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Geneva Geothermal Program - A Unique Stepwise Approach for Exploring Geothermal Energy and Firsts Success

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ABSTRACT

Since years, in Switzerland most of geothermal projects have not been successfull. Thônex well (1993) was almost dry; Basel (2006) encountered seismicity issues; Zurich-Trimmly (2012) was dry and St-Gall (2013) has encountered gas and seismicity issues. The only ones in operation are Riehen with a flow rate of 23 l/s at 65°C for district heating near Basel and Schlattingen for greenhouses heating. For the swiss population geothermal means seismicity, failure, and costly operations because most of them were drilled more than 2500 m deep and without preliminary exploration programs. In 2014, after a preliminary phase of consultation between political, technical and administrative parties the State of Geneva and the local Utility Services SIG (Services Industriels de Genève) launched the GEothermie2020 program aiming at developing in a short to medium time frame, a strategic roadmap to supply geothermal energy to the entire Canton (are of 282 Km2 and ca 482'500 inhabitants). The GEothermie2020 project, rename GEothermies in 2020, aims to develop a step-by-step approach whereby the uncertainties and risks associated with deep geothermal wells (see Basel and St. Gallen examples) will be mitigated by a careful gradual improvement of knowledge of the underground, first passing through the exploration of geothermal resources at shallow to medium depths and subsequently at greater depth. At the same time, efforts are made to work on the legal framework, treat communication and develop a local market for geothermal heat. The Geothermies program is a unique and special opportunity for the development of public and sustainable geothermal projects in Switzerland. This large project consists of three main phases, prospection, exploration and exploitation for medium deep target but also for shallow geothermal exploitation.

The prospection phase is dedicated to both preliminary and detailed investigation. A large job of collection and examination of existing data have been followed by more in depth study with new data sets acquisition and interpretation (e.g. succession of 2D campaigns since 2014, a 3D campaign in progress for 2021, gravimetry and MT acquisition, geological field work and reservoir assessment, seismicity monitoring, etc.). This phase gave us already crucial information about the structural context of the quaternary cover and the molassic basin and about preliminary medium deep targets to drill.

The exploration phase started with a first exploration well GEo-01 which has been successfully drilled in 2018 in Satigny, north-west of Geneva city. Artesian water with a natural flow rate of 50 l/s and a temperature of 34°C is produced by the well at a final depth of 744 m. This well is the most successful exploration well for swiss geothermy since many years! The reservoir is situated in the faulted lower Cretaceous units with several venues at various depth from 460 m to 670 m. The final depth was 744 m and reached the Uppermost Jurassic units. The drilling operation in the productive limestone units has been carried out with water circulation. Continuous water flow measurement and pressure test were done on surface. Because of inadequate well structure due to karstic features at 540 m, the logging program has not been performed deeper but thanks to continuous hydraulic tests on surface, we were able to localise the depth of the main water flow sources. Hydrocarbon have been encountered during the drilling phase and H_2S is present in geothermal water. The second exploration well, GEo-02, started in october 2019. Objectives attached to this second drilling were in continuity with those of GEo-01: testing a geological environment different from that of the first drilling, in this case a thrust system with reverse fault in the lower Cretaceous and Upper Jurassic limestones, reaching the Kimmeridgien reef complex at 950m. Final depth was previously planned at 1130 m but some geological surprises, and good performance of the drilling engine, convinced us to drill till 1455 m. One of the main goals of these two first medium depth wells is to improve our personal knowledge on carrying on geothermal drilling projects and to be ready to drill deeper targets. The third and fourth exploration wells are planned for 2022-2023 and will reach the Dogger at 2000 m.

1. INTRODUCTION

Geneva aims to develop the use of geothermal resources. A country with no extractive industry past like Switzerland has very little information about its subsurface. But as Geneva is surrounded by France where exploration for oil and gas resources has been done between the 60's and the 80's, it gave us some useful information for starting our prospection program. Geneva is characterized by massive use of fossil fuel for building heating, and high heating needs density, the option of using geothermal resources to reach the energy transition goals has been identified years ago (Geothermal potential of Geneva Canton (PGG), 2011). The government officially launched the GEothermie2020 program in 2013, with the aim to massively and sustainably develop geothermal resources in Geneva. The two main aspects that define the program are:

- a public led approach, where the administration (geological and energy departments mainly) pilots the implementation and the progress, and the public Utility company is in charge of financing and putting the plans into actions
- a holistic approach, where not only exploration of the geothermal resources is covered, but all aspects that will eventually result in the program's ultimate goal: regulation, environment and sustainability, cross border

cooperation, communication and public acceptance, data collection, analysis and management, market development and ultimate use of the resources.

Switzerland political system and culture is characterized by systematic use of direct democracy. As such, the public's interest in societal matters is high, and population expectations in terms of information and public debates can strongly influence policies decisions making. The GEothermie2020 program was driven from day one by these considerations, and presents an interesting example of agility, collaboration, and progressive derisking of the use of geothermal resources, to eventually grant success to the development of that resource.

In a dynamic of local wealth creation, the program initially relied on regional academic skills to compile existing data, before turning to service providers sometimes from the oil and gas world. The program continues today to rely on the know-how of these actors but also seeks to participate in the development of specific and complementary skills required in the field of geothermal energy and underground water exploration and exploitation. It is in this full context that GEo-01 has been drilled. Main results are not only on geological domain but also on all the area of work the program aim to develop (fig. 1).

2. GEOTHERMIE 2020 PROGRAM

2.1 Description

The «GEothermie 2020» program is a large transversal program launched in 2013, driven by the Geneva State authorities and Industrial Services of Geneva (SIG) which is the Public Utility company. The goal of the program is to lead to a massive and sustainable development of geothermal energy, to substitute at least 20% of fossil energy use for heating purpose. To do that, nine scopes of work were defined: Governance, legal framework, cross-border coordination, environment and sustainability, resource characterization, data management, energy planning and geothermal integration into existing districts eating, development of the sector (value chain) (Figure 1).

A part of this program is the evaluation of the deep subsurface geology across the transnational Swiss-French Greater Geneva basin but also the characterization of shallow aquifers for low enthalpy energetic system. Since its initial stages, the GEothermie 2020 program financed different academic works aiming at gathering, reinterpreting and jointly valorizing large amount of existing but heterogeneous geological knowledge and data over the Geneva basin, in order to constitute a robust and coherent dataset, harmonize the regional stratigraphic framework and establish the data model and architecture of a structured information system. Since then, this important dataset has been continuously enriched by the acquisition of new geophysical and geological data (including exploration drilling) involving both academia and local private companies, all participating to precise the geothermal potential of the Geneva basin.

Figure 1: The goal of «GEothermie 2020» program is to reach a massive and sustainable development of geothermal energy with 9 scopes of work.

2.2 Planification and strategy for scope 6 – Resource characterization

The time frame of the program is based on the progression of the different scopes of work but also on the upgrading experience of the partners, State of Geneva, public Utilities and private mandatories. The philosophy of the exploration program is to learn as much as possible by ourselves and by sharing experience. For example, the first exploration well was a shallow well done in close collaboration with a drilling water company working on daytime scheduled. It gave the possibility to all partners (inspectors of State for legacy and control purposes, mandatories like civil engineering for the platform's construction or drilling geologists, the project management staff, etc.), to follow and be really implicated, during all the process which is not the same in case of a turnkey project.

Tree main phases are planned for this topic: prospection, exploration and exploitation (Figure 2), evolving in phase with geothermal resource's characterization incremented in depth.

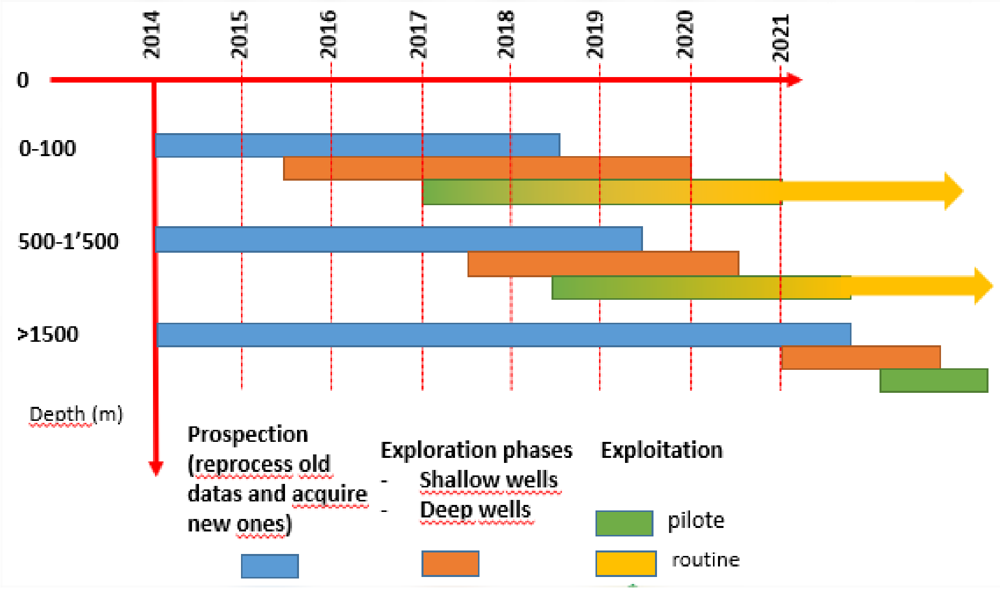

Figure 2: Program general planification

2.2.1 The prospection

The **prospection** phase is mainly the reprocessing of ancient data's and acquisition of new ones (geophysics, core data's, geological field work, hydrological monitoring, etc.). It started in 2014 and will be ended with the final 3D interpretation approximately in 2021. The rhythm of the seismic data acquisition campaigns was oriented by the evolution of the knowledge of the structural context and the need of new data to complete the model. The tick irregular quaternary cover which give various velocity parameters can lead to misunderstand or sur-interpret some of the underground structures. Some specific reprocessing phases and new dedicated seismic lines (for shallow and for deep targets), have led to a very good knowledge of the best parameters for the Quaternary and in the Mesozoic interpretation. As the urban center is not covered because of the difficulty of finding strait paths for 2D seismic lines a 3D seismic campaign is planned for summer 2020 (Figure 3). Its main goal is to fill this gap and better constraints some feature as direction of faults or coral reef complex extension.

Field works and core datas analysis from nearest wells are ongoing projects to precise the stratigraphy and structural comportment of the different geological targets (Rusillon et Chablais, 2017).

To define a circulation model of underground water, it is important to map where the possible inflow is located and where are the outflow. The sustainability of the water resource for this part of the transnational (F-CH) territory with a growing population and development is crucial. Isotopic and geochemical analysis of Thônex well demonstrates that underground water sampled on the well were 10'000 years old (Nawratil de Bono C., 2011). Does it take so long from Jura mountain to travel the 20 km distance through the basin or is the transmissivity around the well very low? In the other hand, pressure test from GEo-01 showed a daily delay response with near karstic source. To better constrain this topic, a monitoring of the aquifer of Jura foothill has started in 2017 with the installation of probes on rivers, karstic sources and wells (Figure 4). Conductivity, level and temperature are registered on sources and pressure is registered on wells. A six months monitoring test will be realized on GEo-01 well (see below Main success).

An important collaboration is done with the academic sector. University of Geneva is not only working on geological purpose, but also energy integration on District Heating and social acceptance. Concerning the subsurface investigation, a non-exhaustive list can be done: on-going seismic monitoring with the installation of 6 new permanent stations, gravimetry mapping and ERT measurements, fluids analysis, 3D model for heat storage supported by SIG and the EC funded GEOTHERMICA/HEATSTORE project, mineralogy and geochemistry, etc.

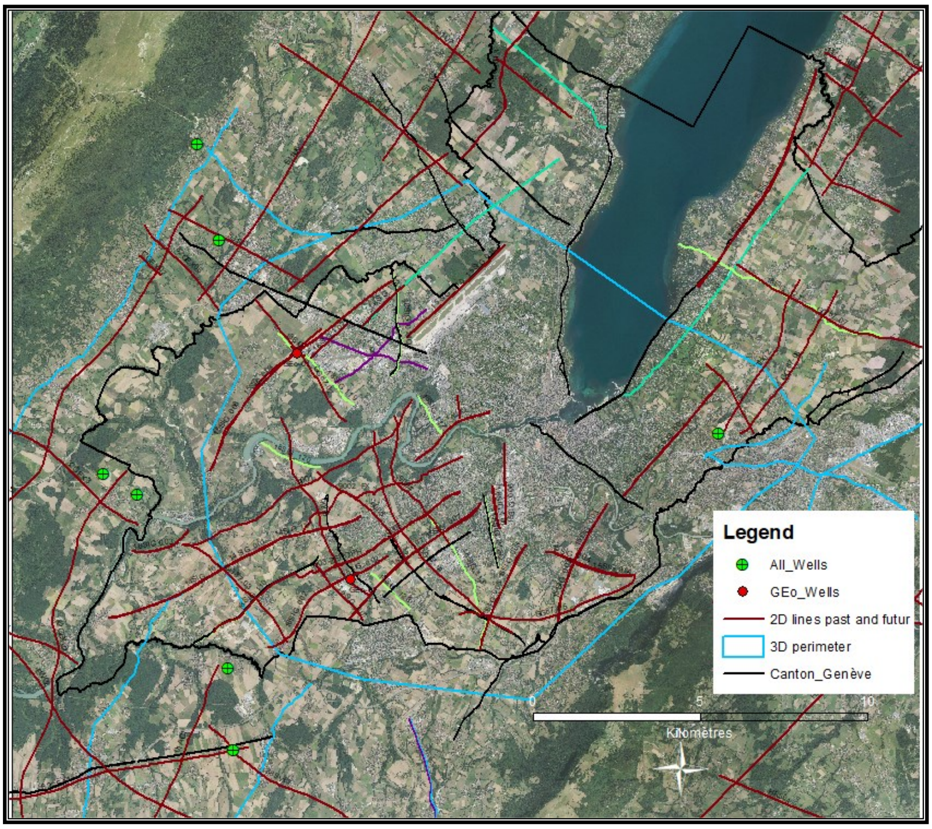

Figure 3: Map of seismic data acquisition since 1950 in Geneva area, exploration wells and 3D perimeter

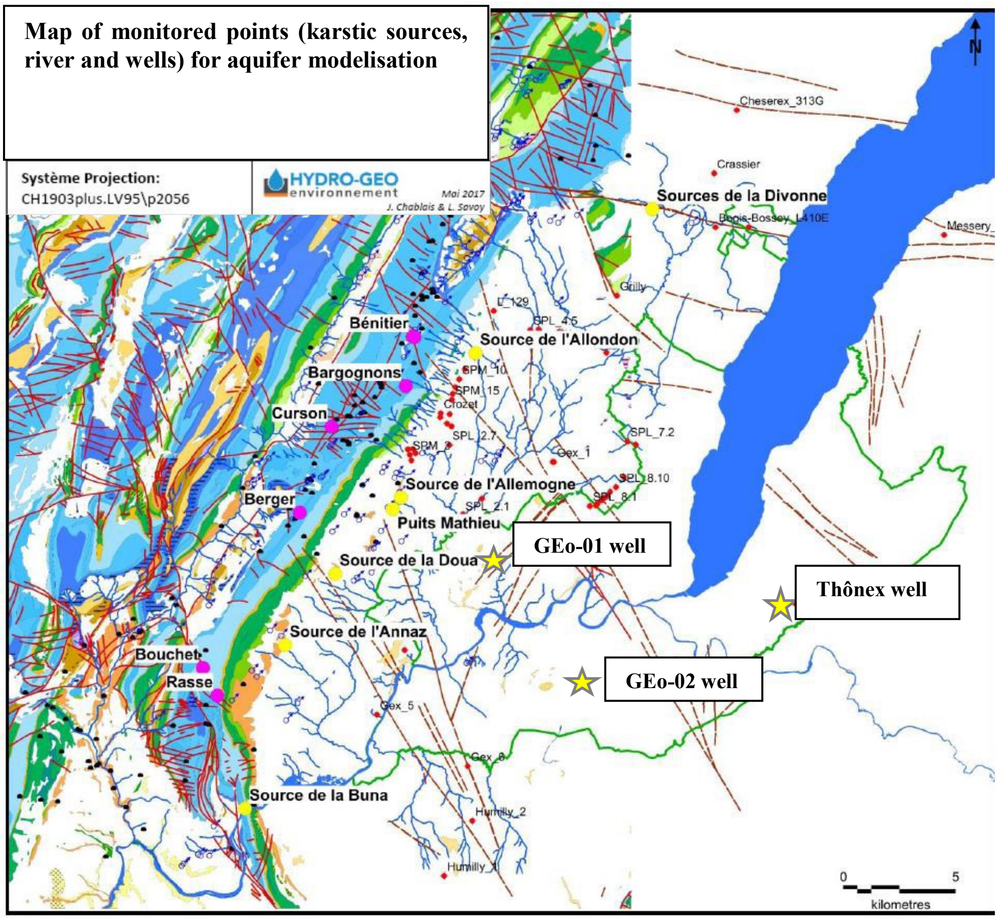

Figure 4: Map of monitored points (karstic sources, river and wells) for aquifer modelisation: pink dots for chemical tracer injection and yellow dots for monitoring

2.2.2 The exploration

The **exploration** phase means the drilling phase in shallow and deep aquifers. The first drilling campaign started with the exploration of quaternary shallow aquifers (0-100 m deep) which has resulted on major changes on the hydrological map of Geneva Canton. In parallel, the exploitation phase started with some pilot projects on shallow quaternary aquifers.

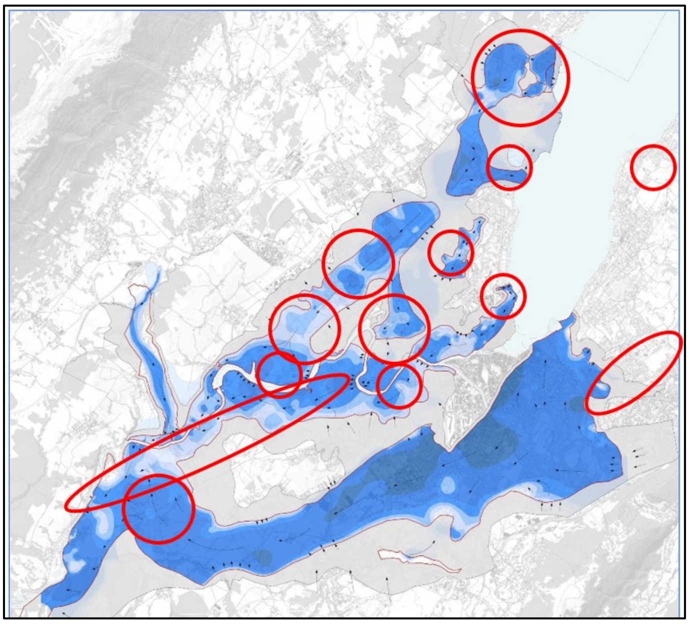

Figure 5: New hydrogeological map of shallow aquifers: main deep lenses in dark blue and dark squared blue for drinking water. Light blue represents the still present uncertainty. Red circles are exploration zones.

The strategy of the exploration phase of deeper aquifers is a step by step approach to minimize the risk. A particularity of the Geneva basin is the deepening of the Mesozoic layer toward the south-east which allow us to explore a variety of structural context with exploration wells less than 1500 m deep. Its first step was the preparation of the Exploration Permit which has been delivered on 25 august 2017. It covers a surface of 145 km2 and concern layers from the base Molasse (or top Mesozoic) until 1500 m deep. No final depth is defined yet for the next exploration permit, but the Dogger layer is a new objective.

The drilling phase started with GEo-01 well at 770 m TVD in 2017, GEo-02 at 1100 m TVD in 2019-2020, and will follow with GEo-3 and GEo-04 at 1500-2000 m TVD. The main targets are the faulted Cretaceous and Jurassic limestones to characterize their geothermal potential. We know from the Thônex geothermal well data's, an ancient exploration well drilled in 1993 at 2600 m deep, that these targeted layers could be hardly cemented and very poorly productive. This part of the Geneva canton is deeper and less fractured, a reason why and for derisking the project, we are looking for faulted and fractured zones in shallower depth (< 1500 m) (Figure 6).

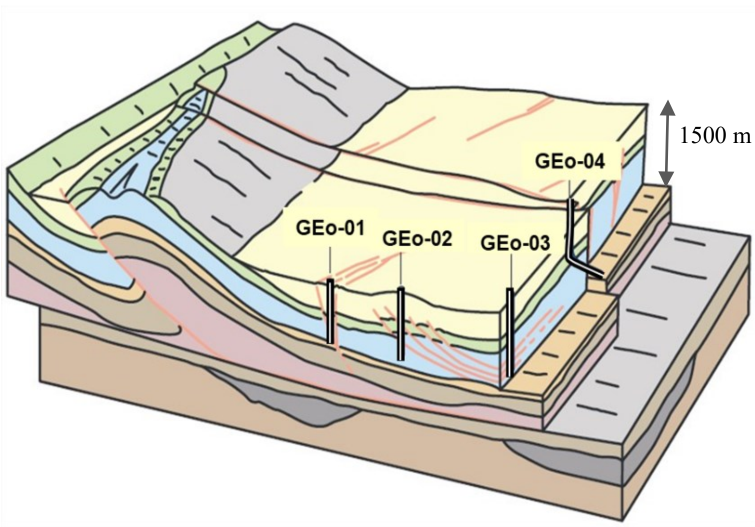

Figure 6: The deepening of the basin toward the south-east allow us to explore a variety of structural context with exploration wells less than 1500 m deep. GEo-01: cauliflower-like structure (< 1000 m); GEo-02: shallow thrust and back thrust structure (1100 m); GEo-03: exploring Dogger at 2000 m; GEo-04: Strike-slip structure (deviated well, 1500 m).

2.2.3 The exploitation

The **exploitation** phase will start when geothermal energy will be available for the existing District Heating grid and for decentralized uses, for warm as well as for cold uses (Figure 7). Some ongoing pilot projects are developed on shallow fresh aquifers. One is the Concorde project where we valorize a shallow aquifer on a temperate sub-network, connected to an existing district heating mainly fed by a waste incinerator. A broad reflection process is launched on temperature level of new network development in order to allow and optimize the integration of medium depth geothermal sources (1000 – 2500 m) with a resource temperature between 40 and 80 °C (Quiquerez et al., 2016).

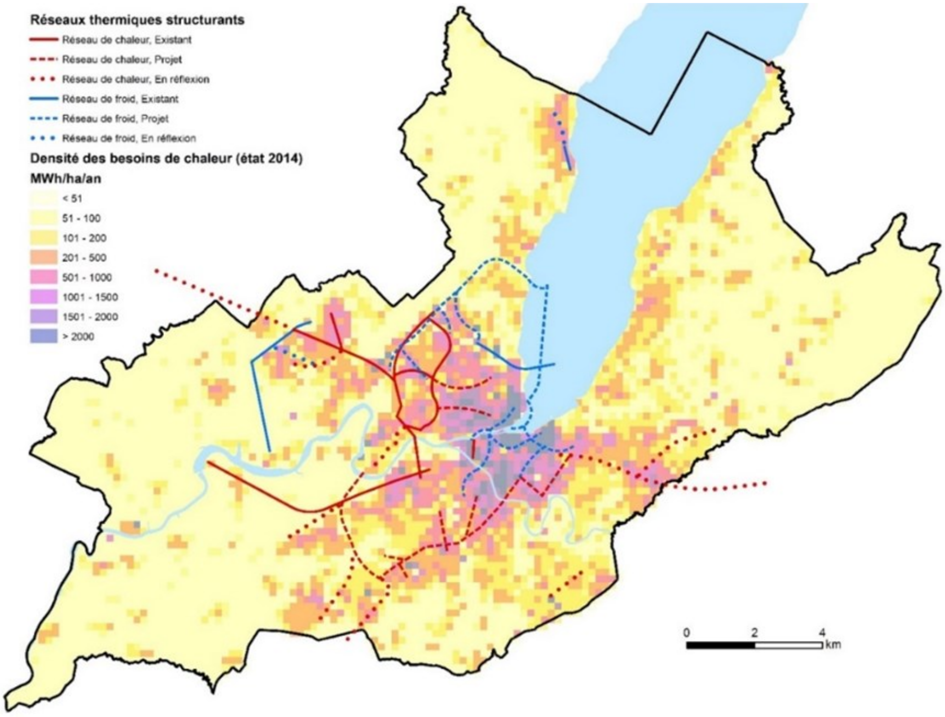

Figure 7: Map of existing and future district heating networks (source SIG)

3. GEOLOGICAL CONTEXT

The Greater Geneva area has been extensively studied over the past on various geological aspects. Some of the first integrated studies include a report on the geothermal potential of the Geneva region (PGG, 2011) delivered to the Geneva State authorities in 2011 and a regional seismic interpretation study in the frame of the European project GeoMol (Clerc, 2016). At the beginning of the program, several master or PhD thesis were launched to characterized more precisely the geothermal potential of the principal deep geothermal reservoir units. It results on many academic's studies which are not presented in this paper.

3.1 Principal Deep Geothermal Reservoir Units

The Greater Geneva Basin (GGB) consists of a thick sedimentary cover of Mesozoic age, principally composed of carbonate and marl formations, overlying a crystalline basement often incised by depressions filled with Permo-Carboniferous sediments. The top of the Mesozoic series forms an erosive and highly karstified surface, overlain by siliciclastic Tertiary Molasse sediments of Late Oligocene to Early Miocene age, thinning out toward the foothills of the Jura Mountains in the Northwest (Figure 8). The Molasse deposits are finally overlain by Quaternary sediments of principally glacial to fluvioglacial origin that locally reach important thickness. Various studies have been carried out on the principal reservoirs in the Greater Geneva Basin, highlighting typical lithologies and characteristics required for a potential reservoir rock in the area: porous sandstone, karstified limestone, reef or peri-reefal deposits, dolomitized limestone altered by dissolution, fractured limestone, brecciated zone (PGG, 2011).

The Permo-Carboniferous sediments held in half-graben could be an interesting reservoir for deep geothermal production because of its tectonic and lithological predispositions but is still poorly understood and documented (only 4 wells reached this layer within a radius of 100 kilometers). The overlying sandstone from the Buntsandstein formation was described as an aquifer in 3 wells, with good matrix and fracture porosity. But estimated permeability remains apparently low (flow rate $\leq$ 2 l/s; hydraulic conductivity$\approx$7.7*10-6 m/s) to be interesting for geothermal exploitation. For Triassic, only the upper part of the Muschelkalk indicates porosity higher than 5%, but permeability seems low except when the rock is fractured or karstified as observed in the northern part of Switzerland where geothermal heat is already used.

Bioclastic and oolithic limestones from the Dogger are potentially porous facies. In the Paris basin, the main oolithic intervals in the Dogger have been used for geothermal heat production for more than 40 years. However, several tests conducted in the same formation in the Jura Mountains revealed important lateral and thickness variations as well as changing fracture and permeability patterns. These heterogeneities could limit the potential of this reservoir.

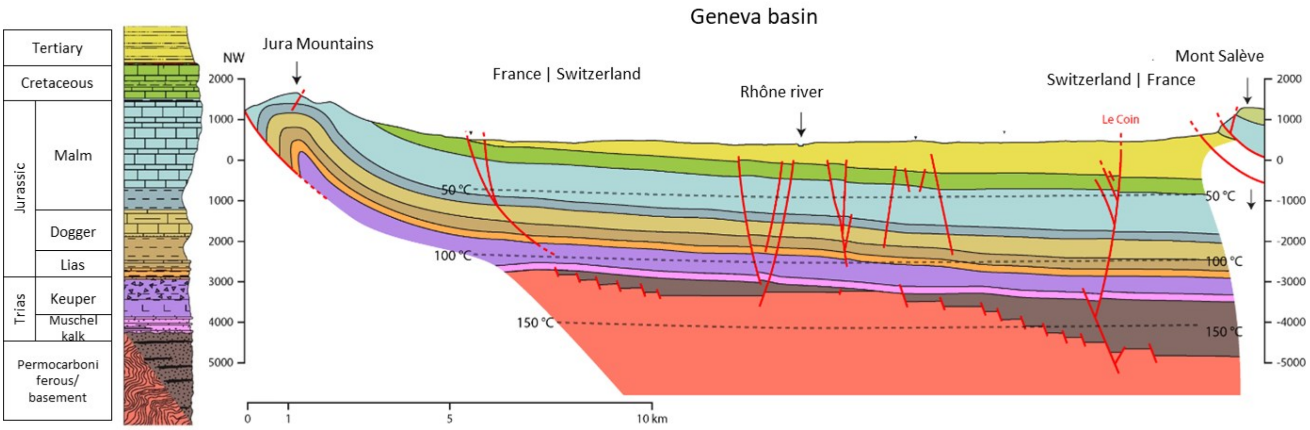

Figure 8: Synthetic stratigraphic log and geological cross-section across the Greater Geneva Basin (modified after PGG report, 2011)

Thick Malm limestones of the Middle Oxfordian, Kimmeridgian and Tithonian represent the main aquifer of the Mesozoic sequence in terms of volumes. This is also the main Bavarian Basin aquifer, which has produced geothermal energy for several years. In the Jura Mountains, this interval constitutes the crest of the internal folds which facilitates aquifer recharge. As for the Dogger aquifer, facies and thickness variability is high in the Malm. The coral reef environment is associated with better reservoir properties and its distribution is still under investigation (Rusillon, 2018). From seismic interpretations and field data, evidences are reported that the whole Malm interval could be highly fractured and karstified which was confirmed by mud loss in the Kimmeridgian interval of the well Humilly-2. However, in Thônex-1 well, disappointing flow rate was encountered in the Malm and revealed that the geothermal reservoir could display important porosity but low permeability and poorly connected fractured zones (Jenny et al. 1995).

The entire Early Cretaceous interval is considered as a regional aquifer except in its Hauterivian marls. The “Calcaires urgoniens” Formation, which forms the top of the Mesozoic sequence, is the shallowest reservoir, but it could reach interesting temperatures where covered by thick Molasse and Quaternary deposits. The “Calcaires urgoniens” Formation is already exploited for thermal baths (Divonne-les-Bains) with several sources of relatively high flow rates. It is intensely karstified, but the well Thônex-1 revealed that main open fractures and karsts are plugged with “Sidérolithique” sandstone causing low permeability. New data’s from GEo-01 exploration well confirmed the high potential of Cretaceous fractured limestones. The total artesian flow rate of 50 l/s has been encountered through the entire section between 420 m to 750 m, mainly through karstic pipes and a main fault.

3.2 Tectonic and Structural settings of the Basin

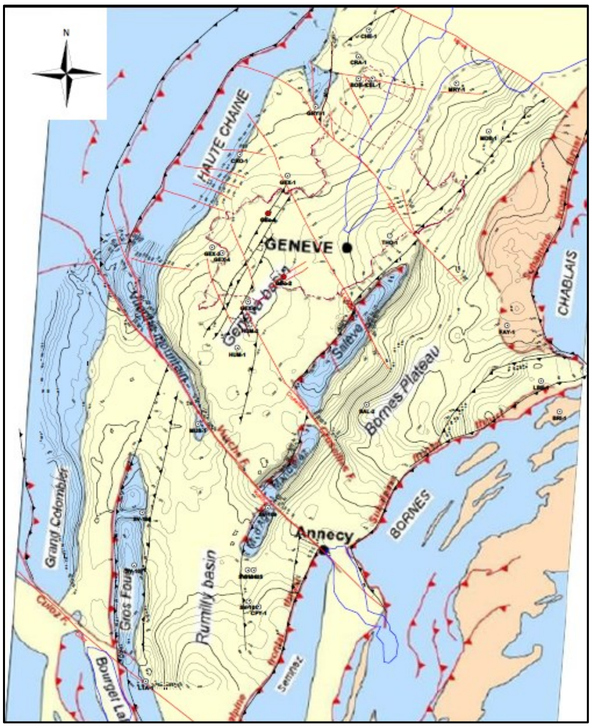

Figure 9: Structural context of the Western end of the Molassic Basin with Geneva at center. Strike-slip faults and thrusts are the main tectonic components which affect the Mesozoic cover.

The Greater Geneva Basin is geographically encompassed between the internal reliefs of the Jura arc Mountains in the Northwest and the front of the Alpine thrusts at the Southeast of the Bornes Plateau (Figure 9**Error! Reference source not found.**). Numerous studies have been done before and during GeoMol project, and recent studies based on new acquisitions and reprocessing proposed a more precise tectonic context. The Geneva Basin is not only affected by strike-like faults but also by complex thrust systems rooted in different layers (Clerc, 2016). A particularity of the Geneva basin is the deepening of Mesozoic layers from Jura to Saleve mountain in a short distance, less than 20 km. Which means that the local structural context can be explored at various depth through exploration wells (see previous Figure 6 and Figure 8).

4. MAIN SUCCESS

The very first exploration well of the GEothermie 2020 program - GEo-01 - was drilled in 2017-2018 and planned to intersect a cauliflower-like structure in the Cretaceous limestones at 650 m (Figure 10). A fault zone has been reached at 600 mMD and total depth was lastly at 750 m TVD. A total of 50 l/s artesian flow is produced through various karstic pipes and fractures. The well has been drilled with a Massenza rig MI60, 44 tons in three sections, two cased sections and an open hole

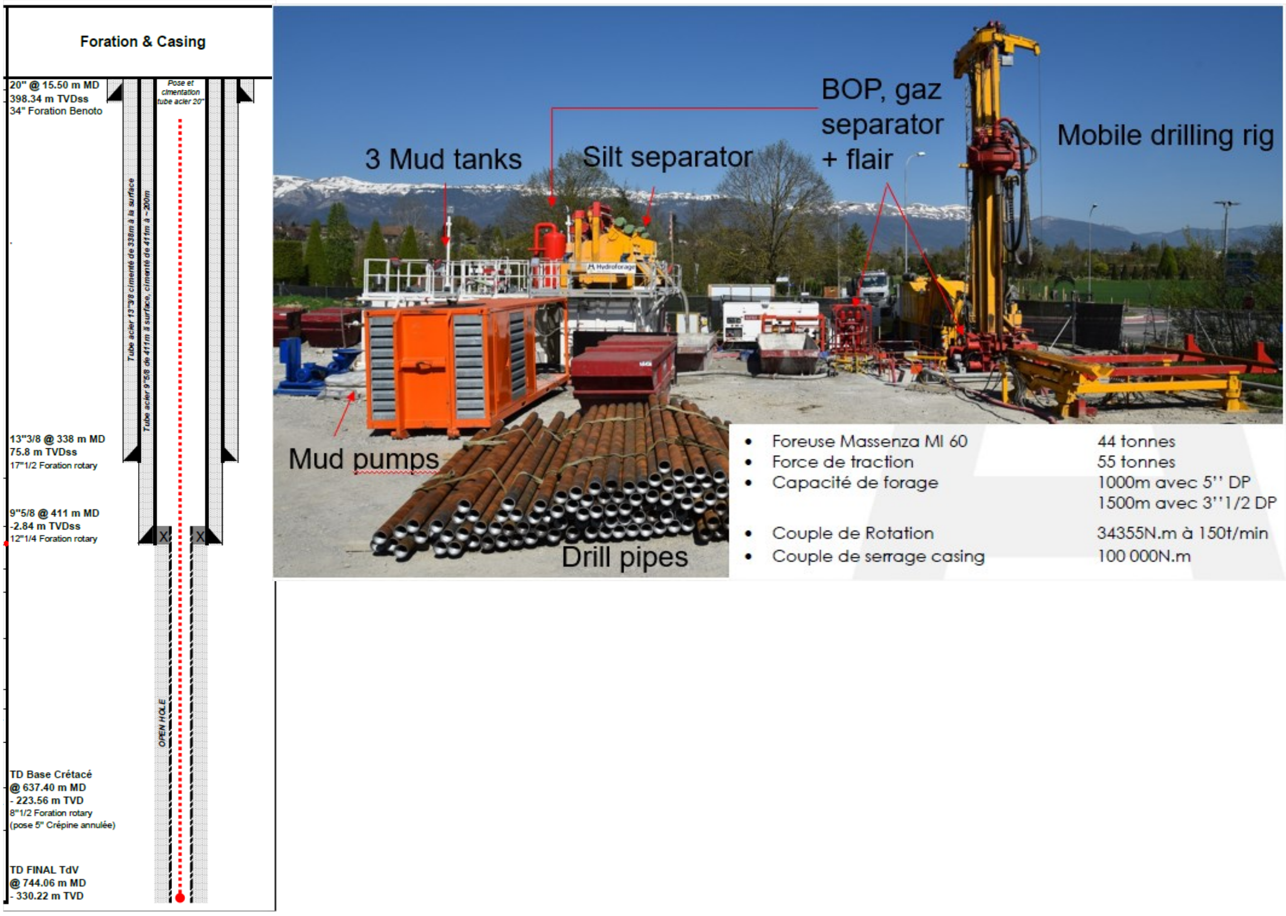

Figure 10 : Rig installation, foration and casing data's

4.1 Success of a non-conventional drilling strategy

The philosophy of the exploration program is to learn as much as possible by ourselves and by sharing experience. For example, the first exploration well was a shallow well done in close collaboration with a drilling water company working on daytime scheduled with a small rig. As we are looking for natural karstic water on a shallow medium fractured limestone, we decided to drill underbalanced with water to avoid aquifer pollution with bentonitic mud once the reservoir entered. But, as the first section was in the molassic layer where natural gas pockets could be trapped, we equipped the rig with a classical annular BOP and flare tools. This section was drilled with benthonic mud.

Once this first section was drilled and the limestone reservoir entered, we adapted the procedures and surface equipment to be able to manage high water flow. Large pumps and connection into the wastewater pipe were needed. The fine lithologic knowledge of the cretaceous section based on previous core and cuttings studies, and fine seismic interpretation (Figure 11) were used to precise the probability to enter the identified fault and fractured zones and predict the possible flow raise.

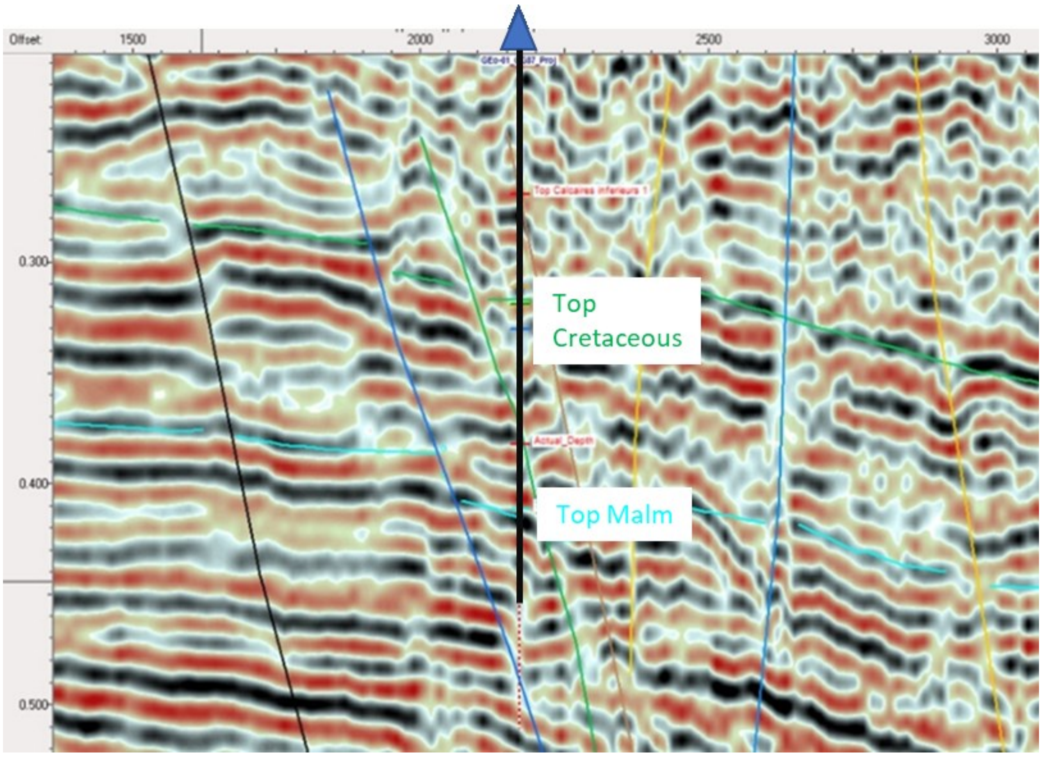

Figure 11: Interpreted seismic line, faults pattern and well position

During the drilling operation, each observed water venue was monitored. In order to be authorized to evacuate this water on the public wastewater pipe, the foration was stopped and specific tests like pressure test, flow rate, temperature and chemical analysis were done. It gave us a very fine water venues model and hydrological behavior of the aquifer. The contribution of each venue has been evaluated as figured on figure 13. Water came from localized karstic pipes or fractures. An unexpected total flow rate of 50 l/s and a final temperature of 34°C were obtained (Figure 12 et Figure 13).

Figure 12: Artesian water flow from GEo-01 at 34°C and 50 l/s

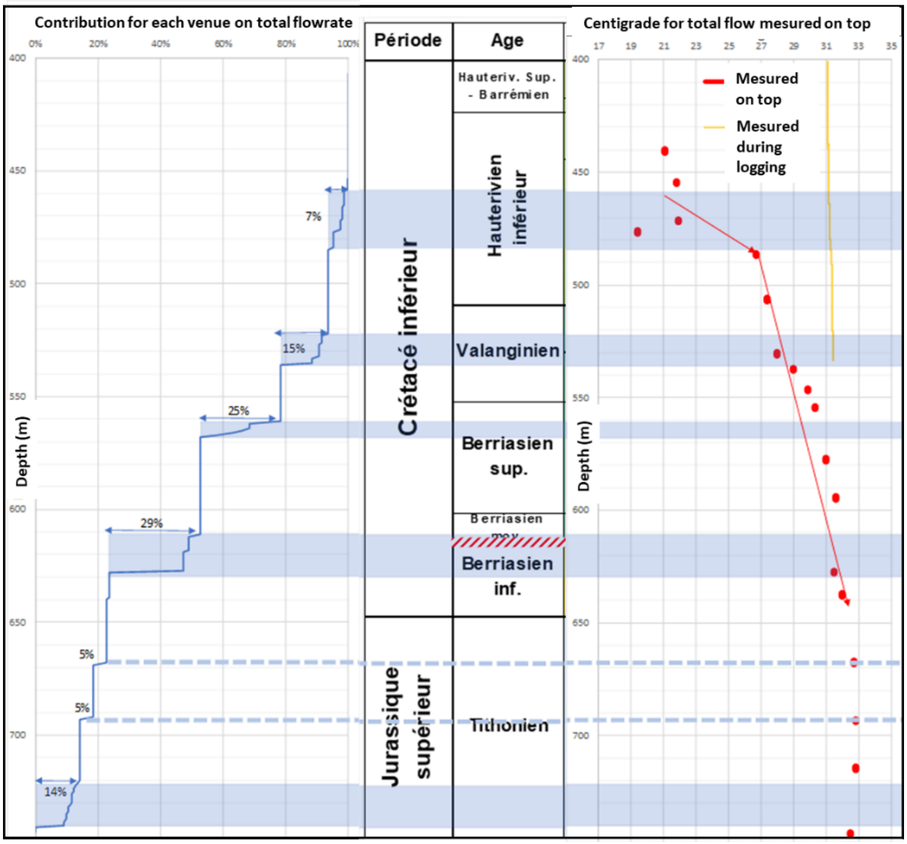

Figure 13 : Evolution through depth of the water venues contribution (%) on total flow and temperature mesured on top (°C)

4.2 Logging operation – problem and solution

We learned that logging compagnies were not used to do acquisition through high artesian flow, and some majors refused to work under this condition. We developed a reduction flow piece for the unique logging operator presents. Unfortunately, the open hole section was blocked by a piece of rock from an adjacent karstic pipe. Neither the logging tools were able to go below 535 m TDV nor the flowrate tool could operate because of this large flow rate. But thanks to the continuous water monitoring on surface, we are still able to know where are located the main venues and the more interesting stratigraphic layers (Figure 13). To understand the reason why tools were stopped, a camera logging has been done. It shows some interesting view of the intense karstified limestone and falling blocks (Figure 14). In these conditions, fluid tests underpacker seem difficult to perform.

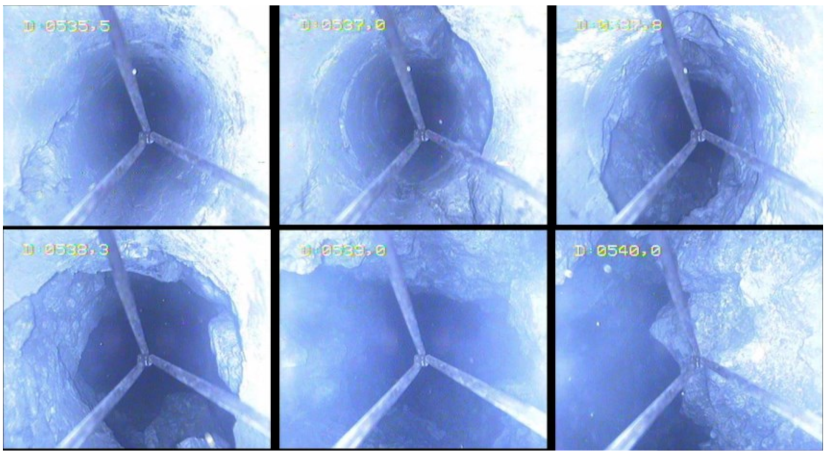

Figure 14 : Camera view of the intensively karstified zone, 540 m TDV.

4.3 Next step

The second well is planned for end of 2019 and 2020 and will reached 1130 m TDV. One of the goals of this second well is to reach the so called "reef complex" in the Upper Malm which should be a quite good porous layer as measured on core and outcrops. The structural context is a shallow thrust with a back-fault thrust. We also want to test the limited depth of this "small rig" for future urban projects.

Thanks to the fine reprocessing work done by our mandatory, a map of numerous fractured targets at various depth has been established along seismic lines (Figure 15). In order to increase the choice of target in urban area, we planned a 3D acquisition seismic campaign to have more precise targets and on a random repartition. This campaign will start during summer 2021.

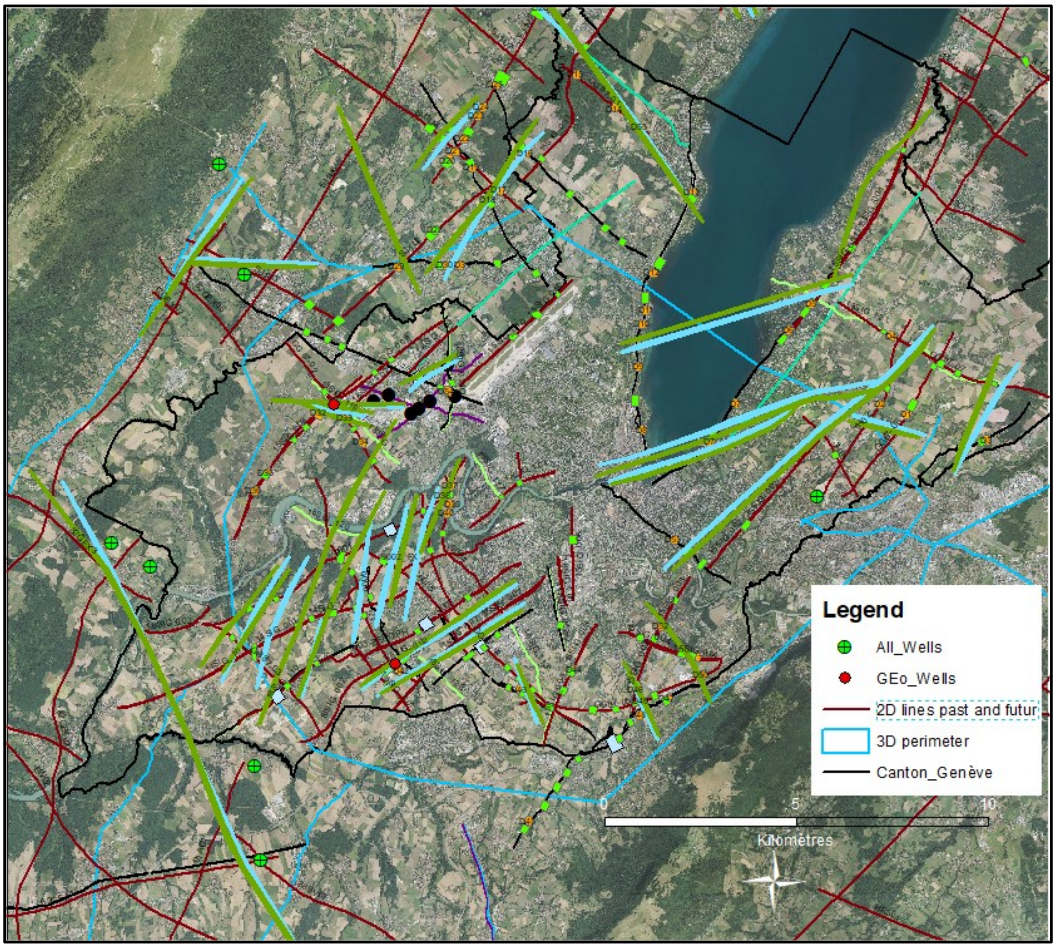

Figure 15: Portfolio of targets based on 2D seismic lines for Geneva geothermal exploration program. Will be improved with 3D seismic acquisition datas.

5. CONCLUSIONS

The GEothermie 2020 program - Scope 6 Resource Characterization - is based on a step-by-step, integrated approach that maximizes all possible prospective and exploratory methods and which is based on return of experience. This approach has been successful beyond expectations with the first GEo-01 exploration well. The challenge of making the right choice of exploration targets is high. It seems that the potential reservoirs of a part of the concerned basin, in this case the deepest zone, is affected by a significant diagenetic cementation, which explains today the low productivity of the Thônex well drilled in the 90's. Even if we presume that some geological environments are quite porous and permeable, it is therefore important to target naturally fractured environments in order to improve the chances of high flow rates.

Since the existing district heating network is mainly based on superheated water (120-80 ° C), it is important to consider the integration of water at medium temperature, with heat pump for example, and at the same time to work to reduce network temperatures and to think about the construction of lower temperature sub-networks in the perimeters that allow it. It is necessary to have a good match between the resource and the surface needs in order to give the best chance to the first projects, and not necessary try to develop immediately the deeper targets that may be riskier and expensive. For instance, it turns out that in low-density urban areas, the power of a doublet, even shallow as GEo-01, may be too high to be competitive and we've to focus on the high density of energy needs zones if we want to really get a relevant decrease in CO_2 emissions. It means that we have to make the prospective and exploration actions enter into the city, which is a considerable challenge, with the next development of 3D seismic acquisitions and drilling operations in dense urban areas.

The strategy put in place must reflect the role that medium enthalpy geothermal energy can play, the future urban development but also the stakes on existing buildings, the geological uncertainties, the limits of exploration and the economic considerations. Thanks to an ambition of sustainable development for the Geneva region, and a joint action plan, the State of Geneva and the public Utility are working together to reach this important challenge.

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