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Geothermal properties of the northern part of the island of Rab

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ABSTRACT

The results of geothermal research in the northern part of the island of Rab are presented. This research was carried out by the Croatian Geological Survey on the initiative of the municipal administration of Lopar. The aim of the study was to determine the geothermal features and possibilities for utilising geothermal energy in this area. Field research included inspection of natural springs, together with the geological screening and sampling of typical rocks. Laboratory studies focused on the measurement of thermal parameters of rock samples collected in the field to demonstrate their ability to conduct and accumulate heat. Research has shown that spring waters do not originate from deep aquifers and that the carbonates of Upper Cretaceous limestones and Tertiary foraminiferal limestones have relatively favourable values of geothermal parameters and are able to conduct and accumulate heat. Given the geological structure, as well as the hydrogeological and geothermal parameters of the study area, the use of geothermal energy from deep boreholes would not be profitable. Cost-effective heating and cooling could be provided using shallow boreholes and ground source heat pumps in layers with favourable thermal properties.

Keywords: geothermal energy sources, heat conduction, heat pumps, Rab, Croatia

1. INTRODUCTION

Geothermal exploration of the northern part of the island of Rab was conducted by the Croatian Geological Survey (CGS). All field and laboratory studies were conducted by the author during the autumn of 2008. The aim of this study was to determine the geothermal properties and the possibility for utilising geothermal energy in the research area. Approximately 27 km^2 were surveyed.

Field investigation consisted of geological prospection of the study area, selection of typical rock samples of individual lithological units to determine their geothermal parameters, inspection of springs and measurements of the basic physico-chemical characteristics of water. Laboratory studies were conducted in the laboratory of CGS, and included measurements of geothermal properties of rock samples. There had been no similar previous geothermal research conducted in the area.

Several previous publications discussed the geothermal characteristics of the wider area. Description of temperatures and thermal fluxes for the coastal area in the territory of Croatia (JELIĆ et al., 1995, 2005) refers to a geothermal gradient and density of thermal flux below the average values. This is also typical for the coastal area of Slovenia (RAJVER & RAVNIK, 2002; RAVNIK et al., 1995). According to KOVAČIĆ (2001) geothermal water in the coastal zones of Croatia is not in use due to the absence of geothermal areas.

2. GEOLOGICAL SETTING

The geological structure of the study area is described on the basis of geological exploration of the terrain, and production of basic geological maps (MAMUŽIĆ & MILAN, 1969, 1973).

Upper Cretaceous limestones with dolomite interbeds are the oldest sediments exposed at the surface. They are generally grey-brown, well-stratified limestones with thinner or thicker intercalations of dolomite limestone and white and yellowish, mostly non stratified, crystalline limestone. Lithological differences that exist in some observed locations are small and are reduced to a different mutual arrangement of gray-brown and white limestone and dolomitic limestone interbeds. Previous studies determined these deposits

Figure 1: Road cut through the Upper Cretaceous sediments (photo: M. Kovačić, 2008).

Figure 2: Tertiary marls and sandstones of the Lopar peninsula (photo M. Kovačić, 2008).

as being Cenomanian – Turonian in age. Their mean thickness is about 600 m (Figure 1).

As mentioned, Turonian and Senonian deposits that consist of light grey and white, occasionally reddish limestone, were continuously deposited over the Cenomanian. These lithological layers are almost indistinguishable from the white and yellowish limestones of the Cenomanian and Turonian. The average thickness of these layers in the wider area is 150–200 m. All of the Upper Cretaceous (K_2) deposits are characteristic of shallow and warm seas.

Upper Cretaceous deposits are located on the southwest side of the study area where they form an anticline of Dinaric strike, as well as on most parts of the islands of St. Grgur and Goli.

Upper Cretaceous sediments are followed by transgressive Tertiary foraminiferal limestones. A geological unconformity is clearly marked by small bauxite deposits and occurrences that may be encountered at several places on the islands of Rab and Goli. According to MAMUZIĆ and MILAN (1973) the foraminiferal limestones belong to the Lower and Middle Eocene, and the average thickness in the wider area is from 100 to 150 m. Foraminiferal limestone outcrops along the edges of these anticlines.

Middle and Upper Eocene flysch was deposited continuously on foraminiferal limestones. According to MAMUZIĆ & MILAN (1973) and MARINČIĆ (2009), they represent typical flysch sediments deposited in a deeper basin. MARJANAC & MARJANAC (2007), suggest these sediments were

Figure 3: Biocalcrudite – nummulitic limestone of Tertiary age (photo M. Kovačić, 2008).

deposited in a shallow sea. They are characterized by the interchanges of fine and coarse grained sediments. The lower part is dominated by marl, while the upper part consists of sandstone with layers of marl. Intercalated marls are of different thicknesses with decametric width. In some places, horizontal and vertical transitions in the sandstone and marl are common suggesting that deposition took place in an estuary (MARJANAC & MARJANAC, 2007) (Figure 2). Bodies of biocalcarenite with abundant nummulites appear in places (Figure 3). The entire Lopar peninsula on Rab island is composed of Tertiary flysch sediments. Structurally, it is a syncline following the Dinaric strike. These layers are the source material for the famous sandy beaches of the Lopar peninsula.

The youngest deposits are quartz sands of Quaternary age. They are characterized by good sorting, rounded grains and the absence of a lime component indicating a long period of transport. The sands were derived from older flysch sediments. According to previous studies, the thickness of these layers is the greatest in Lopar, at about 6 m (MAMUŽIĆ & MILAN, 1973). Quaternary sediments are located in the area between the aforementioned Cretaceous carbonate anticline to the southwest and the flysch syncline of the Lopar peninsula to the northeast, and are observed in deep valleys of the Lopar peninsula (see Figure 4). The Upper Cretaceous and Tertiary are not subdivided into stages on the map.

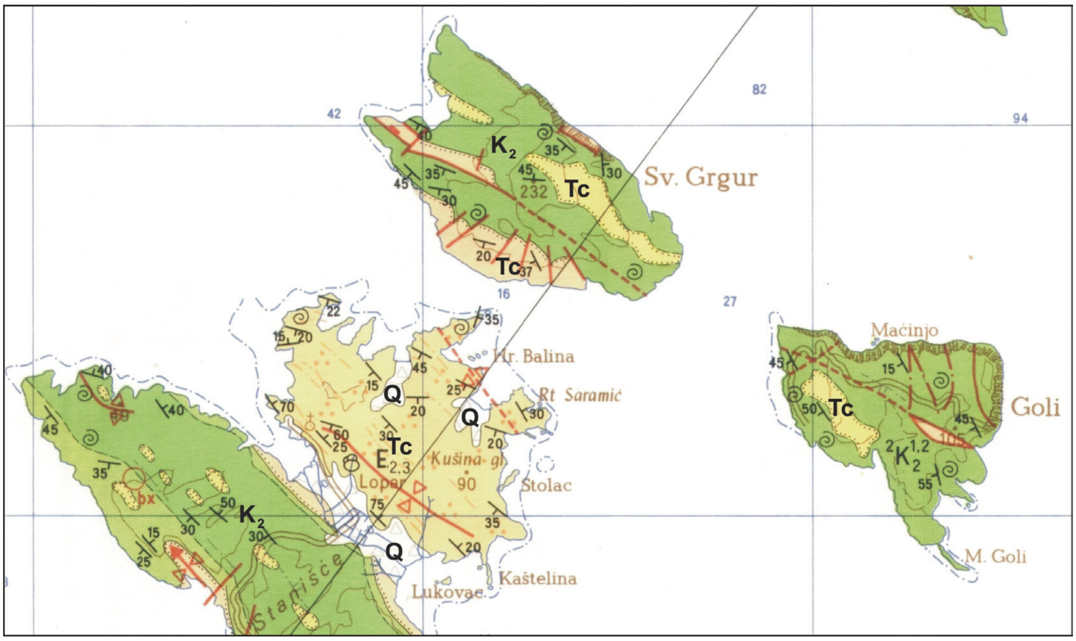

Figure 4: Geological map of the research area M 1:100.000 (K_2 – the Upper Cretaceous sediments, T_c – Tertiary deposits, Q – Quaternary sediments) (by: MAMUŽIĆ & MILAN, 1969).

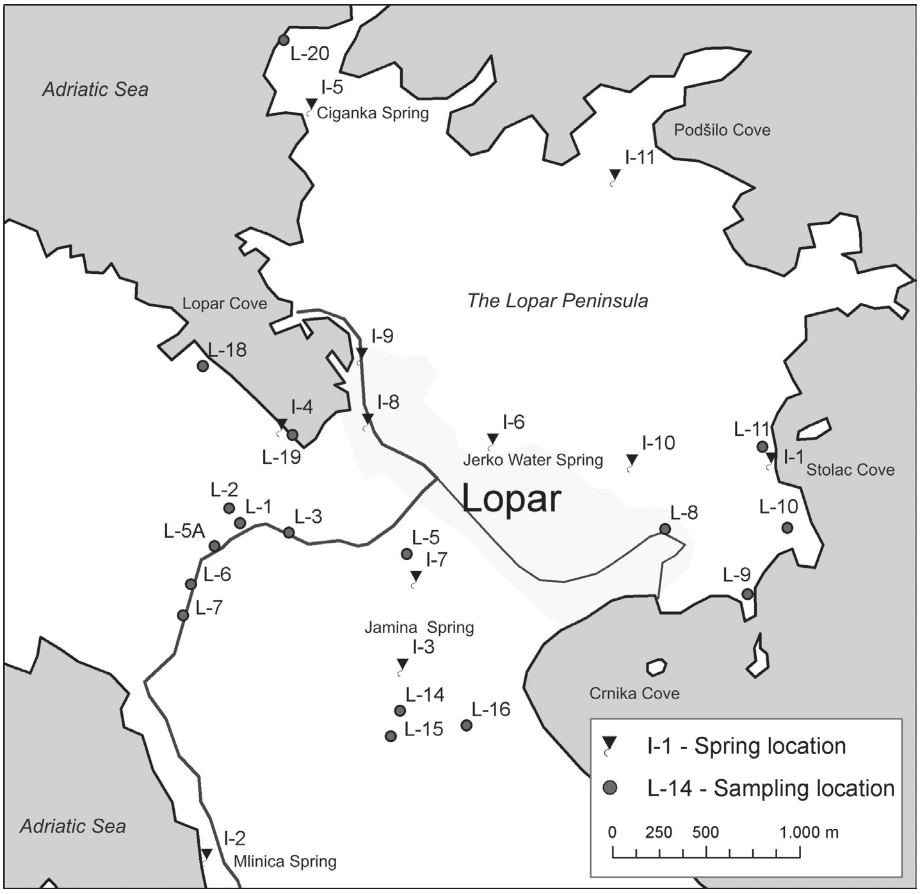

Figure 5: Map showing the springs and sampling locations (sampling locations on Goli Island not included).

3. NATURAL SPRINGS IN THE INVESTIGATED AREA

Observations were made on the condition of the major springs in the study area (those marked on the 1:25000 topographic map sections Supetarska Draga and Rab, and a few springs discovered during fieldwork). The aim of this study was to determine the basic physico-chemical properties of water that could indicate possible flow from deeper aquifers. The following properties of water were determined during fieldwork: clarity, colour, odour and taste. Measured parameters were: temperature (T), electrolytic conductivity (EC) and the proportion of total dissolved solids (TDS). A survey of the springs was carried out during the hydrological mini-

Figure 6: Jerko Water Spring – Jerkovac (photo M. Kovačić, 2008).

Table 1: Statistical analysis of the results of thermal parameters measurement (λ (k) – coefficient of thermal conductivity, c_ρ – volumetric heat capacity, a – thermal diffusivity, Min.- lowest measured value, Max. - highest measured value, Mean – mean value of a thermal parameter)

Sample name	Sample description	GEOTHERMAL PARAMETERS								
		λ (k) ($Wm^{-1}K^{-1}$)			c_ρ ($Jm^{-3}K^{-1}$) ($x10^6$)			a (m^2s^{-1})		
		Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
L -1	crystalline limestone	3.18	3.31	3.26	2.17	2.41	2.31	1.37	1.57	1.44
L -2	crystalline limestone	3.19	3.34	3.27	2.08	2.38	2.25	1.36	1.53	1.45
L -3	crystalline limestone	3.00	3.21	3.09	2.35	2.77	2.6	1.16	1.25	1.2
L -4	crystalline limestone	3.17	3.34	3.28	2.07	2.44	2.32	1.37	1.58	1.44
L -5	yellowish – grey limestone	3.46	3.55	3.50	2.76	2.97	2.88	1.18	1.23	1.20
L –5a	yellowish – grey limestone	3.21	3.28	3.24	2.66	2.70	2.68	1.20	1.22	1.21
L –6	brownish – grey limestone	2.70	3.38	3.03	1.81	2.78	2.16	1.23	1.51	1.35
L –7	white limestone	3.23	3.29	3.26	2.67	2.79	2.72	1.19	1.22	1.21
L-8	coarse – grained sandstone	3.95	4.79	4.26	2.29	2.95	2.79	1.44	1.73	1.53
L-9	coarse – grained sandstone	3.82	3.91	3.85	2.66	2.82	2.74	1.35	1.46	1.39
L-10	nummulite - calcarenite	3.42	3.69	3.56	2.12	2.60	2.37	1.72	1.42	1.50
L-11	slightly sandy marl	1.52	1.77	1.61	1.64	1.85	1.71	0.83	0.87	0.85
L-12	light grey limestone	3.00	3.33	3.14	2.42	2.87	2.71	1.13	1.17	1.15
L-13	light grey limestone	3.21	3.36	3.30	2.07	2.38	2.25	1.33	1.53	1.44
L-14	limestone breccia	3.32	3.42	3.35	2.93	2.97	2.94	1.13	1.17	1.15
L-15	limestone breccia	3.24	3.46	3.34	2.92	2.96	2.82	1.11	1.15	1.13
L-16	foraminiferal limestone	3.59	3.83	3.68	2.72	2.78	2.75	1.31	1.35	1.32
L-17	light grey limestone	3.24	3.44	3.41	2.09	2.38	2.25	1.33	1.51	1.43
L-18	foraminiferal limestone	3.29	3.56	3.37	2.38	2.49	2.45	1.32	1.50	1.40
L-19	grey and yellowish marl	1.42	1.61	1.53	1.65	1.88	1.73	0.81	0.87	0.84
L-20	yellowish sandstone	2.58	2.78	2.68	1.87	2.05	1.96	1.34	1.37	1.35

mum. Spring locations are shown in the overview map (Figure 5), indicated by the following labels: I-1 (spring in Stolac Cove), I-2 (Mlinica Spring), I-3 (Jamina – periodic spring), I-4 (spring in the Lopar cove), I-5 (Ciganka Spring), I-6 (Jerko Water Spring – Jerkovac), I-7 (Vrutak water intake and pumping station), I-8 (Civi – spring and water intake), I-9 (Plimica – water intake), I-10 (Podgabar – water intake) and I-11 (spring in the Podšilo cove).

The Stolac cove and Ciganka spring had no water while the fieldwork was conducted, which is probably the result of the summer dry season. The Vrutak, Mlinica, Ciganka and Jerkovac springs (Figure 6) were previously utilised for the public water supply. Recently however, their use has been discontinued due to an increase in the concentration of sodium chloride.

Measurements of the basic physico – chemical characteristics of spring waters were carried out in September 2008. The air temperature during the measurement period ranged from 23–25 °C. Water temperatures at the source are in the range of 14.6 °C (Jerkovac) to 21.1 °C (Lopar cove). Electrolytic conductivity is in the range of 610 µS/cm (Jamina) to 2.55 mS/cm (Mlinica), and total dissolved solids from 423 mg (Jamina) to 1785 mg / l (Mlinica). The water is clear, colourless and odourless in all of the springs. Springs with increased mineralization have a salty taste, which probably comes from dissolved sodium chloride.

4. THERMAL CHARACTERISTICS OF ROCK SAMPLES

The thermal characteristics of rocks were measured in order to determine their ability to conduct and accumulate heat. Typical samples from the study area were collected in open and stratigraphically well-defined outcrops. In addition, Upper Cretaceous carbonates were sampled from a fresh road cut that runs perpendicular to the direction of the Rab anticline (Figure 1). The main lithological description of the samples is given in Table 1.

Laboratory studies were conducted in the CGS laboratory. The intention was to analyse 15 samples of rock from

Table 2: Mean values of the thermal parameters of rock samples of Upper Cretaceous age (λ (k) – coefficient of thermal conductivity. c_ρ – volumetric heat capacity, a - thermal diffusivity)

Sample name	λ (k) ($Wm^{-1}K^{-1}$)	c_ρ ($Jm^{-3}K^{-1}$) ($x10^6$)	a (m^2s^{-1})
L - 1	3.26	2.31	1.44
L - 2	3.27	2.25	1.45
L - 3	3.09	2.60	1.20
L - 4	3.28	2.32	1.44
L - 5	3.50	2.88	1.20
L – 5a	3.24	2.68	1.21
L - 6	3.03	2.16	1.35
L - 7	3.26	2.72	1.21
L - 12	3.14	2.71	1.15
L - 13	3.30	2.25	1.44
L - 14	3.35	2.94	1.15
L - 15	3.34	2.82	1.13
L - 17	3.41	2.25	1.43

the study area, however, due to the diversity of the lithostratigraphic units, 21 samples were analysed. This ensured that good quality and representative data on the thermal characteristics of the rocks was obtained. After preparation (cutting, polishing) measurements were carried out, including: coefficient of thermal conductivity (λ), volumetric heat capacity (c_ρ) and thermal diffusivity (a) of the rock samples. Measurements were carried out using a non-stationary (Quick Thermal Conductivity Method) (SUMIKAWA & ARAKAWA, 1976; PRELOVŠEK & URAN, 1984) instrument ISOMET 2104 (Applied Precision Ltd.). According to the manufacturer, the measurement accuracy is 10% for Thermal Conductivity and 15% for Volume Heat Capacity 15%.

The number of measurements per sample was 8–10, totalling 190 measurements of thermal parameters. Average values of the coefficient of thermal conductivity, volumetric heat capacity and thermal diffusivity of the samples were obtained from multiple measurements with displacement of sensors and statistical analyses. To obtain the thermal characteristics of samples equal to those in situ, the samples were immersed in water for 20 days. According to previously conducted measurements saturating the porous rock increases the thermal conductivity by up to 33% (KOVAČIĆ, 2007).

It is assumed that the rocks at depths greater than 50 m from the surface are mostly saturated with water. This assumption is supported by the existence of water in the Jamina cave and a number of periodic and permanent springs in the study area. The rocks below sea level are saturated throughout the year.

The results of thermal parameter measurement were statistically analysed and summarised in Table 1. Sampling locations are indicated on the map (Figure 5) (sampling locations on Goli Island not included on the map).

5. THERMAL CHARACTERISTICS OF STRATIGRAPHIC UNITS

The thermal characteristics of stratigraphic units were calculated by statistical analysis of mean parameter values of samples that are typical for individual units. The aim of the calculation was to establish whether the stratigraphic and lithologic units are able to conduct and accumulate heat. Thermal characteristics of the Quaternary sediments were not measured, but estimated.

Upper Cretaceous carbonates

Upper Cretaceous sediments cover a large portion of the investigated area, have a great thickness and different facies features, requiring a greater number of samples to describe this unit than others. Table 2 shows mean values of their thermal parameters and in Table 3 these values are statistically processed to obtain the mean values of thermal parameters for Upper Cretaceous stratigraphic units.

Tertiary (Lower and Middle Eocene) foraminiferal limestone

Foraminiferal limestones make up a small portion of the research area. They are lithologically similar to the underlying Upper Cretaceous. Therefore, only two samples were taken for analysis. The results of the measurements are shown in Table 4 and the mean thermal parameter values in Table 5.

Tertiary (Middle and Upper Eocene) flysch deposits

Tertiary flysch deposits are very diverse in terms of lithology and facies. Samples were collected from the characteristic lithological components, with the number of samples in proportion with their representation in the field (Table 6). Mean values of the stratigraphic unit thermal parameters are shown in Table 7.

Table 3: Thermal parameters calculation for Upper Cretaceous stratigraphic unit (λ (k) – coefficient of thermal conductivity, c_ρ – volumetric heat capacity, a - thermal diffusivity)

Parameter	Minimum	Maximum	Range	Mean	Unit
λ (k)	3.03	3.50	0.47	3.27	(Wm-1K-1)
cρ	2.16	2.94	0.78	2.53	(Jm-3K-1) (x106)
a	1.13	1.45	0.32	1.29	(m2s-1)

Table 4: Mean values of the thermal parameters of rock samples of Lower and Middle Eocene age (λ (k) – coefficient of thermal conductivity, c_ρ – volumetric heat capacity, a - thermal diffusivity)

Sample name	λ (k) $(Wm^{-1}K^{-1})$	c_ρ $(Jm^{-3}K^{-1})$ $(x10^6)$	a (m^2s^{-1})
L - 16	3.68	2.75	1.32
L - 18	3.37	2.45	1.4

Thermal features of Quaternary rocks were not specifically investigated because of their low occurrence in the research area. According ZOTH & HAENEL (1988), the thermal conductivity of sand ranges from 0.2 to 2.48 $Wm^{-1}K^{-1}$, however KOVAČIĆ (2007) suggests that the type of sand in Lopar has a coefficient of thermal conductivity of around 1 $Wm^{-1}K^{-1}$.

6. DISCUSSION OF RESEARCH RESULTS AND THE POSSIBILITIES OF GEOTHERMAL ENERGY UTILIZATION IN THE STUDY AREA

There are a number of natural springs in the study area, some of which are permanent, while others are periodic and active only during the spring, winter and late autumn. The previously strong Ciganka spring, which was once used for public water supply, dried up completely. The content of total dissolved solids in water (TDS) detected by the field measurements indicates increased mineralization. According to geological and balneological criteria (IVEKOVIĆ & PEROŠ, 1981), the Mlinica, Plimica, and Podgabar springs, together with those in the Lopar and Podšilo coves, can be considered as mineral waters because they contain more than 1 g/L of dissolved solids. The Civi and Jerkovac springs, containing 960 and 940 mg/L total dissolved solids respectively, are also close to the lower limit for mineral waters. Since chemical analysis of water from Mlinica shows that sodium chloride is the dominant dissolved solid, and all waters with elevated mineralization have a salty taste, it can be argued that the increased mineralization of these waters is caused by sea water mixing. Accordingly, one can expect that the water chemistry changes during the year, depending on the amount of rainfall and seawater intrusion. Spring water temperatures are slightly higher than the annual mean temperature of the area, which is most likely caused by seepage through the summer due to a warmed rock mass and the fact that intake structures have been built on some of the springs. Intake structures retain the water at shallow depths below the sur-

Table 5: Thermal parameters calculation for Lower and Middle Eocene stratigraphic unit (λ (k) – coefficient of thermal conductivity, c_ρ – volumetric heat capacity, a - thermal diffusivity)

Thermal parameter	Minimum	Maximum	Range	Mean	Unit
λ (k)	3.37	3.68	0.31	3.52	$(Wm^{-1}K^{-1})$
c_ρ	2.45	2.75	0.30	2.6	$(Jm^{-3}K^{-1})$ $(x10^6)$
a	1.32	1.4	0.08	1.36	(m^2s^{-1})

Table 6: Mean values of the thermal parameters of rock samples of Middle and Upper Eocene age (λ (k) – coefficient of thermal conductivity, c_ρ – volumetric heat capacity, a - thermal diffusivity)

Sample name	λ (k) $(Wm^{-1}K^{-1})$	cρ $(Jm^{-3}K^{-1})$ $(x10^6)$	a (m^2s^{-1})
L-8	4.26	2.79	1.53
L-9	3.85	2.74	1.39
L-20	2.68	1.96	1.35
L-10	3.56	2.37	1.5
L-11	1.61	1.71	0.85
L-19	1.53	1.73	0.84

Table 7: Thermal parameters calculation for Middle and Upper Eocene stratigraphic unit (λ (k) – coefficient of thermal conductivity, c_ρ – volumetric heat capacity, a - thermal diffusivity)

Parameter	Minimum	Maximum	Range	Mean	Unit
λ (k)	1.53	4.26	2.73	2.91	$(Wm^{-1}K^{-1})$
c_ρ	1.71	2.79	1.08	2.21	$(Jm^{-3}K^{-1})$ $(x10^6)$
a	0.84	1.53	0.69	1.24	(m^2s^{-1})

face where it warms up. In order to accurately determine the natural regime and spring water temperatures, multiple measurements during different seasons would be required. Based on the chemistry and temperature of spring waters, it can be argued that they do not originate from deep aquifers.

The measurements indicate that the ranges of values of the coefficient of thermal conductivity of all rock samples are relatively small at around 10%, with the exception of three samples. The ranges of the volumetric heat capacity and thermal diffusivity are slightly higher, which is usual for this type of measurement. Given these test results, it can be concluded that almost all the sampled rocks in the research area are thermally homogeneous.

Mean values of thermal conductivity of the Upper Cretaceous carbonate rock samples are very uniform and are in a relatively small range. Given this, it can be argued that the Upper Cretaceous stratigraphic units are thermally homogeneous. In a geothermal context, this unit can also include the foraminiferal limestones. Such a geothermal unit, taking into account stress deformation and the locally karstified carbonate subsurface, has a coefficient of thermal conductivity of 2.7 to 3.3 $Wm^{-1}K^{-1}$. The mean volumetric heat capacity is 2.53×10^6 $Jm^{-3}K^{-1}$, and the thermal diffusivity 1.29 m^2s^{-1}. Actual values are certainly a little lower because of the reasons mentioned above. All things considered, the Upper Cretaceous carbonates and Tertiary foraminiferal limestones have relatively good thermal properties to conduct and accumulate heat.

Unlike the carbonate sediments, the Tertiary flysch deposits are lithologically diverse. Accordingly, the unit is thermally inhomogeneous. The highest average value of the coefficient of thermal conductivity is observed in sandstone, at about 3.6 $Wm^{-1}K^{-1}$. However, the sandstones have very different thermal conductivities ranging from 2.68 to 4.26 $Wm^{-1}K^{-1}$. The mean value of their volumetric heat capacity is 2.5×10^6 $Jm^{-3}K^{-1}$, and the thermal diffusivity of 1.42 m^2s^{-1}. The geothermal parameter values of calcrudites are similar to those for sandstone. The average value of thermal conductivity of the marl is only half the value of the sandstone at 1.57 $Wm^{-1}K^{-1}$. Accordingly, the average values of their volumetric heat capacity of 1.72×10^6 $Jm^{-3}K^{-1}$ and thermal diffusivity 0.84 m^2s^{-1} are also low. The mean coefficient of thermal conductivity of the Tertiary flysch sediments is 2.91 $Wm^{-1}K^{-1}$, with a volumetric heat capacity of 2.21×10^6 $Jm^{-3}K^{-1}$ and a thermal diffusivity of 1.24 m^2s^{-1}. The results indicate that the Tertiary flysch sediments are a thermally highly inhomogeneous unit, suggesting that the average value of its thermal characteristics is only an approximation, and the actual values can vary greatly from place to place, from a good to poor ability to conduct and accumulate heat. Quaternary deposits, largely composed of sands, are characterized by their poor ability to conduct and store heat.

There is no published information on the deep boreholes in the coastal area, which is why the temperature reports at depth can only be deduced from the map of geothermal gradients and from the temperatures prevailing at 2000 m depth (JELIĆ et al., 1995). According to the aforementioned data, the geothermal gradient in this area is about 0.015 °C/m. This is below the average geothermal gradient for the most part Croatia due to the effect of thickening of the earth's crust in the coastal area of Croatia where the Moho discontinuity is extended to depths of 32 to 43 km (ALJINOVIĆ, 1986). According to data from the Meteorological and Hydrological Services of Croatia, the mean annual temperature in the investigated area is about 14 °C (ZANINOVIĆ et al., 2004). From the geothermal gradients and mean annual air temperature, it is possible to estimate the temperature of formations at depth from about 21.5 °C at 500 m, about 29 °C at 1000 m, and about 45 °C at 2000 m. Given these calculations, the temperature suitable for use in balneological and recreational purposes occurs at depths greater than 1500 m, and the temperature of groundwater that would be suitable for the production of heat is at depths below 2000 m. Judging by the broader geological frame, no rocks with primary (intergranular) porosity should occur at these depths. This conclusion is supported by the fact that the waters of investigated natural springs have both a chemistry and temperature consistent with a shallow aquifer origin, possibly from karstified limestones and Tertiary sandstones acting as aquifers at such depths. Therefore, at depths with high enough temperatures, no aquifers suitable for the exploitation of geothermal water can be expected.

Given the good coefficient of thermal conductivity and volumetric heat capacity, Upper Cretaceous and Tertiary limestones could be used during the summer to store excess heat while cooling the closed space by heat pump. During the winter, energy stored in this manner could be used to heat up the indoor space or water (HENDRIKS et al., 2008). This kind of renewable energy could be used to a lesser extent in some locations of Tertiary flysch sediments. Without additional research to establish the porosity and permeability of the aforementioned sedimentary complex it is impossible to estimate which energy storing system could be utilized. Limestones are without primary porosity while the secondary porosity caused by karstification can be vary with location rendering decisions related to energy consumption only possible after constructing new investigation boreholes at the proposed locations. Where porosity and permeability of the rocks is favourable, the open system could be used – Aquifer Thermal Energy Storage (ATES) – which utilizes water circulation in the aquifer for the purpose of the transfer and storage of heat. Considering the good thermal conductivity and capacity of these rocks, the closed system – Borehole Thermal Energy Storage (BTES) – using rocks and underground water for energy storage would be certainly rewarding.

7. CONCLUSIONS

Temperatures of the studied natural spring waters were slightly higher than the mean annual air temperature which most likely reflects the time of the study (early autumn/fall). Increased mineralization of the water in some springs is caused by the hydraulic connection with the sea. Therefore, water chemistry and temperature of investigated springs indicate that they do not originate from deeper aquifers.

Almost all sampled rocks are thermally homogeneous, with their coefficient of thermal conductivity varying in range of about 5% below or above the measured value.

Upper Cretaceous carbonates and Tertiary foraminiferal sediments are thermally homogeneous and have relatively good thermal properties to conduct and accumulate heat.

Tertiary flysch deposits are lithologically and thermally highly inhomogeneous, so the average values of their thermal parameters can only serve as approximate values, while the actual values of thermal parameters can greatly vary from one location to another.

Given the available information and calculations, a temperature of about 21.5 °C can be expected for the Formation at a depth of 500 m. At a depth of 1000 m the formation temperature is about 29 °C and at 2000 m about 45 °C.

Given these formation temperatures, the small possibility for rocks with primary porosity to be found at depths with adequate temperatures, and the high costs of deep drilling, it is suggested that the use of deep geothermal energy would not be profitable in the investigated area.

Alternatively, it is possible to use geothermal energy from shallow boreholes in places where Upper Cretaceous and Tertiary carbonate sediments with favourable thermal characteristics occur. These deposits would serve as heat accumulators. In the warm part of the year heat pumps would be used to transfer excess heat from the buildings into the ground (air - conditioning), and during the cold part of the year the stored heat would be pumped back into the buildings (heating).

In order to define the thermal energy storing system (ATES or BTES) investigative boreholes must be constructed and the porosity and permeability of the rocks be determined.

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