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Review paper

Geothermal Energy Resources in the Republic of Croatia - - Overpressured Zone

PROCEEDINGS

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Ključne riječi: geotermalni izvori, nadtlak, uskladištenje topline.

Abstract

The great quantities of stored heat, at relatively shallow depths, enable us to perform two fundamental human activities, suitable for an industrially clean country. The first one is agriculture throughout the whole year and the second one is tourism with the considerable potential for health resorts. Besides the subsurface and surface hydropotential, there is also good geothermal energy present, especially in the western and central part of the Drava Basin.

Sažetak

Želimo li biti čista zemlja, s dvije temeljne ljudske djelatnosti, poljodjelstvom i turizmom, moramo rabiti čiste energetske izvore. Osim hidropotencijala, površinskog ili podzemnog, imamo velike zalihe toplinske energije u našem podzemlju. Naročito je to izraženo u zapadnom i središnjem dijelu dravskog bazena.

1. INTRODUCTION

Subsurface reservoirs from where the earth's heat is carried upward by steam or hot water convective circulation are classified as hydrothermal convection systems. The existence of a hydrothermal resource depends on two basic components: a heat source, and adequate vertical permeability to allow hot fluids to rise. This type of stored hot water is recognized as two systems. The first one is vapor-dominated or hot water, depending on whether steam or liquid water is the dominant pressure-controlling phase in the reservoir. The second type of this reservoir is hot water. According to the temperature range, hot water systems are divided into three categories:

1) high temperature range (150-360°C), suitable for electric power generation,
2) intermediate temperature range (90 -150°C), suitable for space and process heating,
3) low temperature system (below 90°C) with limited usage.

Although some data do exist in the local literature, no data on basic geothermal classification could be found. Resource geothermal classification follows WHITE & WILLIAMS (1975):

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1. Hydrothermal convection resource (heat carried upward by water or steam convection):
   a) vapor dominated with temperatures around 240°C,
   b) hot water dominated with temperatures from 350°C to less than 90°C.
2. Hot igneous resources (rock intruded in molten form from depth):
   a) part still molten with temperatures higher than 650°C,
   b) not molten or so called "hot dry rock" with temperatures from 650 to 90°C.
3. Conduction dominated resources (heat carried upward by conduction through rock):
   a) radiogenetic (heat generated by radioactive decay), with temperatures between 30-150°C,
   b) sedimentary basins (hot fluid in sedimentary rocks) with temperatures between 30-150°C,
   c) geopressured (hot fluid under high pressure) with temperatures between 150-200°C.

From the economic point of view, three of these systems apparently exist in our country. The first one is "hot dry rock" which can be specified as old rock "intruded" (like basement) with temperatures around 170°C. It is assumed that granite, as in the well Mol-32 (relative depth 3100 m) is the local source for this kind of heating. The second is a hot water dominated systems. These systems are documented in the literature

Fig. 1 Area of investigation; shaded areas are hot spots which refer to the lower part of the Late Miocene.

(JELIĆ, 1987; ČUBRIĆ, 1993). The locations Velika Ciglena, Lopatinec and others can be classified within this system. The third one is the geopressured reservoir recognized over the whole area, and which will be discussed in more detail.

2. GEOLOGICAL SETTING

Sedimentary constituents of the western and southern parts of Drava Basin (Fig. 1), are sandstones and marls from the Miocene period. The Middle and Early Miocene are represented in the western part by sandstones or highstand energy sequences, in the middle part by carbonates sequences (Molve and Gola fields), while in the eastern part they are represented by sandstones (Orešac) but lowerstand energy sequences (MESIĆ, 1995). Sedimentary sequences from the Early

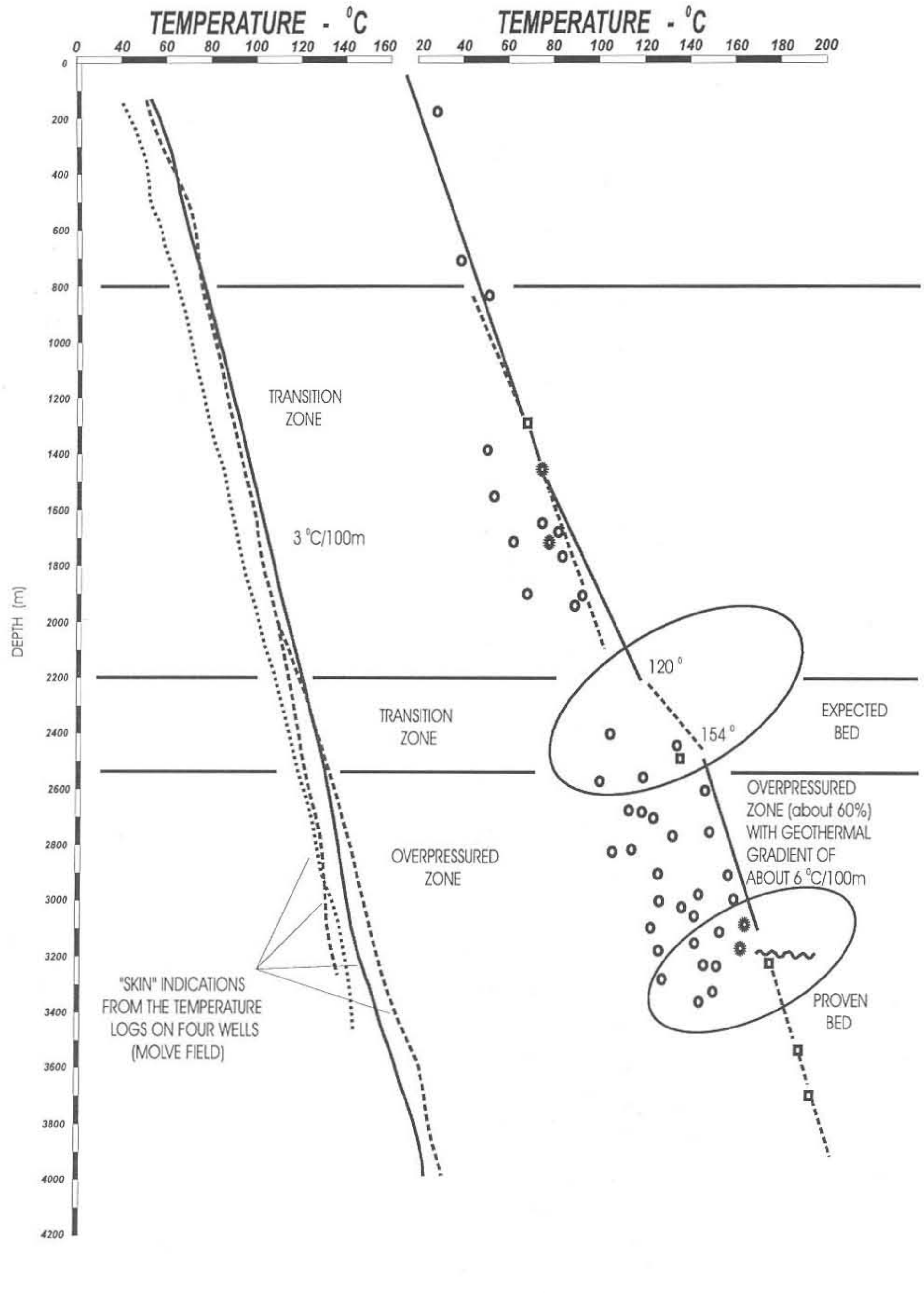

Fig. 2 Temperature versus depth data are extrapolated form logs and DST. Note high geothermal gradient on the top of overpressured zone (over 30°C/100m).

Temperature		Use
200° - 150°		
	180	refrigeration by ammonia absorption, digestion in paper pulp
	170	heavy water via hydrogeology sulfide process, drying of diatomaceous earth
	160	drying of fish meal, drying of timber
150° - 90°		
	140	food canning
	130	extraction of salts by evaporation and crystallization
	120	fresh water by distillation
	110	drying and curing of light aggregates cement slabs
	100	drying of organic materials, seaweed, grass, vegetables, washing and drying of wool
90 - 20°		
	90	drying of stock fish, intensive de-icing operations
	80	space heating, greenhouse by space heating, animal husbandry
	60	greenhouse by combined space and hotbed heating
	50	mushroom growing, balneological baths
	40	soil warming
	30	swimming pools, biodegradation, fermentation
	20	fish farming

Table 1 Characteristic geothermal systems - wide use (WHITE, 1975).

Miocene, i.e. 16-8.7 my, are overpressured. All fluids in this region, particulary water, included in sediments of Mesozoic and Palaeozoic age, are also overpressured (BARIĆ et al., 1991). Water in older sediments is mixed with hydrothermal solutions and contains other components like H_2S, CO_2 etc. This type of water is useless on the surface and has to be used in closed circulation or heat alteration. However, this water is also interesting, for use in small areas of human activity (e.g. electrical power plant). This means there is a great volume of restricted water in which a great mass of heat is accumulated, which is shown by the great value of the geothermal gradient (Fig. 2).

3. PHYSICAL PROPERTIES OF POTENTIAL RESERVOIRS

Overpressure zones are related to deposition of the regressive sedimentary sequences that began in the early Late Miocene. These sequences are recognized, at the beginning, by the sedimentary marker Rs_7. This mudstone bed is both a sedimentary and stratigraphic marker (11.7 my - BARIĆ et al., 1992). This sedimentation event marks the presence of regressive sequences in all these areas, with different physical properties due to the energy in which they were deposited. Examination of this bed shows temperatures around 154°C at the top of the overpressure zone, at approximately 2580 m depth in the central area (Molve), at 3500 m in the western area (Koprivnički Bregi), and at 3800 m in the eastern area (Orešac), as shown in Fig. 3. The thickness of these sedimentary sequences, called "Okoli and Iva sandstones" or sediments between markers Rs_7 (Upper Badenian, i.e. 11 my) and Z' (Sarmatian, i.e. 8.7 my), are different throughout the basin. In the Koprivnički Bregi area the thickness is approximately 1000 m, while in the Molve area it decreases to 600 m and in the eastern part (the Orešac area), only 300 m is recorded (MESIĆ, 1995). These sandstones sequences are of low porosity, depending also on the energy level at the beginning of sedimentation. The western part, representing a highstanding energetic level or delta plain, i.e. the upper part of a delta front, has sediments with an average porosity of around 18%, while the porosity of the central part or lower part of the delta front is around 12%, and the porosity of eastern part (or transition between the lower part of the delta front and to prodelta sedimentation), is close to 8%.

The gas composition, dissolved in the water of overpressured zone, is in the upper part quite different from that in the lower part. This can indicate: 1) influence of the known reservoir and imperfection of the cap rock, or 2) the same carrier fluid in the main reservoir and the lower geopressured zone. The upper dissolved gas is dominantly methane (89%) with low CO_2 (0.5%). Water mineralization is low, around 2.6 g/l eq. NaCl. The composition of the lower dissolved gas is similar to that of the main reservoir, i.e. methane (71%), CO_2 (16%), H_2S (64 PPM), Hg (0.5 mg/m^3), but with higher water mineralization (4 g/l eq. NaCl).

4. ENERGY POINT OF VIEW

The amount of energy in this volume of sedimentary sequences can be roughly calculated. Although all sedi-

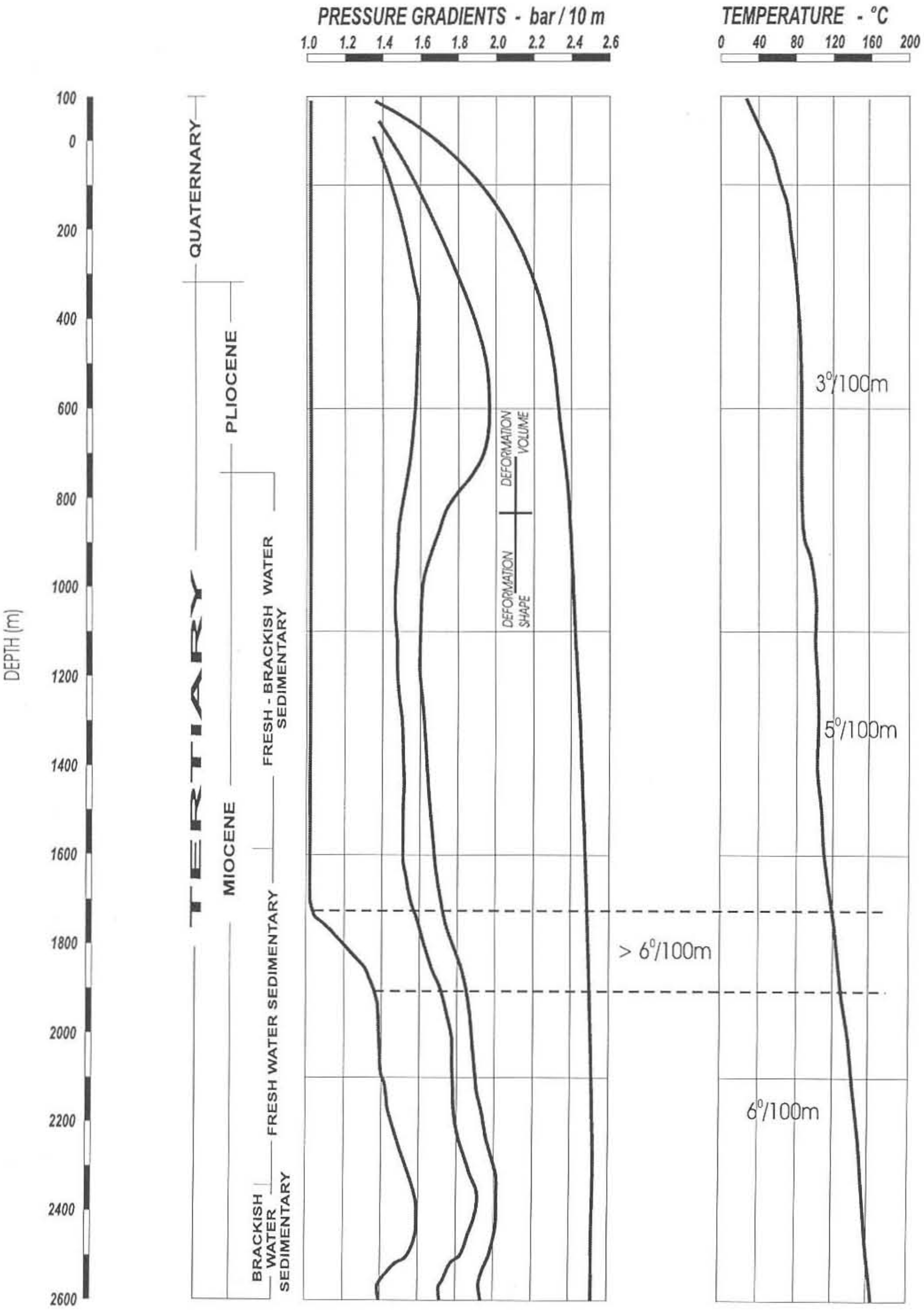

Fig. 3 Prognosis of pressure and geothermal gradient for the average well on the target area.

mentary masses contain accumulated water, the average effective thickness of 100 m, with an average porosity of 8% can result in almost 16 km^3 of storage capacity. The average temperature we used was 154°C.

$Vw = 16\ km^3 = 16*10^9\ m^3 = 16*10^{12} dm^3$

$Cw = 4.187*103\ J/°C*dm^3$

$t_1 = 154°C$

$t_2 = 11.6°C$ (average surface temperature in north Croatia)

$Qw = 16*10^{12}*4.187*10^3*(154-11.6) = 9539*10^{15}\ J = 9.54\ PJ$

The complete stored geothermal energy in these sedimentary sequences is close to

$9.54 * 10^{18}\ J = 9\,540\ PJ = (2.65 * 10^{15}\ Wh = 2.65\ Mwh).$

where Vw = volume of water (dm^3), Cw = caloric value of 1 dm^3 water ($J/°C * dm^3$), t_1 = temperature of water in reservoir (°C), t_2 = average surface temperature (°C), and Qw = storage of hot water (PJ).

Taking in consideration dissolved gas, the total stored current is even greater.

This stored energy can be useful on the surface only if great quantities of water are being produced. The water production depends on the reservoir permeability. The low permeability zone can be avoided by using various attributes of the seismic traces, interval velocity, gradient and AVO (BARIĆ et al., 1991) permitting us to make several maps and a geological model. This model reduces the chances of incorrect estimation of sedimentary environment, and the position of the zone with sufficient permeability for an economically justifiable production rate.

The temperature range of conventional power production is 180-140°C.

5. CONCLUSION

According to world experience, geothermal resources are suitable for a wide variety of uses in human activities. Especially from the ecological point of view, a geopressured reservoir with clean water, the water being clean due to the sedimentary environment, is of great importance to our country. It is shown how important it is to recognize temperature anomalies' vs. depth, not only as the average geothermal gradient. These hot spots, which exist in some parts of the Drava Basin, especially in the area between Koprivnički Bregi and Orešac, make this area suitable for agriculture, tourism, and other activities that are useful, clean, and economically viable. What is required in the future are legislative, institutional and environmental actions.

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