Uncertainty Workflows for a Naturally Fractured Granite, getting to multiple models with 2000 variations.



Greg Walker PhD - Discipline Manager Reservoir Engineering (1)
Sergio Sarmiento PhD - Fracture Specialist (2)
Luis Enrique Navarrete MSc - Global Manager for Res Characterization (2)
Brigida Fontecha MSc - Senior Advisor Geophysicist (2)
Arnulfo Briceno MSc – Discipline Manager Development Geology & Geomodeling (2)
1 Repsol Technical E&P Madrid - 2 Repsol Technical E&P Madrid Houston

Contents



- 1. Introduction
- 2. Dual Porosity Dual Permeability model
- 3. Integrated Workflows
 - Event based history matching to limit run time per case
 - Advantage of including DSTs
 - DFN parameters to use
- 4. Uncertainty Analysis and using a cluster
 - Workflows at their best

Introduction



- Complex field: Fracture Basement
 - Some wells work (10kbopd/well), some don't
 - Some fractures matter, some don't
- Challenge: build a reliable forecast model for infills and waterflood.
 - History matched model including DSTs using DFN / geomechanics to predict Kx,Ky away from well control, for infill wells.
 - Dual porosity model to calibrate K/phi, for water flood expectations.
 - Knowing the Simulation time of 24 core-hours /case
 - Knowing each model is wrong in some detail, use Uncertainty Analysis to capture range of outcomes
 - 1500 cases to get history matches.
 - 1200 cases to do variations
- And do it in 3 months.

Dual Porosity, Dual Permeability model





Dominates permeability Can be very low porosity High K/phi dominates water flood.

Diffusivity, linked to fracture density

Dominates porosity, but fractured granite might be only 0.5% to 1.5%

"Facies" for Dual Porosity, Dual Permeability model





Shallow or deep?

Integrated Fracture Model Workflow Time step DFN geological evolution





Lots of models, so limit simulation time : Event based history matching



- Conventional
- Simulate history
- Compare to history
- If it matches history, assume it matches key issues.



24 core hours

DSTs Production

- Strategic
- Material balance
- DST for primary permeability, porosity
- Deconvolve production history for interference tests



10 minutes: Material Balance DSTs Interference

Dual Porosity, Dual Permeability model





DST for productive fracture permeability, porosity Deconvolve production history for interference tests

Material balance



Stress Evolution and modeling of fracture forming events



Fracture Halos and Hydrothermal Influences



Agus.E.Harabap, 2012







Hydrothermal-Diagenesis Overprint

Fracture Intensity As A False Positive For Productivity

Not all primary fractures matter but the ones that are

- critically stressed
- have sustained communication with the background fractures
- Are not occluded by hydrothermal diagenesis and likely have been reactivated by multiple tectonic events.



Sigma or shape factor represents the fluid flow between the matrix and the macro fractures which are both considered to be in pseudo steady state.



Enhancement





Comparison of Sigma Values and History Matched Permeabilities















A small discrete fracture on Image log has a wider alteration halo and partial mineralization along fracture surface. Calibrating aperture size, mineralization and alteration halo is key to accurate DFN modelling

Separating Fracture Aperture/porosity from total porosity log response is a challenge

DSTs should include fluid losses



- 1. In fractured basement reservoirs, fluid losses indicate high productivity
- 2. Wells are drilled for total losses.
- 3. If a well doesn't get total losses, side track.
- 4. Losses will overcharge the reservoir prior to the DST
- 5. Overcharge linked to extent of fracture, and fracture porosity
- 6. Leak off linked to sigma and background permeability

History Match



Build attributes:

- Orientation of faults
- Orientation of lineaments
- Distance to each type of fault and lineament
- Slip tendency
- Uplift from each tectonic event.

Supply to workflow:

/ • E	dt existing: 📔	DFN1	117Medium5AqNNETweak				
Task:	Un	certainty			✓ Mo. of runs: 20		
Ease	e case	/ariables	Uncertainty				
Base ci	ase: 📫 👬	TSHIFT	r	Edit world	low 🕜		
Pre:	ф		Post: 🕸	Reset origin	* 3 +		
1		V ()	With 3D grid 🏟 🏢	Alv/_1017_Layeri	Use: Specified grid v 🚯	_	-
2		O	Make horizons				
3		O	Layering				
4		1	Geometrical modeling ZI D3 E	Event			
5	\$pemHSD5X	V 🗓	Property calculator 🗌 Use filter	Expression or file:	Pemi (Distance_to_faults\AW_by_directions\AW_EW_Faults_120>0.5.f(Rowering_effect_fa		Use
6	\$D5,(3)	I	Property calculator 🗌 Use filter	Expression or file:	Pemi f(Distance_to_faults\BF_by_directions\BF_NE_Faults_120>0.5.1.0)%(Rowering_effect		Use
7	\$pemHSD4X	S 🛄	Property calculator Use filter	Expression or file:	Pemi 1+Rag ST1*\$pemi		Use
8	Spem(1)	M	Property calculator Use filter	Expression or file:	Pemi 1A+Rag1eature*RagDstrain*Spemi T1A		Use
9	Spem(1)	Image: Contract of the second seco	Property calculator Use filter	Expression or file:	Pemi (FlagH		Up
10	\$D3(3)		Property calculator Use filter	Expression or file:	PermUplift+f(Flowering_effect_factors\D3_Event>\$D3.f(HALO_BF_HIGH>0.5.\$highperm.f(HALO_BF>0		Use
11	Sanis(6)		Property calculator Use filter	Expression or file:	Aniso=1+f(Perm ST1A>0.000001.Saniso4XDST1A-1,0)+f(Per DST1>0.000001.Saniso4	님	Use
12	a la		Property calculator Use filter	Expression or file:	PERMX1X+0+PemI ST1A+Pem ST1+PemNNEWeak+PemUpitt+PemI +Per	님	UM
13	seib		Property calculator Use filter	Expression or tile:	PERMATAREUS/SUP_TENDENUT/SUP_UPERMATA)	H	UN
15			Property calculator Use filter	Expression or file:	PermVMecro+PEPMV1X/Sof(Jeleo)	H	Use Use
16	\$D3 (3)		Property calculator Use filter	Expression or file:	Pomety/Accessormacone//Rowering effect factors/D3 Events/D3 Scomboost 0	Н	Un
17	SDSTe. (2)	⊠ ₿	Property calculator Use filter	Expression or file:	Porosty/Mcro-ef(UplitExtent)0.5.5poroscale*POR0.\$DSTporoscale*POR0)	ň	Use
18	\$D3(4)	× 🖬	Property calculator Use filter	Expression or file:	Signa+f(StrutDFN+1.\$SigmaD3*DFN1117\SIGMA.f(Rowering effect factors\D3 Event>\$D3 \$SigmaD	ň	Use
19	Sback(6)	V 🖬	Property calculator Use filter	Expression or file:	PermMicro+#(\$vietsovpetro+0.#(Rowering_effect_factors\D3_Event>\$D3.\$D3microperm.#(Rowering_effect_factors\D3_Event>\$D3.\$D3microperm.#(Rowering_effect_factors)		Use
20	Selp	2	Property calculator Use filter	Expression or file:	PermMicro=#(D5\SLIP_TENDENCY<\$alp.0.PermMicro)		Upr
21			Property calculator Use filter	Expression or file:	FIPNUM+max(1.Geometrical_Properties\Segments)		Use
22	SAQMuit	V 🗓	Property calculator 🔲 Use filter	Expression or file:	AgMult+f(Depth()<4100,\$AQMult,1)		Use
23	\$OWC,(2)	🗹 🎳	Make fluid model 🎒 Black oil	model 1			
24		ע 🗉	Make rock physics functions	Consolidated sands	stone 1		
25	Segor(4)	V V	Make rock physics functions	Fracture (straight li	ne) 1		
26		- Ax	Development strategy				
27		🗹 📩	Development strategy Av Base	eHistory			
28	\$dept(23)	2	Define simulation case 🐞 TSI	HIFT			
29			Pause Duration: 1				
30		× 🗹	Wait for case results Case refere	nce: 😰 📓 Ou	tput case [glob		

Ideal combination

DST with one lineament. Lineament only intersects one well.

TSHIFT

— TSHIFT 1720 — TSHIFT 2477

REPSOL

Well A is the only well to intersect NW-SE fault

Well A DST interval includes only NW-SE fault.

Less ideal combination

Each well has mutiple lineaments



Each lineament intersects multiple wells



8 different systems:

NE or NNE lineaments,

Visible on top structure or visible in ant tracking In Tectonic Event 3 or Tectonic event 5 uplift events.

Impact two wells.





History Matched model



- 1. 1500 cases for history match.
- 2. Event based history matching to identify key matches
- 3. Workflow to track variables, build batches of 50 cases/ day
- 4. 2 months of calendar time.
 - Iterations on slip factor
 - Iterations on tectonic events and their areal extent
- 5. Constant integration between geomechanics, geophysics, geomodel

Uncertainty and Prediction



- Test alternative geomodels: 3
 Reference and 2 alternative history matches
- 2. Test infill wells and combinations: 32
 5 different options identified, technically 32 options to try including base case.
- 3. Test water flood : 12
 - 4 from water strategy: 3 different injector locations, and base case
 3 from high/medium/low relative permeability, as this is a null space in the history match
- 4. Total is 3x32x12 = 1152 cases
 - 24 core hours per case, or 1 core day.
 - 96 cores of MR licensing and cluster.
 - 12 days of simulation.
 - Technically could have saved time using restarts (slb please improve!)

Summary



- Complex field: Fracture Basement
 - Some wells work (10kbopd/well), some don't
 - Some fractures matter, some don't
- Success: build a reliable forecast model for infills and waterflood.
 - History matched model including DSTs using DFN / geomechanics to predict Kx,Ky away from well control, for infill wells.
 - Dual porosity model to calibrate K/phi, for water flood expectations.
 - Simulation time of 24 core-hours /case
 - Knowing each model is wrong in some detail, use Uncertainty Analysis to capture range of outcomes
 - 1500 cases to get history matches.
 - 1200 cases to do variations
- And did it in 3 months.