Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

3D Conceptual Model Approach for the Assessment of Shallow Geothermal Potential in Urban Areas: The Case Study of the Girona city (preliminary results)

Vaiva Čypaitė[1], Ignasi Herms[1], Georgina Arnó[1], Joan Agustí Nuñez[1], Montse Colomer[1], Victor Camps[1], Clare Baxter[2]

[1] Institut Cartogràfic i Geològic de Catalunya (ICGC), Parc Montjuïc, s/n E-08038, Barcelona, Spain

[2] Seequent UK Ltd, Christchurch, New Zealand

Vaiva.Cypaite@icgc.cat, Ignasi.Herms@icgc.cat, Georgina.Arno@icg.cat

Keywords: 3D geological model, closed-loop, open-loop, shallow geothermal resources

ABSTRACT

European urban areas are decarbonising and energy market is shifting towards renewable energies. Utilization of shallow geothermal energy (SGE) is growing, but more research is needed to ensure effective, sustainable and harmless utilization. The use of ground source heat pump technologies for heating and cooling is increasing in Catalonia, Spain. This paper is presenting the conceptual approach for processing, analysis and assessment of shallow geothermal potential for open and closed-loop systems in the urban area of Girona city (NE Catalonia). In this area geological settings and ground conditions vary significantly. Hence a 3D hydrogeological and heat transport models must be necessarily performed to assess SGE. As a first stage, this paper presents the 3D geological model of the Catalan study case using Leapfrog Geo software. The area acts as one of the study cases of the MUSE project - Managing Urban Shallow geothermal Energy- launched under the GeoERA initiative of the European Geological Surveys (http://geoera.eu/projects/muse3//).

1. INTRODUCTION

Utilization of shallow geothermal energy (SGE) for heating and cooling is increasing in Catalonia (NE Spain) and until now 30MWt have been installed (ICGC, 2019). Despite this increase, SGE still covers just a minor part of the heating market. In 2014 the ICGC started a project aiming to assess SGE potential across Catalonia both at regional and urban scale. Urban area of Girona City was selected as a first pilot area, due to its great potential of SGE utilisation. Although just a few closed/open loop systems have been installed until now, the market of shallow geothermal energy is still poorly developed.

Thermal properties of the subsoil are the main parameters determining how much energy can be extracted via heat exchangers from the subsoil. In Girona urban area, geological and hydrogeological properties of each stratigraphic unit vary significantly; hence a conceptualised 3D model was prepared. Integration of a wide variety of data into the geological model is important in understanding the geological processes and delineation of the resource. In the build-up to the 3D and spatial integration process, an array of complex data was used, i.e. borehole lithology, geological maps, cross sections and geophysical data. A three dimensional representation will guide the preparation of the hydrogeological and thermal models that will be used to communicate and evaluate the shallow geothermal potential of the area and determine opened- and closed-loop potential. Shallow geothermal potential evaluation of Girona urban area is threefold and consists of geological modelling, thermal data collection and numerical modelling. First part of the project focuses on 3D geological modelling, using Leapfrog software. Second part of the project includes extensive groundwater temperature monitoring under the *GeoEnergy- Shallow Geothermal Energy Project*. Results of this monitoring will be used to develop the third part of the project what is a development of groundwater and heat transport numerical models of the area. This paper presents finalised geological model of Girona urban area, first groundwater temperature observations and preliminary results of subsoil thermal properties.

2. ASSESSMENT OF SHALLOW GEOTHERMAL POTENTIAL IN CATALONIA

For the last few years local authorities have been working towards promotion of the shallow geothermal energy. In 2014 the ICGC started the 'GeoEnergy SGE Project' which focuses on: a) data collection and inventory of the existing SGE installations across Catalonia b) the assessment and mapping of SGE potential in Catalonia c) implementation of a monitoring network of ground thermal properties in specific urban areas and d) modelling and simulation of the SGE potential and the performance of specific SGE installations (Figure 1). This project aims to assess SGE potential both in regional and local (urban) areas and aims to help government, municipalities and end-users to utilise SGE in the context of the energy transition process.

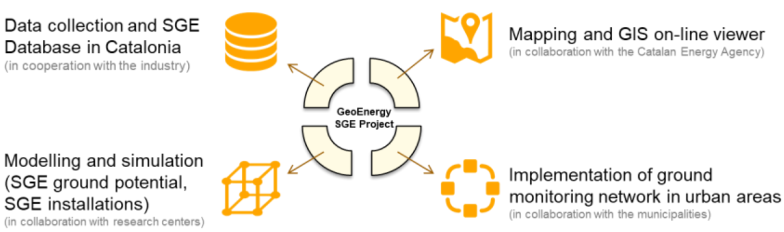

Figure 1: Tools and concept of the GeoEnergy- Shallow Geothermal Energy Project (source: ICGC 2019).

As one of the principal parts of the 'GeoEnergy SGE Project', the Geoindex- Shallow Geothermal Energy Viewer (ICGC, 2019; Arnó et al. 2019), was published in 2018. It incorporates a new SGE potential map of Catalonia for closed-loop systems based on G.POT method (Casasso and Sethi 2016). This viewer assesses SGE potential of all Catalonia by considering thermal properties of the subsoil and local climatic conditions. The viewer provides a broad overview of which areas in Catalonia are more suitable for geothermal energy utilization. On the other hand, in order to perform more localised feasibility studies, the suggested viewer and applied method is too broad and more detailed analysis has to be performed. Hence, Girona urban area was selected as a first pilot area where a more detailed local study is now taking place. Under 'GeoEnergy SGE Project', extensive monitoring network was established in Girona urban area. Data collection consists of periodical groundwater level and temperature measurements. Additionally, a monitoring network with remote data acquisition system is being implemented to obtain continuous data about groundwater level and subsoil temperature. Data compilation also includes planned new Thermal Response Tests (TRT) and an inventory of existing SGE systems in both private and public buildings. The last step towards the geothermal potential assessment under 'GeoEnergy SGE Project' is the modelling and simulation of the performance of specific SGE installations. In the case of Girona urban area, modelling will allow to integrate an important and diverse data to analyse geological, hydrogeological and thermal conditions and simulate energy utilisation and recovery scenarios.

3. GIRONA URBAN AREA

3.1. Climatic setting

Girona Urban area is located in NE of Catalonia, Spain (Figure 2, Figure 3) at 65 to 166 m a.s.l. According to the Köppen–Geiger climate classification system (Rubel et al. 2017) it has a *Csa* climate (C: warm temperature, s: summer dry, a: hot summer). The mean annual air temperature is 14.7 ºC. The mean air temperature of the coldest month ranges between 0 and 3ºC with a total Heating Degree Days (HDD) of 1000 to 1250, and the mean air temperature of the hottest month ranges between 30 and 34ºC with a total Cooling Degree Days (CDD) of 250 to 300 (ICGC, 2019). HDD and CDD have been calculated using a multivariate linear regression analysis of half-hourly meteorological data by considering a threshold value of 15ºC (Arno et al., 2019). The mean annual precipitation in Girona is 740 mm. Girona urban area is approximately 48 km^2 where around 138.000 people live. Based on population density and climatic setting Girona Urban area has a great demand both for heating and cooling which could be supplied by shallow geothermal energy.

3.2. Geological and hydrogeological setting

Geological development of the study area is complex, starting with deformation of Paleozoic basement due to Variscan orogeny. Sedimentation of Mesozoic and Tertiary sediments follows and finishes with the formation of European Cenozoic Rift System during Neogene and Quaternary consequential volcanism, and finally recent sedimentation.

Girona urban area is located at the northern part of *La Selva* sedimentary basin (Figure 2). Tectonic setting of La Selva basin is associated with European Cenozoic Rift System which formed due to the Alpine orogeny. In general, La Selva basin is a tectonic graben formed during Neogene due to extensional tectonics (Saula et al. 1996). Hanging walls of the main NW-SE trending normal faults and associated minor faults determine spatial extension of La Selva sedimentary basin.

The Llorà fault is a principal fault in the study area which not only determines the extension of the sedimentary basin; it also is responsible for the volcanism (Figure 2, A). Development of European Cenozoic Rift system in the study area was accompanied by volcanic activity during the Pleistocene period. Hence the Llorà fault and parallel at the Amer fault in the East are responsible for Quaternary alkaline volcanism in the area. As a consequence, the Catalan Volcanic Zone located in the NW of the study area was formed (Martí et al. 1992, Martí et al. 2017). Two volcanic edifices related to Catalan Volcanic Zone are visible in the study area, *La Crosa Sant Dalmai* volcano in the south-west and *Volcà del Puig d`Adri* in the north (ICGC, 1997; ICGC, 2003) (Figure 2, B).

The geometry of La Selva basin is controlled by horst and graben structures of the bedrock. In the eastern and western sides of the study area Paleozoic and Paleogene materials outcrops are visible (Figure 2, B). Paleozoic bedrock consists in schists, slates and quartzite intruded with quartz and aplite dykes and veins, post-Variscian granodiorites and granites. Paleogene bedrock is formed by lower and middle Eocene nummulite limestones and marls. The thickness of the basin infill is very variable. Recent geophysical studies revealed that the sedimentary basin is 515 m deep with the deepest point in the centre of the study area (Gabàs et al. 2014). La Selva infill consists of Neogene and Quaternary sediments. Neogene detrital sediments are associated with alluvial fans formed by erosion of the surrounding areas. Quaternary sediments cover most of the Neogene sediments in the study area; just a few outcrops are visible in the northern and southern parts of the area. Quaternary sediments are associated with river terraces as well as mountain side alluvial fans. According to geological maps the Quaternary sediment thickness varies between 10 and 25 m.

Three main aquifers are identified in Girona urban area: Quaternary, Pliocene and Paleogene (Figure 2, C). Quaternary aquifers are associated with alluvial sediments of the Ter and the Onyar rivers. These unconfined aquifers are defined by shallow groundwater levels (3 to 8 m), variable permeability and intergranular porosity. Hydraulic conductivity ranges between 4 and 80 m/d and groundwater flows eastwards. Pliocene aquifer is associated with Neogene detrital sediments with low permeability and intergranular porosity. Aquifers are defined as semi-confined or confined, groundwater flows eastward and are situated between 10 to 26m depth (Figure 2, C). Hydraulic conductivity ranges from 0,1 to 5 m/d. Paleogene aquifers are associated with limestone formations which are karstic and have a dual porosity with highly variable permeability and it is mainly confined. Depending on the location, groundwater level is at 70 m depth or has artesian conditions (ICGC, 2015).

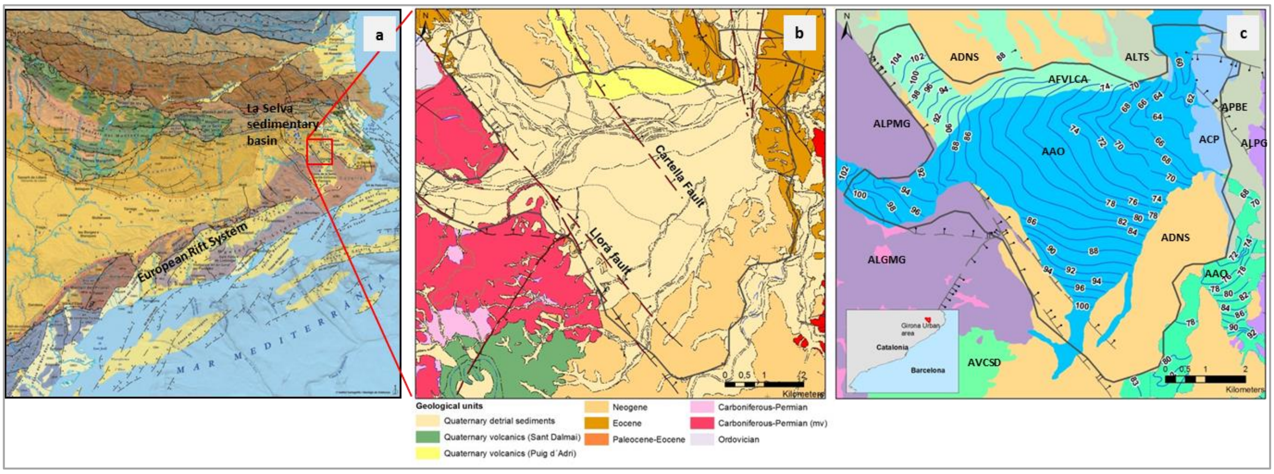

Figure 2: Geological and hydrogeological setting of the study area. A) Regional geological setting. B) Simplified geological setting of the study area (modified from ICGC, 2003). C) Hydrogeological setting of the study area, where ADNS- Neogene detrital aquifer of La Selva, AFVLCA- Llémena and Canet d'Adri fliuviovolcanic aquifer, AAO- Onyar alluvial aquifer, ALTS- low permeability aquifer of marls and sandstones, AAT- Ter alluvial aquifer, ALPMG- low permeability aquifer of shales, ALGMG- low permeability aquifer of granites, AVCSD- Crosa de Sant Dalmai volcanic aquifer, ACP- Paleogene limestones aquifer, APBE- sandstones and marls aquifer, ALPG- low permeability aquifer of shales, piezometric level in the map refers to m a.s.l. (ICGC, 1997; ICGC, 2003; ICGC, 2009).

3. THE 3D GEOLOGICAL MODEL

The 3D geological model of Girona urban area is 10 km wide, 9 km long and approximately 300 m deep (down to -200 m b.s.l.), with a total model volume of 29 km^3. In order to prepare a detailed geological model a wide range of data was used, such as geological and hydrogeological maps, corresponding cross-sections, geophysical data and geological data from geotechnical and water wells. All in all, around 1400 drillholes (Figure 3), 4 geological maps scale 1:25000 (ICGC, 1997, 2003 & 2009), 5 geological maps scale 1:5000 (ICGC, 2014 & 2015) and 2 hydrogeological maps scale 1:25000 (ICGC, 2015) were utilised. From all available drillholes in the area 1353 drillholes are no more than 20 m deep and there are just 11 drillholes deeper than 100 m (Figure 3). Therefore, in order to determine the depth and spatial distribution of the sedimentary basin it was necessary to utilize the geophysical data. Data from Gabàs et al. (2014) study inferred understanding in the zones of scarce subsoil information or where drillholes were not deep enough. Its information has been introduced into the model.

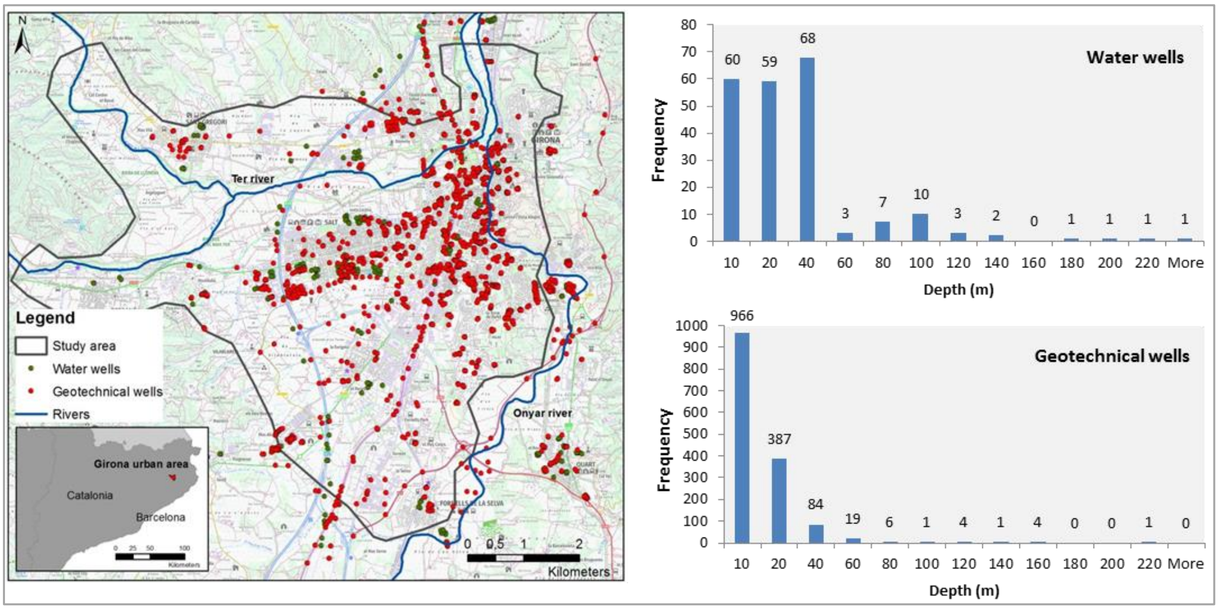

Figure 3: Girona urban area. Map on the left side visualizes the extension of the MUSE case study area and distribution of drillholes used to prepare the geological model. Graphs on the right demonstrate frequency and depth of drillholes used to prepare geological model.

For modelling purposes Leapfrog 3D geological modelling software (Sequent, Ltd.) was used. Leapfrog workflow is based 3D geological modelling software using an implicit modelling method. Utilizing fast RBF algorithm Leapfrog extrapolates surfaces based on known data and input interpretation by the modeller (Cowan et al, 2002).

As previously mentioned, Girona urban area is characterized by complex geological and tectonic setting. In order to interpret and present subsoil geology in the best way possible, it was necessary to build a base model defining the Paleogene-Paleozoic (Figure

4), Neogene (Figure 5) and Quaternary (Figure 6). Neogene and Quaternary deposits form La Selva sedimentary basin and are surrounded by the basement, limited by NW-SE normal faults in the eastern and western parts of the model.

According to the geophysical data the depth of sedimentary basin varies between 0 and 515 m, with the greatest depth in the centre of the study area and outcropping in the East and West. La Selva sedimentary basin fill is associated to detrital alluvial sediments and defined in detail within the Neogene and Quaternary refined models. Visualisation of basement in the base model includes geological units between Ordovician and Eocene and consists of sequence of metamorphic rocks (shale to phylite), sandstones, limestones, marls, lutites, pelites and granites.

The division in detail of units is very important for the further hydrogeological and thermal simulations in the area. As previously mentioned, geothermal potential depends on thermal properties of the subsoil. Hence, knowing where sediments are fine or coarse will enable more precise assessment of the geothermal potential of the area.

3.1. Base Model

The main purpose of the base model is to define the depth and spatial extension of the La Selva sedimentary basin (Figure 4). Overall, sedimentary fill of La Selva basin is going to be used as a principal medium to utilise shallow geothermal resources. In the eastern side of the geological model geological maps of scale 1:5000 were available (ICGC, 2014 & 2015), whereas in the western side geological maps of scale 1:25000 were used (ICGC, 1997, 2003 & 2009). Hence, the geological model in the East is more detailed. The spatial extension of the basin was defined using surface contacts obtained from geological maps, drillhole contacts and geophysical data. The final depth of the basin is -200 m b.s.l. It was decided to terminate the model at this depth due to the fact data below this level is very scarce and the accuracy of the model would decrease significantly.

Based on geological maps of the area, 15 geological units were defined between Ordovician and Quaternary: Eocene: sandstone [Esd], sandstone, marl, lutite [Esdml], marl [Em], numulitic limestone [Enlm], limestone [Elm], sandstone and lutite [Esdl]; Paleocene-Eocene: lutite and breccia [PElbr]; Ordovician: metamorphic rocks, shale to phyllite [Osh], sandstone and lutite [Osdl], sandstone and pelite [Osdp]; Cambrian-Ordovician: pelite [COp]; Paleozoic: granite [PZgr]; Neogene: detrital sediments and Quaternary: detrital sediments (Figure 4). Newly prepared abbreviations for each geological unit reflect its age and lithology. Here volumes defining Neogene and Quaternary sediments define spatial extension of each unit, i.e. specific geological features are not taken into account as volumes defining Neogene and Quaternary were refined in the separate models, which are discussed in the further sub-chapters.

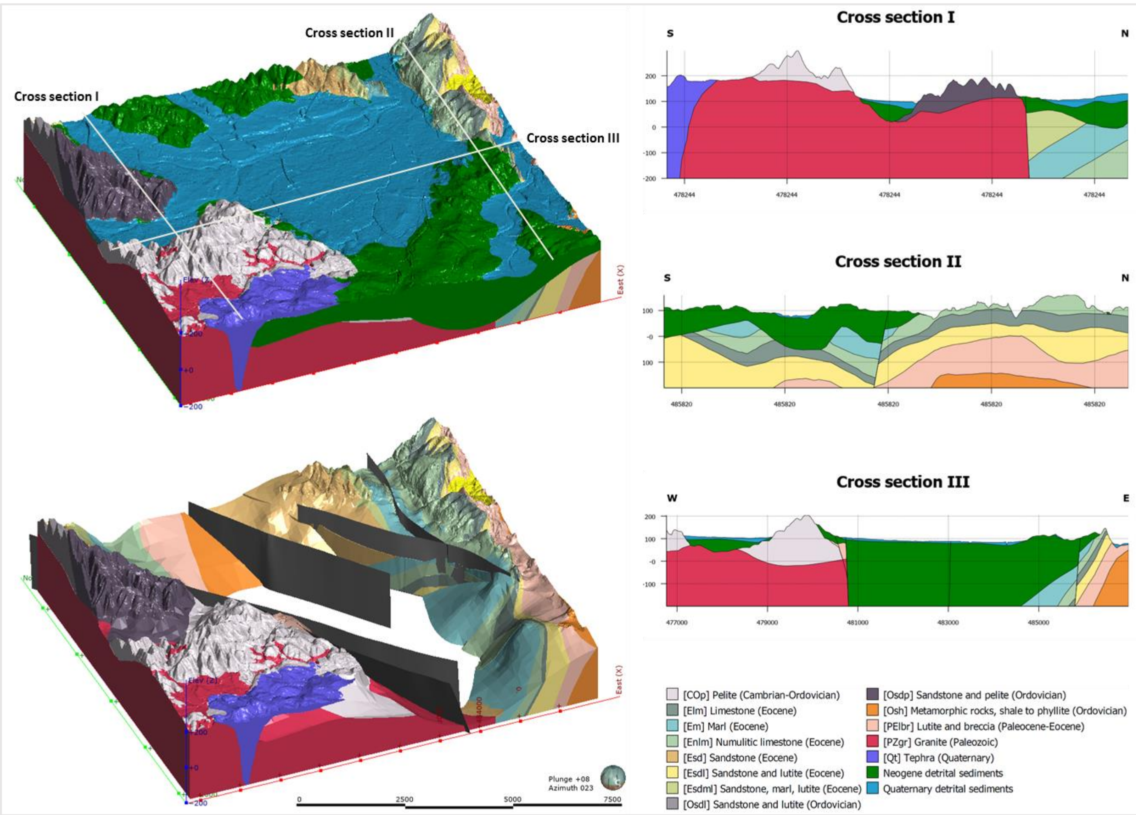

Figure 4: Structure of La Selva basin with unrefined Neogene and Quaternary sediments. The upper left side model visualizes geological setting of Girona urban area. Lower left image visualizes geological setting of Girona urban without Neogene (green colour) and Quaternary (light blue colour) sediments and demonstrates principal faults of the area (grey planes). Cross section I, II and II allows seeing how geological setting varies within study area and allows seeing changes in depth of La Selva sedimentary basin (vertical exaggeration of the model and cross sections is 5).

3.2 Neogene Model

The volume of Neogene defined in the base model was refined to present the Neogene sedimentary fill in greater detail (Figure 5). Refinement of the Neogene sedimentary basin consists of alluvial fan systems which were formed by the erosion of the surrounding material. According to the geological maps the Neogene alluvial fans have two main origins. Neogene sediments in the northern side of the model [Naf2sc] are associated to the distal phase of the Canet d'Adri alluvial fan and is characterised by fine sediments (sand and clay). Neogene sediments in the southern part of the sedimentary basin are associated to the proximal phase of Guilleries, Gavarres and Serres Transversals alluvial fan. The southern part of the model is characterised by coarser sediments, such as sand and gravel. Southern alluvial fan fills most of the sedimentary basin in the study area; therefore it was possible to distinguish between lower and upper parts of that alluvial fan. Closer to the surface the alluvial fan is characterised by finer sediments [Naf1gsc] – gravel, sand and clay, and the lower part of the southern alluvial fan is characterised by the coarser sediments [Naflsg] – sand and gravel (Figure 5). Furthermore, it was also noticed that some localised areas within the southern alluvial fan have higher concentration of clay or gravel sediments; consequently these areas were separated and defined as gravel [Naf1g] or clay [Naf1c] lenses.

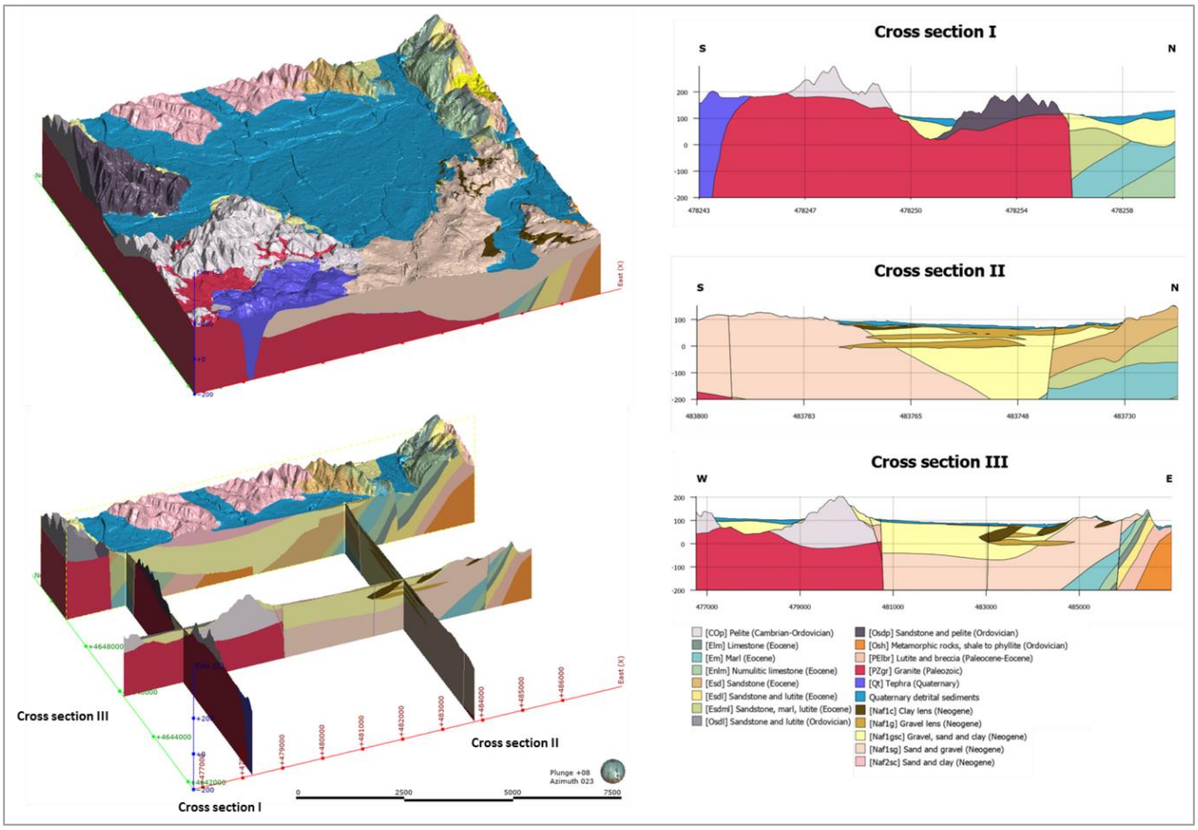

Figure 5: Structure of La Selva sedimentary basin (Neogene sediments). The upper left side model visualizes geological setting of Girona urban area with refined Neogene sediments. Lower left image visualizes location of the cross sections I, II and III and allows seeing distribution of alluvial fans: [Naf2sc] representing fine sediments of Canet d'Adri alluvial fan located in northern side of the model (thick section), [Naf1gsc] representing fine upper sediments of Guilleries, Gavarres and Serres Transversals alluvial fan is seen in cross section II and a thick northern section and [Naf1sg] representing coarse lower sediments of the same alluvial fan are seen just in cross section II. Cross sections I, II and III demonstrate thickness of the sedimentary basin and how it varies within Girona urban area. Cross sections II and III gives a greater detail about the distribution of lenses with finer or coarser sediments than the surrounding material (vertical exaggeration of the model and cross sections is 5).

3.3. Quaternary Model

The abundance of drillhole data at the surface made it possible to define the vertical extension of the Quaternary sedimentary fill in greater detail (Figure 6). Quaternary sediments form the upper part of the Selva sedimentary basin and consist of river terraces, alluvial deposits and volcanic rocks. According to the geological maps, horizontal extension of each Quaternary geological unit was defined. The drillhole data at surface made it possible to define vertical extension of each geological unit more precisely and divide the river terraces and alluvial deposits into finer and coarser sedimentary zones (Figure 6). The definition of each river terrace was defined by the density of data. The first terrace is populated by few drillholes; hence the first terrace was defined as gravel and sand [Qt1gs] only. Many more drillholes are located in the second terrace so it was possible to refine this terrace into finer and coarser sedimentary zones being gravel and sand [Qt2gs] and silt and clay [Qt2lc]. Closer to the outer edges of the quaternary volume alluvial deposits are abundant. The following units, based on the grain size were defined in this area: clay, sand, silt [Qa2csl], sand and gravel [Qa1sg], silt and clay [Qa1lc,] gravel with sand and silt [Qa3g], silt and clay [Qa3lc] and sand with cobbles [Qa3s].

As mentioned earlier, study area stands in the European Rift Zone and whose development caused volcanic activity in the area. Two volcanic edifices are visualised in the model: La Crosa de Sant Dalmai volcano in the SE (tephra [Qt]) and a lava flow originating from Volca del Puig d`Adri in the north (basalt [Qb]).

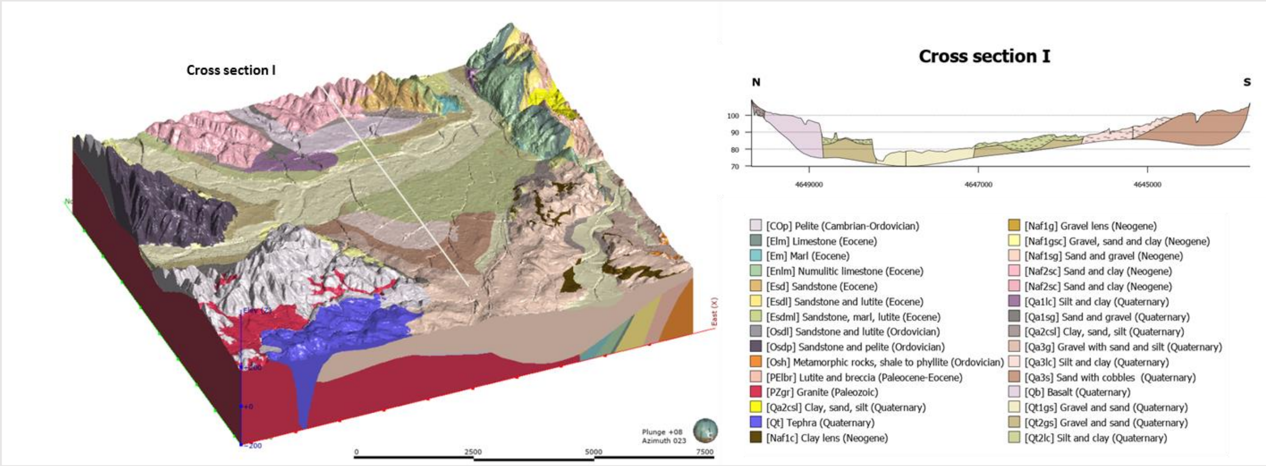

Figure 6: Geological model of Girona urban area. Image on the left visualizes complete geological setting of the study area. Cross section I demonstrate spatial distribution of Quaternary sediments and gives a closer look to the areas with finer ([Qt2lc] and [Qa3lc]) or coarser sediments (vertical exaggeration of the model is 5 and vertical exaggeration of the cross section is 20).

4. SUBSURFACE THERMAL MONITORING AND CHARACTERIZATION

4.1. Data collection

Data from the 'GeoEnergy SGE Project' is going to be used to determine thermal conditions in the study area and will be used to prepare the groundwater and heat transport 3D numerical models. SGE monitoring network consists of primary, secondary and river temperature monitoring points (Figure 7). The primary monitoring network will provide real-time subsoil temperature and groundwater level measurements. Data will be recorded via 11 temperature sensor chains and 6 pressure-temperature probes installed in the newly drilled boreholes (100 m deep) (Figure 7). At the time of writing this paper, only 3 such installations were prepared and data collection had recently started. Furthermore, TRT will be carried out in the following wells: SXG-01, SXG-06, SXG-07 and SXG-10 (Figure 7). These measurements will allow assessing subsoil thermal conductivity and thermal resistance of each borehole.

Secondary monitoring network is installed in already available wells and piezometers. In the secondary monitoring network groundwater level and temperature is continually measured via divers which are installed at the fixed depth (SXGb-01, SXGb-02, SXGb-03, SXGb-04, SXGb-05, SXGb-06, SXGb-07, SXGb-07, SXGb-08, SXGb-09, SXGb-10, and SXGb-11) (Figure 7). In addition to these measurements, once a month groundwater temperature is manually measured throughout the entire depth of the following wells: SXGb-01, SXGb-03, SXGb-06, SXGb-07, SXGb-07, SXGb-08, SXGb-09 and SXGb-10. During the monthly monitoring campaign groundwater level in the secondary monitoring network is also measured, as well as water temperature in the rivers.

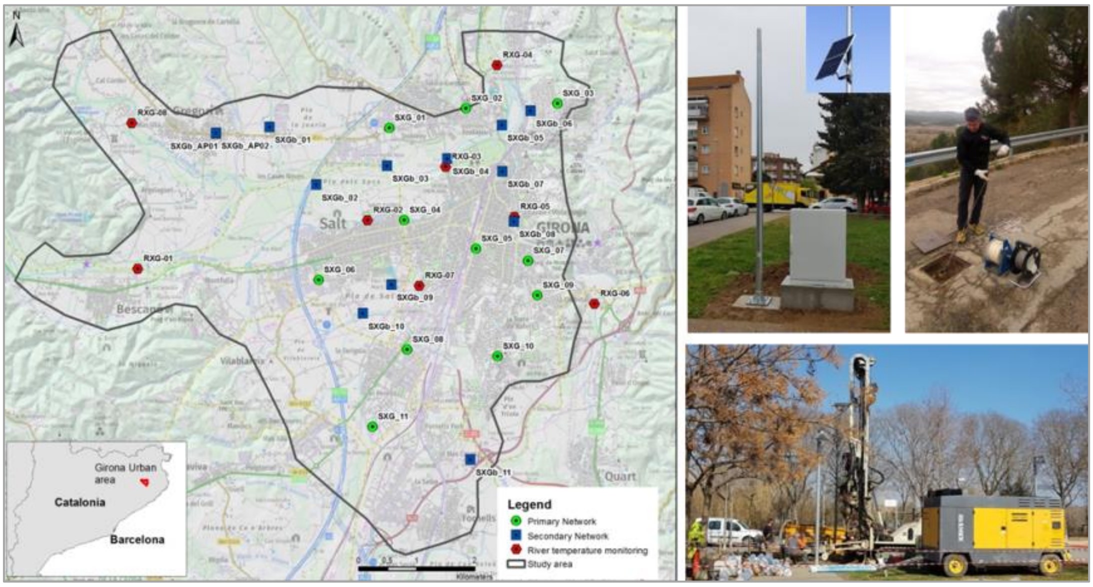

Figure 7: Monitoring network in Girona urban area for the SGE Project, installation of primary monitoring network and temperature measurements carried out in the secondary monitoring network.

4.2. Groundwater temperature

As previously mentioned, groundwater and river water temperature is manually measured in the secondary monitoring network once a month. First measurements we carried out on February 28th, 2019. At the time of writing this publication, 7 monitoring campaigns were carried out and include measurements between 28th of February and 3rd of July, 2019. Data obtained from sensors installed in a secondary network, allowed to evaluate overall groundwater temperature distribution in the study area. It was observed that average groundwater temperature where groundwater temperature remained stable during all monitoring campaigns range between 13.2 and 17.3 °C, with slightly higher temperatures (17.3 °C) in more urbanized areas and slightly lower temperatures (13.2 °C) in less urbanized areas (Figure 8).

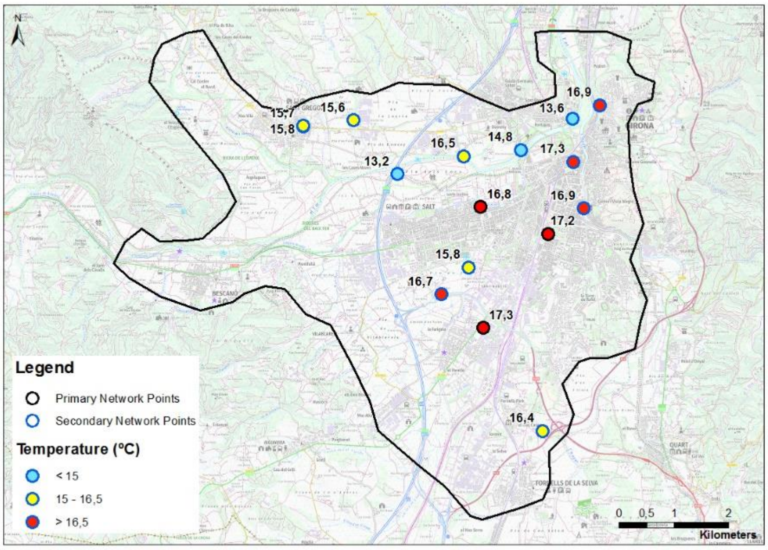

Figure 8: Average groundwater temperature data measured by sensors in the secondary monitoring network between 28th of February and 3rd of July of 2019 at about 40 m a.s.l. and groundwater temperature data measured on 19th of March 2019 in the primary network at 40 m a.s.l.

According to groundwater temperature logs obtained during this period in the secondary network, it was observed that first 25 meters of groundwater are affected by the seasonal air temperature changes, whereas below approximately 25 meter depth, groundwater temperature in all monitoring points remained rather stable during the monitoring period (Figure 9). Temperature gradients in the study area vary between –1.4 ºC/100 m (SXGb-08) and 3.02 ºC/100 m (SXGb-01) (Figure 9). Observed negative temperature gradients and higher average groundwater temperature within Girona city could possibly indicate the so-called "Subsurface Urban Heat Island" effect (Rivera, et al. 2016, Epting J. 2017).

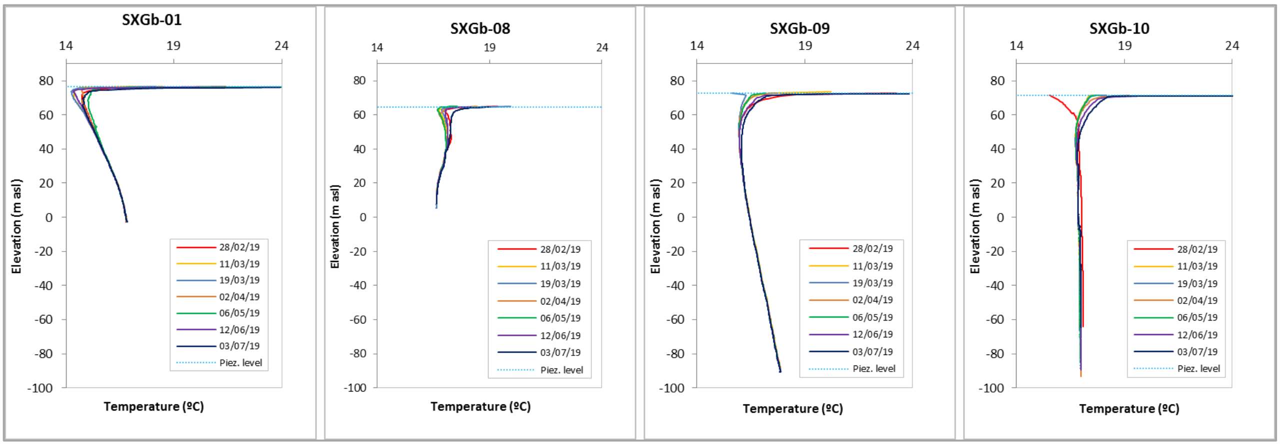

Figure 9: Groundwater temperature profiles manually measured in wells SXGb-01, SXGb-08, SXGb-09 and SXGb-10 in the secondary monitoring network between 28th of February, 2018 and 3rd of July.

4.3. Subsoil geothermal properties

Geological conditions in Girona urban area were defined in geological model. For the primary assessment of SGE potential in the area it is possible to preliminary evaluate the thermal properties of each lithological unit defined in the geological model. According to standard 100715-1:2014 of Spanish association for Standardisation (UNE, 2014) theoretical values of thermal conductivity (W/mK) and specific heat capacity (MJ/m³K) were assigned to each lithological unit defined in base model (3.1. Base Model) (Figure 10). Assigned theoretical values are also in accordance with the theoretic values assigned in Geoindex-shallow geothermal energy viewer (ICGC, 2019; Arnó et al. 2019). Due to the fact the geological model is much more detailed than Geoindex-shallow geothermal energy viewer; the assessment of the SGE potential is much more accurate in this study.

According to the table in Figure 10, highest thermal conductivity and specific heat capacity is observed in the basement, in the geological units such as limestone and sandstone. According to UNE, 2014 Neogene and Quaternary sediments has lower thermal conductivity in comparison with basement, and range between 1.1 –3.1 W/mK and 1.0 – 3.1 W/mK, receptively.

	Lithology	Thermal Conductivity (W/mK)	Saturated	Specific heat capacity MJ/(m3 ·K)	Saturated
Quaternary	[Qa3g] Gravel with sand and silt	0.4 - 0.9	1.6 - 2.5	1.3 - 1.6	2.2 - 2.6
	[Qa2csl] Clay, sand, silt	0.4 - 1	1.1 - 3.1	1.5 - 1.6	2 - 2.8
	[Qt1gs] Gravel and sand	0.4 - 0.9	1.6 - 2.5	1.3 - 1.6	2.2 - 2.6
	[Qb] Basalt	1.3 - 2.3	-	2.3 - 2.6	-
	[Qa1lc] Silt and clay	0.4 - 0.9	1.6 - 2.5	1.5 - 1.6	2 - 2.8
	[Qa1sg] Sand and gravel	0.3 - 0.9	1 - 1.9	1.5 - 1.6	2 - 2.8
	[Qt2lc] Silt and clay	0.4 - 0.9	1.6 - 2.5	1.5 - 1.6	2 - 2.8
	[Qt2gs] Gravel and sand	0.4 - 0.9	1.6 - 2.5	1.3 - 1.6	2.2 - 2.6
	[Qa3lc] Silt and clay	0.4 - 0.9	1.6 - 2.5	1.5 - 1.6	2 - 2.8
	[Qa3s] Sand with cobbles	0.3 - 0.9	1 - 1.9	1.5 - 1.6	1.6 - 2.2
	[Qt] Tephra	0.4 - 0.9	-	1.3 - 1.6	2.2 - 2.6
	[Qa2csl] Clay, sand, silt	1.1 - 2.9	-	2.1 - 2.4	-
Neogene	[Naf2sc] Sand and clay	0.3 - 0.9	1.6 - 2.5	1.8 - 2.6	2 - 2.8
	[Naf1c] Clay lens	0.4 - 1	1.1 - 3.1	1.5 - 1.6	2 - 2.8
	[Naf1sg] Sand and gravel	0.3 - 0.9	1.6 - 2.5	1.5 - 1.6	2 - 2.8
	[Naf2sc] Sand and clay	0.3 - 0.9	1.6 - 2.5	1.5 - 1.6	2 - 2.8
	[Naf1gsc] Gravel, sand and clay	0.4 - 0.9	1.6 - 2.5	1.3 - 1.6	2.2 - 2.6
	[Naf1g] Gravel lens	0.4 - 0.9	1.6 - 2.5	1.3 - 1.6	2.2 - 2.6
Basement	[Esd] Sandstone	1.9 - 3.5	-	1.8 - 2.6	-
	[Esdml] Sandstone, marl, lutite	1.9 - 3.5	-	1.8 - 2.6	-
	[Em] Marl	1.1 - 2.9	-	1.5 - 2.5	-
	[Enlm] Numulitic limestone	2 - 3.8	-	2.1 - 2.4	-
	[Elm] Limestone	2 - 3.8	-	2.1 -2.4	-
	[Esdl] Sandstone and lutite	1.9 - 3.5	-	1.8 - 2.6	-
	[PElbr] Lutite and breccia	1.1 - 2.9	-	2.1 - 2.4	-
	[Osh] Metamorphic rocks, shale to phyllite	1.5 - 2.6	-	2.2 - 2.5	-
	[PZgr] Granite	2.1 - 3.3	-	2.1 -3	-
	[Qa2csl] Clay, sand, silt	1.1 - 2.9	-	2.1 - 2.4	-
	[Osdl] Sandstone and lutite	1.9 - 3.5	-	1.8 - 2.6	-
	[Osdp] Sandstone and pelite	1.9 - 3.5	-	1.8 - 2.6	-
	[COp] Pelite	1.1 - 2.9	-	2.1 - 2.4	-

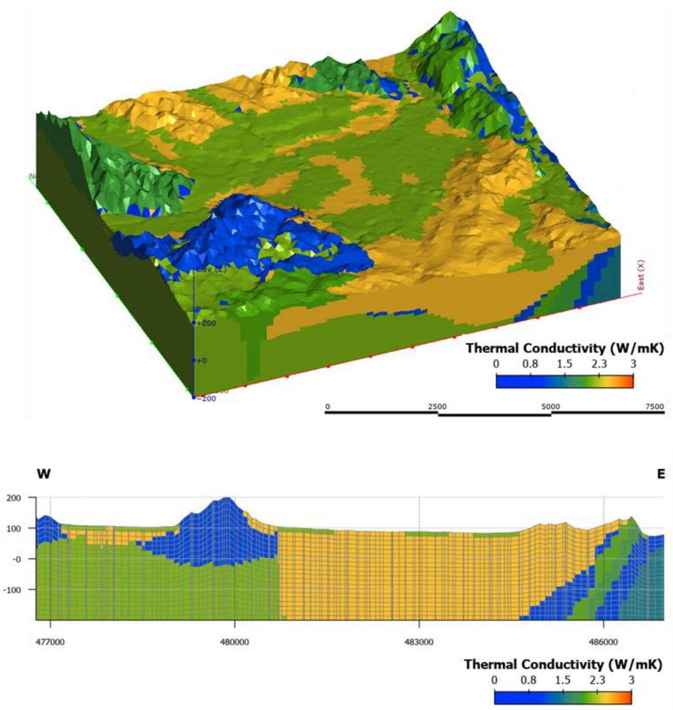

Figure 10: Thermal properties of the subsoil in Girona urban area. Table on the right summarizes range of thermal conductivity and specific heat capacity of each lithological unit preliminary defined in the geological model of Girona urban area according to UNE, 2014. Image and cross section on the left shows thermal conductivity of lithological units defined in base model (3.1. Base Model). Spatial extension of the cross section matches Cross Section III in Figure 4.

This is a preliminary assessment of the ground thermal properties in Girona urban area. At this point it is still too early to accurately determine the exact SGE potential of the area and decide which areas are better or worse for open and closed loop heat exchanger installations. With the detailed prepared geological model and further monitoring in the area it will be possible to develop both hydrogeological and thermal models of the area, which will allow delineating shallow geothermal resources.

5. CONCLUSIONS

Over the course of this project a detailed 3D geological model of Girona urban area was prepared using Leapfrog-Geo software. All in all, around 1400 drillholes, 4 geological maps scale 1:25000, 5 geological maps scale 1:5000, 2 hydrogeological maps scale 1:25000 and geophysical data were utilised to prepare a detailed geological model. 31 geological units were modelled between Ordovician and Quaternary. Preliminary assessment of thermal properties in the area based on UNE, 2014 was also prepared.

Groundwater temperature in the area has been monitored since 28th of February, 2019 with last measurements on 3rd of July, 2019. With these measurements it was possible to determine average groundwater temperature in the study area, i.e. groundwater temperature varied between 13.2 and 17.3 °C with temperature gradient between –1.4 ºC/100 m and 3.02 °C/100 m.

Further development of 'GeoEnergy SGE Project' will enable local government, municipalities and end-users utilising shallow geothermal resources and provide a platform to assess geothermal potential both in regional and local scale. The prepared geological model and continuous monitoring campaigns are going to be used as a basis for a new hydrogeological and heat transport 3D models of the Girona urban area using FEFLOW (Diersch, 2014). Combination of geological and numerical modelling techniques will allow accurately assessing SGE potential in Girona urban area and determine which areas are more feasible for installing open and closed loop systems.

REFERENCES

Arnó, G., Veciana, R., Casasso, A., Herms, I., Amaro, J. & Prohom, M. Assessment of Closed-Loop Shallow Geothermal Potential in Catalonia Using GIS Tools. In European Geothermal Congress (2019, June) (pp.11–14). http://europeangeothermalcongress.eu/wp-content/uploads/2019/07/50.pdf

Casasso, A., & Sethi, R.. G. POT: A quantitative method for the assessment and mapping of the shallow geothermal potential. *Energy*, 106, (2016), 765-773. https://doi.org/10.1016/j.energy.2016.03.091

Cowan, E. J., Beatson, R. K., Fright, W. R., McLennan, T. J., & Mitchell, T. J. (2002, September). Rapid geological modelling. In *Applied Structural Geology for Mineral Exploration and Mining, International Symposium* (pp. 23-25). Retrieved from: https://www.leapfrog3d.com/__data/assets/pdf_file/0014/563/rapid_geological_modelling.pdf

Diersch, H. J. G.). *FEFLOW: finite element modeling of flow, mass and heat transport in porous and fractured media.* Springer Science & Business Media (2014). https://www.springer.com/gp/book/9783642387388

Epting, J. Thermal management of urban subsurface resources - Delineation of boundary conditions. Procedia Engineering. Volume 209, (2017), Pages 83-91. https://doi.org/10.1016/j.proeng.2017.11.133

Gabàs, A., Macau, A., Benjumea, B., Bellmunt, F., Figueras, S., & Vilà, M.. Combination of geophysical methods to support urban geological mapping. *Surveys in Geophysics*, 35(4), (2014), 983-1002. https://doi.org/10.1007/s10712-013-9248-9

ICGC. Mapa Geològic de Catalunya 1:25.000. Geotreball I (1997). Fulls de Canet d'Adri (295-2-2) i Sarrià de Ter (296-1-2). http://icgc.cat/Administracio-i-empresa/Descarregues/Cartografia-geologica-i-geotematica/Cartografia-geologica/GT-I.-Mapa-geologic-1-25.000

ICGC. Mapa Geològic de Catalunya 1:25.000. Geotreball I (2003). Full de Girona (334-1-1).

ICGC. Mapa Geològic de Catalunya 1:25.000. Geotreball I (2009). Full de Salt (333-2-2).

ICGC. Mapa Hidrogeològic de Catalunya a escala 1:25.000. Geotreball V (2015). Fulls de Girona (334-1-1) Salt (333-2-1).

ICGC. Mapa Geològic de Zones Urbanes de Catalunya a escala 1:5000 (2014). Fulls de Taialà - Germans Sàbat (304-097), Girona-Palau (305-098), Girona-Sant Daniel (305-097), Salt (304-098) i Quart (304-099). http://icgc.cat/Administracio-i-empresa/Descarregues/Cartografia-geologica-i-geotematica/Cartografia-geologica/GT-III.-Mapa-geologic-de-les-zones-urbanes-1-5.000

ICGC. Mapa Geològic de Zones Urbanes de Catalunya a escala 1:5000 (2015). Fulls de Salt (304-098) i Quart (304-099).

ICGC. Geoindex. Shallow Geothermal Energy (2019). Retrieved from: https://www.icgc.cat/en/Public-Administration-and-Enterprises/Tools/Geoindex-viewers/Geoindex-Shallow-geothermal-energy

Martí, J., Mitjavila, J., Roca, E., & Aparicio, A. Cenozoic magmatism of the valencia trough (western mediterranean): Relationship between structural evolution and volcanism. *Tectonophysics*, 203(1-4), (1992), 145-165. https://doi.org/10.1016/0040-1951(92)90221-Q

Martí J., Bolós X., Planagumà L.. Geological Setting of La Garrotxa Volcanic Field. In: Martí J., Planagumà L. (eds) La Garrotxa Volcanic Field of Northeast Spain. Geoheritage, Geoparks and Geotourism (Conservation and Management Series). Springer, Cham. (2017) https://doi.org/10.1007/978-3-319-42080-6_2

Rivera, J., Benz, S., Blum, P., & Bayer, P. Increased temperature in urban ground as source of sustainable energy. *International Journal of Energy Production and Management*, 1(3), (2016), 263-271. https://www.witpress.com/Secure/ejournals/papers/EQ010305f.pdf

Rubel, F., Brugger, K., Haslinger, K., & Auer, I. The climate of the European Alps: Shift of very high resolution Köppen-Geiger climate zones 1800–2100. *Meteorologische Zeitschrift*, 26(2), (2017), 115-125. http://koeppen-geiger.vu-wien.ac.at/pdf/Paper_2017.pdf

Saula, E., Picart, J., Mató, E., Llenas, M., Losantos, M., Berástegui, X., & Agustí, J. Evolución geodinámica de la fosa del Empordà y las Sierras Transversales. *Acta geológica hispánica*, 29(2-4), (1994), 55-75. https://www.researchgate.net/publication/39118534_Evolucion_geodinamica_de_la_fosa_del_Emporda_y_las_Sierras_Transversales

UNE 100715-1. Guide for the design, implementation and monitoring of a geothermal system. Part 1: Vertical closed circuit systems. *Asociación Española de Normalización y Certificación*. (2014), 1-39. https://www.une.org/encuentra-tu-norma/busca-tu-norma/norma?c=N0052899