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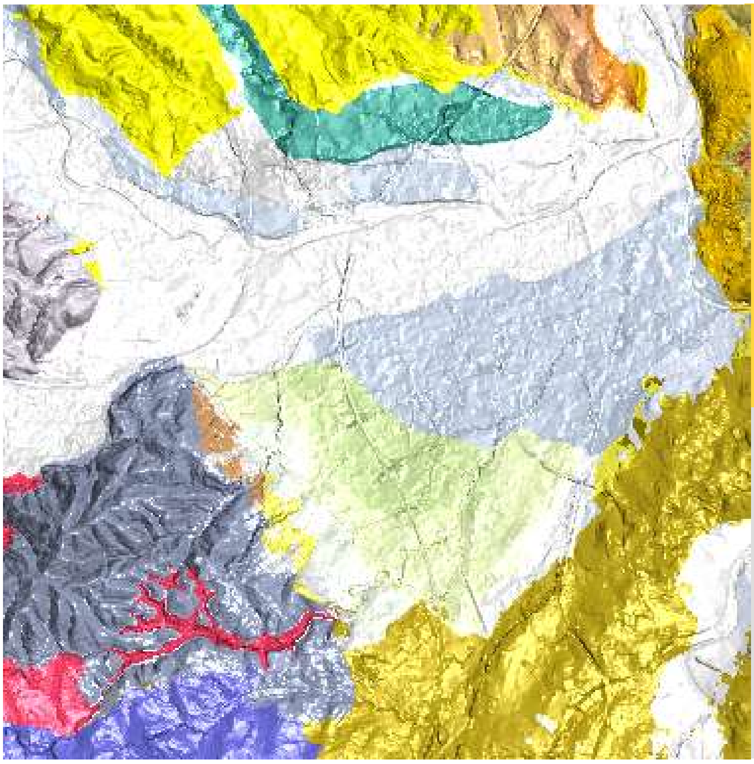

3D geothermal model of Girona-Salt urban area (NE Catalonia). Stage I: Development of the 3D geological model. Version 2.0

European MUSE project (GeoERA)
Managing Urban Shallow geothermal Energy

Hydrogeology and Geothermal Unit.
Area of Geological Resources (ICGC)

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Front cover: 3D geological model

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1 Introduction

Utilization of shallow geothermal energy (SGE) for heating and cooling is increasing in Catalonia (NE Spain) and until now more than 30MWt have been installed (ICGC, 2019b). Despite this increase, SGE still covers just a minor part of the heating market.

In 2014 the ICGC started a "**GeoEnergy- Shallow Geothermal Energy Project**" aiming to assess SGE potential across Catalonia both at regional and urban scale and to help government, municipalities and end-users to utilise SGE. Furthermore, in 2018 **MUSE** project (Managing Urban Shallow geothermal Energy) was launched under the umbrella of the **GeoERA** (H2020 ERA-NET Cofund Action) initiative of the European Geological Survey Organisations (http://geoera.eu/). Partners from 16 national and regional Geological Survey Organisations investigate SGE potential and possible conflicts associated with its utilisation in European urban areas. The assessment of geothermal resources and conflicts of use will lead to the development of management strategies considering both efficient planning and monitoring of environmental impacts to feed into general framework strategies of cities like Sustainable Energy Action Plans (SEAPs). The developed methods will be tested and evaluated together with input from the local stakeholders in 14 urban pilot areas across Europe, which will provide different boundary conditions for the use of SGE. The pilot areas are geologically and climatologically diverse and provide different legal and socio-economic settings making the project outcomes and obtained knowledge relevant to the whole Europe and beyond.

Girona-Salt urban area (Catalonia, NE Spain) and surrounding municipalities were selected for the development of MUSE Project, due to their great potential of SGE utilisation. The market of shallow geothermal energy is still poorly developed in the selected area, even though few closed/open loop systems have been installed. The project will focus on the evaluation of shallow geothermal potential of open and closed loop vertical systems. Framework of MUSE and ICGC Contract Programme for the period 2019-2022 is planning to develop the following objectives:

1. Implementation of a monitoring network of ground thermal properties to obtain new thermal and hydrogeological data;

2. Development of a 3D geothermal model for shallow geothermal energy evaluation. It will be developed in three stages:

    a. Stage I: construction of the 3D geological model with Leapfrog Geo software (Sequent, Ltd.) version 4.5, which use an implicit modelling approach.
    b. Stage II: development of 3D hydrogeological model in order to simulate groundwater flow with FeFlow software (Diersch, H.J.G., 2014) version 7.2 (DHI) which uses a numerical method of finite elements (FEM).
    c. Stage III: construction of 3D geothermal model and characterization of thermal parameters for the coupled groundwater flow and heat transport simulation, with FeFlow 7.2 software.

3. Testing the presence of Urban Heat Island (UHI) and its influence on shallow geothermal potential.

On July 2019, the drilling of three of the eleven points of the monitoring network of ground thermal properties were finished and the Stage I of the 3D geothermal model construction was performed with a first 3D geological model development. During the early 2020 the monitoring network was completed with the drilling of the remaining eight points. New acquired data has been used to update the 3D geological model in autumn 2020. In this document results, methodology and used data to develop Stage I of the project are presented.

2 Girona-Salt urban area

2.1 Climatic setting

Girona and Salt urban area is located in NE of Catalonia, Spain (Figure 1, Figure 7) at 65 to 166 m asl. 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 34 ºC with a total Cooling Degree Days (CDD) of 250 to 300 (ICGC, 2019). The mean annual precipitation in Girona is 740 mm. Girona and Salt urban area is approximately 48 km^2 where around 138.000 people live. Based on population density and climatic setting Girona-Salt urban area has a great demand both for heating and cooling which could be supplied by shallow geothermal energy.

2.2 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 consequential volcanism, and finally recent sedimentation (Figure *1*).

Girona-Salt urban area is located at the northern part of La Selva sedimentary basin (Figure 1). Tectonic setting of La Selva basin is associated with European Cenozoic Rift. In general, La Selva basin is a tectonic graben formed during Neogene due to extensional tectonics (Saula et al. 1994). 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, but it is also responsible for the volcanism (Figure *1*, A). Development of European Cenozoic Rift system was accompanied by volcanic activity, hence the Llorà fault and parallel Amer fault in the East are responsible for Quaternary-Neogene 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, i.e. La Crosa de Sant Dalmai volcano in the south-west and Volcà del Puig d`Adri in the north (ICGC, 1997; ICGC, 2003) (Figure 1, B).

The thickness of La Selva infill is variable due to horst and graben structures of the bedrock. Basin outcrops in the eastern and western sides of the study area, where Paleozoic and Tertiary materials, respectively are visible (Figure 1, B). Paleozoic bedrock consists of sandstones and lutites 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. 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-Salt urban area: Quaternary, Pliocene and Paleogene (Figure 1, 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 26 m depth (Figure 1, 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 are mainly confined. Depending on the location, groundwater level is at 70 m depth or has artesian conditions (ICGC, 2015b).

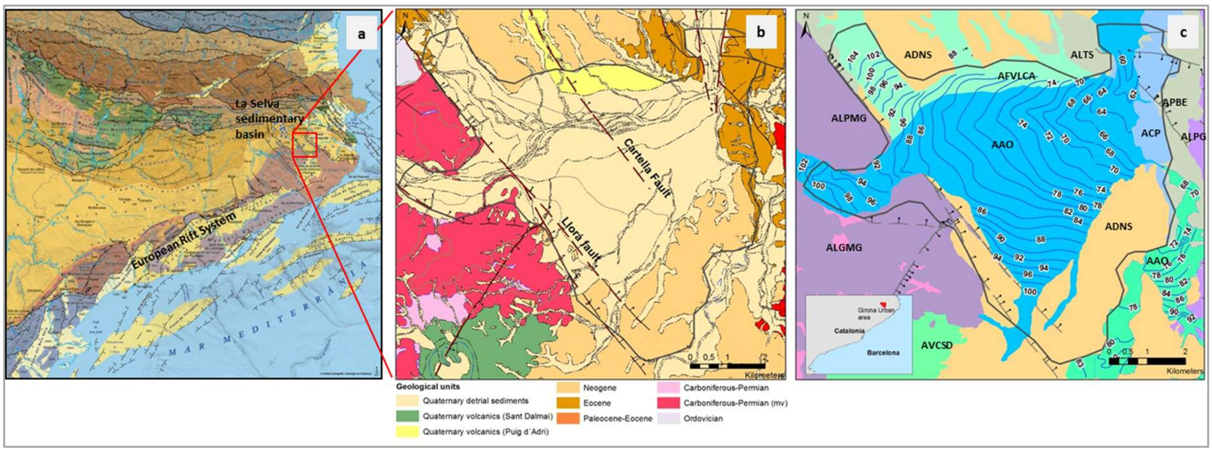

Figure 1. Geological and hydrogeological setting of the study area. A) Regional geological setting. B) Simplified geological setting of the study area (modified from ICGC, 2003). C) Hydrogeological setting of the study area, where ADNS- Neogene detrital aquifer of La Selva, AFVLCA- Llémena and Canet 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 asl. (ICGC, 1997; ICGC, 2003; ICGC, 2009).

3 Methodology

For the modelling purposes Leapfrog 3D geological modelling software (Sequent, Ltd.) was used. Leapfrog workflow is based on 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).

Modelling with Leapfrog is based on creating contact surfaces between different lithologies. Later on these surfaces are activated and they “cut” finite volume into respective units. Using this approach of starting with a finite volume and using contact surfaces to “cut” it into units means that, inherently, there will be no void space or overlapping volumes in the geological model.

As previously mentioned, Girona-Salt 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, Neogene and Quaternary (Figure 2). Later output volumes of Neogene and Quaternary from the base model (Basement) were used to create refined models of Neogene and Quaternary.

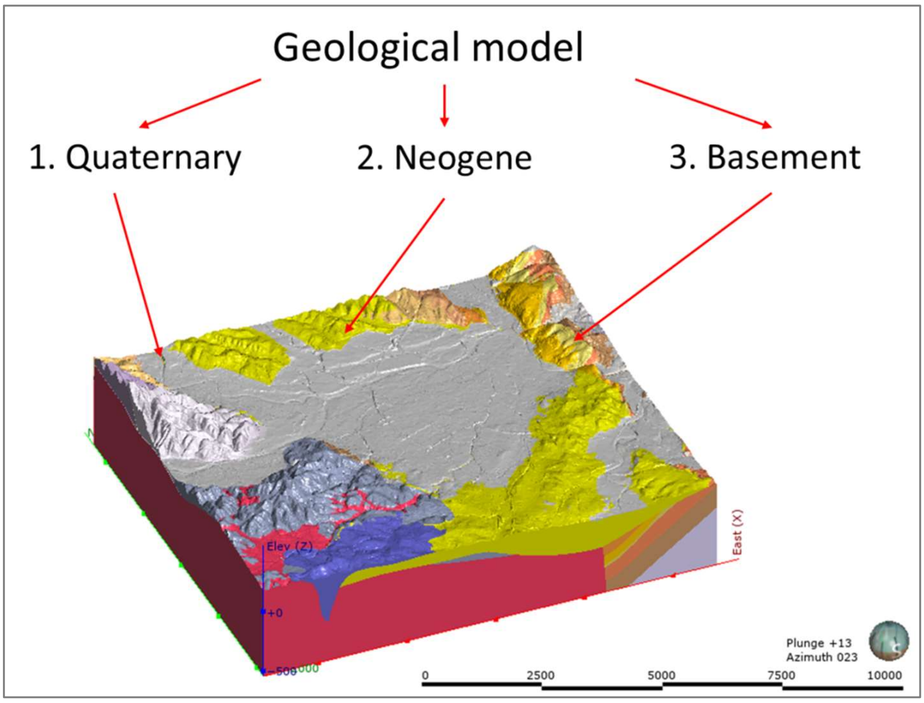

Figure 2. Conceptual approach for modelling Girona-Salt urban area.

Due to multiple faults in the study area it was necessary to divide each model into blocks. Shape and spatial extension of each block is determined by the extension of faults. Each block has its own surface chronology and output volumes (Figure 3). Once surface chronology was defined in each fault block (18 in total), it was possible to generate unified geological model of Girona-Salt urban area (Figure 3).

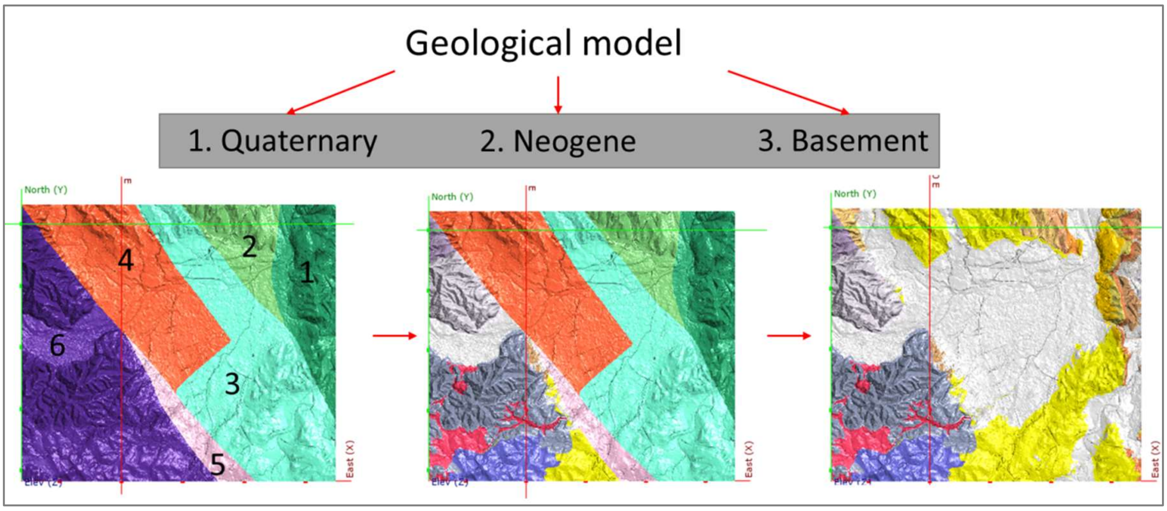

Figure 3. Blocks of the 3D geological model.

4 Stage I: The 3D geological modelling

The 3D geological model of Girona-Salt urban area is 10 km wide, 9 km long and approximately 600 m deep (down to -550 m asl.), with a total model volume of 62 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 drillings and water wells and also from the drilling of the eleven control points of the monitoring network implemented.

According to the geophysical data the depth of sedimentary basin varies between 0 and 500 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 metamorphised rocks, sandstones, limestones, marls, lutites, pelites and granites.

The detailed division 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.

4.1 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. Furthermore, data from 2 hydrogeological maps scale 1:25.000 (ICGC, 2015) was also implemented over entire study area. The spatial extension of the basin was defined using surface contacts obtained from geological and hydrogeological maps, drillhole contacts and geophysical data.

Based on geological and hydrogeological maps of the area, 15 geological units have been considered between Paleozoic and Quaternary: Eocene: sandstone [Esd], sandstone, marl, lutite [Esdml], marl [Em], nummulitic limestone [Enlm], limestone [Elm], sandstone and lutite [Esdl]; Paleocene-Eocene: lutite and breccia [PElbr]; Paleozoic: granite [PZgr]; sandstone and pelite affected by contact metamorphism [Osdp]; sandstone and lutite [Osdl], sandstone, quartzite and pelite [Osh], pelite affected by contact metamorphism [COp]; 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.

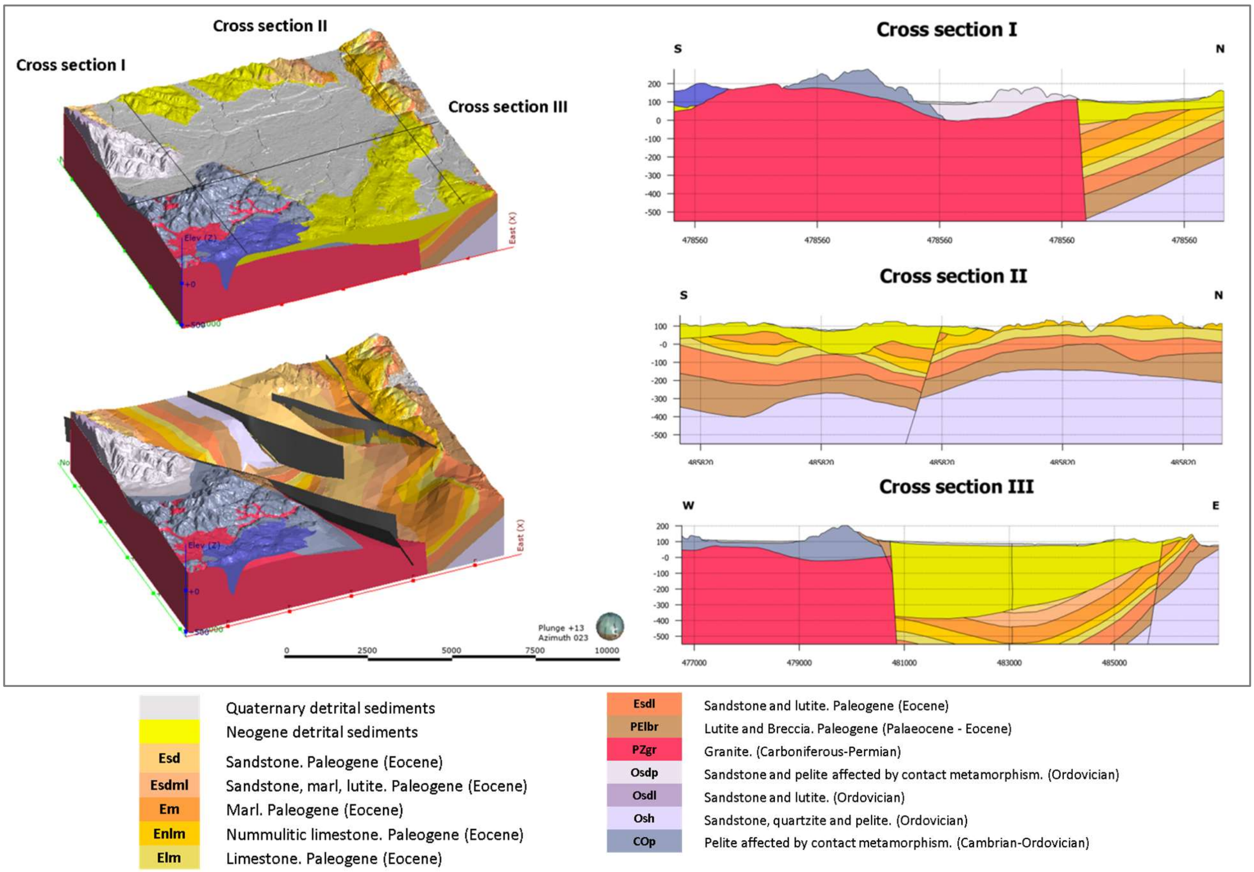

Figure 4. Structure of La Selva basin with unrefined Neogene and Quaternary sediments. The upper left side model visualizes geological setting of Girona-Salt urban area. Lower left image visualizes geological setting of Girona-Salt urban without Neogene (yellow colour) and Quaternary (light grey colour) sediments and demonstrates principal faults of the area. 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 3).

4.2 **Neogene Model**

The volume of Neogene defined in the base model was refined to present the Neogene sedimentary fill in a greater detail (Figure 5). Refinement of the Neogene sedimentary basin consists of alluvial fan systems which were formed by the erosion of the surrounding materials.

According to the geological maps the Neogene alluvial fans have two main origins. Neogene sediments in the northern side of the model [Naf2csg] are associated to the distal phase of the Canet d'Adri alluvial fan and is characterised by clay, sand and gravel. Neogene sediments in the southern part of the sedimentary basin are associated to the proximal phase of Guilleries, Gavarres and Serres Transversals alluvial fan and it 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 [Naf1sgc] – sand, gravel and clay, and the lower part of the southern alluvial fan is characterised by [Naf1cs] – clay and sand (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.

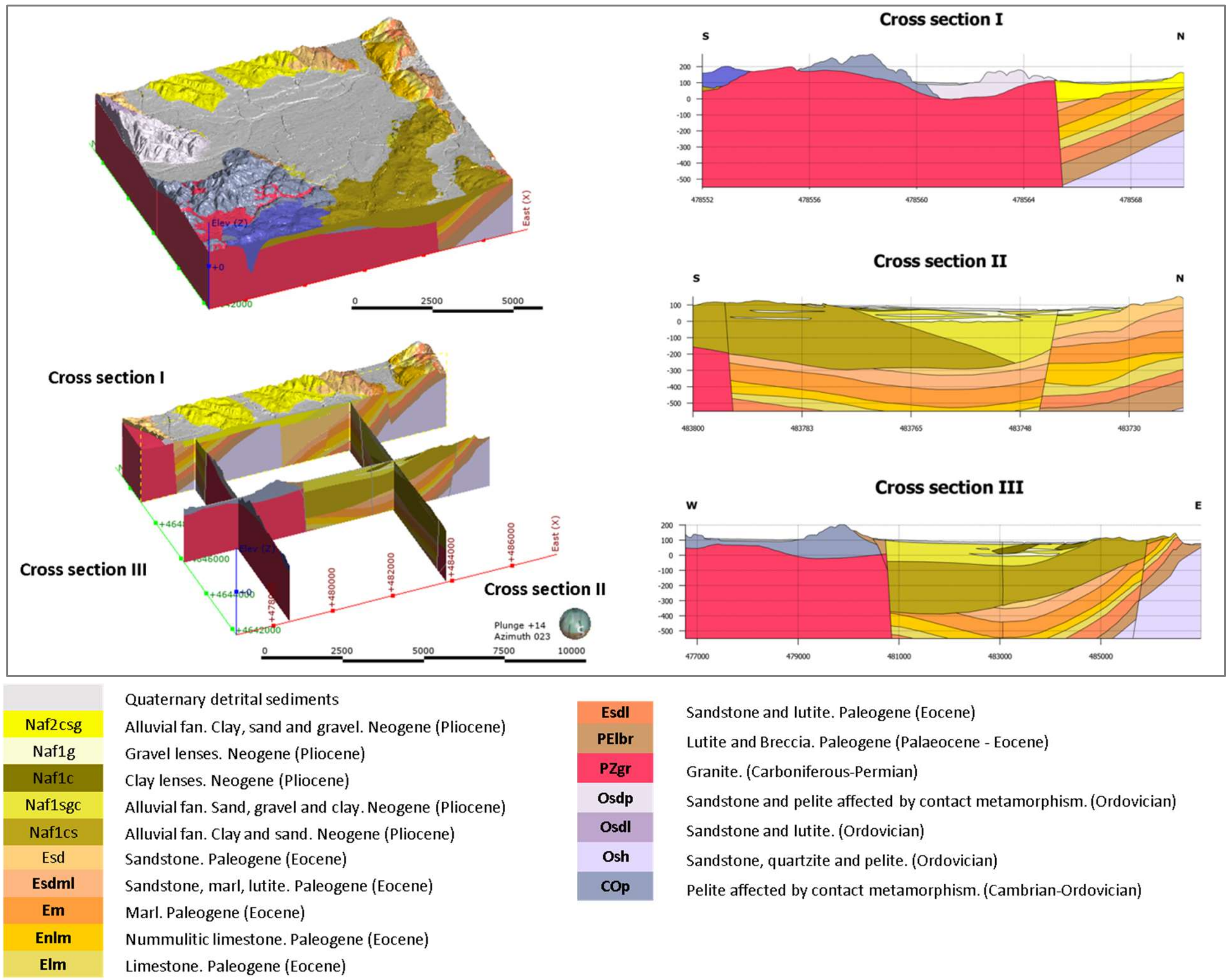

Figure 5. Structure of La Selva sedimentary basin (Neogene sediments). The upper left side model visualizes geological setting of Girona-Salt urban area with refined Neogene sediments. Lower left image visualizes location of the cross sections I, II and III and allows seeing distribution of alluvial fans: [Naf2csg] representing sediments of Canet d'Adri alluvial fan located in northern side of the model (thick section), [Naf1sgc] representing upper sediments of Guilleries, Gavarres and Serres Transversals alluvial fan is seen in cross section II and a thick northern section and [Naf1cs] representing 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-Salt 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 3).

4.3 **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 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 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 Volcà del Puig d`Adri in the north (basalt [Qb]).

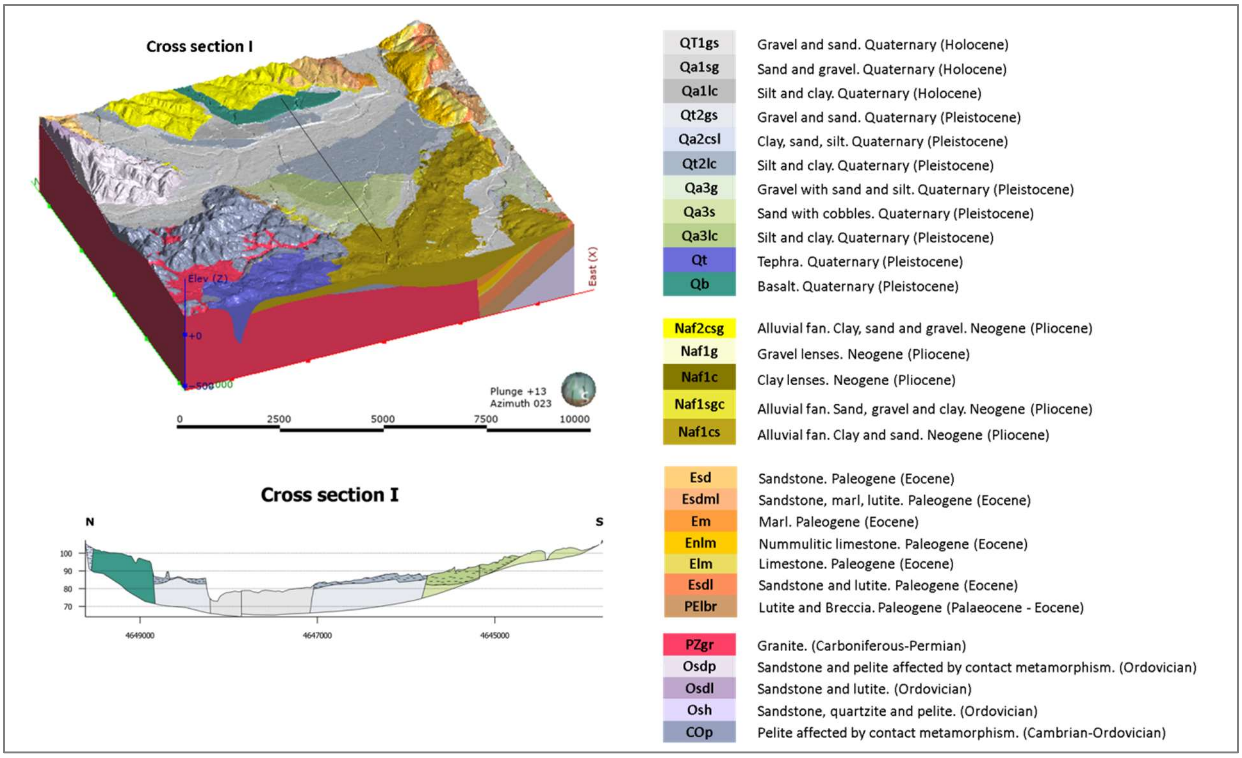

Figure 6. Geological model of Girona-Salt urban area. Image on the left visualizes complete geological setting of the study area. Cross section I demonstrates spatial distribution of Quaternary sediments and gives a closer look to the areas with finer ([Qt2lc] and [Qa3lc]) or coarser sediments (vertical exaggeration of the model is 3 and vertical exaggeration of the cross section is 20).

5 Used data

In order to prepare geological model of Girona-Salt urban area geological and hydrogeological maps, drillholes and geophysical data were utilised. All used data is organised and stored in a Geodatabase. This section of the report presents used data in more detail.

All in all, around 1400 drillholes (Figure 7), 4 geological maps at 1:25.000 scale (ICGC, 1997, 2003 & 2009), 5 geological maps at 1:5000 scale (ICGC, 2014 & 2015) and 2 hydrogeological maps at 1:25.000 scale (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 7). Therefore, in order to determine the depth and spatial distribution of the sedimentary basin it was necessary to utilize 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 to interpolate the geometry and maximum depth of the Selva basin.

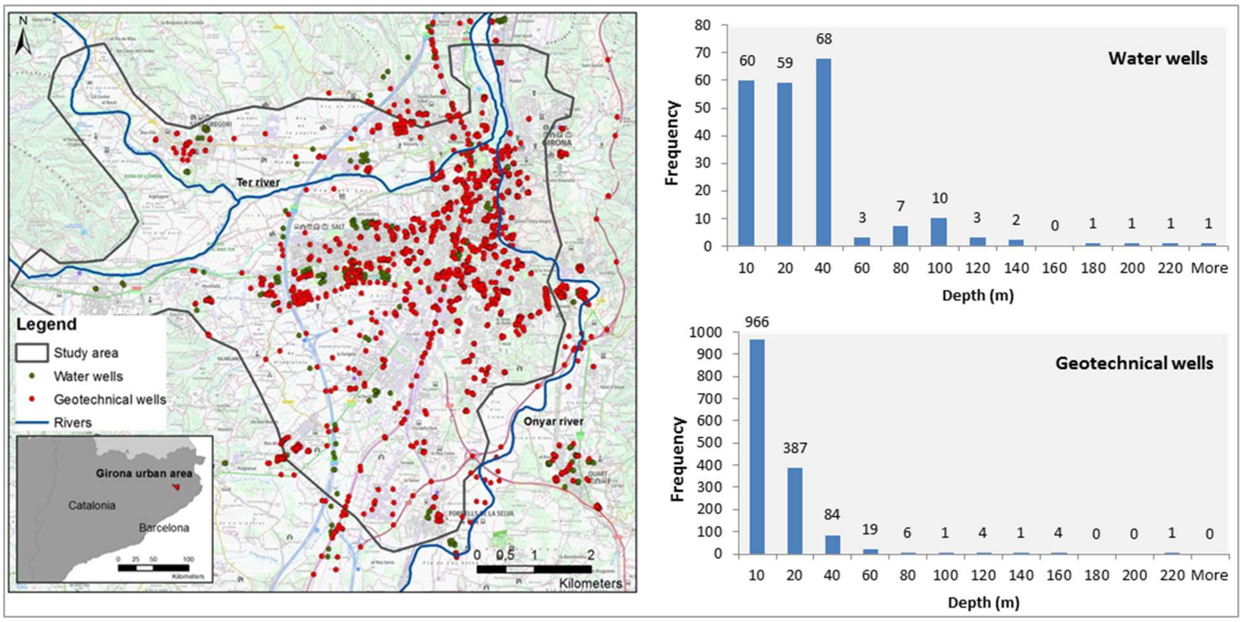

Figure 7. Girona-Salt urban area. Map on the left side visualizes the extension of the MUSE case study area and distribution of drillholes used to prepare the geological model. Graphs on the right demonstrate frequency and depth of drillholes used to prepare geological model.

5.1 Geotechnical boreholes

Geotechnical borehole datasets for the 3D geological model of Girona-Salt urban area were obtained from the ICGC geotechnical data base. Some of them have been also used to elaborate the geological maps at 1:5.000 scale (ICGC, 2014 & 2015). Incorporated data contains information about geotechnical borehole id, location (X, Y, and Z), depth and lithology. The lithology of each geotechnical borehole was divided into intervals (from – to) which indicate lithology changes with the increasing depth. Detailed lithology description of each interval is provided in the original language (Catalan), whereas simplified lithology is provided in English. For modelling purposes simplified lithology intervals were used.

In order to keep data well organised and referenced, each geotechnical borehole includes identification number (id) and lithology epigraph used in the published maps (ICGC, 2014 & 2015). Hence, knowing both geotechnical borehole and geological map id number, allows to easily track were data was used previously and access information in the original language.

During the geological modelling process new and more detailed interpretation of the local geology was made therefore abbreviations used in the geological maps were not applicable. Furthermore abbreviations in the geological maps are in local language; hence for the final version of the geological model new legend in English was prepared. Both legends can be found in the geological model and in the respective files.

5.2 **Water wells**

In order to prepare 3D geological model of Girona-Salt urban area as detailed as possible, data from water wells from the Catalan Water Agency (ACA) and from the ICGC database were incorporated as well. As geotechnical borehole data, incorporated water wells contain information about their id, location (X, Y, and Z), depth and lithology. Lithology is also divided into intervals and is referenced.

5.3 **New wells**

Between February 2019 and January 2020, 11 new wells were drilled by the ICGC in the study area named: SXG-01, SXG-02, SXG-03, SXG-04, SXG-05, SXG-06, SXG-07, SXG-08, SXG-09, SXG-10 and SXG-11 (Figure 8). As geotechnical boreholes and water wells, new wells were also incorporated into the geological model with the following data: id, location (X, Y, and Z), depth and lithology. Lithology is also divided into intervals and referenced.

Figure 8. Drilling new wells in Girona-Salt urban area.

5.4 **Geological and hydrogeological maps**

Geological and hydrogeological maps were incorporated as well: 4 geological maps at 1:25.000 scale (ICGC, 1997, 2003 & 2009), 5 geological maps at 1:5.000 scale (ICGC, 2014 & 2015) and 2 hydrogeological maps at1:25.000 scale (ICGC, 2015). Incorporated maps contain data such as surface contacts between lithological units, faults, dip and azimuth of the lithological units, outcrop location and polylines of quaternary base. Hydrogeological maps also contain data about the permeability and porosity. Thermal properties of each lithological unit depend on its hydraulic properties, so having permeability and porosity data incorporated in the model will also allow easily assign those values to the modelled geological units. Furthermore cross-sections from discussed geological and hydrogeological maps were also incorporated.

5.5 **Geophysical data**

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. All in all 63 data points referring to contacts between basement and/or Neogene/Quaternary sediments were implemented (Figure 9).

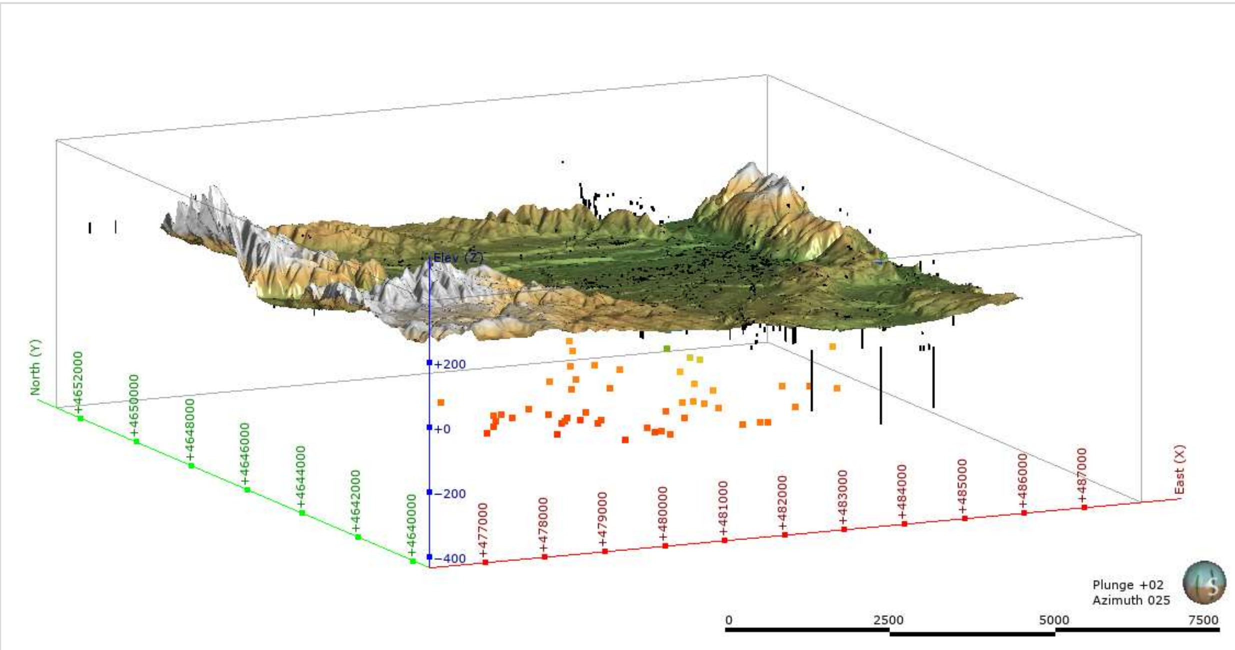

Figure 9. Geophysical data points (colourful squares) which were used to determine the spatial extension of the basement. Surface view refers to the topography of the area and black tubes refer to the drillholes (vertical exaggeration of the image is 5).

5.6 **Other data**

Digital elevation model at 5 m cell size from ICGC was introduced into the model to determine relief of the area, as well as topographical maps. Digital elevation model is also used to drape all data on topography, so that data analysis and representation is accurate (Figure 9).

6 Model limitations and uncertainties

The presented 3D geological model of the urban area of Girona-Salt responds to the first stage of the 3D geothermal model construction project. The objective of the geological model is to obtain a better understanding of the geology of the subsoil and to facilitate the parameterization process of the flow and heat transport models that will serve as the basis for simulating the geothermal potential of the aquifers.

Prepared geological model contains various types of data, such as geological and hydrogeological maps, geotechnical boreholes, water wells and newly drilled wells, and geophysical data (5.1, 5.2, 5.3, 5.4, 5.5, 5.6). Even though wide variety of high quality data was used to prepare the geological model, it is important to emphasise that data distribution in the model area is uneven. For instance, as mentioned in chapter *5* most of the boreholes are rather shallow, naturally geological model has more precision closer to the surface and vice versa. Secondly, the scale of used geological maps and associated cross-sections is also variable within the geological model. To define lithology in western side of the model geological maps at 1:25.000 scale were used, whereas in the eastern side, geological maps at 1:5.000 scale were used. Hence, model precision also varies depending which side of the model is being analysed.

Even though geological and hydrogeological maps (ICGC, 1997, 2003, 2009, 2014, 2015) were used to prepare the geological model, new abbreviations and legend was prepared for the model. During the geological modelling process new and more detailed interpretation of the local geology was made therefore abbreviations used in the geological maps were not applicable. Furthermore abbreviations in the geological maps are in Catalan; hence a new legend in English was prepared

Provided model viewer in the associated website is prepared to present subsurface geology of Girona-Salt urban area and introduce user how geological model was built and visualise overall result of Stage I of 3D geothermal model. A provided geological model presents used data and its distribution over the study area, but does not provide data itself. Interested parties can refer to reference list, were links to publically available geological and hydrogeological maps are provided. Due to the fact that provided viewer contains great amount of information, it can take time to load information about each geological unit. For continual model analysis it is recommended to refer to the legend provided in the chapter 7 (legend) of the present document, which gives overview about the geology and provided legend of the viewer.

While reviewing 3D geological model via online viewer or in the report, it is very important to keep in mind that vertical exaggeration is 3. Vertical exaggeration of the model allows visualising finer parts of the model, such as Quaternary sediments of Neogene lenses, but changes overall perspective of the model.

The viewer does not provide solutions to possible geological, hydrogeological or geothermal issues in the area. The viewer has to be used a platform to obtain better understanding about the geology in the area. Competent engineering and consulting companies are responsible to perform various feasibility and design studies.

7 Legend

Girona-Salt urban area is characterized by complex geological and tectonic setting. Neogene and Quaternary deposits form La Selva sedimentary basin and are surrounded by the basement consisting of sequence of metamorphised rocks sandstones, limestones, marls, lutites, pelites and granites formed between Ordovician and Eocene and is 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 500 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 formed during Neogene and Quaternary. Following subchapters provide a legend which was prepared for the 3D geological model of Girona-Salt urban area.

7.1 Basement

Visualisation of basement includes all geological units between Paleozoic to Eocene periods and consist of several sequences of metamorphised rocks sandstones, limestones, marls, lutites, pelites and granites. All in all 15 geological units were defined between Paleozoic and Quaternary.

Paleogene

Esd	Sandstone. Paleogene (Eocene)
Esdml	Sandstone, marl, lutite. Paleogene (Eocene)
Em	Marl. Paleogene (Eocene)
Enlm	Nummulitic limestone. Paleogene (Eocene)
Elm	Limestone. Paleogene (Eocene)
Esdl	Sandstone and lutite. Paleogene (Eocene)
PElbr	Lutite and Breccia. Paleogene (Palaeocene - Eocene)

Paleozoic

PZgr	Granite. (Carboniferous-Permian)
Osdp	Sandstone and pelite affected by contact metamorphism. (Ordovician)
Osdl	Sandstone and lutite. (Ordovician)
Osh	Sandstone, quartzite and pelite. (Ordovician)
COp	Pelite affected by contact metamorphism. (Cambrian-Ordovician)

7.2 **Neogene**

According to geological maps, La Selva sedimentary basin fill is associated to detrital alluvial sediments. Neogene sediments in the northern side of the model [Naf2csg] are associated to distal phase of the Canet d'Adri alluvial fan and are characterised by clay, sand and gravel. Southern part on the sedimentary basin is associated to proximal phase of Guilleries, Gavarres and Serres Transversals alluvial fans system. 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, alluvial fan deposits are characterised by [Naf1sgc] –sand, gravel and clay, and the lower part of the alluvial fan deposits are characterised by [Naf1cs] –clay and sand. Furthermore, in some localised areas the available data has allowed to differentiate higher concentration of clay or gravel sediments, therefore the model represents individualised clay [Naf1c] and gravel [Naf1g] lenses.

Naf2csg	Alluvial fan. Clay, sand and gravel. Neogene (Pliocene)
Naf1g	Gravel lenses. Neogene (Pliocene)
Naf1c	Clay lenses. Neogene (Pliocene)
Naf1sgc	Alluvial fan. Sand, gravel and clay. Neogene (Pliocene)
Naf1cs	Alluvial fan. Clay and sand. Neogene (Pliocene)

7.3 **Quaternary**

Quaternary sediments form the upper part of the La Selva sedimentary basin and consist of: 1) river terraces: [Qt1gs] Gravel and sand (Quaternary), [Qt2gs] Gravel and sand (Quaternary), [Qt2lc] Silt and clay (Quaternary); 2) alluvial deposits: [Qa2csl] Clay, sand, silt (Quaternary), [Qa1sg] Sand and gravel (Quaternary), [Qa1lc] Silt and clay (Quaternary), [Qa3g] Gravel with sand and silt (Quaternary), [Qa3lc] Silt and clay (Quaternary), [Qa3s] Sand with cobbles (Quaternary); and 3) volcanic rocks: [Qb] Basalt (Quaternary), [Qt] Tephra (Quaternary). According to geological maps, horizontal extension of each Quaternary geological unit was defined. Due to abundance of drillhole data at the surface, it was possible to define vertical extension of each geological unit more precisely and divide them into finer and coarser parts. Hence both river terraces and alluvial deposits are divided into two parts: 1) fine sediments and 2) coarse sediments. Furthermore, 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]).

QT1gs	Gravel and sand. Quaternary (Holocene)
Qa1sg	Sand and gravel. Quaternary (Holocene)
Qa1lc	Silt and clay. Quaternary (Holocene)
Qt2gs	Gravel and sand. Quaternary (Pleistocene)
Qa2csl	Clay, sand, silt. Quaternary (Pleistocene)
Qt2lc	Silt and clay. Quaternary (Pleistocene)
Qa3g	Gravel with sand and silt. Quaternary (Pleistocene)
Qa3s	Sand with cobbles. Quaternary (Pleistocene)
Qa3lc	Silt and clay. Quaternary (Pleistocene)
Qt	Tephra. Quaternary (Pleistocene)
Qb	Basalt. Quaternary (Pleistocene)

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