Geothermal Technologies Program 2010 Peer Review

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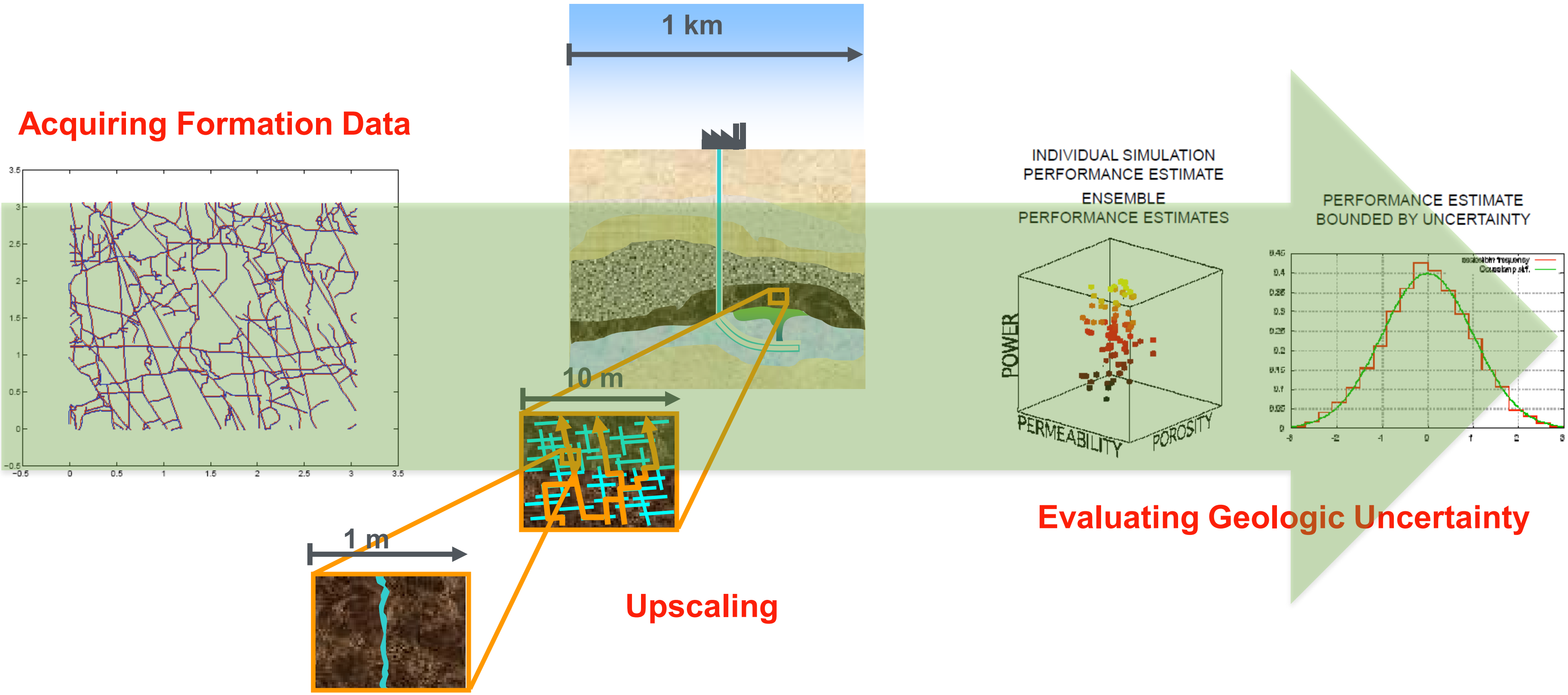

Predicting Stimulation Response Relationships For Engineered Geothermal Reservoirs

May 20, 2010

Principal Investigator

Charles R. Carrigan

Lawrence Livermore Nat. Lab.

Stimulation Prediction Models

Overview

Timeline

Oct 2009 → May 2010 (~7 Mon) → Oct 2011 (2 Yrs) → Oct 2012 (3 Yrs)

~20% complete

No cost extension

Budget

FY09: $0	FY10: $455K	FY11: $470K	Project Total: $925K

Barriers/Challenges Addressed

- High exploration risks and high up-front costs

Relevance/Impact of Research

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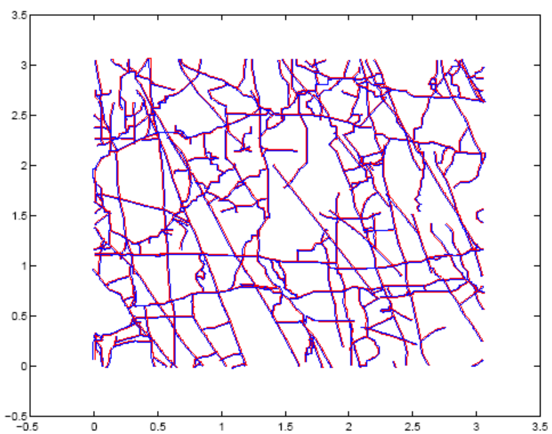
- Using existing LLNL programs, develop computational test bed to evaluate permeability/transmissivity enhancement mechanisms
- Provide insight and decrease costs by reducing need for trial-and-error approach
- Simulations can point to what formation characteristics must be better known/understood saving exploratory effort and money
- Will upscale real fracture distributions to produce realistic formation initial conditions to enhance impact of results
- Will apply exploratory approach in computational test bed (rather than actual formation) to evaluate application of an enhancement methods to a range of formation realizations
- Can perform hundreds of enhancement experiments at low cost using LLNL massively parallel computer systems
- Can evaluate likely effect of uncertainty in formation parameters on enhancement results

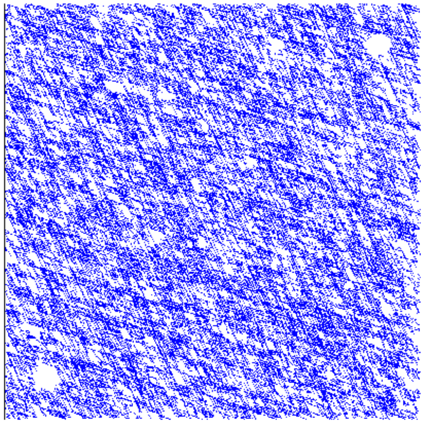
- Acquire realistic formation fracture data

LLNL Large Block Test fracture characterization

- Develop discrete fracture models using actual or stochastically generated synthetic data

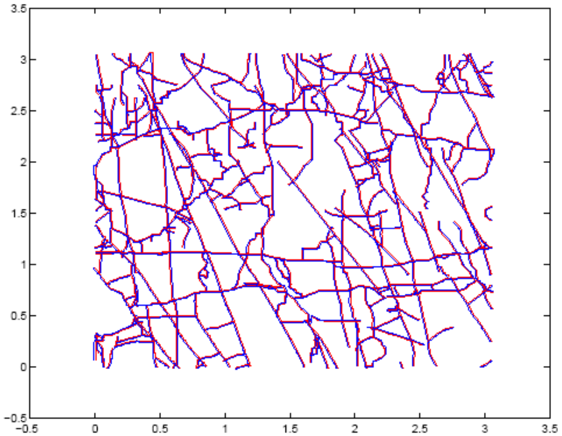


Fracture Map on Top Side of LB

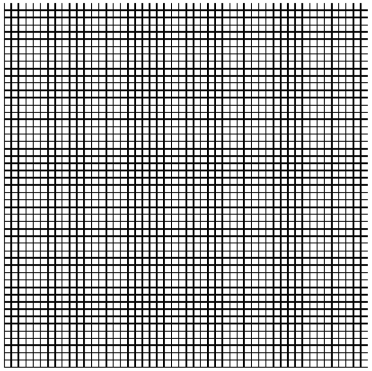


Stochastically Generated Synthetic Discrete Fracture Network

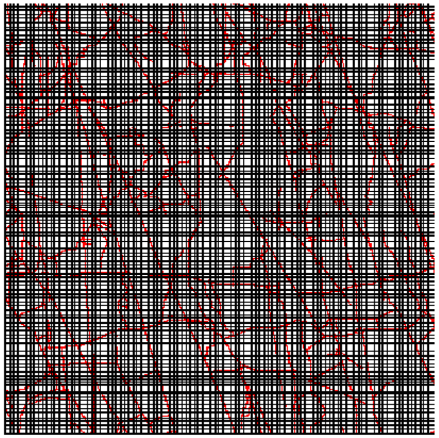
- Map fractures onto regular finite difference grid



Fracture Map on Top of LB



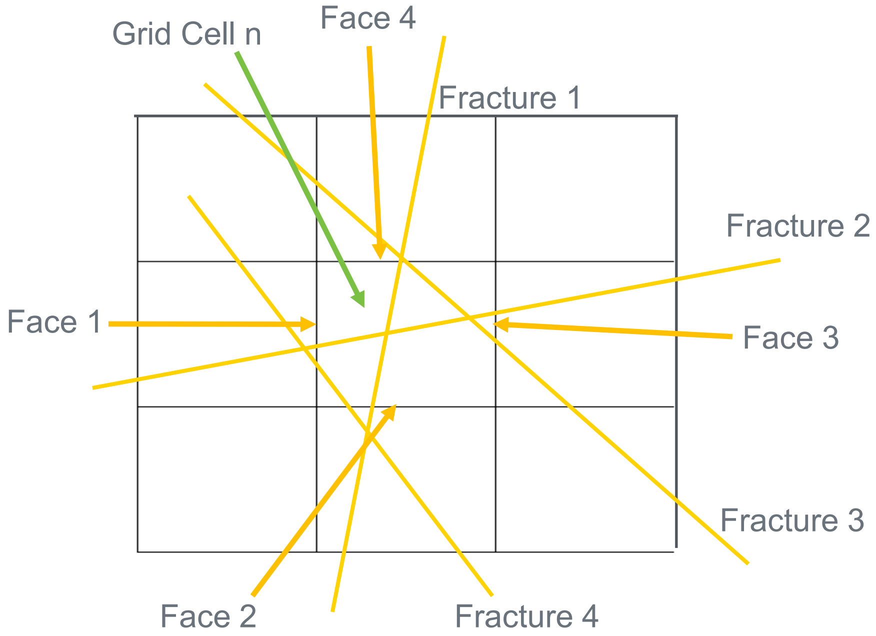
Regularly-Spacing Grid



Fracture Map on Top of LB
Discretized by Regular Grid

Scientific/Technical Approach (3)

- Transmissivity between grid cells in each principal direction is based on intersections between fractures and grid cell faces



$$T_{xx}^{face} = \sum_{face}^{m} a_m^{face} T_m$$

$$T_{yy}^{face} = \sum_{face}^{m} a_m^{face} T_m$$

$$m \rightarrow \text{fracture id}$$

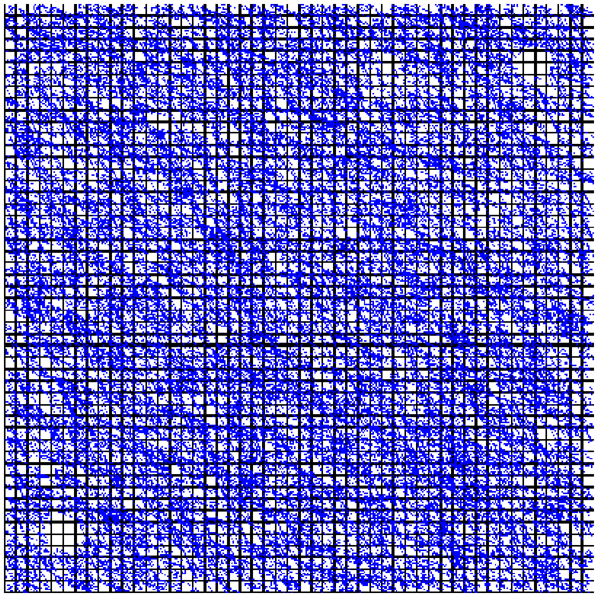
Example:

$$T_{xx}^{face\,3} = a_2^{face\,3} T_2 + a_3^{face\,3} T_3$$

$$T_{yy}^{face\,4} = a_1^{face\,4} T_1 + a_3^{face\,4} T_3$$

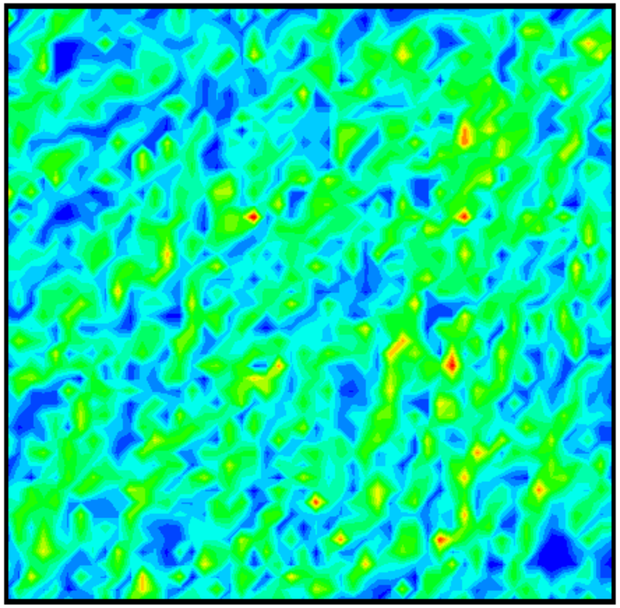
Upscaling Example

A 100 X 100 m^2 domain is discretized by 50 x 50 Cartesian grid cells



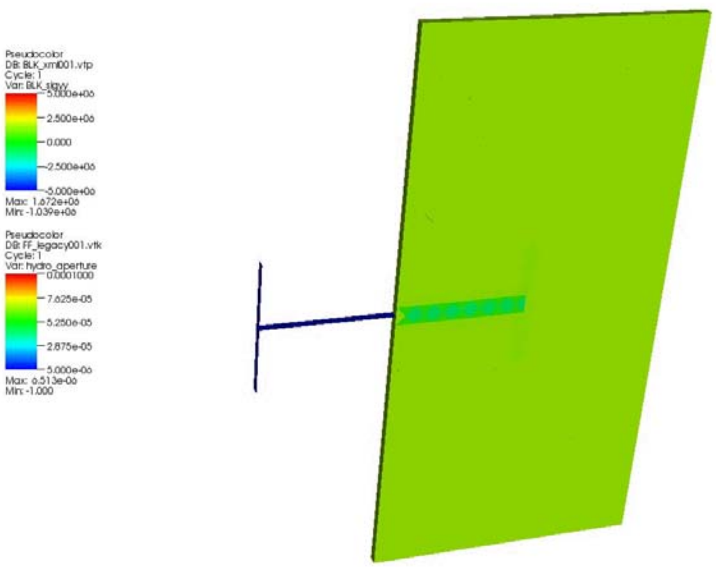
Discrete Fracture Network on Regular Grid

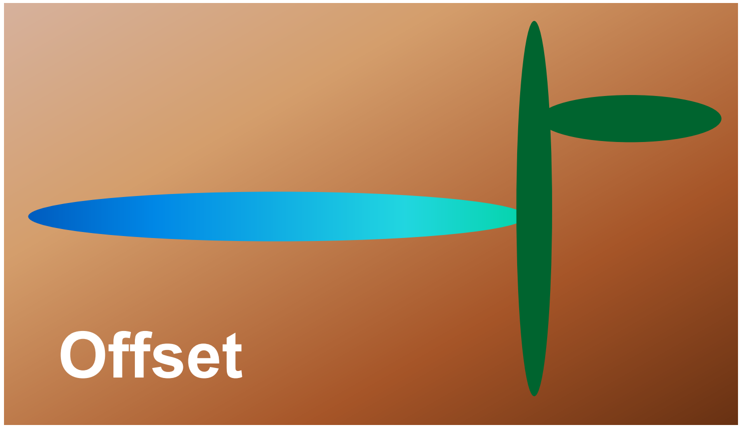
Upscaling



Transmissivity in X-Direction T_{xx} on Regular Grid

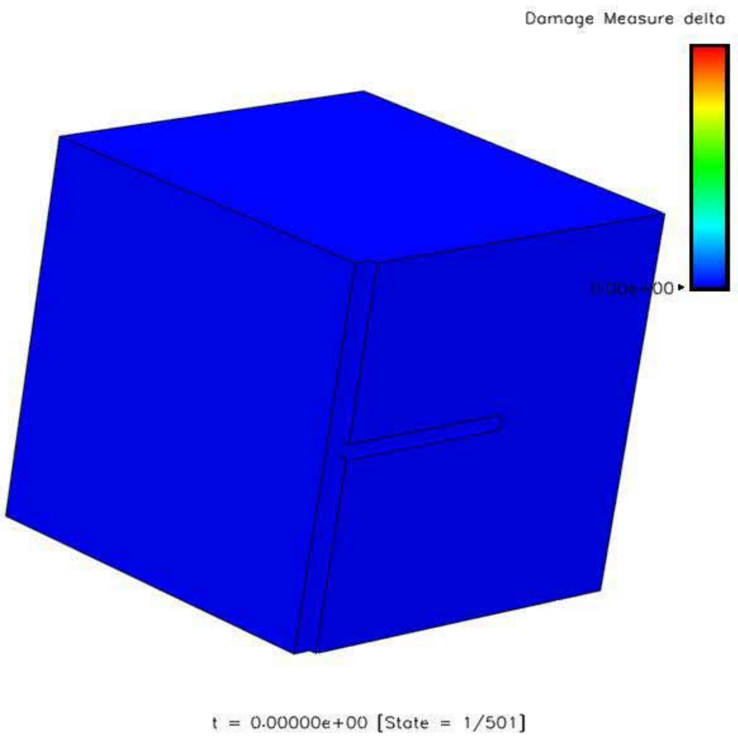
- Perform hydrofracture analyses on initial fracture field using Livermore Distinct Element Code (LDEC) on LLNL massively parallel computing platform





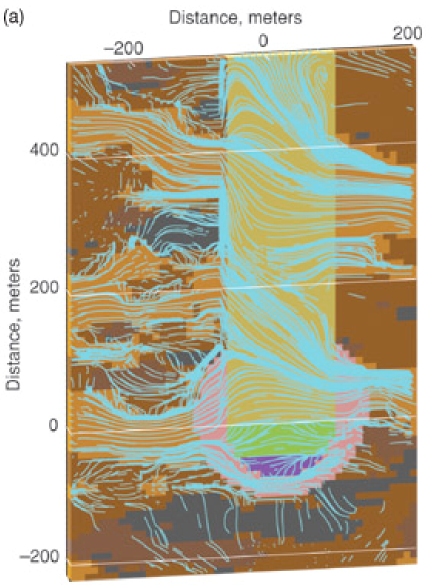
Scientific/Technical Approach (6)

- Perform explosive fracture analyses varying well geometries in initial fracture field using DYNA on LLNL massively parallel computing platform



Scientific/Technical Approach (7)

- Use LLNL's Non-Isothermal Unsaturated Flow & Transport (NUFT) code to evaluate heat transfer improvement associated with hydrofrac/explosive frac induced flow path modification



NUFT subsurface
Fluid flow/heat transfer
simulation

Accomplishments, Expected Outcomes and Progress

Accomplishments

- Acquired fracture data set from well-studied block of tuff
- Literature study of current EGS industry needs.
- Upscaling approach identified
- LDEC under evaluation as hydrofracing code
- Initial explosive fracing calculations performed with DYNA

Expected Outcomes

- Computational test bed for evaluating enhancement techniques and performing parameter variation studies
- Project will provide basis for evaluating impact of *uncertainty* in geologic characterizations on success of enhancement techniques

Leveraging LLNL Capabilities

Team

- C.R. Carrigan, PhD (UCLA), porous flow & heat transport
- W.O. Miller, PhD (Duke), CFD & solid mechanics modeling
- Y. Hao, PhD (Johns Hopkins), finite elem methods, CFD
- S. Johnson, PhD (MIT), distinct elem methods, solid mech
- G. Burton, PhD (Stanford), CFD simulations
- P. Fu, PhD post doc (UC Davis), distinct elem methods, CFD

Tools

- DYNA – solid mechanics code
- LDEC – solid mechanics code with hydrofracturing
- NUFT – non-isothermal porous flow and transport code
- LLNL massively parallel computers

Tasks and Schedule

Task	Yr 1	Yr 2	Yr 3
Task Integration (TI)	TI	TI	TI
Data Acquisition (DA)	DA		
Explosive Fracturing (EF)	EF	EF	
Hydrofrac Sim Dev (HSD)	HSD		
Frac Upscaling (FU)	FU		
Heat Transport (HT)		HT	
Hydrofrac Sim (HS)		HS	HS
EGS Assessment (EGSA)			EGSA

Management/Task Integration (TI): [3 years]

Required to manage and integrate other tasks to achieve the goal of producing a model-based evaluation of the degree of enhancement in desirable heat-transfer characteristics in an enhanced geothermal system.

Project Management/Coordination (2)

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FY10 Tasks

FY10 Tasks

Task	Yr 1	Yr 2	Yr 3
Task Integration (TI)	TI	TI	TI
Data Acquisition (DA)	DA		
Explosive Fracturing (EF)	EF	EF	
Hydrofrac Sim Dev (HSD)	HSD		
Frac Upscaling (FU)	FU		
Heat Transport (HT)		HT	
Hydrofrac Sim (HS)		HS	HS
EGS Assessment (EGSA)			EGSA

Spend Plan

Quarter	FY 10	FY 11	FY 12	
1	52	59	62	
2	109	71	62	
3	132	71	62	
4	110	71	64	
Total	$403k	$272k	$250k	

Future Directions

Expected Outcomes

Computational test bed for evaluating enhancement techniques and performing parameter variation studies

Project will provide basis for evaluating impact of *uncertainty* in geologic characterizations on success of enhancement techniques

FY10 Milestones

Introducing improved material models into DYNA simulations

Upscaling Large Block Test fracture data for large-scale simulations

Introducing Large Block Test fracture models as initial formation in LDEC

Summary Slide

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- We are using “in house” capabilities to develop a test bed for evaluating impact of EGS permeability/transmissivity modification techniques
- Being able to perform hundreds of simulations, each with slight parameter differences, provides insight into effect of parameter uncertainty (e.g., uncertainty quantification – UQ)
- This computational test bed approach can reduce costs by suggesting what will/will not work
- Approach can reduce costs by better focusing exploratory efforts on determining formation properties that are most critical for successful enhancement

Supplemental Slides

Publications/Presentations

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C.R. Carrigan, Predicting stimulation-response relationships for engineered geothermal reservoirs. Invited presentation at DOE GTP Geothermal Analysis Forum (FY10-Q1), Washington DC (DOE HQ), 19 November 2009.

W.O. Miller and C.R. Carrigan, Predicting the performance benefits of EGS engineered fracture systems. Invited presentation at Enhanced Geothermal Systems Conference & Expo, Reno, Nevada, May 11-12, 2010.