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Low to Medium Temperature Geothermal Resources in the Limagne Basin (France)

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ABSTRACT

As most of the French geothermal potential inventories are more than 25 years old, an updated project has been launched in 2002, jointly funded by Ademe and BRGM, based on a geoscientific synthesis. The main goal of this geothermal compilation is focused on the low to medium temperature resources encountered in some French Tertiary basins, namely the Limagne system, surrounding the northern part of the French Massif Central. Those basins correspond to a graben system that was developed at the Oligocene time. They are filled by tertiary sediments of 2-km thick that overlain Palaeozoic basement. The maximum temperature measured in an old well, at 1500 m is about 100°C and the flow rate of the geothermal fluid is about 20 m^3/h.

The geology of several hundred of old wells was revisited in terms of potential reservoirs or non-reservoirs. The main potential reservoir corresponds to clastic rocks (sand, feldspathic sandstone, conglomerate), overlying the pre-Tertiary basement. 26 old seismic lines were also reinterpreted in order to built a 3D model of these deep-seated reservoir rocks. Those seismic lines underline a high fault system indicating that those reservoirs are fractured.

The combination of the potential reservoir location with those of the socio-economic needs of this region allows prioritising some promising zones in terms of geothermal developments.

1. INTRODUCTION

In order to promote renewable energy in France, Ademe (French Agency for Environment and Energy Management) and BRGM (French Geological Survey) launched a new research project for a geothermal appraisal of the low to medium temperature resources in France. This project was focused on sedimentary basins close to Clermont-Ferrand (Puy de Dôme) outcropping in the northern part of the French Massif Central, namely the Allier basin, the Loire Basin, the Ambert basin, which constitute the Limagne system (fig. 1). Geologically, those basins correspond to a large-scale graben system, namely the western European rift system that developed at the Oligocene time. Locally, they are NNE to NS oriented basins bounded by regional normal faults (fig. 1). They are filled by tertiary sediments of 2-km thick which overlain Palaeozoic basement. Tertiary and Quaternary volcanism occurred inside and outside the Limagne system. The target in terms of geothermal reservoirs corresponds to clastic to detritic rocks such as sand, sandstone and fluvial conglomerate. The last geothermal inventories in France were done 25 years ago, when geothermal reservoirs were still expected to consist of hot wet and permeable geological bodies. Thanks to progress in geothermal engineering, a new inventory taking into account geothermal resources of low to medium temperatures is needed. Thus, the aim of this project is (1) to compile the scientific (geology, borehole, temperature, fluid composition, …) data collected from that time, (2) carry out a whole reinterpretation of the reservoir occurrences with new tools such as sequential stratigraphy, geochemical tools or 3D modeling and (3) to cross-check the potential geothermal resources of this area with its economic needs. In this paper, we focused on the two primary objectives. The final objective is to propose new geothermal guidelines to end users in terms of geothermal projects for heating and/or cooling purposes. According to the available data, most of the work has been focused on the Limagne d'Allier basin.

2. GEOSCIENTIFIC INVENTORY

Based on published literature and previous oil field campaign (wells, seismic lines), an exhaustive scientific compilation has been done in order to gather geothermal reservoir information (lithology, temperature, flow rate, thickness, fluid composition) in a database. A part of this database has been used for building a 3D geometrical model of the deep-seated detritic geothermal reservoirs.

2.1 Geothermal Data

Within the Allier Limagne basin, the main reservoirs are distributed within the arkose sandstone formations located close to its border faults. Based on a geothermal synthesis of France done by Gable (1978), the temperature distribution at 3 different depths (500, 1000, 1500 m) shows elliptical-shaped isotherms with their main axis oriented NNE, following the basin structure (fig. 2 and fig. 3). For example at 1500 m, the maximum temperature is about 105°C between Riom and Clermont Ferrand. The geothermal gradient deduced from borehole data is about twice (60°C/km) those well known within the Paris basin. Locally inside the basin, thermal heat flux is also quite high with 120 mW/m². A geothermal borehole, namely Les Vergnes - Croix Neyrat, has been drilled and logged for temperature in the 80's in the northern part of Clermont Ferrand, the main city of this area. The temperature profile is plotted versus depth in figure 4. The maximum temperature at the bottom depth, is about 107°C at 1885 m. In this well, the geothermal gradient is not constant versus depth: 25°C/km between 0 and 1000 m, 37°C/km between 1000 and 1500 m and 46°C/km between 1500 and 1885 m.

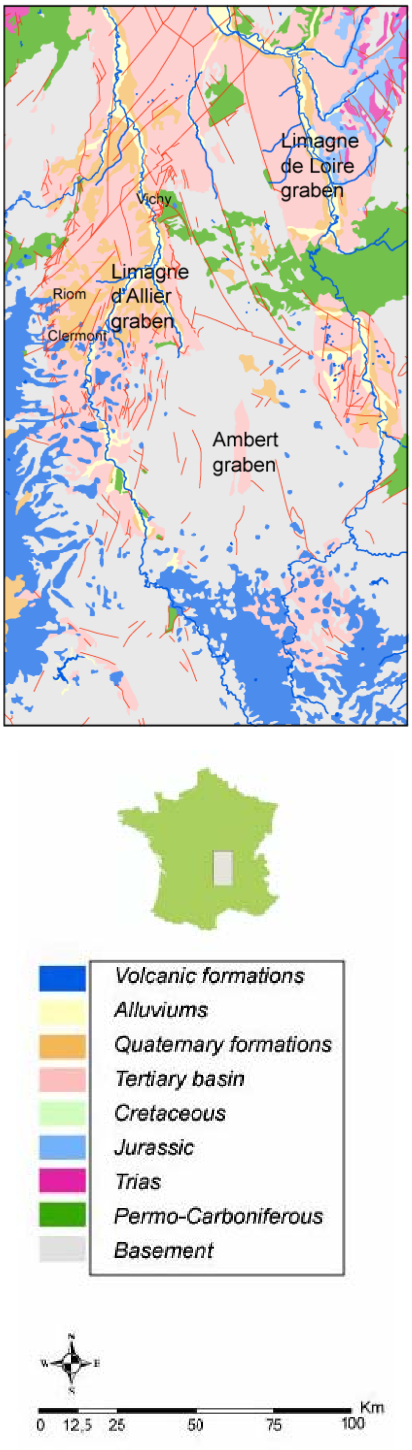


Figure 1: Geological map and fault system of the Limagne area and its surrounding with Clermont-Ferrand, being the main city. The potential geothermal basins are plotted in pink.

Preliminary measurements of thermal conductivity on representative rock samples tend to suggest that vertical heat flow in the deepest part of this borehole (below 1000m depth) would be much higher than the subsurface heat flow estimate (85 mW/m² versus 31 mW/m²). Such estimates need to be confirmed but would bring strong constraints on lateral heat transfer at depth. At about 1550 m, there are permeable detritic formations but they produced only 20 m^3/h (Geoservice, 1979). Although the temperature was rather high at 1500 m, the geothermal project was abandoned due to the lack of fluid permeability.

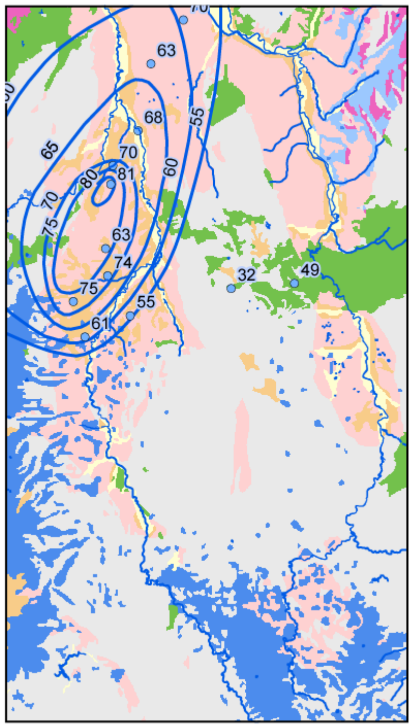


Figure 2: Temperature data in degree Celsius and isotherms at 1000-m depth within the Limagne basin. Same geological legend than in figure 1.

In the southern suburb of Clermont Ferrand, a second geothermal project was done at Beaumont (Geotherma, 1981). A deep well, inclined in the lower part was drilled down to 1335 m. The temperature at the bottom depth in the granitic basement was quite low with 45°C. The target of this well was also a detritic reservoir of Oligocene age composed of argillaceous sands and dense feldspathic sandstones. The low temperature measured in the Beaumont well as well as the null thermal gradient at depth was interpreted by the occurrence of a fractured reservoir. Due to the low temperature conditions and the low permeability of the reservoir (< 2 m^3/h), this geothermal project was also abandoned.

Nowadays, high temperatures and high permeabilities are not necessary conditions for geothermal exploitation. For example, the deep heat pump can be installed for cooling or heating application. That is the reason why this updated geothermal inventory of the Limagne system could offer potential developments in terms of geothermal projects.

2.2 Geological and geophysical data

Within the Allier basin, the geology of about 100 old wells has been reinterpreted in terms of lithofacies and sequential stratigraphy. Five different sedimentary cycles have been identified which overlain the Paleozoic basement. Each sedimentary sequence is made of 3 major sedimentological components: (1) a basal detritic unit which represent the potential geothermal reservoirs, (2) an intermediate unit made of sandy to argillaceous formations and (3) an upper unit composed of limestones or evaporitic rocks. A database with the thickness of each lithofacies has been constructed and used for the geometrical modeling.

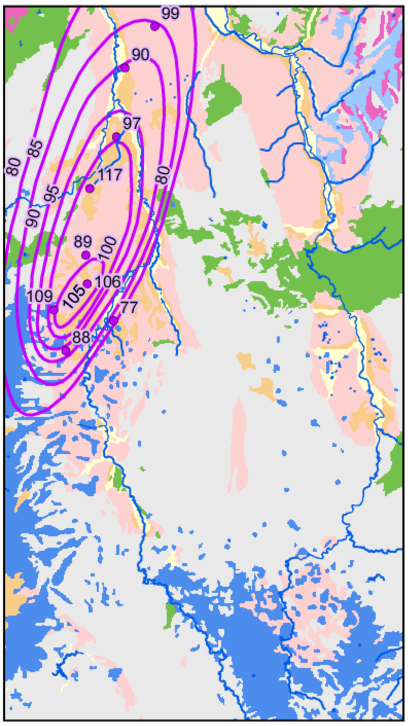


Figure 3: Temperature data in degree Celsius and isotherms at 1500-m depth within the Limagne basin. Same geological legend than in figure 1.

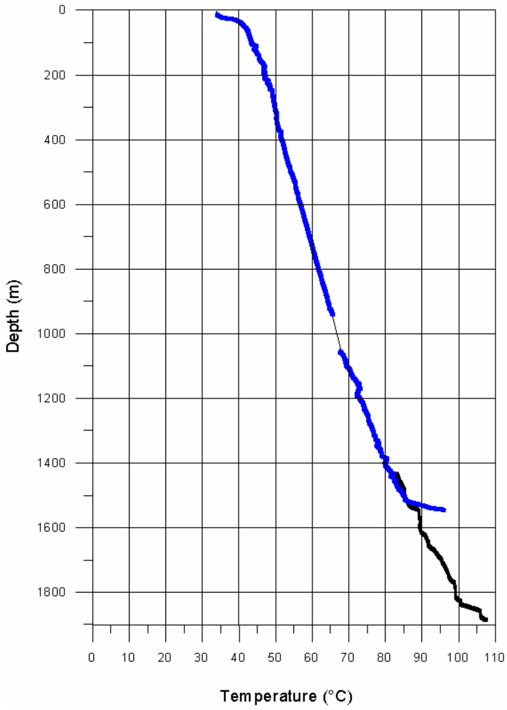


Figure 4: Temperature profiles versus depth in the former borehole Les Vergnes - Croix Neyrat. In blue, temperature between 0 and 1550 m and in black, temperature between 1440 and 1885 m.

In this area, several seismic campaigns have been done for oil and uranium exploration between 1958 and 1979. For this study, 26 old seismic profiles have been calibrated on borehole data, digitized and reprocessed through specific seismic software. A reinterpretation of these seismic lines has been performed and 3 main geological interfaces acting as seismic reflectors were mapped as well as a series of normal faults (fig. 5). The reflectors correspond to an intra Eocene interface, the top of the Eocene and the top of the Oligocene, namely Rupelian. As the top of the pre-Tertiary basement is not visible on the seismic profiles, gravimetric data were used for calculating the geometry of this lower interface that constitutes the bottom of the sedimentary basin.

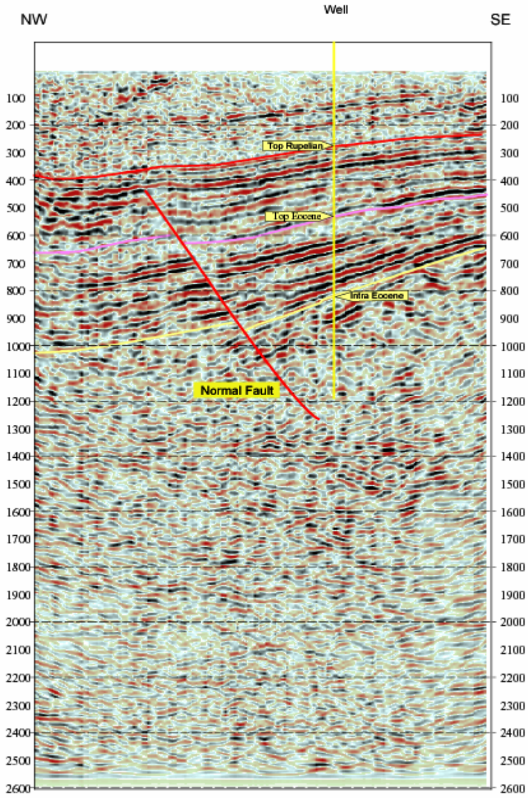


Figure 5: Example of seismic profile interpretation of the Limagne basin showing the offset of a normal fault and the 3 main geological levels. The horizontal distance on the seismic section is about 4 km.

2.3 Hydrogeology and fluid chemical composition

Hydrogeology of the Limagne is mainly controlled by the geometry of the large-scale normal faults, which induced some compartments or sub-basin inside the major graben. Due to its complex sedimentological history, lateral and vertical facies variations occur throughout the basin. Thus the basin presents mainly discontinuous deep aquifers. Sand, sandstone and conglomerate could represent the main lithology of these aquifers but their thickness variations and their distribution through the basin are difficult to forecast because they have conic shape geometry. The most promising reservoir rocks are sandstones lying at depth in the vicinity of some major western border faults acting as fluid pathways as it is evidenced by the location of the main natural thermal springs which are aligned along some major faults. For example, in the western part of the Allier basin, the thermal springs located between Vichy and Chatelguyon aligned along a NE-SW direction which correspond to the Aigueperse fault, a regional large-scale normal fault (fig. 6). Deep exploration wells drilled for geothermal energy indicated low flow rate with values ranging from 1 to 20 m^3/h. During oil exploration, porosity and permeability measurements have been done on core samples. Average porosity values within the detritic formations are about 20% and average permeability values are below 0,3 mD.

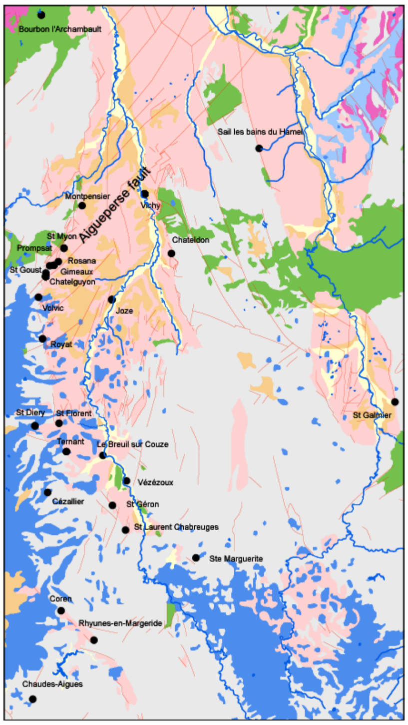


Figure 6: Location of the thermal springs inside the Limagne system and its surroundings. Same geological legend than in figure 1.

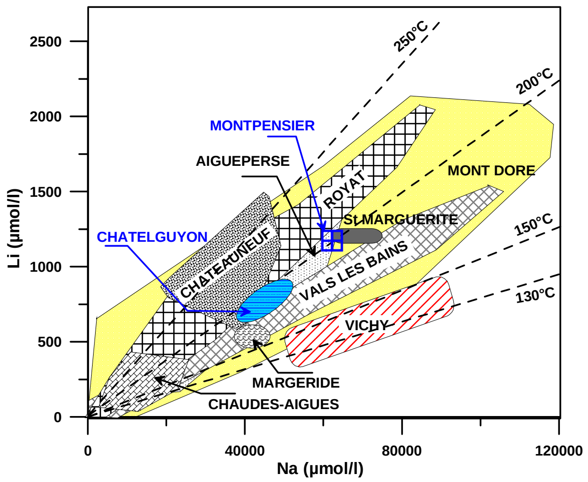


Figure 7: Lithium content versus sodium content in the thermal springs of the Limagne basin and its surrounding area. The temperatures are deduced from geothermometer calculation.

Based on published geochemical fluid composition originating from boreholes or mineral springs, a study of fluid typology helped to identify the fluid origin and the maximal temperature reached in the potential reservoir by using cationic geothermometers (Serra et al., 2003). Fluids are CO_2 rich and Na is the major dissolved cation. The maximal TDS (Total Dissolved Solids) is 10g/l on the western part of the basin. The ubiquitous presence of CO_2 in the fluid is interpreted as a crustal contribution. Calculations of the reservoir temperature based on cation geothermometers (Na, Li) gave values ranging between 170 and 200°C for the western part of the basin (Montpensier, Aigueperse, Royat, Chatelguyon) (fig. 7). For the northeastern part (Vichy), calculated temperatures are lower with about 130°C (fig. 7). For the southern part (Margeride, Chaudes Aigues), the calculated temperatures are higher than 150°C. Based on the geochemical data, fluid flow paths could be related to large-scale fluid percolations through deep crystalline or volcanic fractured rocks. After reaching 130 to 200°C, fluids migrated upward to the detritic reservoirs connected to the fault system.

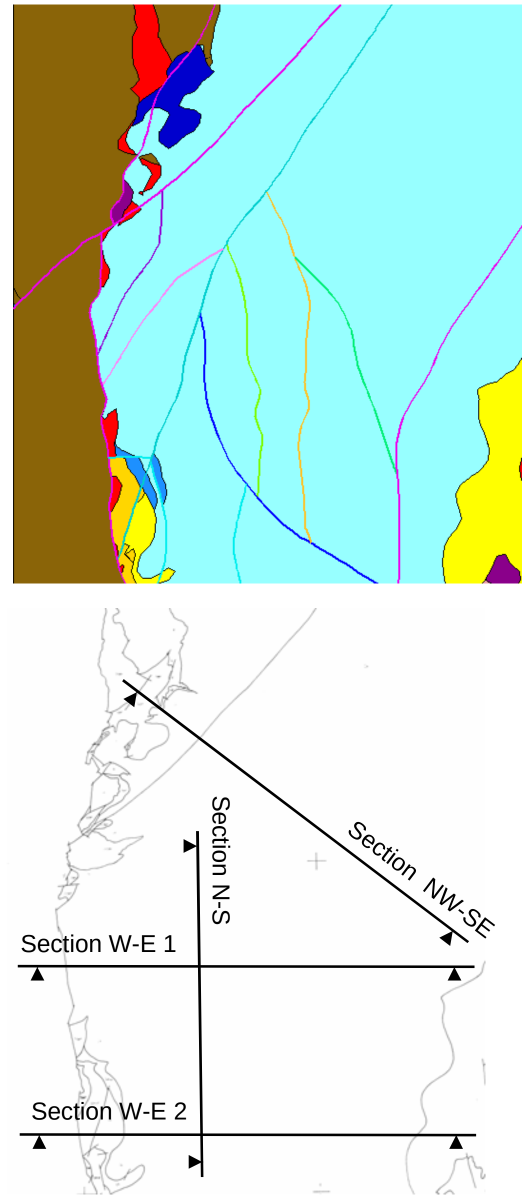


Figure 8: On the top, simplified geological map of the different sedimentary units used in the modeling procedure of the Limagne basin. The geological legend is given in figure 9. On the bottom, location of the main cross-sections done in the 3D model. The scale is 30 km on X-axis and 35 km on Y-axis.

3. GEOMETRICAL RESERVOIR MODELLING

Within the Limagne d'Allier, a 3D modeling procedure was applied on a block of 30 km on X-axis, 35 km on Y-axis and 5 km along the vertical (fig. 8 and fig. 9). This specific procedure was chosen for taking into account the conic shape of the detritic formations representing the potential reservoirs as it is illustrated schematically on the conceptual model (fig. 10). The potential detritic reservoirs correspond to the early sedimentary deposits which are transported by fluvial sedimentation within the basin. These porous sediments which result from the erosion of the paleogranitic relief, do not outcrop horizontally as limestone for instance but they show a conic shape (fig. 10). The main input data for this model are a geological map, an interpretation of the seismic lines and borehole data interpreted in terms of lithofacies as well as major fault system. Data were integrated within a home-made software, called "*Editeur Géologique*". 13 geological levels belonging to 4 sedimentological sequences were taking into account (fig. 9). They represent the top of successive reservoir and non reservoir interfaces. The resulting 3D model of the Limagne is illustrated in several cross-sections in figure 11. The deep geothermal potential reservoirs belong mainly to the basal sedimentological cycles, called sequences 1 and 2, and they are located in the deepest zones of the graben in the vicinity of the western border faults. Due to the intense fault system, a lot of compartments are isolated in the deepest parts of the basin (fig. 11). Through this geometrical modeling procedure, the volume of the detritic formations have been estimated.

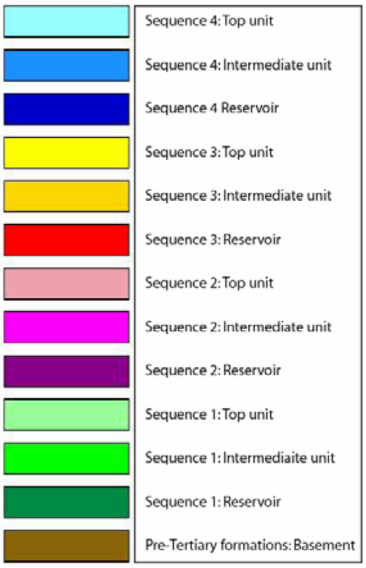


Figure 9: Legend used in the 3D model in terms of reservoir and non-reservoir.

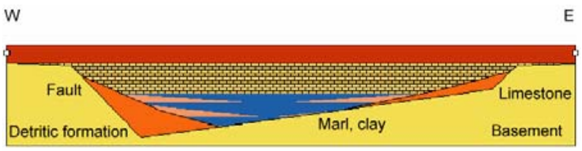
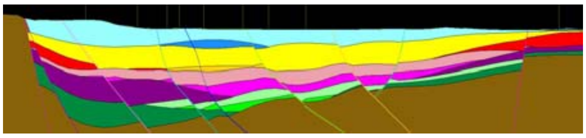


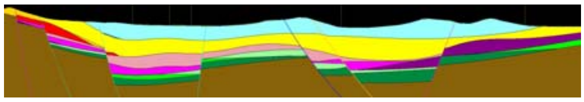
Figure 10: W-E cross section illustrating the schematic conceptual model of basin infilling during sedimentation. Notice that the deep potential detritic geothermal reservoirs (orange) have a conic shape, which follows the graben dissymmetry.

4. CONCLUSION

The Limagne basin has geothermal resources in detritic reservoirs lying at depth close to the major normal faults. Thermal springs are aligned along some major faults in the western part of the Limagne d'Allier graben. Based on old well data, temperature conditions are rather good with 100°C at 1500 m depth. However, permeability is not yet proved. Geochemical investigations on thermal fluid show that reservoir temperature varies from 130 to 200°C. A specific procedure has been defined for constructing 3D models in order to determine the volume of these reservoirs.



Section W-E n°1



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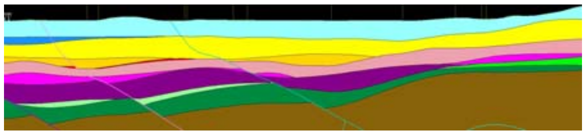

Section N-S

Section NW-SE

Figure 11: Geological cross-sections inferred from the 3D model of the Limagne d'Allier. Their location is plotted in figure 8. Detailed legend of the different geological units is presented in figure 11. Vertical scale is 5 km and horizontal scale is 22 km. The software used for building the 3D model is the *"Editeur Géologique"*.

ACKNOWLEDGEMENTS

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