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Brochure

Subsurface Science & Engineering Solutions for

Geothermal Energy Production

Overview

Climate change policies are driving the growth of geothermal energy, recognized today as a key resource for the provision of clean, reliable and sustainable energy. 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.

AspenTech recognizes the unique challenges associated with the different types of geothermal projects: conventional and enhanced systems, as well as advanced geothermal systems that tap into geothermal energy using closed loop designs. Through a comprehensive offering of customized subsurface software and services, we provide geothermal technologies for:

- Improved resource discovery and assessment
- Multi-type data integration and management
- Unified 3D visualization, geologic modeling and time-dependent data analysis
- Permeability structure detection and characterization
- Chemistry of thermal fluid analysis
- Risk assessment and mitigation
- Well planning and drilling engineering
- Seismicity monitoring and reporting

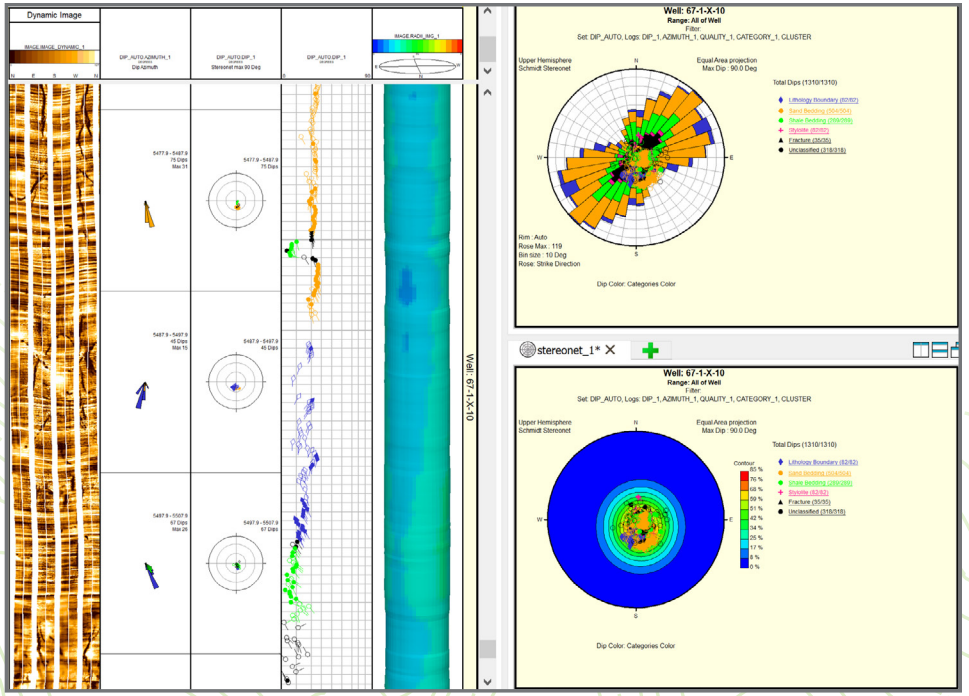

Figure 1. Image log interpretation for dip and fracture interpretation in Aspen Geolog.

Geothermal Resource Assessment

With the high cost of drilling, the early stages of geothermal products are critical, in order to minimize the many geological uncertainties in a resource. One of the best ways to reduce geological risk is to base geothermal resource assessment on a 3D model that integrates the outcomes of a thorough characterization of the geothermal system. Integrating all geothermal resource information within a 3D geological model leads to a deep understanding of rock heterogeneities, temperatures and fluid flow paths.

The Aspen SKUA-GOCAD™ subsurface modeling solution provides tools for building regional-to-local scale 3D models from various data types. For over 20 years, SKUA-GOCAD has led the industry in providing advanced capabilities for geological modeling. This comprehensive offering enables users to build 3D models of geothermal systems that preserve structure integrity and property heterogeneities. Geoscientists can use SKUA-GOCAD to model stratigraphic sequences, veins, complex intrusions, volcanic deposits and complex faults.

Well data interpretation from the Aspen Geolog™ formation evaluation system, together with geophysics, microseismic, geology and trend data, are all integrated with the 3D model to capture facies architecture, rock property heterogeneities and temperature.

The 3D subsurface model can be used directly to identify areas with high geothermal potential, generate heat flow maps and estimate heat-in-place. For a more accurate assessment of available energy, the 3D model can be exported to a dynamic simulator.

SKUA-GOCAD is able to pre- and post-process input and output files of the TOUGH (Transport of Unsaturated Groundwater and Heat) suite of flow and transport simulators (developed at Lawrence Berkeley National Laboratory). SKUA-GOCAD enables the export of grid geometry, properties, well trajectory and perforation simulator input files. The simulation results can then be loaded, visualized and analyzed within the SKUA-GOCAD environment.

It is also possible to leverage the thermal capabilities of the Tempest™ MORE simulator to dynamically simulate geothermal production and forecast the recoverable resource.

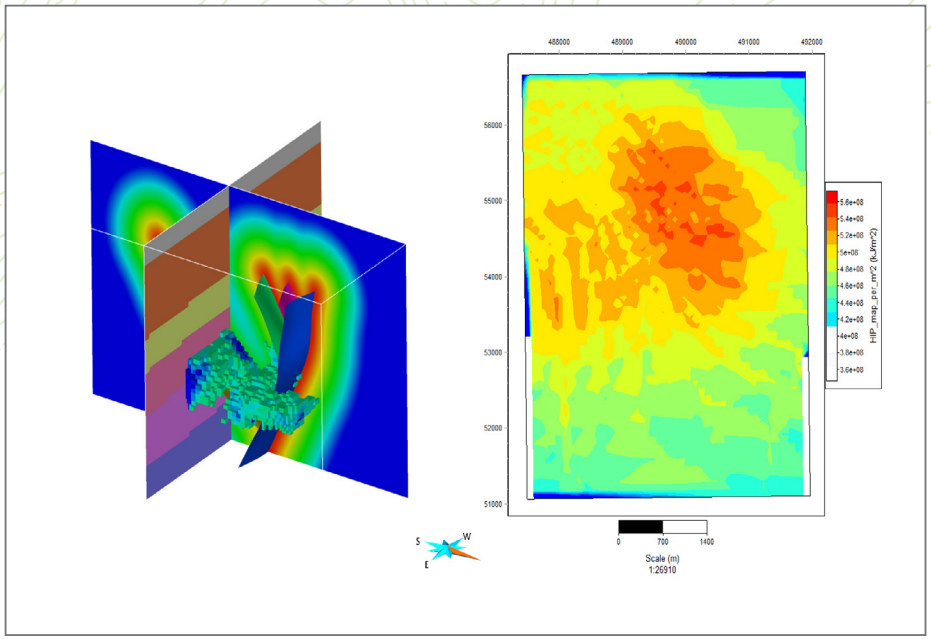

Figure 2. 3D play fairway analysis (left) and heat-in-place per m^2 map (right) of a geothermal field in SKUA-GOCAD.

Water Chemistry Analysis

A sound understanding of fluid chemistry in the geothermal exploration phase facilitates the building of a conceptual model and helps define the exploitation plan. The water chemistry of geothermal fluids is very effective in determining water origin, identifying mixing effects and predicting scaling and corrosion.

The Geolog water analysis module provides various programs and many interactive graphic plots (Piper, Schoeller, Ludwig-Langelier, ternary, etc.) that can be used in geothermal prospects.

The ionic composition of collected water samples can be analyzed in Geolog to assess various properties, such as:

- Class and origin of the water
- Physical properties such as alkalinity, hardness and ionic strength
- Tendency to precipitate or dissolve calcium carbonate or calcium sulfate minerals

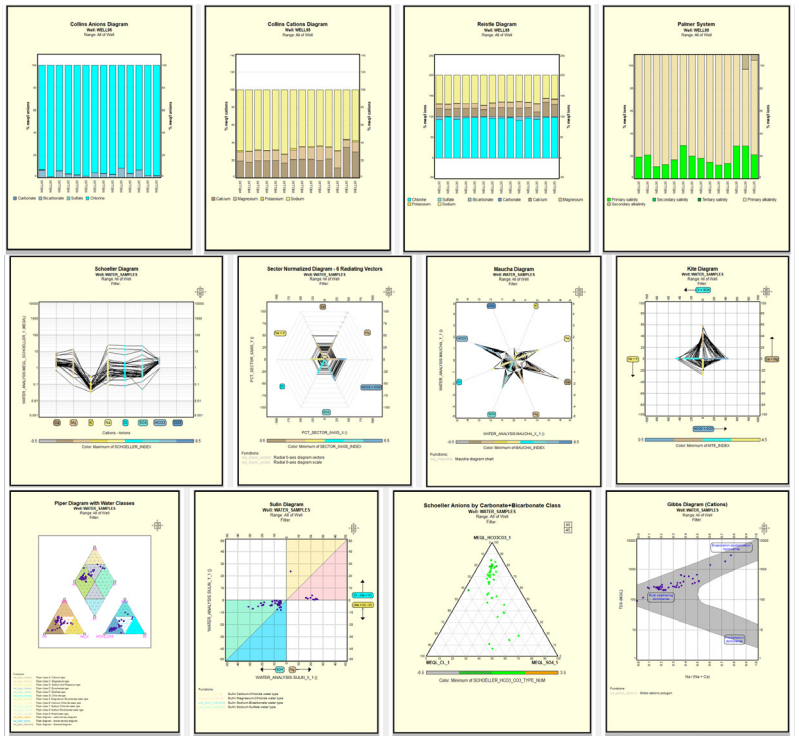

Figure 3. Water analysis graphic plots in Geolog help define the origin of the water, physical properties and tendency to precipitate.

Permeable Pathways Characterization

Faults, natural fractures and induced fractures represent permeable channel ways for fluids, and can also be a source of seismicity. In order to enable both safe and productive geothermal exploration and development, these structures must be accurately characterized and modeled. AspenTech offers a complete set of solutions to detect, characterize and model faults and fractures.

For geothermal areas where seismic data can be acquired, cutting-edge seismic processing, imaging and interpretation software provides advanced technologies to detect and interpret faults and natural fractures.

Aspen Geolog enables the direct detection of fracture size, aperture, distance and orientation from cores, drill cuttings, image and sonic log interpretation. It enables users to understand the correlation of bedding and fractures with stress direction, pressure, lithology, lithology contacts and permeable zones. The analysis of mud and drilling data provides a better understanding of fracture intensity. Using Aspen Geolog engineering modules, permeable entries can be identified from production logs (or Pressure-Temperature-Spinner logs).

Aspen Interpret™ provides accurate and reliable well test analysis. This helps understand flows in the reservoir by deriving the adequate flow model and evaluating existing fracture and fault systems. Powerful and intuitive diagnostics allow users to easily select a number of different model behaviors. Analysis is validated and optimized using all analysis plots in combination, resulting in the highest analysis quality and confidence.

Aspen SKUA-GOCAD Fracture Modeling (FracMV*) uses fracture density and orientation information to generate geologically constrained discrete fracture networks (DFN) and compute effective fracture flow properties. Fracture density constraints result from structural analysis (SKUA-GOCAD, Aspen Kine3D™), seismic analysis (Aspen QSI, Aspen SeisEarth™, Aspen EarthStudy 360™) and well analysis (Geolog).

These solutions combine this rigorous natural fracture modeling workflow with mapping of induced fractures from microseismic data. Patented stimulated path generation and stimulated rock volume analysis allow users to simulate hydraulic fracture networks in high definition (HD). This leads to an in-depth understanding of permeable pathways, enabling an informed geothermal field development plan.

**Developed by Midland Valley*

Planning Wells for Long-Term Productivity

Geothermal well drilling carries a number of risks, including extremely high subsurface temperatures and pressure. AspenTech's fully integrated well planning tools enable the planning of safe trajectories, from simple to complex closed loop. Geolog formation stress and fracture zone identification technologies contribute to safety and make it possible to target sweet zones.

Drilling engineers can simulate a number of drilling scenarios, including complex geothermal gradients and horizontal wells. The integration between Aspen Sysdrill™ and Aspen Geolog Geosteer™ provides an independent way to model, monitor and interactively modify a well as it is drilled, in order to ensure accurate well positioning for optimal production or injection.

Reservoir Monitoring

While exploiting a geothermal field, physical and chemical changes in the reservoir can arise, undesirable geomechanical effects such as induced seismicity and surface subsidence can happen, and the productivity and injectivity of geothermal wells can change over time. Monitoring the changes through time allows us to understand and model the effects of the production and minimize undesirable effects in a timely manner.

The Geolog water analysis module provides interactive graphic plots that help to analyze the variations of the water chemical composition over time. This provides important information about the response of the geothermal reservoir to exploitation. Changes in temperature profiles of wells can be identified through the interpretation of distributed temperature sensor data in Geolog.

Aspen Interpret provides tools to perform build-up and fall-off test analysis, allowing us to monitor well productivity and injectivity, and geothermal reservoir pressure decline.

Integrating all geothermal resource information within SKUA-GOCAD improves understanding of the relationships between water injection/ steam production, induced seismicity, subsidence and fracture systems. This leads to an ultimate understanding of fluid flow paths and subsurface response to production, enabling a long-term sustainable reservoir management strategy. In addition, data integration within a unified 3D modeling environment has proven to be an effective tool for communicating with national, state and local regulating bodies.

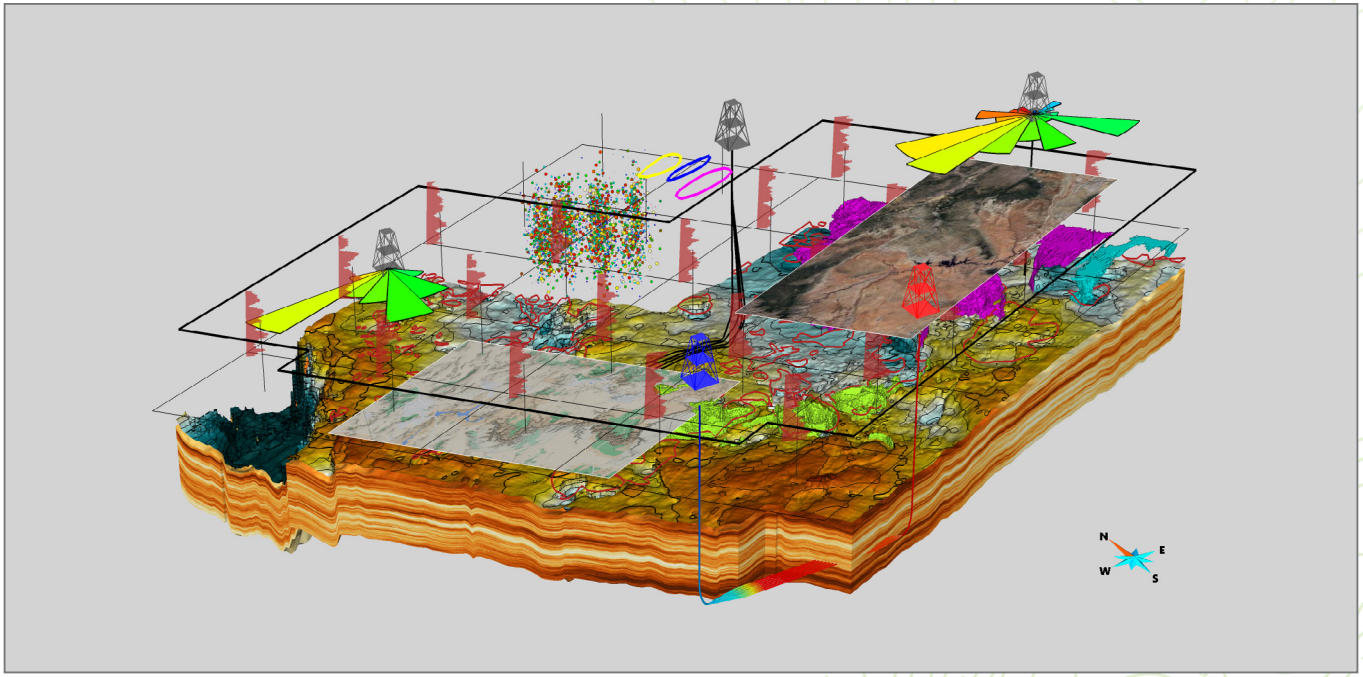

Figure 4. Multi-type data management and integration in SKUA-GOCAD for long-term reservoir management and seismicity mitigation.

About AspenTech

Aspen Technology (AspenTech) is a leading software supplier for optimizing asset performance. Our products thrive in complex, industrial environments where it is critical to optimize the asset design, operation and maintenance lifecycle. AspenTech uniquely combines decades of process modeling expertise with machine learning. Our purpose-built software platform automates knowledge work and builds sustainable competitive advantage by delivering high returns over the entire asset lifecycle. As a result, companies in capital-intensive industries can maximize uptime and push the limits of performance, running their assets safer, greener, longer and faster.

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