Modeling Production/Injection Strategies in Fracture-Dominated Geothermal Reservoirs

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Quarterly Progress Report for July-September, 2000

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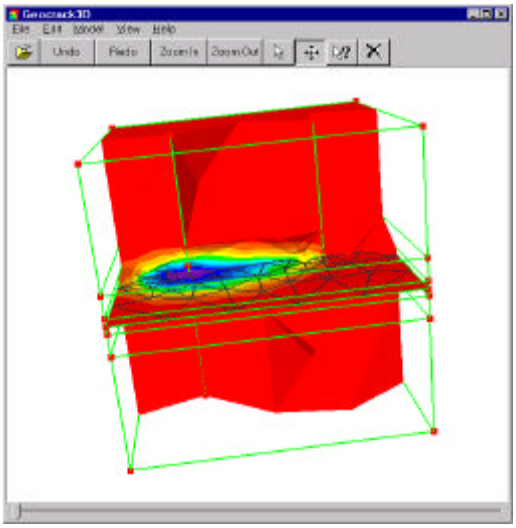

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1 Summary of Progress this Quarter

In this quarter, development focused on multiple tasks needed to complete the analysis capabilities of the project. This included implementing a special logarithmic element to ensure accurate solutions near the wells. We also implemented and performed initial verification of the coupled elastic solution. Design work was completed on restart capability, with implementation nearly completed. Tracer capability was updated to match the latest input data. A simple demonstration manual has been placed on the web site (www.mne.ksu.edu/~geocrack) and the latest executable is available for download.

Details of this quarter's progress are given below.

2 Background Summary of Project

The goal of this project is to develop more realistic models of flow in fracture-dominated geothermal reservoirs. The objective is to improve injection/production strategies to maximize economic extraction of energy from geothermal reservoirs.

Realistic reservoir models are needed because long-term, economic operation of geothermal reservoirs requires that injection be used to recharge fluid and recover additional thermal energy. However, the potential to develop a short-circuit and prematurely cool the produced fluid makes reservoir operators cautious when approaching injection. The model, Geocrack3D, will focus on explicit representation of flow in fractures, including fracture opening due to pressure and temperature changes in the reservoir. This will make it possible to address more clearly issues such as the effect of thermal cooling on flow in the reservoir. A feature-based geometric description will simplify the task of the analyst when developing a reservoir model. Further information can be found at www.mne.ksu.edu/~geocrack.

3 International Collaboration

3.1 Work with Tohoku University

Professor Takatoshi Ito from the Institute of Fluid Science, Tohoku University, spent most of August at Kansas State University, working with us on Geocrack2D and Geocrack3D. He used Geocrack2D to simulate the effect of changes in temperature on permeability of rock. As a result of different thermal expansion coefficients of the minerals in rock, it is hypothesized that microfractures will open as temperatures are changed. He completed initial analyses of this effect.

Professor Ito also created a model to examine the effect of thermal cooling on radial fractures extending from a borehole. Figure 1 shows temperatures calculated near the

borehole. When elasticity coupling is completed, this cooling will change the fracture apertures and flow in the fractures. At that time the analysis will be completed.

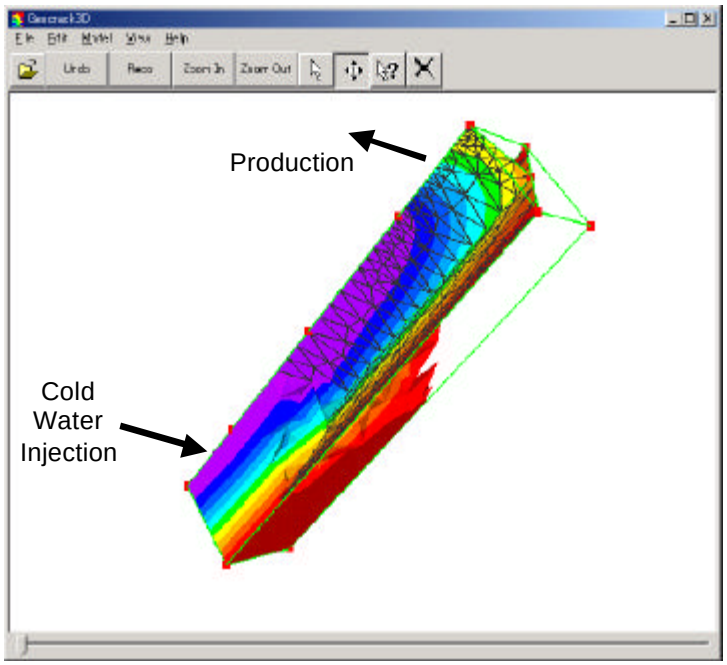

Figure 1: Model of cooling of fractures around a borehole

4 Progress on Geocrack3D

In this quarter, development focused on multiple tasks needed to complete the analysis capabilities required of the project. These included:

- Implementation of logarithmic well elements
- Coupled elastic solution
- Restart capability
- Update of tracer analysis
- Update of web, with new manual and current executable (www.mne.ksu.edu/~geocrack).

Details of each are discussed below.

4.1 Special Logarithmic Well Elements

The solution for flow in the vicinity of a well has a logarithmic pressure distribution. To properly capture the solution near the well, one can either use a fine mesh of elements around the well or use larger elements with the exact logarithmic solution included in the element shape functions. In this quarter, we implemented a new finite element that uses the logarithmic shape function approach, thus ensuring that the correct analytic solution is obtained near a well.

Using methods described by T. J. R. Hughes and J. E. Akin, we start by deriving a three-noded 1D element that includes constant, linear, and logarithmic approximating functions. We then create a 2D element as a cross-product of the 1D logarithmic and standard 1D linear shape functions. Finally, we add two mid-side shape functions to obtain an eight-noded element that includes a logarithmic radial approximation and the standard quadratic approximation on the outer edge. Using a ring of these elements around a well provides an accurate approximation that is still compatible with standard quadratic finite elements on the outer edge of that ring. For a single well test case, calculated pressures have an error of less than one tenth of one percent compared to the analytic solution. An abstract to the 2001 Stanford conference has been submitted.

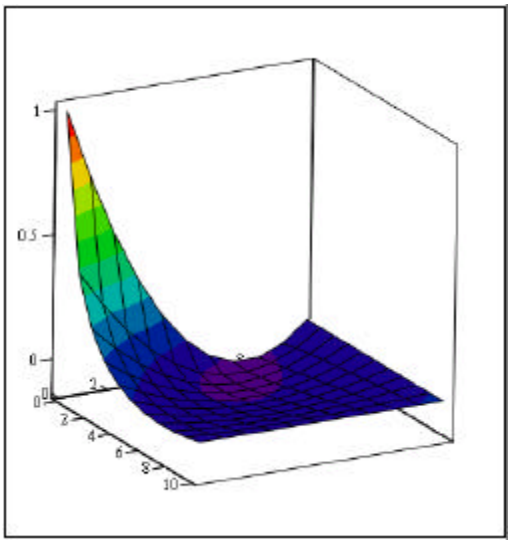

Figure 2: Plot of logarithmic shape function in element

4.2 Coupled Elastic Solution

We completed initial implementation of the coupled fluid flow and elasticity capability. This was tested using a simple mesh. Work on the user interface is proceeding to make it possible to perform more complex coupled analyses. These will be reported next quarter.

4.3 Restart Capability

Design work was completed on a general approach to saving all model data in a restart file. Implementation is proceeding and should be completed by the middle of November, 2000. This include storage of results data, although the results data format might change in the future when we work on speeding display of the 3D results.

5 New Example Manual and Executable on Web

A new example manual was prepared that illustrates the use of Geocrack3D for steady state and transient fluid flow/heat transfer analyses. The example used is flow on a single fracture with injection and production wells spaced 100 m apart.

Figure 3 shows the results of the steady state calculation where the temperatures of the top and bottom surface are held fixed at 250 C. Figure 4 shows the results of the transient calculation at 1000 days. As can be seen, in the transient solution cooling on the fracture occurs, but this is local to the fracture. The volume of cooled rock is much smaller than in steady state. This illustrates the potential for thermal short-circuiting due to flow on fractures.

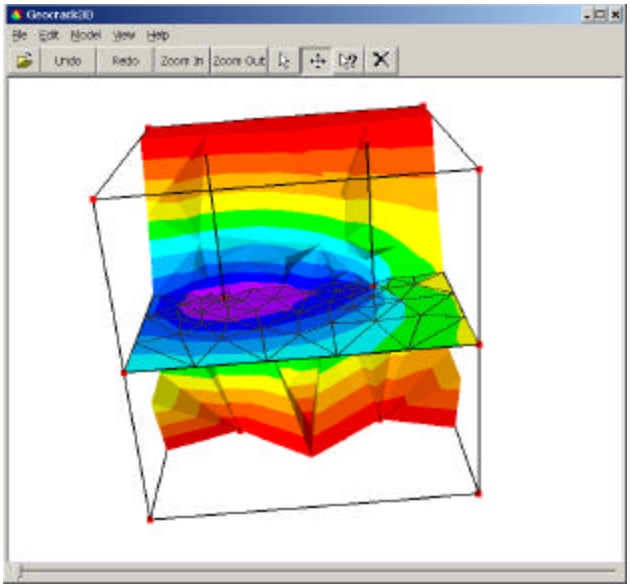

Figure 3: Steady state solution

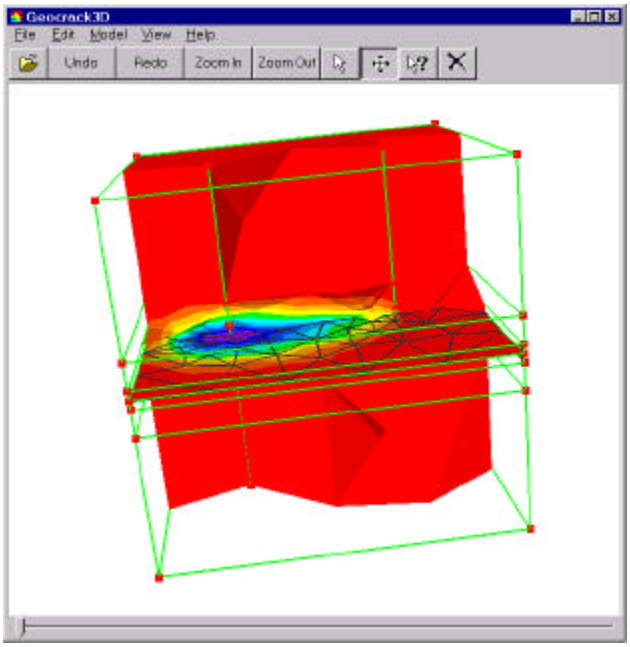

Figure 4: Transient solution at 1000 days