Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

A Cloud Based System for Interactive Collaboration and Management of Integrated Geothermal Subsurface Models and Data

Janina Elliott[1], Brennan Williams[2], Jeremy O'Brien[2], Bastien Poux[1] and Robert K. Podgorney[3]

[1]Seequent, #506-1168 Hamilton Street, Vancouver, BC, Canada, V6B 2S2

[2]Seequent, 20 Moorhouse Avenue, Addington, Christchurch, 8011, New Zealand

[3]Idaho National Laboratory, Energy and Environment, PO Box 1625, Idaho Falls, ID, USA 83415

janina.elliott@seequent.com

Keywords: Data management, version control, Seequent, Central, FORGE, earth reference model, numerical modelling, 3D model

ABSTRACT

There are many issues with integrated sub-surface geothermal studies; different disciplines are involved (geophysics, geochemistry, geology, reservoir engineering), alternative models and scenarios need to be investigated, new (sometimes conflicting) data are collected and interpreted to update the models, multiple organisations and people working in different locations and time zones may also be involved. When data and models are housed in siloed file structures and on individual computers finding the most up to date version of the information required can be cumbersome and often leads to repetition of work or the wrong version of information being used to make interpretations/decisions. The paper describes a cloud-based solution that tackles this challenge including powerful visualisation and collaboration whilst providing the "one version of the truth". A case study from the FORGE project, sponsored by the US Department of Energy's Geothermal Technology Office encompasses all these issues. This highlights the challenge of how a multi-disciplinary distributed team can work together in a coherent way on a day to day basis and at the same time be able to present their work to inform a wider audience. In this paper we present a workflow and a software system for providing an integrated environment that supports multiple users and disciplines, model management, audit trails, visualisation and collaboration.

1. INTRODUCTION

In modern geothermal exploration and resource management integrated resource teams need to be able to communicate effectively. This concerns not only the timely exchange of version-controlled models and associated data, but also the provision and retention of intellectual information in a three-dimensional (3D) context. When a consistent and uninhibited flow of information is achieved, productivity can be increased and a robust decision-making process facilitated, both lending surety to the project as well as sponsoring partners.

In order to establish effective communication as well as a coherent audit trail, most commonly a strategy is employed that involves regular meetings (ideally with minutes taken), the set-up of a server-hosted folder structure with global access, specific naming conventions and a hand-over process in case of shift work, time-zone differences and more; however, this strategy strongly relies on everyone's commitment to execution and tends to suffer from the cumulative effect of everyday occurrences of both technical (e.g. internet connectivity, bandwidth) or human nature (e.g. absence, change in position). It also does not fully address the issue of data security and retention of intellectual information derived from conversation and testing different hypotheses. In addition, it inhibits cross-disciplinary team members, third party providers and other decision makers lacking software access from viewing the latest information unless provided by secondary means such as emails, images and so on which are rarely recorded in full.

Creating a truly integrated sub-surface geothermal study requires the use of modern technology that is designed to specifically address the common issues outlined above. In this paper, we present the use case for Central, a data and model management solution that is currently employed in several geothermal research projects as well as numerous commercially driven operations around the globe in the mining, civil engineering and geothermal industries. We will highlight the concept behind Central as well as its technical application and merits in a collaborative environment. Further, we will outline its use case at one study site, namely The Frontier Observatory for Research in Geothermal Energy (FORGE) project and demonstrate the short and long-term value the solution brings to the research teams, sponsoring partners and the public.

2. DATA MANAGEMENT THROUGH CENTRAL

2.1 The concept behind Central

Central is a data management system that is designed for individuals and teams to visualise, track and manage geoscience data from a centralised, auditable environment. It provides a platform not only for data exchange and retention, but also cross-collaborative communication in a 3D environment. By being able to interoperate between multiple software solutions employed in multi-disciplinary projects, Central allows the users to face the challenge of a holistic data integration approach to modelling and breaks down perceived barriers between traditionally siloed groups.

2.2 Deployment, system components and interoperability

Produced by Seequent Limited (Elliott, J., 2019), the developers of Leapfrog Geothermal, Central is a server-based system built for Windows environments and can be deployed either on-site or hosted (by Seequent Limited) utilising the Microsoft Azure cloud. This paper describes Central and its system components in correspondence with the software versions used at the defined study site at the time of publication.

2.2.1 The Central Browser

This desktop application provides the main visual interface between the server environment and the system users. Depending on the permission status of the individual user, he or she can access select Central projects that contain the complete version history of site-specific 3D models. The latter is presented in form of a stylised version tree that records the publication of Leapfrog models in a temporal hierarchy (Fig. 1).

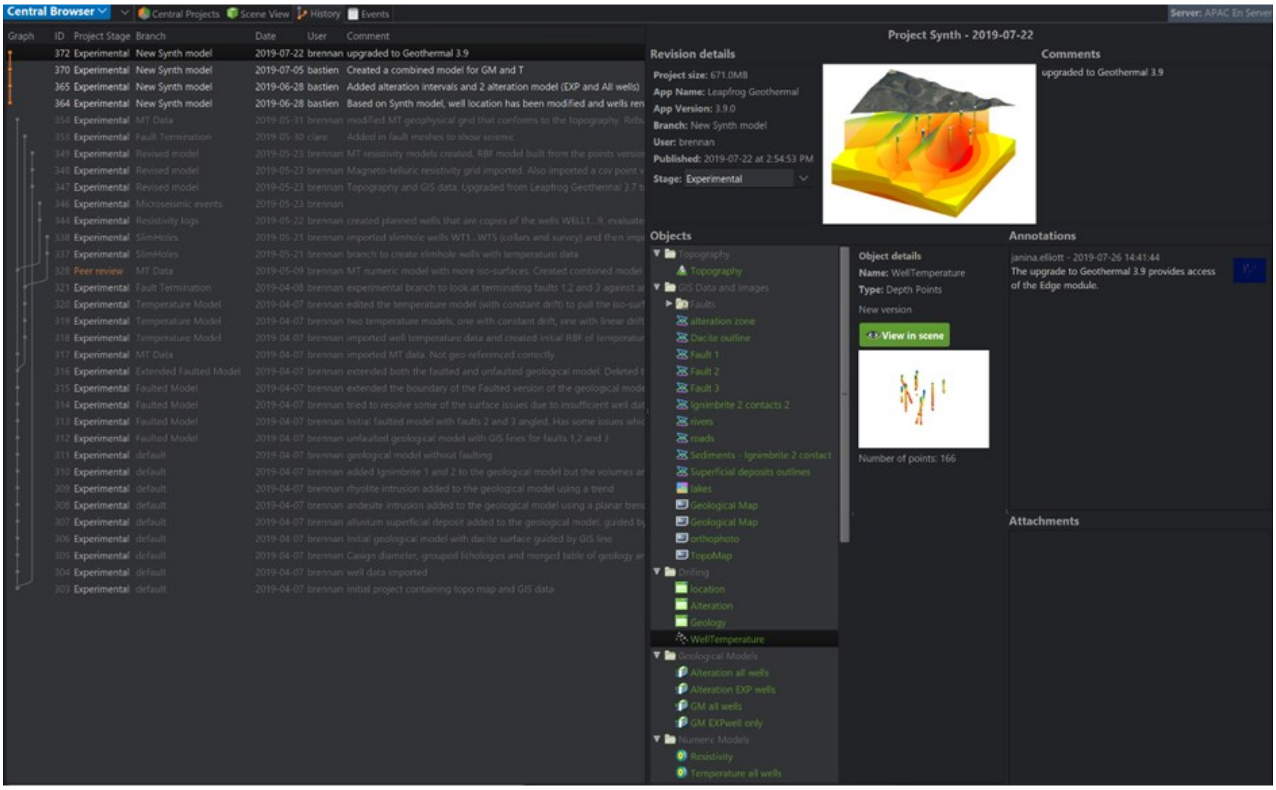

Figure 1: The Central Browser (v.2.2.1). View of the History tab with a well-established version tree and node-specific commentary.

Each node is representative of a publication (upload) event and outfitted with meta-data such as a publication date, name of the publisher, a short commentary and available data content, thus allowing for easy navigation. In addition, nodes can be outfitted with stage labels that are fully customisable to match team's approval process throughout the lifecycle of a model.

The version tree may also show distinct branching. Each branch and associated nodes define a deviation from the base or master project and are commonly utilised to provide separate workspace allowing each team member to model in parallel without compromising the master project.

Each version upload provides a view of the Leapfrog model which can be explored in 3D space (Fig 2.); this includes model objects such as wells, numeric data, GIS information, georeferenced sections, point files, polylines and meshes as well as geologic, numeric and reservoir models. Each object can be changed in terms of its visual representation and in some cases allows for a direct export by permitted users. The file export is not limited to Leapfrog specific file formats.

In the Scene view, a horizontal panel of publication dates appears at the lower portion of the screen which allows for a quick switch between different project versions and thus, the visualisation of the modelling progress over time (Fig 2.). The Central Browser also provides a specialised Compare feature (Fig. 3). Here, the objects from two temporally discrete versions can be juxtaposed in the same view and the differences enhanced through filter options.

Each Scene view, including the Compare view, allows for the placement of annotations (Fig. 2, and 3) providing all users with the capability to leave comments with a geotag to provide a 3D context. These commentaries are recorded and create a coherent audit trail that enables the team to reliably return to and understand important decisions that were made in the past. A summary of the annotations is also available in the History (Fig. 1) and Events tabs where they are outfitted with a hyperlinked thumbnail that directs the user to the correct conversation and Scene view.

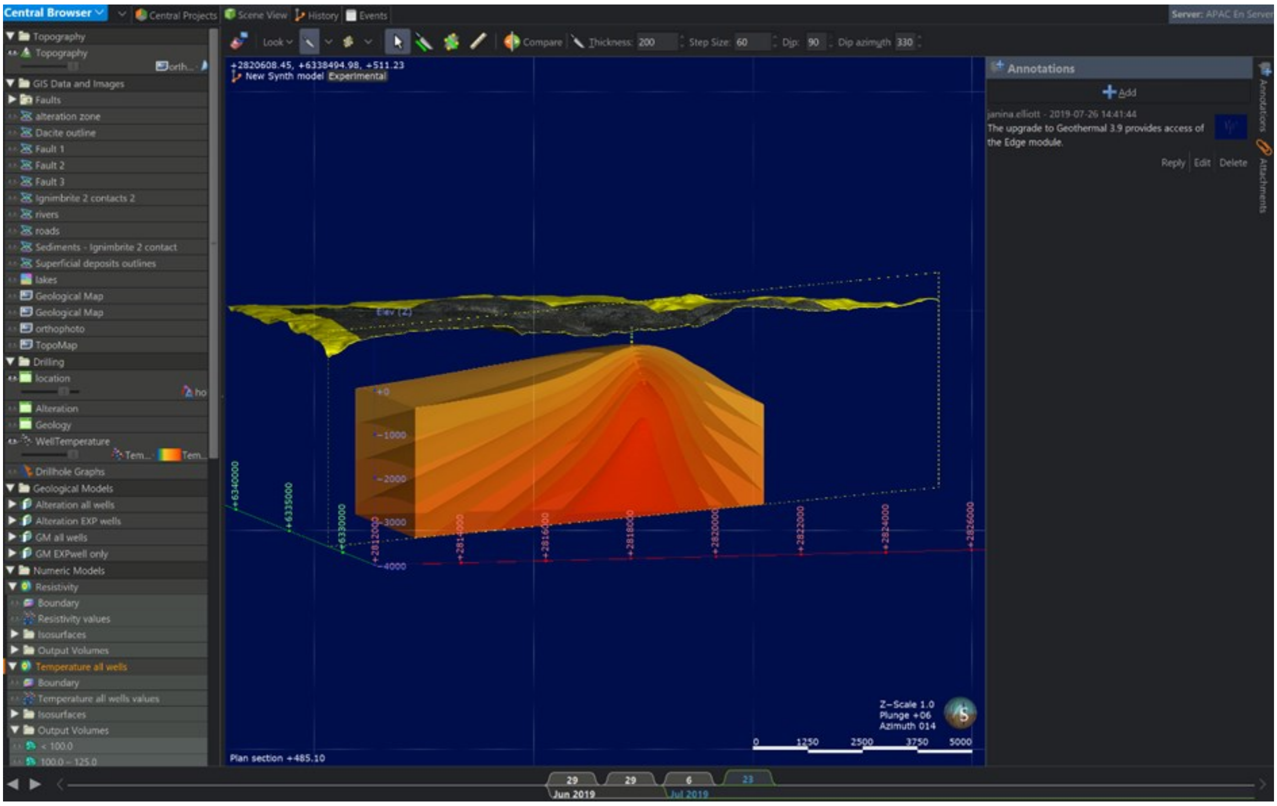

Figure 2: The Central Browser. View of the Scene View tab highlighting the version/date panel at the bottom and the annotation panel on the right.

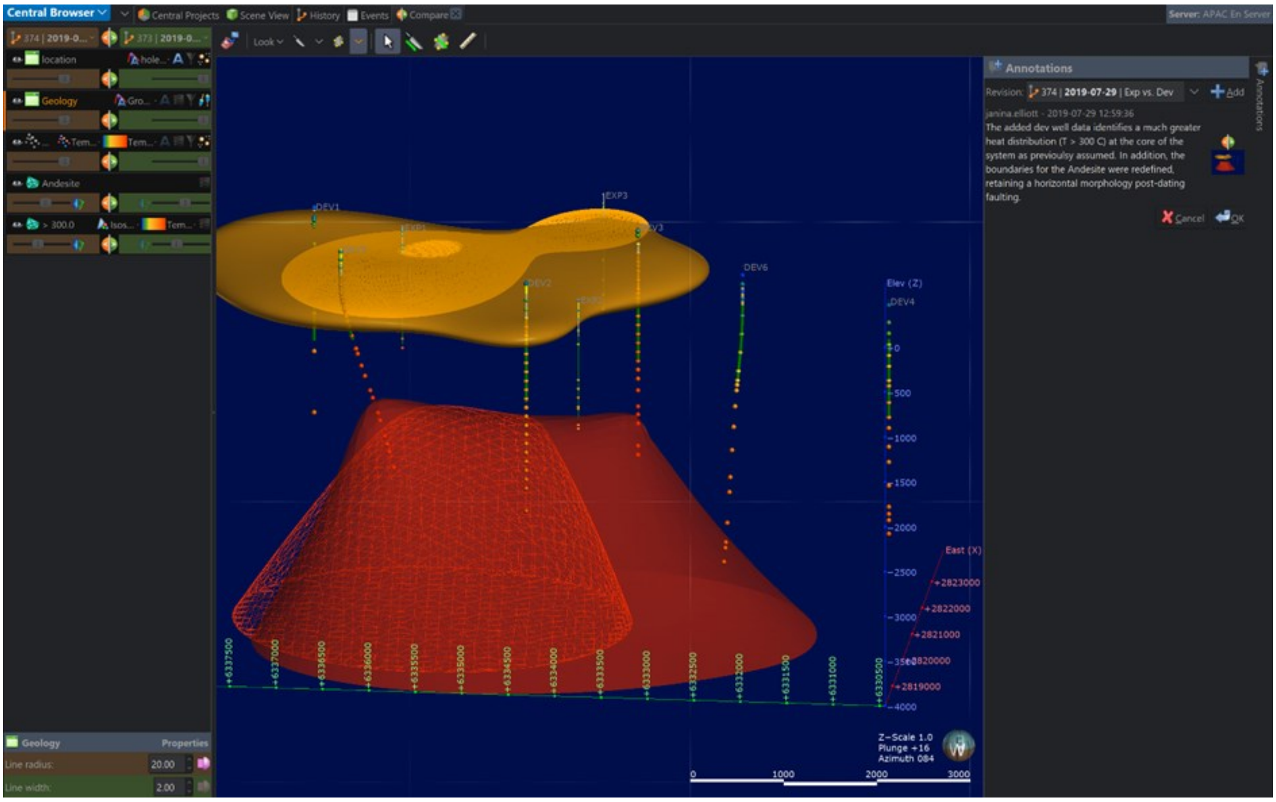

Figure 3: The Central Browser. View of the Compare tab showcasing objects of two different model versions as well as the annotation panel on the right. The model meshes with the triangular texture represent the original version, whereas the meshes with the smooth outlines represent the updated model.

2.2.2 The Portal and Data Room (v.2.2.3)

This web-based interface has a two-fold application. Firstly, the Portal serves the administrator of an organisation as a control panel to define license distribution and Central project access for each team member whether internal or external (consultants, JV partners, sponsors, etc.). Within the Central system permissions are organised through four tiers of access: the Admin (all-encompassing rights), the Owner (project administrator), the Editor (project access in Leapfrog software and the Central Browser), and the Viewer (Central Browser only +/- exporting rights). Further, the administrator can remove data redundancies, create stage labels for the internal approval process and link Seequent's integration partners to different Central projects.

Secondly, the Portal provides access to project specific Data Rooms that can store any file type and organises them in a version tracked folder structure (Fig. 4). In Central v.2.2.3, the Data Room also supports the direct linking and consumption of any mesh (irrespective of the software source) in the Leapfrog modelling software. This dynamic link is consistently refreshed when a new version of the source file is imported to the Data Room.

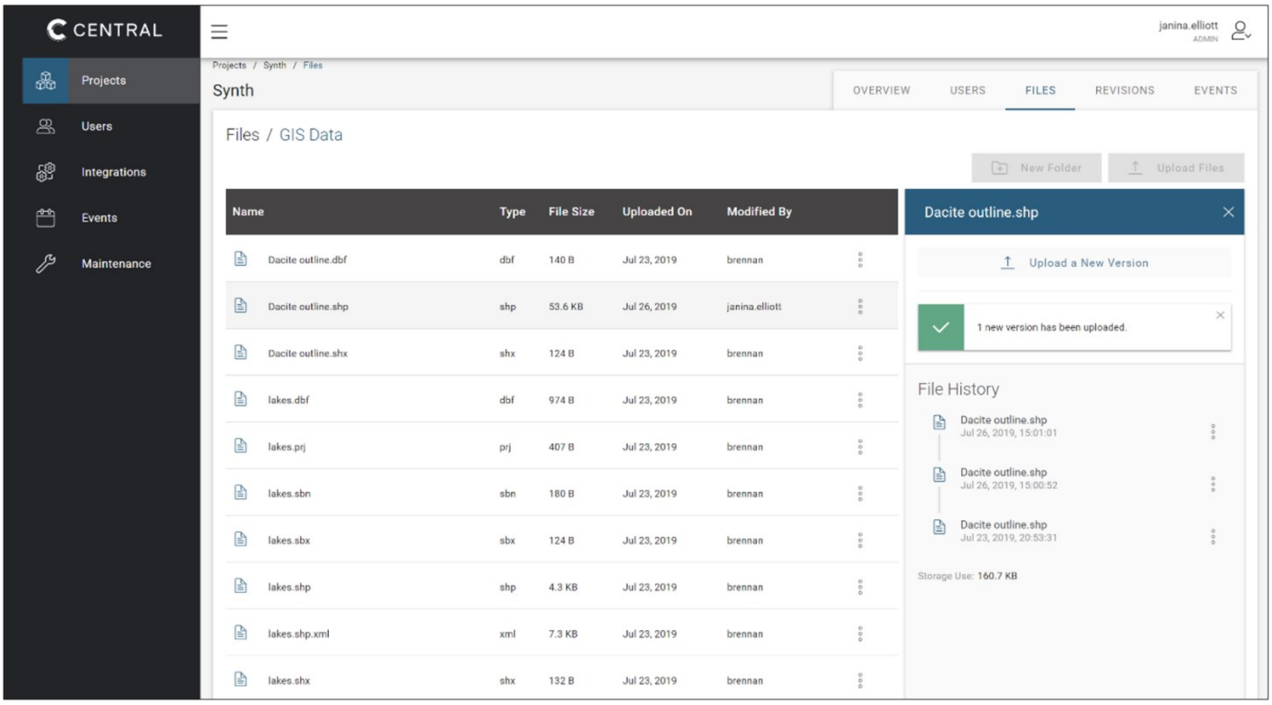

Figure 4: The Central Portal (v.2.2.3) View of the Data Room highlighting the folder structure and version tracking panel of individual files on the right.

2.2.3 Leapfrog Geothermal

The implicit 3D modelling software is a desktop application that can be linked to the Central server environment through the internet. Once connected, it is possible to either start a new Central project or access the version history of an existing Central project. Any model stored over time can be downloaded which includes version-specific annotations and Scene views (Fig. 5). The downloaded copy of a model is disconnected from its original source and any subsequent changes made during the local modelling process need to be published back into the server environment. During the publication process, the user has several choices regarding the visualisation of the model in the Central Browser, the stage labelling, the compression type applied to the model (if attached to the upload) and the positioning of the model on the version tree (branching) (Fig. 5). Once the publication process is initiated, the Central server will automatically recognise which objects have been modified relative to the previous version stored. Only the Delta ($\Delta = \delta 2 - \delta 1$), i.e. the incremental changes between model versions, will be uploaded keeping the data transfer to a minimum. When the model version is required by another user then the full model (not just Δ) is available for download.

Another feature of the Leapfrog modelling software is the capability to actively integrate meshes from other Leapfrog models stored in Central or any mesh file tracked in the Portal's Data Room (Fig. 6). By downloading a mesh directly from the Central server into an active Leapfrog model, a dynamic link is established that notifies the modeller with a clock-symbol when a new version is available. Then, the modeller decides whether he or she should proceed with an automatic (or manually guided) refresh of the linked mesh. If permitted, then an automatic exchange occurs that subsequently informs all further dependencies or linked objects in the implicit model.

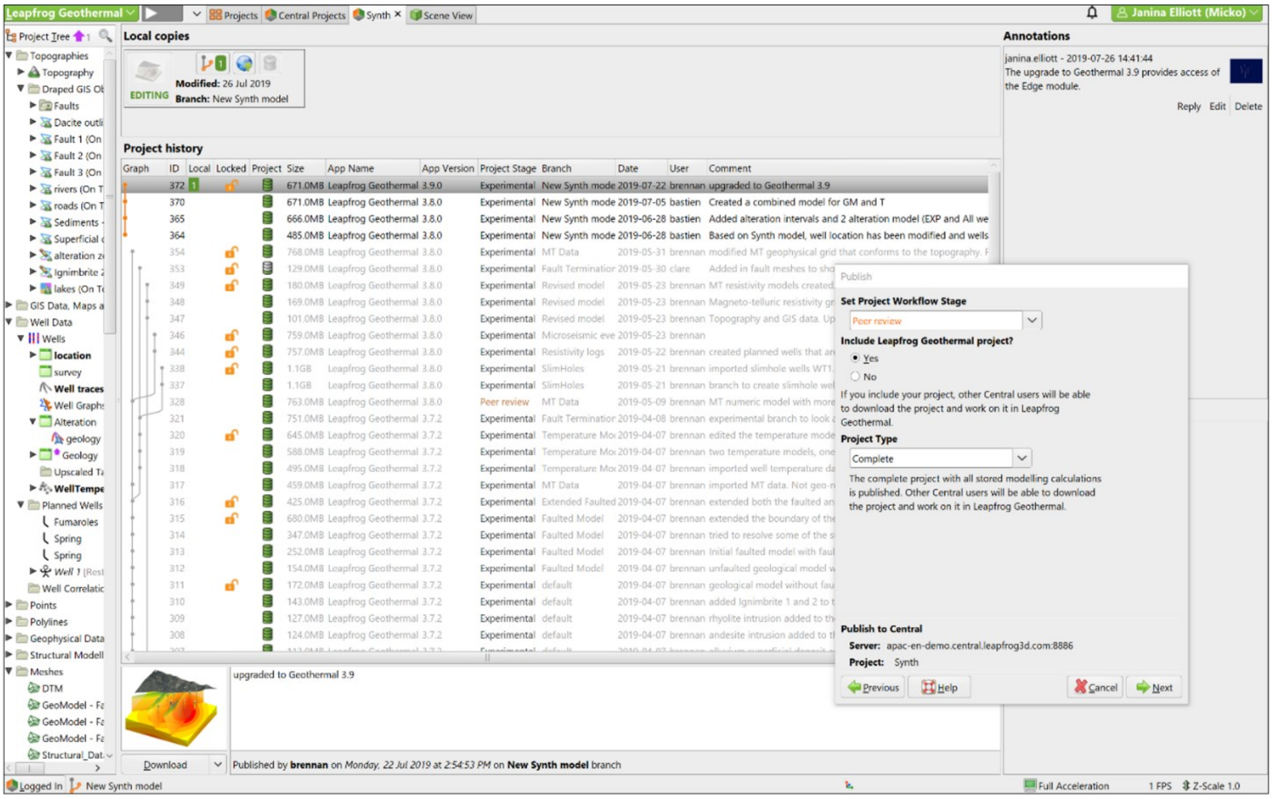

Figure 5: Leapfrog Geothermal. View of the Central project's History tab with a well-established version tree, associated annotations and publication panel.

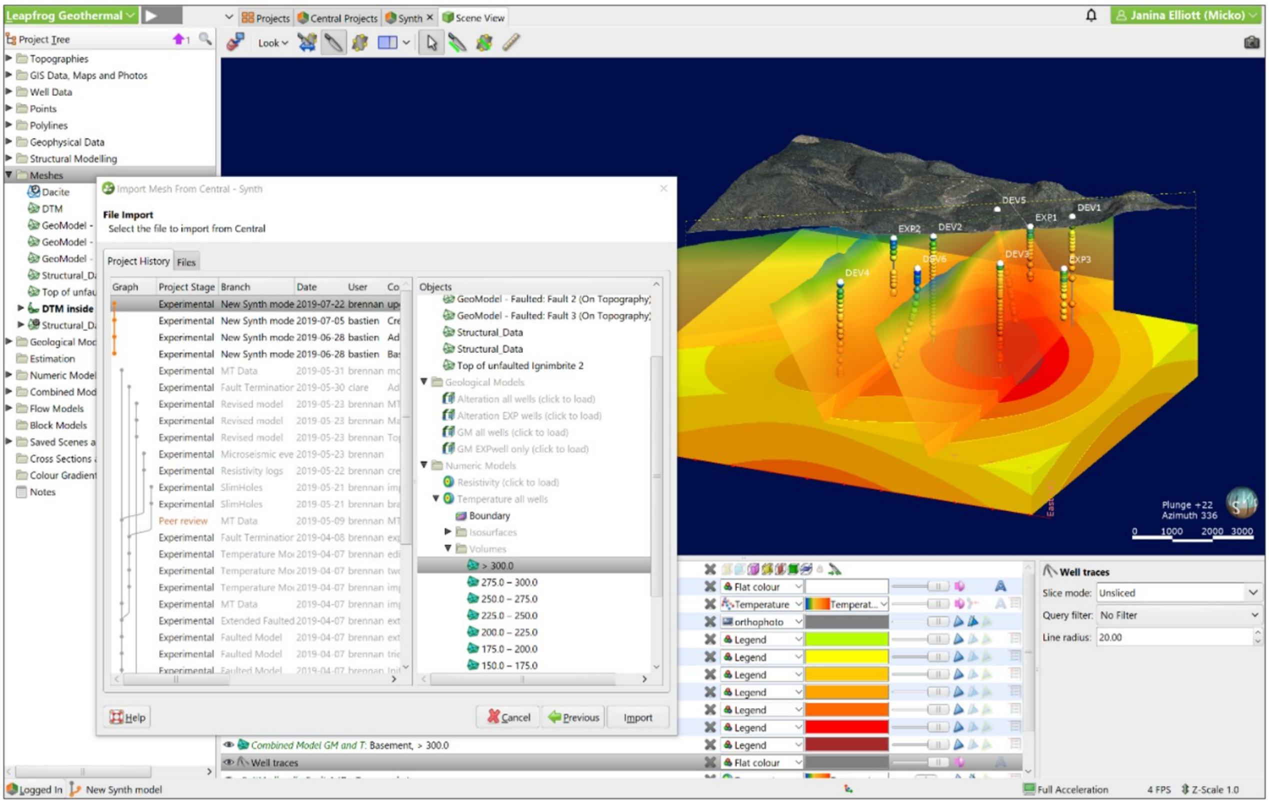

Figure 6: Leapfrog Geothermal. The Object Integration panel showing access to the version tracked model history in Central as well as the Files tab relating to Data Room in the Portal.

2.3 Use cases and advantages

2.3.1 Building a true holistic model

The principal challenge that multi-disciplinary teams face is how to collaboratively assess and process large volumes of varying data types to create an integrated geothermal model. One aspect that provides part of the solution is the ability of the Leapfrog software suite and Central to import and export almost all conventionally used file types which supports the interoperability with a variety of software products (Elliott, J., 2019).

Another aspect relates to the branching functionality in Central; here, it is possible to define distinct workspaces for each disciplinary group that stem from the base project or regional master (Figs. 1 and 5). Within each branch, the specialised team members can progress their pared-down and lightweight Leapfrog models without compromising the master version. At the same time, they can visualise parallel branches and actively discuss and cross-reference their work by using the Annotations and Compare functions respectively. Thus, the team can exchange ideas across boundaries of traditionally siloed groups and test different hypotheses while preserving all thought-processes in a continuous audit trail. Once certain aspects of the model are fully agreed upon through a peer-review process (using stage labels), the results can be integrated back into the master project. At this point, the parallel branches can be terminated marking the beginning of a new modelling cycle.

One option to dynamically update the Master project is by linking it with the output volumes of the branch-propagated models using the mesh integration function. Any time an update occurs, the master model will receive a notification which allows the modeller in charge to refresh the linked meshes. The result is a master model that is live and does not suffer from version control errors.

Mesh integration resides at the core of several dynamic workflows applicable to team members that rely on each other's latest model components (Fig. 6). For example, a structural geologist has created several fault surfaces that inform a colleague's geological model. By accessing the fault meshes through Central, the geological model will receive an instant notification that a new version mesh is available. Another example is where the resource conceptual model of a conductive clay cap is directly informed by a colleague's surfaces produced in a resistivity model. In both cases, by refreshing the dynamic link the meshes are instantly updated with the latest version stored in Central, as are all subsequent dependencies in the overall Leapfrog Geothermal project.

2.3.2 Near real time decision making

With Central's ability to branch and recognise the incremental changes between versions, models can be published quickly taking up minimal bandwidth during the upload process. This supports sites with reduced bandwidth and ensures that all Central users have access to the latest version of the Leapfrog model almost immediately.

When new geological, alteration, structural, and drilling engineering data are generated from cuttings, core and logs, it is possible to visualise this new information in the relative context of an up to date and strongly version-controlled 3D model. For example, the direct comparison allows geologists to instantly inform a wellsite when a fault location is detected or requires an update (Figs. 2 and 3). The results from this direct comparison can influence decisions about whether to continue drilling to plan or changing the plan for the wellsite, resulting in cost savings. It may also highlight current discrepancies in the 3D modelling approach and allows the team to comprehensively discuss a new strategy, thus mitigating the risks associated with a misinterpreted model.

2.3.3 Stakeholder engagement

Larger scale decision-making processes surrounding budget, technical resources, contract negotiations, etc. within a collaborative project seldomly rest with the modellers but involve the higher, commonly less technical tiers of the organisation as well as stakeholders beyond (Fig. 7). To be heard and considered for resources, highly technical information needs to be communicated as quickly and clearly as possible. By using the Central Browser as a 3D presentation tool, the modeller can inform a less technical audience of progress and up-to-date results, thus creating confidence in the team and its work.

When time is of the essence, an even more succinct data story can be told with Seequent "View". (Ref; Fig. 7). This free, web-based tool allows anybody with a link to navigate a 3D data story generated through Leapfrog modelling software and partake in a live conversation through annotations and feedback. View also comes with public embedding capabilities, allows all stakeholders to gain true insight of the project through self-directed 3D navigation.

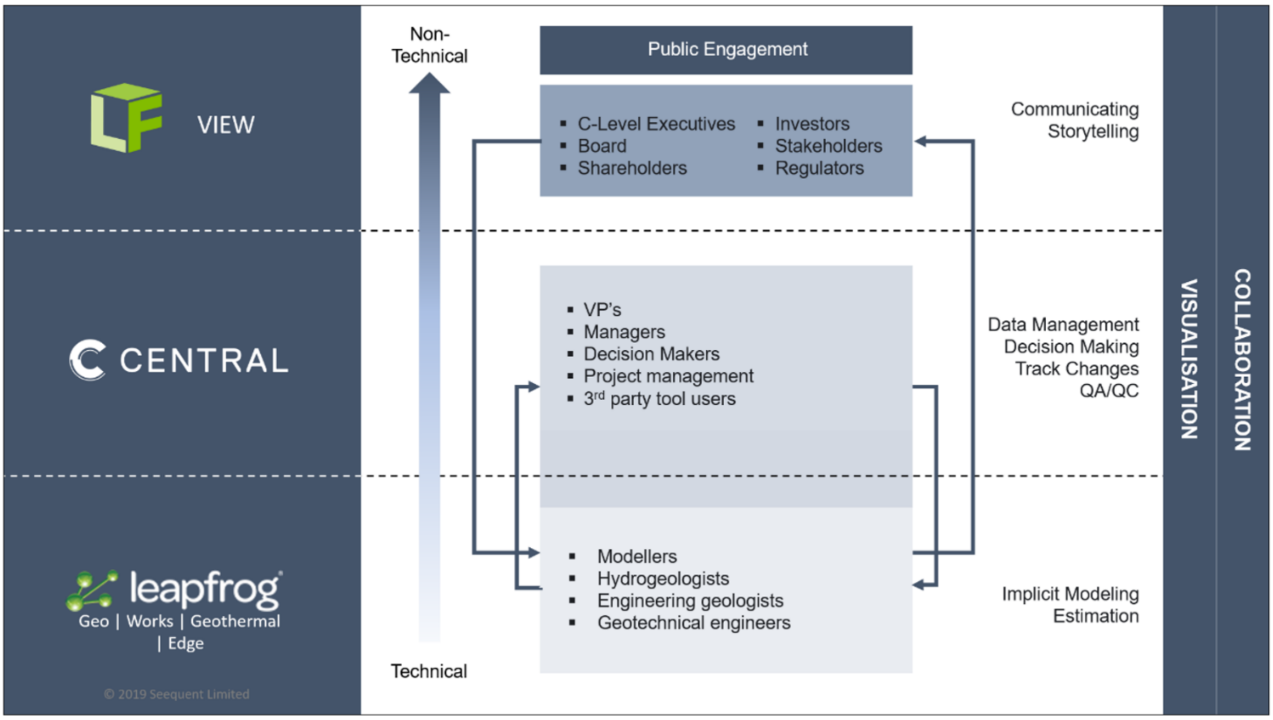

Figure 7: The Seequent Solution. Highlighting the interconnectivity of the product suite and its capability to support fluid flow of information through all tiers of an organisation and beyond.

3. A CASE STUDY, FORGE UTAH

FORGE is a multi-year and multi-phase initiative funded by the US Department of Energy (DOE) for testing targeted Enhanced Geothermal System (EGS) research and development. Located inside the southeast margin of the Great Basin near the town of Milford, Utah, the project has several collaborators spread geographically both within the United States and internationally. Podgorney et al. (2018; 2019a, b) detail the complex nature of the project and its challenges to integrate multiple concurrent technical workstreams along with ongoing decisions regarding active drilling and simulation modelling, particularly in Phase 2c of the current project. In order to ensure quantitative comparability of simulation results, and consistent initial and boundary conditions, Leapfrog Geothermal and Central is employed to provide reference earth and numerical models with version control (Podgorney et al., 2019a, b).

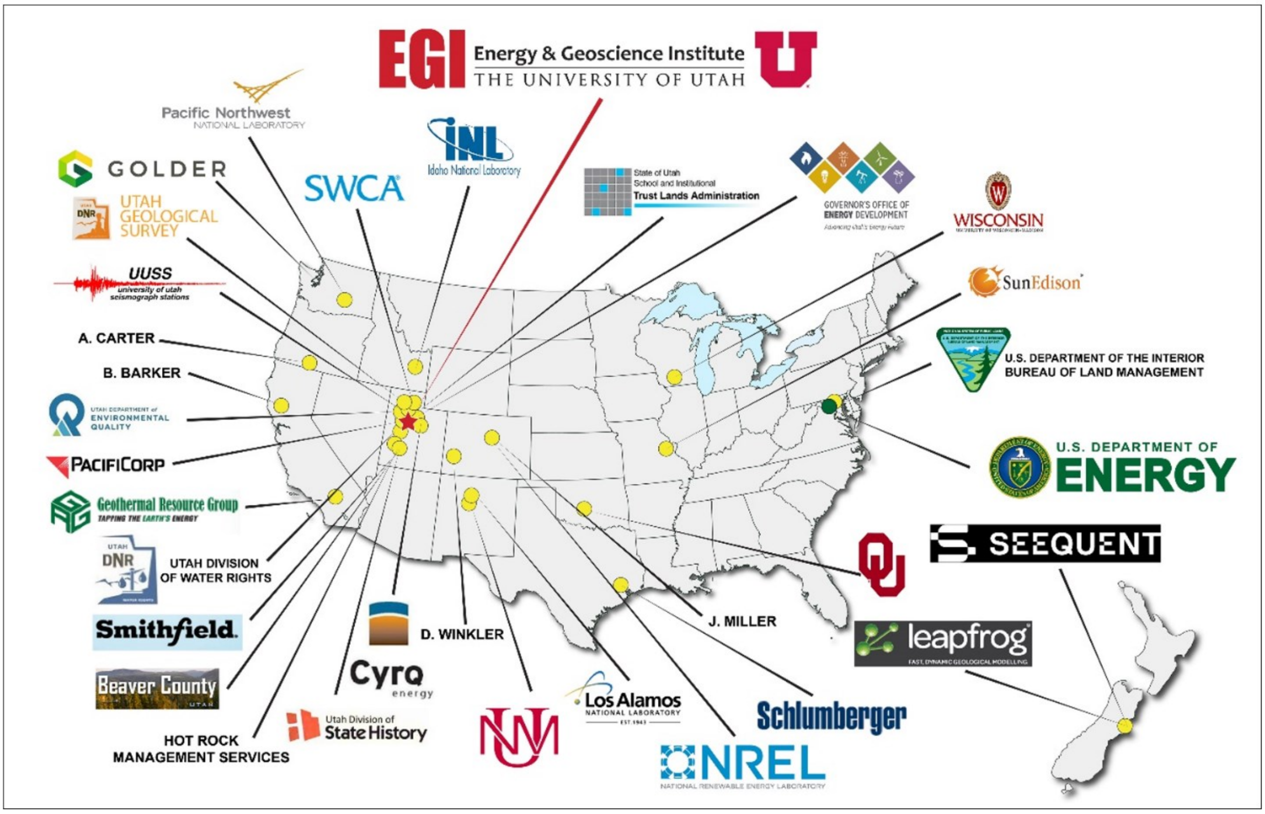

Figure 8: The FORGE Utah project. An international research effort funded by the US Department of Energy and industry.

3.1 Methodology

To manage effective team collaboration, the following workflow for earth model updates, numeric model structure and the input of revisions is employed:

1.) The key outcome from the earth modelling, in addition to incorporating the geologic, geophysical, geochemical data, etc., was the establishment of a "reference" earth model for use by numerical modellers as a means to ensure consistent geologic structural features and reservoir parameters in numerical simulations (Kirby, S. 2018, Podgorney et al., 2018; 2019a, b). The process of defining a baseline or reference model is crucial and concerns subsurface geological, geo-mechanical, alteration, temperature and simulation models amongst others. Finalised in Phase 2B (Energy and Geoscience Institute at the University of Utah, 2018; Finnila, A., B. Forbes, and R.K. Podgorney, 2019; Kirby, S. 2018; Podgorney et al., 2018), the base model was published into the Central server environment to form a discrete Master branch (Fig. 8).

2.) From the Master upload, several sub-branches were established that create autonomous workspaces which preserve the integrity of the reference earth model. Housing the results, particularly from numerical simulators, in separate branches allows for quantitative comparison of results from various simulations such as detailed numerical modelling of the site, native state models, DFNs, stimulation models, and long-term performance/ sustainability models (Podgorney et al., 2019). These modelling efforts associated with Phase 2C of FORGE are in the process of being concluded.

3.) Subsequent modelling and simulation are critical scientific discovery tools to elucidate the behaviour of EGS systems as well as to develop a deterministic or stochastic tool to plan and predict specific activities (Podgorney et al., 2019). Individual characterisation activities and hypothesis testing utilises the specific branches stemming from the earth reference model to allow for an independent evaluation without modifying the reference model. Version control will be maintained over all branches of the earth model, thereby maintaining a record of processes and data involved (Podgorney et al., 2019a, b).

4.) As new data are collected over the lifetime of FORGE, periodic updates of the reference earth model will be published. This activity will be supported through the object integration function in Central as well as the introduction of collectively approved model changes via Leapfrog Geothermal. Note that the current version of the earth model (Master v3) was locked on March 5th, 2018 (Podgorney et al., 2019-b; Fig 9). The next planned revision to the earth model will occur at the end of Phase 2C of FORGE, scheduled for fall 2019 (Podgorney et al., 2019-b). This distinct event is marked in the Central environment through the termination of various contributing sub-branches.

5.) The steps above will be repeated at least annually during Phase 3 of FORGE, and likely more often during periods of intense activity such as potential field experimental campaigns (Podgorney et al., 2019a, b). This method will ensure continued version control and visually marks the onset of a new modelling cycle.

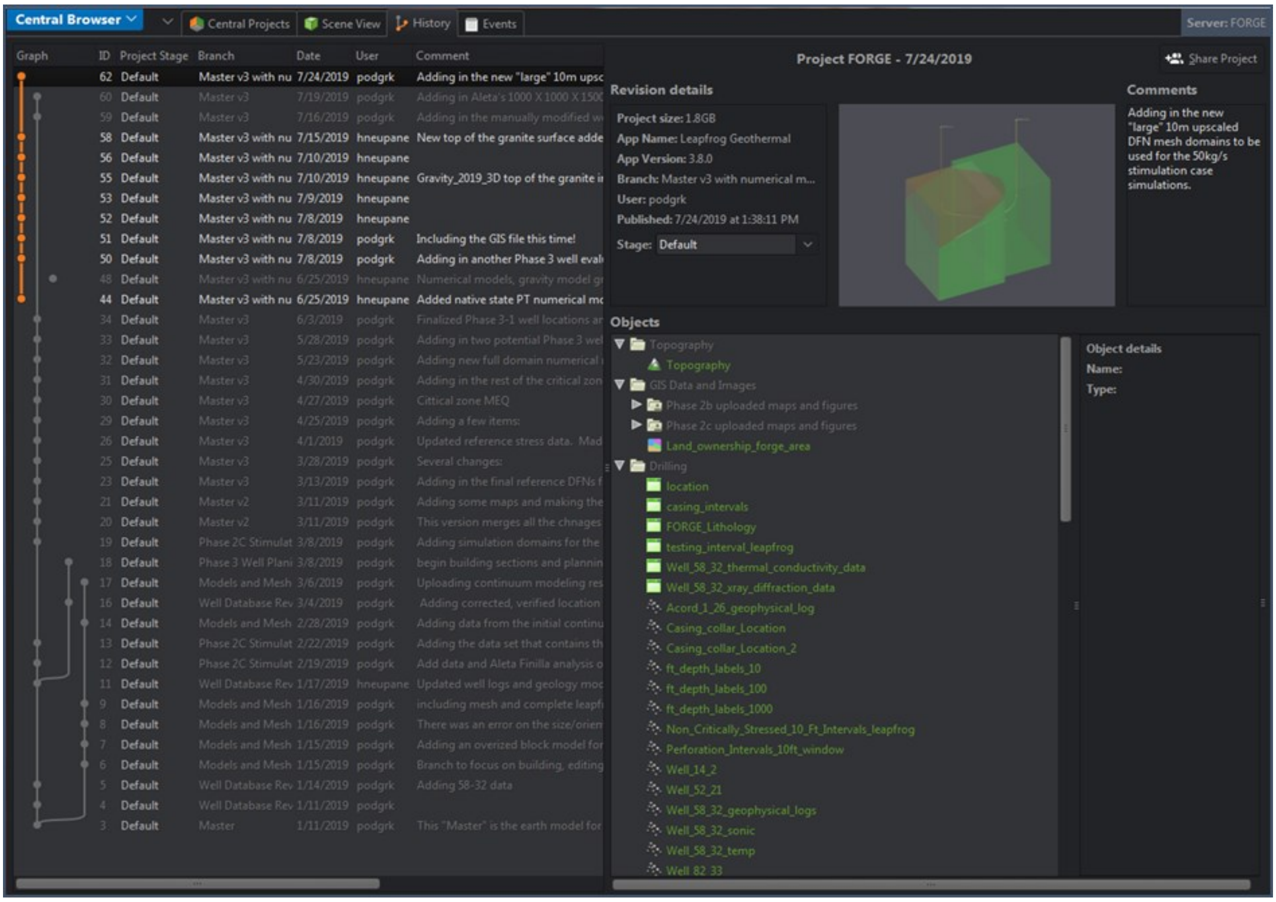

Figure 9: The FORGE Utah Central Server (Browser View by Podgorney et al., 2019-b). Development of a Master branch to host the all-encompassing reference earth model. From this master branch stem multiple branches that create separate workspaces for collaborators.

3.1 Collaboration and public engagement

Central's Browser and the Data Room, as well as graphical on-line tools are implemented to share data with collaborative partners of FORGE such as Enhanced Geothermal Systems (EGS) COLLAB project (Kneafsey et al., 2019). Derived from strongly version-controlled environment, the geological data are exported from Central as interoperable file formats that provide the foundation for continued numerical modelling on alternate software platforms.

The consistently updated reference earth model also acts as a communication tool, presenting the FORGE project's analytical results in 3D for public consumption. Primarily delivered through a web-interface using YouTube (Fig. 10) and Seequent View, the non-technical stakeholders in the project as well as direct collaborators have the opportunity to interactively experience the modelling progress as it unfolds. In addition, the data from this reference earth model are made publicly available through links on the Utah FORGE website (Energy and Geoscience Institute at the University of Utah, 2019) and the Idaho National Laboratory (2019).

4. CONCLUSION

In modern geothermal exploration and resource management integrated resource teams need to be able to communicate effectively. The FORGE project has shown that this can be achieved through the diligent application of modern technology, primarily the use of Central, but also the commitment to change in a culture of communication among its team members and partners. Using the Seequent software suite, they address the issues of the timely exchange of version-controlled models and associated data, as well as the provision and retention of intellectual information in 3D context. A consistent and uninhibited flow of information is achieved, thus increasing productivity, reducing risk and unnecessary costs, as well as facilitating a robust decision-making process involving all collaborators.

ACKNOWLEDGMENTS

We thank Dr. Robert Podgorney and the FORGE team for their use of the Seequent Software and the shared experiences throughout the lifetime of the project. Their advice greatly supports our continued effort to create purpose-build software for geothermal research and associated industry. We would also like to extend our thanks to the many stakeholders who are supporting the FORGE project, including U.S. DOE Geothermal Technologies Office, Smithfield (Murphy Brown LLC), Utah School and Institutional Trust Lands Administration, and Beaver County as well as the Utah Governor's Office of Energy Development.

REFERENCES

Elliott, J., 2019, Leapfrog website, accessed July. 30. 2019. https://www.leapfrog3d.com/products/leapfrog-geothermal; https://www.leapfrog3d.com/products/central

Energy and Geoscience Institute at the University of Utah, 2018. Roosevelt Hot Springs, Utah FORGE Final Topical Report 2018 [data set]. Retrieved from http://gdr.openei.org/submissions/1038

Energy and Geoscience Institute at the University of Utah, 2019. Roosevelt Hot Springs, Utah FORGE Earth Model 2019 [video]. Retrieved from https://utahforge.com/project/earth-model/

Finnila, A., B. Forbes, and R.K. Podgorney, 2019, Building and Utilizing a Discrete Fracture Network Model of the FORGE Utah Site, *in* PROCEEDINGS, 43rd Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, February 11-13, 2019, SGP-TR-214

Idaho National Laboratory, 2019. Utah FORGE Roosevelt Hot Springs Earth Model Mesh Data for Selected Surfaces [data set]. Retrieved from http://gdr.openei.org/submissions/1107

Kirby, S. 2018, Revised geologic mapping of the central mineral mountains adjoining the Utah FORGE Site, Millard and Beaver Counties, Utah, Appendix to the Utah FORGE Phase 2B Final Topical Report.

Kneafsey, T., D. Blankenship, H. Knox, T. Johnson, J. Ajo-Franklin, P Schwering, P. Dobson, J. Morris, M. White, P. Fu, R. Podgorney, W. Roggenthen, T. Doe, E. Mattson, A. Ghassemi, C. Valladao, and the EGS Collab team, 2019, EGS Collab Project: Status and Progress *in* PROCEEDINGS, 43rd Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, February 11-13, 2019, SGP-TR-214

Podgorney, R.K., Janis, M. Simmons, s., Allis, R., Moore, J., 2018, Earth Modeling of the Utah FORGE Site, Geothermal Resources Council 42nd Annual Meeting, Reno, NV, October 14-17, 2018

Podgorney, R.K., Finnila, A., McLennan, J., Ghassemi, A., Huang, H., Forbes, B., and J., Elliott, 2019-a, A Framework for Modeling and Simulation of the Utah FORGE Site, Proceedings, 44th Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, February 11-13, 2019, SGP-TR-214

Podgorney, R.K., Simmons, S., Finnila, A., McLennan, J., Neupane, H., O'Brien, J., Elliott, J., Williams, B., Poux, B., 2019-b, A Framework for Coordinated Earth and Numerical Modeling and Simulation of the Utah FORGE Site, Proceedings World Geothermal Congress 2020 , Reykjavik, Iceland, April 26 – May 2, 2020