Multiscale workflow and methodology for the assessment of geothermal potential

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ABSTRACT

This paper presents an integrated, multi-disciplinary workflow for the assessment of a region's geothermal energy potential, evaluated from basin to reservoir scale through the generation of 3D reservoir and dynamic simulation models, applied as a case study to an abandoned Oil and Gas (O&G) field in Italy (Malossa field). Through the application of this workflow, a hypothetical Doublet system is simulated to be capable of generating 3.2 MW of electricity (P50) related to 1200 m$^3$/day of extracted fluid; similar values to the outputs of plants already operating in Europe and Africa (Soultz-sous-Forêts and Olkaria).

GEPlan Consulting and ALS Oil and Gas developed this workflow to assess, simulate and de-risk prospective geothermal projects. Advancing on principles and experience gained through hydrocarbon exploration, the multidisciplinary team evaluates deep geothermal potential using forefront core analysis technologies and modelling software to evaluate the subsurface potential for generating economically exploitable geothermal resources.

Existing subsurface datasets including 2D and 3D seismic data, well logs, petrophysical and geomechanical data, were incorporated in order to generate a 3D conceptual model to be used as input for the static and dynamic model of the reservoir. By using the available composite logs and the public literature, it was possible to identify the reservoir interval. The main data used included; the bottom hole temperatures (BHT), production test of some wells at certain depths, pressure at different depths, heat flow, burial history, mineralization, and salinity of the frost present in the surface. Ultimately, data were integrated and included into a 3D structural and stratigraphic model of the reservoir by using the Petrel\textsuperscript{TM} software. The static model was used to run hypothetical models simulations. Ultimately, the most effective system was simulated by the TNO Doublet Calculator software, concluding that a Doublet system was optimal for the field.
1. Introduction

Considering that geothermal subsurface characterization involves geological and geophysical investigation techniques already studied in hydrocarbon exploration, GEPlan Consulting and ALS Oil and Gas sought to further develop on the services and expertise of two Oil and Gas industry companies to generate a reservoir geothermal assessment workflow. The principals of this workflow are demonstrated through a case study on the Malossa field, Italy.

The objectives of the workflow are:
1. Collect quality-data from O&G legacy projects.
2. Perform a multiscale regional study.
3. Generate a 3D static model to be used for the geothermal model simulation.

The Malossa was a hydrocarbon field exploited throughout the second half of the 20th century. By using the workflow described in this paper we focused on studying the legacy data for the identification of an ultra-deep aquifer, and generated a geological model used for evaluating the geothermal capacity.

The work is performed by a multidisciplinary team of structural geologists, petrographers and geophysicists. Through the generation of structural and fluid flow extraction models, it is simulated that applying a Doublet system in the Malossa field could generate levels of power comparable with plants already in operation in Europe and Africa.

2. Workflow

The workflow covers all technical activities concerning data processing and elaboration with a broader view on geothermal project management. It requires continuous interaction with the operator and involves constant support for the development plan and feasibility assessment.

The primary step comprises the collection of information from public literature and integration with the team’s regional experience. A more in-depth study of the surface and subsurface is undertaken by studying geothermal surface expressions in the region and viewing neighboring oil wells and surface data.

Advanced laboratory analytical techniques can then be applied to existing archive core to profile the heterogeneity of reservoirs’ properties and enhance the reservoir characterisation.

Integrating the datasets generated through these approaches into modern software packages, three-dimensional models are built to analyses the site in high detail and a through a range of scales.

The workflow can thus be divided into four main steps; preliminary evaluation, advanced evaluation, geothermal simulation, and field appraisal (Figure 1).
2.1 Preliminary Assessment and Feasibility

This initial approach sets both to identify the exploration area, and understand the real possibilities of exploiting the aquifer. In this phase the collection of public data and available literature allows for a preliminary screening to be performed by looking into properties including the geothermal gradient, the regional geological setting, the rock thermal conductivity, regional heat flow and the production test. Existing down well and core analysis data can be used to model the stratigraphic and petrophysical properties. The data can be refined; heat flow, density and gravimetry maps can be revised, geological maps updated, flow properties and mineralogical alterations can be investigated. Through this Preliminary Assessment, the presence of a geothermal tank can be determined and a strategy for the Advanced Evaluation, created.

2.2 Advanced Evaluation

The Advanced Evaluation builds on the subsurface potential identified in the previous step by enhancing the datasets through direct analysis on archive samples using modern analytical techniques, and modelling of the data with modern software. This stage harnesses the expertise of a multi-disciplinary team, and is subdivided by relation to scale, into Core Analysis and the Regional Context.

2.2.1. Core analysis

The importance of including core analysis on rock cores acquired from the reservoir lies in more accurate and representative data. This impact in the study of the quality of the reservoir and their ability to produce the expected volume of warm geothermal brine. Thus, great emphasis should be place on investigating and understanding the relationships between reservoir sandstone, porosity, permeability, petrography, diagenetic processes and alterations related to variable sediment sources, basin entry points, depositional systems and climate, burial and thermal history. (Weibel, R., 2020). The other key factor is the nature of fractures within a reservoir; porosity and permeability are key, fundamental properties that need to be well understood.
Through investment in forefront technologies, we are able to generate continuous profiles into a core’s heterogeneity at the micro scale, using non-destructive analytical techniques. Specialist development of Dual energy CT scanning, hyperspectral mineral mapping and integration with permeability and rock hardness profiles allows a spatial distribution of fractures, minerals, cements and fine laminations to be mapped, unlocking a greater level of detail and formulating more advanced reservoir characterisation than has previously been possible.

These methods enhance the understanding of reservoirs heterogeneities and allow the subsampling strategy to be designed for further geomechanics, mineralogy, and fluid interaction test. The mineralogical study can be very useful for identifying possible alterations of minerals due to the high temperature and therefore confirming the geothermal gradient or understanding the chemistry of the gases present. All this can take place through the study of hyperspectral images. Further analyzes can be made for the study of fluids to calculate the different chemical characteristics, but also for the study of image log for a more complete identification of the stratigraphic sequence and the fractures present. This result can be useful even if there was a re-injection to calculate the variable chemical conditions of the fluid so as not to damage the stressed aquifer.

2.2.2. Regional context

The Regional Context is performed to integrate and upscale the precise data generated from the core analysis, into an understanding of the setting on a large scale. Advancing on the Preliminary Assessment, the main study involves interpretation of seismic sections for the geological structure of the surface, the study of the logs for a more complete stratigraphic sequence identification, sections obtained from the magnetotelluric (MT) study, using the resistivity of the surface and the anomalies of consequences due to the presence of a geothermal reservoir. The study on a regional or basin scale must be carried out to understand the structure of both the major fractures and the succession of the layers, as layer seals can be identified which increase the pressure in the reservoir or block the fluid below a certain altitude.

2.3 Reservoir modelling and geothermal simulation

The stratigraphic and structural data collected and interpreted in the previous phases at different scales are integrated and summarised into a comprehensive conceptual model that will be used as input for the generation of the static model of the reservoir and finally for the geothermal simulation. The reservoir static model is built in a Petrel™ environment. The aim is to understand the relationship between the selected stratigraphic interval for geothermal /target level) with major faults and fractures system, ultimately assessing whether there are favourable geological conditions to develop a geothermal field.

2.4 Field appraisal and model update

This step offers the customer technical and scientific support during the drilling and setting up of the plant, therefore after assuming the presence of a geothermal reservoir. The objective of this phase is to continue in collaborating with the client even after having identified the potential for exploitation of the geothermal source with very few risks. This includes the technical support while drilling where data can be collected and used to update the model. We offer the possibility to analyze, store and transport the cores to the laboratory for analysis and sample storage.
3 Case study

The Malossa field is one of the most important HC fields in Italy. It was discovered and exploited by AGIP (ENI) in the 1970s - 1990s. A total of 26,800,000 MSCF of gas and 4,770,500 BBL of condensate were extracted. The field was abandoned due to overpressure issues. Thanks to the composite logs and papers of Mattavelli & Margarucci (1992), Errico et al., (1980), Vaghi et al. (1980) we used this existing field to validate our workflow. At regional scale, the team explored the regional geological setting of the Alps front and constricted foredeep in the subsurface looking for a potential structure which was finally identified in a structural high characterized by a carbonate sequence, in the Malossa structured. By integrating the data, it was possible to identify a suitable reservoir interval characterized by a carbonate succession(2.1 Assessment and feasibility step). The data used in this initial phase were: the bottom hole temperatures (BHT), the production test of some wells at certain depths, the pressure at different depths, the heat flow, the burial history, and the mineralization and salinity of the frost present in the surface. The reservoir is located at about 5000 meters. The data confirmed the presence of a good flow in proximity of the Malossa 2 well, of 943 m$^3$/day at about 15000 psi pressure. The temperature was observed as 175 °C at the same depths. In the advanced evaluation phase, we managed to derive the resistivity and permeability data of the carbonate levels by using the Archie equation (1942) and the Darcy equation (CPH). Advanced core analysis was not performed in this particular case study as the objective was to demonstrate the effectiveness of the workflow and verify the feasibility of the presence of the aquifer and the extraction of the fluid with data already available. The results from the interpretation of the data were integrated into a 3D structural and stratigraphic model of the reservoir by using the Petrel™ software. The static model was used to run hypothetical models simulations. One of the models was generated with the TNO Doublet Calculator software which allowed us to hypothesize a geothermal doublet system capable of generating 3.2 MW of electricity (P50) related to 1200 m$^3$/day of extracted fluid; similar values to the outputs of plants already operating in Europe and Africa (Soultz-sous-Forêts and Olkaria).
Figure 1: Pump volume flow results by Doublet Calculator

Figure 2: Geothermal power results by Doublet Calculator
Figure 3: 3D model of the subsurface in Malossa area, with porosity values.

Figure 4: Conceptual model of the geothermal doublet system.
4 Conclusions

The increase interest for geothermal energy opens new opportunities for exchanging knowledge in different disciplines. The oil and gas expertise and infrastructure play a key role in geothermal studies. The case study and approach presented in this paper is evidence of this.

The four part approach to the developed workflow allows assessment of regions potential and built in stages, from general to detailed, micro and macro. The flow begins with the use of existing available data, then moves on to a more in-depth study once the area with highest feasibility has been identified. This is the phase with the greatest interest, divided into two steps, since it is necessary to use highly performing laboratory equipment (CT scan, and different profiling tools) and special software useful for underground research such as Petrel from Schlumberger, which allows the integration of all the data available.

The next step is to move on to the actual development of the system with the fluid extraction data (brine) with continues support during drilling, and the integration of new data into the generated model.

This generated workflow allows, therefore, to assist the customer from the dawn of an exploration idea in the geothermal field and can also be used in other types of research such as CCUS (or CCS), compressed air or storage of radioactive waste, therefore a milestone for the energy transition in this area. This is the main strength. Basically, it is a set of processes designed to go into more and more detail in the search for a suitable tank for ongoing research. In conclusion, this integrated workflow stands as one of the most complete and safe flows that can be used for geothermal research.

REFERENCES:


