Poster 1.14

Mitigation of Geothermal Induced Seismicity Through Data Integration and 3D Geomodeling in a Cloud-Hosted Environment

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Summary

Induced seismicity events, with magnitudes large enough to be felt by local communities and impact surface infrastructures, are an undesirable potential result of geothermal operations, and significantly impact social acceptance. Mitigating the possible adverse effect of induced seismicity on the environment, human health, social acceptance and project economics, is of upmost importance if one wishes to increase the number of geothermal projects in a safe and sustainable manner. Increasing understanding of the subsurface through the creation of an accurate 3D earth model is key to risk mitigation, since induced seismicity is closely related to local geology and fault structure. As the project progresses and more data is collected, 3D visualization and 3D seismicity analysis are needed to refine understanding of fracture and fault systems and to identify spatial and spatiotemporal relationships between operational parameters and induced seismicity. A cloud-hosted digital twin of the subsurface unlocks the possibility for geothermal teams and partners to access the model from anywhere at any time. It supports communication around a shared understanding of the subsurface and the ability to quickly react to the latest insights as operations progress.

Introduction

Geothermal energy is a key resource for the provision of clean, reliable and sustainable energy. Today, the global contribution of geothermal energy is still a relatively low part of the energy mix. However, the geothermal industry is set to accelerate as countries seek to meet climate goals and reduce CO_2 emissions. If the number of geothermal projects worldwide is to grow, the support of local populations is critical. Induced seismicity events, with magnitudes large enough to be felt by local communities and impact surface infrastructures, are an undesirable potential result of geothermal operations, and will significantly impact social acceptance.

Induced seismicity is a result of the reactivation of pre-existing faults and fractures by geothermal operations. These events are caused by pressure and temperature changes in the subsurface linked to geothermal production or reinjection, or to operations performed to enhance permeability in Enhanced Geothermal Systems (Foulger et al, 2018). Small induced events producing earthquakes that are too far below the threshold to be felt are not harmful and can even increase geothermal productivity. However, larger magnitude events can occur. Examples of earthquakes related to geothermal operations include the 2006 Mw 3.4 earthquake in Basel, Switzerland, the 2017 Mw 5.5 near Pohang, Korea (Wassing et al, 2021), and more recently (December 2020), the MLv 3.6 earthquake near Strasbourg, France (Schmittbuhl et al, 2021).

Mitigating the possible adverse effect of induced seismicity on the environment, human health, social acceptance and project economics, is of upmost importance if one wishes to increase the number of geothermal projects in a safe and sustainable manner. Induced seismicity depends highly on local geology and fault structures (Buijze et al, 2019). Increasing understanding of the subsurface through the creation of an accurate 3D earth model is key to risk mitigation. As the project progresses and more data is collected, 3D visualization and 3D seismicity analysis are needed to refine understanding of fracture and fault systems and to identify spatial and spatiotemporal relationships between operational parameters and induced seismicity.

Increasing subsurface predictability through the creation of a digital twin

Fault systems play a major role in induced seismicity. The seismic events felt near Strasbourg following geothermal operations were located along a complex fault zone intersected by the geothermal wells (Schmittbuhl et al, 2021). The creation of a digital twin using Emerson SKUA-GOCAD™ geomodeling software that integrates all available subsurface information, including complex fault systems, can shed light on the fault structure and help support a robust geothermal development plan and induced seismicity mitigation.

Non-simplified fault surfaces that are fully integrated in a 3D model are built using UVT technology (Mallet, 2004) and embedded in a cloud-hosted geomodeling solution. The model maintains geological integrity by honoring all structural and stratigraphic interpretations and obeying geological rules such as fault throws and intersections. Geoscientists can integrate faults of any scale and throw into a common 3D structural model, without unwarranted simplifications. Representations of this shared model are then discretized into fit-for-purpose grids and used by specialists from various disciplines to answer specific questions. Use of a shared underlying model enables rapid iterations and effective collaboration and communication between geothermal team members.

When performing risk analysis, it is important to integrate existing structural uncertainties into the digital twin building process. The shared underlying model is perturbed to reflect fault and horizon position uncertainty while maintaining geological consistency (Mallet et al, 2010). As a result, geoscientists have a clear representation of the fault position envelope. This gives them more confidence when planning geothermal well trajectories.

Unstructured grids created directly from the common subsurface model honor all interpreted structural and stratigraphic features. This is critical for a proper assessment of stress changes in the subsurface (Gringarten et al, 2008), and the prediction of fault reactivation leading to seismicity events. Fine scale finite element mesh along faults (Figure 1) ensures that the fault network geometry is preserved when assessing the subsurface geomechanical response to geothermal operations. Accurate assessment of the geomechanical response is another contributing factor to induced seismicity mitigation.

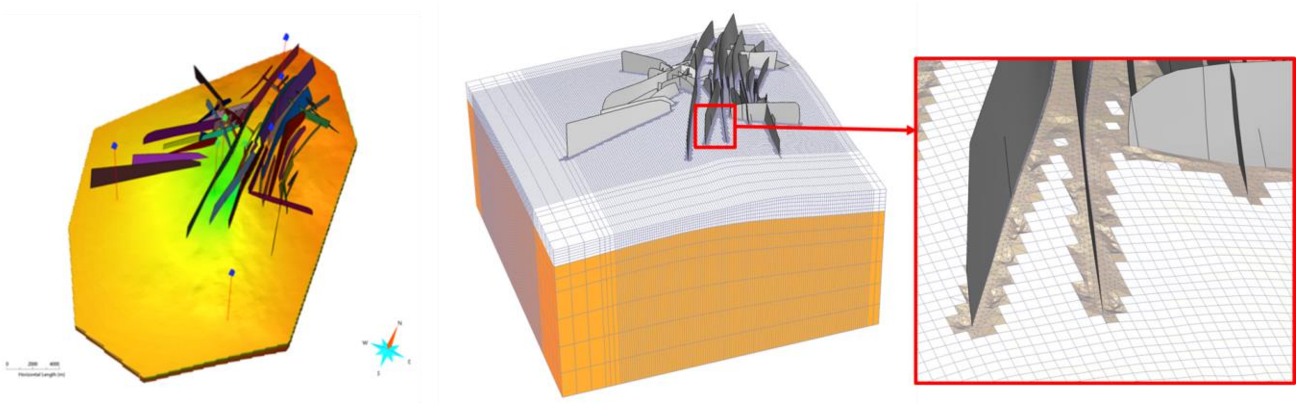

Figure 1 *Non-simplified fault surfaces integrated in a 3D structural model (left) and preserved in an unstructured grid optimized for geomechanical simulations (right).*

3D seismicity and microseismicity analysis

Induced seismicity has seriously affected and even stopped geothermal projects. In many geothermal projects, regulators accept small scale seismic events. However, if the magnitude starts to grow, operators are obliged to adjust operations. In cases where the earthquakes are too strong, the project is simply terminated. The ability to control induced seismicity and maintain an event size that is small enough not to affect local communities and surface structures is critical.

The integration and analysis of induced seismicity hypocenters along with injection, production and geological information in a geological digital environment provide valuable information for controlling induced seismicity. Through time-synchronized 3D views, geothermal project stakeholders can gain a deep understanding of the spatial and spatiotemporal correlation between geothermal operations and induced seismicity (Hartline et al, 2019). As more data are acquired, the analysis can easily be refined by loading the additional project data to the cloud. This provides an on-the-fly understanding of the connection between geothermal operation and induced seismicity.

Time-synchronized animations of induced seismicity data also help refine the understanding of fracture and fault systems and provide insights into fluid flow patterns. Hartline et al (2019), interpret fracture/fault surfaces and structural discontinuities within the Geysers geothermal field from seismicity alignments. Such interpretations provide additional constraints to the 3D model and contribute to better subsurface predictability through an updated 3D model that integrates all available information.

In Enhanced Geothermal Systems, high-pressure fluid is injected in order to hydrofracture or thermofracture the rock and enhance permeability. Microseismicity is an inevitable consequence of a successful EGS project, therefore requiring a close monitoring of stimulation operations. The recorded microseismic events are analyzed along with injection information (Figure 2) to gain a better understanding of the induced seismicity propagation and correlation with the injection rate. In addition, patented stimulation path generation allows geoscientists to simulate the generated fracture network. This leads to an in-depth understanding of permeable pathways and an informed geothermal operation plan that will be considered safe and sustainable.

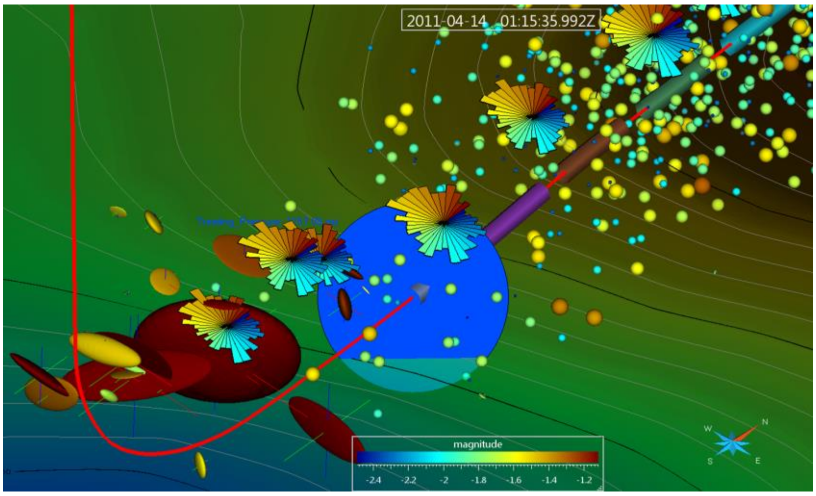

Figure 2 *Analysis of recorded microseismicity induced by stimulation operations in an EGS well, through a time-animated 3D view, including injection rate information and geological map.*

Using a cloud-hosted digital twin of the subsurface as a communication tool

Communication with the public and with regulatory authorities is an integral part of geothermal projects. Being able to easily share data and results is key to providing insights about exploitation activities and induced seismicity analysis.

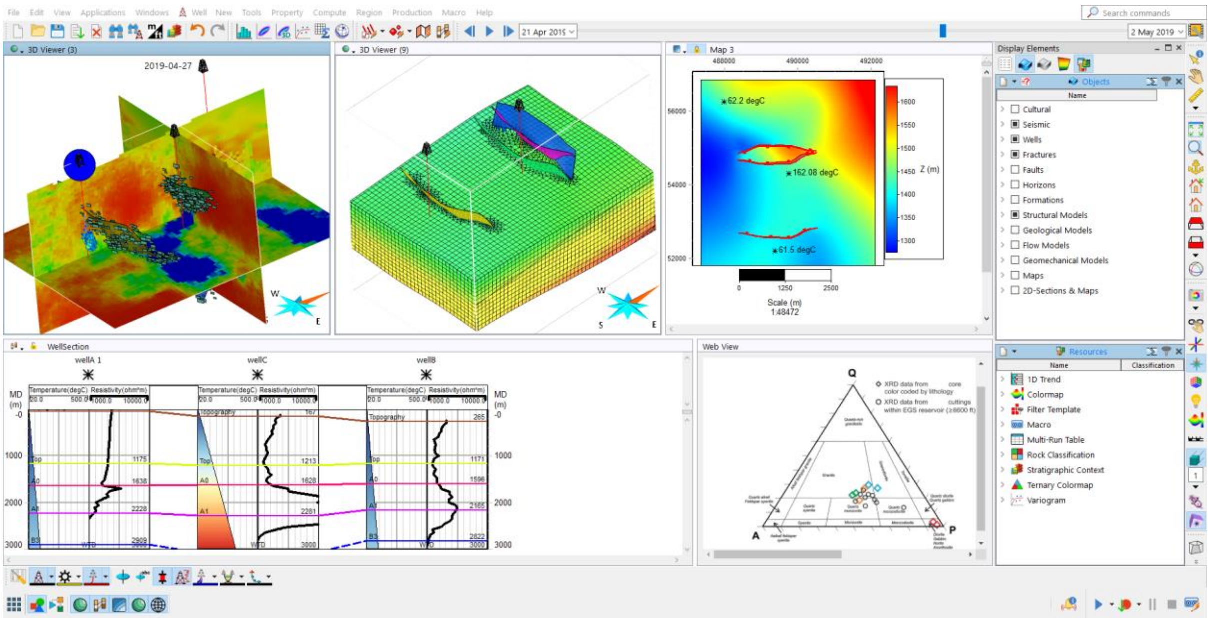

Figure 3 *3D views, map and well section available in the cloud-hosted geomodeling project make communication with team members and public easier.*

A cloud-hosted digital twin unlocks the possibility for geothermal teams and partners to access it from anywhere at any time. It supports communication around a shared understanding of the subsurface and the ability to quickly react to the latest insights as operations progress. The audit trail provided through workflow-driven geomodelling processes enables stakeholders to understand the context behind each technical decision. In addition, easy access to the digital twin makes it easier to convey subsurface information to the public through the use of 3D visualization, maps and cross-sections (Figure 3). These tools help disseminate understanding of the subsurface response to geothermal operations and reinforce the social acceptance of geothermal projects.

Conclusions

Large scale induced seismicity events can be avoided by increasing the predictability of the subsurface through the creation of a digital twin and the analysis of any seismicity information collected throughout the project lifetime. Accurate modeling of the fault network, and the preservation of the fault geometry in a grid optimized for geomechanical simulation, allow the operator to predict with more confidence the response of faults to pressure and stress changes. The digital twin of the subsurface is used as a support tool when defining the geothermal development plan. It is then continuously updated with new data to refine subsurface understanding and support operational decisions. Analyzing acquired seismicity data along with geological, injection and production information is critical to adapting the development strategy based on observed correlations between geothermal operations and induced seismicity. Creating the digital twin in a cloud-hosted solution unlocks the possibility for geothermal teams and partners to access it from anywhere at any time, improving communication and collaboration between team members and helping to quickly react to changes as the project progresses.

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