Utah FORGE Large Upscaled DFN Models 2023

— GDR SUBMISSION NOTES

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The FORGE modeling team is making five discrete fracture network (DFN) realizations of a large reservoir model available to researchers. These models have been upscaled to a continuum mesh or grid at resolutions of 10 m and 20 m providing reservoir properties for fracture porosity, permeability, and compressibility. The models are available in both the reference global coordinate frame and a local coordinate frame aligned with principal stress directions.

Keywords: geothermal, energy, Utah FORGE, FORGE, Utah geothermal, reservoir, engineering, hydraulic, fracturing, EGS, DFN, discrete fracture network, well 16A78-32, Utah, Enhanced Geothermal System, Engineered Geothermal System, FracMan, Roosevelt Hot Springs, Roosevelt Hot Springs Geothermal Site, Milford, CSV, stimulation, model, modeling, permeability, porosity, compressibility.

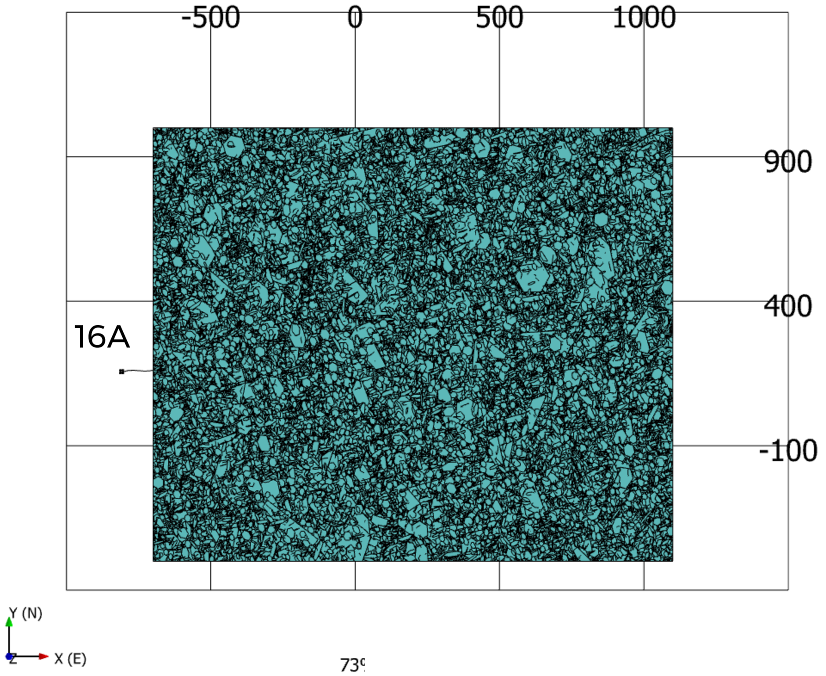
Available files for five realizations of the DFN at 10 m and 20 m resolution

— BOTH GLOBAL AND LOCAL COORDINATES FILES AVAILABLE

Name	Size
FORGE_2023_Large_Model_DFN_Global_All_Upscaled_Properties_10m.zip	1.66 GB
FORGE_2023_Large_Model_DFN_Global_All_Upscaled_Properties_20m.zip	251.15 MB
FORGE_2023_Large_Model_DFN_Global_Basic_Upscaled_Properties_10m.zip	452.06 MB
FORGE_2023_Large_Model_DFN_Global_Basic_Upscaled_Properties_20m.zip	56.74 MB
FORGE_2023_Large_Model_DFN_Global_Fractures.zip	138.21 MB
FORGE_2023_Large_Model_DFN_Global_Grids_10m.zip	1.63 GB
FORGE_2023_Large_Model_DFN_Global_Grids_20m.zip	274.57 MB
FORGE_2023_Large_Model_DFN_Global_Objects.zip	20.86 kB
FORGE_2023_Large_Model_DFN_Local_All_Upscaled_Properties_10m.zip	1.18 GB
FORGE_2023_Large_Model_DFN_Local_All_Upscaled_Properties_20m.zip	185.60 MB
FORGE_2023_Large_Model_DFN_Local_Basic_Upscaled_Properties_10m.zip	269.73 MB
FORGE_2023_Large_Model_DFN_Local_Basic_Upscaled_Properties_20m.zip	33.60 MB
FORGE_2023_Large_Model_DFN_Local_Fractures.zip	150.47 MB
FORGE_2023_Large_Model_DFN_Local_Grids_10m.zip	1.37 GB
FORGE_2023_Large_Model_DFN_Local_Grids_20m.zip	224.44 MB
FORGE_2023_Large_Model_DFN_Local_Objects.zip	24.95 kB

Local coordinates have the objects rotated 20 deg counterclockwise from global coordinate frame (looking down) so that the direction of S_{Hmax} aligns with the Y axis

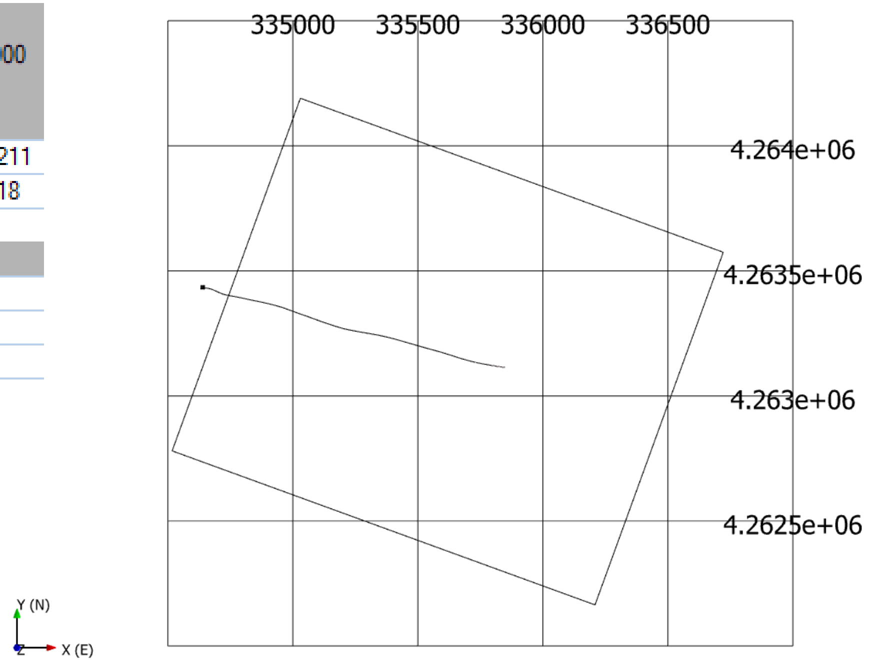
```
BEGIN CREATEREGION
    ObjectName = "RegionBox_Large_Model"
    Type = "Box"
    Center = 200, 250, 350
    Size = 1800, 1500, 1000
END
```

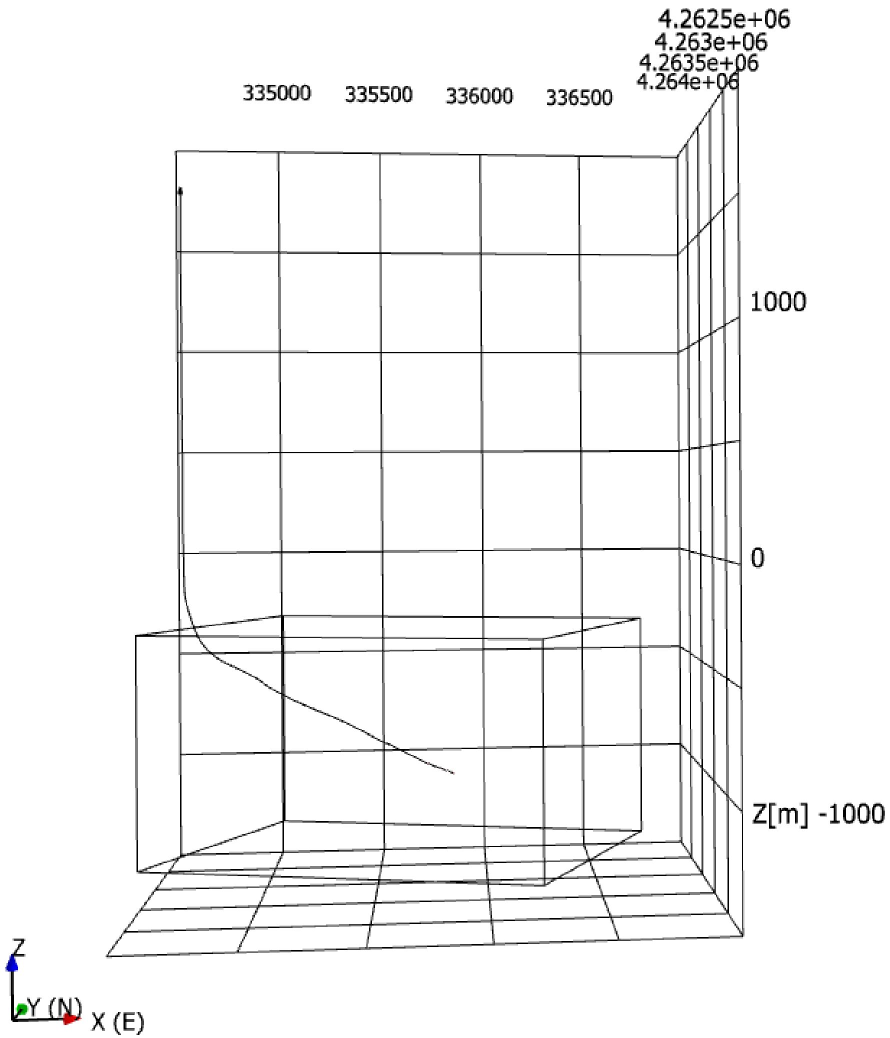


Model region – 1800 m x 1500 m x 1000 m

— GLOBAL COORDINATES

Region Type:	Box
Region Volume [m3]	2700000000
Convex	True
Center [m]	
X	335618.9211
Y	4263177.18
Z	-800
Size [m]	
SX	1800
SY	1500
SZ	1000





Coordinate Frame Conversions

— EXAMPLES

Local to Global

```
BEGIN TranslateObject
    Object = "RegionBox_Large_Model"
    Object = "Well_Collars_Local_1"
    Translate = 335408.68, 4263010.9, -1150.
END

BEGIN RotateObject
    Object = "RegionBox_Large_Model"
    Object = "Well_Collars_Local_1"
    Rotate = 0., 0., -1.
    Degrees = 20
    RotateAbout = 335376.400482041, 4263189.99998761, 250.093546450195
END
```

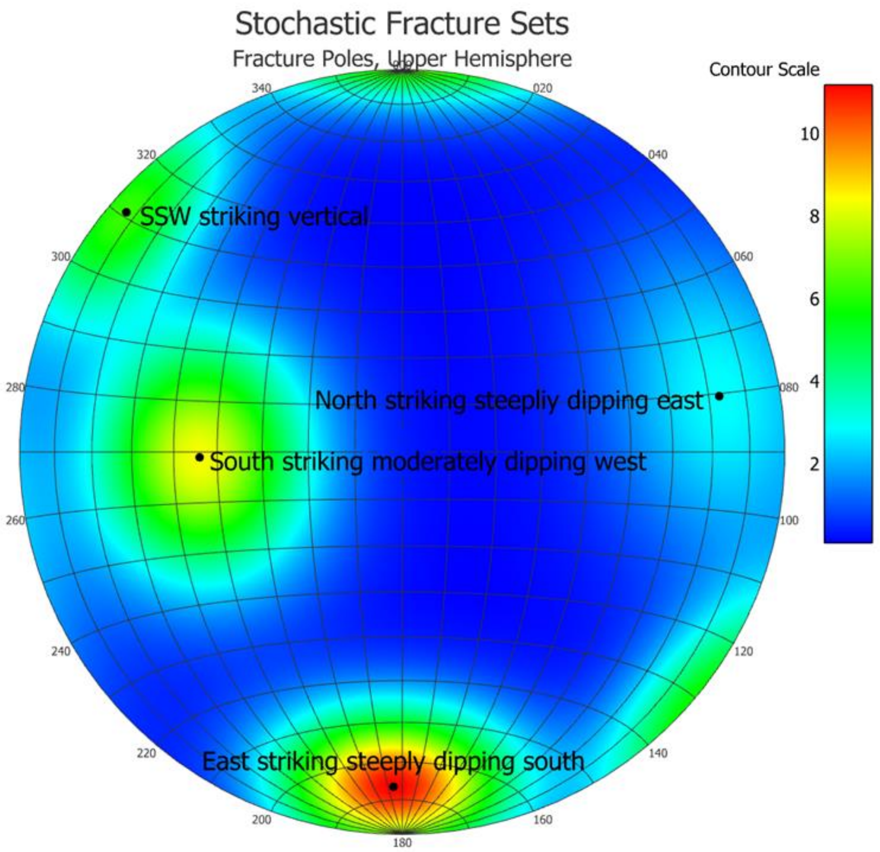
Global to Local

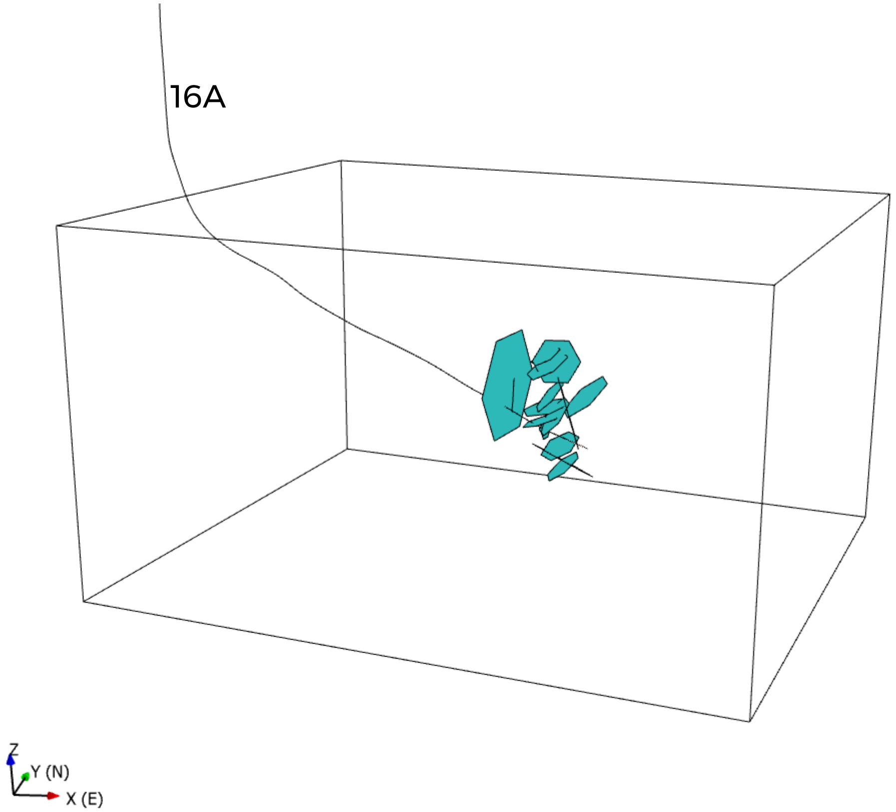
```
BEGIN RotateObject
    Object = "Global_Grid_10m_%d"
    Object = "Global_Grid_20m_%d"
    Object = "Large_Discrete_Fracture_Set"
    Rotate = 0., 0., 1.
    Degrees = 20
    RotateAbout = 335376.400482041, 4263189.99998761, 250.093546450195
END

BEGIN TranslateObject
    Object = "Global_Grid_10m_%d"
    Object = "Global_Grid_20m_%d"
    Object = "Large_Discrete_Fracture_Set"
    Translate = -335408.68, -4263010.9, 1150.
END
```

Fracture Sets

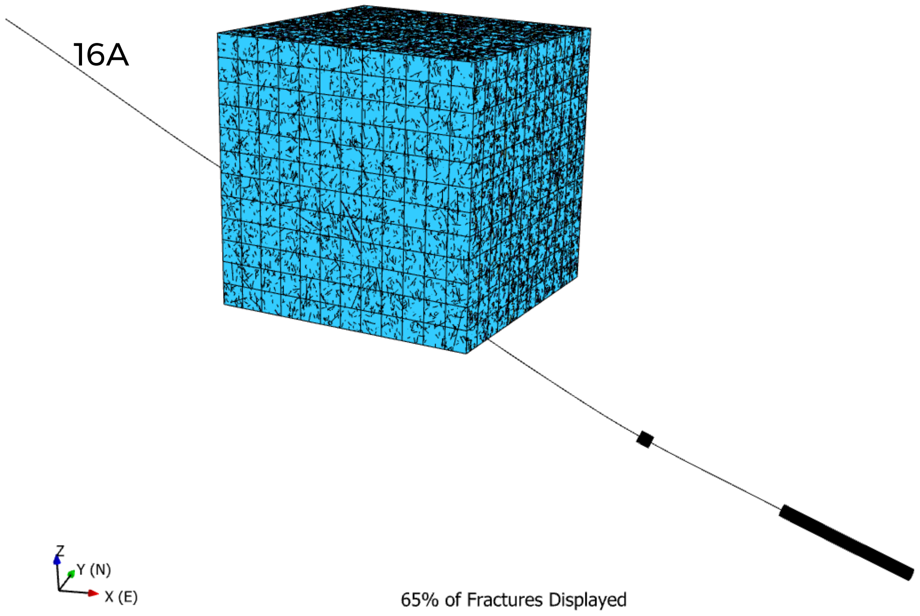
— FOUR STOCHASTIC FRACTURE SETS + DISCRETE SET FIT TO MEQ DATA

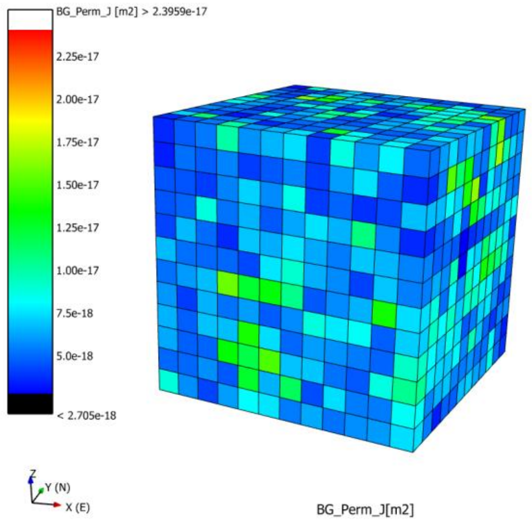




Background Fractures

- UPSCALED STOCHASTIC DFN USING FRACTURE RADIUS 0.63 M TO 10 M IN A 120 M X 120 M GRID AT 10 M AND 20 M RESOLUTIONS
- INDIVIDUAL BACKGROUND CELLS WERE RANDOMLY SELECTED TO USE IN THE LARGE MODEL
- ALL PROPERTIES FROM ONE CELL WERE COPIED TOGETHER SO CORRELATED PROPERTIES ARE CONSISTENT





Fracture Properties

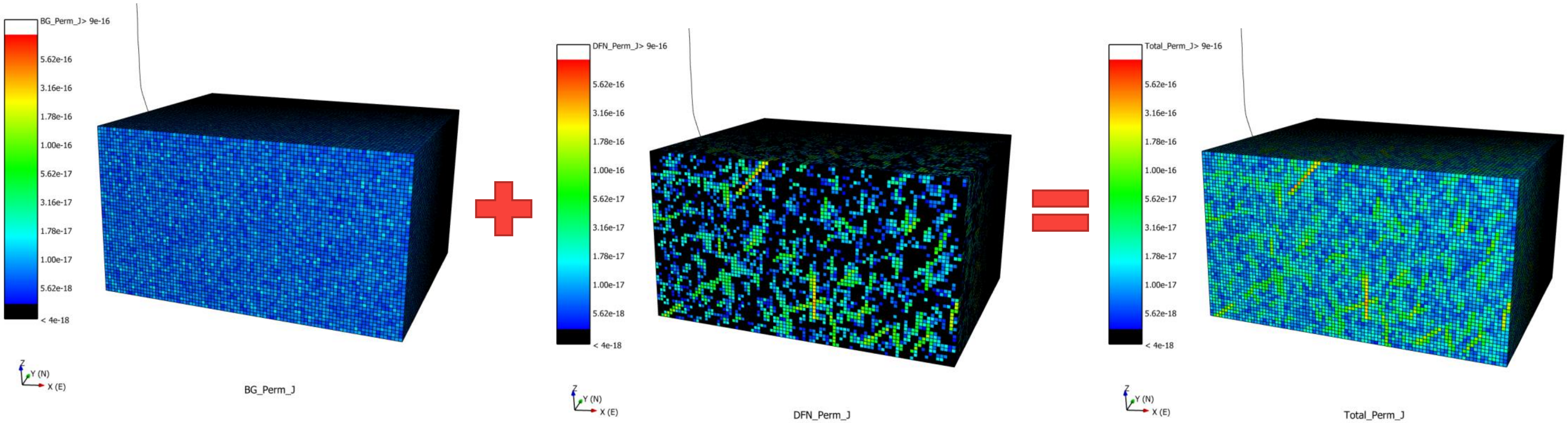
— FORMULAS ARE BASED ON PREVIOUS WORK BUT NOT WELL CONSTRAINED, SO OK TO ADJUST UPSCALED VALUES TO EXPLORE SENSITIVITIES

Stochastic Fractures
Mechanical Aperture [m] = 1.7e-5 * (Equivalent Radius [m])^(0.5) : function of the square root of fracture radius, used for porosity
Hydraulic Aperture [m] = 0.1 * (Mechanical Aperture [m])
Permeability [m^2] = (Hydraulic Aperture [m])^2 / 12 : function of the square of the hydraulic aperture
Compressibility [1/kPa] = 5e-6

Discrete set fit to MEQ data
Mechanical Aperture [m] = 2e-4
Permeability [m^2] = 3.3e-9
Compressibility [1/kPa] = 5e-6

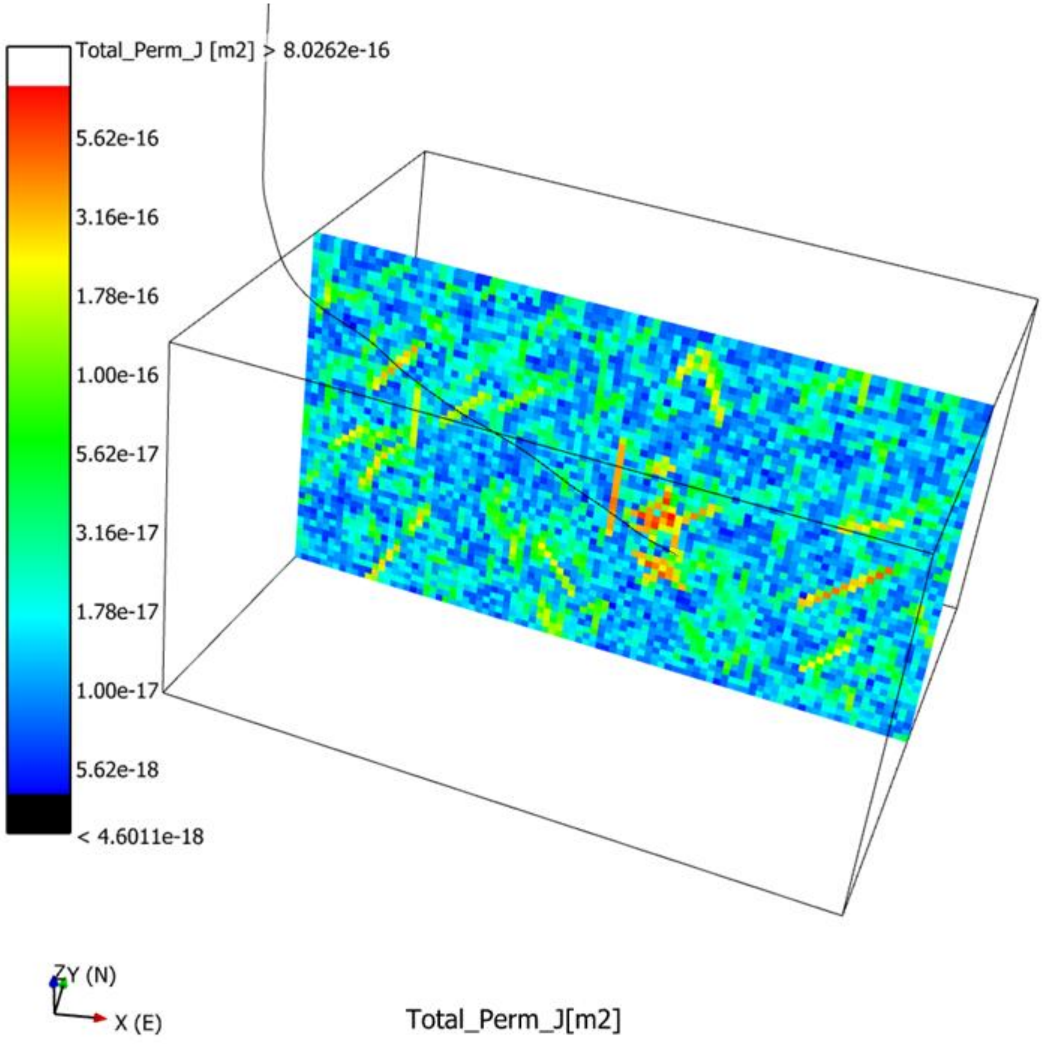
Upscaled Properties include DFN (fractures having a radius > 10 m) and Background fractures (contribution of smaller fractures)

— REALIZATION #1 AT 20 M RESOLUTION SHOWN AS EXAMPLE BELOW (PERM J)



Example slice of upscaled permeability tensor component

— CAN SEE EFFECT OF DISCRETE (STIMULATED) SET BASED ON MEQ DATA WITH HIGHER VALUES NEAR TOE OF 16A



Upscaled Properties

— MAY JUST WANT TO DOWNLOAD BASIC PROPERTIES (SMALLER FILE SIZES)

Basic Properties include:

a. Cell centers XYZ (3)
b. Total Perm I, Perm J, Perm K [m^2] -includes permeability from DFN plus background perm from smaller fractures. I, J, K directions from principal stress directions (S_{hmin}, S_{Hmax}, S_V) (3)
c. Total Porosity [fraction] – includes fracture porosity from DFN plus background porosity from smaller fractures and matrix (1)
d. Total Compressibility [1/kPa] – combined DFN and background (1)

All Properties include the basic properties plus these:

a. Total Perm X, Perm Y, Perm Z [m^2] - X, Y, Z directions from global coordinate frame (EW, NS, Vertical) (3)
b. DFN Perm I, Perm J, Perm K, Perm X, Perm Y, Perm Z [m^2] (6)
c. DFN Fracture Porosity [fraction] – just DFN contribution (1)
d. DFN Fracture Compressibility [1/kPa] – just DFN contribution (1)
e. Background Perm I, Perm J, Perm K, Perm X, Perm Y, Perm Z [m^2] (6)
f. Background Porosity [fraction] (1)
g. Background Compressibility (1)
h. DFN Fracture Permeability Tensor components in IJK [m^2] – just DFN contribution (6)
i. DFN Fracture Permeability Tensor components in XYZ [m^2] – just DFN contribution (6)

<u>Mean Property Values</u>

Permeability [m^2]:		
	DFN	1.7e-17
	Background Fractures	7.8e-18
	Total	2.5e-17
Porosity [fraction]:		
	DFN	3.3e-6
	Background Fractures	2.3e-5
	Total	2.6e-5
Compressibility [1/kPa]		
	DFN	1.6e-11
	Background Fractures	1.1e-10
	Total	1.3e-10

File Formats

Upscaled properties (both Basic and All options) – csv
Upscaled properties in Eclipse-style grids – grd
DFN fractures in FracMan format – fab
Other model objects:
- 16A well trajectory (helpful for understanding global to local coordinate transformation) – wl, csv or txt
- Region box as a GOCAD surface - ts

Helpful References

Stochastic DFN orientations, intensity, size distribution

- Finnila, A.: Estimation of Fracture Size for a Discrete Fracture Network Model of the Utah FORGE Geothermal Reservoir using Forward Modeling of Fracture-Borehole Intersections. Paper presented at the 55th U.S. Rock Mechanics/Geomechanics Symposium, physical event cancelled, June 2021. Originally accepted for the 3rd International Discrete Fracture Network Engineering Conference. DFNE 21-2329 (2021).
- Finnila, A., Doe, T., Podgorney, R., Damjanac, B., and Xing, P.: Revisions to the Discrete Fracture Network Model at Utah FORGE Site, GRC Transactions, Vol 45, (2021).

Discrete DFN from MEQ data

- WSP Golder: Utah FORGE Well 16A(78)-32 Stimulation DFN Fracture Plane Evaluation and Data [data set]. Retrieved from https://dx.doi.org/10.15121/1901784, (2022).
- Finnila, A., Doe, T., Damjanac, B, and Podgorney, R..: Development of a Discrete Fracture Network Model for Utah FORGE using Microseismic Data Collected During Stimulation of Well 16A(78)-32. Proceedings, 48th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA (2023).

Earlier Utah FORGE upscaled models available in the GDR

- Golder Associates Inc.. (2021). Utah FORGE Well 16A(78)-32 Simplified Discrete Fracture Network Data [data set]. Retrieved from https://dx.doi.org/10.15121/1787506.

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