9. Frac Candidate Selection

Tight Gas 19th Sept 06

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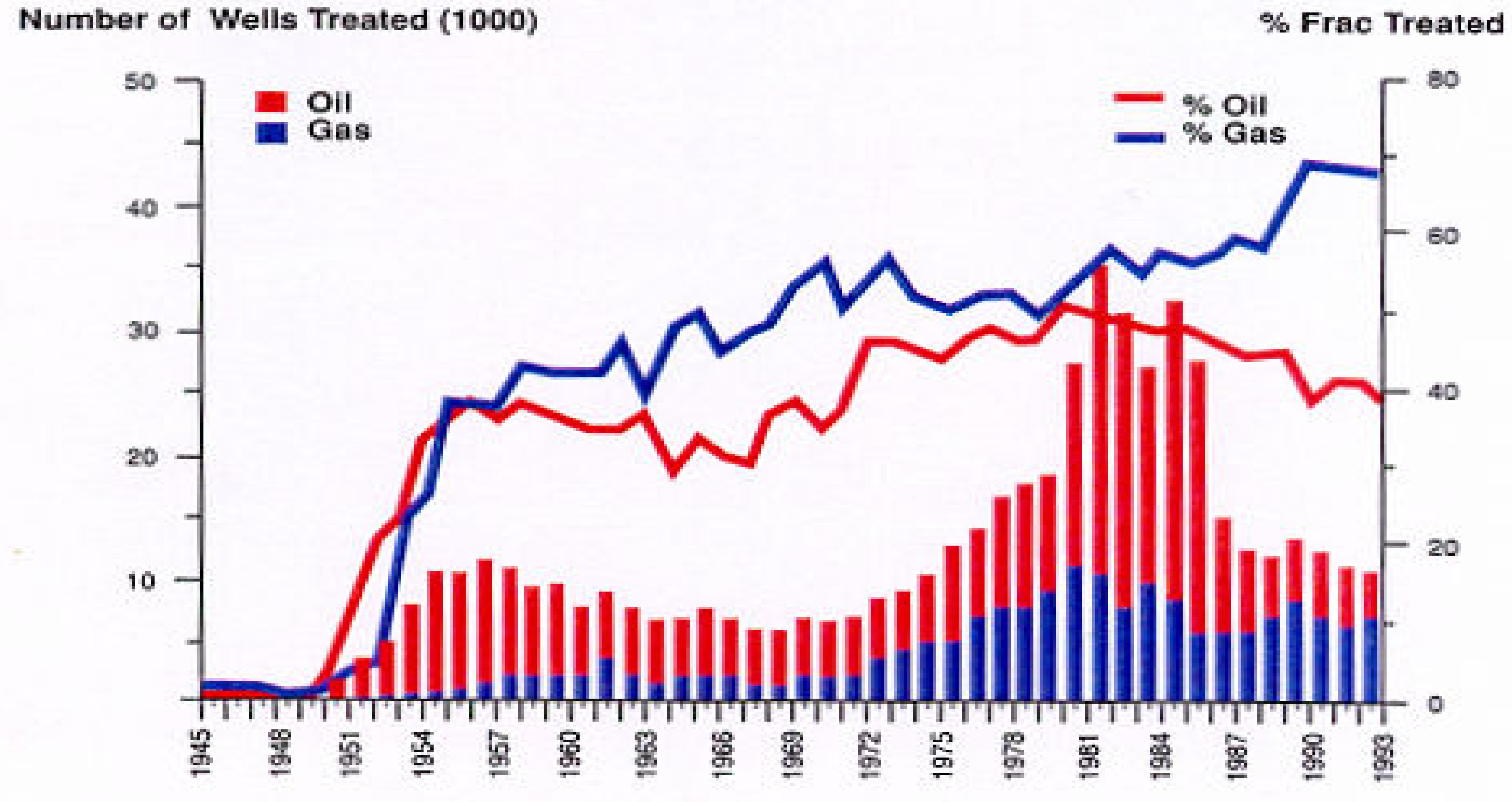
Hydraulic Fracturing History in Brief

- Hydraulic fracturing was implemented in the USA as early as the 1940’s without sand – hence production enhancement was limited
- In the late 50’s and 60’s proppant was introduced (natural sand)
- In the the sixties the technique became well established for production enhancement of tight reservoirs. Analytical techniques (Cinco-Ley et al) were developed to estimate negative skin
- In the 80’s Mini Frac analysis (Nolte et al) was developed, which made fracturing into a science rather then an art.
- In the mid 80’s tip screen out was developed (by Paul Martins in BP) which was valuable in medium-high permeability reservoirs.
- In 2000 reservoir and fracture numerical modeling (Stimplan a and WellWhiz) were introduced for fracture production optimisation and design
- Currently 80% of the production from the USA is from hydraulically fractured wells.

Fracturing History in USA

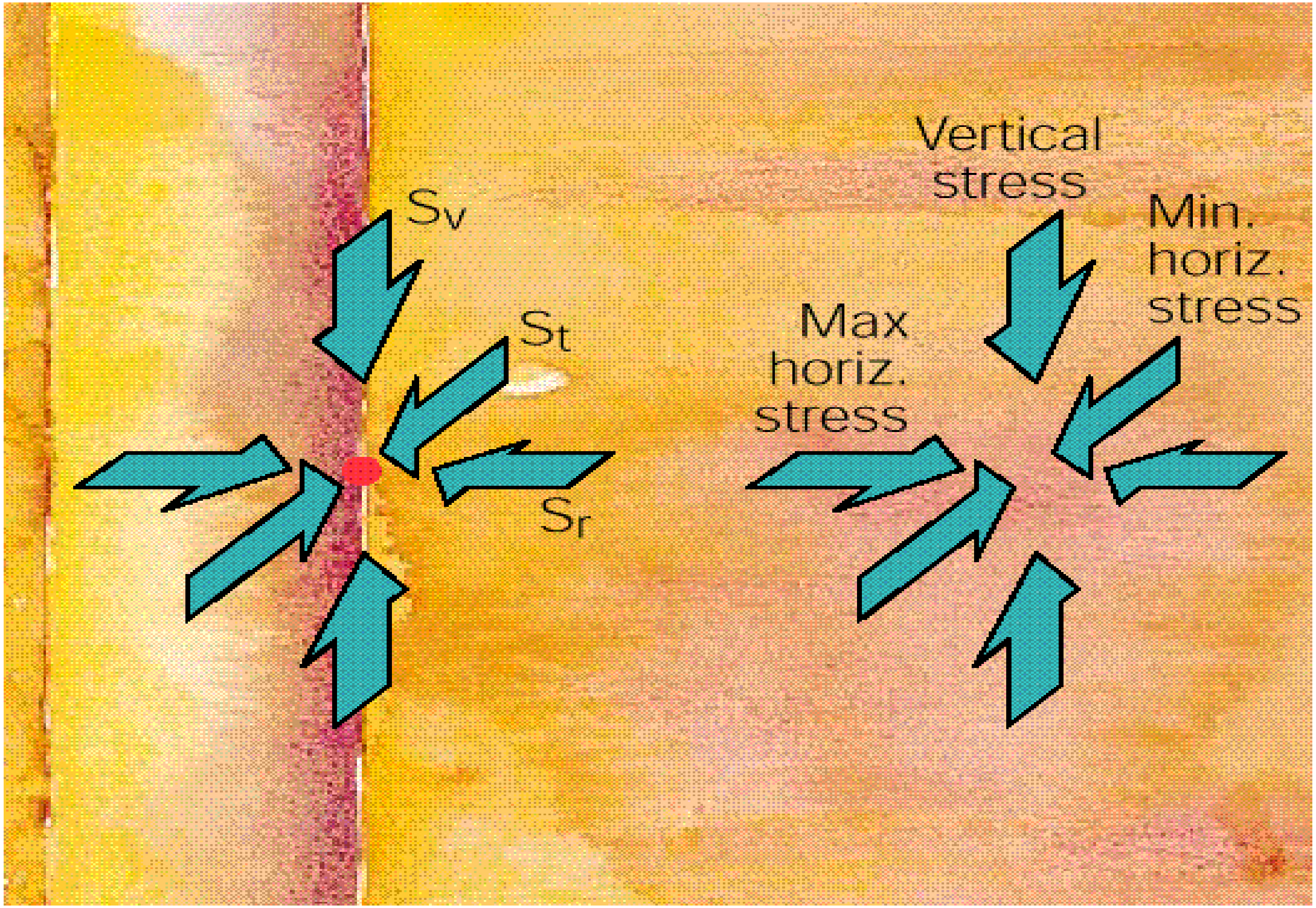
Figure 1: Fracturing's Importance Has Increased for Gas Wells



North Sea Fracturing

- Under utilized. Historically we tends to develop the better reservoir and leave behind marginal ones.
- Costly to apply, and hence carries a high risk.
- Proppant flow back was a threat in the past in - some Companies still believe that is a deterrent.
- Current oil prices suggests lots of opportunity to develop marginal reservoirs.
- Better tools, products and experience has evolved in the last 10 years that does improve results

Fracturing and Stresses



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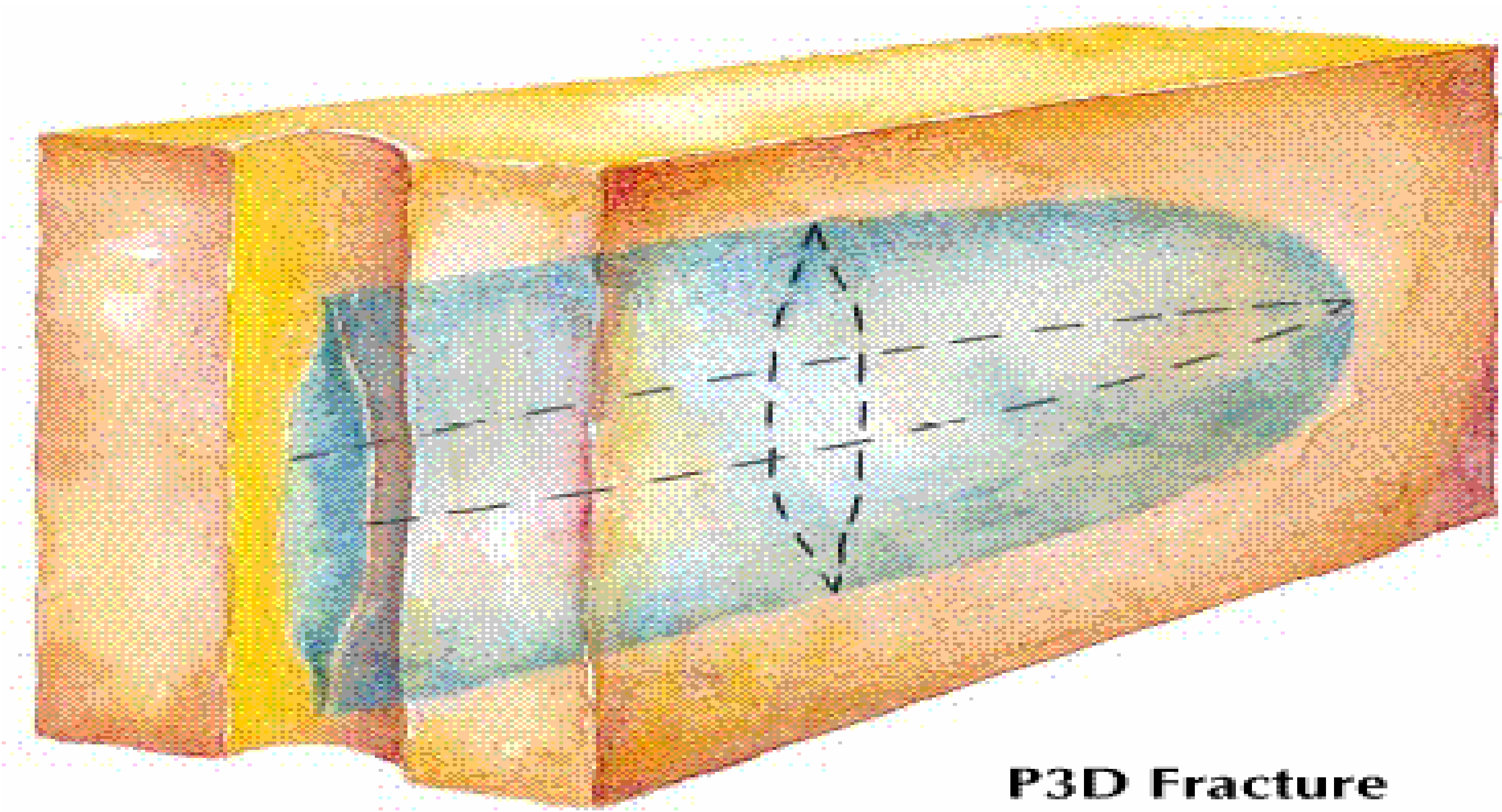
Fracture Dimensions
Simplistic View



Complex Geology Fracturing Realistic

□Laminated pay zone with sand-shale sequences. The sand laminae may be connected to the wellbore by short, wide fractures.

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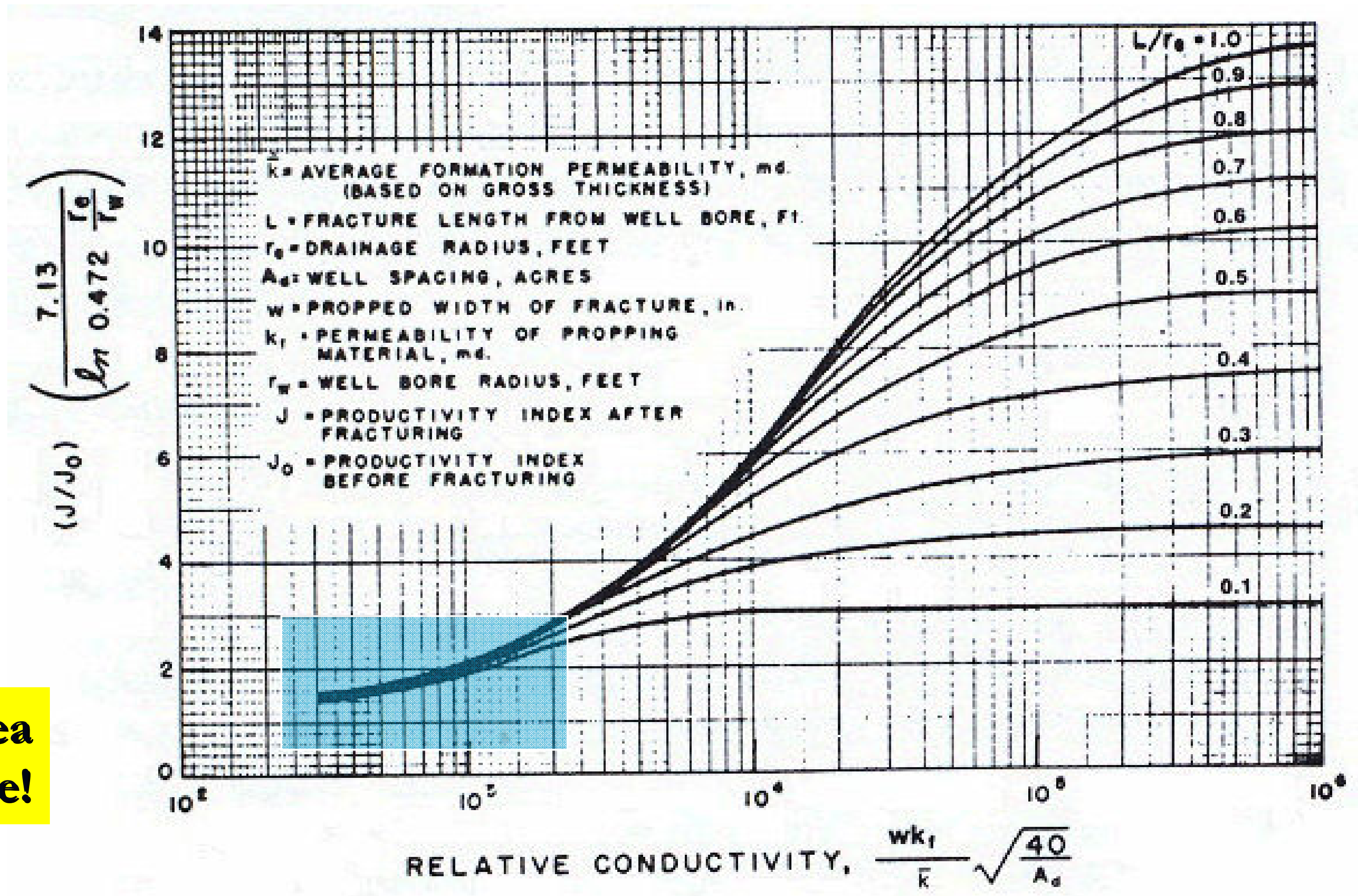
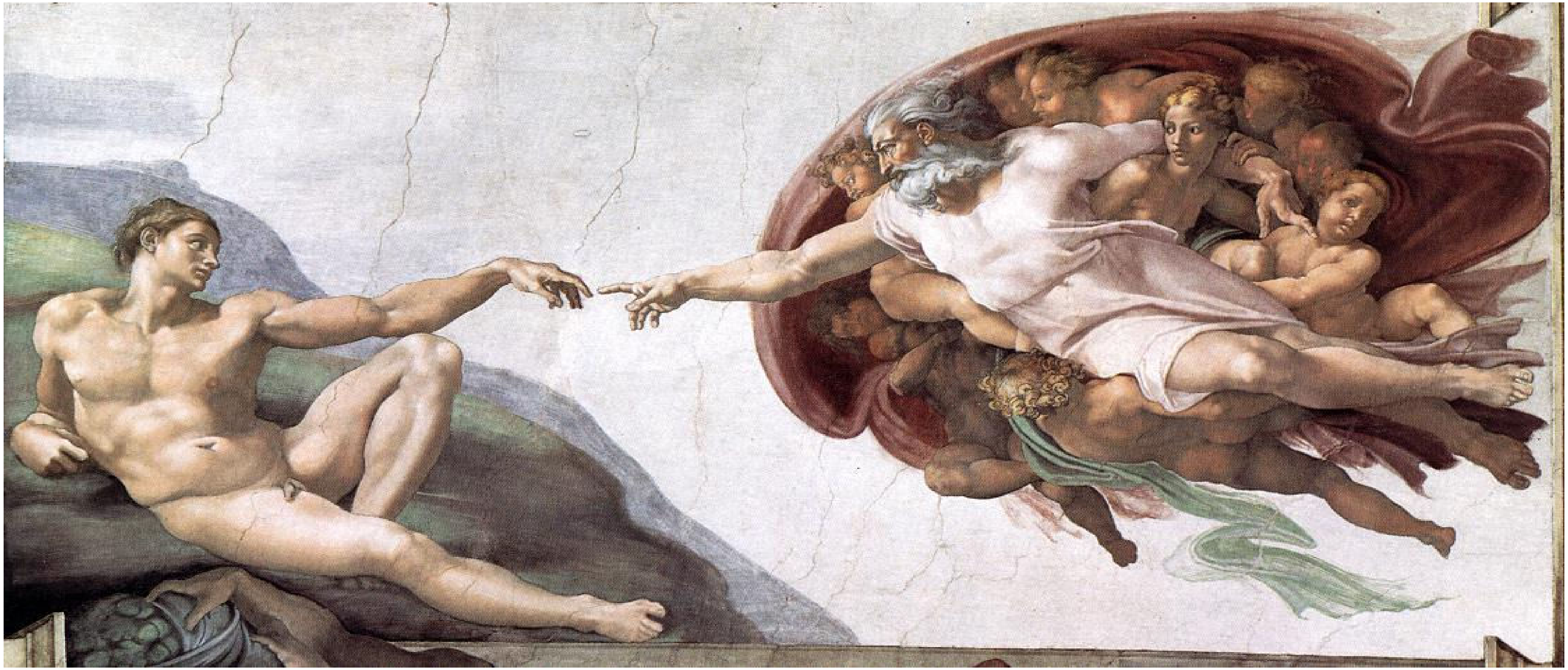
Analytical Methods
PI increase in Vertical Wells



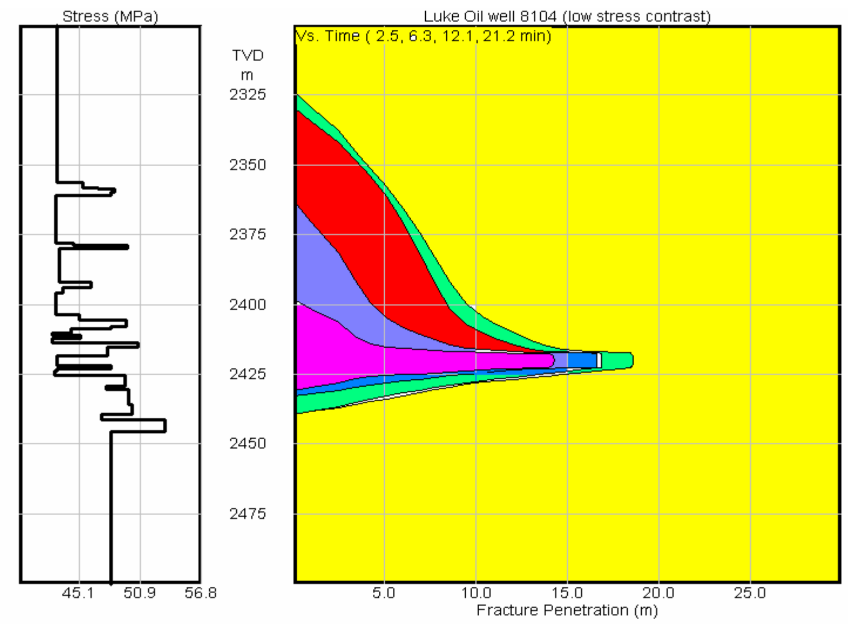
North Sea Range!

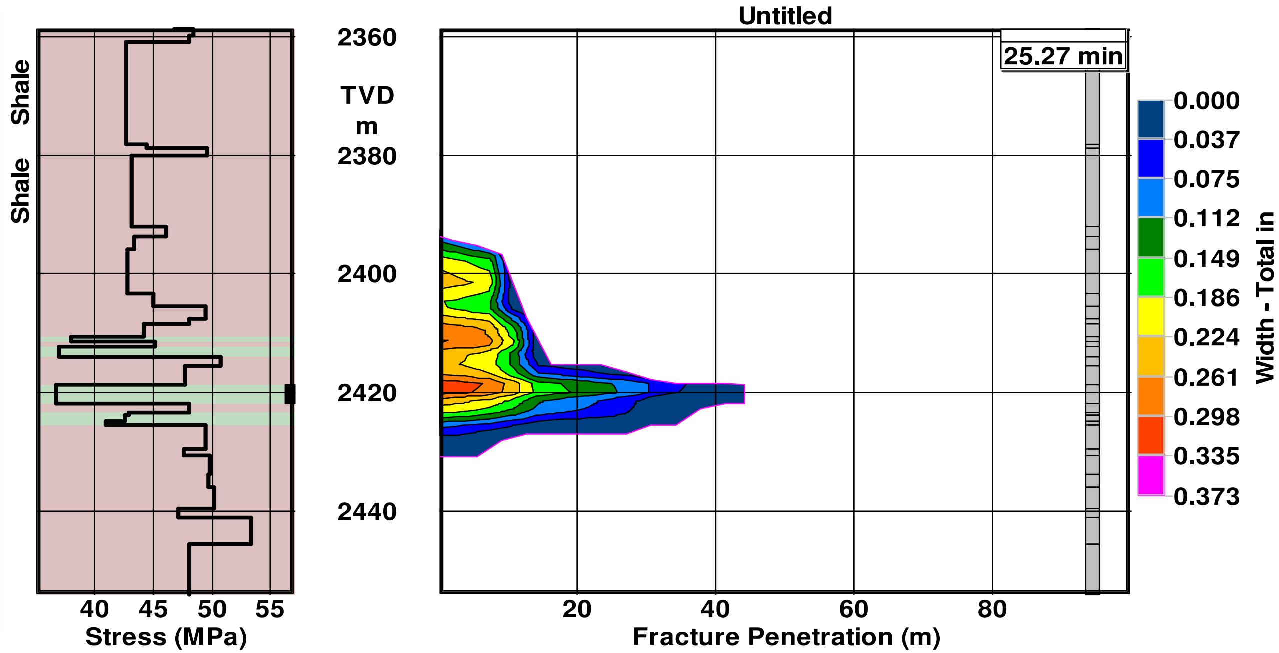
Frac Design 'Old'
In 'Frac Models' we Trust!



Or Do We?!

(Same input/ same software Two answers)





Analytical Solution

Numerical Solution

New Ways

- New tools are now available for better design
  - In depth Fracture design – field data collection
  - Numerical Reservoir Simulation
  - Sensitivities and field calibration of models
  - Etc……..

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Candidate Selection-A Field Example
Mechanical Screening

Primary Screening								
Selection Criteria	conventional well	Well Rate 11 to 30mmscf/d	inc < 15deg any azimuth OR inc < 40deg azimuth +/-30deg from E-W					
Well	Well Type	Gas Rate [mmscf/d] @ Sept 2004	Well-Bore Orientation, single or multi-frac regime	Inclination	Azimuth	Perforated Zones	Zonal Access	Issues
		5.8	single	0.9	36.9	Z50, Z45, Z40		**Rate too low**
	existing frac	9.4	single	6.2	338.1	Z50, Z45, Z40	failed flapper valve	
		7.1	single	17.2	109.6	Z50, Z45		
		12.3	multi	16.5	57.1	Z50, Z45, Z40		
		36.2	multi	23.9	236.8	Z50, Z45		
	existing frac	10.7	multi	18.3	24.5	Z50, Z45, Z40		
		16.3	single	32.8	85.9	Z50, Z45, Z40, Z10	no Z10 access	**produced water**
		19.6	single	31.9	102.3	Z50, Z45, Z40	yes(not verified)	**annulus communication**
	HAW	11.5	single	68.1	61.2	Z50, Z45, Z40, Z30, Z20 Z10	guns across the perfs	
		14.6	multi	16.9	153	Z50, Z45		
		18.0	multi	50.7	121.7	Z50, Z45, Z40		**Wire line e ntry difficult due to dop**
		12.9	single	14.1	199.2	Z50, Z45	yes (not verified)	
		9.0	single	31.2	82.1	Z50, Z45, Z40		aborded high p/u weight during w
		11.7	single	1.8	326	Z50, Z45	yes	
		4.4	single	1.4	280.7	Z50, Z45		**Rate too low**
	Failed Frac	12.6	single	11.7	56.5	Z50, Z45, Z40, Z20, Z10	yes (No Z10 access anymore!!)	
		17.9	single	20.8	98.2	Z50, Z45, Z40, Z30	yes	
	HAW	5.9	single	33.3	75.7	Z50, Z45, Z40, Z30	no access	
		17.0	single	40.7	108.1	Z50, Z45, Z40		Stepout???
	HAW	15.2	multi	81.1	10.5	Z45, Z40	HAW/ guns	
		8.4	multi	20.1	52.5	Z50, Z45, Z10		
		25.7	single	39.9	95.9	Z50, Z45, Z40, Z20, Z10	guns across the perfs	
		21.4	single	37.5	84.4	Z50, Z45, Z40, Z20, Z10	guns not dropped	
	HAW	14.6	single	71.2	298.8	Z50, Z45, Z40	HAW	
	HAW	28.9	multi	76.1	17.3	Z50, Z45, Z40, Z10	HAW	
		32.3	multi	18.2	147-150	Z50, 45 (Perfs 13540 - 13815)		Split Slot
		14.4	multi	32.5	25.0	Z50,45,40,20,10 (Perfs 14735 -15071)	no access	Split Slot
		22.3	single	45	107	Z50, Z45, Z40 (GWC ?)		water? Split Slot
		14.6	multi	45 - 58	56	Z50,45,40,30,20,10 Perf 16655-17290	no access	9 5/8" Split Slot
		32.9	multi	26	235	Z50, Z45 Perf 14804 - 15027		9 5/8" Split Slot
		26.9	single	28	73	Z50,45,40,30,10 Perf 14307-14784	no access zone 10	9 5/8" Split Slot
		25.8	single	11	334	Z50,45, 40, 10 (Perfs 14900 - 15205)		9 5/8" Split Slot
	HAW	35.0	multi	80.9	4.8	Z50, Z45	guns across the perfs	
		?	single	26.8	260.8	Z50, Z45, Z40		

Basis of Selection

- GIIP in model obtained from P/Z
- KH obtained from PBU (a challenge in tight gas where the well might not flow)
- Layer permeability obtained from PLT
- Model is initially history matched with prod data
- Well trajectory and CBL, etc..
- Frac modeling includes multi-phase flow (condensate banking) and non Darcy effects numerical techniques used)
- Fracture placement

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Inputs to Numerical Reservoir Simulator (*WellWhiz*)

Inputs to WellWhiz

Fracture Geometry
- Multiple fractures
- Width/ Height/ Length
- Conductivity, non-Darcy β

Reservoir Parameters
- Perm, Φ
- Multiple Rel perm regions
- Multiple shale/ sand units
- Condensate drop-out

Sensitivities
- Tunnel Permeability
- non-Darcy β,
- # of Effective
- Frac Fluid
- Annular Pack “D”
- Early Screen-out
- Flow thru’ frac/ non-frac perfs
- Zonal contribution

Wellbore Hydraulics
Prosper generated VLP

Screen Effects
- Screen selection
- Annular pack perm
- “D” non-Darcy coefficient

Perforation
- **Diameter**
- Tunnel Permeability
- non-Darcy β,
- # of Effective

Inputs to Frac Simulator (WellWhiz)

Wellbore Hydraulics

Prosper generated VLP

Perforation

- Diameter
- Tunnel Permeability
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- # of Effective

Screen Effects

- Screen selection
- Annular pack perm
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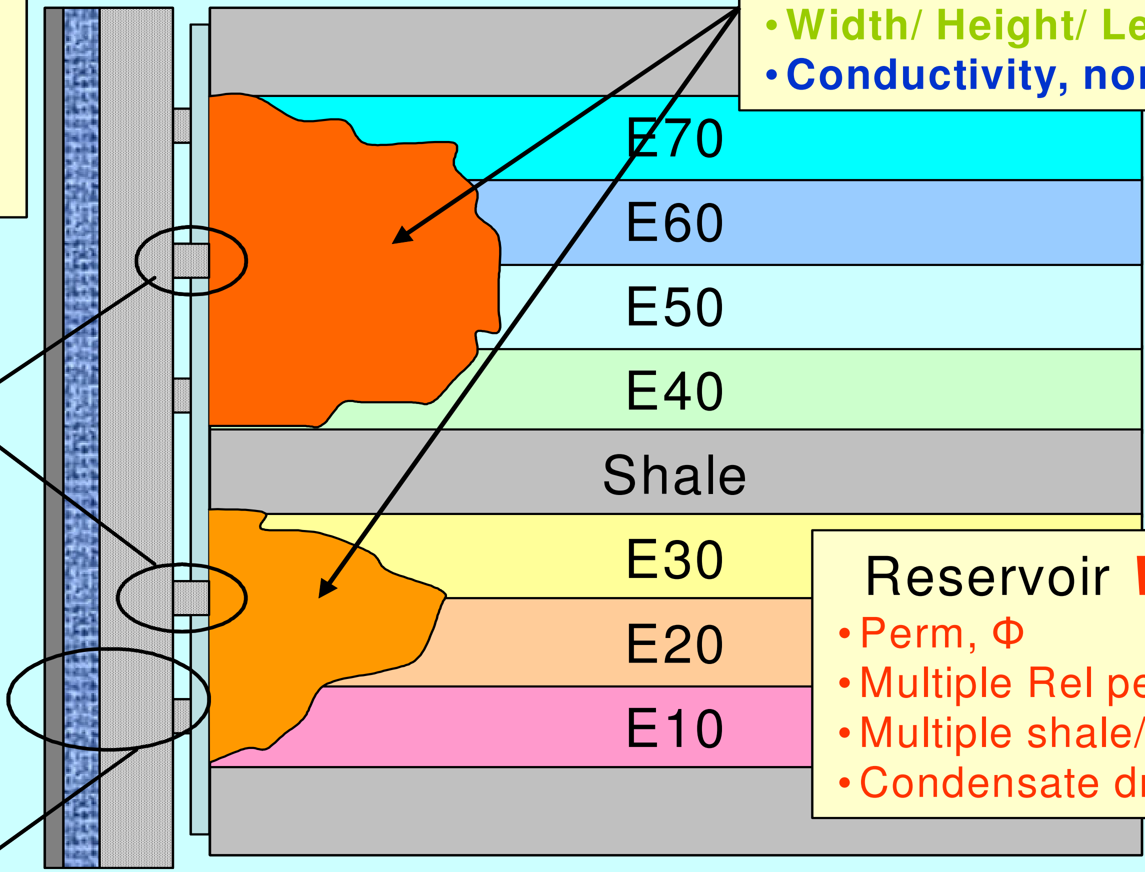


Fracture

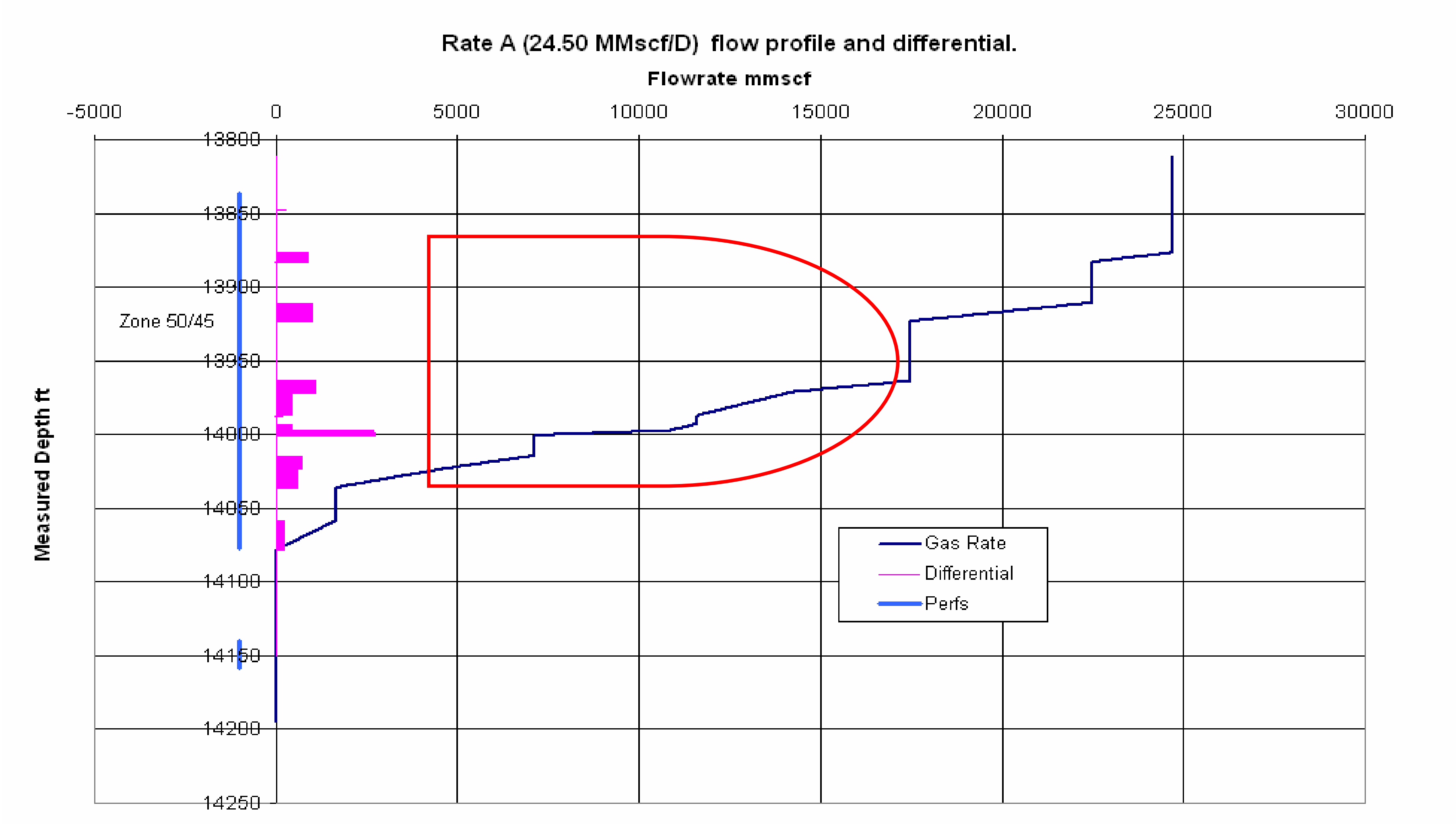
- Multiple fractures
- Width/ Height/ Length
- Conductivity, non-Darcy β

Reservoir *WellWhiz*

- Perm, Φ
- Multiple Rel perm regions
- Multiple shale/ sand units
- Condensate drop-out

StimPlan | Lab Work | Tests | WellWhiz

Production Log Data



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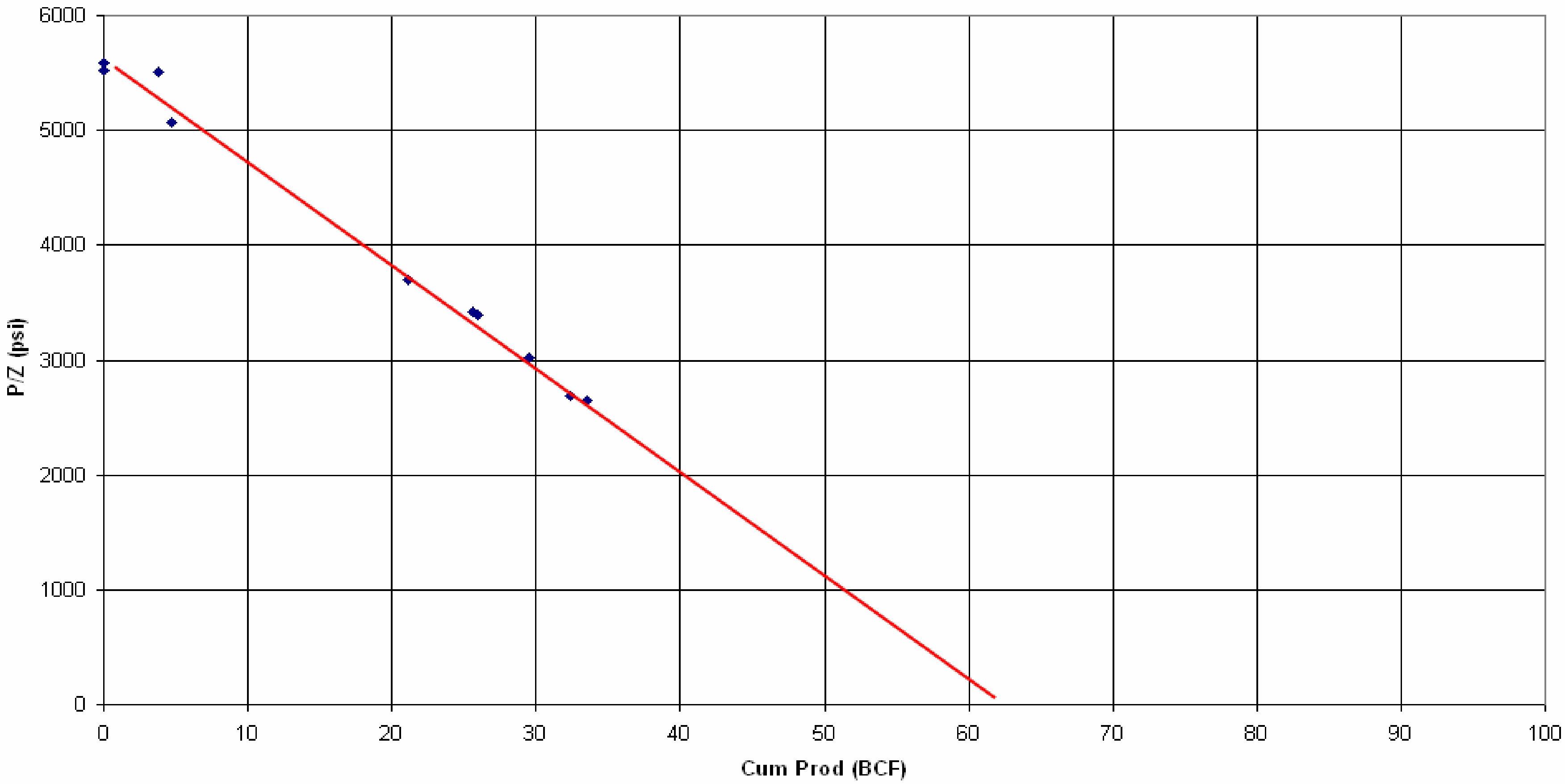
P/Z Plot



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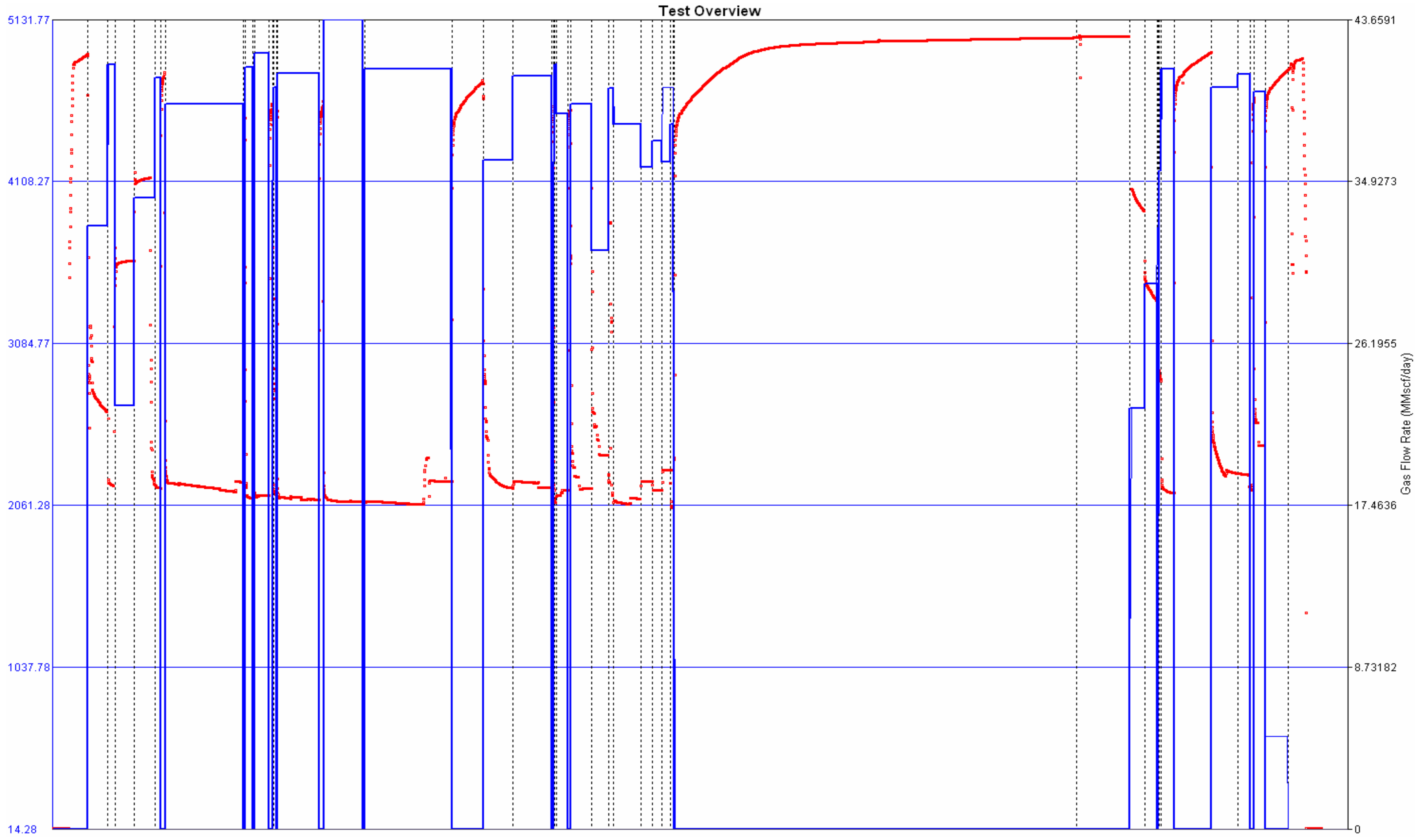
PBU- June 1999



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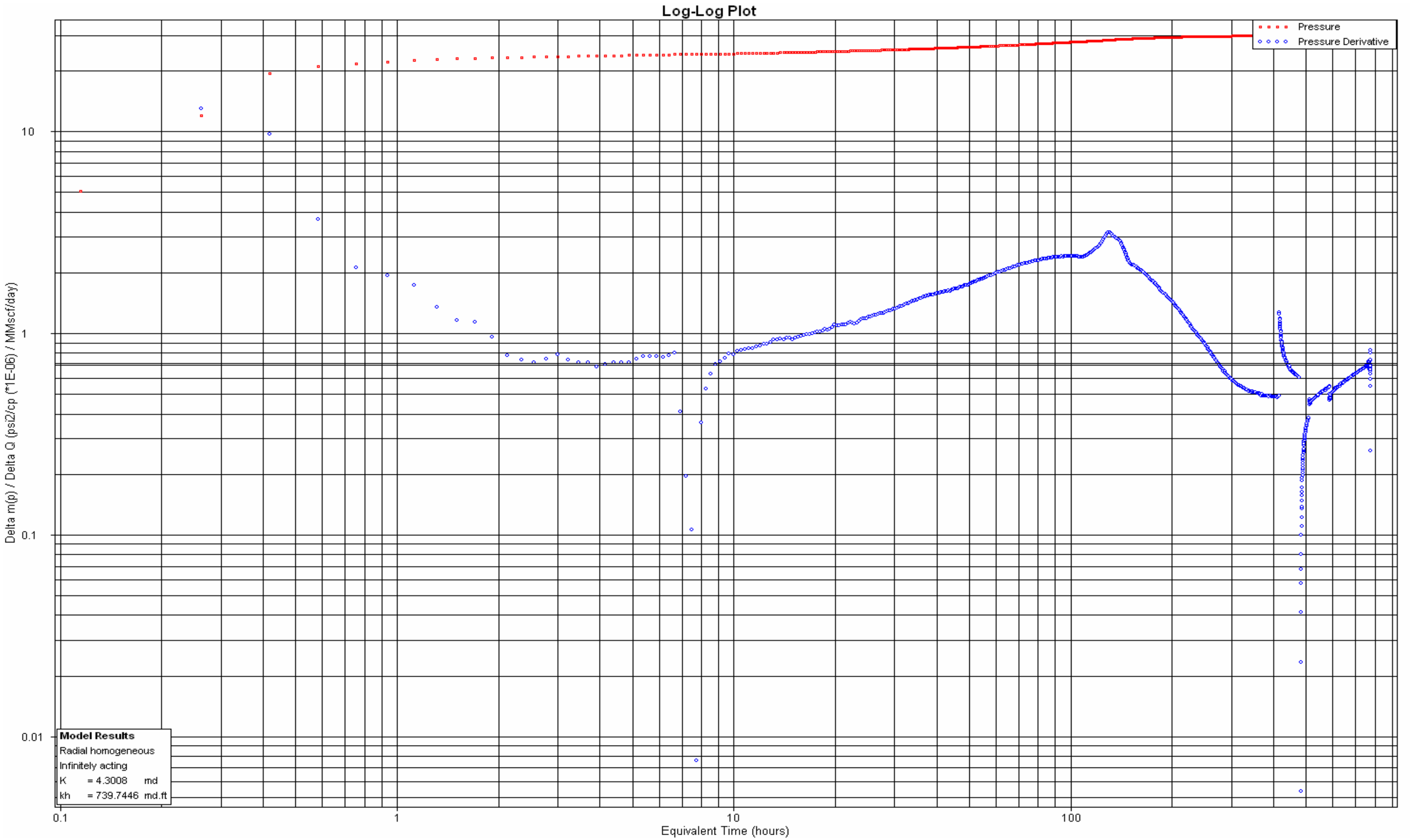
Log Log (kh=740 mD-ft)



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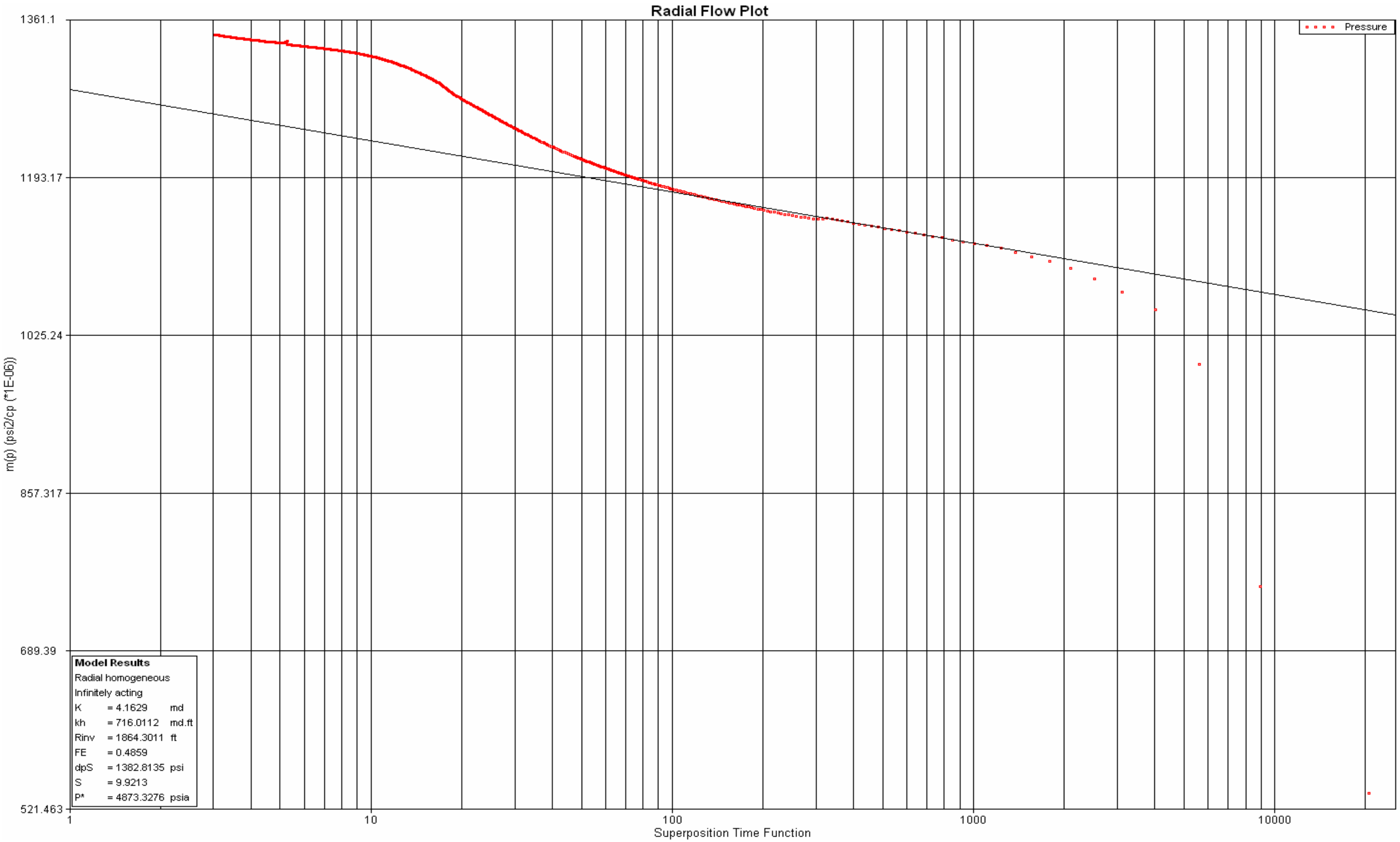
Horner Plot (kh=720 mD-ft, S=9)



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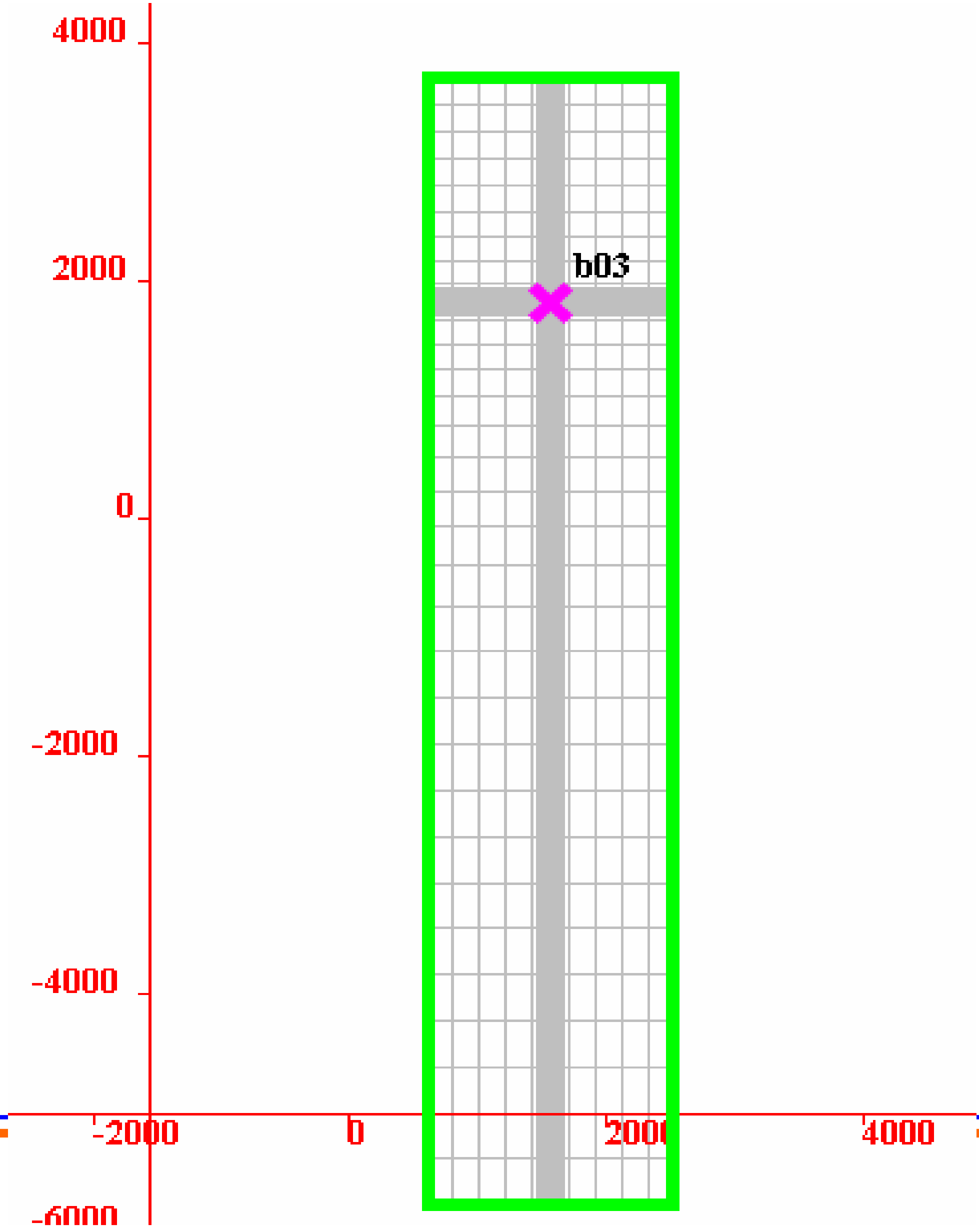
WellWhiz Reservoir Modeling
GIIP=62 BCF from P/Z



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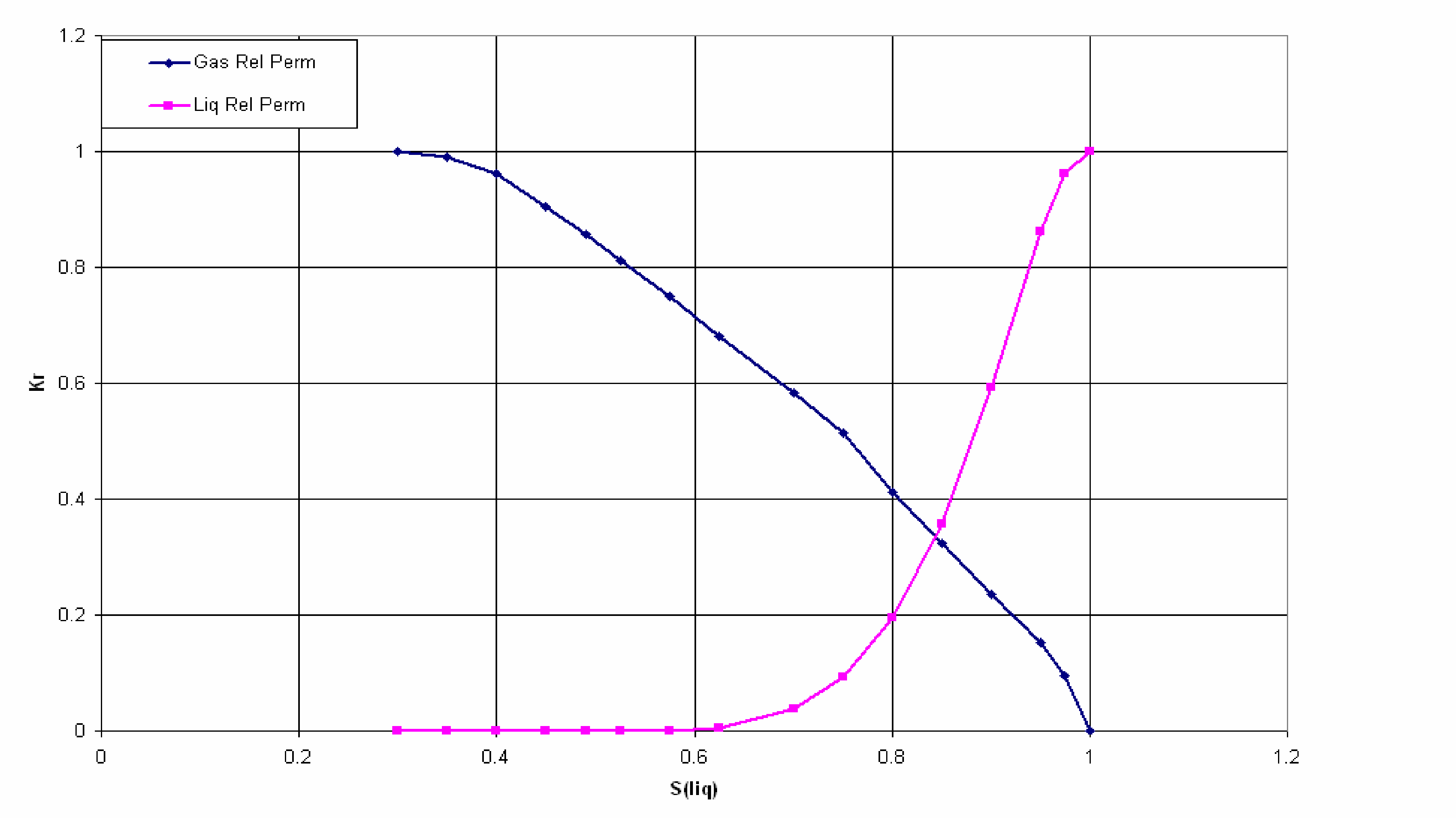
Layers Model
Calibrated to PLT and PBU (sort of)

TOP	12,750		Skin=4							
tops	thickness	bottoms	permi	permk	por	swcrit	swcon	ntg		KH m(mD-ft)
12,750	10	12,760	10.04	0.753	0.18	0.4	0.25	1		**100.4**
12,760	25	12,785	0	0	0	0.4	0.25	0.01		**0**
12,785	10	12,795	25.3	1.8975	0.18	0.4	0.25	1		**253**
12,795	45	12,840	0	0	0	0.4	0.25	0.01		**0**
12,840	35	12,875	14.34	1.0755	0.18	0.4	0.25	1		**501.9**
12,875	5	12,880	0	0	0	0.4	0.25	0.01		**0**
12,880	30	12,910	9.18	0.6885	0.18	0.4	0.25	1		**275.4**
12,910	15	12,925	0	0	0	0.4	0.25	0.01		**0**
12,925	15	12,940	7.28	0.546	0.18	0.4	0.25	1		**109.2**
										1,239.90

Gas-Condensate Rel Perm (all models)



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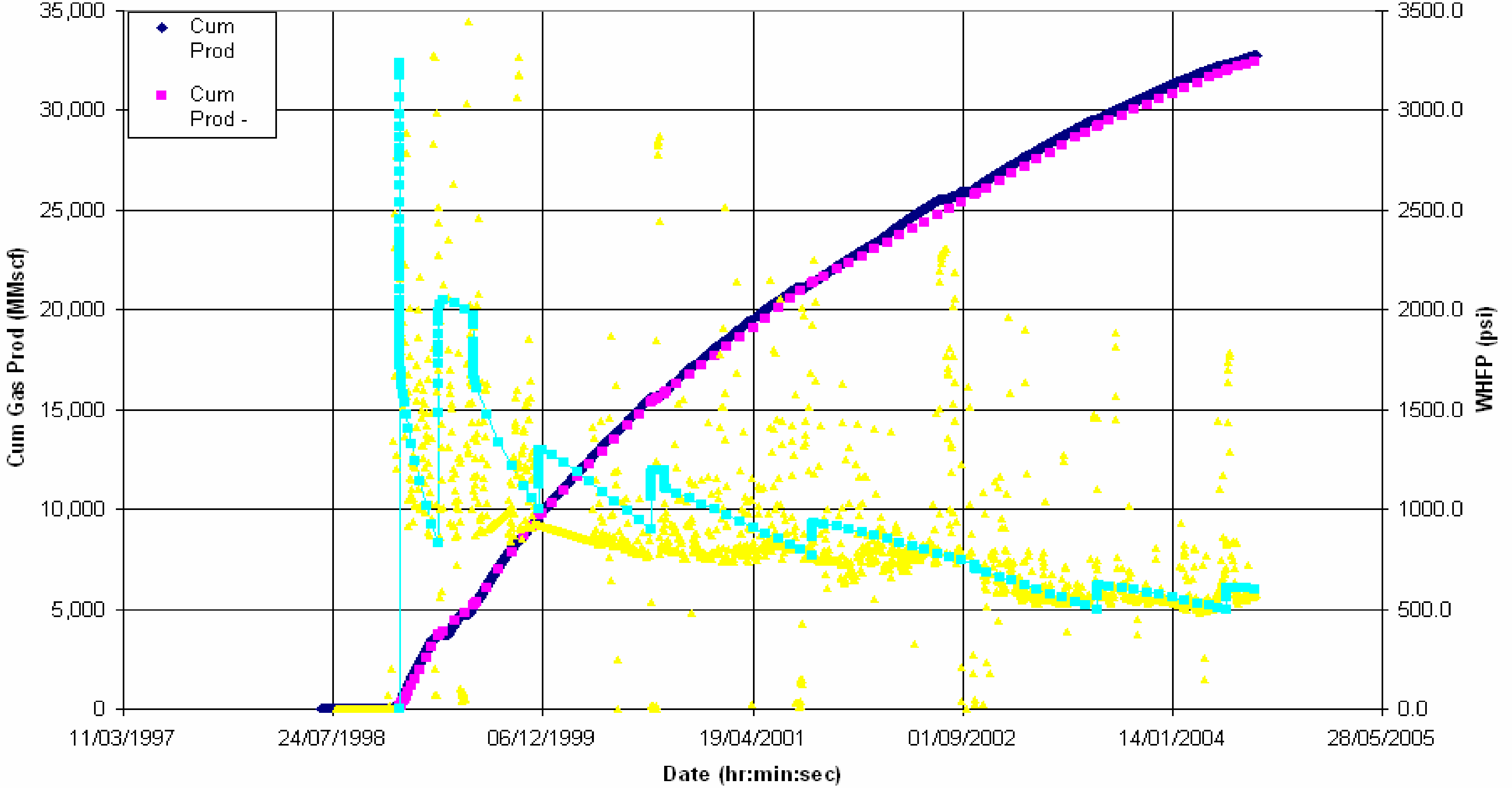
History Match



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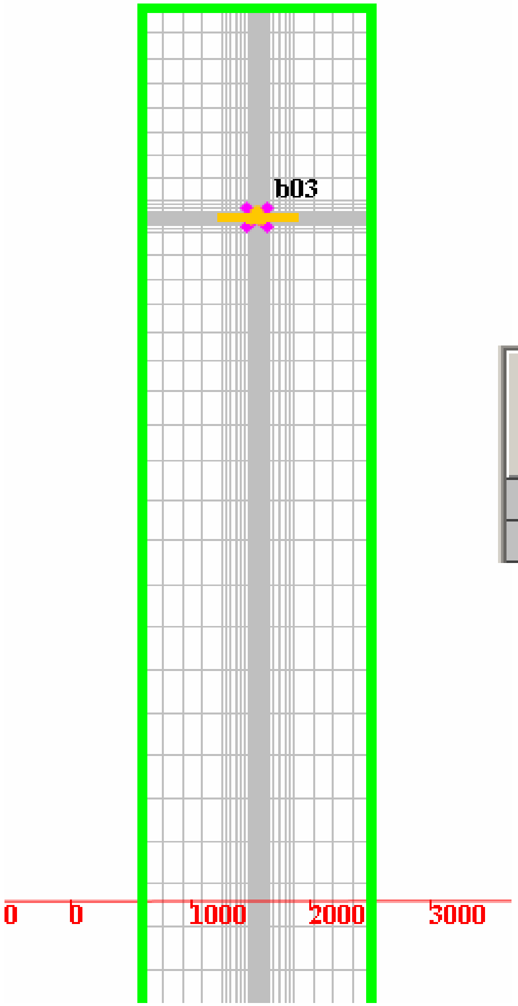
Explicit Frac Modeling



Fracture No.	At (M.D.) ... feet	TVD feet	Orienta... deg E ...	Width at Well... inches	Width at Tip in inches	Length feet	Height feet	Fraction Above...	Porosity fraction	Perme... mD
1	12,845.0	12,845.0	90.0	0.1	0.1	300.0	190.0	0.5	0.35	100,000.0
1	12,845.0	12,845.0	-90.0	0.1	0.1	300.0	190.0	0.5	0.35	100,000.0

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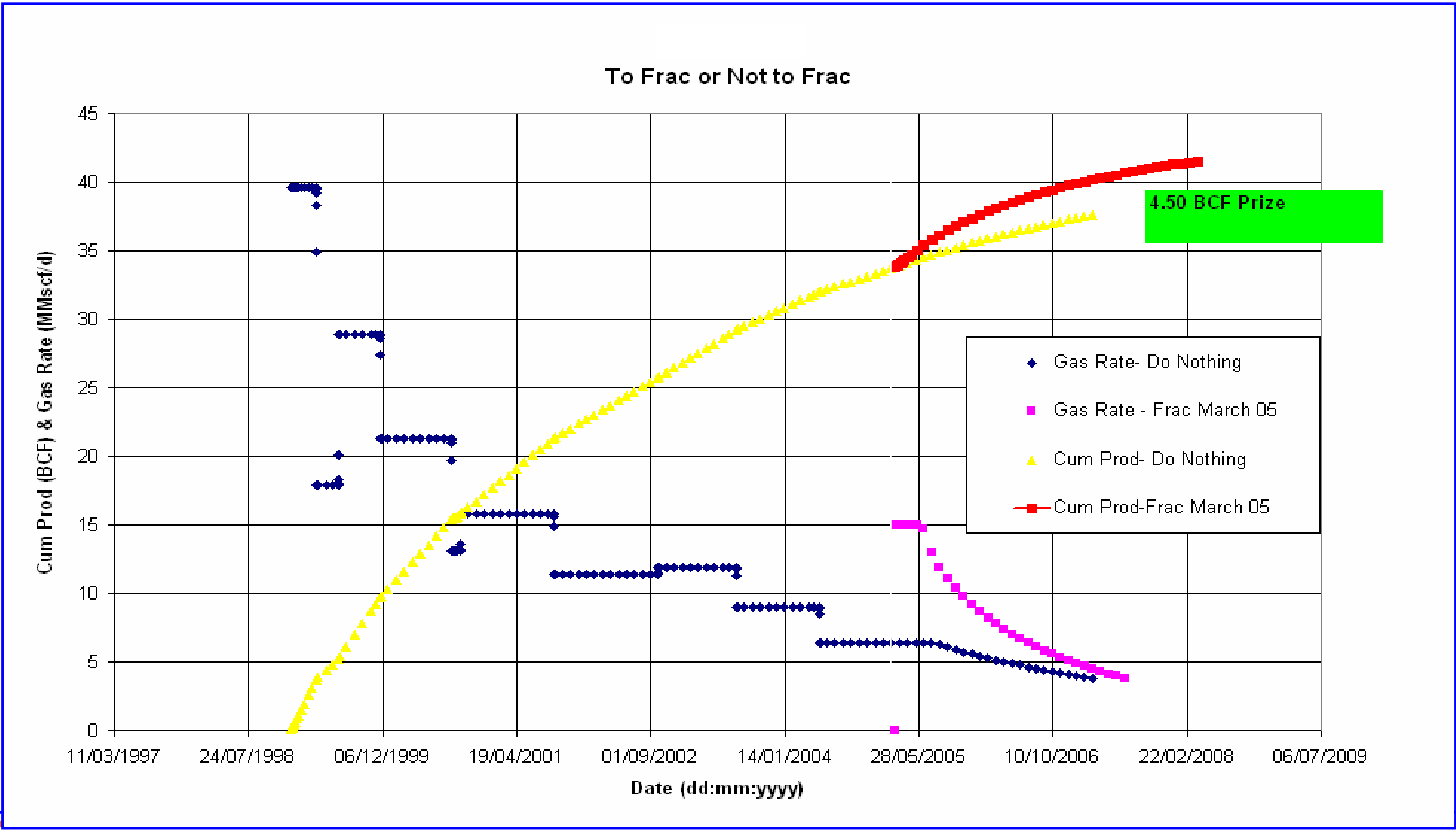
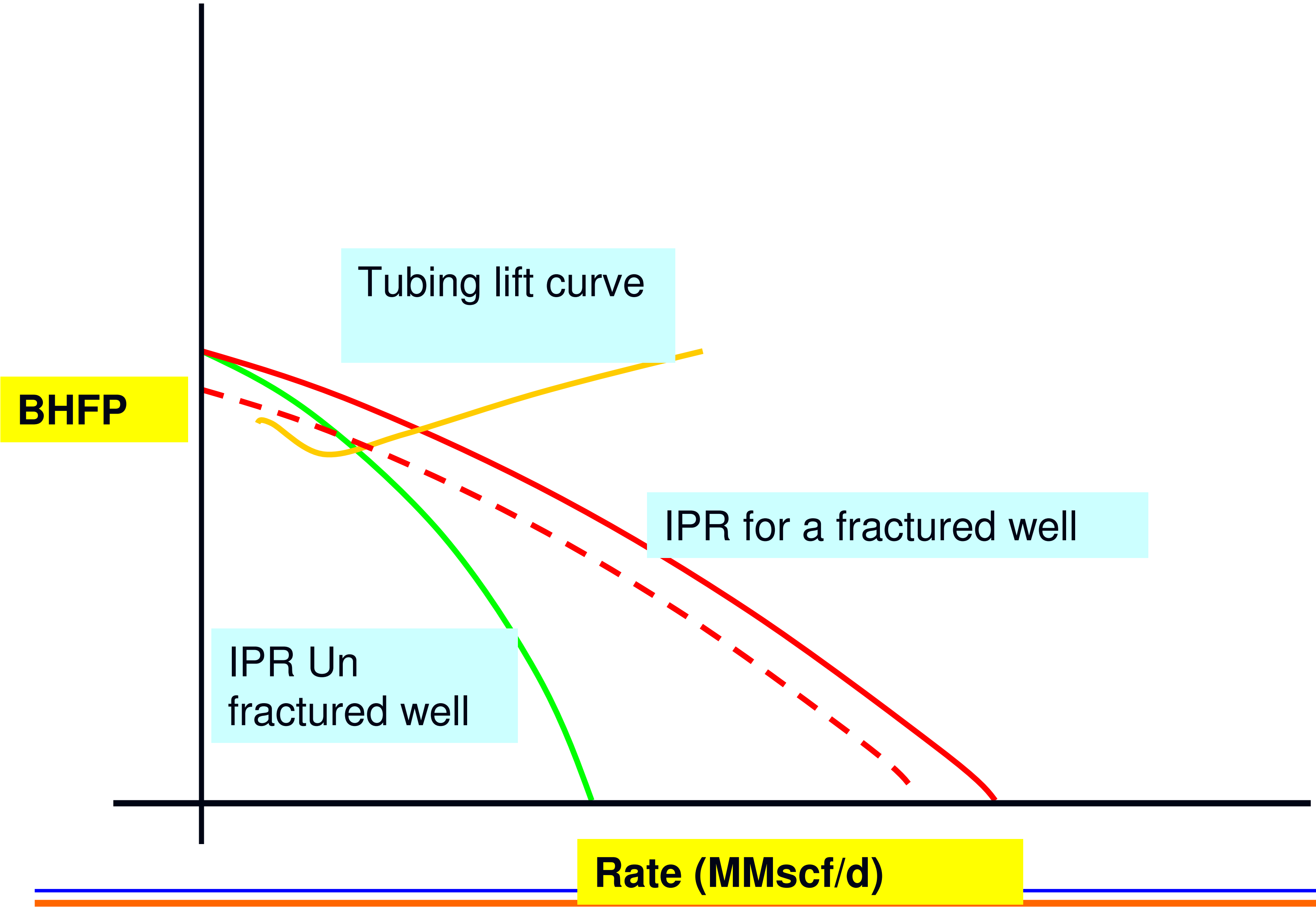
Frac Performance



Extra Reserves with fracturing!



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Summary of Data

Well	Pre Frac Gas Rate	SIBHP	Cum Prod	P/Z GIIP	Transient pressure testing				Post Frac Rate	Frac incremental GIIP
	(MMscf/d)	(psi)	(BCF)	(BCF)	KH (mD-ft)	Skin D (1/Mscf/d)	P* (psi)	PLT	(MMscf/d)	(BCF)
	5.8	2,200	16.5	32	Sept 00 125	0.97	4,158	Dec 01 Z50 20% Z45 75% Z40 5%	13	**3.6**
	7.1	2,250	33	62	June 99 716	9.9	4,873	Dec 04 Z50 15% Z45 85%	15	**4.5**
	12.9	2,520	**38.86**	82	Apr 99 929 Aug 01 539	(Smech=-1.5 D=9E05) S=9	5,198 3,625	N/A	15	**2.7**
	11.7	2,252	**32.06**	70-80	Jan 00 537	Smech=-3.80 D=4.35E-05	Fault effects	Nov-01 Z45 70% Z30 30%	-----	-----
	4.4	2,496	16.7	42.5	Mar 00 109	-2.5	4,696	Nov 01 Z50 30% Z45 70%	-----	-----
	17.9	2,400	**31.99**	80	June 03 671	10.58	2,912	Nov01 Z45 64% Z30 36%	23	**3.7**

Conclusions

- Hydraulic fracturing like any other technology will work when selecting the right well and conducting the correct design.
- Statistics from the last 15 wells (over the last few years) indicate a success ratio of over 95%.
- Fracturing should be considered an a completion strategy (during field development studies), and not an after thought when production does not meet expectations.
- Finally, for success consider expertise, up to date tools and good data when selecting a well for fracturing, and of course post frac evaluation

One Slide on Post Frac Evaluation

- Post frac net pressure match using frac models to assess fracture geometry and proppant concentration
- Post frac PBU tests to detect Bi-Liner flow period
- Post frac production history match
- Learn and re design next job