Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Comparison of Geological and Shallow Geothermal Characteristics of some Adriatic Regions in the Circum–Adriatic Countries (LEGEND project)

Dušan Rajver[1], Joerg Prestor[1] and Francesco Tinti[2]

[1]Geological Survey of Slovenia, Dimičeva 14, 1000 Ljubljana, Slovenia

[2]University of Bologna, Department of Civil, Chemical, Environmental and Materials Engineering, via Terracini 28, Bologna, Italy

dusan.rajver@geo-zs.si, joerg.prestor@geo-zs.si, francesco.tinti@unibo.it

Keywords: shallow geothermics, geothermal parameters, geology, hydrogeology, geothermal heat pumps, circum-Adriatic regions

ABSTRACT

The Adriatic Area shows one of the best climatic and geological conditions for fully exploiting the potentials of low temperature geothermal energy with ground-source heat pumps (GSHP) due to the presence of a medium temperature sedimentary basin across the Western Adriatic shore and the shallow geothermal conditions which characterize the entire Eastern Adriatic Countries. The participating regions in the LEGEND project (IPA Adriatic programme) provide benchmarking reports to be able to exchange experiences of shallow geothermal energy potential and to overcome barriers for faster development of GSHP for heating and cooling in the Adriatic region. The whole Adriatic territory has very diverse geological and hydrogeological characteristics. The Southern Alps, the External Dinarides and the Apennines are mostly represented by carbonate rocks, the latter two also by marl and sandstone (flysch rocks). Alluvial sediments (conglomerate, gravel, sand, silt, clay) are found along the narrow riverbeds and in wider groundwater basins, i.e. Po valley alluvial fan deposits (Italy). Thermal conductivity and volumetric heat capacity values are quite similar to the same rock types everywhere in the Adriatic region, in dry and wet conditions, typically in the range 2.4 to 3.0 W/(m·K) and 2.3 MJ/(m^3K) respectively for limestones, 2.4 W/(m·K) and 2.2 MJ/(m^3K) for flysch rocks, or for example, important for alluvial deposits as clay with 1.6 W/(m·K) and 2.4 MJ/(m^3K), and as gravel including sand and silt with 2.1 W/(m·K) and 2.4 MJ/(m^3K). Temperatures, geothermal gradients and heat flow density (HFD) are mostly below the world mean values for continents, i.e. geothermal gradient in the karstic areas of south west Slovenia and in Istria is in a range 10 to 25 mK/m, similar in Montenegro (Podgorica region) with up to 30 mK/m and HFD of 20 to 50 mW/m^2. However, restricted areas with elevated values exist, e.g. in the upper 500 m of the Slovenian coastal area the geothermal gradient is up to 45 mK/m with a HFD same as the world mean value for continents (71 mW/m^2). Average and elevated values are found also in Province of Ferrara with gradients from 20 to 65 mK/m.

1. INTRODUCTION

Geothermal energy is an inexhaustible source of renewable energy everywhere beneath our feet. With today's technology it is also available to households through shallow underground. Since it does not depend on the presence of hot water deep basins, the low enthalpy thermal power generation utilizing ground-source (geothermal) heat pumps (GSHP) can be exploited everywhere, by using borehole heat exchangers (BHEs). This shallow geothermal energy can be captured in very different ways to adapt to natural geological and climate conditions and different project ideas. The capture of shallow geothermal energy usually does not extend more than 300 m in depth. LEGEND (**L**ow **E**nthalpy **G**eothermal **En**ergy **D**emonstration) is an European project co-financed by the IPA Adriatic CBC Programme. Its overall objective is the promotion of energy efficiency concepts and the low-enthalpy geothermal energy benefits in the Adriatic area through 10 demonstration GSHP cases in public buildings, SWOT analysis, pre-investment surveys, Life Cycle Analysis methods, thematic worskhops, technical seminars and political and technical memorandum and guidelines. It is worth stressing that two major GSHP types exist (Lund et al., 2000): ground-coupled (closed loop) heat pump (GCHP) and water source (open loop). GCHP types are just a subset of GSHPs. GSHPs also include groundwater and lake water heat pumps (water source), while GCHPs are connected to a closed-loop network of tubing that is buried in the ground. The most common method of ground-coupling is to bury thermally-fused plastic pipe either vertically or horizontally.

The aim of this paper is to present some natural geological, hydrogeological and ground thermal characteristics in several regions dealt with during this project, belonging both to the Adriatic coastal and hinterland areas (Figure 1, left), and their inter-comparison. Data and description of the values, which are important for appropriate planning of GSHP installations, are substantially taken from benchmark reports, made by each partner in the framework of the project and for some regions real data originating from 10 demonstration projects.

2. GEOLOGY AND HYDROGEOLOGY OF THE REGIONS, GROUND PROPERTIES

The simplified geo-structural pattern of the wider analysed regions' area shows the complexity, which is a consequence of the well known thrusting of the African tectonic plate under the Eurasian (Figure 1, right). This is evident also in the pattern of the depths to the Mohorovičić (Moho) discontinuity, which show great variations, from only 27 km in the central part of the Italian Po valley to around 48 km in the Dinarides of Montenegro and north Albania. Beneath the Adriatic Sea depths are in the range of 24 km in the south east to 40 km in the north western part. As a result geological and hydrogeological characteristics of the regions described herein are quite heterogenous and complex, which is reflected in geothermal parameters, such as heat-flow density (HFD) and temperatures at certain depths.

Regarding the Italian peninsula, the Adriatic side is generally considered the “cold side” in respect to the hotter Tyrrhenian side (Figure 2) with high enthalpy geothermal fields. Geophysical campaigns and monitoring of operating wells were conducted over many years, mainly related to the research of hydrocarbons. They showed HFD (Figure 2, left) and temperatures at a depth of 1,000 m (Figure 2, right) much lower on the Adriatic side than on the Tyrrhenian side. Nevertheless, some geothermal anomalies exist, almost all in the northern part, as well as several operating geothermal wells. The Adriatic regions interested and involved in geothermal exploitation are Emilia Romagna (Ferrara Province), Veneto (Vicenza and Venezia Province) and Friuli Venezia Giulia (Udine Province). As described further the shallow underground of northern Italy is suitable for both open-loop and closed loop GSHP systems.

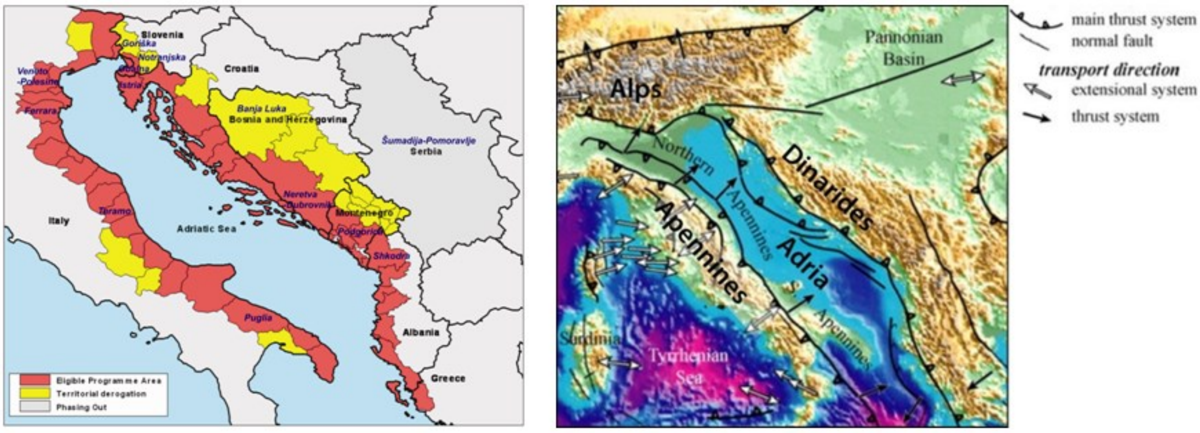

Figure 1: Analysed regions of the Circum-Adriatic countries with the eligible programme and territorial derogation areas (left) and simplified geo-structural pattern of the area (after Vignaroli et al., 2009) (right).

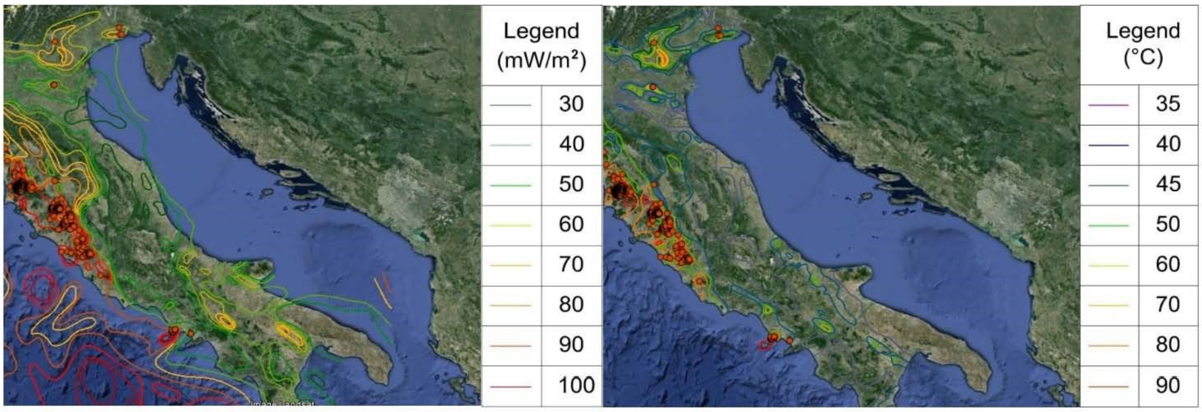

Figure 2: Map of heat-flow density (left) and map of temperature at 1,000 m depth (right) in Italy, Adriatic side. Red points are the operating geothermal wells (Cataldi et al., 1995; Italian Ministry of Economics, webgis on geothermal sources and potential, based on Google Earth, 2014).

2.1 Veneto Region – Focus on the Province of Rovigo, Italy

In the Province of Rovigo the geothermal potential has been studied in order to broaden the knowledge concerning the geological and hydrogeological context of the area of 1800 km^2 (Polesine and Po delta areas) and to evaluate the ability of the subsurface to host low enthalpy geothermal systems (open or closed loop system). The current territory of Polesine is, speaking in **geologic** sense, very recent, which is due to the alluvial deposits from the Adige and Po rivers, and through the land reclamation. The common features are generally the low altitude, the very gentle slope of the terrain, the abundance of water regulated by consortia with levees, canals and draining pumps. Following the bibliographic acquisition and identification of large amount of geological, hydrogeological and technical data, scattered in numerous and fragmentary archives, a database logical relationships was established for their better organization and validation. Some experimental field investigations followed, such as piezometer surveys, seismic studies, penetration tests and hydrogeological investigations. Then the following activities were realized (Veneto Region study, 2014): (**a**) 15 electrical tomography lines (470 m of length and about 95 m of investigation depth for each line); (**b**) 8 continuous core drillings to depths of 15 to 20 m b.g.l. for obtaining survey area stratigraphy. Later the 2" diameter piezometers have been installed in boreholes. Also 8 static penetration tests were realized using electric tip, piezocone and resistivity cone penetration testing tool, driven to a depth of about 20 m b.g.l.. (**c**) Thermal conductivity measurements on surface soil samples (a measurement campaign at 1 m depth b.g.l. at 120 sites distributed within a grid with 4 km side square mesh) and on samples taken from drillings (measurements on each different lithology variation or at least once every 3 meters); (**d**) Multiparameter logs in available points, measuring T, pH, EC, redox, dissolved oxygen parameters, in order to verify the variation of these parameters with depth; (**e**) Installation of 7 automatic dataloggers for groundwater monitoring in wells representative of different aquifers; (**f**) Permeability tests (slug tests); (**g**) single well tracking tests for aquifer parameterization; and (**h**) Phreatimetric level measurements to define groundwater flow direction. The analysis of acquired data allowed to reconstruct geological and hydrogeological layout of the province with identification of permeable and impermeable layers as well as transformation of the geological profiles into hydro-stratigraphic sections. Better knowledge of groundwater thermal conditions led to elaboration of thematic maps.

Hydrogeology between the Po and Adige rivers is linked to the nature of alluvial sediments and to their relationship with rivers. It is composed of a complex of overlapping aquifers, almost all confined, within sandy layers, and intercalated with non-permeable layers. The **geothermal gradient** is relatively low, if compared with other zones of the Veneto Region, as e.g. the volcanic zone of Colli Euganei (Figure 3, left). The gradient is reflected in shallow temperatures, for example at a depth of 50 m (Figure 3, right).

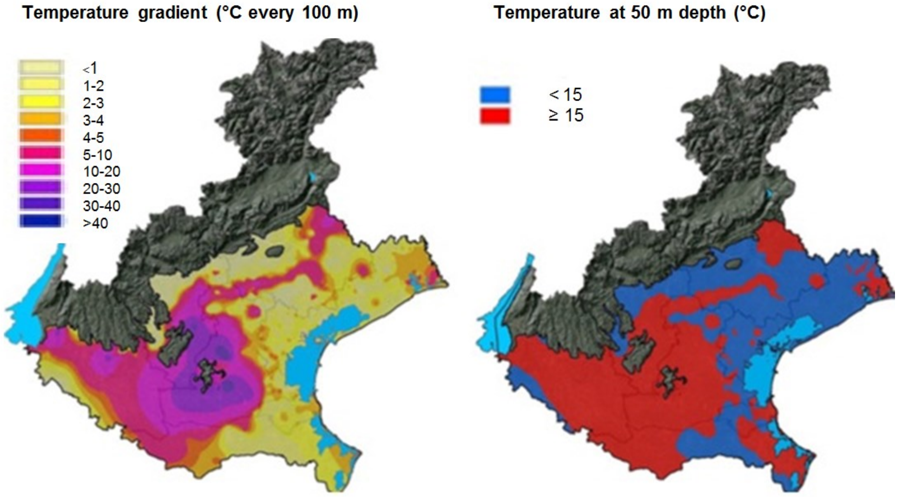

Figure 3: Map of temperature gradient values (°C/100 m) in the Veneto Region (left, Veneto Region Benchmark report, 2014) and map of expected temperature at 50 m depth in the Veneto Region (right, Tosoni, 2012).

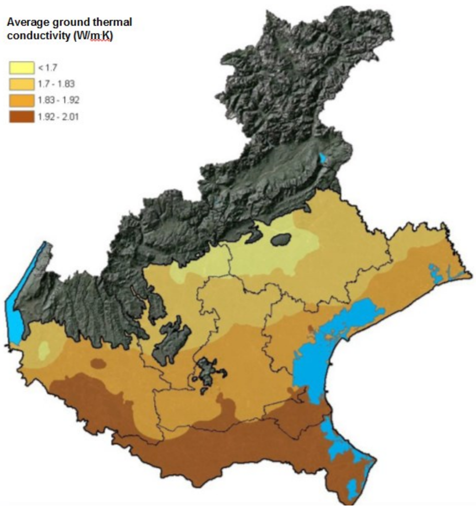

Figure 4. Map of the underground thermal conductivity values (W/(m·K)) in the Veneto Region (Tosoni, 2012).

Thermal conductivity values are related to unconsolidated soils (mainly sands) with high degree of saturation. However, the latest results of temperature logging in the Province of Rovigo, not deeper than 100 m, show geothermal gradients of 15 to 75 °C/km as locally constrained, since the range of values for the Veneto region is generally 15 to 45 °C/km (Table 2). Together with thermal conductivity values of 1.4 to 1.8 W/(mK) from the detailed survey in this Province (Figure 5) a suitable geothermal heat-flux map

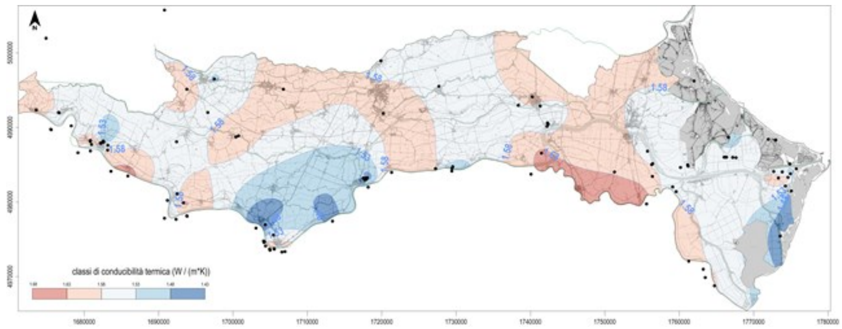

Figure 5. Equivalent thermal conductivity map at 50 m b.g.l. for the Province of Rovigo (Veneto Region study, 2014).

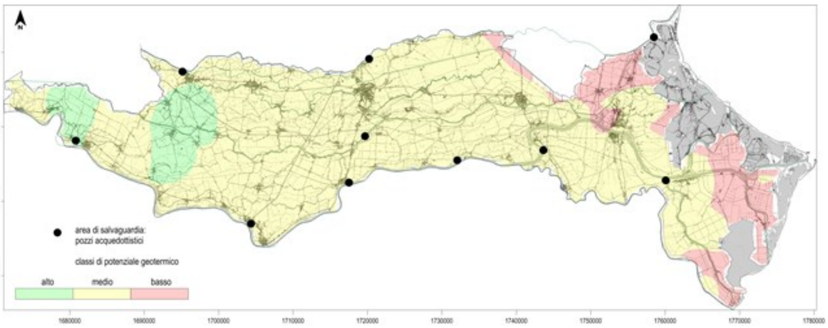

Figure 6. Closed loop systems suitability map for the Province of Rovigo (Veneto Region study, 2014).

shows exceptional values of 30 to 120 mW/m^2 at 50 m depth. However, the HFD in the Veneto Region and Rovigo Province in general have values of 35 to 80 mW/m^2 (Table 2). The closed loop systems suitability map (Figure 6) is a result from the overlay of the closed loop systems' geothermal potential map, which is practically of the same contours, with other conditioning factors.

2.2 Emilia Romagna Region – Focus on the Province of Ferrara, Italy

Geological and hydrogeological settings. The whole Ferrara territory is located in the south eastern sector of the sedimentary Po basin, which is characterized by a complex geological structure called "Ferrara Folds", formed in the late Tertiary, and which influenced the stratigraphic architecture of the Quaternary deposits. This last sedimentary succession, going from late-middle Pleistocene to Holocene, represents the aquifer group A (Ferrara Province Benchmark report, 2013). The oldest, deep and confined aquifers are characterized by coastal and marine sediment gradation. The sediments are generally coarse (medium sand with high permeability) and can be found at depths 100 to 300 m. Younger aquifers are characterized by delta-fluvial deposits and alluvial sediments (fine sand and silty sand with average permeability). The phreatic aquifer is a few meters thick, while the other aquifers' thickness is 40 to 100 m. The aquitards separating the aquifers are characterized by lagoonal, prodelta and platform deposits composed of silty clay sediments with low permeability. Except for the shallow aquifer, receiving the total input directly from rainfalls, the rest of the aquifer complexes are confined and they do not receive recharge from precipitations. The A1 system receives direct recharge from the wide reaches of the Po River and remote recharge from both the alluvial Apennine and Alpine fan systems and the outcropping sands of the Adriatic Sea. The A2 system is only recharged by the alluvial Apennine and Alpine fan systems. The systems A3 and A4 are not affected by the hydrological cycle but are characterized by the presence of fossil water (Figure 7). The permanent reserves of A1 and A2 were estimated by Ferrara Province at 330 Mm^3 and 400 Mm^3, respectively.

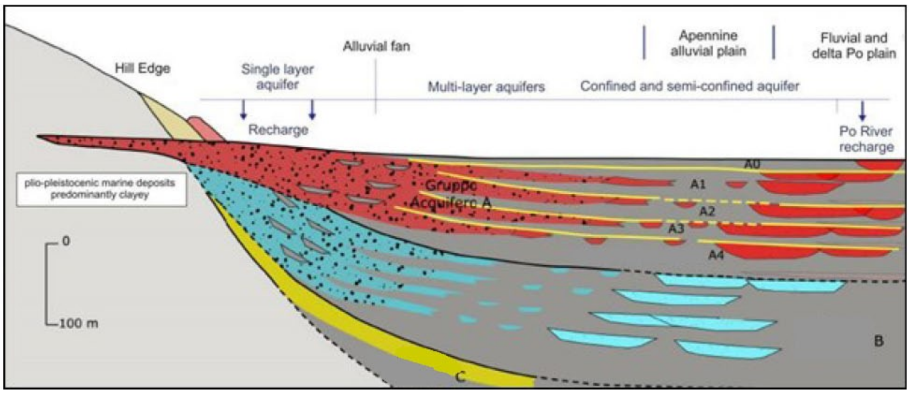

Figure 7: Sequential hydrostratigraphic unit in the Emilia-Romagna plain (Ferrara Province Benchmark report, 2013).

Ground properties and soil types. In the topographically depressed areas of the Ferrara floodplain the soils have high clay content and are, therefore, subjected to contraction and swelling phenomena producing large and deep cracks on the surface. Soils of morphologically high areas, developed on ancient fluvial bumps, show internal reorganization of particles, no evidence of mobilization processes and re-deposition of calcium carbonate in deep layers. The predominant soil textures in the province are silt loam and silty clay (68% of the territory), while peaty soil is less frequent (23%). The remaining 9% is covered by sand and silty sand (Figure 8).

Thermal and hydraulic parameters. The hydraulic conductivity of the permeable coarse and sand deposits in the alluvial plain varies in a range between 7-8·10^{-3} m/s (alluvial fan deposits) and 7-8·10^{-5} m/s (very fine sand in coastal aquifers and river bank deposits). Thermal conductivities of the sediments have normal values in dry and wet conditions. Geothermal reservoirs are present in the eastern part of Ferrara. Three hydrothermal systems have been identified: G1 (Early Pliocene Formations), G2 (Late Messinian Formations) and G3 (Early Jurassic Formations). Each reservoir can be considered hydraulically separated from the others by aquitards that prevent significant leakages. The shallow system G1 comprises the aquifer group A without thermal anomalies. The hydrothermal system G2 consists of fine and medium sand intercalated with Early Miocene marl layers. The reservoir top is 650-800 m deep and the system is characterized by an average temperature of 45 to 60°C. The hydrothermal system G3 is composed of fractured dolomite and limestone. The reservoir thickness is 700 to 1,000 m with the reservoir top at 600 to

1,700 m depth. The average temperature in this reservoir is around 85 to 95°C. Drilling data collected during oil and gas investigations in the Po plain indicate a geothermal gradient of 1°C/100 m in the shallow deposits. Generally the geothermal gradient is not linear and the studies in Ferrara indicate gradients from 2 to 6.5°C/100 m in the deepest geothermal reservoir G3. This is due to the high permeability of the carbonate rocks, permitting heat transfer via deep water circulation. The geothermal field is explained with the HFD values of 30 to 65 mW/m^2 and expected temperatures at 1,000 m depth between 35 and 80°C (Figure 2).

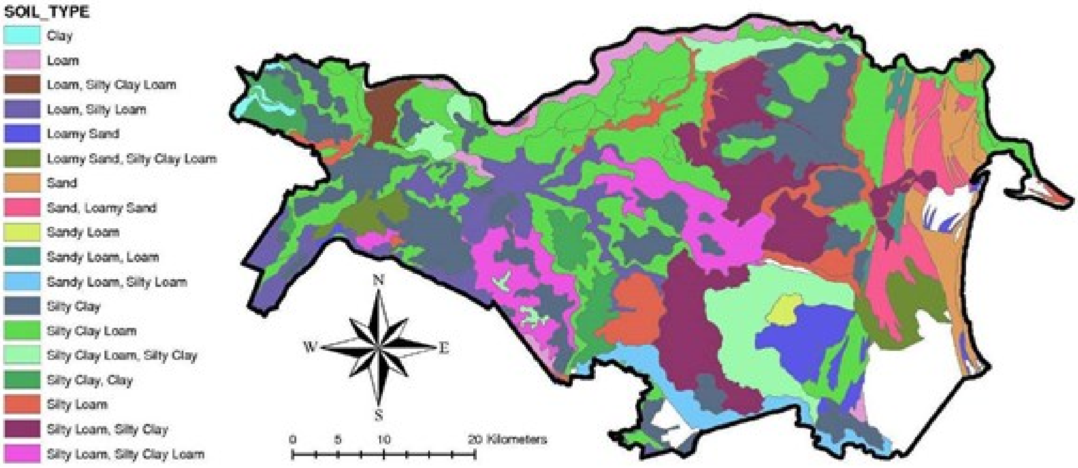

Figure 8: Soil map of the Province of Ferrara 1:50.000 (Ferrara Province Benchmark report, 2013).

2.3 Province of Teramo, Italy

Geological and hydrogeological settings. The mountains are made up of limestone rocks for the most part, of marine origin, belonging to the Mesozoic (Triassic to Cretaceous). The inaccessible walls of the Gran Sasso are opposed to the different morphology of the Laga, in the far north of the province, with forests, gorges and waterfalls. Along the Adriatic coast, sandy beaches are stretched with Mediterranean climate. Most of Teramo province is hilly: several rivers flow along the valleys, including the Vomano and Val Vibrata (Teramo Province Benchmark report, 2013). The hills are high and sometimes gruff, sometimes characterized by gentle green slopes. There are formations of "badlands" due to erosion, in any case, there are areas with groves of oaks, poplars, willows and maples. The plain in the province of Teramo takes only 1% of the territory which in this case extends only in the coastal part (Figure 9). This plain and the lower parts of the river valleys are more suitable for GSHP installations. The expected temperatures at 1,000 m depth in the Teramo Province are on average from 30 to 40°C, and the HFD values between 30 and 65 mW/m^2 (Figure 2).

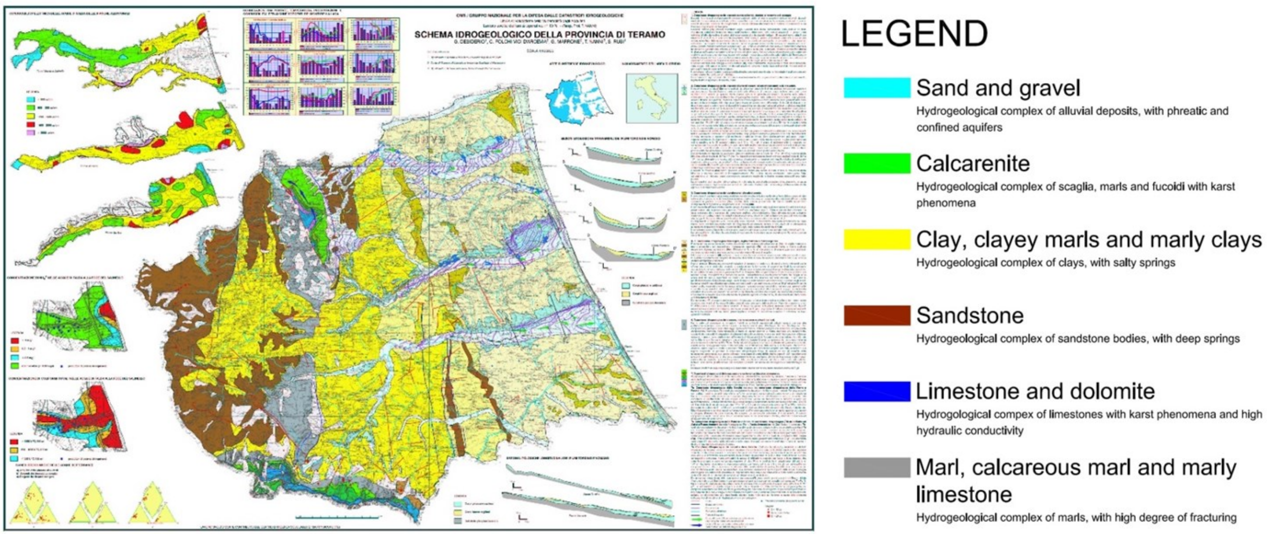

Figure 9: Hydrogeological study of Teramo Province. The text in the legend on the right side of the map describes the main characteristics of groundwater flow dynamics in connection with lithology and tectonics, hydrogeochemical type and vulnerability of groundwater (Desiderio et al., 2005; Source: CNR - GNDCI).

2.4 Puglia Region, Italy

Geological and hydrogeological settings. The most part of Puglia represents the emerged southeastern portion of Carbonate Adriatic Plate and consists of thick sequences of limestones and dolomites formed within the carbonate platform during the Late Cretaceous, covered by bioclastic limestones, calcarenites and clays (Figure 10, left). Today, the region is fragmented into horsts and grabens by a series of faults with NW-SE direction. In many zones the karst is developed underground with extensive network of caverns, and with lithotypes varying from limestones to marl. Confined aquifers are generally situated deeper than 100 m.

Hydro and geothermal conditions. In the most part of the region it is possible to exploit shallow geothermal energy. The temperature generally does not exceed 20°C up to 300 m depth. Consequently, the HFD values are quite low, around 30 to 40 mW/m^2, with levels up to 80 mW/m^2 in the inner area of Murge (Figure 10, right). At 1,000 m depth the expected temperatures are mainly not above 30°C (Figure 2). In the frame of the VIGOR project the tests of thermal conductivity and other properties were carried out in laboratory (dry and wet condition) on rocks and loose materials. Previously obtained values from the screening of literature data have been validated by comparison with those directly measured on samples. Reasoned values, ranging from 0.6 to 3 W/(mK) (Table 2) were assigned to the most representative geological units (Figure 11, left). The aquifer carbonate systems correspond to wide limestone areas. There the water infiltrates through discontinuities in rocks, therefore the water has very low temperature variations, and the resulting geothermal gradient is lower than the continental average. In these areas the underground heat is redistributed by stormwater, which infiltrates into the underground, by maintaining surrounding rocks at low temperatures. In the presence of water springs, for example along the coast, the inverse effect happens: pre-heated water, circulating in deep underground layers, rises up to the surface, by increasing temperature of surrounding rocks. Anomalies also exist, where shallow aquifers merge with hotter water, coming from very deep reservoirs; it is the case of thermal springs, such as San Nazario and Santa Cesarea Terme. In some zones, for example, the borders of the Gargano peninsula towards Tavoliere, the borders of Murge towards Basilicata, the eastern part of the Salento peninsula, the temperature of underground water can rise up to 25°C or more. The map for direct use of geothermal low enthalpy energy (Figure 11, right) shows the possibilities for realization of closed-loop systems with GHPs to depth of 100 meters. The best heat exchange performances for closed loops are found between the Ofanto River and Murge (140-160 kWh/m^2). Puglia region is endowed with numerous wind, solar and bioenergy heating and/or cooling plants, but as regard the air conditioning using low enthalpy geothermal energy, there were 8 operational plants in the whole region as of 2011.

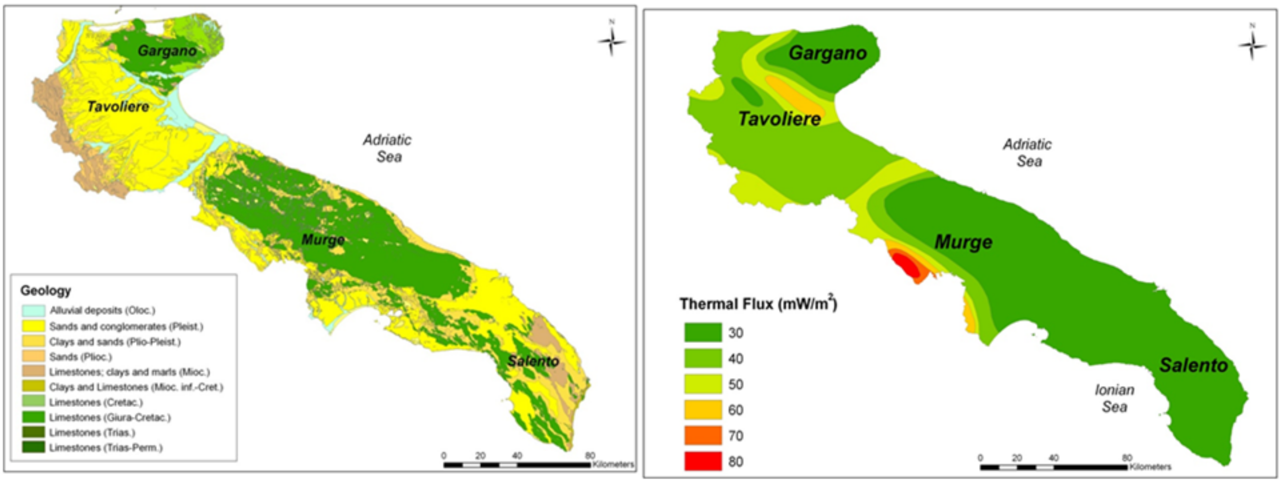

Figure 10: Lithological units (left) and HFD values (right) in the Puglia region (Puglia Region Benchmark report, 2014).

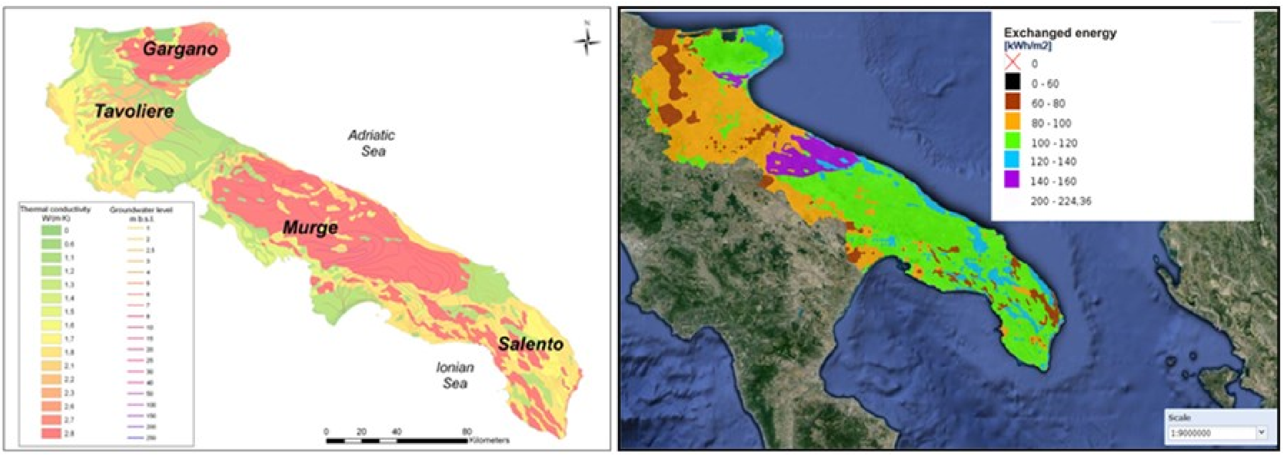

Figure 11: Thermal conductivity of surface rocks with groundwater levels (left) and geo-exchange map for closed-loop systems (in kWh/m^2) in the Puglia Region (Puglia Region Benchmark report, 2014; www.vigor-geotermia.it).

2.5 Obalno-kraška, Goriška and Notranjsko-Kraška Regions, southwestern Slovenia

The southwestern part of Slovenia (24% of the total Slovene territory) has very diverse **geological** and **hydrogeological** characteristics (Prestor et al., 2013). Tectonically, it lies in the small part of the Southern Alps, made of carbonate rocks (limestone and dolomite), and mostly in the External Dinarides with predominant carbonate rocks, and to smaller extent in the Adriatic foreland with marl and sandstone as flysch rocks. Carbonates cover 62% of the project area, alteration of clastic and carbonate rocks 27%, non-consolidated sediments (gravel, sand, silt, clay) 11%, while acid and basic volcanic rocks are negligible (Figure 12, left). The area has a complex hydrogeological structure with a high recharge (>300 mm/year). Carbonate rocks are favourable for drilling, yet demanding owing to the unpredictable encounter of caverns, while in the flysch rocks it may be easier (rotary or down-the-hole) but still more difficult than in nonconsolidated sediments. Alluvial deposits are found along many streams with widely sedimented deposits especially along the rivers Soča (Isonzo), Vipava, Rižana and Dragonja. Deposits along Soča and Rižana rivers are more permeable and consequently also suitable for open loop GSHP systems. The denser settlement area is situated along downstream of the Soča river. Alluvial deposits of lower yield are along the Vipava, Dragonja and Badaševica rivers, since they contain more clay. Clay deposits are thicker downstream along the Dragonja. Along the Vipava river alluvial deposit can reach thickness of more than 15 m and is in places more clayey but mostly composed of sandstone and marl pebbles, which is suitable for closed loop horizontal (H) and vertical (V) heat exchangers systems.

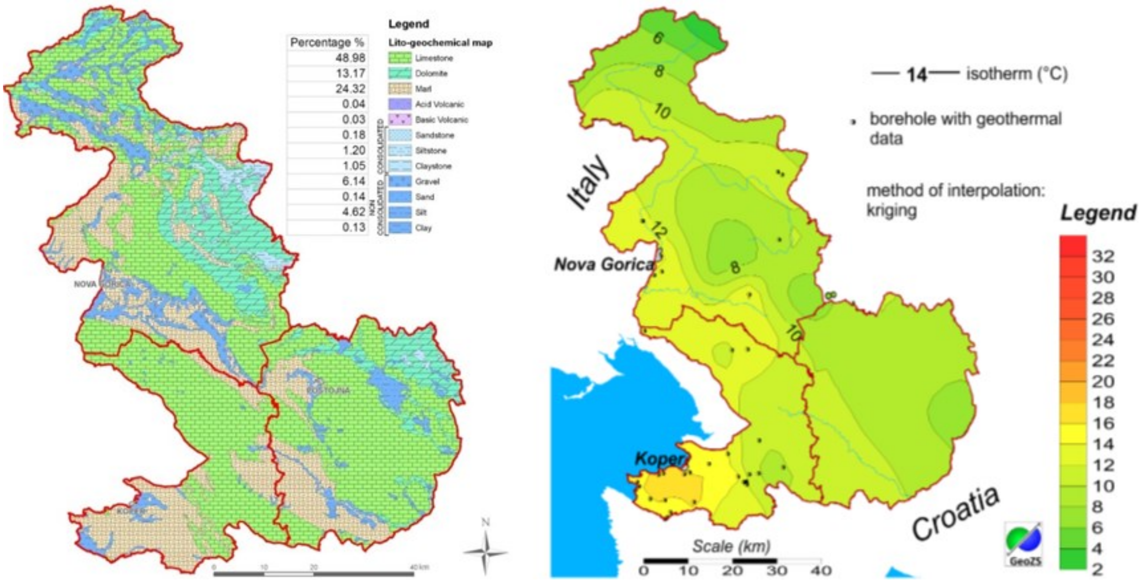

Figure 12: A map of lithological setting (left) and a map of expected temperature at 100 m depth below surface (right) of the LEGEND project area in south western Slovenia (Prestor et al., 2013).

Ground thermal and hydraulic parameters. In southwestern Slovenia, the rocks and soils with higher thermal conductivity are suitable for installation of horizontal and vertical heat exchangers in the shallow subsurface. For horizontal heat exchangers the more suitable are sand, sandy clay, flysch rocks as silty marl, loose sandstone and sandy clay. For vertical heat exchangers rocks such as sandstone, limestone and marly limestone are suitable provided that no caverns are encountered in limestones. The main towns in the area are developed and situated on different rocks, such as flysch, alluvial river deposits, and carbonate rocks or on mixture of these rocks. Only locally along the Vipava river and in some places along the Soča river (Tolmin, Bovec) can individual open vertical GSHP systems be successfully used where intergranular aquifers of medium hydraulic conductivity are developed. More than half of the territory is covered by limestone aquifers, where the accessibility of groundwater is rather low and conditions unfavorable for open vertical GSHP systems. Closed vertical systems are more applicable. Similar conditions are for the territory with only minor and discontinuous aquifers (flysch layers, marl, sandstone, siltstone, claystone) where closed vertical and horizontal systems are mostly applicable. Groundwater within these aquifers of low to medium hydraulic conductivities (flysch layers) is generally slightly more mineralized. Geothermal measurements in about 30 boreholes in these three regions, everywhere temperature logging and much less thermal conductivity determinations of cored rocks, made a good basis for geothermal picture. At a depth of 100 m below the surface the expected temperature in the northern mountain and hilly area is mostly 6 to 11°C, and 12 to 17°C in the coastal area, where higher temperatures are expected close to Izola and Koper and in the hinterland towards Croatia (Figure 12, right). At a depth of 250 m around 8 to 12°C are the prevailing temperatures in the northern part. Around 12 to 16°C are expected in the Vipava valley, and around 18 to 20°C in the coastal area between Izola and Koper and in the hinterland towards Croatia. The **geothermal gradient** of the upper 500 m is in range of 10 to 45 mK/m, with low values in karstic and mountainous areas and higher between Koper, Piran and the Dragonja River. The HFD pattern is similar, showing elevated values around 70 mW/m^2 at Izola, and elsewhere between 30 and 55 mW/m^2 (improved after Rajver and Ravnik, 2002).

2.6 Istria region, Croatia

In **geological** sense, Istria, as the most western part of Croatia, constitutes the northwestern part of the old Adriatic carbonate platform with thick limestone deposits and less dolomite or dolomite-limestone breccia. Its surface is largely covered by thin layer of Quaternary sediments. The flysch riverbeds were created in Tertiary, and then the thrust structures of Učka and Ćićarija. The oldest sedimentary unit comprises a sequence of Jurassic (Dogger to early Malm) layers of a shallow water filled limestone in the area between Poreć, Rovinj and the Lim canal. One of the largest Jurassic bauxite deposits is located north of Rovinj. The Paleogene sediments were formed by gradual flooding sedimentation and later to karst converted diverse land phases and karst relief. Owing to the sea level uplift the lowest parts of the relief were gradually transformed into swamps, in which in-between carbonate sediments became the source material for thick coal layers (mines in Labin area).

Hydrography and hydrogeology of the Istrian peninsula is determined by its geological structure, or multiple tectonic movements and faulting during the Quaternary and by relief formation. Only few surface streams, such as the longest Istrian river Mirna, flow from the source to the sea, while a considerable part of them flow underground due to karst surface and continues to the lower elevations of karst springs or to submarine springs along the coast. **Hydrogeological** characteristics of Istria depend also on depth of the underground water flows. Depth of less than 50 m was recorded in the area around Pula and the western coast of Istria. Undercurrents at depths of 50 to 200 m are located in central Istria, and those at depths greater than 200 m in the eastern and northern part of Istria in area of Ćićarija. Due to karstification of deposits, links are established between important karst springs and submarine springs on the Kvarner side. The underground water course in the Učka mountain flows to the Kvarner and is connected with numerous submarine springs spreading on the Kvarner side. In **geothermal** conditions Istria belongs to the Dinarides and to the Adriatic foreland, both characterized by a low geothermal gradient and HFD. Depths to Moho discontinuity in Istria are between 30 and 40 km. The HFD values are consequently low, between 20 and 55 mW/m^2. The **geothermal gradient** is also relatively low, generally between 10 and 25 mK/m, but varies significantly (Figure 14, left). At a depth of 1,000 m below the surface temperatures between 35 and 40°C may be reached (IRENA Benchmark report, 2013). In the northern part a thermal mineral spring, St. Stefan, has been used for a spa thermal resort. The spring is located at the contact of permeable limestone and impermeable flysch clastic sediments. The cold water source was terminated by reactivating activities in 1903 and the water temperature increased afterwards from 28.5°C to 34.5°C. On three newly captured sources the temperature was 36.5°C, 20°C and 29°C, respectively. For the use of GCHP units with horizontal heat exchangers the most convenient areas are the southeastern part of the Čepić field with Quaternary lacustrine sediments of sand and clay with maximum thickness of 28 m and also red soil sediments along the western onshore areas from Savudrija to Mrlera and in the vicinity of the towns of Poreč, Rovinj, Barban, Pazin, as well as north of Pula towards Raša.

2.7 Dubrovnik - Neretva county region, Croatia

Dubrovnik-Neretva county is the most southern county in Croatia with a total area of 9,272 km^2 (10.3% of Croatian land and sea), of which 1,782 km^2 is land area. The county consists of two main parts: a relatively narrow coastal line with a number of offshore and coastal islands and the Pelješac peninsula and the area of the Neretva valley with its coastal part. Coastal relief is similar to the rest of the Croatian coast with identical, Dinaric NW-SE direction. The county belongs to the External Dinarides with a high degree of tectonic disturbance, and **geologically** built mainly of Mesozoic and Tertiary carbonates and Tertiary clastic sediments. The narrow coastal belt is characterized by Paleogene clastic sediments covered with older Mesozoic limestone deposits. The alluvial sediments along the natural waterways and Quaternary erosional sediments are partly present, but could be a good geological environment in places for the horizontal heat exchangers or energy baskets layout with GSHP units. The largest part of the county area is predominantly composed of limestone. Limestone, dolomite, flysch and alluvial material dominate the composition of the coastal cliffs. The Moho depth in the county (35 to 40 km) reflects the underthrusting of the Adriatic carbonate platform beneath the Dinarides and is directly related to the geological origins of the area. Consequently the geothermal parameters are quite low. For most of the county the HFD is 20 to 30 mW/m^2, corresponding to the average of the Croatian coastal area. The **geothermal gradient** reaches to only 10 to 20 mK/m (Figure 14, left). At a depth of 500 m temperatures of 20 to 27°C may be reached (DUNEA Benchmark report, 2103), but at 1,000 m depth pretty low values are to be expected, yet not confirmed by drillings.

2.8 Podgorica and Primorje Regions of Montenegro

The city of Podgorica has a favorable position at the confluence of the Ribnica and Morača rivers. The Podgorica municipality covers 10.4% of Montenegro's territory. With an average discharge rate of 40 l/s/km^2, or about 19.5 km^3/yr, Montenegro holds 4% of the world's territory with the highest average water runoff. Bearing in mind that as much as 95.3% of the river basin is formed in the country, it is reasonable to assume that water is one of the greatest natural resources of the country.

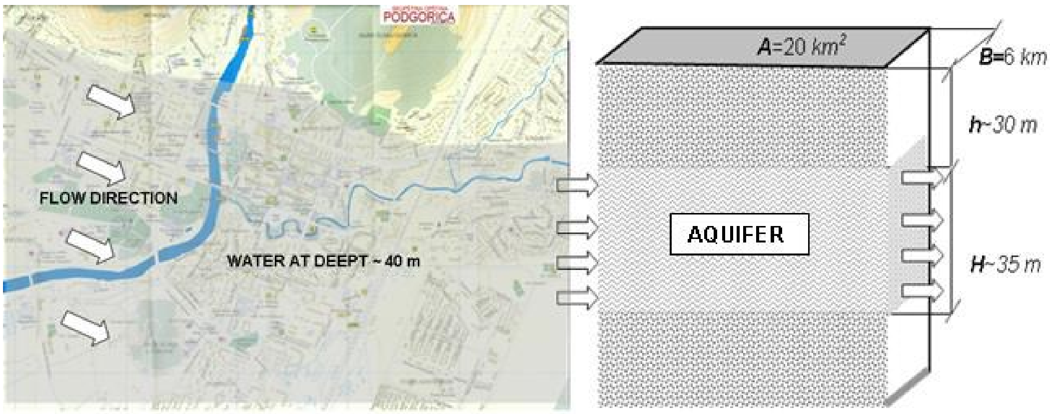

Figure 13: The aquifer beneath the city of Podgorica (MGBC and Mun. Danilovgrad Benchmark report, 2014).

Geological and hydrogeological settings. The region is characterized by thick Late Cretaceous sedimentary sequences, known as the Durmitor flysch formation. It is composed of Turonian dolomites, dolomitic limestones and limestones, then Sennonian basal breccias and conglomerates, sandstones, marlstones and stratified limestones, dolomitic limestones and dolomites, and marly limestones of Maastrichtian. Thin layers of Pleistocene sediments cover the Cretaceous sequence in the Zeta plain and Bjelopavlići valley. In Podgorica at a depth of 40 m an aquifer is encountered with enough water to be renewed and that could be used as a source of underground energy (Figure 13). The research showed a real small "river" flow under Podgorica with temperatures close to 14°C (MGBC and Mun. Danilovgrad, 2014). New drilling has confirmed the existence of a large aquifer system. In the vicinity of the pilot building for the GSHP facility in Danilovgrad city centre, near the river Zeta, a well of 50 m depth has been recently drilled, where a confined aquifer has been detected, which is the same aquifer from Danilovgrad to Podgorica. The drilled rocks are probably marly limestones of the Maastrichtian age which can obviously have fissure and/or karstic permeability.

The thickness of the Quaternary sediments in the plain of Podgorica (sandy gravel and conglomerate) is usually in range of 50 to 65 m. Beneath the neutral temperature zone, the ground **temperature gradient** is about 30 mK/m (MGBC and Mun. Danilovgrad, 2014). The HFD values in the Podgorica area are pretty low, 20 to 40 mW/m^2. Consequently, at a depth of 1,000 m only around 25 to 30°C can be expected, which is typical for the Dinarides in general due to thick Earth's crust. In the Primorje (coastal) area the thermal springs with the highest flow rate of 3.7 to 6 l/s and temperature of 24°C are found in the Valdanos bay close to the town of Ulcinj. The total flow rate capacity of the springs there is 200 l/s with 22°C. **Thermal water** emerges from Cretaceous limestones along the contact with Eocene flysch, and from Miocene limestones with clays. Ideal thermal power is 6.7 MW$_t$, however, it may be utilized as geothermal potential using the GSHP units (Burić, 2013), which is especially important for touristic buildings in local communities. Thermal energy from sea water, lake and river waters could also be interesting for such utilization.

2.9 The District of Shkodra Region, Albania

The district of Shkodra, situated in northern Albania, is one of the largest districts in the country (Municipality of Shkodra, 2013). It stretches from the Northern Alps (the highest peak 2,694 m) to the coastal lowlands. The climate is Mediterranean with average yearly temperatures from 7.5°C in Vermosh to 14.8°C in the city of Shkodra. The average yearly rainfall is 2,000 mm. The Albanides represent the assemblage of **geological** structures, and together with the Dinarides in the north and the Hellenides in the south, have formed the southern branch of the Mediterranean Alpine Belt (Figure 1, right). Several tectonic zones extend into district of Shkodra, as the Albanian Alps, Krasta-Cukali and Kruja zones of the External Albanides and Mirdita of the Internal Albanides (Municipality of Shkodra, 2013; Frasheri et al., 2004). The tectonic zones of the External Albanides outcrop are chiefly in the western Albania. The Alps zone continues into the High Karst of the Dinarides with Permian sandstone and conglomerates, but in general the Alps are represented by limestone monoclines, and smaller anticlines in their background. The Krasta-Cukali zone continues in the Pindos zone in the Hellenides and into the Budva zone of the Dinarides. The Krasta subzone lies from Shkodra in the north to Leskoviku in the southeast, with three outcropping formations: the Albian-Cenomanian early flysch, Senonian limestone serie and Maastrichtian - Eocene flysch. The Kruja zone continues into the Dalmate zone in the Dinarides and into the Hellenides. It consists of a series of anticline structures with Cretaceous-Eocene carbonate cores of neritic limestone, dolomitic limestone and dolomites covered with Eocene to Oligocene flysch deposits.

The **geothermal field** is characterized by low temperatures, a characteristic of the sedimentary basins with a great thickness of sediments. The temperature at 100 m depth varies from <10 to 19°C, with the lowest values in the mountain regions of the Mirdita zone, as well as in the Albanian Alps (Figure 14, right). In these areas, an intensive circulation of underground cold water (5 to 6°C) occurs. The highest temperatures at 100 m depth characterize the Adriatic coastline of the External Albanides where the **geothermal gradient** reaches the values of 21.3 mK/m in the Pliocene clays in the center of the Peri-Adriatic Depression. The highest gradients are detected in the anticline molasse structures of the central Pre-Adriatic Depression. The lowest values of 7 to 11 mK/m are observed in the deep synclinal belts of the Ionic and Kruja tectonic zones. The characteristic temperatures at a depth of 500 m range from 21 to 30°C. The regional pattern of HFD shows higher values of 42 mW/m^2 in the center of the Peri-Adriatic Depression of the External Albanides and around 30 mW/m^2 towards the Adriatic Sea Shelf. The values around 25 to 30 mW/m^2 or lower are typical for the Albanian Alps due to great thickness of sedimentary crust.

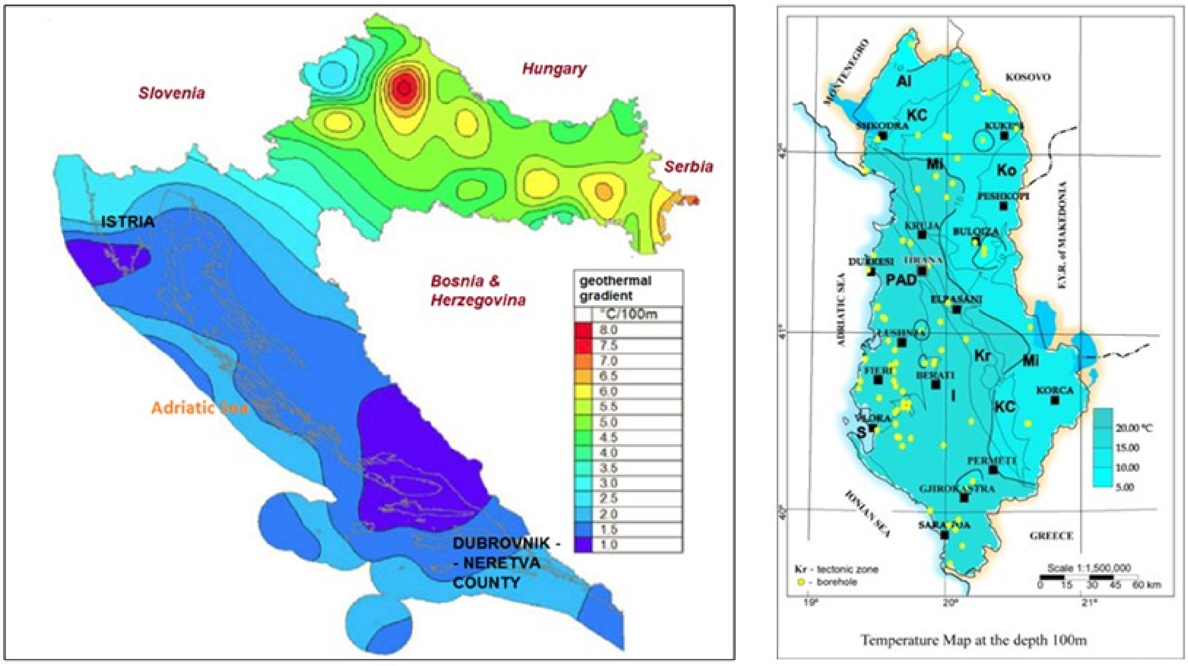

Figure 14: Map of geothermal gradient for Croatia, in °C/100 m (Fištrek et al., 2013) (left) and map of temperature at a depth of 100 m in Albania (Frasheri et al., 2004) (right).

2.10 Banja Luka Region of Republica Srpska, Bosnia and Herzegovina

The northwest territory of Republika Srpska, with municipalities Banja Luka, Gradiška, Prijedor and Laktaši, is characterized with a complex **geological** and **tectonic** setting (LIR Benchmark report, 2013). The territory comprises the central part of the Dinarides orogene system and a smaller part of the south edge of the Pannonian Basin in the north. Hydro-geologically few different areas are present, each characterized with specific geothermal characteristics. The terrain is shaped by strong tectonic movements resulting in complex geological structures (Figure 15), which outline three different basic **hydro-geological** structures: (**a**) Artesian basins and intermountain depressions with fissure permeability, circulation between layers, slowed water interchange in Tertiary and Cretaceous sediments; (**b**) Hydro-geological folded regions with fissure permeability and circulation between layers, the Paleogene flysch zone in the north, complex regime of charging and discharging in the Tertiary, Cretaceous and undivided Mesozoic sediments such as limestone, clastic rocks, Jurassic-Cretaceous flysch and diabase-chert formations; and (**c**) Hydro-geological massifs with fissure and karstic permeability, circulation in the plutonic, volcanic, schist, serpentine and carbonate Mesozoic massifs. The most important defined structures in a geothermal sense are the large artesian basins in the north and the central-ophiolitic zone in the central part of the territory. The boreholes with **thermal and thermo-mineral water** in use currently give about 44 MW_t of thermal energy (plus about 3 MW_t from springs), but much more energy can be obtained from hydrothermal systems with new wells in the territory of Republica Srpska. Plenty of underground water basins and rivers (Vrbas, Vrbanja, Sana, Sava) may be used for the open loop GSHP systems. Several GSHP systems with water well utilization have been installed, mainly for heating of kindergartens and buildings. Great resources of geothermal energy are found in thermal waters with temperature of up to 90°C, accumulated in the sediments of the Mesozoic age down to a depth of 2 km. There are several thermal water spas, e.g. Srpske Toplice (Banja Luka), Slatina and Laktaši. The thickness of the hydro-geothermal reservoir of sedimentary rocks and dolomites is approximately 1 km. The **geothermal gradient** in the region ranges from 25 mK/m in the south to over 45 mK/m in the north along the Croatian border (Jolović et al., 2012). The HFD values show identical pattern, from 45 in the south to over 70 mW/m^2 in the north.

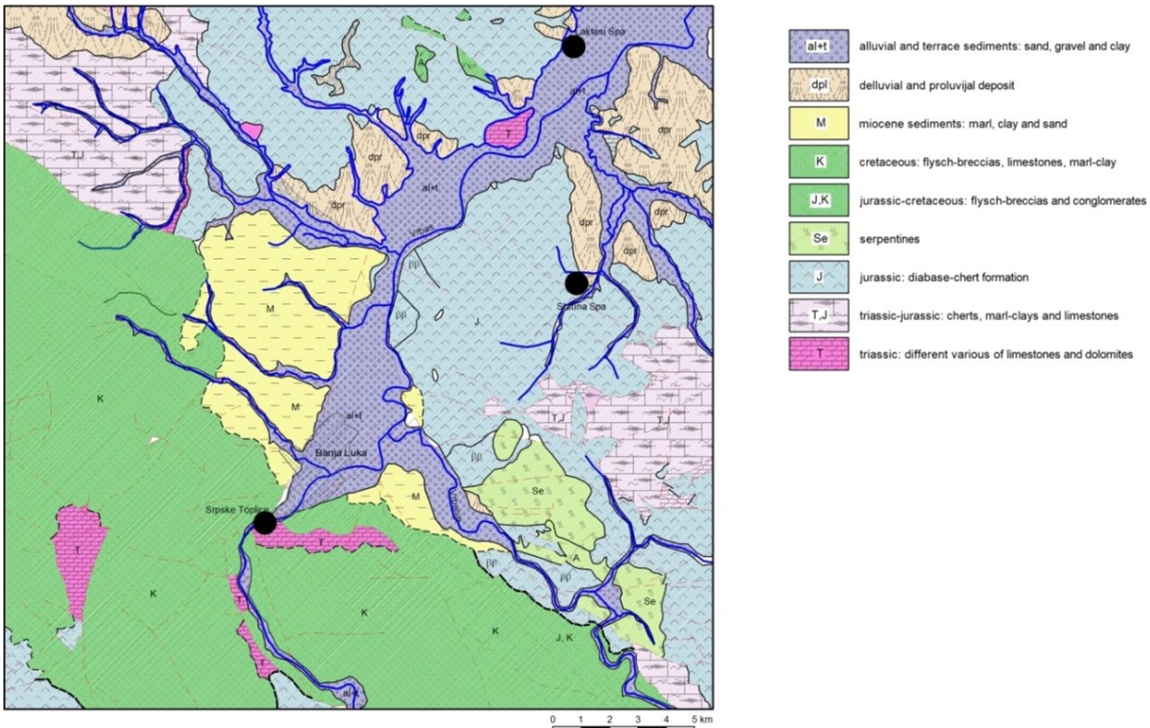

Figure 15: Geological map of the Banja Luka region (Begović and Ivanković, 2014).

2.11 Šumadija and Pomoravlje Region, Serbia

The region of Šumadija and Pomoravlje is situated in the central area of the Republic of Serbia between the Sava and Danube rivers in the north, and Morava in the east, Zapadna Morava in the south and Kolubara in the west (REDASP Benchmark report, 2013). The overall area of the region amounts to 5,001 km^2, which is 5.6% of the total area of the Republic of Serbia, of which the agricultural area is approximately 3,300 km^2. The region is characterized by hilly-mountainous area, with the exception of the Morava valley with outstanding alluvial characteristics. The river courses are numerous, but short. The main reason for such special characteristics is the limit of the whole area by the big rivers. The region is **geologically** very diverse and built predominantly of Jurassic (silt, sandstone, serpentinite), Cretaceous (marl, sandstone, silt, breccia limestone, etc.), Middle Miocene (sandstone, clay, marl, marly limestones), Late Miocene (conglomerate of up to 30 m thick, sandstone, clay, clay sand, quartzlatites, etc.) rocks and Quaternary deposits (Figure 16). The latter alluvial and diluvial sediments of shallow depths in the wider Kragujevac area are not so rich in groundwater for implementation of open-loop systems (GES, 2014). Geothermal energy use is applied only at the spa resort "Bukovička banja" in the municipality of Arandjelovac where 3 known thermomineral springs appear with temperatures in the range of 20 to 40°C. The most abundant quantities of thermomineral water can be found in the Bukulja mountain south of Arandjelovac. They mainly belong to the hydrocarbon-sodium-carbon-acid type of water. The spring "Banja" can also be classified as the spring of the so-called warm waters with potential to heat buildings and greenhouses, the temperature of which is 13°C.

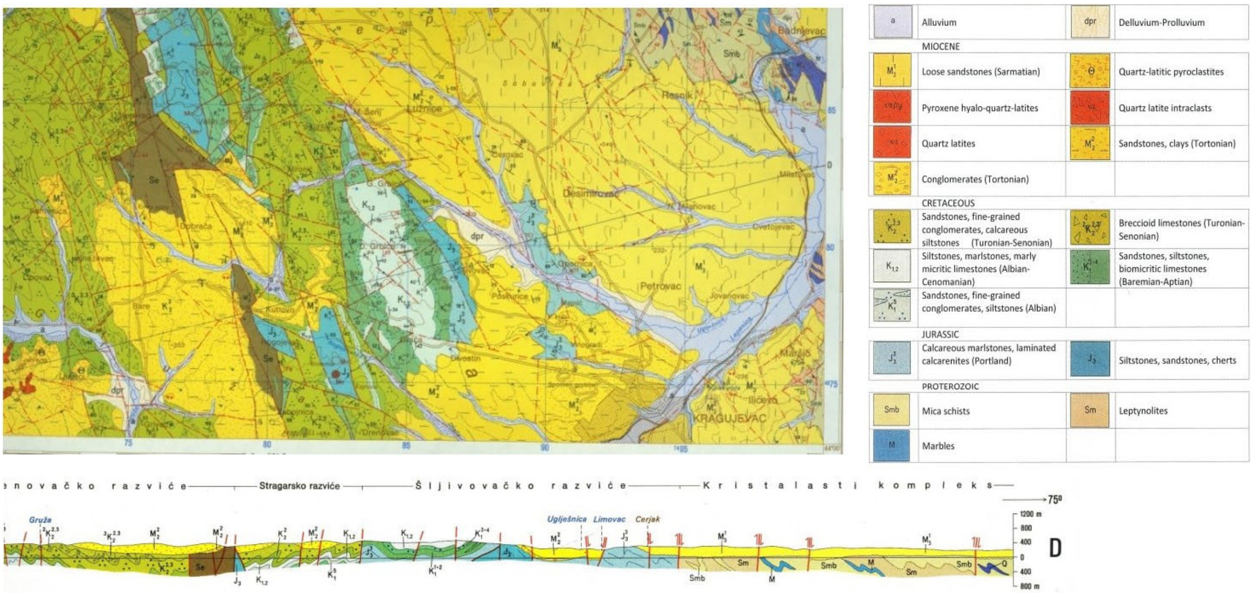

Figure 16: Geological map of Šumadija and Pomoravlje region with a cross section (Brković et al., 1979).

Geothermal conditions and thermal parameters. Thermal waters in the territory of the Despotovac municipality (east of Kragujevac) originate from depths of over 1,000 m. The water flows through the underground gaps in the limestone of Beljanica Mtn. towards the spa spring, where at a certain depth the cold water mixes with thermomineral. The main spring of Despotovac spa was warmer and more affluent in the past. The spa water temperature dropped by 4°C (from 30°C in 1928 to 26°C in 1997), and the water supply diminished to a great extent, in 1975 it was only 2 l/s. The HFD values are around or above 100 mW/m^2, which is characteristic for the Serbian-Macedonian massif tectonic unit. Also the **geothermal gradient** is elevated, from 40 to 50 mK/m, which is reflected in the expected temperatures of around 33 to 42°C at 500 m depth and 50 to 70°C at 1,000 m depth (Hurtig et al., 1992; Milivojević, 2001). However, elevated temperature gradients in shallow sedimentary layers, which could be used for horizontal or vertical BHEs, are not expected everywhere.

3. COMPARISON OF GEOTHERMAL PARAMETERS FOR THE GSHP APPLICATIONS

Overview of the geothermal parameters in all the regions studied has revealed a very high diversity of conditions, both geological and geothermal. The summarized geological and structural units (Table 1) show anticipated heterogenous hydrogeological conditions, which affect the type of system installation. The availability and usefulness of more precise geological maps and cross sections for the studied regions is very different, yet the comparison is important for geologists and geothermal specialists to see where there is a necessity to produce or elaborate on such specific geoproducts. For the Italian regions of Veneto, Emilia-Romagna and Puglia and specifically Rovigo and Ferrara provinces, such maps and cross sections already exist, they serve as a basis for the planning of GSHP investments and are good practice examples. This kind of information for the Slovene south-western regions is almost at this level. However, for the other regions such concrete maps for planning in the use of shallow GSHP systems are still not widely accessible, or are probably in development phase (e.g. Teramo, Podgorica). Despite the difference in geological-hydrogeological conditions there are areas in each studied region comparable and favorable by the shallow geothermal values (Table 2). The goal of the project itself is exactly to encourage the shallow geothermal energy by the recognition of favourable conditions. Availability of geothermal data in the regions and specifically their processing is in different phases. The Italian and Slovene regions are elaborated in detail, while some other regions still don't have enough accessible information or there is a need for producing specific maps and information, as well as for collecting and interpreting the basic data from well loggings.

Table 1. Characteristic geological and structural units of the Circum-Adriatic regions.

	region or province		Characteristic geological and structural units
1	**Veneto_Rovigo**	ITA	alluvial sediments of Adige and Po rivers
2	**Ferrara**	ITA	delta-fluvial and alluvial sediments, multi layer aquifer complex A1 to A4, silty clay aquitards
3	**Teramo**	ITA	sands in the coastal plain (covers 1% of territory); badlands Fms; river valleys of gentle slopes
4	**Puglia**	ITA	carbonate aquifer systems within wide limestone karst area
5	**Obalna-Goriška-Notranjska**	SLO	flysch in Adriatic foreland; alluvial river deposits; carbonate karst in Dinarides and Southern Alps
6	**Istria**	CRO	carbonate karstic platform; flysch riverbeds in places; red soil sediments in west onshore
7	**Neretva-Dubrovnik**	CRO	alluvial sediments along rivers; limestone above clastic sediments; flysch in coastal cliffs
8	**Podgorica**	MNE	Durmitor flysch Fm with shallow aquifer in the plain covered by sandy gravel and conglomerate
9	**Shkodra**	ALB	External Dinarides: Alps and Krasta-Cukali zones, Kruja zone (S); limestone and flysch in the plain
10	**Banja Luka**	BIH	artesian basins, Pg flysch (N); intramountain depressions, HG folded fissure to karstic massifs, ophiolitic zone
11	**Šumadija-Pomoravlje**	SRB	gentle hilly area with Mio and Q sediments (E part); hilly area with J - K diverse rocks (central-W part)
	Legend:		Fm: geological formation; Mz: Mesozoic; J: Jurassic; K: Cretaceous; Pg: Paleogene; Mio: Miocene; Q: Quaternary
			N: north, S: south; E: east; W: west

Table 2. Geothermal parameters of the Circum-Adriatic regions, useful for the GSHP design. From top to bottom: mean annual surface temperature, temperature at 100 m depth, temperature at 500 m depth, geothermal gradient, thermal conductivity of mainly shallow underground, surface heat-flow density.

		1	2	3	4	5	6	7	8	9	10	11
	region / province	**Veneto Rovigo**	**Ferrara**	**Teramo**	**Puglia**	**Obalna-Goriška-Notranjska**	**Istria**	**Neretva-Dubrovnik**	**Podgorica**	**Shkodra**	**Banja Luka**	**Šumadija-Pomoravlje**
	country	Italy	Italy	Italy	Italy	Slovenia	Croatia	Croatia	Montenegro	Albania	Bosnia - Herze	Serbia
parameter		ITA	ITA	ITA	ITA	SLO	CRO	CRO	MNE	ALB	BIH	SRB
T_0	**°C**	9 to 18	9 to 17	10 to 17	12 to 20	7 to 14	10 to 14	10 to 16	10 to 16.4	8 to 15	8 to 12	9 to 12
$T_{100\ m}$	**°C**	14 to 16	15 to 18	14 to 16	17 to 20	8 to 17	11 to 17	11 to 15	11 to 17	9 to 19	12 to 17	12 to 20
$T_{500\ m}$	**°C**	25 to 45	30 to 43	20 to 25	20 to 25	12 to 28	15 to 26	20 to 27	14 to 22	21 to 30	22 to 33	33 to 42
G	**°C/km**	15 to 45	20 to 65	10 to 20	10 to 20	10 to 45	10 to 25	10 to 20	12 to 30	7 to 21	25 to 45	40 to 55
λ	**W/(m·K)**	1.4 to 2	0.5 to 3	1 to 4	0.6 to 3	1.4 to 4	1 to 4	1 to 3.6	1 to 4	1.2 to 4.6	1.2 to 4.4	1.2 to 4.7
q	**mW/m^2**	35 to 80	30 to 65	25 to 45	30 to 80	30 to 75	20 to 55	25 to 40	20 to 40	30 to 45	45 to 75	90 to 110

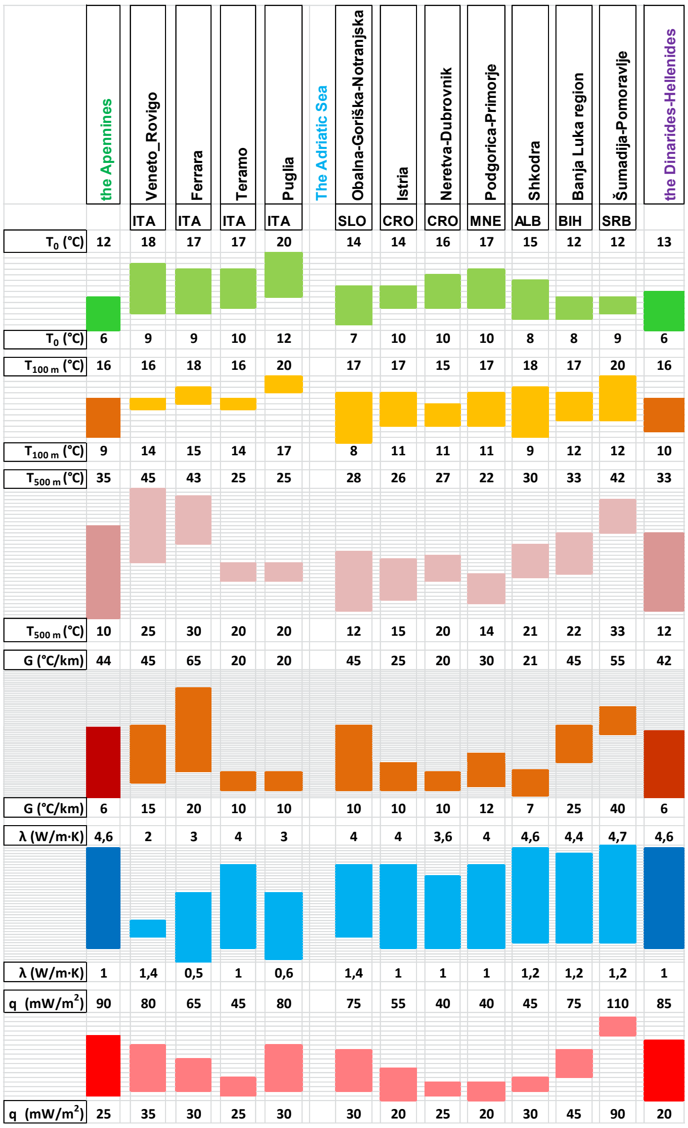

Figure 17: Geothermal parameters, useful for the GSHP design, of the Circum-Adriatic regions (see Table 2). The coloured blocks represent the range of values for the geothermal parameters which can be encountered in the described regions. The range (minimum and maximum values) for each parameter is shown with numbers below and above the blocks for each parameter. Due to different geothermal and geological conditions for the regions there are different heights of the blocks.

The Circum-Adriatic area exhibits predominantly low enthalpy geothermal characteristics, however with only the eastern part of the Apennine mountain chain included in the overview (Figure 17). The mean annual surface temperature is quite high on the

Italian side, distinctly in Puglia, and along the southern Adriatic regions (Podgorica), depending on geographical varieties. The formation temperature at shallow depths (100 m and 500 m) show great differences, depending on the geological heterogeneity of the regions, but also on the availability of the processed precise temperature measurements in the exploration or production boreholes. In a sense this is reflected in narrow temperature intervals within the Italian regions. In the province of Ferrara temperatures at 500 m depth are high due to a convection geothermal anomaly in the deep Jurassic aquifer. Wide temperature intervals for the south western Slovene regions are due to a heterogenous geological structure and karstic phenomena in the hilly and mountainous hinterland. Beside Province of Ferrara also the Šumadija-Pomoravlje region on the other side is endowed with high temperatures, typical for the Serbo-Macedonian Massif geological structure. The other eastern Adriatic regions mostly have average shallow temperature values for the continents, typical for the areas with thicker Earth’s crust, or even below average, owing to deep karstic meteoric water circulation, which decreases the formation temperatures. The Banja Luka region is a slight exception with elevated temperatures in its northern Pannonian part. Geothermal gradients basically almost follow the intervals of temperatures at 500 m depth. The exceptions are the Province of Ferrara and the Veneto region with greater gradient interval, as well as all three Slovene regions.

The highest geothermal gradients, for this purpose mostly calculated down to a depth of 500 m, are again in the Ferrara province and in the Šumadija-Pomoravlje region, followed by the Veneto, southwest Slovene and Banja Luka regions. The thermal conductivity values of the rocks and soil of the regions are mostly in wide intervals, with the exception of the Veneto region where the measurements have been conducted on only specific rocks and mostly soil samples in place from the drilled boreholes. This is the case with the Slovene data as well, but showing greater intervals, from clays to sandstone, and dolomite included as possible rock encountered. As for the other regions, the values are in a wide interval due to the absence of any results from the conductivity measurements, therefore data are taken from experience. The values of the volumetric heat capacity are not presented because this parameter is, with exception of few Italian laboratories, not measured in geothermal laboratories of the regions. Besides, this parameter doesn't vary so much as does the thermal conductivity. The HFD intervals are mostly narrow with the exceptions in the Ferrara province (convection zone at greater depth), south western Slovenia (geological structure varieties, Moho depth), Istria and Banja Luka region (Moho depth). As comparison only the generalized data for the Apennines and the Dinarides-Hellenides are presented (mostly from Hurtig et al., 1992; see also Figure 18).

As can be seen, for some regions geothermal maps are not of good detailed quality or not available yet. In a sense geothermal conditions in the analysed regions can be presented in a more convenient general manner as the maps of HFD and expected temperatures at depth of 500 m below surface (Hurtig et al., 1992) for the whole Circum-Adriatic area (Figure 18). The HFD values in the circum-Adriatic regions generally fall in range of 20 to 70 mW/m^2, with only the Banja Luka region are they on average higher, up to 80 mW/m^2, and in Šumadija – Pomoravlje region the HFD reaches 110 mW/m^2. Similar is the pattern of temperatures at 500 m depth. With the latter map, the expected temperatures at shallow depths may be roughly ascertained, i.e. at 100 m, 200 m and similar. In general the regions around the Adriatic Sea are characterized with low values, giving rise also to low temperatures at shallow depths below the surface, however with a few exceptions, i.e. in the Province of Ferrara, where the convection zones may bring thermal anomalies close to the surface. Nevertheless, there are geologically favourable conditions in places, practically for all three types of GSHP application, open-loop water-water (W), and closed-loop vertical (V) and horizontal (H) systems.

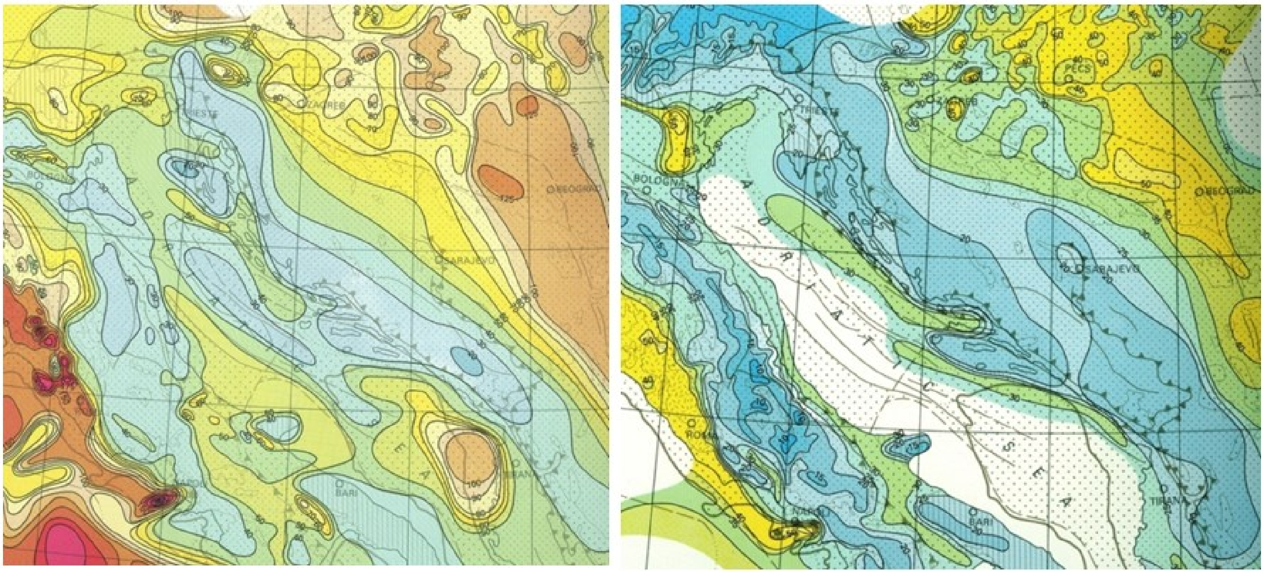

Figure 18: Map of surface heat-flow density (in mW/m^2) (left) and map of temperature (°C) at a depth of 500 m (right) in the Circum-Adriatic regions (Hurtig et al., 1992).

Within distinctive areas in most of the regions the water protection zones prohibit the utilization of shallow geothermal energy with the open-loop GSHP systems. Some restrictions also exist about closed-loop GCHP systems, when interacting with drinking water aquifers, concerning the drilling procedures and the risk of glycol leakage.

4. CONCLUSIONS

The Adriatic area, although it seems not very favourable for geothermal exploitation, because of low geothermal gradients and low heat flow, on the contrary is very favourable for GSHP installations, because of availability of groundwater for open loop systems and the possibilities of installing closed loop systems almost everywhere, both for heating and cooling purposes. In fact, the climate conditions are very favourable for the all year round use of GSHP, which can be important for many business sectors in the Adriatic area, above all tourism, recreation and spas.

A common regulatory framework can be set up in all Adriatic area, in order to harmonize the sector, protect the environment and favour investments; in particular, similar regulations and guidelines should be addressed for the following three types of use:

- Open – loop systems near the coast with salt water intrusion,
- Vertical closed – loop systems in the alluvial plains,
- Vertical closed – loop systems in the karstic underground.

From the geological overview of the regions a picture can be gotten of the extension of the karstic areas on both sides of the Adriatic Sea. As some difficulties are expected in installing vertical closed loop systems in the karstic underground, a common strategy about shallow and surface GCHP installations (mainly horizontal) should be taken at the Adriatic level.

REFERENCES

Begović, P. and Ivanković, B.: Geothermal energy market uptake in Bosnia Herzegovina: perspectives, Presentation at the 4th SC meeting of the LEGEND Project, Banja Luka (2014).

Brković, T., Radovanović, Z. and Pavlović, Z.: Basic geological map SFRJ, sheet Kragujevac, Scale 1:100.000, Geozavod-OOUR Geološki institut Beograd (1979).

Burić, M.: General geothermal characteristics and hydrogeothermal potential of Montenegro, Workshop on alternative energy sources, CANU, Podgorica (2013).

Cataldi, R., Mongelli, F., Squarci, P., Taffi, L., Zito, G. and Calore, C.: Geothermal ranking of Italian Territory, *Geothermics* **24/1**, Pergamon, (1995), 115-129 with 6 plates.

Desiderio, G., Folchi Vici d'Arcevia, C., Marron, G., Nanni, T. and Rusi, S.: Schema idrogeologico della Provincia di Teramo – CNR - GNDCI Gruppo Nazionale per la Difesa della Catastrofi Idrogeologiche (2005).

DUNEA: Benchmark report. Dubrovnik-Neretva county. Local report on potentials for ground coupled heat pump introduction in Adriatic countries' market of heating and cooling, DUNEA – Regional development agency, Dubrovnik (2013), 12 p.

Ferrara Province: Benchmark report. Local report on potentials for ground coupled heat pump introduction in Adriatic countries' market of heating and cooling (2013), 15 p.

Fištrek, Ž., Bačan, A., Karadža, N. and Živković, S: Potentials of renewable sources in Istria. EIHP, Zagreb (2013), 25 p. (in Croatian).

Frasheri, A., Čermak, V. (coords.), Doracaj, M. et al.: Atlas of geothermal resources in Albania, Faculty of Geology and Mining, Polytechnic University of Tirana, Tirana (2004), 122 p.

GES (Green Energy Systems, d.o.o.): General design of application of heating and cooling system fro the indoor swimming pool in Kragujevac, Belgrade (2014), 67 p.

Hurtig, E., Čermák, V., Haenel, R. & Zui, V. (eds.): Geothermal Atlas of Europe, GeoForschungsZentrum Potsdam, Publ. No1, 156 p., 25 maps (1992).

IRENA: Benchmark report. Istria peninsula. Local report on potentials for ground coupled heat pump introduction in Adriatic countries' market of heating and cooling, IRENA - Istrian regional energy agency, Labin (2013),13 p.

Italian Ministry of economics, General Direction for Mining and Energetic Resources: National Inventory of Geothermal Resources. Webgis (2013).

Jolović, B., Glavaš, S. and Toholj, N.: Geothermal atlas of the Republic of Srpska, RSMIEM, Geological research institute of Republic of Srpska, Zvornik (2012), 24 p.

LIR: Benchmark report. Four municipalities of NW Bosnia and Herzegovina. Local report on potentials for ground coupled heat pump introduction in Adriatic countries' market of heating and cooling, LIR - Local development initiative, Banja Luka (2013), 12 p.

Lund, J.W.: Ground-source (geothermal) heat pumps. In: Lienau P.J.(conv.), Heating with geothermal energy: Conventional and new schemes, Course on WGC 2000 *Short Courses*, Tohoku District, Japan, (2000), 209-236.

MGBC and Municipality of Danilovgrad: Benchmark report. Podgorica and Danilovgrad regions. Local report on potentials for ground coupled heat pump introduction in Adriatic countries' market of heating and cooling, MGBC – Montenegro green building council, Podgorica, Mun. Danilovgrad (2014), 14 p.

Milivojević, M.: Geothermal map (№. 11). In: Dimitrijević M.D. (chief ed.), Geological atlas of Serbia 1:2.000.000, Ministry of Mining and Energetics of Serbia, Belgrade (2001).

Municipality of Shkodra: Benchmark report. Minicipality of Shkodra. Local report on potentials for ground coupled heat pump introduction in Adriatic countries' market of heating and cooling, Minicipality of Shkodra, Shkodra (2013), 36 p.

Prestor, J., Pestotnik, S., Rajver, D., Meglič, P. and Rikanovič, R.: Benchmark report. Three regions of SW Slovenia. Local report on potentials for ground coupled heat pump introduction in Adriatic countries' market of heating and cooling, Geological Survey of Slovenia, Ljubljana (2013), 29 p.

Puglia Region: Benchmark report. Local report on potentials for ground coupled heat pump introduction in Adriatic countries' market of heating and cooling, CNR-IRSA, Mun. Bari (2014), 14 p.

Rajver, D. and Ravnik, D.: Geothermal pattern of Slovenia - enlarged data base and improved geothermal maps, *Geologija* **45/2**, Ljubljana (in slovene with english abstract). (2002), 519-524.

REDASP: Benchmark report. Kragujevac Region. Local report on potentials for ground coupled heat pump introduction in Adriatic countries' market of heating and cooling, REDASP – Regional Economic Development Agency for Šumadija and Pomoravlje, Kragujevac (2013), 5 p.

Teramo Province: Benchmark report. Local report on potentials for ground coupled heat pump introduction in Adriatic countries' market of heating and cooling (2013), 8 p.

Tosoni, D.: Presentation of the Veneto Region at the Kick Off meeting of the LEGEND Project, Ferrara (2012).

Veneto Region: Study of geothermal potential on the territory of Polesine and the Po delta. Database on interactive dvd about geothermal systems called "small local utilisations", Final summaries, Regione del Veneto (2014), 10 p..

Veneto Region: Benchmark report. Local report on potentials for ground coupled heat pump introduction in Adriatic countries' market of heating and cooling. (2014). 18 p..

Vignaroli, G., Faccenna, C., Rossetti, F., Jolivet, L.: Insights from the Apennines metamorphic complexes and their bearing on the kinematics evolution of the orogeny, *Geological Society Special Publications* **311**: 235-256 (2009).