CALPINE®

Aspen SKUA™ Provides Deeper Insight for The Geysers, One of the World's Largest Geothermal Systems

aspentech | Case Study

"The use of Aspen SKUA's 3D structural modeling techniques and its powerful data integration capabilities have provided Calpine with a much deeper understanding of The Geysers geothermal field and its potential for sustainable energy production."

- Craig S. Hartline, Senior Geophysicist, Geysers Technical Services, Calpine Corporation

CHALLENGE

In order to mitigate seismicity, and to optimize geothermal field development, Calpine needs a deep understanding of The Geysers fluid flow paths, reservoir heterogeneity and compartmentalization.

SOLUTION

Aspen SKUA enabled the creation of a highly constrained and continually refined 3D structural model that assists with water injection and steam production well planning, reservoir management, drilling analysis and a better understanding of induced seismicity.

VALUE CREATED

Aspen SKUA 3D visualization is an effective tool for sharing subsurface information with geoscientists, reservoir engineers, drilling specialists and regulators. Together with public outreach efforts, this has enabled productive discussion around induced seismicity mitigation efforts while highlighting the potential of geothermal energy to support a cleaner, more dependable and more sustainable energy future.

Overview

The Geysers, located in Northern California (Figure 1), is a unique and complex geothermal system that has been the subject of ongoing exploration, development and research for over 50 years. With a fieldwide production capacity of 825 million watts of electrical power output and an area of 29,000 acres, it is the largest producing geothermal field in the world. Calpine Corporation operates 13 geothermal plants at The Geysers, harnessing the energy from 321 steam production wells, with an average wellhead temperature of 359°F and an average steam production of 35,470 pounds/hour/well.

In order to sustain power generation, water is injected into the steam reservoir, using natural gravity force. This water injection cycle contributes to an induced seismicity phenomenon at The Geysers, primarily as relatively cool water encounters hot rock and reactivates existing fractures, and secondarily by modest pressure perturbations.

In order to mitigate seismicity, and to optimize well planning, real-time drilling analysis and steam reservoir management, Calpine needs a deep understanding of the Geysers' fluid flow paths, fluid boundaries, reservoir heterogeneity and reservoir compartmentalization.

The complexity and scale of The Geysers geothermal field presents significant challenges for 3D modeling. Following a comprehensive evaluation and selection process that considered all modeling software options in the market, Calpine chose the Aspen SKUA subsurface modeling suite, which enables the integration of all available data related to reservoir properties and boundaries.

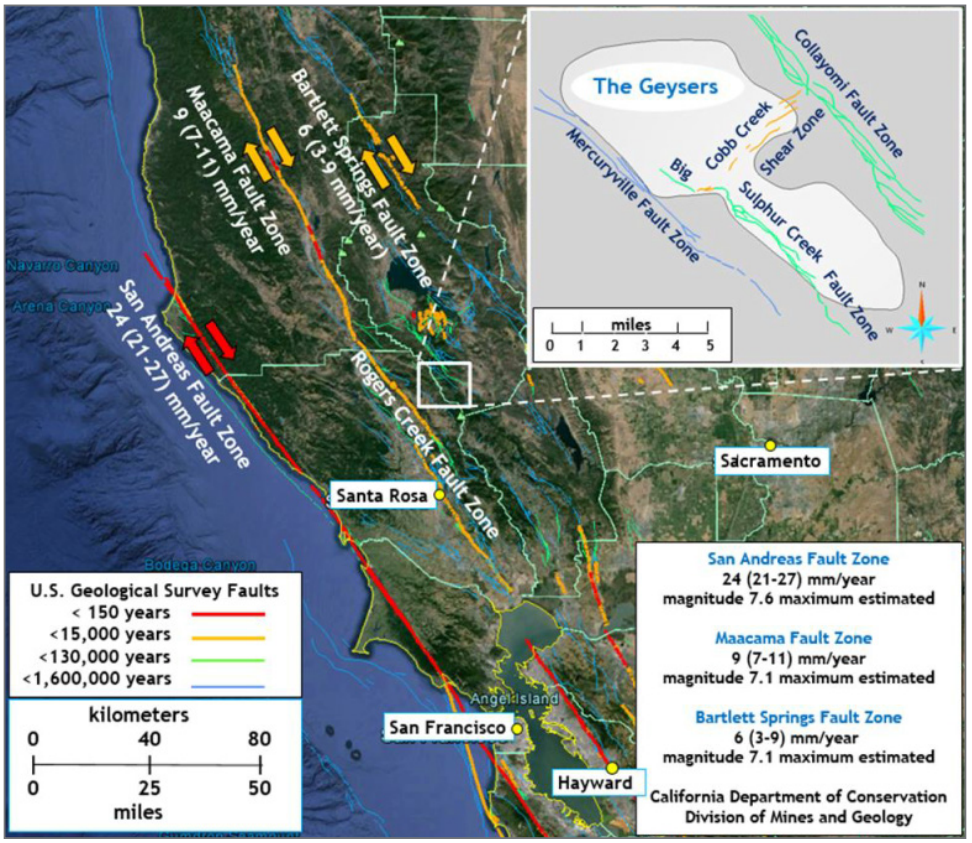

Figure 1. The San Andreas Fault System, including the Maacama/Rodgers Creek Fault Zone and Bartlett Spring Fault Zone (Source: USGS). Faults with activity in the past 1.6 million years overlaid on Google Earth image. United States Geological Survey Faults with activity in the past 1.6 million years overlain on Google Earth image. Primary Geysers bounding fault zones shown in the upper right inset, and fault parameters from the California Division of Mines and Geology (1996) shown in the lower right inset.

A Comprehensive 3D Structural Model Using All Data Constraints

In the first stages of the program, the Aspen SKUA solution was used to:

- Develop an extensive and properly formatted project database.
- Develop a 3D structural model representing the complex geology of The Geysers using all available data constraints.
- Use 3D visualization and 3D seismicity analysis software to better understand the spatial and spatiotemporal relationships between water injection and induced seismicity.
- Deepen understanding of fracture systems and fault zones.
- Develop a refined 3D Vp/Vs velocity model to enhance 3D seismicity hypocenter positioning, using lithology determinations and rock properties as a proxy for velocity; perform tomographic updates based on this Vp/Vs velocity model.
- Perform well planning and real-time drilling analysis within a continually refined 3D structural model.
- Transfer the 3D structural model elements into The Geysers reservoir engineering model, as an improved basis for upscaling and simulations.
- Provide a more integrated approach to field development and reservoir management by linking geoscience, drilling and reservoir engineering. Knowledge gained from reservoir modeling, history matching and drilling activities will provide feedback for continuing refinement of the 3D structural model.

In The Geysers' 3D structural model development program, Aspen SKUA was able to integrate diverse data into a single environment. These included approximately 950 lithological log segments, surface geology maps, isotopic patterns, reservoir temperature and pressure, reservoir tracer test patterns, heat flow patterns, non-condensable gas concentrations, and seismicity hypocenter databases provided by the Northern California Earthquake Data Center (NCEDC) and Lawrence Berkeley National Library (LBNL) (Figure 2).

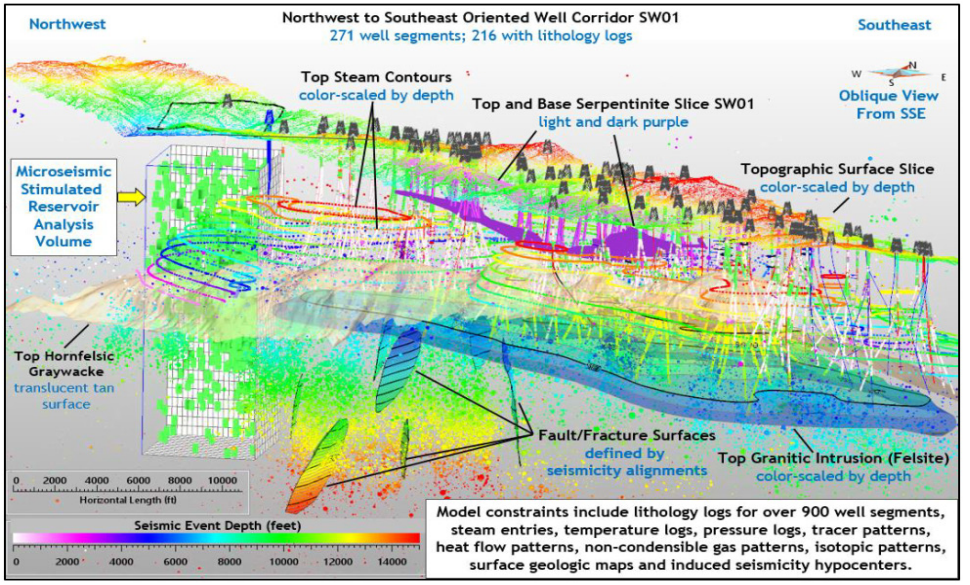

Figure 2. Oblique view from the south-southeast of The Geysers 3D structural model including several identified horizons, a well corridor including 216 wells with lithology logs, preliminary fracture surfaces and a microseismic stimulated reservoir analysis volume in the northwest portion of the field associated with the Department of Energy co-funded Northwest Geysers Enhanced Geothermal System Demonstration Project. Modified from Hartline et al. 2019.

Aspen SKUA software allows the synchronized time animation of water injection and induced seismicity hypocenters at any appropriate time step and interval. While completing the induced seismicity analyses and visualization associated with required semi-annual technical presentations and 3D pre-drilling analysis projects, it became increasingly clear that seismicity patterns/alignments indicative of fluid flow and subsurface structure were present on a series of seismicity slices and could be analyzed slice by slice through time.

Seismicity patterns or alignments evident in static displays, or those that evolve during time-animations of variously oriented seismicity slices (Figure 3), contribute to the interpretation of fracture/fault surfaces, structural discontinuities and lithology contrasts, providing an additional significant constraint on the 3D structural model building process.

A Deeper Understanding of the Subsurface

Aspen SKUA allowed the creation of a highly constrained (and continually refined) 3D structural model that assists with reservoir management, water injection and steam production well planning, real-time drilling analyses, and a better understanding of induced seismicity at The Geysers.

Utilizing Aspen SKUA 3D visualization capabilities to visualize seismicity hypocenters through time not only helped better constrain the 3D model but was also key to obtaining a deeper understanding of the structural relationships, fluid flow paths, fluid boundaries, reservoir heterogeneity, and compartmentalization at The Geysers.

More recently, these techniques have been useful fieldwide, and contributed greatly to Calpine's understanding of the subsurface during the Department of Energy co-funded Northwest Geysers Enhanced Geothermal System (EGS) Demonstration Project. The progression of induced seismicity away from the EGS water injection well in time-animated view provides strong evidence of initial fluid flow along NW-SE and SW-NE fracture networks and possible compartmentalization of the reservoir.

Calpine now uses 3D visualization as an effective tool for sharing technical subsurface information with geoscientists, reservoir engineers, drilling specialists and regulators, when both analyzing drilling targets and during real-time drilling. Together with public outreach efforts, this has enabled productive discussion around induced seismicity mitigation efforts while highlighting the potential of geothermal energy to contribute to the transition to a cleaner, more dependable and more sustainable energy future.

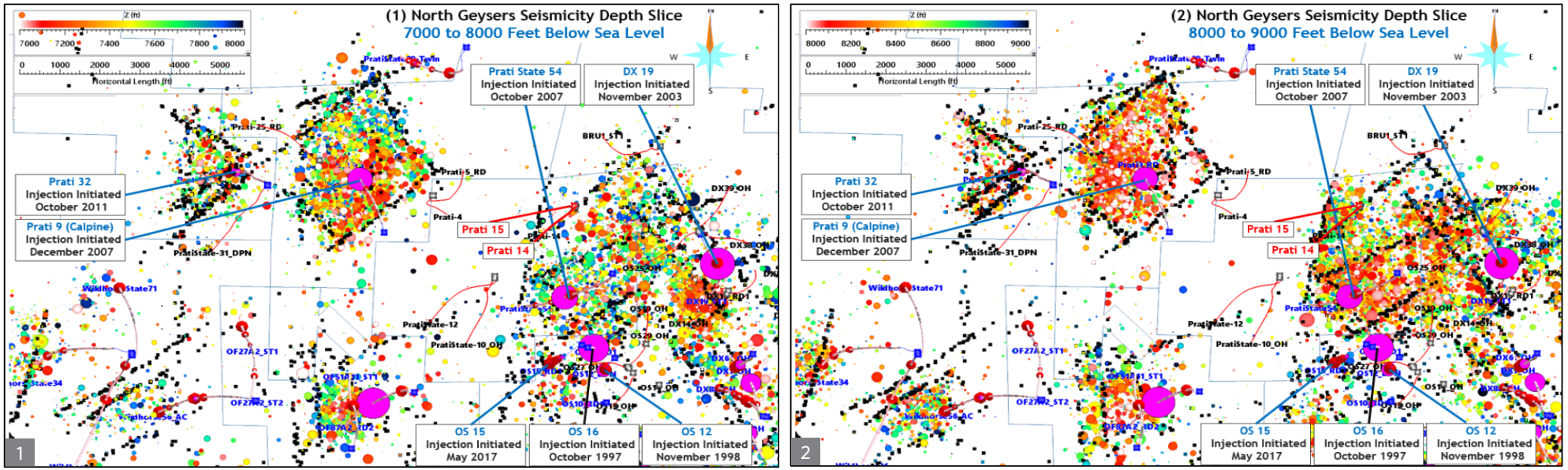

Figure 3. North Geysers seismicity depth slices from (1) 7000 to 8000 ft subsea and (2) 8000 to 9000 ft subsea for the time interval from 2000 to 2018. SKUA picks (in black) completed directly on aligned seismicity hypocenters are shown at a depth interval of 6500 to 8000 ft subsea in each image. The resulting aligned picks are believed to be indicative of fault/fracture surfaces, hydrological discontinuities and reservoir compartmentalization.

Conclusion

The 3D visualization, data analysis and structural model building techniques in Aspen SKUA have long-term benefits for effective geothermal reservoir management, including optimizing water well placement, real-time drilling decisions, and the potential for induced seismicity mitigation. 3D structural model development is part of a program to honor a vast collection of field data and more closely link geoscience, reservoir engineering and drilling. This is anticipated to contribute to the geothermal reservoir management and induced seismicity mitigation efforts at The Geysers.

About AspenTech

Aspen Technology, Inc. (NASDAQ: AZPN) is a global software leader helping industries at the forefront of the world's dual challenge meet the increasing demand for resources from a rapidly growing population in a profitable and sustainable manner. AspenTech solutions address complex environments where it is critical to optimize the asset design, operation and maintenance lifecycle. Through our unique combination of deep domain expertise and innovation, customers in capital-intensive industries can run their assets safer, greener, longer and faster to improve their operational excellence.

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