

Project: Desert Peak EGS



(Photograph Courtesy of Ormat Technologies)

Location	Western Nevada
Operator	Ormat Technologies, the Department of Energy and others

A new analytic-adaptive model for EGS assessment, development and management support

May 19, 2010

Principal Investigator
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- Timeline
 - Project start date: 12/29/2009
 - Project end date: 1/31/2013
 - Percent complete: 20% of 2010
- Budget
 - Total project funding: \$1,629,670
 - DOE share: \$1,278,070
 - Awardee's share: \$351,600
 - Funding received in FY09: NA
 - Funding for FY10: \$443,596
- Barriers addressed in GTP 2008
 - Reservoir Characterization (Barrier F)
 - Validation (Barrier I)
 - Scale Up (Barrier L)
 - Sustainability (Barrier M)
- Partners
 - Sub-Contractor: Lawrence Berkeley National Laboratory (LBNL)
 - Co-supporter: ORMAT

Overall:

1. Develop an in depth model of EGS systems that will allow engineers, practitioners, and researchers to more accurately predict how new fluid technologies would work in a reservoir.
2. Test and apply the new model to:
 - Cases with known solutions for benchmarking and comparison.
 - ORMAT's EGS sites (Desert Peak, Brady) for capability demonstrations.
3. Study new fluid flow applications and cooling technologies to improve geothermal power extraction from an EGS.

Phase I, 1st year:

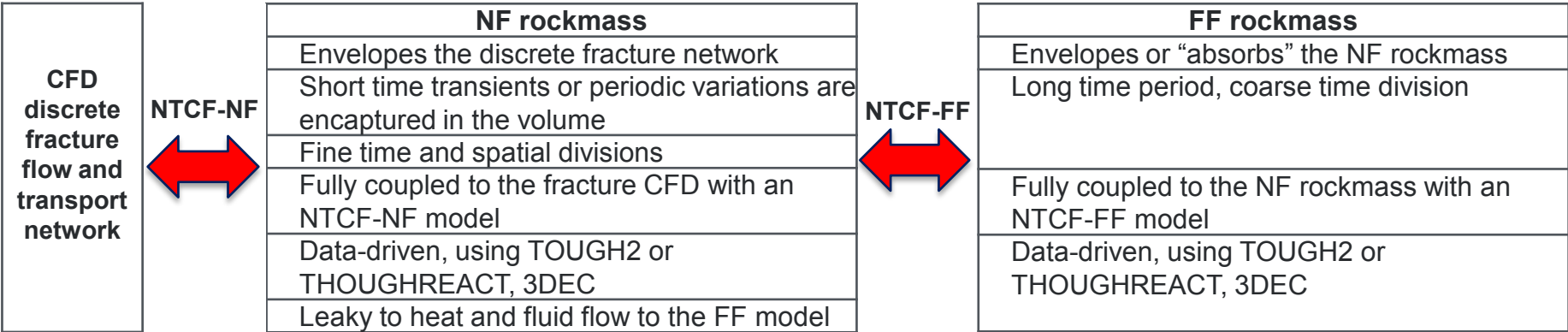
Develop a Geologic Heat Exchanger (GHE) model that simulates discrete fracture network flow and transport in a coupled way to a dual-porosity and dual-permeability rockmass.

The GHE, a coupled THMC (Thermal, Hydrologic, Mechanical, and Chemical) model is the core building element of a numerical simulator for the studies.

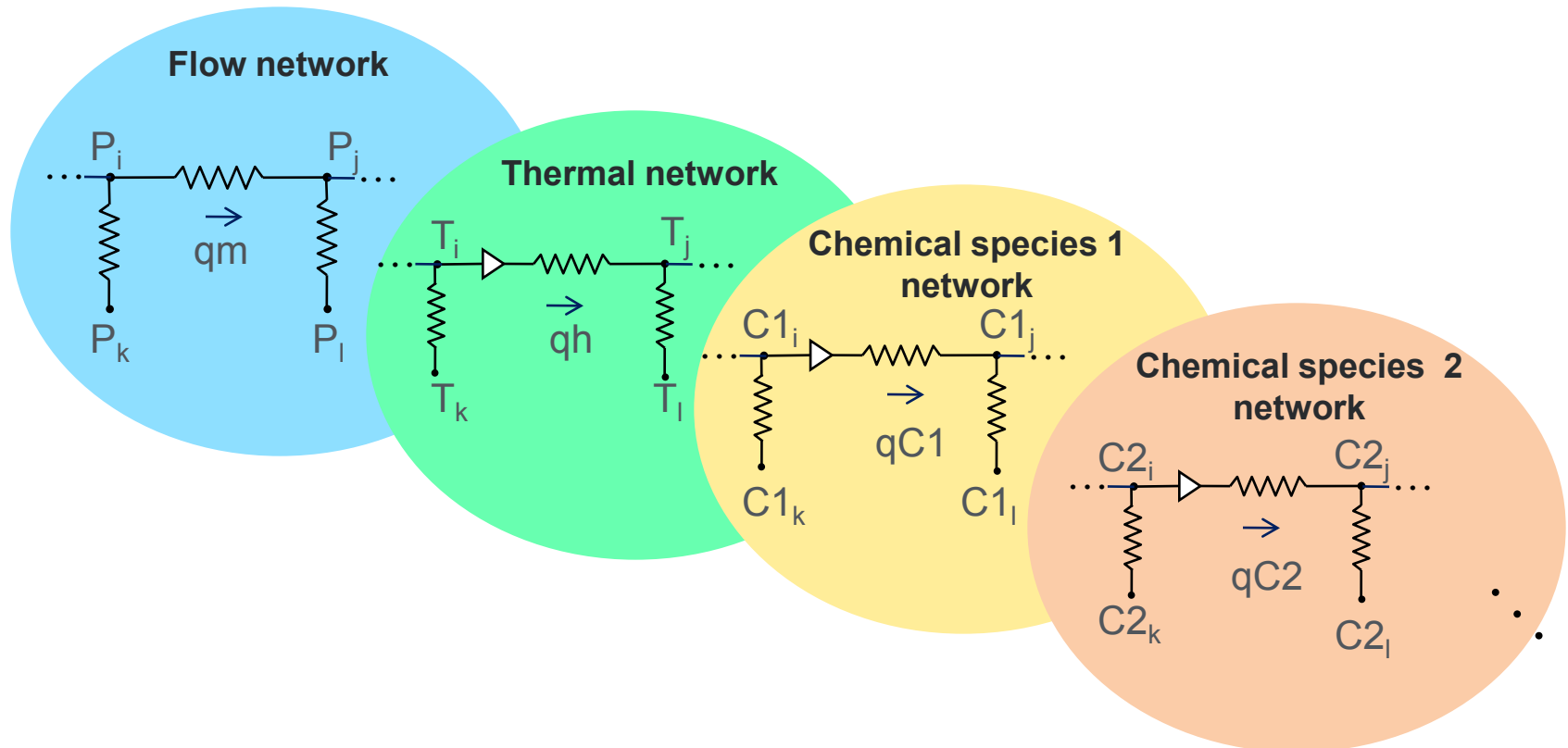
- For discrete fracture flow and transport, apply the integrated-parameter CFD (Computational Fluid Dynamics) model-element of MULTIFLUX 5.0. Import previous model-elements developed for Yucca Mountain (YM) to EGS application

Fracture network CFD: T-H-M-C	
Thermal	: Convection, conduction and heat transfer at the fracture surface
Hydrological	: Pressure, flow rate in fracture, percolation loss into rockmass
Mechanical	: Fracture aperture variation with pressure and temperature
Chemical	: Species convection, diffusion and mass transfer at the fracture surface

- For coupling the discrete fracture CFD model to the rockmass, use the NTCF (Numerical Transport Code Functionalization) modeling technique (See supplemental material).
- For the rockmass, separate and re-couple the Near-Field (NF) rockmass from the Far-Field (FF) rockmass:



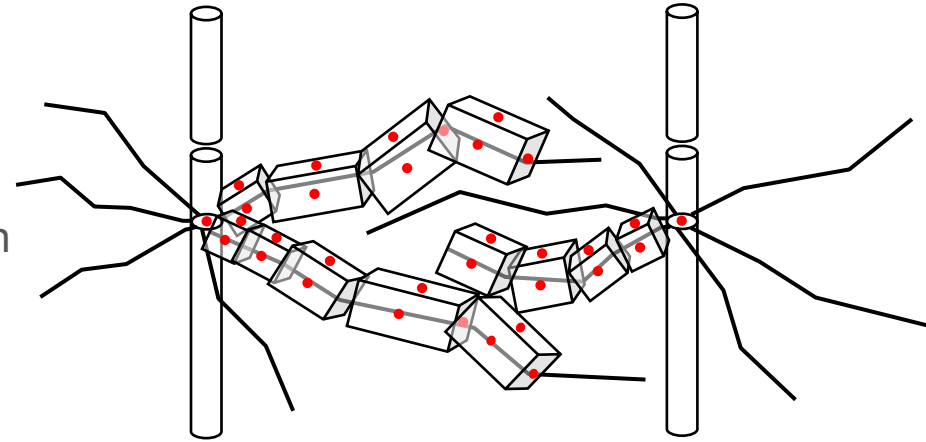
Discrete fracture network model in the GHE



An overlaid set of transport networks for T-H-M-C

Near-Field Model in the GHE

- Envelopes the fracture network in a near-field rockmass
- Fine-grid, it may be 2-D in normal direction to the fracture plane



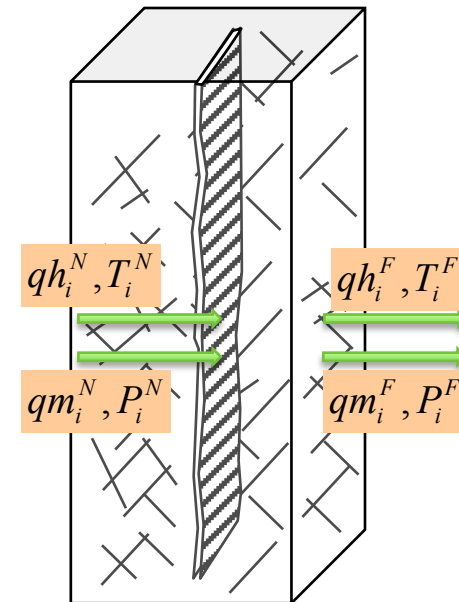
NTCF-NF matrix model for heat and mass at the fracture surface:

$$[qh_i^N] = qh_i^F + hh_i^N \cdot [T_i^N - T_i^F] + hm_i^N \cdot [P_i^N - P_i^F]$$

$$[qm_i^N] = qm_i^F + mm_i^N \cdot [P_i^N - P_i^F]$$

$hh_i^N, hm_i^N, \dots$: NTCF – NF matrices (fixed size)

$T_i^N, P_i^N, \dots$: vectors with finely – sampled variables with time



Far-Field model in the GHE

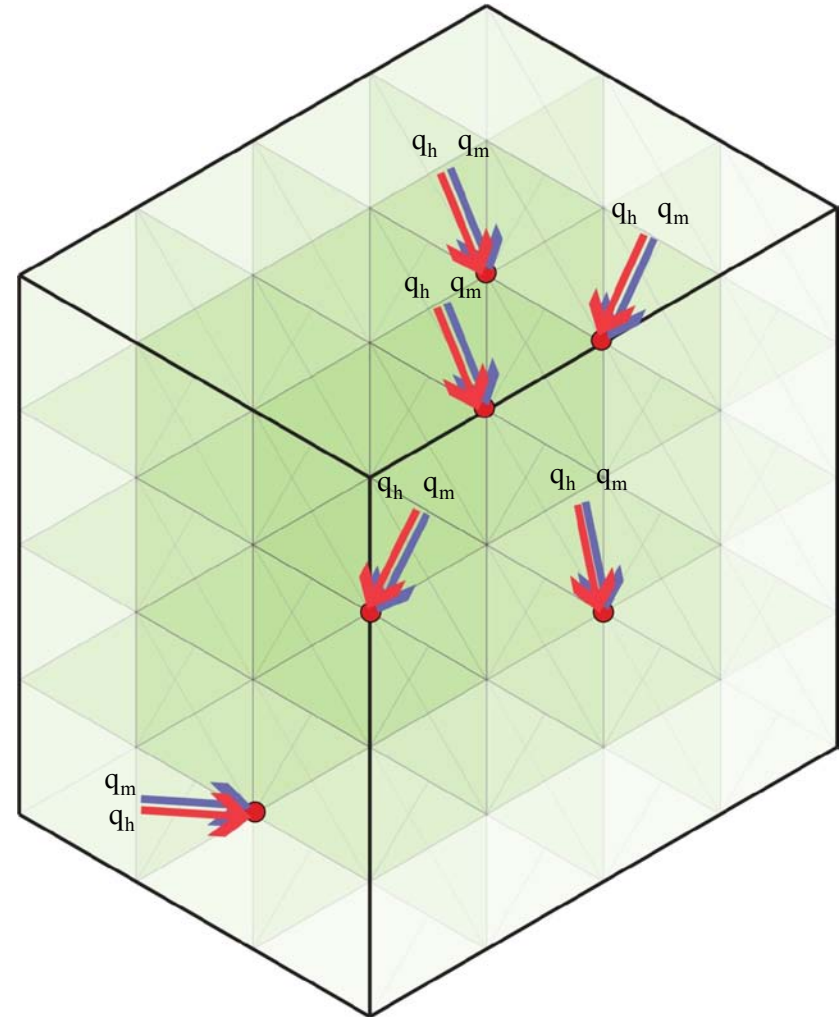
- Dual-porosity, dual permeability THMC model based on data from TOUGH or TOUGHREACT.
- Site-Scale, includes all relevant hydrogeology that affects energy flow
- NTCF-FF model evolves coarse time-step by time-step

NTCF-FF matrix model for heat and mass at the NF-FF contact boundary:

$$\begin{aligned} [qh_i^F] &= hh_i^F \cdot [T_i^F - T_i^{VR}] + hm_i^F \cdot [P_i^F - P_i^{VR}] \\ [qm_i^F] &= mh_i^F \cdot [T_i^F - T_i^{VR}] + mm_i^F \cdot [P_i^F - P_i^{VR}] \end{aligned}$$

$hh_i^F, hm_i^F, \dots$: NTCF – FF matrices

$T_i^F, P_i^F, \dots$: vectors with coarsely – sampled variables with time



Coupling the CFD discrete fracture network model to the rockmass NF and FF model-elements in the GHE

1) Coupling between CFD and NTCF-NF and NTCF-FF

- Coupling to CFD uses both NTCF-NF and NTCF-FF model elements.
- NTCF-NF is a fixed-size matrix model capturing short-time transients in a limited time period, e.g., 10 to 20 days, prepared for the entire time period.
- NTCF-FF is a growing-size matrix model for slow and deep-penetrating transients covering the reservoir life span, prepared for one coarse, forward time step.
- Matrix equation coupling is derived for both NTCF-NF and NTCF-FF model-elements without iteration, a new and unique result from the project.

$$qh_i^N = Fh_1(hh_i^N, hh_i^F, T_i^{VTR}, P_i^{VR}) + Fh_2(hh_i^N, hh_i^F) \cdot T_i^N + Fh_3(hm_i^N, hm_i^F) \cdot P_i^N$$

$$qm_i^N = Fm_1(mm_i^N, mm_i^F, P_i^{VR}) + Fh_2(mm_i^N, mm_i^F) \cdot P_i^N$$

$Fh_1, Fm_1, \dots$: heat and percolation fluid loss vectors sampled at fine time divisions;

all are functions of the $hh_i^N, hh_i^F, \dots$ NTCF matrices

Fh_2, Fh_3, Fm_2 : heat and percolation matrices, all are functions of the $hh_i^N, hh_i^F, \dots$ NTCF matrices

Coupling to CFD is accomplished using the DISAC (Direct Iteration and Successive Approximation Coupler), imported from MULTIFLUX:

$$qh_i^N = qh_i^{CFD}; qm_i^N = qm_i^{CFD}$$

$$T_i^N = T_i^{CFD}; P_i^N = P_i^{CFD}$$

2) Coupling between NTCF-NF and NTCF-FF

- Explicit prediction without iteration:

$$T_i^F = Fh_4(hh_i^N) \cdot T_i^N + Fh_5(hm_i^N) \cdot P_i^N + Fh_6(T_i^{VTR})$$

$$P_i^F = Fm_3(mm_i^N) \cdot P_i^N + Fm_4(P_i^{VTR})$$

Both can be refined by iteration if NTCF-FF is strongly-nonlinear (re run TOUGH, re-do hh_i^F , re-solve for T_i^F, P_i^F)

Fluxes can be directly calculated:

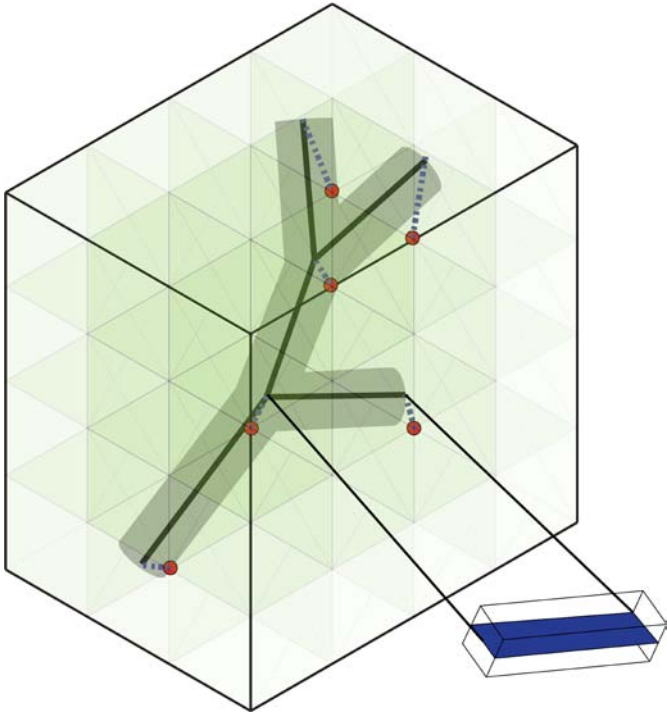
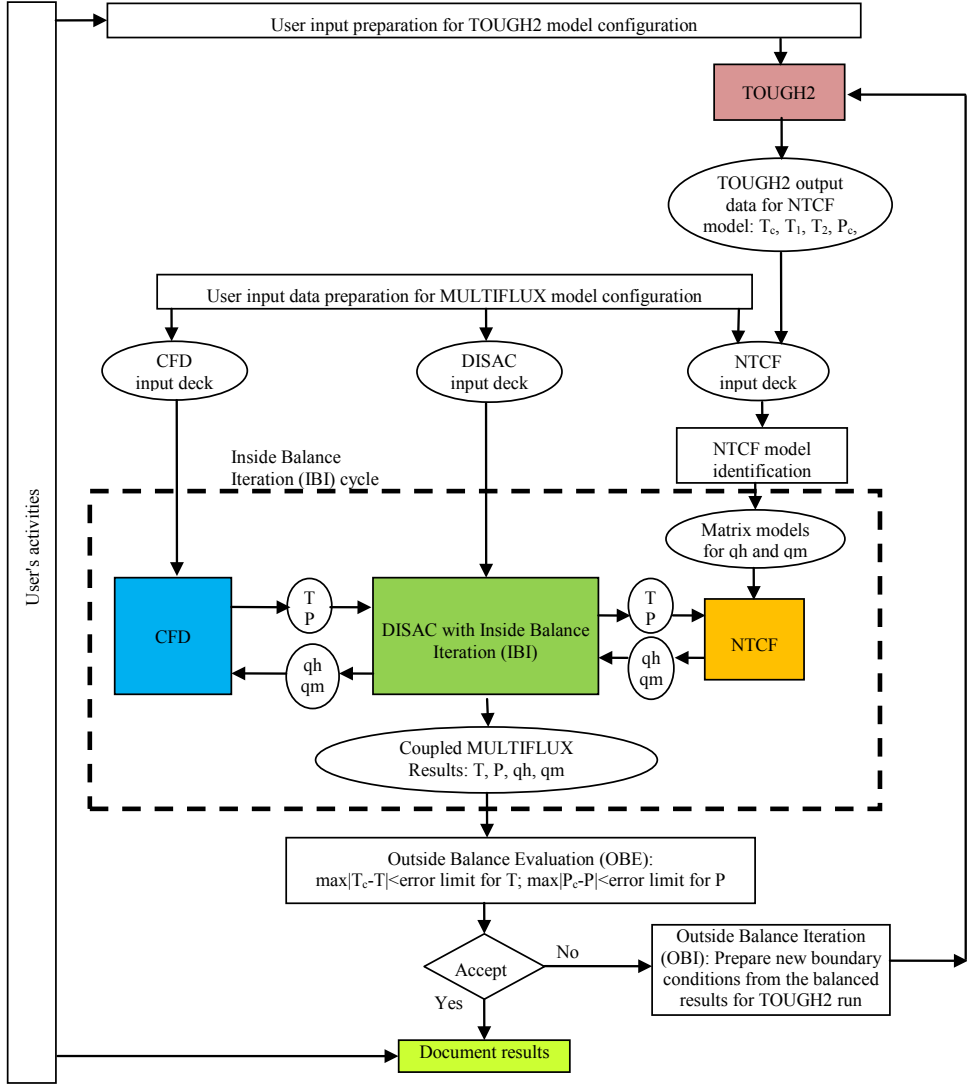
$$qh_i^F = hh_i^F \cdot (T_i^F - T_i^{VR}) + hm_i^F \cdot (P_i^F - P_i^{VR})$$

$$qm_i^F = mm_i^N \cdot (P_i^F - P_i^{VR})$$

- Progress with NTCF-FF for next time step, assuming that the last flux vector elements hold constant over the next time period.
- Add new lines to $hh_i^F, hm_i^F, \dots$

Note: $T_i^F, qh_i^F, P_i^F, qm_i^F$ are used only for NTCF model identification, not as boundary conditions for coupled solution.

Coupling between the CFD and the combined NF and FF NTCF models



Complete, 3-year project components:

Phase I. Multi-scale GHE sub-model (THMC) development

- Fully coupled Thermal-Hydrologic (TH) model
- Mechanical and Chemical (MC) models use surrogate models
- TH model is fully iterated

Phase II. Life-cycle sub-model development of the EGS

- Rock mechanics surrogate development
- Fracture coating surrogate model development

Phase III. Total system model studies and verification exercises

- Literature examples
- ORMAT examples: Desert Peak, Brady

Progress:

- A Key Research Scientist position was created on Jan, 1st, 2010.
- A sub-contract to the Lawrence Berkeley National Laboratory (LBNL) has been set up.
- We have collected and organized the numerical model-elements in Tasks 1 through 3 during the first quarter of the work.
- A literature search was conducted on two-phase flow and heat transfer model-elements in Task 1.
- The TOUGH2 code was requested and installed at UNR to support Task 2.
- A structural coupling model configuration in MULTIFLUX was developed which allows for increasing the discretization distances to cover a large model domain with lower discretization error in Task 3.
- Multi-scale, near- and far-field rockmass model elements were separated and re-coupled non-iteratively using the NTCF technique.
- Organizational and two technical meetings with ORMAT took place.

Expected Outcome, Phase I:

- A functional GHE numerical model.
- Some numerical verification examples.
- Preparation for CFD network adaptation to an EGS site, based on matching borehole, seismic, pumping and tracer test data.
- To accelerate the numerical studies, it is of mutual interest of UNR as well as ORMAT to use the Desert Peak EGS field data for the first application example.

Management and Schedule:

- All tasks are worked on, shown in table below.
- Work contact with LBNL is according to the Subcontract.
- Work contact with ORMAT is according to the support pledge.

		PHASE 1 (FY10)			
PHASE 1	Multi-scale geologic heat exchanger sub-model	*	*	*	*
Task 1	THMC model-elements for fracture network system	*	*	*	*
Subtask 1.1	Two-phase flow and pressure fields model-element	*	*	*	*
Subtask 1.2	Heat flow and temperature fields CFD model-element	*	*	*	*
Subtask 1.3	Chemical species flow and concentration CFD model-element	*	*	*	*
Subtask 1.4	Fracture aperture and morphology variation model-element	*	*	*	*
Task 2	Model-element for TH transport in rockmass	*	*	*	*
Task 3	Boundary coupler between fracture network and rockmass	*	*	*	*
Delivery 1	Annual progress report, and publications as applicable. Closure of the working GHE sub-model.	*	*	*	*

Plan for the rest of this year (FY10) and next year (FY11):

- Add new elements to MULTIFLUX:
 - Fracture aperture variation and
 - Two-phase heat transport surrogate model elements
 - Material properties database expansion
- Validate by numerical demonstration of the practical separation of domains between near-field and far-field model elements.
- Milestone I is a functional GHE model with functional near-field and far-field model-elements adaptable for EGS with variable discrete fracture network assumptions.
- The model uses MULTIFLUX, a qualified software with proven NTCF rockmass model technique and integrated-parameter, CFD model-elements.
- High ambitions, no threat to reach Milestone I. In cases of difficulties, we will cut back model size or increase computer computational capacity.

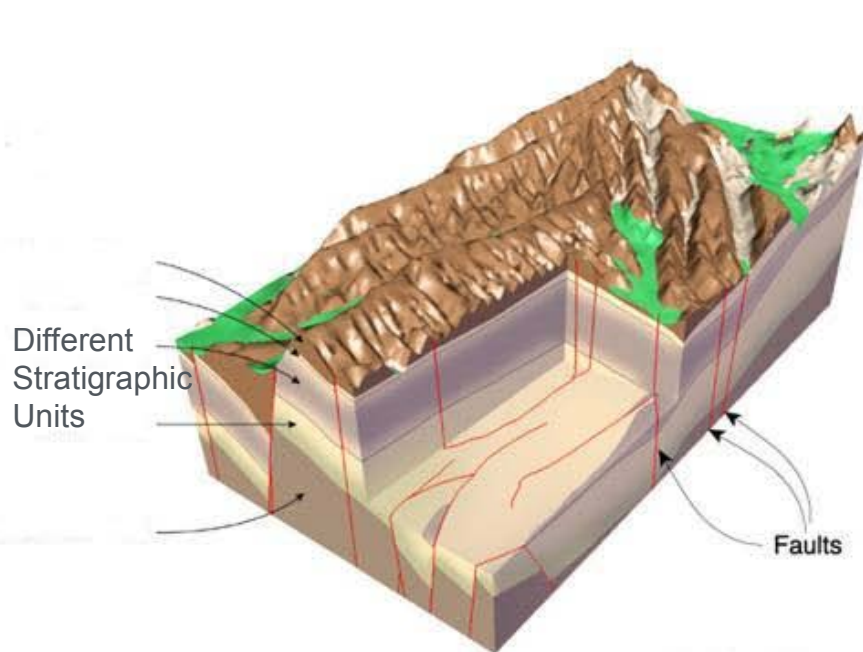
- A validated and qualified, integrated-parameter CFD model in MULTIFLUX is imported from Yucca Mountain to EGS studies for flow and transport in a discrete fracture network. It is very efficient, and dramatically reduces the necessary number of grid nodes as compared to conventional CFD models.
- A validated and qualified NTCF modeling in MULTIFLUX is imported for separating a near-field model domain from the far-field THMC rockmass model domain, a new development.
- The near-field model for a hypothetical discrete fracture flow network offers a promise for adaptability to field data for a given set of seismic, borehole, pumping and tracer test results.
- The discrete fracture network model coupled with the near-field rockmass model will be a new reservoir assessment tool.
- The coupled near-field and far-field models offer a promise for energy recovery predictions to support management and operation.
- The discrete fracture network model coupled with the near-field rockmass model will run fast on fine time scale, and will be a new tool to study fluid flow delivery, and management support options.

Supplemental Slides

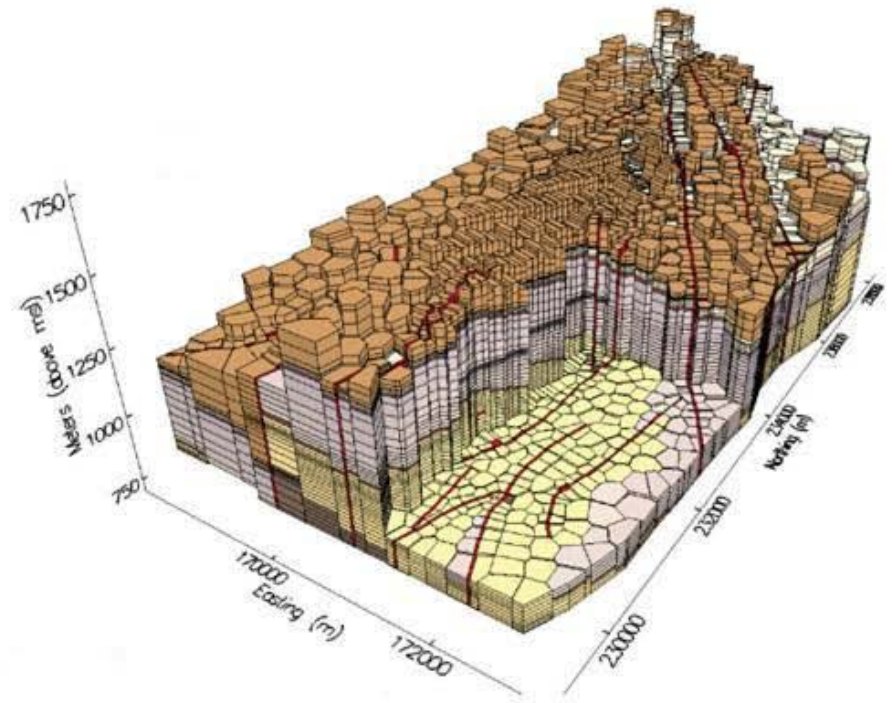
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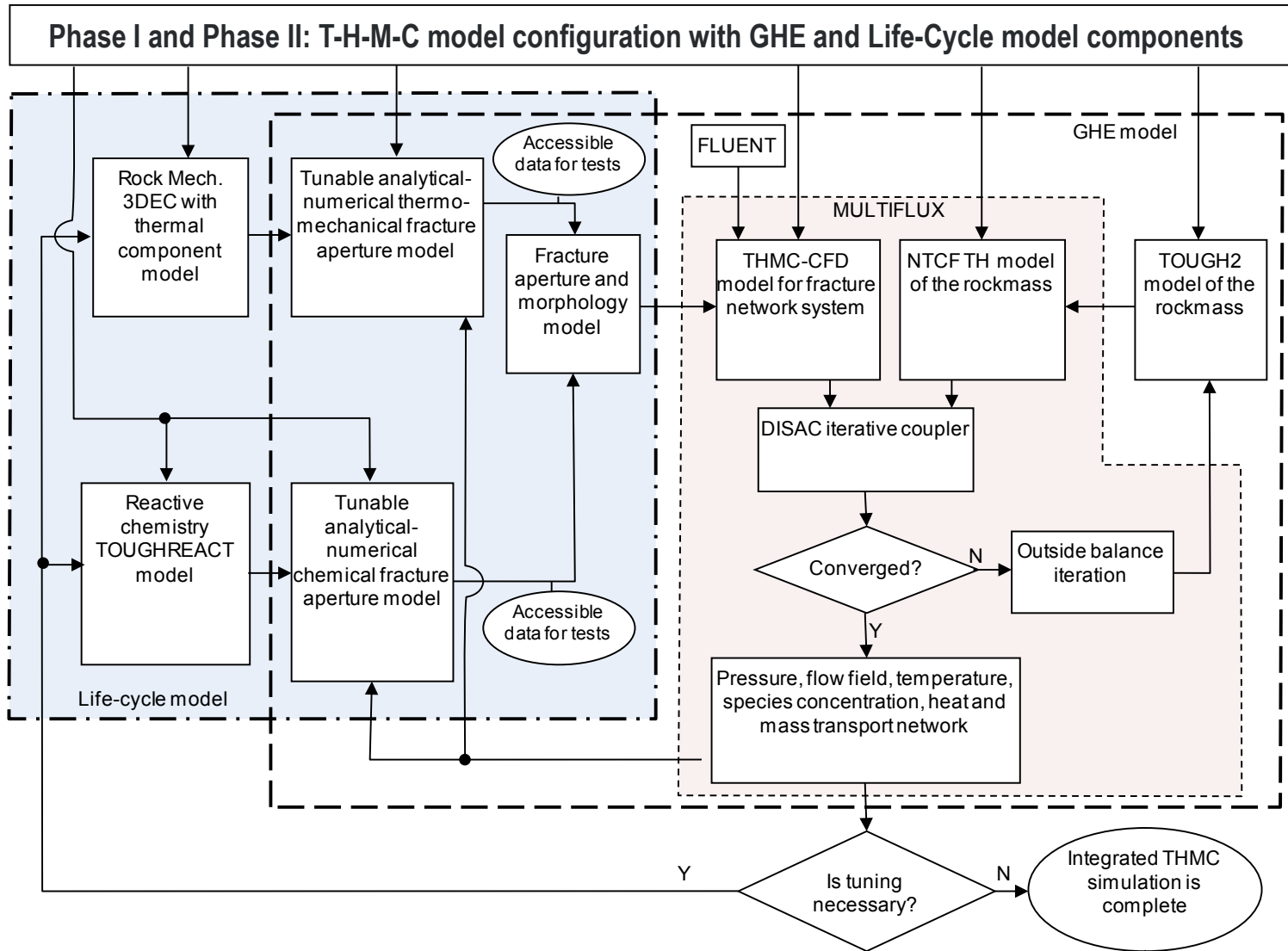
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Industrial Partner	ORMAT Nevada, Inc. Paul Speilman, Manager Operation support
Marketing Contributor	REA250 Susan Clark Renewable Energy Accelerator

Far-Field Model Capabilities – A previous example in TOUGH2



(from Bodvarsson, LBNL)





Simplified diagram

