

A New DFM Dynamic Modeling Workflow through a Non-Intrusive EDFM Method to Quickly Calibrate Fracture Model with Production Data: Practical Application on a Granite Reservoir Case*

Cheng Lei¹, Xianbin Li¹, Jijun Miao², Ruifeng Wang¹, Felipe Medellin³, Feng Xu¹, Wei Yu⁴, and Kamy Sepehrnoori⁴

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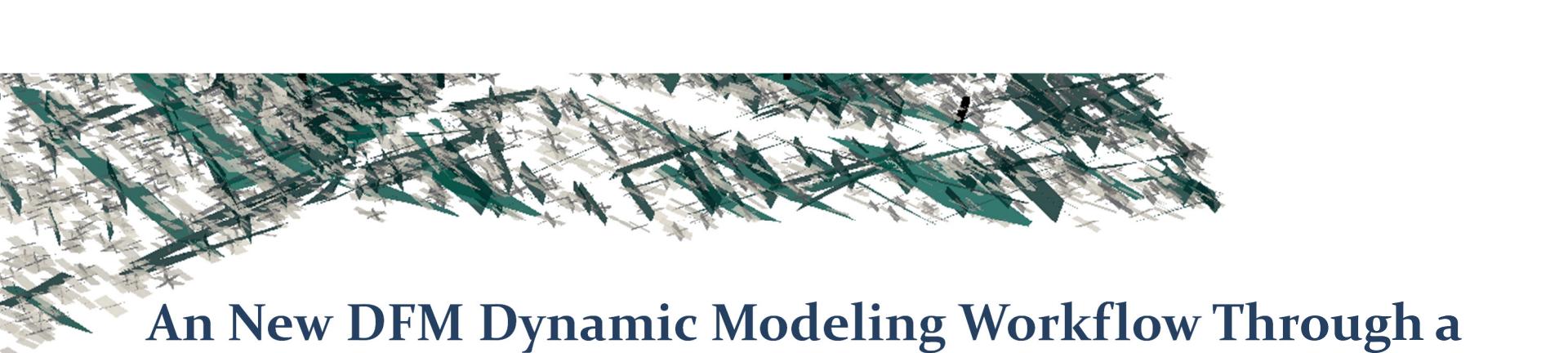
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Abstract

The presence of multi-scale natural fractures, low matrix porosity and permeability greatly increases the heterogeneity of granite reservoirs, adding significant complexity for reservoir modeling and simulation. Typical DFN models are commonly challenged for its representation by reservoir engineers, and the DFN upscale simulation method is blamed by geologists for low accuracy representing the DFN model. In this article, an innovative solution to bridge the gap between geological modeling and reservoir simulation with EDFM (Embedded Discrete Fracture Modeling) method was introduced for the first time, while preserving the complexity of the DFN and avoiding additional run time or steps into the conventional fluid flow simulation workflow. Unlike previous fracture modeling techniques, EDFM method allows integrating any complex fracture geometry into a reservoir grid model without compromising fracture resolution and with much higher computational efficiency, which makes the quick high-resolution fracture reservoir modeling feasible. This method is introduced into DFN calibration to streamline the DFN to real fracture geometry reservoir simulation and History Matching with real production data. Therefore, a closed-loop fracture modeling, calibration and optimization workflow is developed.

This workflow includes four steps: (1) Building a single well DFN and geological model based on the detailed geological data, such as seismic interpretation, borehole images and core analysis of the granite reservoir. The faults and natural fractures were identified, and their geometrical properties were vested. The fractures are characterized into two groups according to their size grades and their hydraulic impact on the fluid flow in the reservoir, which are those large-scale fractures representing highly conductive corridors, and those small-scale diffuse fractures with lower overall conductivity and connectivity. (2) Calibration of the DFN through pressure forward modeling to align with well testing data, the fracture number and size could be optimized. (3) Calibration of the fracture properties. In this process, the single well DFN is integrated into the reservoir model through the EDFM processor and run numerical simulation to perform history matching, the fracture properties will need to

be adjusted to agree with the production data. (4) Definition of the DFN properties to bigger range for block DFN model. This workflow was successfully applied on a fractured granite oil reservoir; 3 single wells' DFN model were built up and calibrated under this workflow. All 3 wells' DFN model matched with the production history very well. And with less additional grids, the computational performance could be 2 to 3 orders of magnitude higher than traditional methods. And with the increasing number and the complexity of fractures, much higher computational efficiency could be achieved.



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2019-05

Presenter's notes: The first time I (Cheng Lei) learned about EDFM (Embedded Discrete Fracture Modeling) was about two years ago, and I was attracted immediately by it as a new method to deal with the actual fractures of the reservoir and their function in numerical simulation. But at that time, EDFM could only handle a few hundred fractures, and it was considered as an academic tool only. Last year we developed a corporate project with Sim Tech company and UT Austin. This project was a perfect opportunity to test and improve EDFM continuously in a naturally fractured reservoir. This article covers a new EDFM application to demonstrate a new solution for a massively fractured reservoir, and to characterize the actual fractures in a granite reservoir.



Overview

❑ **Introduction**

- ❑ **A new nature fracture modeling workflow**
- ❑ **A comparison study between EDFM and DPDK**
- ❑ **EDFM+DPDK full field application**
- ❑ **Summary**

EDFM=Embedded Discrete Fracture Model

DPDK=Dual Porosity Dual Permeability

Presenter's notes: This report includes five parts.

First, I will introduce a new natural fracture modeling workflow.

Second, I will talk about a benchmark study between EDFM and DPDK.

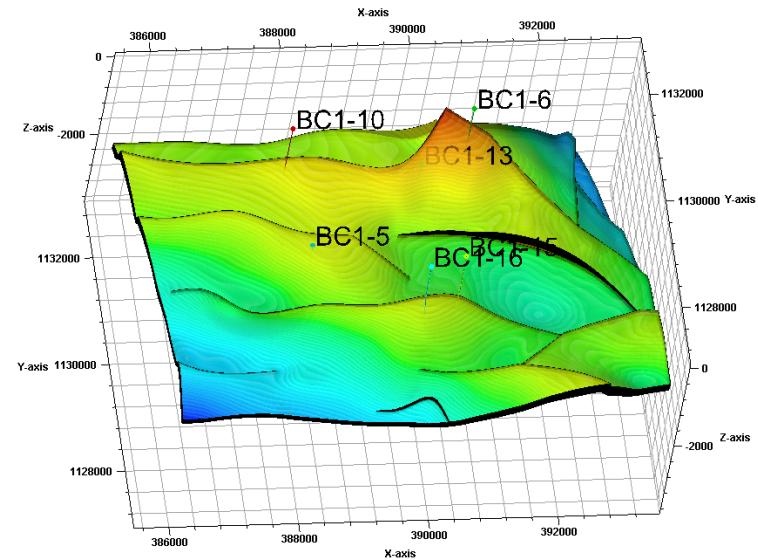
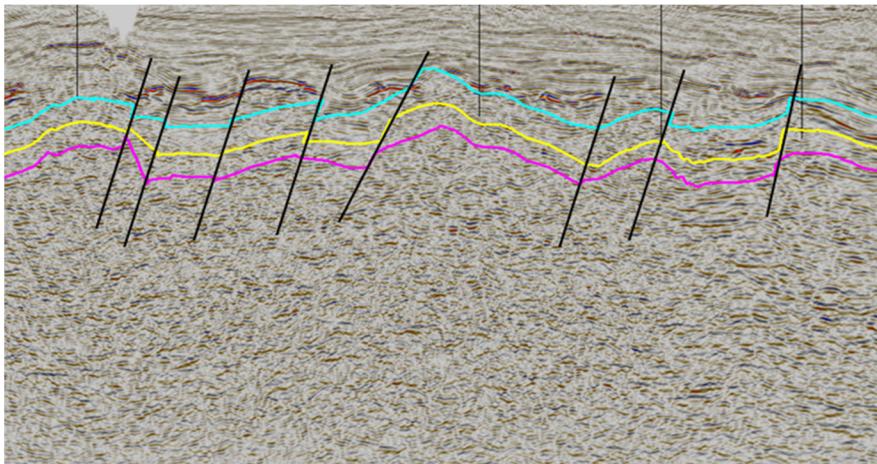
Then, I would like to introduce the preliminary result of the EDFM application in conjunction with DPDK in a full field scale.

Finally I have the conclusions.



Background

- Granite reservoir on a basement paleo-uplift
- Cut by 16 major faults
- 15 wells with oil production 70~7000 bbl/day
- Model size 5*10 km²



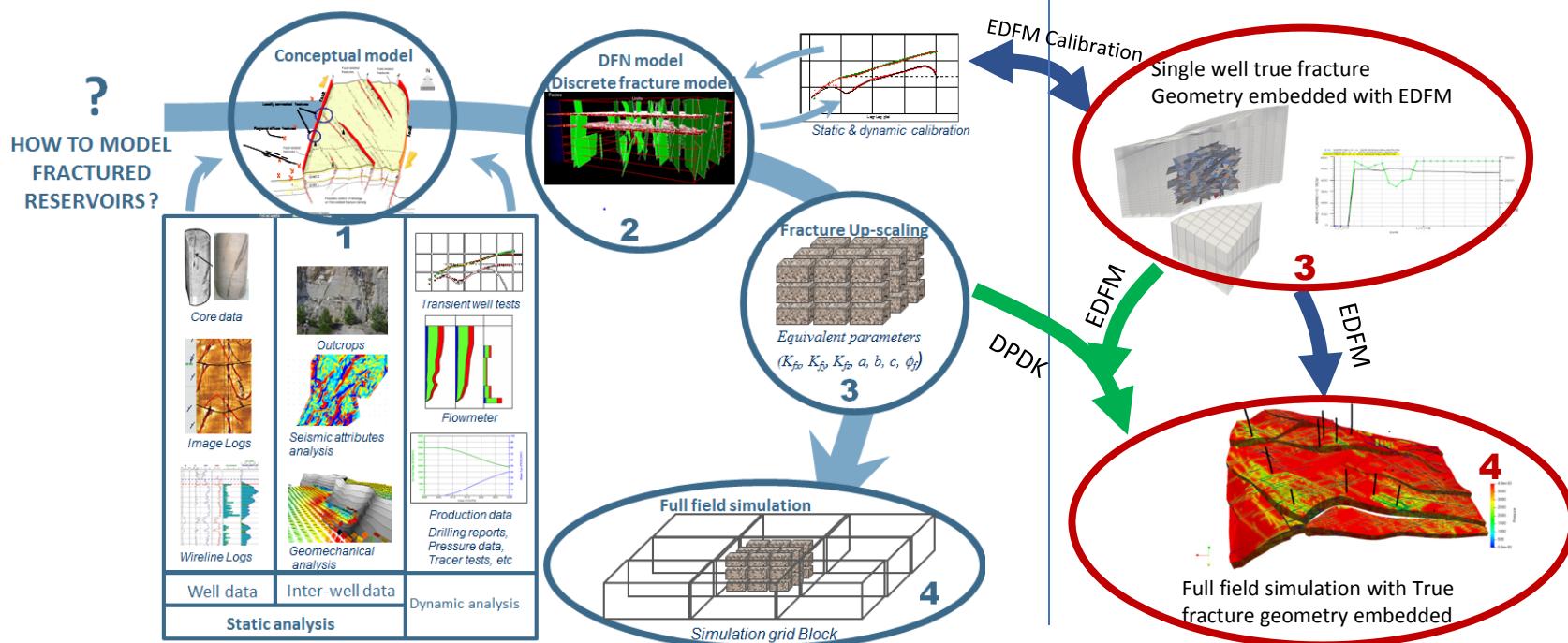
Presenter's notes: Our research is about a granite reservoir on a basement paleo-uplift.

The granite reservoir is cut by 16 faults. There are 15 wells with oil production, ranging from 70 bbl to 7000 bbl per day. As you can see from the production, this oil field reservoir has strong heterogeneity.



Methodology

Fracture modeling to DPDK workflow



New workflow to reduce uncertainty and improve the simulation accuracy

Presenter's notes: This slide demonstrates the methodology. On the left side is a traditional fracture modeling and simulation workflow. First, the geologists will collect core, well log, seismic, drilling data and production data to do fracture characterization and come up with a conceptual model.

Then a single well DFN will be generated and populated to a full field DFN model.

After that, the engineers will upscale them to a DPDK numerical model to do history matching and production prediction.

The DPDK upscaling method is a simplification process; this process naturally reduces the accuracy of the fracture network.

On the right side is our improved workflow, first we introduced the EDFM method into single well DFN calibration to quickly and accurately calibrate the DFN model. Second, we implement the EDFM method to conduct full field numerical simulation. This workflow will reduce the uncertainty and improve the fracture simulation accuracy.



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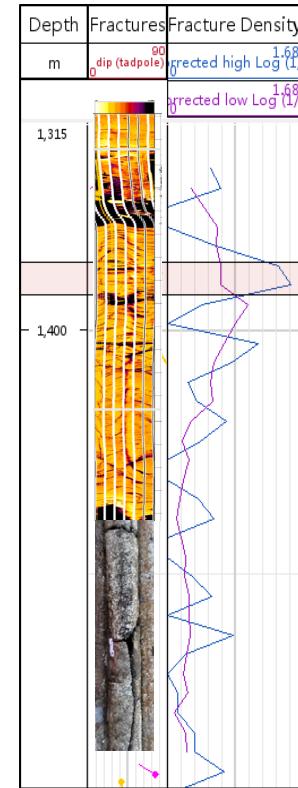
Presenter's notes: First, I will talk about the new fracture modeling workflow



Single well fracture characterization

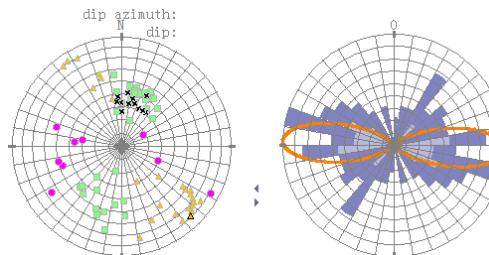
- 6 wells have reliable well logging data

Available data					
well	Mud loss	Production	lithology	Fracture	KH
BC1-5	✓	✓	✓	✓	✓
BC1-6	✓	✓	✓	✓	✓
BC1-10	✓	✓	✓	✓	✓
BC1-13	✓	✓	✓	✓	✓
BC1-15	✓	✓	✓	✓	✓
BC1-16	✓	✓	✓	✓	✓



BC1-5: 72 fractures are identified and organized in 3 sets

- Main WNW-ESE (38 fractures)
- Secondary ENE-SWS (25 fractures)
- Minor NS (9 fractures)



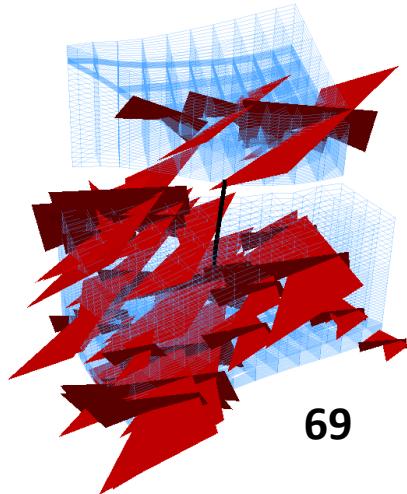
Fracture basic properties : orientation, density , aperture. etc

Presenter's notes: Here I will show how we build the fracture model and try to reduce the uncertainty. In this oil field, we have 15 wells, but only 6 wells have reliable well log data and other dynamic data. The image log and core data are the best options. You could identify the fractures with your eyes. For example, in this well, we picked up 72 fractures, organized in 3 sets. This feature relates to the regional structure and stress field. Here, we have the basic fracture properties, such as orientation, density, and aperture.

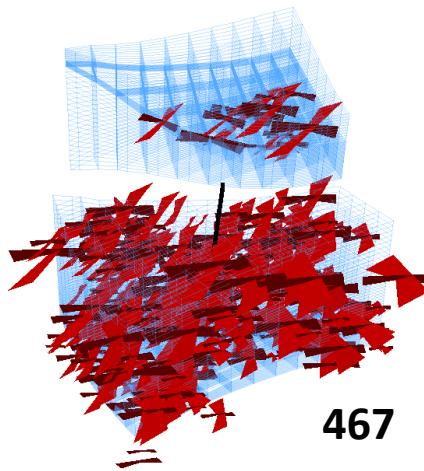


Single well DFN models

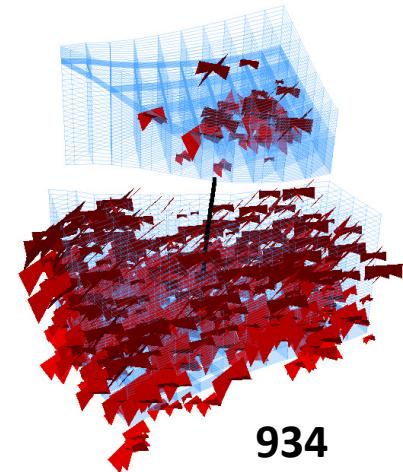
- The fractures are characterized into two groups based on their size and hydraulic impact on the fluid flow
- The fracture property is constrained by seismic, cores and BHI data
- Multiple DFN models can be generated.



Size 200-500 m



Size 50-300 m



Size 20-200 m

Presenter's notes: According to the seismic anisotropic analysis, cores and borehole images data, the properties of fractures, such as density, orientation, dip angles, length and height are obtained for each of three sets.

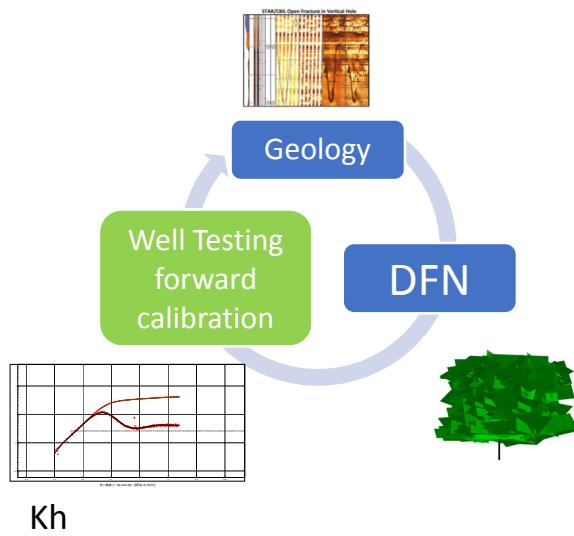
With these single well fracture inputs, we can generate the single well fracture model.

The fracture size and number are unknown out of the wellbore. So we have to estimate and test the fracture size and fracture number. Here are three examples of the many possible representations. Their fracture size and number will change accordingly. We need to calibrate these models.

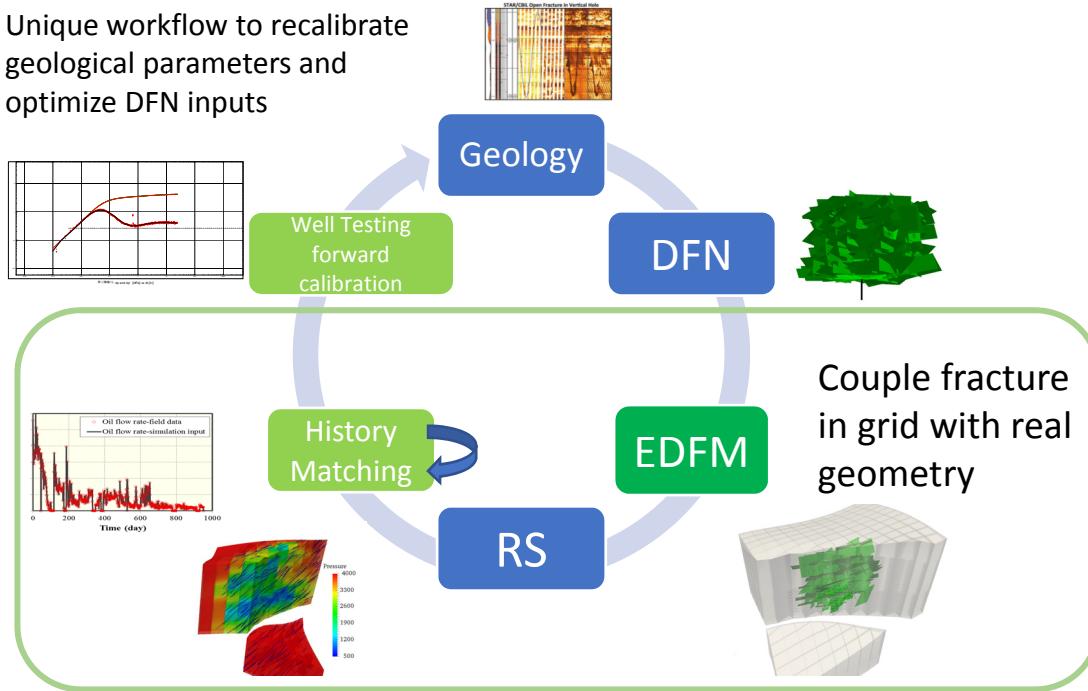


New calibration to reduce uncertainty

Traditional DFN calibration



EDFM single well DFN calibration



Presenter's notes: Here is the calibration. On the left side is a tradition calibration workflow. DFN model will match with well testing Kh. It is a very rough simulation. Many DFN models could be matched, and those matched parameters are not sense to future reservoir simulations most of the time.

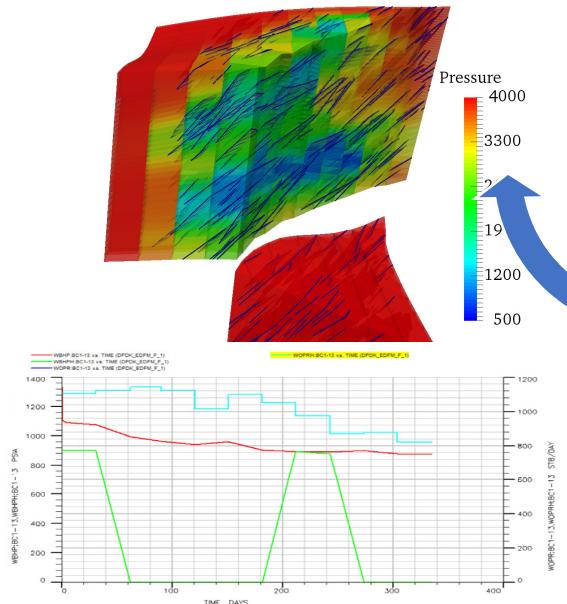
On the right side is our improved calibration workflow. Here, we conduct history matching before well testing calibration. We use the EDFM method to do the single well reservoir simulation, to make sure of the accuracy. If a DFN model passes the two step calibration, that model will be considered as a representative model. Otherwise, we need go back to change our DFN model or even to redo the geological fracture characterization.

This process will iterate until a DFN model passes these two steps.

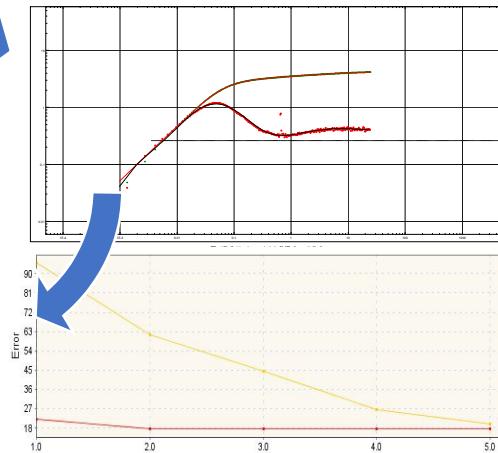


Calibration

1nd Step: EDFM RS and History Matching
---Key calibration: fracture permeability

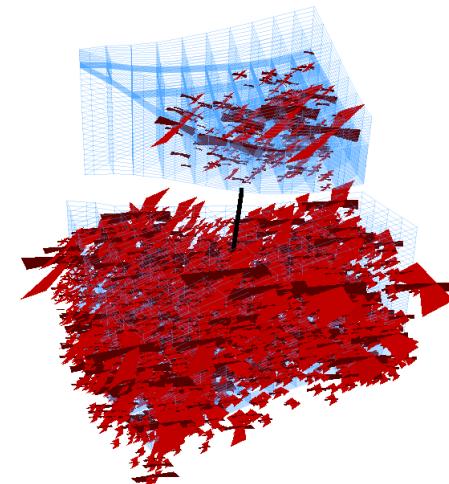


2st Step: Well testing forward modeling Validation
---modeling the Kh



Fracture well testing Kh Quick Calibrate

3st Step: finalizing DFN model



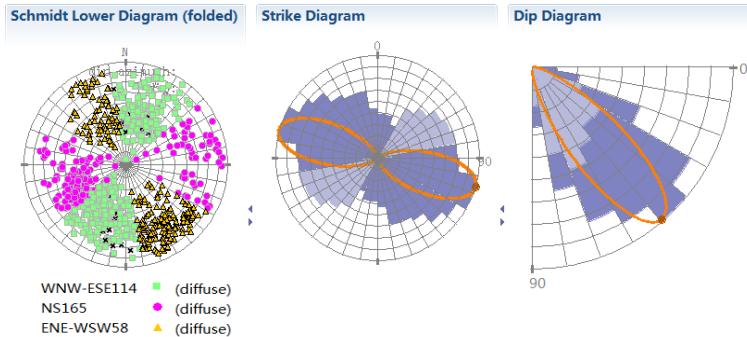
458+553

Two groups
Size: 10~50 m, 60~200 m

Presenter's notes: First we do EDFM history matching with the field production data and the permeability will be updated. Then the updated DFN model will be validated with well testing. Before we get the best result, we may need to run multiple iterations. This is a calibration result, we added more than 5000 small size fractures, to get better matching. This step is very critical in DFN modeling, and we will base this model to do full field DFN population and benchmark study.



Full field DFN modeling



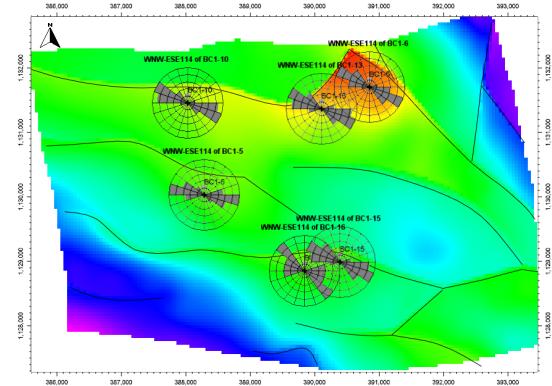
Global fracture statistics					
Well	Set orientation	Fracture number	Mean orientation(°)	Mean dip(°)	Fracture density (frac/m)
All wells	WNW-ESE	412	114	43	0.3
	ENE-WSW	216	58	73	0.19
	NS	179	165	51	0.155

Global fracture statics observed 807 fractures in the reservoirs.

They are organized in 3 sets:

- **WNW-ESE (Main set)**
- **ENE-WSW (Secondary set)**
- **NS (Minor set) (thermal decrease)**

The total number of fractures is relatively high with an average fracture density value for all wells ranging between **0.155 frac/m** to **0.3 frac/m**



WNW-ESE

Presenter's notes: After doing the 6 wells calibration, we then have 6 control points in this field. And now we are confident in generating a regional DFN model.

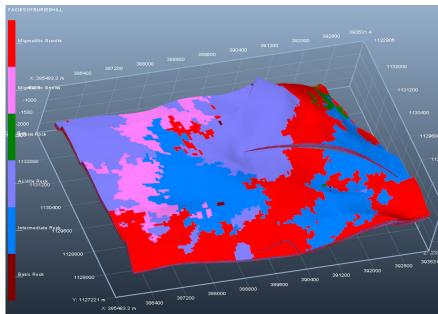
Here we do global fracture statistics with all the fractures. We will need more space control factors to constrain the DFN population. Here I would like to point out that the fracture dip angle changes from 43 to 73; this slant fracture could be accurately handled with EDFM processor.



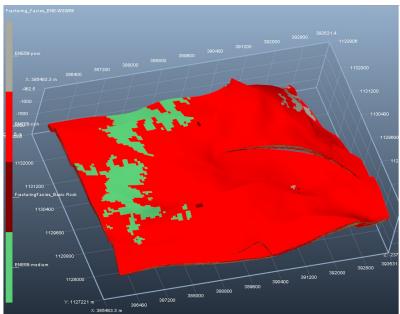
Control factors

- Example of one representation of the geology: Reclassify the lithofacies into three categories, which are rich, medium and poor, the fracture density per category and per set will be used to populate the model.

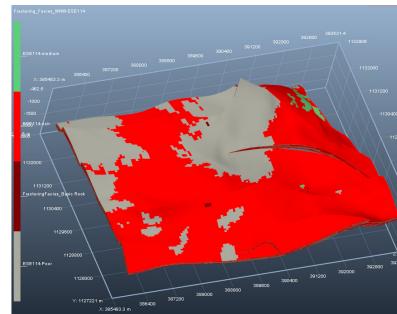
Facies	W NW -ESE set		ENE-E SW set		NS set	
	Density	Deviation	Density	Deviation	Density	Deviation
M ign atitic G ranite (frac/m)	0.221	0.3	0.092	0.068	0.098	0.085
M ign atitic G neiss (frac/m)	0.237	0.252	0.074	0.023	0.036	0.029
G neiss Rock (frac/m)	0.298	0.269	0.142	0.02	0.228	0.158
Acid ite Rock (frac/m)	0.143	0.179	0.041	0.045	0.082	0.03
I nterm ediate Rock (frac/m)	0.097	0.109	0.085	0.107	0.067	0.176



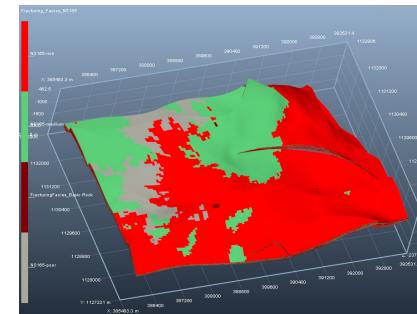
Lithofacies



Fracturing facies of ENE



Fracturing facies of ESE

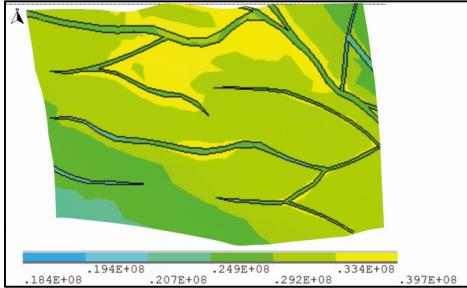


Fracturing facies of NS

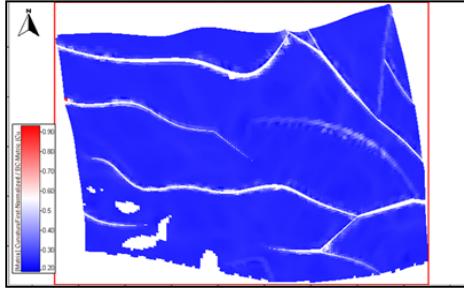
Presenter's notes: More control factors will be analyzed, for example regional structures, stress, lithology and any effective data. In a lithofacies example, geologists found that the rock type has a strong correlation with fracture density. So they reclassified the lithofacies according to the fracture sets, to confine the fracture density.



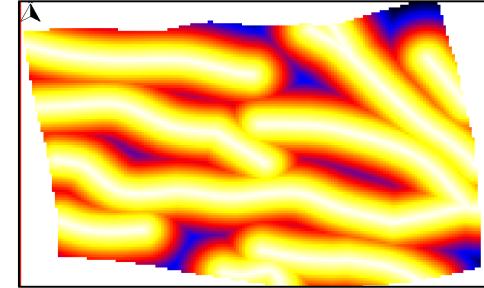
Control factors



Maximum principle stress

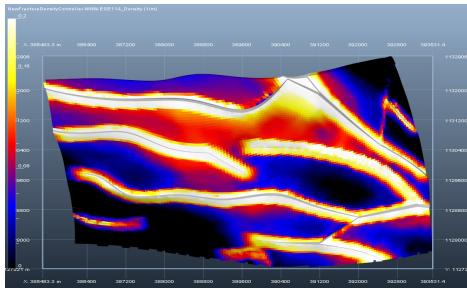


Curvature

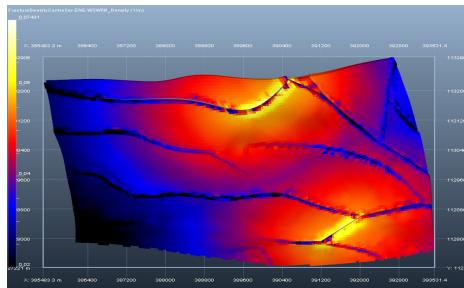


Distance to fault

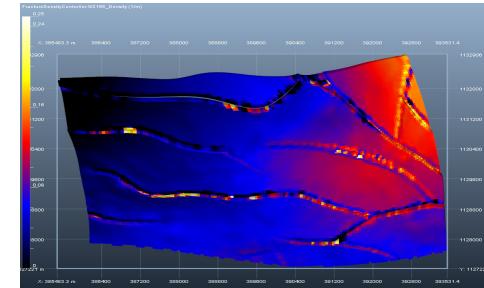
- Final fracture density are calculated based on the correlation between fracture property from well and four parameters that analyzed above.



Fracture density driver of ESE



Fracture density driver of ENE



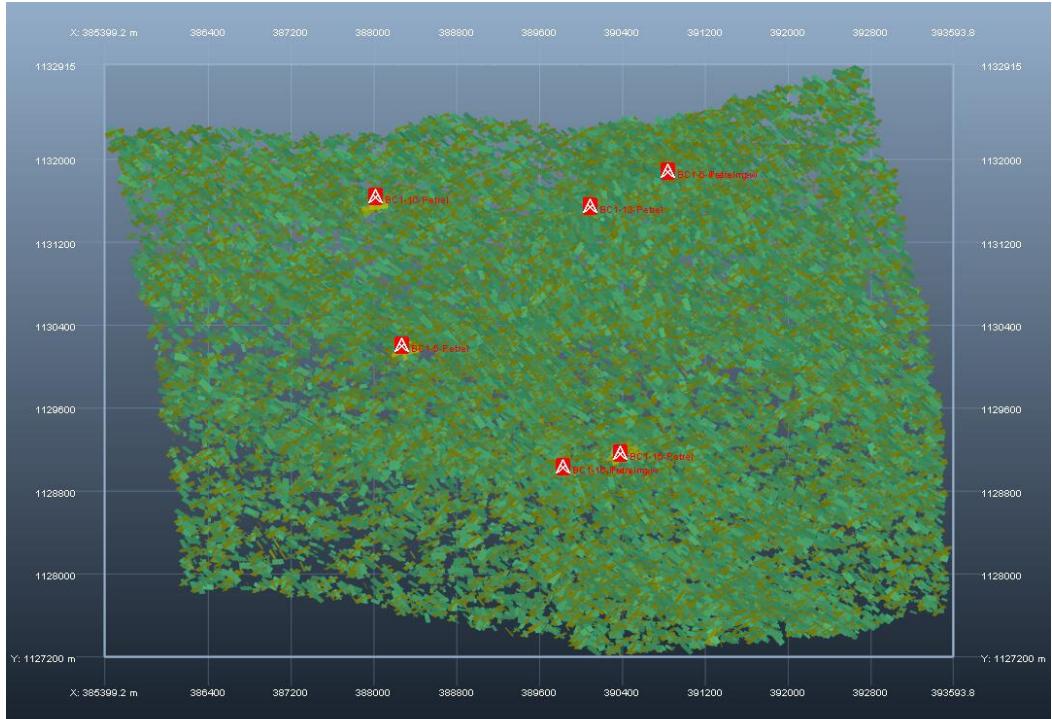
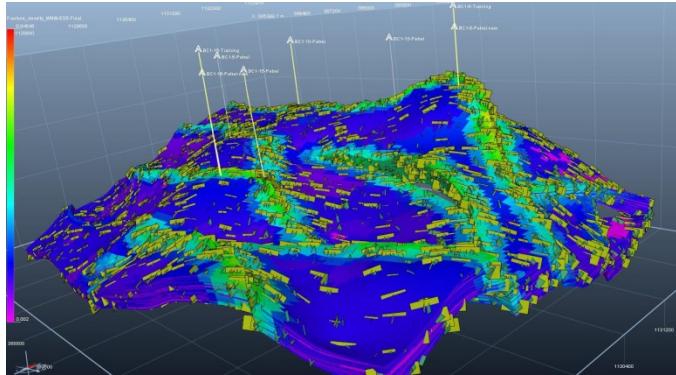
Fracture density driver of NS

Presenter's notes: The top part shows the other factors in our project, which are maximum principle stress, curvature and distance to fault. Then, all the control factors are merged together using the entropy weigh method, and we get the fracture density driver and orientation map for each set. We can tell the ESE fracture set will be the dominate fracture set, which will have the major impact on well production.



Full field DFN model

- 2 size scale groups:
- Large fracture 12,958
 - (50-200 m, > 1 grid size)
- Small fracture 267,000
 - (10-50 m, < 1 grid size)



Grid size=50*50 meters

Presenter's notes: Based on the above work, we now have the full field DFN model, and the fractures are characterized into two groups according to their size grades and their hydraulic impact on the fluid flow in the reservoir, which are those large-scale fractures representing highly conductive corridors and those small-scale diffuse fractures with lower overall conductivity and connectivity. The large fracture size is larger than the grid size, ranging from 50-200 m. Another group of fractures is smaller than the grid size.



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Presenter's notes: Next, we discuss EDFM and DPDK.

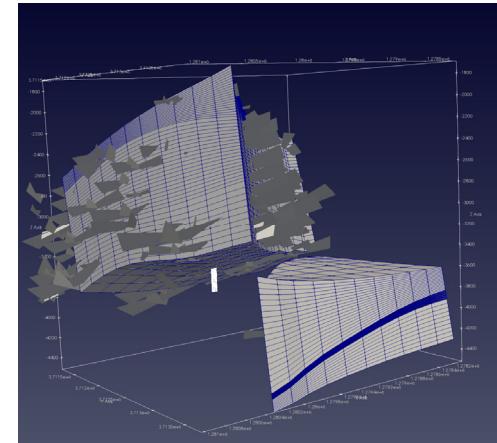


Single well model

- Based on single well DFN calibration, a single well reservoir model is generated.

Matrix Grid	11*11*50
Total Frac Number	6001
Large frac Size	50~200m(> one grid size)
Large frac Number	458
Large frac aperture	0.1 m
Large frac perm	1000 md
Small frac size	10-50 m(< one grid size)
Small frac number	5553
Small frac aperture	0.001
Small frac perm	100 md

	Range
Matrix Perm	0.0023~149md
Matrix Por	0.001~0.167%



Presenter's notes: Based on single well DFN calibration, we generated a single well reservoir model. Which includes two groups of fractures, large fractures (458), and small fractures (5553).



Simulations four scenarios

Frac Scale Classify		Case1	Case2	Case3	Case4
		Total EDFM	Single Por + EDFM	EDFM + DPDK	Total DPDK
Large frac	458	EDFM	EDFM	EDFM	DPDK
Small Frac	5553		Upscale to Matrix	DPDK	
Grid Number		51*11*50	21*11*50	21*11*100	11*11*100
Basic (11*11*50)		28,050	11,550	23,100	12,100
CPU Time(s)		9.87	5.27	11.09	4.61

- Case 1, we use EDFM to simulate both large frac and small frac.
- Case 2, we treat large frac with EDFM, but small frac will be simple upscale into Matrix.
- Case 3, large fracture treat with EDFM, but small frac will be upscaled to DPDK model.
- Case 4, both large and small frac will be treated with DPDK model.

Presenter's notes: In terms of the two groups of fractures, we use different treatment methods. We set 4 different cases accordingly.

Case 1, we use EDFM to simulate both large and small fractures.

Case 2, we treat large fractures with EDFM, but small fractures will be simply upscale into Matrix.

Case 3, large fractures are treated with EDFM, but small fractures will be upscaled to DPDK model.

Case 4, both large and small fractures will be treated with the DPDK model.

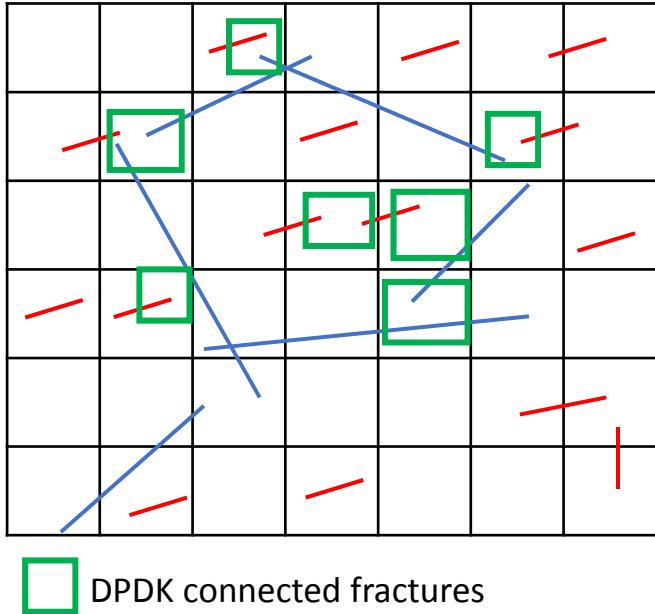
Different case's grid number and cpu times are list below.

Because the case size is small, the timing is not comparable.

Analytical method is used to upscale small fractures into matrix grid, which is quick and simple but not as accurate as DPDK method through Oda to contain more information on the fractures.



EDFM & DPDK comparison



- The Oda based DPDK homogenizes the contribution to the flow of all the fractures included in the same cell, notwithstanding they belong to separate networks.
- On the contrary, EDFM is capable of explicitly accounting for each single fracture contribution without any artificial communication between independent fractures.

Presenter's notes: With this diagram, we review the different treatment methods between DPDK and EDFM.

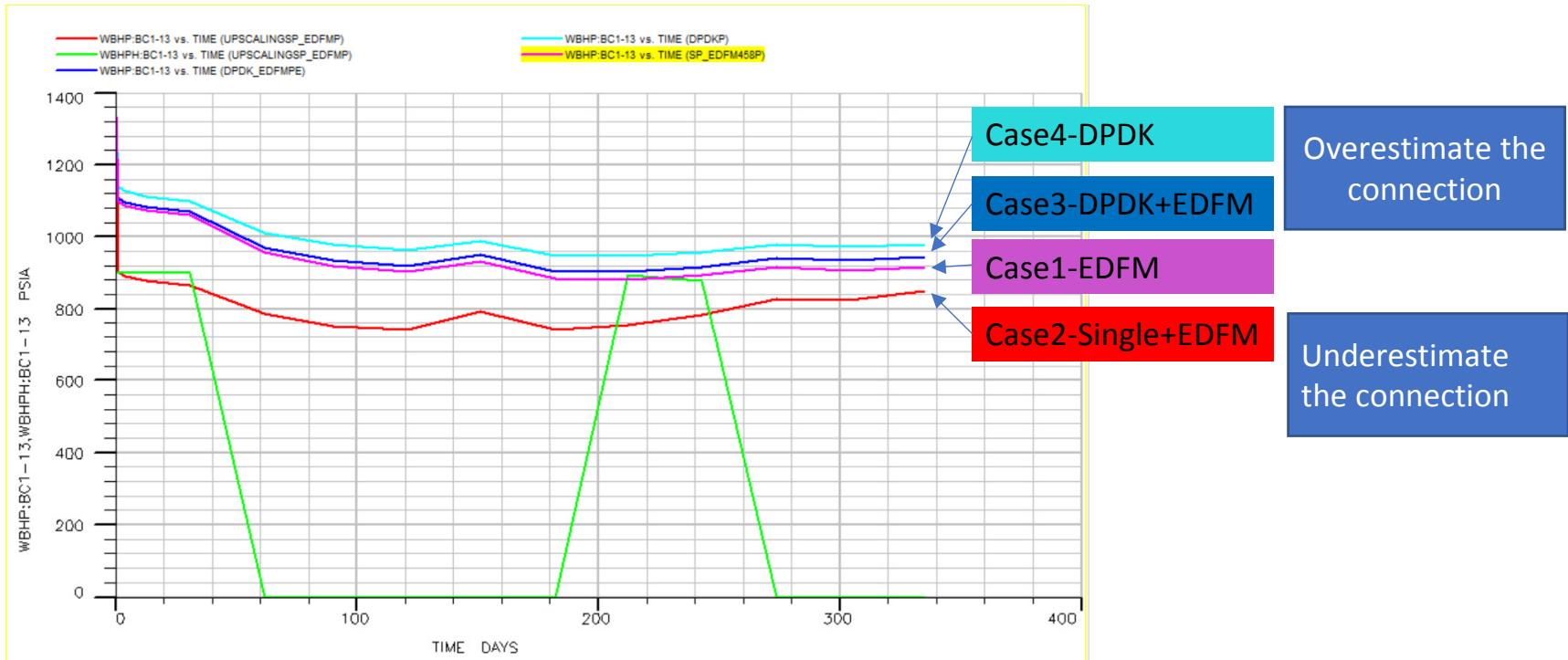
The red and blue lines are small and large fractures, in the green box more than one fracture is in one cell. DPDK and EDFM will treat them distinctively. DPDK will assume those fractures inside the boxes are connected. On the contrary, EDFM treat them separately.

Which means the DPDK method may create artificial flow-path that significantly increased the fractures connections. This, of course, affects the accuracy of the simulation.



Pressure response comparison

- Using EDFM history matching parameters to simulate the other 3 scenarios



Presenter's notes: We use the parameters from EDFM history matching to simulate the other three cases and this picture shows the pressure response.

Here the purple line is the EDFM result.

Case 2 has lower pressure response because this model underestimates the fractures connections.

Case 3 and Case 4 have high pressure response due to DPDK method overestimating the fractures connections.

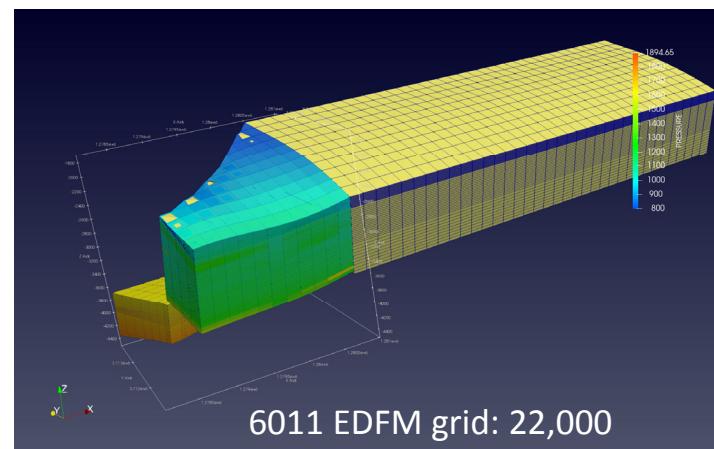
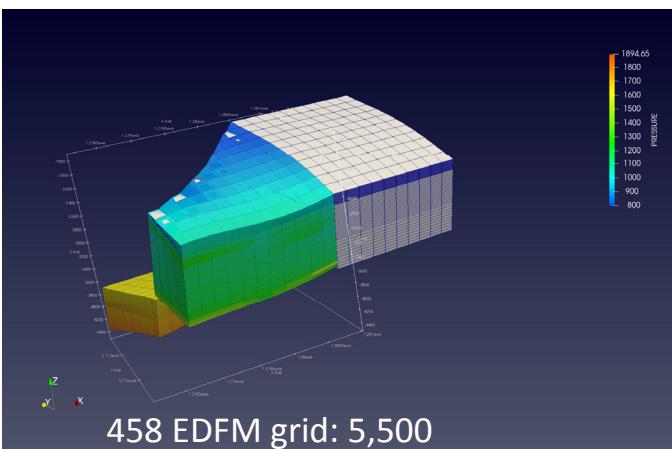
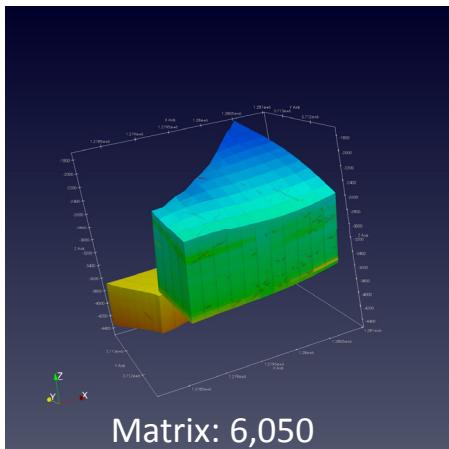
Comparatively, EDFM+DPDK model result close to totally EDFM model.

The largest one is Case 2 because this model ignores the small fractures porosity, so the reserves is not enough. Case 3, DPDK+EDFM is the closest one, but DPDK case overestimated the fracture connecting.



Why EDFM+DPDK

- More fracture embedded, more fracture grids added. It could be bigger than DPDK model, for massive fractures DFN model.
- EDFM+DPDK method chose as an optimal compromise between accuracy and computational efficiency, to deal with 10K+ fractures.



Presenter's notes: Since EDFM is more accurate, why don't we use EDFM to do full field simulation?

Through this example, we can see EDFM will generate additional grids. We can imagine for a huge amount of fractures a new fracture grid will be overwhelming for EDFM processing, beyond the current capability of the current EDFM processor. It is not feasible for the full field model.

So we proposed EDFM + DPDK, to take advantage both EDFM's accuracy and DPDK's computational efficiency.

Regarding the large scale reservoir model, the major task is to balance the matrix grid and fracture scales in order to implement EDFM in fractured reservoir simulation, so that both computational efficiency and accurate flow behavior could be achieved.



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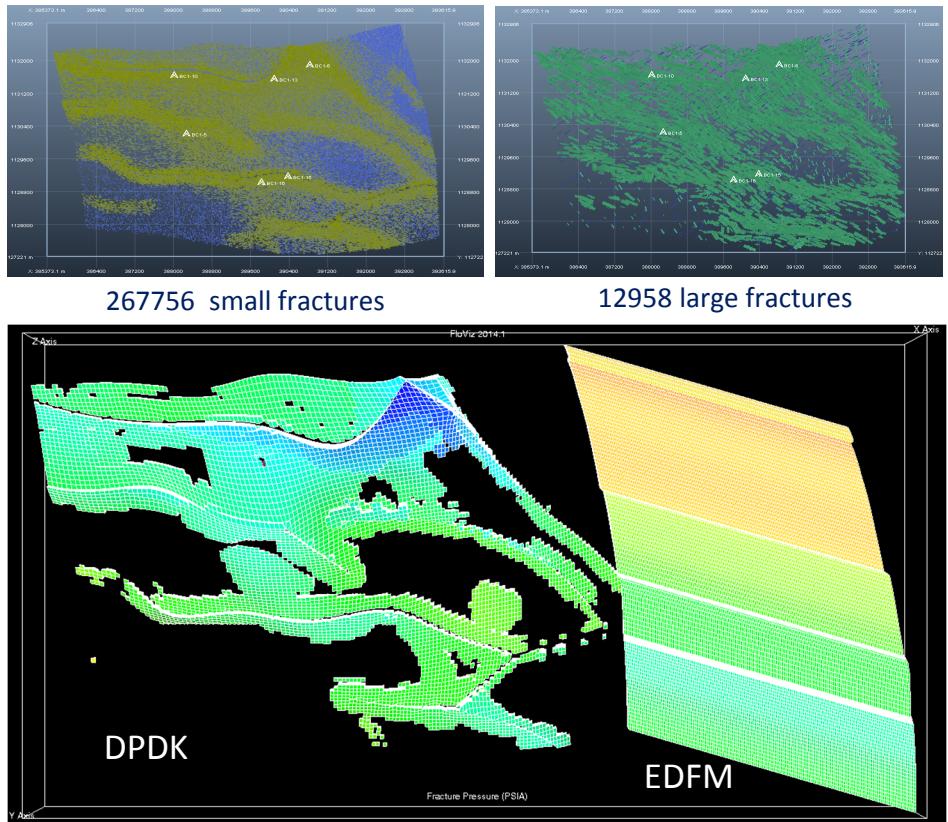
Presenter's notes: So let's implement this solution to test if it is feasible at full field scale.



Full field EDFM + DPDK modeling

- 12,958 large fractures
- 267,756 small fractures

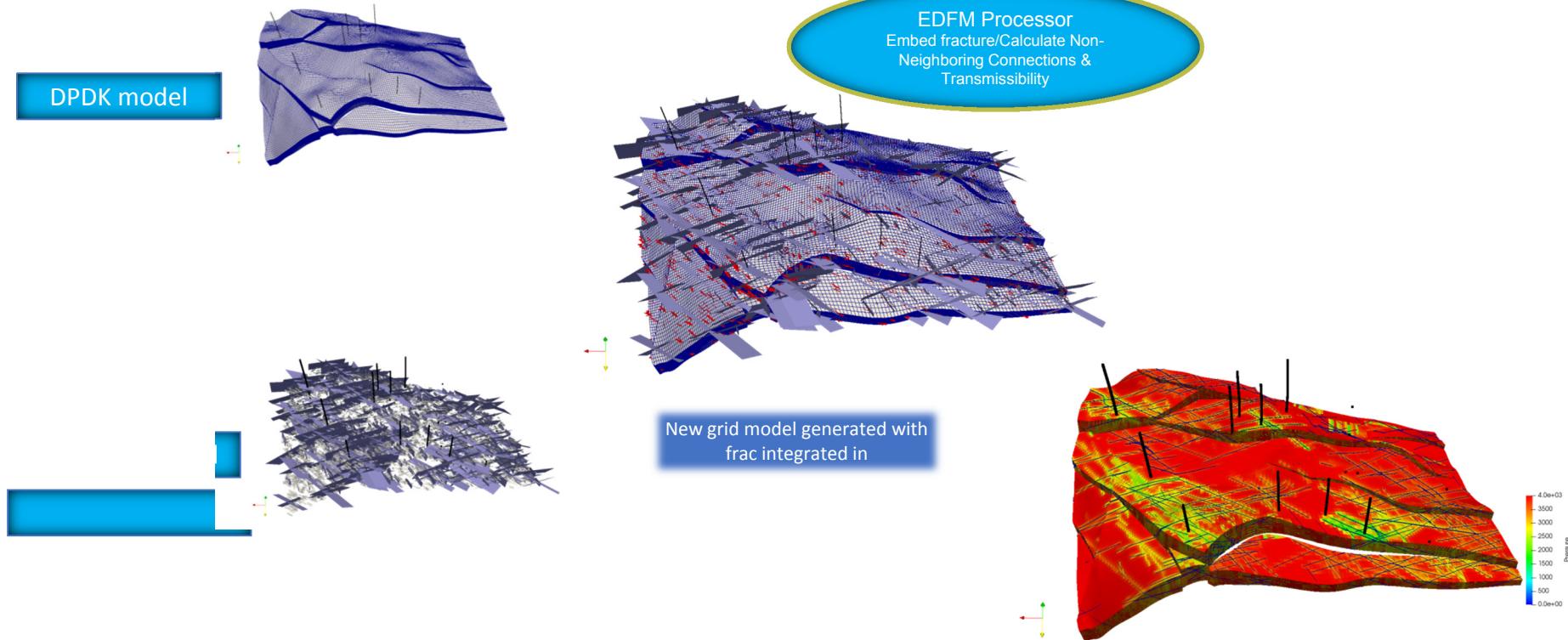
Matrix Grid	146*96*50
Large frac Size	50~200m
Large frac Number	12,958
Large frac aperture	0.01 m
Large frac perm	1000 md
Small frac size	10-50 m
Small frac number	267,756
Small frac aperture	0.001
Small frac perm	100 md



Presenter's notes: Here is the same as what we did in the comparison models. We have developed a coupled DPDK and EDFM method to simulate production from granite reservoirs. Large-scale fractures are modeled explicitly using EDFM, and numerous small-scale fractures are modeled using DPDK approach. This is the EDFM additional grid.



Full field EDFM + DPDK modeling

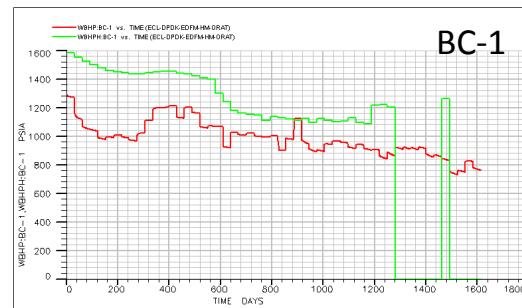
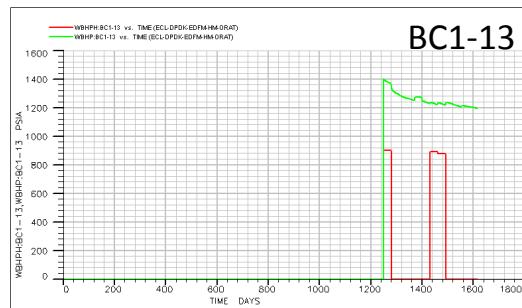
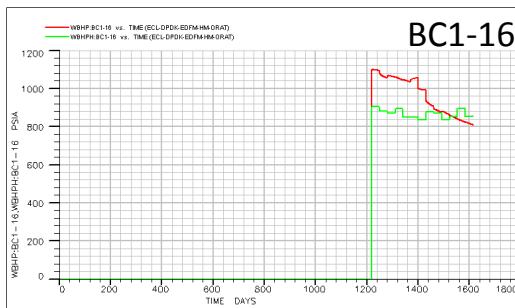
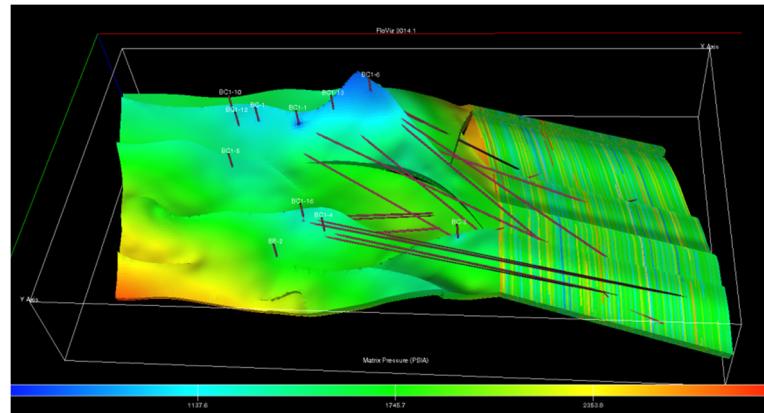


Presenter's notes: This is a concrete process of simulation conducted on ECL simulator.



3 years history matching

- First DPDK + EDFM full field fractured reservoir simulation application
- More history matching options
 - Through DPDK fracture parameters
 - Through EDFM fracture parameters



Presenter's notes: With this model, we run a 3 year 15 wells history matching. This is the direct simulation results with the DFN model we generated before. The field engineers are very excited about the preliminary results. We did not change any parameters yet, and the trend is not bad.



Overview

- Introduction**
- A New nature fracture modeling workflow**
- A benchmark study between EDFM and DPDK**
- EDFM+DPDK full field application**
- Summary**



Summary

- A new fracture modeling workflow integrated with EDFM is developed
- A full field reservoir simulation with EDFM + DPDK is conducted successfully
- Further works will be done to improve the performance of the EDFM in this case.