Case study: Wayang Windu geothermal field, Indonesia

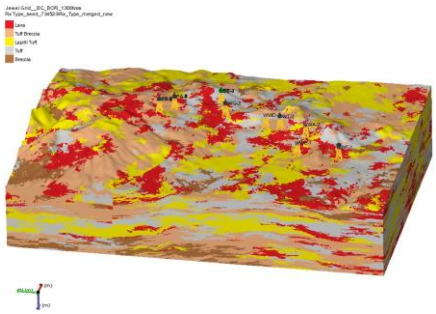
Integrated 3D geothermal workflow delivered basis for expansion of Indonesian geothermal power plant

The Wayang Windu field, Indonesia, is a fracture/fault-hosted geothermal field where fracture and fault permeability provides permeable conduits for fluid migration. Subsurface characterization of these fractures and faults and the host rock is critical to successful operations. Microseismic events induced by injection are difficult to interpret due to simultaneous production operations. The field has three distinct pressure domains: water, steam, and brine below an impermeable barrier. Any stimulation design, therefore, must be tailored to optimize hydro shearing while maintaining wellbore stability and cap rock integrity. Complicating the objectives, the field has very high topographic relief and relatively shallow resources resulting in extreme topographic effects on the *in situ* stress magnitudes and orientations. Stimulation causes the rock to cool resulting in extreme changes in the *in situ* stress magnitudes due to time dependent thermoelastic effects.

The operator of this field did not possess a broad understanding of heterogeneity in fracture intensity throughout the field. In addition, some of the well designs drilled into the fracture networks experienced unexplained poor production. Surface subsidence risk was high due to pressure depletion as well as a potential cap rock seal breech. All these factors proved all the more problematic by time dependent wellbore instability.

Seeking a solution, the operator reached out to Baker Hughes, a global leader in oil, gas, and geothermal geomechanics. The recommendation centered on a 4D geomechanical model supplied by the **JewelSuite™ integrated reservoir modeling software**. This application is an innovative, powerful tool to quickly create precise geological models—regardless of the reservoir's structural complexity—in half the time as traditional solutions. This modeling tool can seamlessly transfer into any industry standard simulator. Reservoir models can be updated and modified easily with new well information or alternative geological scenarios to optimize field development plans and drive greater production.

In this project—one of the first integrated 4D geomechanical analysis of a 3-phase geothermal system applied to a diverse set of operator challenges—the 4D dynamic geomechanical model was verified against both well-based observations and an independent analysis of microgravity changes (subsidence)



The 3D structural and lithologic model of the Wayang Windu Field, Indonesia

Challenges

- Increase production
- Understand hydro-mechanics between reservoir fractures and faults and away from well controls
- Mitigate wellbore instabilities
- Develop a full-field well planning strategy

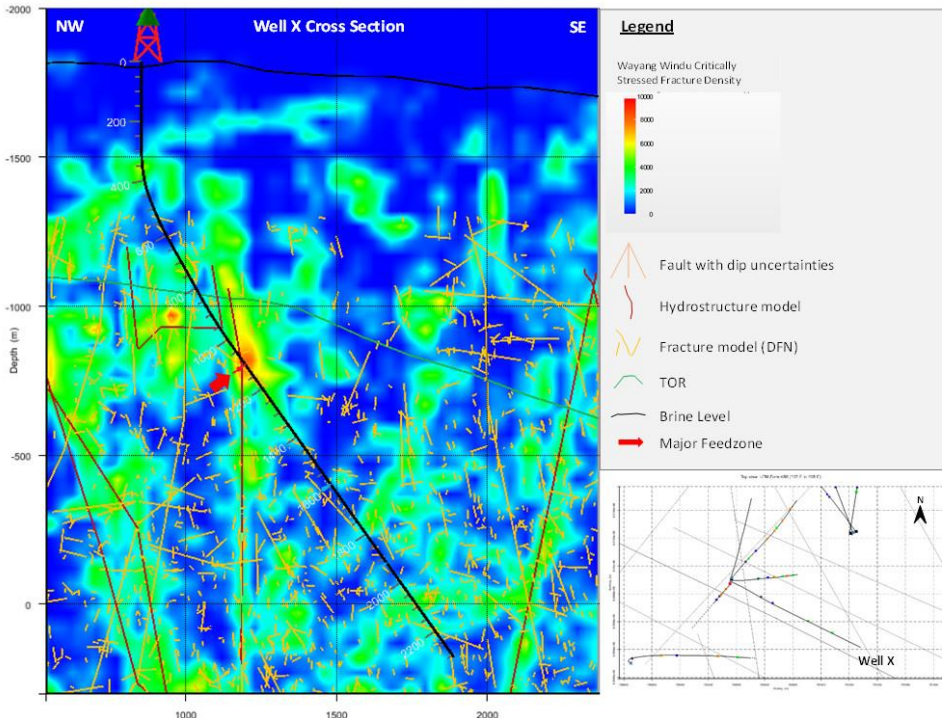
Results

- Delivered first integrated 4D geomechanical analysis of a 3-phase geothermal system
- Identified target sweet spots for immediate field development with an estimated 20% increase in production over standard output capacity (up to 424 MW)
- Reduced risk of well loss due to fault reactivation or hole collapse over 25 wells, an estimated savings of $25 million
- Reduced field-wide risk of cap rock integrity loss during stimulation and production by establishing pressure maintenance criteria
- Experienced no health, safety and environmental (HSE) issues or nonproductive time (NPT)

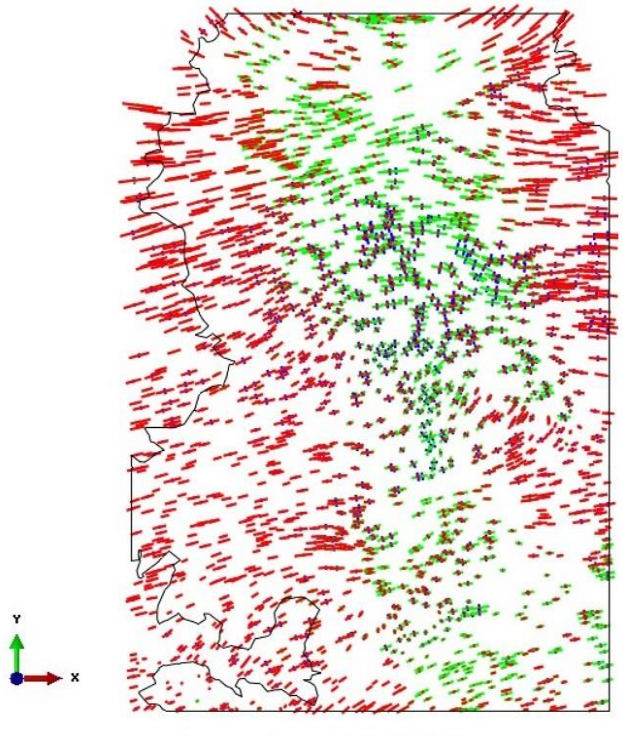
due to depletion from production. Fracture architecture, defined statistically using available field measurements, provided an inter-connected discrete fracture network (DFN) model. The DFN model was calibrated with independent observations of pressure and tracer communication and used to make predictions of permeability in planned wells. The DFN modeling demonstrates how currently available data and 3D geologic and geomechanical models can be integrated to develop a hydro-structural model closely related to interpreted surface lineaments, microcosmically delineated faults, and a statistical description of fracture geometries away from well controls.

Baker Hughes experts provided the operator with a more complete understanding of the ways in which the geomechanics of the reservoir impacted the day-to-day operational decisions. Also provided was geomechanical training and a robust workflow to guide future field development. The workflow developed for this project has become the standard process to assess subsurface structural permeability distribution at Wayang Windu and other geothermal reservoirs.

In particular, the 3D reservoir model of the target sweet spots for immediate field development identified 9 existing wells as candidates for well intervention by stimulation. Given the operator's output capacity of 354 megawatts (MW), the JewelSuite model suggested an estimate increase of an additional 70 MW, a 20% improvement. The expansion would also reduce the risk of well loss due to fault reactivation or hole collapse. Over the 25 wells in the field, Baker Hughes could save $25 million for the operator. Lastly, the field-wide risk of cap rock integrity loss during stimulation and production was reduced by establishing pressure maintenance criteria.



Slice through Wayang Windu Field 3D volume showing the intensity of critically stressed fracture intersections



The orientations of the principal stresses are strongly affected by the topography of the Wayang Windu Field

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