The new Digital Geothermal Atlas of Catalonia for very Low Temperature (GACvLT)

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ABSTRACT

The use of geothermal energy of low and very low temperature in Europe is very extensive and is widely developed especially in the Nordic countries but also in Central Europe. There is an evident contrast between these countries and Catalonia where its implementation has been delayed and moderate even more.

However, the target known as "20-20-20" approved by the EU Council in March 2007 and later the emergence of the European Directive 2009/28/EC of the European Parliament has been the basis for the development and promotion of the use of geothermal energy in Catalonia resulting in a significant increase in number of geothermal installations executed in very low and low temperature reservoirs.

There is certainly still a long way to go and so the Cartographic and Geological Institute of Catalonia (ICGC) aims are to collaborate in the dissemination of scientific knowledge on geothermal energy of very low temperature providing our users with the necessary information available on thermogeology to use it in the phases of feasibility study and the planning of horizontal and vertical heat exchange systems (either open or closed loops).

With these two objectives, the ICGC is developing the new *digital Geothermal Atlas of Catalonia for very Low Temperature* (GACvLT), which will be a collection of thematic maps focused on very low temperature resources (< 30ºC) and indirectly on low temperature resources (30º - 100ºC).

One of the added values of the project is its transversal character due to the information generated comes from different disciplines such as climatology, geophysics, geology, hydrogeology and soil science.

The GACvLT is directed towards all types of collectives such as technical profile, geologists, architects, environmentalists and industrial engineers involved all of them in different stages of designing a ground loop heat exchange system.

The GACvLT includes the following sets of information:

Table 1: Information sets contained in the digital Geothermal Atlas of Catalonia for very Low Temperature (GACvLT).

Geological information	Drilling complexity prognosis map
Soil information	Depth, texture and thermal conductivity of soil map
Hydrogeological information	Depth to groundwater surface level, Langelier Saturation Index, confined aquifers with potential artesian phenomena and hydrothermal sources location
Subsoil thermal properties	Thermal conductivity, volumetric heat capacity, thermal diffusivity, heat flow, geothermal gradient and thermometry location maps
Climatology	Temperatures and surface thermal oscillations maps
Subsoil temperatures	Temperature distribution at 2, 50, 100, 150 and 200 meters deep maps
Geothermal potential	Geothermal potential for both open loop and closed loop heat exchange systems

All these information layers will be available on 2017 for users through a web map viewer providing online access: INSTAMAPS (a platform entirely developed by the ICGC). Each one of the layers will be accompanied by its corresponding legend, the methodology used to estimate it and clear disclaimers to make known the limitations of the information given. The datasets is expected to be also available as future Web Map Services (WMS).

1. INTRODUCTION

Catalonia covers 32.108Km^2 and has 7.5M residents. The minimum low and very low geothermal power installed in Catalonia is 10.700kW. Much less compared to other countries as France, Switzerland or Finland where the kW installed per inhabitant is higher (IDAE, 2011).

The so called "20-20-20" approved by the EU Council in March 2007 and later the emergence of the European Directive 2009/28/EC of the European Parliament and also of the Council on April 23, 2009 (which establishes that the geothermal energy captured by heat pump is considered an energy from a renewable source) has given an important boost to this sector. In addition, the publication in 2014 of the UNE 100715-1 by the Spanish State, offers to end users a guide for the design, implementation and monitoring of a geothermal system (vertical closed circuit systems).

On the other hand, our internal country policy is clearly evolving towards the shallow geothermal use as renewable source energy supply.

These facts together with the increasingly energy cost, which results from nonrenewable sources, and the growing collective consciousness about renewable energies, have boosted the shallow geothermal energy in Catalonia over the last few years.

This is why the Cartographic and Geological Institute of Catalonia (ICGC), started to create the new digital Geothermal Atlas of Catalonia for very Low Temperature (GACvLT) on 2014. This atlas would cover the whole Catalonian territory (Figure 1) and mainly includes information about geological, thermal and hydrogeological determining factors that affect the design and dimensioning of ground loop heat exchange systems.

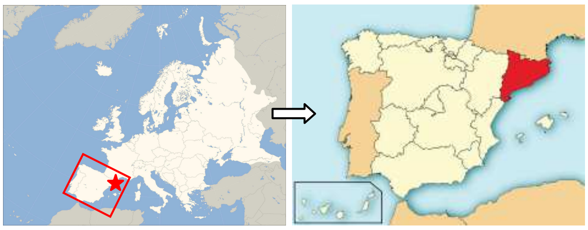

Figure 1. Catalonia situation map and the area where the Geothermal Atlas of very Low Temperature is developed.

It should also be taken into consideration that there isn't any public administration to centralize the information concerning about number and characteristics of shallow geothermal installations. For this reason most of the information referring to the subsoil characteristics is dispersed or unreachable. In this sense, special emphasis has been placed in collecting, sorting and systematizing basic information in a way homogeneous and understandable for potential users.

2. PROJECT BACKGROUND AND ORIGIN

All over the world and especially in Europe there are several initiatives related with atlas allowing thermogeological data visualization with different levels of interpretation and applicability.

In 2012, was finished and published the Geothermic Atlas of Catalonia (GAC) at a scale 1:500 000 (Puig, C et al, 2010). This project was planned as a product for the dissemination of geothermal energy knowledge in Catalonia and therefore, the factors influencing the use of geothermal energy in our country (Figure 2).

Based on the information provided by this atlas the geothermal potential of Catalonia is well accounted with regard to high and medium temperature geothermal energy. It also includes useful information in the context of the geothermal energy of low and very low temperature.

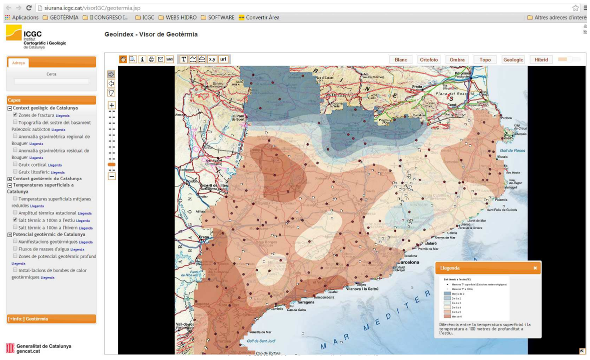

Figure 2. Geothermal Atlas of Catalonia at a scale of 1:500 000 mainly for high and medium temperature resources. See it at www.icgc.cat.

The GAC includes twenty layers of information related to the following issues:

- Geological context: main geological structures in order to characterize the deep structures that can determine the existence of deep thermal anomalies.
- Geothermal context: theoretical maps temperatures at 100 m, 3 Km, 15 Km depth and at the crust base.
- Surface temperature: map representing the average air temperatures for different seasons and the temperature difference with the theoretical temperature at 100 m depth.
- Geothermal potential: maps of geothermal indicators and areas with deep geothermal potential.

After the experience in the implementation of the GAC project in 2012 and due to the need for deeper understanding shallow geothermal energy in Catalonia, the ICGC completed a pilot project focused on geothermal resources of very low temperature.

The aim of this pilot study was to define the content and structure of the layers of information that might be part of the future GACvLT, establish the methodology to generate them, and finally identify the possibilities and limitations of implementing this methodology to all over the country.

Lastly, in December 2014, the Executive Board of the Government of Catalonia established the creation of the new GACvLT as one of the ICGC main lines of work for the period 2014-2017.

3. OBJECTIVES AND POTENCIAL USERS

The aims of the new GACvLT are:

a) To diffuse geothermal energy knowledge, its implementation and future development in Catalonia for ground loop heat exchange systems.

b) To promote the use of this type of renewable energy disseminating concepts and estimation methodologies.

c) To make all data available to all users compiling and generating new information about thermal parameters and subsoil temperatures.

d) To provide useful data to preliminary feasibility assessment of very low geothermal energy installations and give a fair indication about the associated costs.

It must also be said that is not the purpose of GACvLT to replace the technical studies and reports that necessary have to be done by companies suited to that task. These deeper research studies are essential to design accurately heat exchange systems.

Key potential user of GACvLT have been identified: every general and local public administration entity of Catalonia, as reinforcement to land planning and management; any type of school center as a tool for disseminate very low temperature geothermal energy knowledge; and for technician collectives as geologists, engineer or architects as a development support tool in the evaluation, design, implementation and control stages of ground loop heat exchange systems.

4. PROJECT DEVELOPMENT

4.1 Stages of development

The project has been developed in 4 stages:

STAGE 01. Planning and design necessary period to contextualize the project; searching worldwide references and previous information; establishing the final contents and structure of GACvLT. This stage is considered to be 20% of the total project.

In this stage, different private and public sector actors have been contacted in order to identify the real needs of information of the potential users. In this stage it has also been gathered necessary information for the atlas generation: thermogeological and hydrogeological data and previous cartography.

STAGE 02. Execution. Stage of production of different information layers that will be part of the GACvLT according to STAGE 01. This stage is considered to be 55% of the total project.

STAGE 03. Supplementary documentation creation. Legends, methodological report and technical description of the initial data used to make each layer. This stage is considered to be 10% of the total project.

This supplementary documentation enables a correct understanding and interpretation of GACvLT contents.

SATGE 04. Web services implementation. Map viewer design and creation of geoservices (WMS). This stage is considered to be 15% of the total project.

At present, 51% of the GACvLT content is finished; 30% is in working phase; and 19% is still in starting up phase.

4.2 Resources

This project is entirely carried out in the Geological Resources Department of the ICGC. There is a close collaboration between ICGC and other public and private institutions, who contributed in different ways to the project. Emphasizing Catalan Water Agency (ACA); Territory and Sustainability Department (DTiS); Animal Biology, Vegetal Biology and Ecology Department of Autonomous University of Barcelona (UAB); Structure, Dynamics of the Earth and Crystallography Department of CSIC, International Hydrology Foundation Center (FCIHS) and Energy Catalan Agency (ICAEN).

ArcGIS (ESRI) and QGIS v14 have been used as main software and SGEMS to process geostatistics data. Lithological columns and temperature profiles have been done with LOGPLOT v7 and on the other hand GLD 2014 software has been used for ground loop heat exchange systems simulation.

5. STRUCTURE AND CONTENTS

The new GACvLT will be published in digital format with a maximum information resolution equivalent to 1:50 000 scale map and it will provide information for the first 200 m of the subsoil.

5.1 General structure of the GACvLT

The GACvLT is divided into three main parts (Figure 3):

a) **7 thematic geoinformation sets.** The total number of layers is 29, including both raster and vector (point and polygon) format layers.

b) **Methodological report.** Methodology will be explained for each information layer. Both the original data used (metadata) and the significance results obtained, will be pointed out.

c) **Technical specifications report** explaining the structure and organization of data and how to symbolize them.

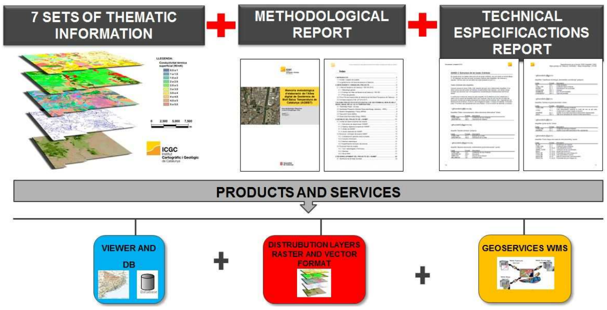

Figure 3. General structure of the GACvLT and future products derived from it.

In the near future, generated information will be available for external users through different formats such as raster layers (.TIF), vector layers (.SHP) and WMS geoservices.

A GACvLT viewer prototype application has been created using the webGIS platform 'INSTAMAPS', entirely developed by the Cartographic and Geological Institute of Catalonia (ICGC).

INSTAMAPS is an open webgis platform for the creation, dissemination and sharing of maps on the Internet. It is a public tool that allows non-expert users to create their own map, drawing it or loading data files from another users.

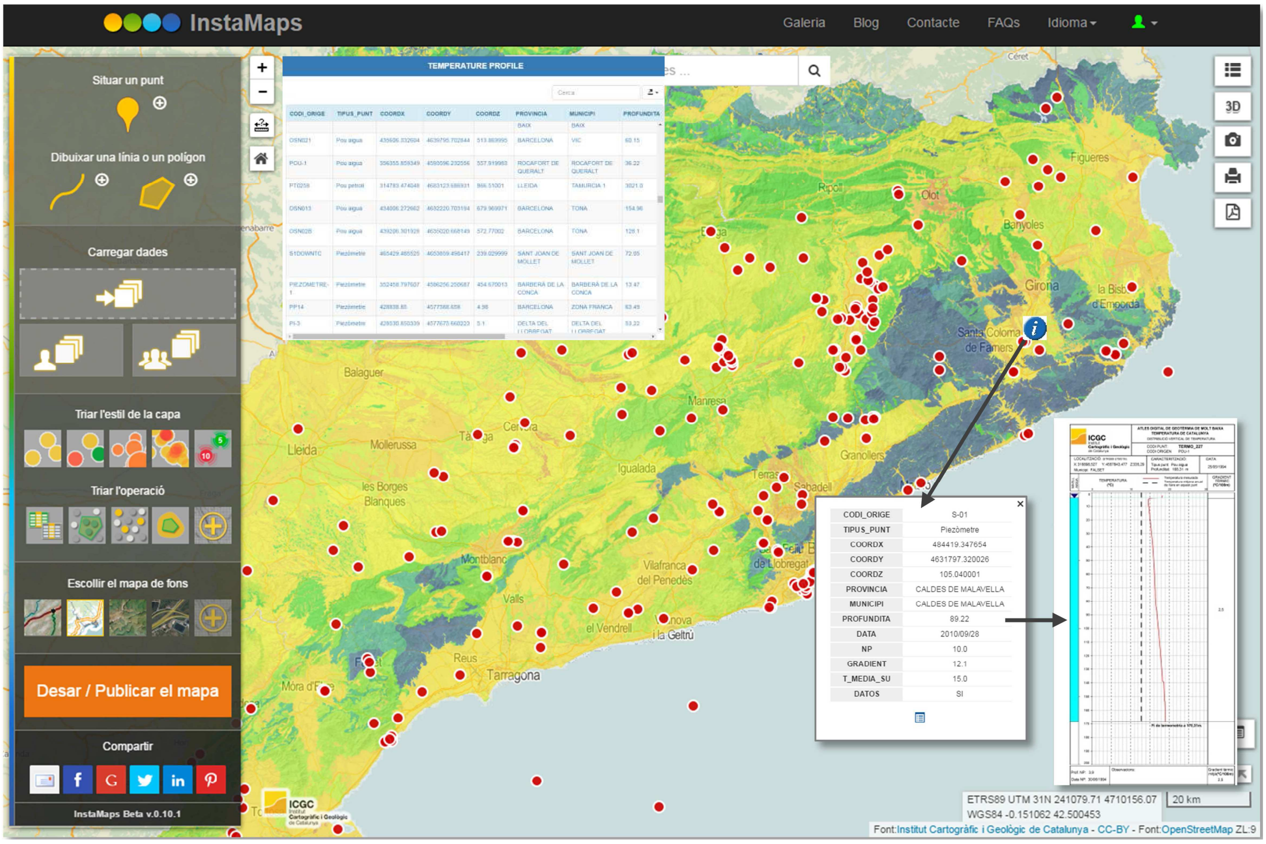

Figure 4. The GACvLT viewer prototype application using the webGIS platform 'INSTAMAPS'. The figure shows thermal conductivity map and temperature profile locations. The user can request information such as points and get a temperature profile imatge (http://www.instamaps.cat/).

5.2 Detailed contents

7 out of 8 sets of information contained in GACvLT, will support the feasibility studies of ground loop heat exchange systems. Only the soil information data set is directed toward to horizontal heat exchange systems planning.

Table 2 shows all the layers included in the GACvLT and a brief description of each one of them.

a) **Geotechnical information**

This data set includes one layer: drilling complexity prognosis map (Figure 5).

Considering the subsoil mechanic characteristics, three difficulty levels have been assigned (moderate, medium and high). They indicate the likelihood of instability during drilling.

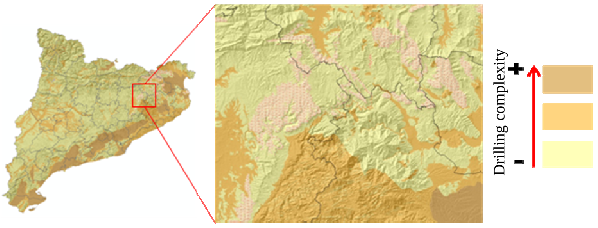

Figure . Drilling complexity prognosis map.

As additional warning during drilling and subsequent installation of heat exchange loops, this layer also includes superficial zonation areas with karstification evidence.

a) **Soil information data set**

Consist of three information layers about soil depth and texture, soil thermal conductivity and soil profiles localization.

Table 2: Summary and brief description of the 29 information layers included on the GACvLT.

LAYER SET	LAYER	DESCRIPTION
Geotechnical information	Drilling complexity prognosis map	Drilling complexity level (moderate, medium and high) for the first 150 m of subsoil with possible karstification or discontinuities warnings. Established according to material mechanic characteristics
Soil information	Soil depth and texture map	Effective soil depth to a rock or impenetrable for roots layer and cartographic unities grain size represented on soil map 1:250.000
	Soil thermal conductivity map	Soil thermal conductivity. Based on Kerten (1949) and Dehner (2007) method, taking into account two scenarios according to sand size particle content
	Soil pits localization map	14.022 soil profiles location. Information from ICGC database
Hydrogeological information	Water points with groundwater level information map	Water level of over 8.500 water points. Specifying either artesian or confined character
	Depth to water range map	Groundwater level depth. Manual interpolation of level timely data
	Langelier Saturation Index map	Groundwater tendency to dissolve or precipitate calcium carbonate ($CaCO_3$). From over 5.200 water analysis automatic interpolation with Langelier Saturarion Index (LSI) has been done
	Aquifer distribution 1:50 000 scale map	Aquifer delimitation at a 1:50 000 scale from Catalan Water Agency (ACA) specifying typology and exploitability range
	Hydrothermal springs and wells location map	Hot well and springs location which are possible indicators of positive thermal anomalies in depth
Subsoil thermal properties	Surface thermal conductivity map	Thermal conductivity values assigned to each geological unit from Geological map 1:50 000 (ICGC, 2014)
	Surface thermal diffusivity map	Thermal diffusivity values assigned to each geological unit from Geological map 1:50 000 (ICGC, 2014)
	Surface volumetric thermal capacity map	Volumetric thermal capacity values deduced from the relation between conductivity and diffusivity
	Stratigraphic columns with thermal parameters assignment	Location of stratigraphic columns deeper than 50 m with thermal parameters assignation
Surface temperature maps	Annual average air temperature map	Average interpolated temperature estimated by multiple regression method taking into account: altitude, latitude, continental nature, solar radiation and regional geomorphology. Pons X. (1996) & Ninyerola, M. (2000)
	Average minimum temperature of the coldest month map	
	Average maximum temperature of the hottest month map	
	Annual semi-amplitude between the hottest month and the coldest month	Thermal semi-amplitude values between the coldest month and the hottest one
Subsurface temperature maps	Average minimum temperature of soil at 2 m depth map	Theoretical calculus using Kusuda, T. (1965) method
	Average maximum temperature of soil at 2 m depth map	Theoretical calculus using Kusuda, T. (1965) method
	Annual semi-amplitude at 2 m depth map	2 m deep thermal semi-amplitude values between the coldest month and the hottest one
Average temperature of subsoil maps	Average temperature of subsoil up to 50 m depth map	Theoretical subsoil average temperature values up to 50 m deep
	Average temperature of subsoil up to 100 m depth map	Theoretical subsoil average temperature values up to 100 m deep
	Average temperature of subsoil up to 150 m depth map	Theoretical subsoil average temperature values up to 150 m deep
	Average temperature of subsoil up to 200 m depth map	Theoretical subsoil average temperature values up to 200 m deep
	Temperature profile points location map	380 temperature profiles location deeper than 50 m
Geothermal potential	Geothermal potential map for closed vertical heat exchange systems	Geothermal potential qualitative values estimated from lithology. For vertical heat exchange systems where no water extraction is needed
	Geothermal potential map for open vertical heat exchange systems	Geothermal potential qualitative values estimated from aquifer exploitability range. For open vertical heat exchange systems where water extraction is needed

The information comes from manual interpolation of over 14.000 soil pits.

Thermal conductivity has been estimated from *Kersten* (1949) i *Dehner* (2007) methods which have been applied also in the Thermomap Project (Mapping area of superficial geothermic resources by soil and groundwater data).

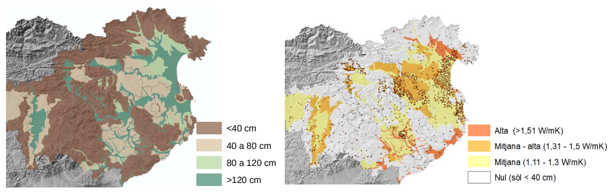

Figure 6. Soil depth and thermal conductivity distribution obtained in a pilot area of northeastern Catalonia.

b) **Hydrogeological information data set**

Includes five layers related to hydrological environment quantitative and qualitative state and potential artesian phenomena. All layers are directed to planning and feasibility studies mainly for open vertical heat exchange systems. Another layer of hydrothermal sources location is included as positive thermal anomalies indicators.

To produce these layers over 8.500 groundwater level data and over 5.000 groundwater chemical analyses have been used.

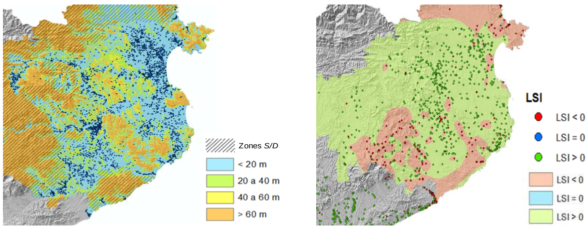

Figure 7. Depth to water (left) and Langelier Saturation Index (LSI) obtained in a pilot area of northeastern Catalonia.

c) **Subsoil thermal properties data set**

Different values for thermal conductivity, volumetric heat capacity and thermal diffusivity have been assigned to geological units from 1:50 000 ICGC geological maps depending on lithology and porosity.

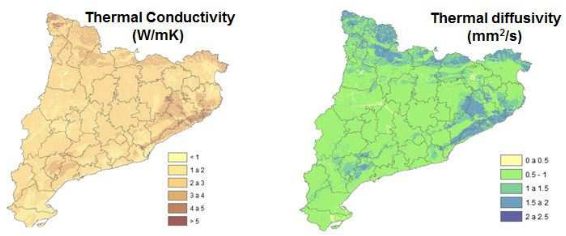

Figure 8. Thermal conductivity and thermal diffusivity assigned according to lithology and porosity.

Due to the limitation of 2D representation, more than 430 lithological columns deeper than 50 m have been incorporated. User can see a vertical distribution of geothermal parameters (Figure 9).

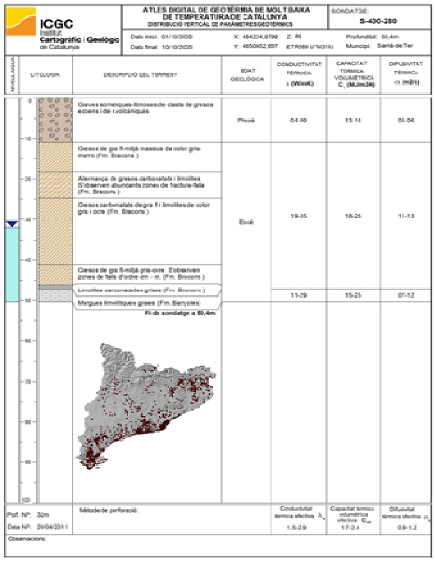

Figure 9. Example of lithological column and assigned thermal parameters according to lithology and porosity.

d) **Climatology layer set**

Includes a map set of annual average air temperature, average minimum temperature of the coldest month and average maximum temperature of the coldest month. These data are essential in dimensioning the heat exchange system.

These layers have been done by the Animal Biology Department, Vegetal Biology and Ecology Department of the Autonomous University of Barcelona (UAB) based on available climatological data. Using multiple regression techniques (Ninyerola, M., 2005) these maps take into account height, latitude, continental nature, solar radiation and regional geomorphology parameters

e) **Subsoil temperatures data set**

From the annual average air temperature data and based on Figure 9 conceptual model, expected subsoil temperature has been calculated for different depths (2, 50, 100, 150 and 200 m deep).

On the subsuperficial zone, where soil temperature depends on seasonal air temperature fluctuation, Katsuda, T. (1965) method has been used (see Figure 10).

454 temperature profiles have been compiled to show the differences between theoretical temperature estimated and reality (Figure 11).

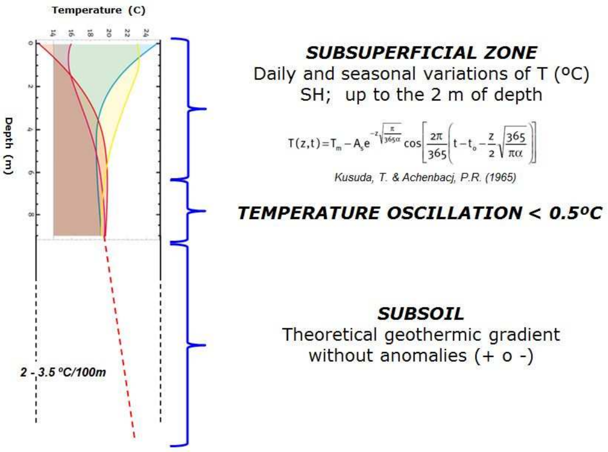

Figure 10. Conceptual model of soil and subsurface temperature distribution took into account for the estimations of temperatures at 2, 50, 100, 150 and 200 m deep.

For each profile, geothermal gradient has been calculated so the user would be able to compare the theoretical value predicted with a real temperature profile value carried out near the location of interest.

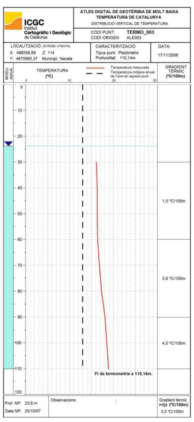

Figure 11. Temperature profile of 110 m deep and determination of the average geothermal gradient.

f) <u>**Geothermal potential layer set**</u>

There are two more layers in the GACvLT which provide the user with information of geothermal potential (in W/m) for vertical heat exchange systems.

With regard to closed systems, the estimated geothermal potential is directly related to rock lithology and the heat extraction capacity. For open loop systems, geothermal potential depends on groundwater temperature and water extraction capacity of the subsoil.

6. CONCLUSIONS

In summary and synthesis of the work, should be noted that the GACvLT ought to become a support tool for the promotion and development of the very low temperature geothermal energy in Catalonia.

On the other hand, is a project under construction so it's open to changes, improvements and innovations that could be included any time.

Finally, given the characteristics of the data that make up some of the layers, it is expected a continue performing for:

- Update the layers of variable information
- Inclusion of new data and updates the results
- Implementation of new applications through the viewer

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