UTILIZATION OF GEOTHERMAL ENERGY IN SLOVENIA

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ABSTRACT:

Slovenia is locatcd between the colliding margins of the Eurasian and the African plates, more precisely on the Adriatic microplate and on the western border of the Pannonian basin. Its complicated tectonic and stratigraphical setting is reflected in the Earths thermal field. In the upper few kilometres of the crust temperatures increase from southwest to northeast. Low-temperature geothermal systems occur in both fractured and, more widely, intergranular **reservoirs.** Geothermal energy potential is concentrated in the eastern part of the country. The main geothermal parameters have been ascertained from **72** borcholcs, with a depth range from 100 to 4000 m. The direct use of geothermal energy, from **21** geothermal localities, amounted, in **1994,** to **762** TJ. There are more than **400** heat pump units extracting an additional heat of **40** TJ from shallow groundwater. Total geothermal resources in eastern Slovenia amount to about **7.66·10⁶** TJ. A feasibility study for electric power generation of about 1 MW is under preparation.

1. INTRODUCTION

The production of electricity and heating energy in Slovenia, amounting to **12,874** GWh/yr, is based. as of January, 1995, on partly imported fossil fuels **(63.5%),** domestic hydro power (20.1%) and nuclear power **(16.4%).** Increasing attention is being paid to alternative energy sources, such as geothermal energy, which are ecologically preferable.

In Slovenia, geothermal exploration began immediately after the first energy crisis in **1973,** and some years later systematic geothermal investigations were introduced.

Hydrogeological and geochemical research was active already some decades before **1973** in all the important spa locations. We began to explore first those localities where thermal baths, thermal springs or just hot water encountered during oil and gas drilling were already known. Over the last decade, geothermal research has been extended to areas without any surface manifestations. Besides geological and hydrogeological research methods, geophysical surveys have also been included in gcothermal exploration, Maps of geothermal parameters were constructed during this period. They are reliable guides for the planning of future geothermal exploration and development.

The Institute for Geology, Geotechnics and Geophysics, of Ljubljana, is the only organization in Slovenia which is engaged in fundamental research and applied geothermal investigations. In the near future, some new private enterprises and other organizations intend to become active in geothermal investigation and development.

2. GEOLOGICAL BACKGROUND

The geological and tectonic setting of Slovenia is complicated because its territory lies in the wnvergent area of the African and Eurasian tectonic plates or, more precisely, on the Adriatic microplate and on the SW part of the Pannonian basin. The greater part of Slovenia lies within the Alps and the Dinarides, which were formed during the collision phase of these two great tectonic plates that has continued from the Jurassic to the present. Folding and thrusting occurred in several phases, and numerous deep fracture zones were formed, enabling thermal water to circulate from depths **of** several kilometres to the surface.

Within the territory of Slovenia, several tectonic units can he distinguished: the most NE part belongs to the Pannonian basin, while the Eastern Alps, the Southern Alps, the Transition Zone and the Outer Dinarides represent parts of the Adriatic microplate (Fig. **1).** The area that belongs to the Pannonian basin **is** situated mostly N and **NE** of Maribor and Ptuj. It is filled by Tertiary marine and fresh water sediments deposited in the former Pannonian sea. Clays and mark predominate, with intercalations of porous sands and sandstones, where mineral, thermomineral and thermal waters are found. In this area the most extensive aquifer has an effective maximum thickness of **60** m of Lower Pleistocene **sands,** lying at depths of between **600** and 1500 m. The thermal and thermomineral waters found in this layer have temperatures of **40** to **70 ºC**. Each of the wells drilled yields from 10 to *30* kg/s. The basement of Tertiary layers, at depths of from 500 to more than 5000 m, consists mainly of Paleozoic metamorphic rocks, but also includes Mesozoic dolomites, limestones and shales. Mesozoic rucks were discovered in some parts of the Pannonian hasin during oil exploration in areas around the towns of Murska Sobota, Ljutomer and Lendava. They comprise layers of carbonate rocks, with thicknesses of between several tens and several hundreds of metres, overlying the metamorphic basement. There, the thermomineral waters have temperatures from **75** to 180 "C. At depths of over **4000** m, temperatures from 150 to ***200* "C** can he found, as has already been confirmed at some locations.

The elongated depression, lying to the east of the town of Novo mesto (included, according to some authors, in the Pannonian basin) is filled by Tertiary mark, sandstones and lithothamnion limestones. Carbonates and shaly Mesozoic rocks compose the border and basement of the depression. According to the geophysical and drilling data, the Tertiary layers attain thicknesses of 300 to **1700** m. Thermal water accumulates in the carbonate basement with temperatures ranging from **21** °C in the western part of the depression, to **70** °C in the eastern part. The thermal water discharges as thermal springs along the fault zones on the border of the depression, with yields ranging from less than 10 **kgis** to several **10** kgis.

The Eastern Alps (Austrides) reach northern Slovenia. They are composed of metamorphic rocks, whereas the Pohorje Mountains are characterized by tonalite that intruded the metamorphic rocks during the Tertiary. The Transition Zone and the Southern Alps consist of Paleozoic and Mesozoic sediments and, in lesser amounts, of magmatic **rocks** that are very weakly metamorphosed. Narrow and up to 1500 m deep Tertiary depressions and synclines form wedges in the Paleozoic and Mesozoic layers along the faults. They are filled with Oligocene and Miocene **marls** and thin layers of sandstone and conglomerate. Andesitic tuffs are **also** present here. The basement consists of Paleozoic and Mesozoic carbonate and clastic sediments, where thermal water with temperatures of 20 to 45 "C has been reported. The thermal springs in these areas yield from less than 10 kgis to 50 kg/s. These springs are located in fault zones, running in carbonate rocks along the Tertialy depressions.

The tectonic unit of the Outer Dinarides forms the SW and S part of the country. It is built upon Mesozoic limestones and partly on dolomites that are intensively and deeply karstified. Depressions, filled with Eocenic flysch, are situated between the the tectonic limestone blocks. Descending surface water penetrates to great depths due to karstification; this water cools the rocks far below the surface. This is the reason for the absence of thermal springs in this geological structural unit.

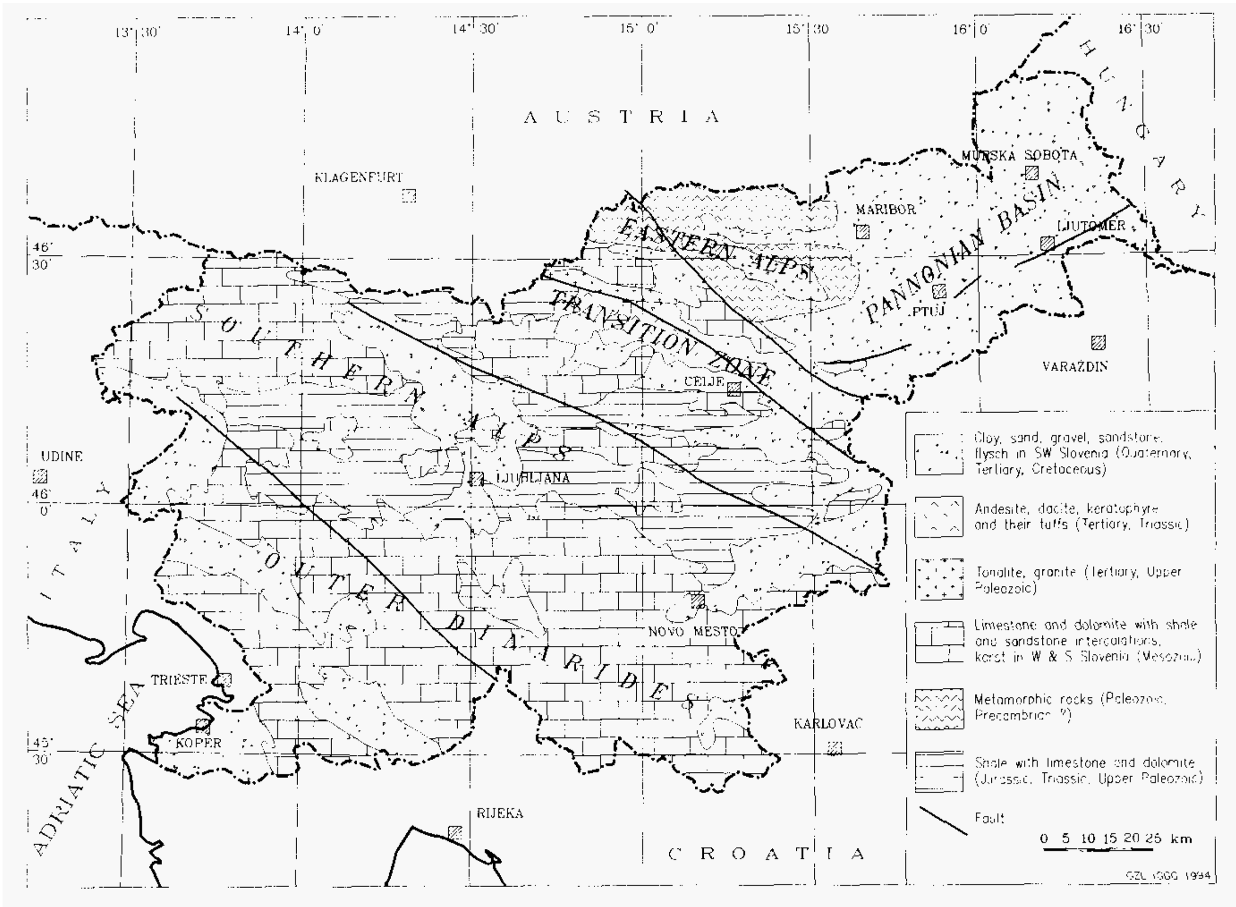

Fig. 1. The main tectonic units of Slovenia and their lithological composition

3. GEOTHERMAL INVESTIGATIONS

Systematic geothermal investigations started in 1982, aimed at the acquisition of fundamental geothermal parameters: virgin rock temperature and its gradients, thermal conductivity, and the concentrations of radiogenic elements in the rocks. All the results and a geothermal energy assessment for Slovenia were then published (*Ravnik*, 1982). Later on, the construction of temperature-depth maps, heat flow density maps and maps of potential geothermal areas was accomplished for the entire former Yugoslavia (***Ravnik*** et *al., 1992a*), while, solely for Slovenia, a detailed geothermal study was completed (***Ravnik,*** 1991). Geothermal energy resources were calculated in detail for the Pliocene sedimentary aquifer (Ravnik *et al., 1992b*), and for the pre-Tertialy sedimentary basement (*Kralj* et *al.,* 1993) in the Slovenian part of the Pannonian basin.

The temperature map for a depth of 1000 m (Fig. 2) illustrates the Earth's thermal field in Slovenia, with a distinct tendency of temperature increase from the SW to the NE part of the country. In this map all 21 localities for direct heat utilization are marked by triangles.

Temperatures in Slovenia, up to a depth of 4000 m, do not exceed 200 "C, whereas the temperature gradients change within the broad interval from less than 10 mK/m to about 70 mK/m.

4. RESULTS

A comparison of the tectonic map (Fig. 1) with the temperature map for a depth of 1000 m (Fig. 2) identifies quite well all those areas which are potentially important for geothermal energy utilization. In Fig. 3 the potential geothermal areas are shown with the maximum temperatures that can be encountered in known or probable aquifers, while for NE and E Slovenia estimates of geothermal resources are also given. For NE Slovenia, the geothermal resource assessment was carried out separately for the Lower Pleistocene aquifer and for the mostly assumed Mesozoic aquifers, where enough information about their hydrogeological and thermophysical properties had been acquired. The identified resources at the wellhead (H,) were determined using the volume model of heat extraction (*Muffler and Cataldi, 1978; Čermák and Haenel, 1988*), taking into account the douhlet scheme. In NE Slovenia, for the above-mentioned aquifers the geothermal resources amount to about $7 \cdot 10^6$ TJ. Taking into acwunt the aquifers of the Krško-Brežice depression, which provide resources of ahout $0.66 \cdot 10^6$ TJ, the total geothermal resources of E Slovenia (Fig. 3) amount to about $7.66 \cdot 10^6$ TJ ($\approx 180 \cdot 10^6$ TOE). There are some other areas, especially the Tertialy depressions, where resources could have been calculated but were not due to scarce data (only reservoir temperatures are given) and mostly unknown aquifer extensions.

The metamorphic complex acts as an aquifer system only where it has been tectonically fractured. The total geothermal energy consumption at 21 locations amounted, in 1994, to about 762 TJ, or to 17,880 TOE. Thermal spas and recreation centres arc the main wnsumers. Hot water is used a little for **space** heating, and the heating of greenhouses, but even less for industrial processes. About 400 heat pumps of the water to water type are in use all over Slovenia, contributing an additional 40 TJ (940 TOE) of thermal energy.

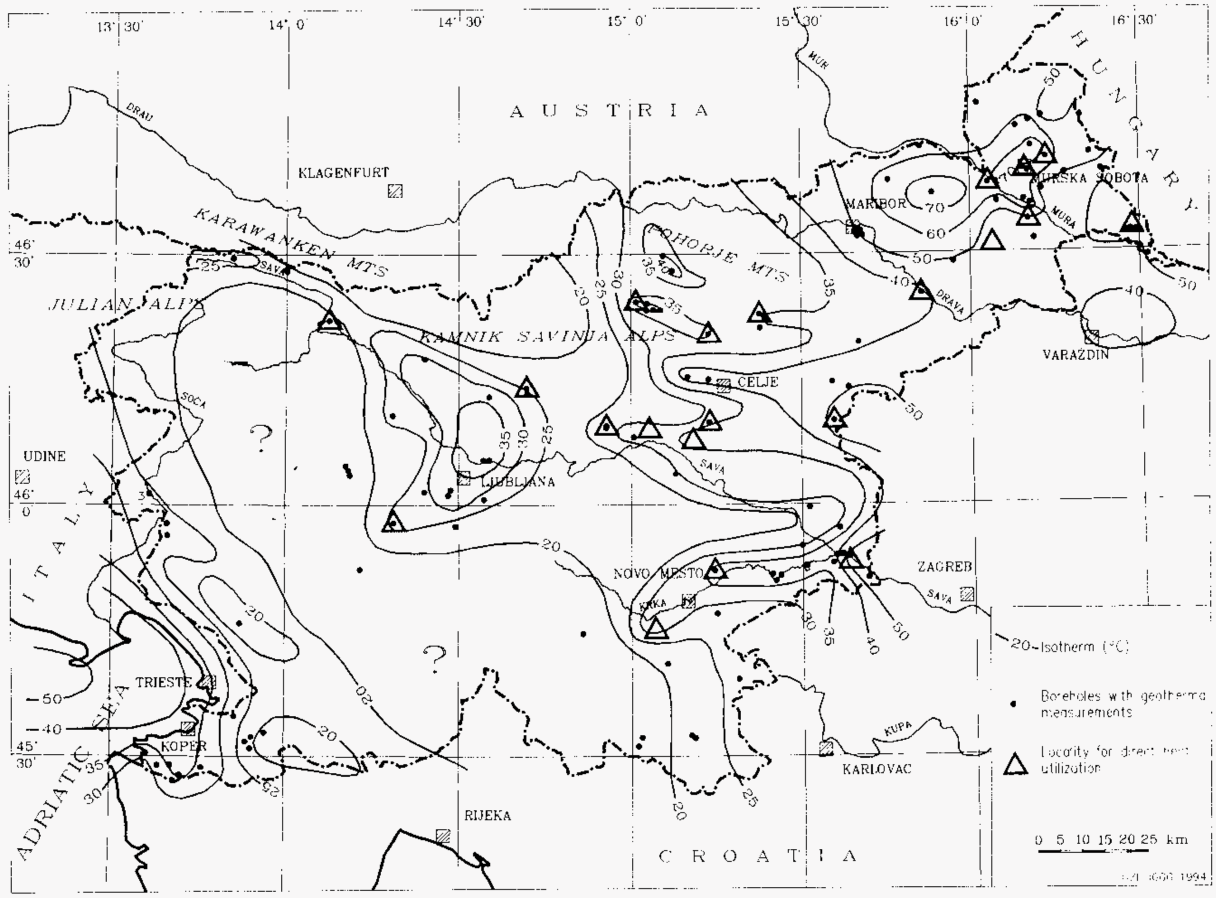

Fig. *2.* Isotherms at a depth of 1000 m, and geothermal localities for direct heat utilization in Slovenia

At one locality (Ljutomer, Fig. **1)** electrical energy generation of the order of **1 MW** is expected, in addition to the use of thermal water for district heating. There, a feasibility study is under way. Geothermal investigations over the last *5* years have resulted in **32** boreholes with a total depth of about **24.4 km. Most** of them **(26)** were intended for the further exploration of already known centres andlor for increasing their capacities or for tapping new aquifers. The remaining boreholes were drilled for exploitation purposes.

5. DISCUSSION

Accumulations of geothermal fluids are clearly related to the tectonic and lithological setting of the country (Figures 1 and 2). The geothermal wnditions in the **W** part of Slovenia are influenced by the large crustal thickness in the area of the Outer Dinarides and the Southern Alps (up to 40 **km).** These tectonic units consist, in the upper few kilometres, of karstified carbonate rocks, where cold groundwater circulates. This is the cause for **low** geothermal gradients, and consequent low temperatures down to greater depths. In this area, the fractured type of geothermal reservoir prevails. The springs discharge mostly along the **SW** border area **of** the Pannonian basin. There, the carbonate rocks of the Southern Alps, the Outer Dinarides and partly also of the Transition Zone, are overlain locally by young Tertiary sediments. The pre-Tertiary depressions in this area were formed mainly along the fractured zones, where most thermal springs with temperatures of below **45** *"C* are located.

In contrast, the NE part of Slovenia is affected by the large positive geothermal anomaly of the Pannonian basin, characterized by thin crust (up to 30 km) and thick Tertiary and Quaternary sedimentary layers (up to *5* km). Geothermal reservoirs of the intergranular type occur here. At depths greater than 2500 **m,** thermal fluids reach temperatures within the range of 100 to 200 °C.

The occurence of geothermally promising areas has been ascertained in approximately 3,200 km^2 (Fig. 3) **out** of the entire territory of Slovenia (20,250 km^2). These areas mostly lie in the eastern half of the country.

All known geothermal resources are of the low enthalpy type. High enthalpy resources are still poorly known. At one location a feasibility study for high enthalpy use is in progress.

The extraction of geothermal fluids (heat mining) has been limited to the use of exploitation boreholes only; doublet schemes are not yet in use. Shallow geothermics arc also heing promoted, but at a slow rate. The main reasons for this are the high price of electricity for driving the heat pump units, and the proportionally lower prices for fuel oil.

Geothermal activity is constantly increasing. The total number **of** professional personnel engaged in geothermal activities was, in **1994,** allocated **as** follows (in man years): 9 - Public Utilities, 1 - University and **3** - Private Industry. Geothermal resources are mostly utilized directly in recreation and balneology ***(55%)*** and, to a lesser extent, for space heating (29%) and other purposes. The former two activities produce greater benefits due to their reputation and tradition than all other types of **use.** Another reason is that the low grade technology required does not use much complicated operational equipment. The cascade mode of exploitation is practically absent.

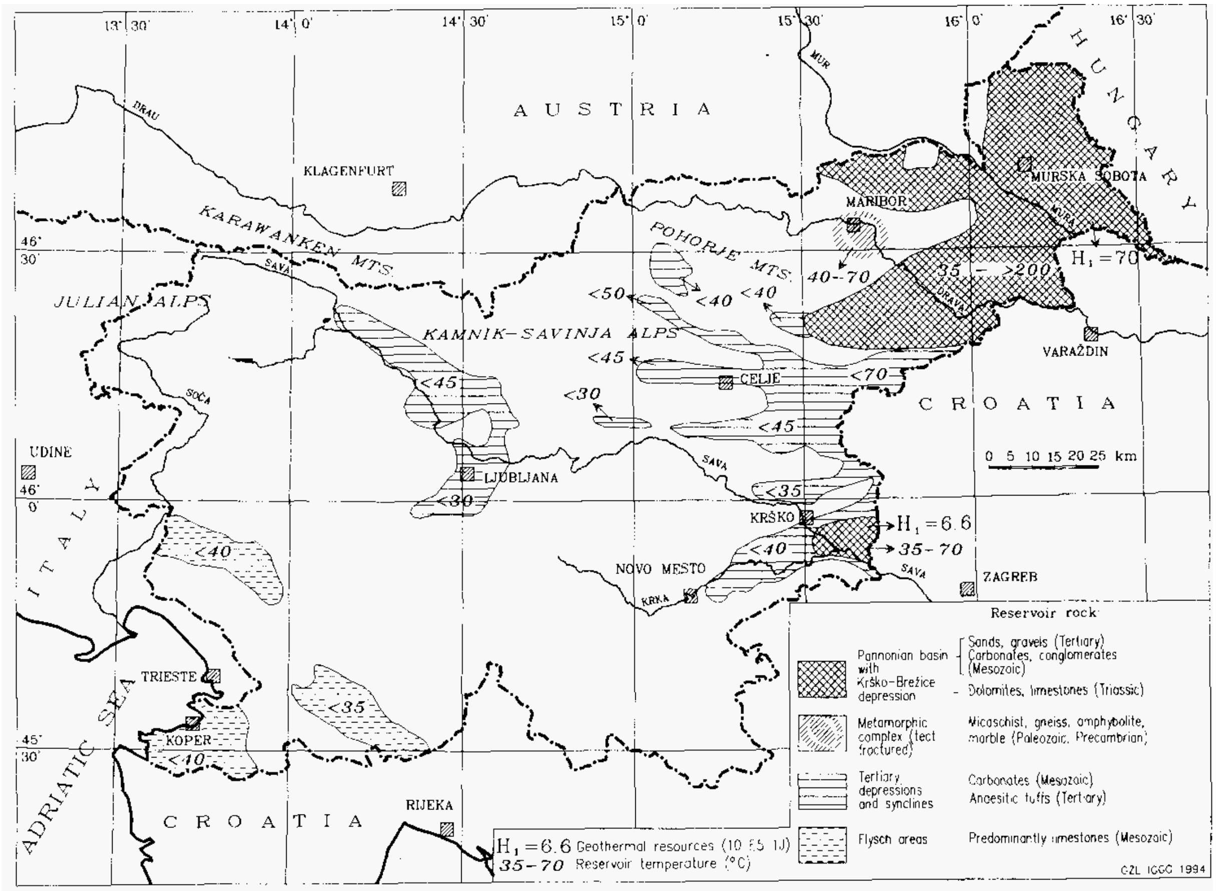

Fig. 3. Potential geothermal reservoirs in Slovenia

6. CONCLUSIONS

In Slovenia, increasing utilization of geothermal energy has been in progress for about 12 years, but the history of its actual use, especially in balneology and recreation, is much longer. Taking into account Slovenia's high level of dependence upon imported oil and gas, it is believed that the development of geothermal resources will receive more attention in the near future. On the basis of recent geothermal data, only low temperature heat energy use is of importance. The total amount of geothermal heat used in 1994 amounted 762 TJ. Potential geothermal energy resources are the most abundant in eastern Slovenia, reaching about $7.66 \cdot 10^6$ TJ.

A feasibility study is under preparation for electrical energy generation and heating from one high temperature reservoir. Without doubt more attention needs to be paid to hydrogeothermal investigations in general, to shallow geothermics and above all to the rational use of the presently available geothermal resources.

7. ACKNOWLEDGEMENTS

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Table 1. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT IN DECEMBER 1994

1) I=Industrial process heat B=Bathing and swimming
C=Air conditioning G=Greenhouses
D=Space heatir

2) Energy use (TJ/yr)=. ınual av ge water flow rate (kg/s) x [Inlet ten (°C) - Outlet temp.(°C)] x 0.1319

Locality	Type"	Maximum Utilization Flow Rate kg/s	Temp.(°C) Inlet	Temp.(°C) Outlet	Average Flow Rate kg/s	Energy Use[2] TJ/yr	Load Factor
Moravci	DBGC	46	66	36	30	119	0.70
Murska Snhofa	DBC	26	50	35	14	26	0.68
Radenci	B	6	40	25	4	8	0.60
Lendava	DBIC	18	65	28	9.5	36	0.50
Ptuj	B	15	39	29	7	9	0.50
Moravci/Bučkovci	B	7	35	25	2	3	0.29
Bannvci	BD	10	58	28	6	24	0.50
Zreče	BD	37	28	22	18	14	0.56
Podčetrtek	BD	16	32	15	14	31	0.64
Čatež	BDG	120	62	33	80	276	0.42
Dobrna	B	8	36	25	2.8	4	0.35
Topolšica	BDC	30	32	20	22	35	0.73
Medija	BD	35	24.4	20.9	13.5	7	0.39
Šmarjeta	BD	40	32	20	40	63	1.00
Laško	B	15	34.2	30	15	8	1.00
Rimske Toplice	B	45	38	32	10	8	0.30
Dolenjske Toplice	B	51	34.5	31.8	8	3	0.25
Bled	B	10	22	15	10	9	1.w
Vrhnika	I	20	21 5	16	14.4	11	0.72
Trbovlje	BI	10	25	20	3	2	0.30
Snovik	B	16	22	18	4	2	0.25
Total		581			327.2	698	

DIRECT HEAT USES
x [Inlet temp.(°C)
(kg/s) x [Inlet temp.(°C)

	Installed Thermal Power" (MW,)	Energy Use[2] (TJ/yr)
Space healing	9.39	205.07
Bathing and swimming	17.40	382.83
Greenhouses	5.31	71.89
Industrial process heat	0.59	12.88
Air conditioning	1.37	25.19
Subtotal	34.06	697.86
Heat pumps	2.94	63.88
Total	37.00	761.74

R=Regional assessment F=Feasibility studies (Reservoir evaluation and Engineering studies)
P=Pre-feasibility U=Comm

Locality	Location To Nearest 0.5 Degree Lat.	Long.	Reservoir Rock[1]	Dissolved Solids[2] mg/kg	Status]' in January 1995	Reservoir Temp. (°C) Estimated	Measured
Pannonian basin	46.5	16.(	**Sand,** gravel	800 - 7,000	F + U		35 - 69
			Sandstone, conglomerate	10,000 - 20,000	P + F	45 - 110	
			Carbonates	6,000 - 30.000	P		90 - 202
Krško-Brežice Tertiary **basin**			Dolomite	3 w - 1,000	U	30 - 70	30 - *64*

TABLE 3. cont'd.

Tertiary depressions inside folded Eastern and Southern Alps	46.0 - 46.5	15.0	Dolomite, limestone	1,000 - 6.000	P + U		24 - 48
Metamorphic complex of the Eastern Alps	46.5	15.5	Gneiss, schist, amphybolite, marble, tonalite and other magmatics	up to 28,000	P + F		40 - 68
Ljubljana-Kranj depression	46.0	14.5	Carbonates	300 - 1,000	P	25 - 65	42
Flysch-coastal area	45.5	13.5	Limestone				
Vipava-Nova Gorica flysch area	46.0	13.5	Limestone	300 - 1,200	P + F	30 - 35	32
Total							

Table 4. WELLS DRILLED FOR DIRECT HEAT UTILIZATION OF GEOTHERMAL RESOURCES FROM JAN. 1, 1990 TO DEC. 31, 1994

(Thermal gradient wells less than 100 m deep are not included)

[1] Type or purpose of well and manner of production

(a) T = Thermal gradient or other scientific purpose
E = Exploration
P = Production
I = Injection

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

[2] Total flow rate at give wellhead pr re (W

Locality	Year Drilled	Well N°	Type of Well[1] (a)	(b)	Total Depth m	Max. Temp. °C	Fluid Enthalpy kJ/kg	Well Output[2] Flow Rate kg/s	WHP bar
Banovci	1991	1	P	A	1481	58	243	10	1.7
Moravci	1993	1	I	A	991	62	260	12	1.2
Lendava	1994	1	E	A	1504	65	272	13	1.8
Čatež	1991	I	E	P	500	20	84		
Otočec	1993	1	P	P	3 w	IS	63	15	
Dolenjske Toplice	1992	I	P	P	45	36.8	154	40	
Rogaška Slatina	1990/92	2	E	A	1954	63	350	5.7	3.6
	1991	I	T	P	1500	40	167	0.1	0
	1990	1	T	P	1000	38	159	1	
	1990194	7	E	P	8063	68.7	288	9?	
Vaseno	1990	1	P	P	983	22	92	15	0
Okonina	1994	1	T	P	201	18.5	71	0.3	0
Ljubljana	1990	1	T	P	171	21	88		
Gozd Martuljek	1993	1	T	P	150	8.6	36		
	1991	1	T	A	653	20	84	4	
Nova Gorica	1993	2	T	P	388	16	67		
Šempeter	1994	I	E	P	1563	32	134	I	
Dragonja	1990193	3	T	P	638	18.7	78		
Sečovlje	1993	1	T	P	370	21.5	90		
Marezige	1994	1	E	P	470	30	126		
Lucija	1994	1	E	A	801	27.5	115		
Portorož	1994	1	P	P	705			1.4	0.3
Total		32			24,431		3,027		

Period	Research & Development Incl. Surf. Exp. & Exp. Drilling	Field Development Incl. Prod. Drilling & Surf. Equipment	Utilization Direct	Utilization Electrical	Funding Type	
	Million US$	Million US$	Million US$	Million US$	Private %	Public %
1975 - 1984	2.3	1.5	21.8			100
1985 - 1994	3.6	5.3	h4.h			100*