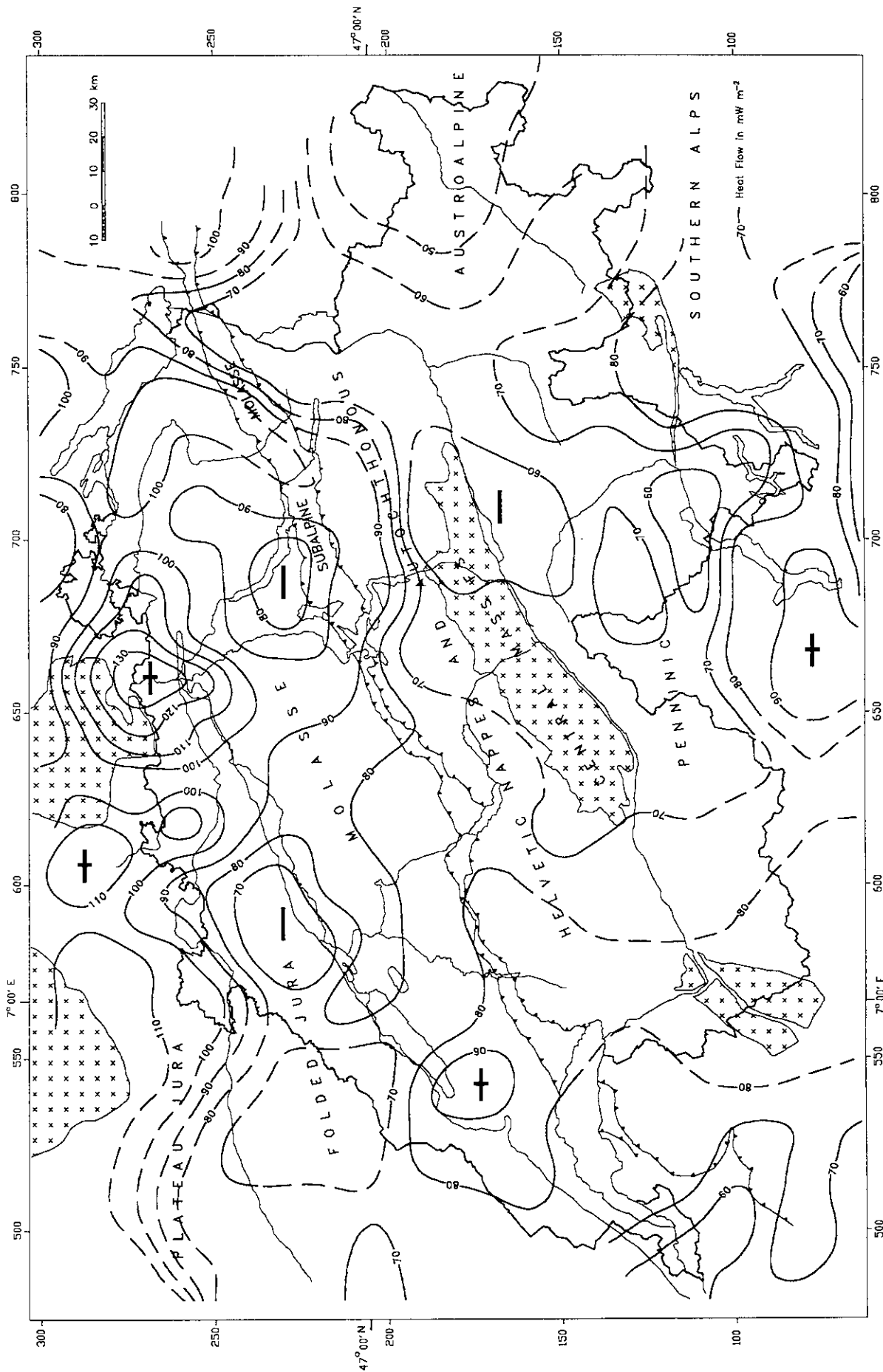


Figure 8. Swiss Geothermal Map with topography corrected data

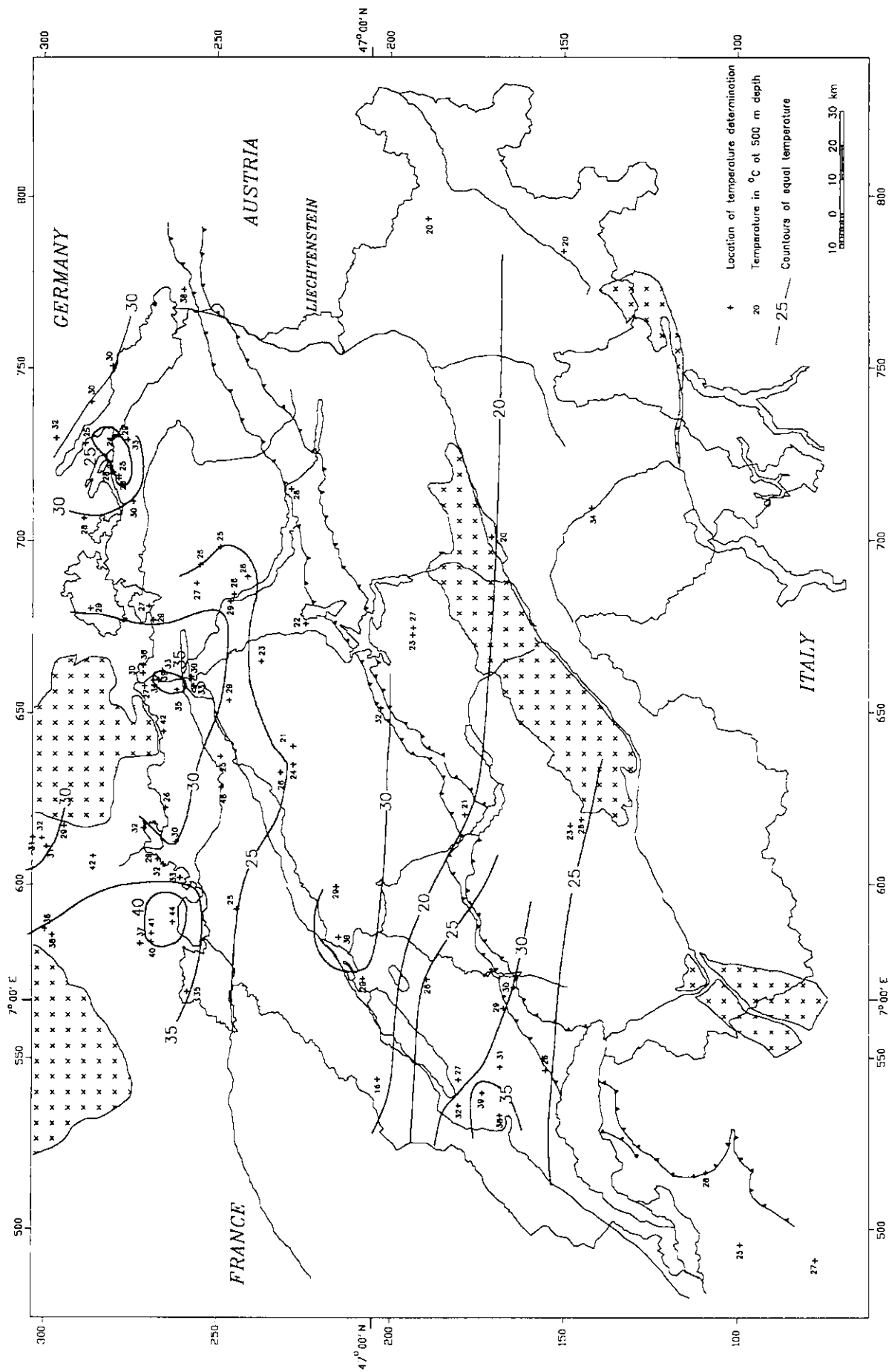


Figure 9. Map of temperatures at 500 m depth

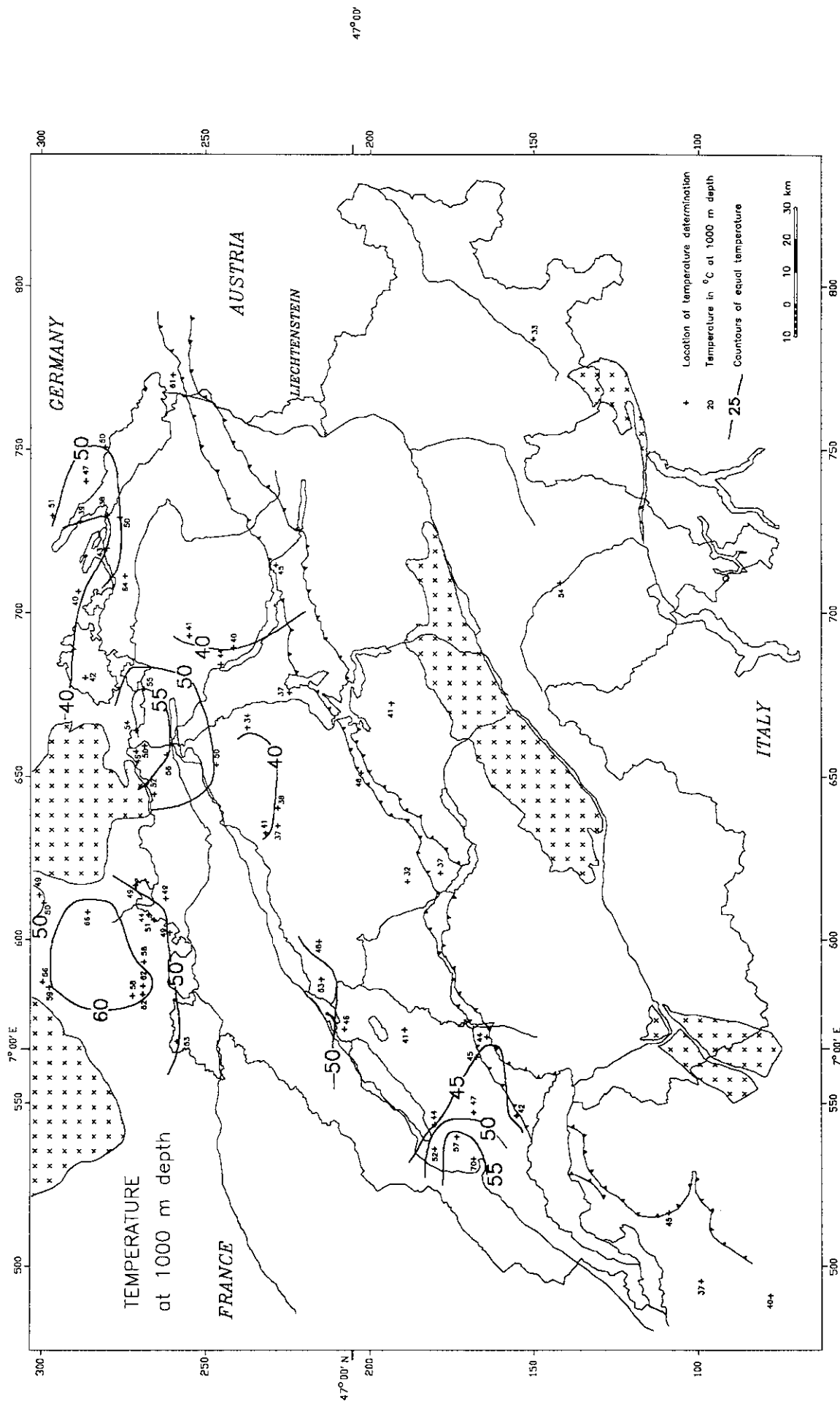
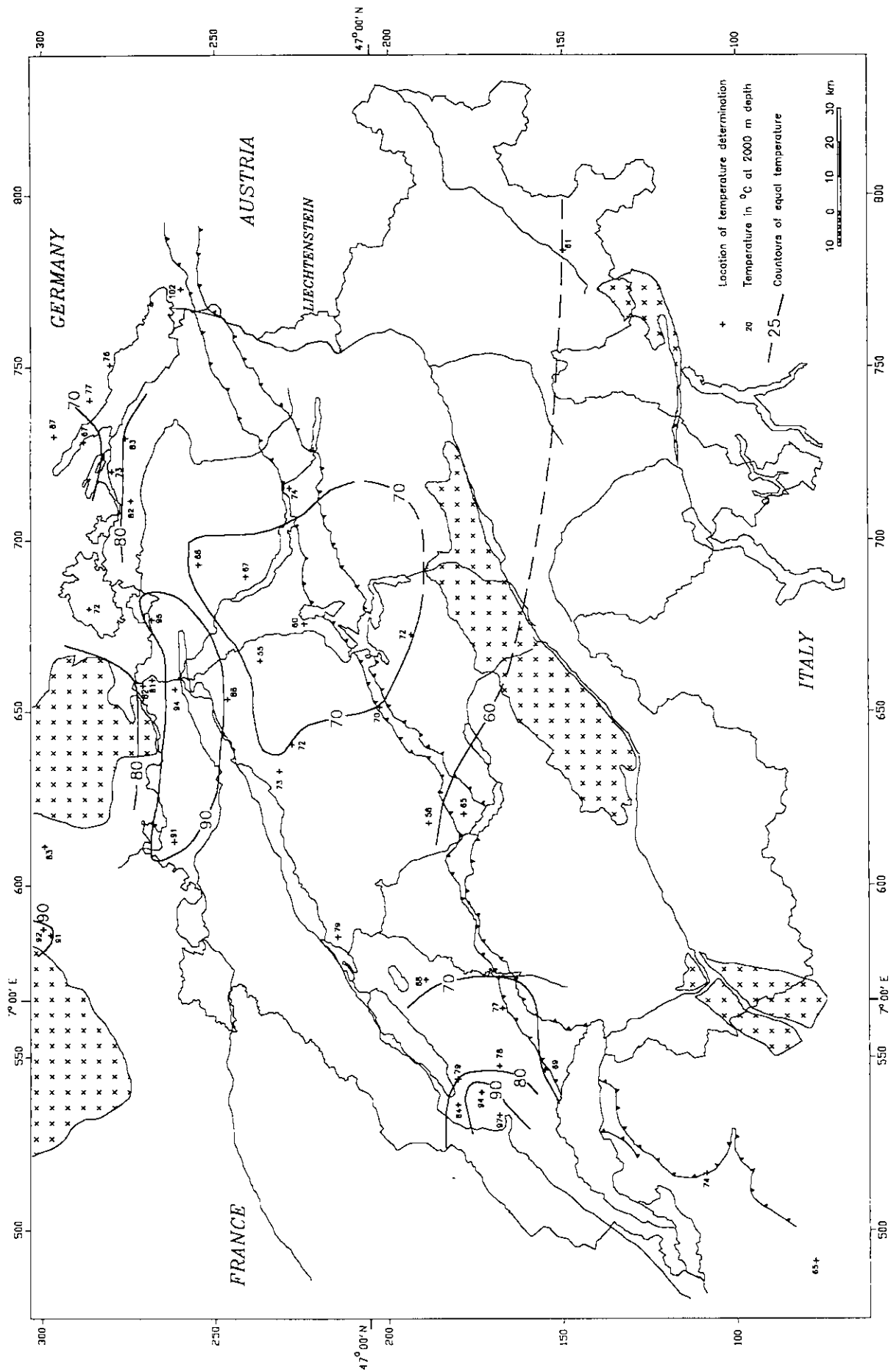


Figure 10. Map of temperatures at 1000 m depth



7. Conclusions

More than ten years have passed since the first edition of the Geothermal Map of Switzerland was published. In the meantime, numerous new HFD determinations have approximately doubled the available database. The need of a revised edition of the geothermal map thus became evident. The database at the time of the first edition consisted of about 150 HFD values; nowadays about 340 HFD determinations, 150 in Switzerland and 190 in the surroundings, are available. Most of foreign HFD values were taken from the EGT HFD compilation. Except for the Quaternary layers and a few local disturbances the temperature-depth profiles in the Tertiary sediments of the Molasse basin are nearly linear. However many local and regional temperature disturbances due to water or gas movement can be detected within the Mesozoic sediments in the Molasse basin and along the Jura.

The methodology for calculating HFD values has not changed since the first geothermal map, but more powerful and user friendly software have reduced the amount of work needed. The usual corrections methods, which take into account the conditions at the earth's surface, were applied to the temperature data: the topographic and paleoclimatic correction. However for the HFD map at 1 : 500'000 only the topographic correction was applied according to common practice. The Swiss HFD map is therefore compatible and can be compared with the HFD maps of other European countries.

Many interpolation methods are available to plot HFD contour lines on a map. For establishing the new Swiss HFD map a special methodology proved to be suitable. Due to the distribution of the data points a quadratic Inverse-Distance algorithm was chosen, where the weighting factor of a data point is inversely proportional to the distance of the other (see chapter 6). In a first stage an automatic contouring at intervals of 10 mW m⁻² and a subsequent smoothing of the generated isolines were performed by computer. In a second stage some of the isolines produced only by numerical computations (i.e. where no data points are present) or that presented an "unrealistic" pattern were corrected or eliminated manually. For the interpolation a mesh size of 10 x 10 km was chosen, inside the Swiss co-ordinates 480.000/60.000 and 840.000/300.000. The interpolated region is consequently composed of 36 x 24 squares. The data points outside the mesh, until a distance of ca. 50 km from each country extremities (i.e. inside Swiss co-ordinates 430.000/10.000 and 890.000/350.000), were also taken in account for the interpolation.

In Switzerland the mean regional HFD field decreases towards the south, from the Jura to the Central Alps and increases slightly again south of the Central Alps. The minimum lies approximately in the Central massifs where the earth's crust reaches its maximum thickness. Otherwise there is no or very little correlation with the surface geological features. Several local anomalies can be attributed to deep groundwater circulating systems, in particular the pronounced positive anomaly in the northern part of Switzerland. The presence of the Permocarboniferous trough and intense fissuration allow deep warm waters to reach the surface or surface near formation (Schärli and Rybach, 1991). The hot springs in the area of Schinznach, Baden and Zurzach are testimonies of these deep water circulation systems.

The HFD data density in Switzerland is among the highest in the world, nevertheless periodic updating on the basis of new data will be indispensable. More HFD determinations, especially in the Alpine area, are needed to delineate more precisely the terrestrial heat flow pattern.

8. Acknowledgements

Most HFD determinations have been performed in objects available for measurements ("opportunity boreholes", tunnels or shafts). In this regard the co-operation of numerous construction and oil/gas exploration companies, consulting bureaux and various cantonal and communal authorities must be mentioned. We would also thank St. Eugster (Zürich) for calculating about 20 new HFD values and for his efforts in using new methods for the representation of a new edition of the geothermal map.

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Appendix 1 HFD Database, sites outside Switzerland

HFD site	C	Latitude N ° ' "	Longitude E ° ' "	Q ₀ mW m ⁻²	Q _{topo} mW m ⁻²	Q _{topo} mW m ⁻²	HFD site	C	Latitude N ° ' "	Longitude E ° ' "	Q ₀ mW m ⁻²	Q _{topo} mW m ⁻²	Q _{topo} mW m ⁻²
Arlberg	A	47 7 0	10 12 0	90	-	-	Cernusco 5	I	45 30 40	9 21 0	45	50	-
Dornbirn	A	47 26 0	9 44 20	132	115	-	Cernusco 1	I	45 31 20	9 21 20	50	55	-
Hard 2	A	47 30 0	9 40 40	-	68	-	Cernusco 2	I	45 29 40	9 20 20	34	37	-
Plansee (mean)	A	47 28 0	10 47 40	-	101	-	Cernusco 4	I	45 30 40	9 20 40	40	43	-
Waizenhausen	A	47 26 20	9 34 20	-	70	-	Cernusco 6	I	45 30 40	9 18 40	37	40	-
Alpsee (mean)	D	47 33 0	10 43 40	89	101	-	Cernusco 7	I	45 32 0	9 21 40	51	56	-
Ammersee (mean)	D	47 59 40	11 7 20	50	86	-	Chero C2	I	45 54 40	9 51 20	26	31	-
Bad Bellingen 3	D	47 43 40	7 33 0	123	135	136	Chezaliet	I	45 43 40	7 33 40	51	82	-
Badenweiler 3	D	47 48 0	7 39 40	-	117	-	Collere	I	45 26 20	7 48 20	46	-	-
Baitenhausen 1	D	47 26 40	9 18 0	105	105	106	Corsico 1	I	45 25 0	9 5 20	46	53	-
Bäratal	D	48 5 50	8 54 20	67	76	-	Dello 1	I	45 25 20	10 4 20	35	38	-
Bodensee 1a	D	47 42 0	9 11 0	88	82	-	Gallign 1	I	45 26 0	9 51 0	40	46	-
Bodensee 1b	D	47 41 0	9 13 0	81	84	-	Gallign 2	I	45 25 40	9 48 20	37	43	-
Bodensee 1c	D	47 41 0	9 13 0	66	71	-	Gerola 1	I	45 46 6	9 26 40	55	57	-
Bodensee 1d	D	47 39 40	9 16 0	80	78	68	Lago d' Iseo 1	I	45 43 0	10 4 0	74	96	-
Bodensee 2 (mean)	D	47 37 40	9 27 2	83	88	-	Lago d' Iseo 2	I	45 44 0	10 4 0	71	70	-
Bodensee 3a	D	47 31 40	9 28 0	31	94	-	Lago d' Iseo a	I	45 45 40	10 3 20	-	102	-
Bodensee 3b	D	47 30 0	9 32 0	23	92	-	Lago d' Iseo b	I	45 42 40	10 4 40	-	100	-
Bodensee 4 (mean)	D	47 28 0	9 38 0	38	67	-	Lago d' Orta 1	I	45 48 40	8 23 40	-	97	-
Buggingen 1	D	47 51 40	7 38 20	70	79	-	Lago d' Orta 2	I	45 50 40	8 23 40	-	95	-
Dingelsdorf 1	D	47 42 40	9 8 40	-	83	-	Lago di Cavedine	I	46 1 0	10 57 0	64	70	-
Ettenkirch 1	D	47 39 40	9 26 40	82	82	83	Lago di Como a	I	46 8 0	9 19 4	-	86	-
Ettersbach	D	48 4 40	8 3 0	92	-	-	Lago di Como A1	I	45 55 0	9 9 0	67	57	-
Feldsee (mean)	D	47 52 20	8 2 0	98	78	69	Lago di Como A2	I	45 56 0	9 9 0	72	61	-
Geschahse	D	48 12 30	8 5 40	77	-	-	Lago di Como b	I	46 6 0	9 18 0	-	90	-
Hausen im Tal	D	48 5 0	9 2 0	70	88	-	Lago di Como c	I	46 2 0	9 16 0	-	86	-
Hechtsberg	D	48 17 0	8 8 0	89	-	-	Lago di Como d	I	45 58 40	9 17 0	-	98	-
Hegau	D	47 47 20	8 46 20	64	70	-	Lago di Como e	I	45 57 20	9 10 40	-	96	-
Heilershalm	D	47 53 0	7 37 20	-	130	-	Lago di Como f	I	45 53 0	9 21 0	-	97	-
Kirchzarten	D	47 58 40	7 58 40	72	81	-	Lago di Como g	I	45 52 20	9 8 40	-	88	-
Konstanz	D	47 39 40	9 10 20	-	102	-	Lago di Como h	I	45 50 20	9 5 20	-	97	-
Kunklerwald	D	48 1 40	7 59 20	71	-	-	Lago di Como M	I	46 1 0	9 17 0	69	89	-
Moosengrund	D	48 14 0	8 16 40	88	-	-	Lago di Garda 1	I	45 41 0	10 43 0	77	98	-
Owlingen	D	47 48 40	9 10 20	104	103	104	Lago di Garda 2	I	45 43 0	10 44 0	83	100	-
Peisenberg	D	47 47 20	11 3 20	79	79	-	Lago di Garda a	I	45 47 6	10 48 0	-	88	-
Pfundersdorf 3	D	47 57 0	9 15 20	126	126	-	Lago di Garda b	I	45 44 20	10 46 0	-	96	-
Riegelsberg	D	48 17 40	8 13 40	89	-	-	Lago di Garda c	I	45 41 20	10 42 40	-	101	-

HFD site	C	Latitude N ° ' "	Longitude E ° ' "	Q ₀ mW m ⁻²	Q _{topo} mW m ⁻²	Q _{topo} mW m ⁻²	HFD site	C	Latitude N ° ' "	Longitude E ° ' "	Q ₀ mW m ⁻²	Q _{topo} mW m ⁻²	Q _{topo} mW m ⁻²
Salgau	D	48 1 0	9 28 40	98	95	-	Lago di Garda d	I	45 39 0	10 40 40	-	107	-
Schönmatt	D	48 15 0	8 8 0	81	-	-	Lago di Garda e	I	45 36 0	10 38 20	-	105	-
Silberberg	D	48 20 20	8 20 40	103	-	-	Lago di Garda f	I	45 32 0	10 36 0	-	103	-
Singen	D	47 45 0	8 49 40	69	80	-	Lago di Sirio	I	45 29 20	7 53 0	-	66	-
Überlingersee	D	47 45 0	9 10 20	69	74	-	Lago Maggiore 1	I	45 58 0	8 39 0	92	87	-
Vulkan	D	48 16 0	8 7 0	82	-	-	Lago Maggiore 2	I	46 0 0	8 41 0	95	91	-
Waldkirch	D	48 5 20	7 56 40	72	-	-	Lago Maggiore a	I	45 58 20	8 39 40	-	93	-
Aneuville	F	48 13 0	6 1 0	78	87	-	Lago Maggiore b	I	45 56 20	8 37 0	-	81	-
Areville	F	48 12 0	6 0 0	63	71	-	Lago Maggiore c	I	45 55 20	8 28 20	-	92	-
Belmont Buss	F	47 46 0	5 32 0	150	150	161	Lago Maggiore d	I	45 52 0	8 34 20	-	106	-
Besancan	F	47 15 0	6 5 0	74	74	83	Lago Maggiore o	I	45 49 20	8 35 40	-	89	-
Beuz-dessus	F	47 16 6	6 24 40	78	62	-	Lago Mergozzo	I	45 57 0	8 28 0	-	86	-
Bizonnés	F	45 30 6	5 24 0	96	96	101	Lago Vivierone	I	45 26 0	8 3 0	-	65	-
Blombières	F	47 57 0	6 20 0	97	108	-	Lambrate 1	I	45 29 20	9 15 40	44	47	-
Crancot	F	46 40 40	5 37 40	95	79	-	Lambrate 2	I	45 28 40	9 15 0	35	39	-
Essavilly 1	F	46 47 20	6 4 40	61	61	59	Lambrate 3	I	45 28 40	9 15 0	44	49	-
Eternoz	F	47 0 40	6 0 40	83	67	-	Lambrate 4	I	45 28 20	9 15 40	49	54	-
Faucigny	F	46 12 40	6 21 20	92	82	-	Leno 1	I	45 23 20	10 12 0	34	38	-
Feldkirch	F	47 51 0	7 16 0	86	86	88	Macdodi 1	I	45 28 20	10 8 20	35	37	-
Heimersdorf	F	47 34 20	7 13 0	-	110	111	Macdodi 4	I	45 28 20	10 7 40	30	32	-
Hirtzbach	F	47 36 0	7 13 0	141	146	-	Magnago 1	I	45 34 0	8 49 0	42	50	-
Humilly 1	F	46 7 0	6 1 40	81	65	-	Malossa 1	I	45 30 20	9 33 30	50	58	-
Humilly 2	F	46 7 0	6 2 40	51	51	48	Malossa 2	I	45 29 20	9 33 40	49	56	-
Ilie	F	48 21 0	7 19 0	97	106	-	Malossa 3	I	45 30 0	9 35 0	52	59	-
Jura 101	F	46 20 0	5 24 0	83	83	91	Malossa 4	I	45 31 20	9 32 40	47	54	-
Knoeringue	F	47 34 20	7 20 40	73	74	74	Malossa 7	I	45 30 40	9 33 0	46	53	-
Lac Annecy 1	F	45 52 0	6 10 0	95	94	-	Malossa 8	I	45 30 20	9 34 20	49	56	-
Lac Annecy 2	F	45 48 0	6 13 0	54	58	-	Montich 1	I	45 24 40	10 23 20	29	32	-
Lac de Bourget 1	F	45 45 0	5 52 0	56	53	-	Montiro 1	I	45 26 20	10 13 20	40	44	-
Lac de Bourget 2	F	45 46 0	5 52 0	53	51	-	Orzinuovo 1	I	45 23 20	9 56 20	36	-	-
Leymen	F	47 30 0	7 28 0	70	74	-	Orzinuovo 2	I	45 24 20	9 54 0	30	34	-
Mont Blanc	F	45 51 0	6 53 20	83	83	-	Orzinuovo 3	I	45 24 0	9 57 40	29	33	-
Paladru	F	45 27 0	5 32 40	87	73	-	Orzivec 1	I	45 27 20	9 57 0	37	39	-
Ronchamp	F	47 43 0	6 36 0	108	108	116	Orzivec 2	I	45 27 0	9 57 0	35	40	-
Saint Di	F	48 19 0	7 4 0	88	97	-	Orzivec 3	I	45 26 40	9 56 40	39	41	-
Salève 2	F	46 2 0	6 11 0	58	58	61	Orzivec 4	I	45 26 40	9 57 40	35	37	-
Savoie	F	45 56 0	5 53 20	82	66	-	Pandino 1	I	45 25 0	9 27 20	34	39	-
Soulitz 1	F	47 52 0	7 14 0	109	109	107	Pandino 11	I	45 24 40	9 29 0	33	37	-
Soulitz 2	F	47 51 20	7 14 20	134	118	-	Pandino 7	I	45 25 40	9 27 20	37	42	-
St. Germain	F	45 46 0	5 54 0	46	46	51	Pandino 8	I	45 25 40	9 27 40	37	41	-
Staffelfelden	F	47 49 20	7 14 20	-	120	-	Pernate 1	I	45 27 40	8 41 30	37	40	-

HFD site	C	Latitude N ° ' "	Longitude E ° ' "	Q ₀ mW m ⁻²	Q _{topo} mW m ⁻²	Q _{topa} mW m ⁻²	HFD site	C	Latitude N ° ' "	Longitude E ° ' "	Q ₀ mW m ⁻²	Q _{topo} mW m ⁻²	Q _{topa} mW m ⁻²
Sundgau 201	F	47 30 40	7 17 20	-	98	-	Planeng 1	I	45 23 40	9 42 0	45	51	-
T Die	F	48 18 0	7 5 0	85	95	-	Romanen 10	I	45 23 20	9 49 0	33	38	-
Uiseaux	F	46 30 0	5 22 40	87	71	-	Romanen 4	I	45 23 0	9 47 40	36	41	-
Vevy	F	46 39 40	5 38 40	125	126	132	Romanen 8	I	45 22 40	9 47 40	30	35	-
Antegna 1	I	45 29 0	9 48 20	36	42	-	Romanen 9	I	45 23 40	9 47 20	30	33	-
Aronate 1	I	45 31 20	8 50 20	42	46	-	Romentti 1	I	45 28 40	8 44 40	38	41	-
Arese 1	I	45 33 20	9 3 40	34	38	-	Seregna 1	I	45 33 40	9 22 0	51	56	-
Arluno 1	I	45 29 20	8 56 40	39	44	-	Sergnan 6	I	45 24 40	9 45 20	36	39	-
Bagnolin 2	I	45 25 20	10 7 40	30	33	-	Sergnano 8	I	45 25 20	9 41 40	34	36	-
Borgosa 1	I	45 28 20	10 15 0	48	52	-	Soncino 1	I	45 25 0	9 50 0	36	41	-
Brughe 1	I	45 32 40	9 17 0	40	44	-	Soncino 2	I	45 25 0	9 50 40	31	35	-
Brughe 10	I	45 33 20	9 15 0	44	49	-	Soncino 3	I	45 24 20	9 52 0	39	45	-
Brughe 13	I	45 34 0	9 15 40	48	53	-	Soncino 4	I	45 24 40	9 52 40	37	42	-
Brughe 17	I	45 33 40	9 14 0	40	45	-	Trenzano 2	I	45 27 40	9 57 40	24	26	-
Brughe 8	I	45 34 20	9 14 0	42	47	-	Trenzano 3	I	45 27 40	9 58 0	34	36	-
Brughes 1	I	45 32 0	9 15 40	50	55	-	Trenzano 5	I	45 28 20	10 4 40	44	47	-
Camisano 1	I	45 27 20	9 46 20	35	41	-	Trescor 1	I	45 24 20	9 39 0	34	39	-
Capriac 1	I	45 27 0	10 8 20	42	45	-	Trevigi 1	I	45 32 0	9 35 20	50	58	-
Caravag 1	I	45 29 20	9 38 0	33	38	-	Turbigo 1	I	45 31 40	8 46 0	52	59	-
Casirate 1	I	45 29 20	9 34 0	49	57	-							
Cassano 1	I	45 31 0	9 32 40	31	35	-							
Castene 2	I	45 27 40	10 16 40	41	44	-							
Cavagli 2	I	45 33 20	8 28 40	41	46	-							

LEGEND

C = Country; A = Austria; D = Germany, F = France; I = Italy

Q₀ = uncorrected HFD

Q_{topo} = HFD corrected for topography

Q_{topa} = HFD corrected for topography and paleoclimate

Appendix 2 HFD Database, sites in Switzerland

HFD site	Swiss coordin.		Latitude. N			Longitude. E			Q_0 (mW m ⁻²)	Q_{topo} (mW m ⁻²)	Q_{topo} (mW m ⁻²)	a.s.l (m)	Depth (m)	Geology at bottom	Year	T_{500} (°C)	T_{1000} (°C)	T_{2000} (°C)							
	x (km)	y (km)	°	'	''	°	'	''											1	2	3	4	5	6	7
Allschwil 1	607.500	267.400	47	33	25	7	32	40	114	114	114	-	276	326		1920	29	44	-	x					
Allschwil 2	605.960	265.820	47	32	30	7	31	5	117	117	117	129	332	922		1927	32	51	-					x	x
Allshofen	640.380	228.130	47	12	10	7	58	25	87	87	87	95	478	2166		1954	21	38	72						x
Aqui 1	682.130	246.560	47	21	35	8	31	30	97	94	94	116	417	500		1973	29	-	-		x			x	
Baldeggersee *	662.400	227.700	47	11	50	8	15	50	98	103	78	-	463	66 / 9.5		1978	-	-	-					x	
Balzeis	757.000	214.000	47	3	30	9	30	20	78	78	78	79	480	620		-	-	57	-				x		
Berlingen 1	719.690	280.200	47	39	40	9	2	55	90	91	91	92	593	2311		1964	27	43	73	x				x	
Berlingen 2	719.600	280.880	47	40	10	9	1	50	116	116	116	-	538	505		1984	28	-	-						x
Beznau KKW	659.490	267.240	47	33	10	8	13	50	117	117	117	135	326	322		1980	39	-	-				x		
Blaschena	709.250	142.050	46	25	20	8	51	40	122	79	79	80	455	653		1972	34	54	-				x		
Bielersee *	580.380	218.290	47	7	0	7	11	0	46	47	47	-	429	74 / 10		1977	-	-	-					x	
Birmenstorf BT 4	660.050	257.460	47	27	50	8	14	10	163	163	163	-	367	241		1983	-	-	-						x
Birmo AG	660.350	257.680	47	28	5	8	14	25	155	155	155	-	368	160		-	30	-	-				x		
Bodensee 1 B *	749.470	273.870	47	36	0	9	25	0	87	104	104	-	396	248 / 9		1977	-	-	-					x	
Bodensee 2 B *	747.020	275.660	47	37	0	9	23	0	101	103	103	-	396	252 / 10		1977	-	-	-					x	
Bodensee 3 B *	743.220	277.420	47	38	0	9	20	0	108	109	109	-	396	240 / 10		1977	-	-	-					x	
Bodensee 4 B *	748.440	262.730	47	29	55	9	24	40	96	105	105	-	396	250 / 10		1977	-	-	-					x	
Boswil 1	664.850	237.420	47	17	5	8	17	50	82	82	82	90	648	1836		1965	23	34	55	x					
Böftstein	659.340	268.560	47	43	0	8	13	10	169	192	192	192	347	1501		1982	34	51	81						x
Bronschhofen	719.500	260.160	47	28	55	9	1	30	97	97	97	-	540	40		-	-	-	-				x		
Brunnadern	728.610	243.300	47	19	40	9	8	25	52	34	34	35	680	60		-	-	-	-				x		
Buix	568.780	258.620	47	28	35	7	1	25	114	109	109	110	395	1053		1919	35	53	-					x	
Bulle	570.250	164.380	46	37	50	7	3	0	86	85	85	101	765	800		1992	30	44	-					x	
Campo Vallemaggia	680.920	126.740	46	17	20	8	29	20	99	81	81	100	1398	252		1990	-	-	-					x	
Chapelle 1	547.310	168.360	46	39	55	6	45	0	90	92	92	93	764	1531		1958	31	47	78	x				x	
Chigglogna	706.210	147.380	46	28	10	8	49	20	87	49	49	50	700	305		-	-	-	-				x		
Courillon 1	572.410	189.420	46	51	25	7	4	35	69	69	69	70	599	3084		1960	26	41	68	x				x	
Quarney	543.470	180.350	46	46	10	6	42	55	101	103	103	110	555	2229		1940	27	44	79						x
Delemont 1	592.870	244.480	47	21	0	7	20	40	80	72	72	92	426	432		1991	25	-	-					x	
Densbüren	646.480	255.050	47	26	45	8	3	20	-	120	120	-	516	237		-	-	-	-					x	
Eclepens 1	533.220	168.380	46	39	50	6	34	0	86	86	86	87	515	2150		1981	38	70	97	x				x	

HFD site	Swiss coordin.		Latitude. N	Longitude. E	Q_0 (mW m ⁻²)	$Q_{T_{500}}$ (mW m ⁻²)	$Q_{T_{1000}}$ (mW m ⁻²)	a.s.l. (m)	Depth (m)	Geology at bottom	Year	T_{500} (°C)	T_{1000} (°C)	T_{2000} (°C)	1	2	3	4	5	6	7
Egilsau 2	x (km)	y (km)	°	'	°	'	'	°	'												
Egg	680.800	269.880	47 34 30	8 30 50	120	120	120	-	423	Malm	1957	27	-	-	-	x				x	
Entlebuch 1	707.000	269.500	47 28 40	8 51 25	71	75	92	92	107	OSM	1986	-	-	-	-				x		
Eptingen 1	651.210	202.850	46 58 30	8 6 40	88	88	89	89	5282	Permocarboriferous	1980	32	46	70	x				x		
Esserlines	628.360	249.040	47 23 40	7 49 0	99	98	113	113	555	Upper Muschelkalk	1987	48	-	-	-				x		
Fehraltorf	539.780	173.490	46 42 35	6 39 5	102	105	105	105	2936	Gipskeuper	1963	39	57	94	-				x		
Frekendorf	698.060	249.230	47 23 10	8 44 25	93	93	110	110	940	USM	1984	25	-	-	-				x		
Frekendorf	621.040	262.370	47 30 40	7 43 5	176	176	201	201	250	Middle Muschelkalk	-	-	-	-	-				x		
Furka°	676.830	153.740	46 31 55	8 26 25	28	-	-	-	1450	Crystalline rocks of the Alps	-	-	-	-	-						x
Furthal 706	674.350	255.890	47 27 0	8 25 30	79	79	94	94	215	OSM	1979	-	-	-	-				x		
Furthal 709	676.000	256.000	47 27 6	8 26 50	122	122	-	-	205	OSM	1979	-	-	-	-				x		
Gossau Niederdorf	735.200	252.670	47 24 42	9 13 50	-	134	-	-	153	OSM	-	-	-	-	-				x		
Gossau Slihang	738.860	253.180	47 24 54	9 16 50	-	187	-	-	31	OSM	-	-	-	-	-				x		
Gothard 2a Strass.°	686.630	159.480	46 34 54	8 34 6	-	60	-	-	1200	Crystalline rocks of the Alps	-	-	-	-	-						x
Gothard 2b strass.°	686.690	159.290	46 34 48	8 34 10	-	43	-	-	1200	Crystalline rocks of the Alps	-	-	-	-	-						x
Gothard SBB 1°	688.380	164.400	46 37 30	8 35 40	-	51	-	-	600	Crystalline rocks of the Alps	-	-	-	-	-						x
Gothard SBB 3°	689.090	156.200	46 33 6	8 36 0	-	50	-	-	1200	Crystalline rocks of the Alps	-	-	-	-	-						x
Gothardstr.tunnel°	687.510	166.480	46 38 42	8 35 55	-	69	-	-	660	Crystalline rocks of the Alps	-	-	-	-	-						x
Greifensee 1°	693.040	246.150	47 21 42	8 40 0	105	89	89	89	31 / 10	Lacustrine sediments	1977	-	-	-	-				x		
Greifensee 2°	694.120	244.940	47 21 0	8 40 55	106	89	89	89	32 / 9.5	Lacustrine sediments	1977	-	-	-	-				x		
Grellingen	610.570	254.310	47 26 25	7 34 40	110	110	131	131	213	Dagger	-	-	-	-	-				x		
Gubrist	677.310	252.760	47 25 20	8 27 50	101	101	144	144	200	OSM	1977	-	-	-	-				x		
Guspispach (Schacht)	686.230	161.050	46 35 40	8 34 55	125	86	87	87	520	Crystalline rocks of the Alps	-	-	-	-	-				x		
Habsburg 5556.19	655.150	256.780	47 27 35	8 10 10	-	184	-	-	43	Upper Muschelkalk	-	-	-	-	-				x		
Hauenstein°	635.520	247.640	47 22 50	7 54 35	-	85	-	-	410	Jurassic	-	-	-	-	-						x
Hausen HH1	657.840	256.940	47 27 35	8 12 5	168	168	190	190	408	Upper Muschelkalk	1983	33	-	-	-				x		
Herdern 1	711.310	274.600	47 36 50	8 55 10	109	109	118	118	2155	Crystalline basement	1982	29	64	82	-						x
Hermigen 1	584.600	214.890	47 5 10	7 14 5	76	77	80	80	2425	Middle Muschelkalk	1982	39	53	79	x						
Holzisberg	757.080	245.780	47 20 40	9 31 5	56	50	51	51	194	Dagger	-	-	-	-	-				x		
Homburg 1	719.150	278.850	47 39 0	9 1 35	115	115	-	-	904	USM	1982	25	-	-	-						x
Hünenberg 1	675.520	224.590	47 10 5	8 26 5	70	70	72	72	3288	Malm	1965	24	37	60	x				x		
Kaiseraugst WB5	622.500	265.100	47 32 0	7 44 25	71	69	70	70	293	Rotliegendes (upp. Permian)	-	26	-	-	-				x		
Kaisten	644.640	265.620	47 32 25	8 2 0	99	118	118	118	1303	Crystalline basement	1984	30	49	-	-				x		
Klingnau 1	661.460	271.500	47 35 35	8 15 25	127	127	147	147	398	Lower Muschelkalk	1977	31	-	-	-				x		
Klingnau 2	661.510	271.570	47 35 35	8 15 25	-	111	-	-	282	Lower Muschelkalk	-	30	-	-	-				x		

HFD site	Swiss coordin.		Latitude, N		Longitude, E		Q_0 (mW m ⁻²)	Q_{topo} (mW m ⁻²)	Q_{topo} (mW m ⁻²)	a.s.l (m)	Depth (m)	Geology at bottom	Year	T_{500} (°C)	T_{1000} (°C)	T_{2000} (°C)	1	2	3	4	5	6	7
Klingnau 3	661.830	271.950	47 35 50	8 15 40			-	148	-	440	271	Lower Muschelkalk	-	-	-	-							
Kloten	687.350	256.200	47 27 0	8 35 25			101	101	119	444	400	USM	1985	27	-	-							
Kreuzlingen 1	729.200	276.170	47 37 25	9 9 30			104	105	106	539	2550	Permocar., Crystall. Basement	1962	33	50	83	x						
Kreuzlingen 2	730.650	278.850	47 38 55	9 10 40			115	113	132	417	655	USM	1988	29	-	-							
Krone	682.400	248.120	47 22 55	8 32 55			86	85	101	440	283	OSM	1992	-	-	-							
Küsnacht	689.300	241.490	47 19 5	8 37 10			69	71	72	642	2693	Malm	1960	26	40	67	x						
La Foulte	593.580	235.340	47 15 50	7 21 30			-	46	-	560	559	Jurassic	-	-	-	-							x
Lac de Neuchâtel 1 *	559.000	199.800	46 57 0	6 54 0			59	68	-	429	138 / 10	Lacustrine sediments	1977	-	-	-							
Lac de Neuchâtel 2 *	553.950	194.300	46 54 0	6 50 0			60	70	-	429	153 / 10	Lacustrine sediments	1977	-	-	-							
Lac Leman 1 *	536.700	144.200	46 27 0	6 37 0			55	76	-	372	310 / 10	Lacustrine sediments	1977	-	-	-							
Lac Leman 2 *	532.900	144.200	46 27 0	6 34 0			60	70	-	372	310 / 10	Lacustrine sediments	1977	-	-	-							
Lac Leman 3 *	525.200	142.250	46 26 0	6 28 0			75	82	-	372	310 / 10	Lacustrine sediments	1977	-	-	-							
Lago di Lugano 1 *	723.000	96.400	46 0 30	9 1 30			66	59	-	271	288 / 10	Lacustrine sediments	1978	-	-	-							
Lago di Lugano 2 *	724.100	97.300	46 1 0	9 2 20			66	59	-	271	288 / 10	Lacustrine sediments	1978	-	-	-							
Lago di Lugano 3 *	717.400	89.000	45 56 30	8 57 10			84	68	-	271	107 / 10	Lacustrine sediments	1978	-	-	-							
Lago di Lugano 4 *	713.100	87.700	45 55 50	8 53 50			93	81	-	271	74 / 10	Lacustrine sediments	1978	-	-	-							
Lago di Lugano 5 *	712.900	90.800	46 57 30	8 53 40			75	68	-	271	95 / 10	Lacustrine sediments	1978	-	-	-							
Lavin 1	803.990	182.450	46 45 50	10 6 35			73	46	47	1390	400	Crystalline rocks of the Alps	1908	-	-	-							
Leuggern	657.660	271.210	47 35 25	8 12 10			138	159	159	359	1632	Crystalline basement	-	27	45	82	x						
Lindau	692.820	255.100	47 26 25	8 40 10			109	107	109	516	2377	Crystalline basement	1964	25	41	68	x						
Linden	617.710	188.570	46 50 55	7 40 20			61	61	62	881	5448	Lower Keuper	1973	-	32	58	x						
Lostorf Bad 3	637.330	249.240	47 23 35	7 56 0			80	96	98	549	584	Upper Muschelkalk	1972	25	-	-							
Lötschberg *	621.800	140.930	46 25 10	7 43 20			80	62	-	1220	1560	Crystalline rocks of the Alps	-	-	-	-							
Lötschberg SB6	617.150	148.280	46 29 10	7 39 50			82	57	67	1183	550	Flysch (Dolder nappe)	1992	23	-	-							
Lötschberg SB7	618.970	145.000	46 27 25	7 41 10			130	86	104	1390	622	Crystalline rocks of the Alps	1992	26	-	-							
Malvaglia	721.870	142.810	46 25 35	9 1 30			-	57	-	980	107	Crystalline rocks of the Alps	-	-	-	-							
Marlet Dornier	543.730	203.610	46 58 55	6 42 55			62	60	61	1025	300	Cretaceous	-	16	-	-							
Menzingen	688.200	226.600	47 11 10	8 36 20			44	44	52	685	400	Molasse	-	-	-	-							
Mörschwil Steinach	748.180	258.680	47 27 50	8 13 40			179	179	-	540	103	OSM	-	-	-	-							
Mülligen BT2	659.490	257.200	47 27 50	8 8 50			-	93	-	355	72	Upper Muschelkalk	-	-	-	-							
Oberbüren Sonnentäl	728.740	257.490	47 27 25	9 8 50			-	93	-	490	104	OSM	-	-	-	-							
Oberuzwil Bichwil	728.870	253.400	47 25 10	9 8 50			-	85	-	640	-	OSM	-	-	-	-							
Otefingen	671.450	257.560	47 28 0	8 23 15			93	93	124	460	104	OSM	1985	-	-	-							
Palagnedra 1 °	692.460	114.920	46 10 50	8 38 10			-	48	-	400	870	Crystalline rocks of the Alps	-	-	-	-							x

HFD site	Swiss coordin.		Latitude. N		Longitude. E		Q_0 (mW m ⁻²)	Q_{topo} (mW m ⁻²)	$Q_{T_{2000}}$ (mW m ⁻²)	a.s.l. (m)	Depth (m)	Geology at bottom	Year	T_{600} (°C)	T_{1000} (°C)	T_{2000} (°C)	1	2	3	4	5	6	7
	x (km)	y (km)	°	'	°	'																	
Palagnedra 3°	692.830	124.050	46	15	40	8	38	35	-	400	1400	Crystalline rocks of the Alps	-	-	-	-							
Payerne	562.200	184.900	46	49	0	6	56	40	66	490	251	OSM	1991	-	-	-							
Pfaffnau 1	632.710	231.790	47	14	10	7	52	10	91	500	1843	Crystalline basement	1963	26	41	73	x						
Pfaffnau Süd 1	634.950	228.120	47	12	0	7	54	0	80	616	1209	Malm	1964	24	37	-	x						
Pratteln 41J8	620.740	264.540	47	31	55	7	43	55	76	270	127	Middle Muschelkalk	-	-	-	-							
Reinach 1	612.530	262.130	47	30	40	7	36	25	99	292	1793	Middle Muschelkalk	1989	30	49	91							
Riburg 2	629.210	267.200	47	33	20	7	49	35	80	300	214	Mesozoic	-	-	-	-							
Riehen 2	616.440	271.470	47	35	0	7	39	0	97	285	1247	Middle Muschelkalk	1988	32	49	-							
Rinken	656.600	261.900	47	30	25	8	11	30	122	385	1801	Rotliegendes (upp. Permian)	-	35	56	94							
Romanens 1	564.200	167.400	46	39	30	6	58	20	86	947	4022	Keuper	1977	29	45	77							
Ruckfeld	662.090	266.090	47	32	40	8	16	0	124	415	770	Mesozoic	-	33	-	-							
Rueras 2	700.070	169.620	46	40	20	8	45	55	87	1412	510	Crystalline rocks of the Alps	1974	-	-	-							
Ruppoldsried	599.450	215.600	47	5	30	7	26	55	96	481	986	Portland	1977	29	48	-							
San Bernardino °	733.800	150.090	46	29	25	9	10	50	79	1650	400	Crystalline rocks of the Alps	-	-	-	-							
Savigny 1	546.270	155.310	46	32	50	6	44	20	85	840	2486	Barrême/Hauterive	1960	26	42	69	x						
Schafshausen	653.620	246.760	47	22	10	8	9	0	115	421	2006	Crystalline rocks of the Alps	-	29	50	88	x						
Schinznach 5256.26	652.470	256.730	47	27	35	8	8	0	90	460	61	Muschelkalk	-	-	-	-							
Schinznach QN 83	653.900	255.430	47	26	55	8	9	10	91	350	25	Muschelkalk	-	-	-	-							
Sevelen 13	755.360	221.900	47	7	50	9	29	10	-	460	-	Mesozoic	-	-	-	-							
Sevelen 14	754.840	222.010	47	7	55	9	28	50	-	450	-	Mesozoic	-	-	-	-							
Siblingen	680.090	286.690	47	43	40	8	30	25	86	574	1522	Crystalline rocks of the Alps	-	29	42	72							
Simplon N (2) °	650.660	124.600	46	16	20	8	5	50	-	700	1700	Crystalline rocks of the Alps	-	-	-	-							
Simplon S (1) °	651.810	123.610	46	15	40	8	6	35	-	700	2200	Crystalline rocks of the Alps	-	-	-	-							
St. Moritz	783.700	150.260	46	28	35	9	50	5	78	1786	1562	Crystalline rocks of the Alps	-	20	33	61							
Sta. Maria	704.350	160.700	46	35	25	8	48	0	70	1823	1441	Crystalline rocks of the Alps	-	-	-	-							
Steckborn	719.020	279.750	47	39	20	9	1	25	125	643	632	Molasse	1983	26	-	-							
Tavanasa °	719.365	170.909	46	40	50	9	0	0	58	1380	900	Crystalline rocks of the Alps	-	-	-	-							
Thal Büchelberg	759.780	260.260	47	28	30	9	33	30	-	470	55	OMM	-	-	-	-							
Thun 1	620.350	178.550	46	45	30	7	42	20	82	1077	5952	Lias	1989	21	37	65							
Tiefenbrunnen/Zürich	684.200	245.350	47	21	10	8	33	10	83	97	736	USM	1981	26	44	-							
Treycoavagnes 1	536.140	180.270	46	46	20	6	36	10	85	77	3220	Buntsandstein	1978	32	52	84							
Tschugg 1	572.610	207.910	47	1	20	7	4	40	105	98	704	Portland (Malm)	-	29	46	-							
Tuggen	714.750	228.760	47	12	0	8	57	10	103	408	1648	Chaffien (USM)	-	28	45	74							
Tujetsch SB1	700.950	170.940	46	40	55	8	45	30	54	1510	543	Crystalline rocks of the Alps	1991	20	-	-							

HFD site	Swiss coordin.		Latitude, N ° ' "	Longitude, E ° ' "	Q ₀ (mW m ⁻²)	Q _{topo} (mW m ⁻²)	Q _{topa} (mW m ⁻²)	a.s.l (m)	Depth (m)	Geology at bottom	Year	T ₅₀₀ (°C)	T ₁₀₀₀ (°C)	T ₂₀₀₀ (°C)	1	2	3	4	5	6	7
	x (km)	y (km)																			
Tujetsch SB2	700.920	170.910	46 40 55	8 45 30	52	29	59	1510	834	Crystalline rocks of the Alps	1991	-	-	-					x		
Uster 401	697.240	244.340	47 20 40	8 43 30	91	91	107	500	136	?	-	-	-	-							x
Verbano 1	696.870	111.410	46 8 55	8 41 35	-	48	-	1280	850	Crystalline rocks of the Alps	-	-	-	-							x
Verbano 2	694.550	112.510	46 9 10	8 40 40	-	28	-	910	480	Crystalline rocks of the Alps	-	-	-	-							x
Vereina	793.210	189.190	46 49 35	9 58 20	70	49	28	1817	621	Silvretta Kristallin	1980	-	-	-				x			
Vierwaldstättersee 1 *	675.600	207.850	47 1 0	8 26 0	93	105	-	434	150 / 10	Lacustrine sediments	1973	-	-	-					x		
Vierwaldstättersee 2 *	679.400	204.150	46 59 0	8 29 0	83	104	-	434	215 / 9	Lacustrine sediments	1973	-	-	-						x	
Vierwaldstättersee 3 *	681.900	204.150	46 59 0	8 31 0	75	94	-	434	215 / 10	Lacustrine sediments	1973	-	-	-						x	
Welach	676.740	268.620	47 33 50	8 27 30	136	133	133	369	2482	Crystalline basement	1983	29	55	95	x			x			
Wellenberg SB1	674.430	193.430	47 53 20	8 25 0	83	58	84	846	600	Berrisian (Cretaceous)	1991	27	-	-				x			
Wellenberg SB3	672.340	193.510	47 53 20	8 23 25	79	63	74	738	1514	Berrisian (Cretaceous)	1991	23	41	72				x			
Yverdon/Beaير	539.680	180.320	46 46 15	6 39 0	80	96	100	438	599	Sequan	1981	-	-	-				x			
Zugersee *	680.500	217.100	47 6 0	8 30 0	100	92	-	413	197 / 10	Lacustrine sediments	1973	-	-	-					x		
Zugersee *	680.500	217.100	47 6 0	8 30 0	106	98	-	413	197 / 10	Lacustrine sediments	1973	-	-	-						x	
Zürichsee 1 *	687.800	235.585	47 16 0	8 36 0	107	97	-	406	136 /	Lacustrine sediments	1973	-	-	-						x	
Zürichsee 2 *	687.800	235.585	47 16 0	8 36 0	114	103	-	406	136 / 10	Lacustrine sediments	1977	-	-	-							x
Zürzach 3	663.740	271.480	47 35 30	8 17 10	127	127	-	346	701	Crystalline basement	1980	36	54	-				x			

LEGEND

Q₀:	uncorrected HFD.
Q_{10p0}:	HFD corrected for topography.
Q_{10pa}:	HFD corrected for topography and paleoclimate.
Year:	Year of drilling or of temperature measurements.
T₅₀₀:	Temperature at 500 m depth.
T₁₀₀₀:	Temperature at 1000 m depth.
T₂₀₀₀:	Temperature at 2000 m depth.
a.s.l	Altitude of sites (meters above sea level) For tunnels and shafts their altitude For lakes surface altitude
Depth	Maximal depth of boreholes. In lakes: 1st. Nr. = water depth 2nd Nr. = corer penetration (approx.) In tunnels and shafts overburden
*	Measurements in lakes
°	Measurements in tunnels and shafts

Temperature data category:

- 1: Uncorrected BHT
- 2: Corrected BHT
- 3: Test temperature
- 4: Continuous temperature log
- 5: Several temperature data
- 6: Single temperature measurements
- 7: unknown temperature measurement method

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