ATLAS OF GEOTHERMAL RESOURCES IN THE EUROPEAN COMMUNITY, AUSTRIA, AND SWITZERLAND

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1. Introduction

The first requirement for the exploration of geothermal energy is the understanding of temperature distribution below subsurface. In addition, to determine the resources, it is necessary to measure also hydrogeological and rock characteristics of the subsurface. The acquisition of data for the assessment was occasionally complicated or even prevented because of the absence of information, unreliable data, the confidentiality of data, etc. The ambitious aim to catalogue both resources and reserves had therefore to be restrictet - for the time beeing - to the assessment of the resources only. Even this would have been impossible without the excellent teamwork and enthusiasm of all the research teams involved.

The Atlas of the Commission of the European Communities is one of the major achievements of the Community's Geothermal Energy Research and Development Programme, and represents the results of work in many countries over several years and is the first attempt in the world to present comparable data on geothermal resources both within and across national borders. The Atlas, consisting of 110 Plates representing more than 400 maps, is a fundamental document for the exploration of geothermal energy.

2. Definition and Assessment of Resources

The terms resources and reserves are defined as follows:

Resources are that part of the geothermal energy which might be extracted economically and legally at some specified time in the near future. There are various categories of resources, reflecting the degree of certainty in each case. The resources include also reserves.

Reserves are the known resources demonstrated by drilling or by geochemical, geophysical, and geological evidence and which can be extracted economically and legally at the present time.

Reserves are subdivided further in terms of their geological assurance into proven (evidence from boreholes), probable (evidence from geological, geophysical, and/or geochemical investigations), and possible (only geological evidence) reserves.

The lower temperature limit of usefulness for geothermal energy is also open to definition. In theory, any groundwater with a temperature above 0 °C can be used for heat pumps. However, heat pumps cool the water passing through them, and in practice, the lower limit for temperature supply is set by the consideration that the water rejected from the heat pumps must not be so cool as to have an environmental impact on lakes, rivers or near-surface groundwater.

Under normal conditions, the fluid extraction is governed by the hydraulic conductivity or transmissivity. It is not usually possible to determine hydraulic conductivity during exploration because a borehole and costly pumping tests would be necessary. It is easier to determine effective porosity. Therefore, the assessment of resources is based on the effective porosity.

From experience the depth for economical heat extraction rarely exceeds 3 km under present day condition. To obtain an estimate of the total heat content of an area at that depth, the accessible resource base down to 3 km (ARB_3 expressed in joule) in low enthalpy areas can be determined by using the following simple equation:

$$ARB_3 = V \rho c (T_3 - T_o)/2, \qquad (1)$$

where:
- V = volume from the Earth's surface to 3 km depth, m^3
- ρ = mean density of the rock column, kg/m^3
- c = mean specific heat capacity, J/(kg K)
- T_3 = temperature at 3 km depth, °C
- T_o = surface temperatur, °C.

The heat in place (H_o in joule) contained within a given aquifer can be determined using a volume model of heat extraction (MUFFLER & CATALDI, 1978):

$$H_o = [1 - P)\rho_m c_m + P\rho_w c_w] [T_t - T_o] A \Delta z, \qquad (2)$$

where:
- P = effective porosity, unitless
- T_t = temperature at the top of the aquifer, °C
- Δz = net thickness or thickness of the aquifer, m
- A = surface area under consideration, m^2

and subscripts m and w refer to the rock matrix and water respectively.

It is obvious that only part of H_o can be recovered. This is expressed by a term called the recovery factor R_o. The product of R_o and H_o are the resources.

In most cases, the water has to be reinjected after use, either because it is highly saline or because there is a need to maintain pressure in the aquifer. The resource at wellhead for a doublet (i.e. a related pair of extraction and injection boreholes) is given empirically as follows (LAVIGNE, 1978):

$$H_1 = R_o H_o \qquad (3)$$

with:

$$R_o = 0.33 (T_t - T_r)/(T_t - T_o), \qquad (4)$$

where: T_r = temperature of the reinjected water.

In order that the data from each country should be reported on a comparable basis in this Atlas, the CEC expert group recommended that a value of T_r = 25 °C should be used for the purposes of calculation.

If only a production well without reinjection is considered (a singlet), the recovery factor is (GRINGARTEN, 1979):

$$R_o \approx 0.1. \qquad (5)$$

Only a part of the geothermal energy resources can be exploited economically at present. This can be expressed by introducing a recovery factor R_1. The reserves can then be calculated as follows:

$$H_2 = R_1 H_1. \qquad (6)$$

The recovery factor R_1 is difficult to determine. It depends on site-specific geological conditions as well as on the cost of the installation of a singlet or doublet.

The main data necessary for resource assessment are the thickness Δz, the temperature T, and the effective porosity P. The depth of the aquifer is also an important parameter because of the drilling cost. Data which can be obtained easily are the densities ϱ_m and ϱ_w, the specific heat capacities c_m and c_w, the Area A, and the mean annual surface temperature T_o. Other parameters, such as permeability, transmissibility, salinity etc., are of value in improving the assessment of the resource, and their knowledge is essential to evaluate the reserves.

3. Example

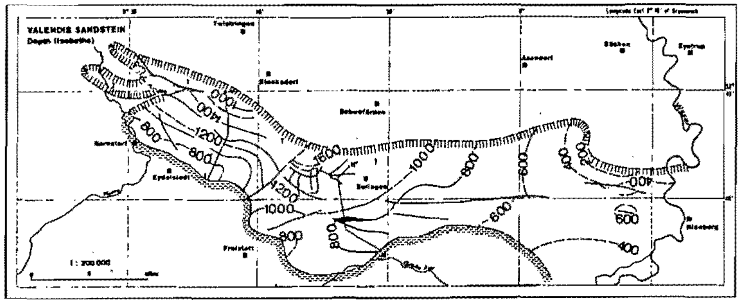
The first 5 Plates of the Atlas give a general view of the results acquired on a European scale and represent the geodynamics and geothermal perspectives, the heat-flow density, the temperature at 1000 m depth, the temperature at 2000 m depth and a review of geothermal resources based on available information including all geothermal installations at present operational or under construction. They are followed by more than 100 Plates on national or regional scale representing mainly the essential characteristics for each acquifer, such as depth, thickness, temperature and - as far as possible - porosity, permeability, transmissibility and salinity.

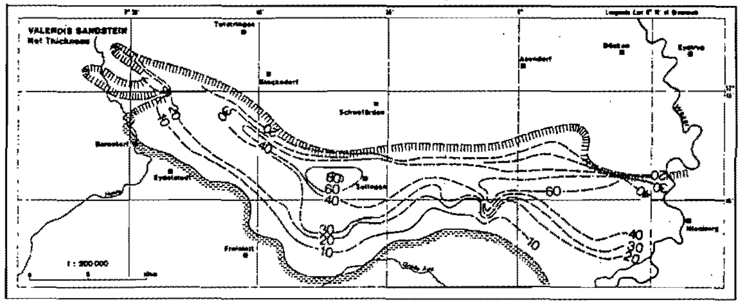
Syntheses of the results lead to the presentation of geothermal resources, expressed in joule per square metre, or of geothermal potential areas. To set these data in context, also maps demonstrating the relationship between geological structures and geothermal reservoirs are presented for each country.

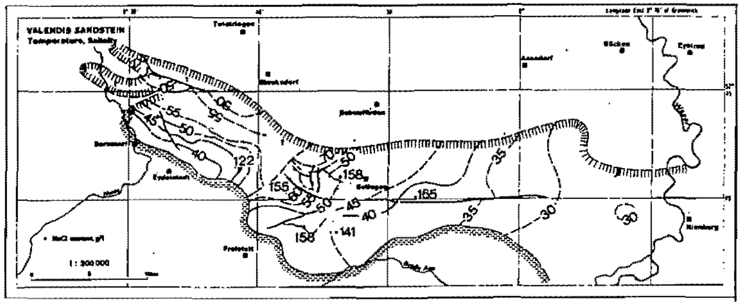
An example is given for the Valendis Sandstein of the Northern Basin of the Federal Republic of Germany. The structure of this formation, which is also an important oil reservoir, is characterized by a wide, east-west directed syncline. Its geothermal resources are close to the clayey line in the south, and maximum values of 2.5 GJ/m^2 have been assessed. The water consists of a highly saline brine with temperatures of about 50 °C at an average reservoir depth of 1000 m. The probable reserves have also been calculated and amount to 0.24 GJ/m^2.

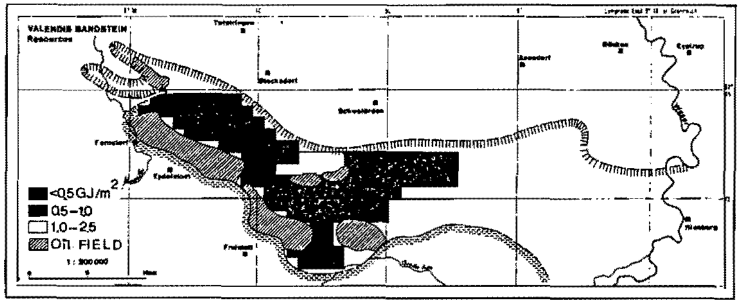
4. Summarized Results and a Short Outlook

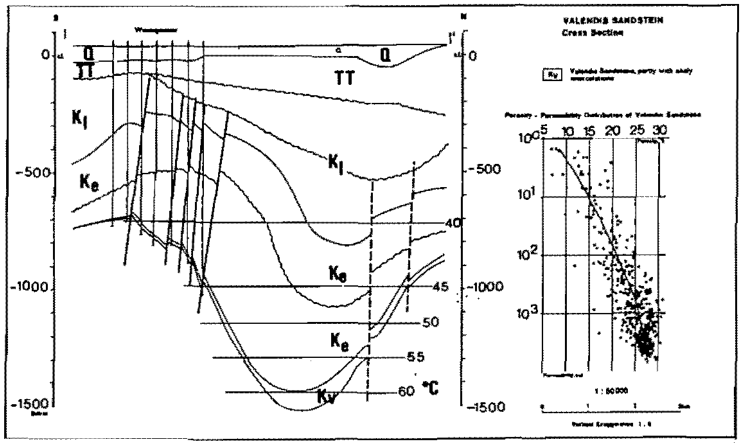
Geothermal resources have been investigated in promising areas. They are presented on national and European scales and summarized in the following table which demonstrates the present state of knowledge:

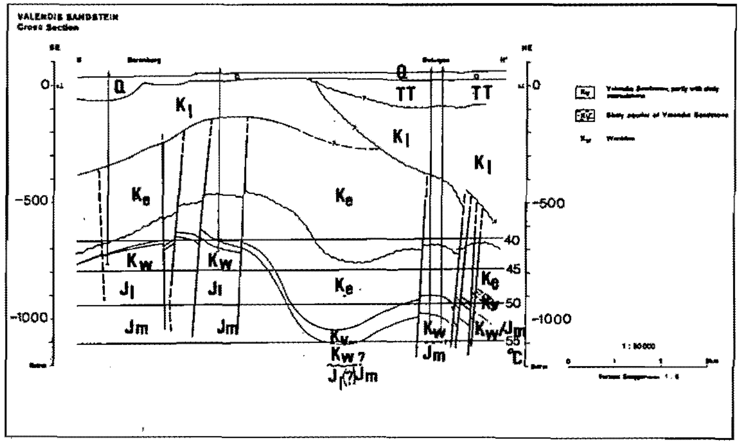

VALENDIS SANDSTEIN
Depth (Isobaths)
1 : 200 000


VALENDIS SANDSTEIN
Net Thickness
1 : 200 000


VALENDIS SANDSTEIN
Temperature, Salinity
1 : 200 000


VALENDIS SANDSTEIN
Resources
<0.5 GJ/m²
0.5–1.0
1.0–2.5
OIL FIELD
1 : 200 000


VALENDIS SANDSTEIN
Cross Section
1 : 50 000


VALENDIS SANDSTEIN
Cross Section
1 : 50 000

Country	Surface km^2	ARB_3 10^{18} Joule	HIP H_o 10^{18} Joule	Resources H_1 10^{18} Joule
Belgium	50	11	0.6	0.1
Denmark	42000	14900	770	206
Fed.Rep.of Germany	21470	7170	482	124
Greece	150	34	0.9	0.2
Spain	9760	2400	229	55
France	100800	32800	4100	830
Italy	8740	184865	141589	-
The Netherlands	5200	1950	78	21
Portugal	290	70	4.3	1
United Kingdom	25000	6000	400	40
Austria	4520	1980	345	90
Switzerland	4000	1350	100	2

Outside these areas, no assessment of geothermal resources can be made with current data. This of course does not exclude the existence of further resources. The fact that certain aquifers have been presented within a given area should not be taken to preclude the existence of others within the same zone. In Italy the indicated value corresponds to the highest value of heat in place, H_o, assessed within one area of the Main Reservoir.

Finally, the resource maps are thought to be a basis for scientists and engineers, as well as for governmental and industrial decisions makers. Furthermore, it is hoped that the present document is encouraging other groups to continue this work, to improve the procedure of assessment and to establish also a method for an evalutation of reserves, which could be acceptable by most of the groups, working in this field.