VOI + Geothermal + Seismic: an assessment of the value of seismic survey in geothermal prospects

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Summary

Geothermal systems are characterized by sub-vertical fractures, favoring fluid circulation: their presence, density and orientation seems to be key information for prospect exploration, evaluation and stimulation. In oil and gas, the characterization of compartmented and fractured reservoirs is done with 3D seismic acquisition. As geothermal economics are different, 3D seismic is not often considered an option for cost reasons. In which condition could it be worth considering 3D seismic in a geothermal contest?

A methodology is developed to assess the worth of seismic in geothermal from the value of information (VOI) theory of magnetotelluric data (Trainor-Guitton et al, 2014). The method is tested on an exploration scenario in northern Italy and the stimulation one in France.

The results show that a 3D seismic campaign is economically justified in case of exploration of large prospects with multiple well planning and/or lack of prior reliable information. In this situation, well design will greatly benefit from the acquired data, and subsurface risks will be drastically reduced. In the context of a stimulation and production enhancement scenario, however, seismic may not be justified. Although the results of this work are affected by the scenarios considered, the VOI should still be a standard analysis.

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Introduction

Seismic methods are considered one of the key geophysical techniques in assessment of hydrocarbon prospects. In the geothermal environment they are often considered marginal, due to their irrelevance in volcanic basins where other exploration techniques are preferred such as gravity and magnetic surveys (Pina-Veras et al., 2016, Ceci and Battaglini, 2021) and due to seismic acquisition and processing cost. However, recently, examples have been presented where reflection seismic methods are used for geothermal exploration (Mazzotti, 2011), with the idea to reduce risks and exploit geothermal systems in a sustainable and zero impact way (Manzella, 2008). As one characteristic of geothermal systems is the presence of sub-vertical fracturing, anisotropy estimation can be valuable to derive from seismic data, analysing time delays anomalies at various offsets and angles.

In recent years, the price of seismic acquisition and processing has considerably diminished because of the general improvement driven by the mainstream digital industry. This, together with a general loss of the major client bases, the petroleum industry has led many medium to small size seismic enterprises to target the geothermal industry offering a wide range of services, from well based passive seismic to surface multicomponent. However, the majority of the commercialised seismic business consists of standard reflection wave surveys; therefore, an assessment of the benefits of using such technology seems necessary for geothermal environments.

This research uses the Value of Information (VOI) analysis to assess the financial value of seismic in geothermal prospects. The Value of Information approach has been used routinely for addressing the benefits of specific geophysical studies also in the hydrocarbon sector (Bratvold et al., 2009, Eidsvik et al., 2015). We propose here an extension to the evaluation of seismic data in geothermal with comparison to market survey costs. This study presents the methodology and applications to two existing case studies, taken for illustrative purpose, an exploration scenario in northern Italy and stimulation and production for an enhanced geothermal system in France.

Methodology - VOI Applied to Seismic Data for Geothermal Systems

The methodology for assessing the Value of Information (VOI) of seismic for geothermal systems is an adaptation of the framework developed by Trainor-Guitton et al. (2014) for magnetotelluric surveys and geothermal exploration. The VOI of seismic, VOIseismic, is defined as the difference between the best possible outcome considering seismic information, Vseismic, and the initial outcome without considering seismic information, Vprior:

$$\text{VOIseismic} = \text{Vseismic} - \text{Vprior}$$

Vprior is computed on the basis of all the possible values of the geothermal resource estimated on current commercial drilling-operation costs, resource price and their initial probability.

Vseismic is computed on the previously estimated value, Vprior, prior to the information from seismic data and considering the ability of seismic method to identify the model.

To compute the value of exploration outcome of geothermal systems without seismic data, Vprior, each assumed geothermal system model is evaluated with its characteristics such as reservoir thickness and depth, to estimate an exploration value but also its exploration costs. Each model corresponds to a financial gain or value from the difference between exploration value and exploration costs (Fig.1).

The velocity models are generated assuming an interval where subvertical fractures, present in the geothermal reservoir, create an anisotropic layer, with distinct horizontal and vertical P-wave velocities. For all models, the anisotropy value is set constant in the fractured layer. Only the layer thickness changes. The seismic response is generated using anisotropic seismic software ASOFI3d (Kabanov, 2022). For each synthetic seismic dataset, the added value in terms of characterization of the geothermal reservoir, Vseismic is estimated. The assessment of the accuracy of the seismic method is done through measurement of the time delay of the cross correlation between near and far offset within CMP gathers, which provides an estimation of anisotropy. The random noise is added to the gathers before correlation, while the NMO velocities are constant, corresponding to the vertical P-wave velocities. Then, correlations provide a simple type of seismic processing with the minimum human bias (Fig. 2). Once the values with and without seismic data are estimated considering the best possible outcome, the VOI is calculated, representing the economic benefit of acquiring the data, considering an actual monetary value and its associated costs (Fig. 1).

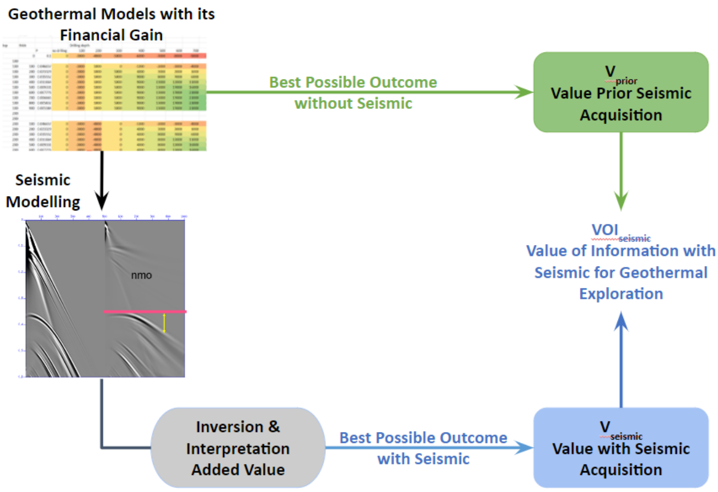

Figure 1: *VOI methodology applied to seismic data for the geothermal system exploration, considering value with and without seismic data acquisition.*

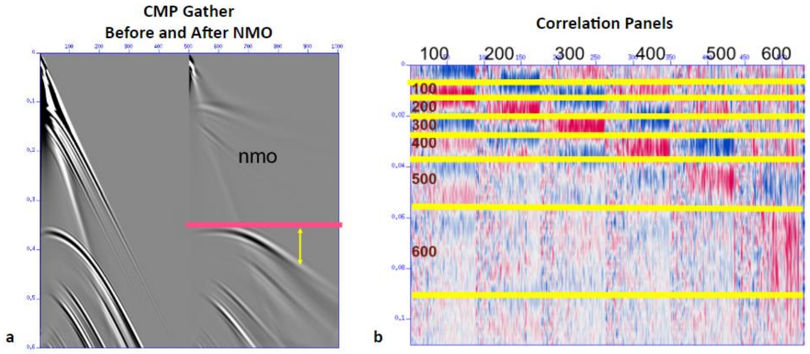

Figure 2: *Evaluation of seismic data velocity models through correlation panels within CMP gathers*

Evaluation of Exploration Example – northern Italy Case Analysis

The VOI of seismic methodology is applied to the evaluation of the Grado geothermal exploration, in Northeast Italy, consisting of a low enthalpy calcareous Cretaceous fractured reservoir (Della Vedova et al. 2015), a geological setting common for northern Italy. The Grado reservoir plant has been developed in the past, and this analysis is conducted a-posteriori. The VOI analysis is performed to assess the value of a 3D seismic survey prior to the drilling of a single exploration well. Seismic simulations for variable thickness reservoirs within the Cretaceous formation are carried out on multiple locations. The Gardo fractured reservoir is assumed to have a pay of 60,000 €/m per year sold as warm water for home heating and greenhouses. Drilling costs are estimated at 1,900 €/m with additional completion cost to 500 Euro/m. Fixed costs for a well are estimated to be 5 million €. Based upon historical knowledge of drilling in the Po Valley (Northern Italy), a dry well probability is 45%. The turnaround time is considered 5 years, standard for exploration/assessment programs. Reinjection well drilling costs are not considered at this stage as the risk is assumed to cover for the assessment phase.

The values with prior information only and with seismic information (Fig 3a, 3b) are computed and interpolated throughout the area. Results showed a VOI for a single well not exceeding the costs involved with acquiring seismic of 30-36 sq Km (assumed to be of the order of 1.5 million €) (Fig 3). In this scenario the 3D seismic is not fully justified based on economic considerations alone. It can still become very appealing and economically justifiable if the prior knowledge of the subsurface is limited (which was not the case for the Grado site), and if the cost of a 3D seismic survey can be further decreased, as is the case in very recent surveys. In conclusion, seismic can still be used for de-risking a single well and even more if multiple wells are planned.

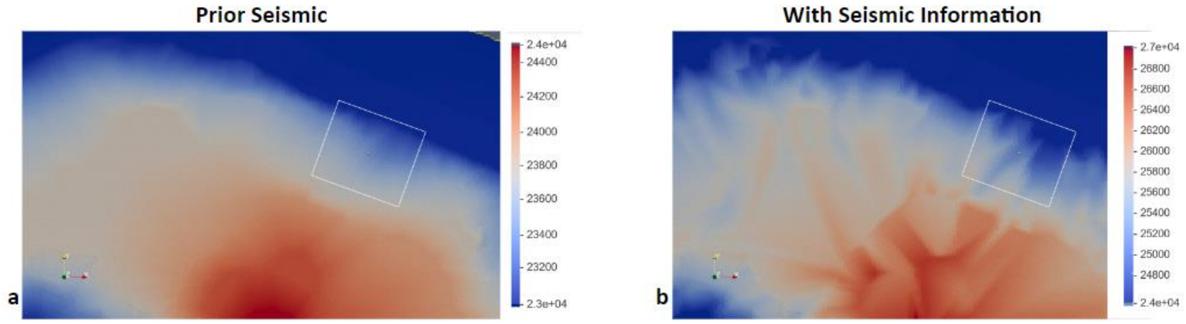

***Figure 3**: Example of VOI analysis prior (a) and with seismic information for a single well (b).*

Evaluation of a Production Example – Enhanced Geothermal System stimulation Case Analysis

The Rittershoffen is an enhanced geothermal system consisting of an injection well at 2 km distance from a production one in the granitic basement, with a production interval of ca. 250 m (Fig 4a). It has a nominal output of 26 KW warm water and 2.5 KW electricity, with a flow of 75 l/s (Baujard et al., 2016). As for the Grado case, this plant exists already and the VOI analysis as been run for illustrative purposes only. The scenario consists of assessing the justifiability of shooting a 3D seismic survey after an initial stimulation corresponding to 10% of porosity which does not give any return. This assumption starts with the identification of an area extending horizontally 200 m with a decrease of fracturing. Multiple velocity models are generated based on this location. Nine subsequent additional fracturing stages are modeled each corresponding to an additional 2.5% porosity increase. No further stimulation was applied once near injection well porosity reached 40% as the well is then considered mechanically unstable.

Following the Kozeny-Carman equation (Guéguen and Palciauskas, 1994), differential pressures are computed and electricity consumption of pumps is subtracted to the nominal. Pressures above 250 Bar were considered unviable, so no financial gains are applied (Fig 4b). The turnaround time is only a year, reasonable for a stimulation operation. The VOI of seismic acquisition and processing, aimed at evaluating the effect of a stimulation phase, based on 2022 estimated European electricity and utility prices, is less than 400K Euro, too small to justify a 3D seismic campaign.

Conclusions

A VOI methodology was developed to evaluate the value of seismic methods in geothermal environments based on the added information provided by seismic reflection data in terms of reservoir depth, thickness or presence of subvertical fractures, common to geothermal systems. To implement this VOI analysis procedure, tools and specific knowledge of geothermal modelling were developed to adapt this methodology previously applied to magnetotelluric data, to seismic data. Finally, this VOI analysis was used on specific decision-making scenarios where a seismic survey might be beneficial for two real case scenarios in geothermal exploration and production. The results show that a 3D seismic campaign is economically justified in case of exploration of large prospects with multiple well planning and/or lack of prior reliable information. In this situation, well design will greatly benefit from the acquired data, and subsurface risks will be drastically reduced. Although 3D seismic data can be valuable to enhance the well planning optimization and drilling success, in the context of a stimulation and production enhancement scenario, the value of 3D seismic acquisition should be evaluated more carefully.

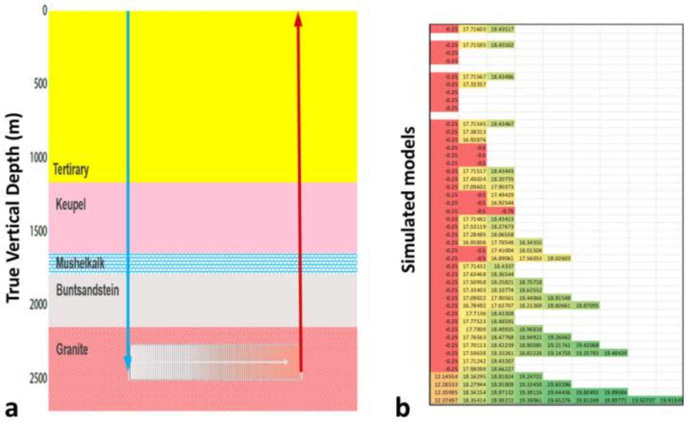

Figure 4: *Rittershoffen model (a) and total energy production minus the stimulation costs in € with negative and positive values in red and green, respectively.*

The methodology has been developed here for 1D velocity models, as applied for sets of CDP gathers. Therefore, it can be extended using multiple and diverse 1D models to represent roughly a complex geologic model. Finally, this methodology could be expanded to other measurements such as passive surface or downhole microseismic data. For the moment, the method is applied to one measurement at a time, but it would be interesting to evaluate the results for multiple measurement analysis.

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