Reservoir Engineering Studies in Hugoton-Panoma Systems

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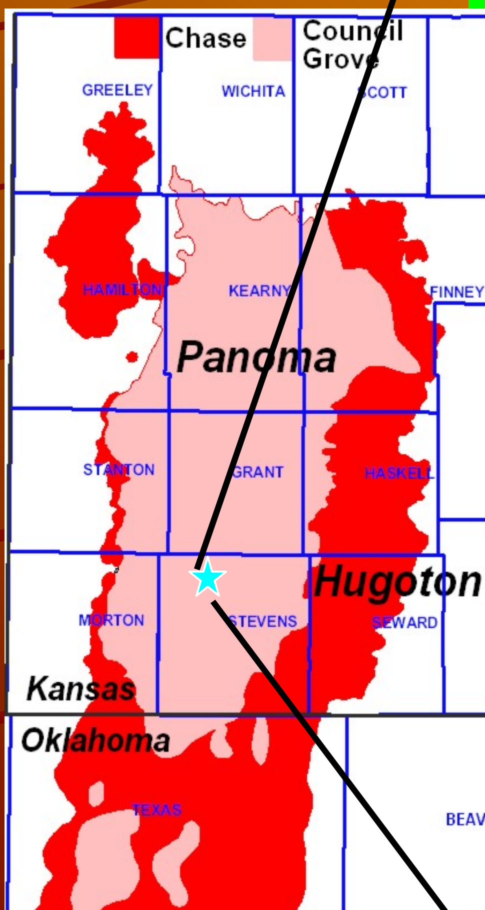
Opinions expressed in this presentation are those of the authors and are not necessarily those of the project's sponsors

Statement of the Obvious

- Reservoir simulation provides non-unique solutions
- Results do not describe the reservoir
  - Primary Input – A reservoir geomodel
  - Results provide insights to production/pressure responses from wells located in the input geomodel
- Objective of this study
  - Build a consistent geo-model for the Hugoton-Panoma reservoir system by
    - Integrating available wireline log, core, petrophysical, production and DST data
  - Input geo-model into CMG's IMEX Simulator
  - Study production and pressure responses from wells located in the geomodel
  - Compare simulator predicted results with historic records
  - Identify geomodel modifications to improve history match
- THIS IS A WORK IN PROGRESS

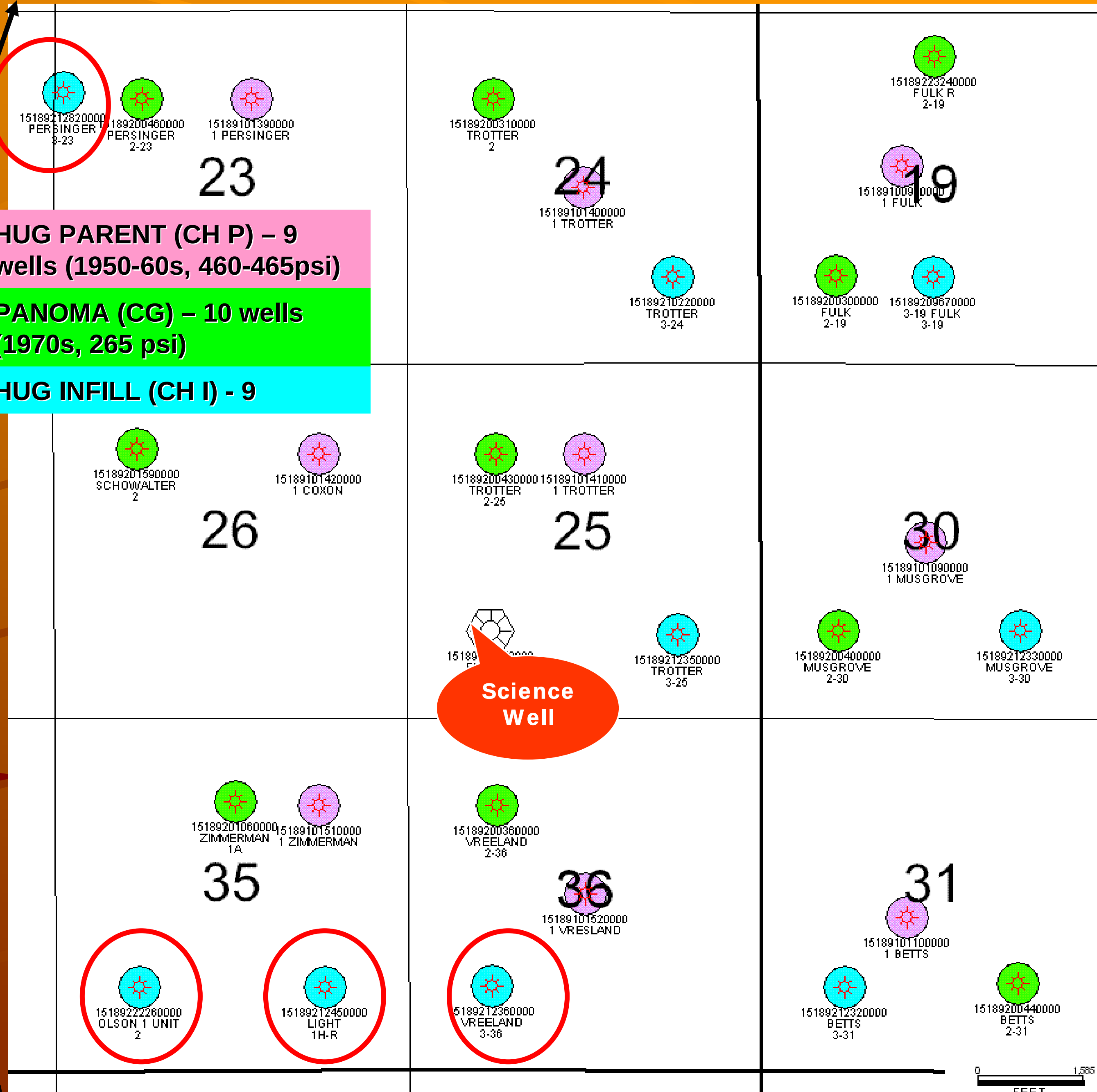
Simulation Study Area – 28 wells



HUG PARENT (CH P) – 9 wells (1950-60s, 460-465psi)

PANOMA (CG) – 10 wells (1970s, 265 psi)

HUG INFILL (CH I) - 9



Simulation Inputs – 9 Section 28 wells

- 25 layer Model
- Layer permeability - Tensor upscaling (Petrel)
  - Appropriate multipliers – Layer K close to that cal from DST
- All wells were hydraulically fractured
  - Physical characterizations of hydraulic fractures not available
  - Fractures tend to increase well productivity
  - Well productivity factor (ff) used to model enhanced well productivity
    - ff = 1.0 – unfractured well
  - Starting ff = 6.0 assigned to all wells
    - Well-level ff modifications carried out during history match
- Well naming convention
  - Chase Parent – Prefix P
  - Chase Infill – Prefix I
  - Council Grove – Prefix CG
- Starting well completions
  - Chase Parent – Herrington-Paddock to L Fort Riley (L1 to L9)
  - Chase Infill – Herrington-Paddock to Wreford (L1 to L11)
  - Council Grove – A1 LM to B5 LM (L13 to L23)

Inputs – Upscaled K and Flow Constraints

Flow constraints imposed on wells

All wells flowed under rate constrained till end of production data, i.e., Jun 2003.

Thereafter, all wells flowed under constant BHP = 14.7 psi from Jul 2003 to Jan 2004.

The intent is to see if the simulator calculated production rates from Jul 2003 follow the same decline trend established by the previous history.

Layer K inputs (at SCIENCE well) into simulator

Layer	Formation	Upscaled K, md	DST K, md	Multiplier
1	Hrngtn-Paddock	5.668	6.9	1
2	Krider	47.422	90.30	1.9
3	Odell	0.017	9.7*	1
	Wnf SS			
4	Wnf LS	1.620	**7.60**	**4.7**
5	Gage	0.064	Not Tested	1.0
6	Towanda	1.666	1.20	1.0
7	B/TWND	1.859	Not Tested	1.0
8	FTRLY	0.948	0.43	1.0
9	L/FTRLY	0.019	0.001	1.0
10	B/FTRLY	0.039	0.1	1.0
11	WREFORD	0.107	**0.5**	**4.7**
12	A1_SH	0.001	Not Tested	1.0
13	A1_LM	0.023	3.141**	1.0
14	B1_SH	0.002	Not Tested	1.0
15	B1_LM	0.123	0.1	1.0
16	B2_SH	0.004	Not Tested	1.0
17	B2_LM	0.755	**10.2**	**13.5**
18	B3_SH	0.002	Not Tested	1.0
19	B3_LM	0.047	0.01	1.0
20	B4_SH	0.001	Not Tested	1.0
21	B4_LM	0.676	**3.2**	**4.7**
22	B5_SH	0.002	Not Tested	1.0
23	B5_LM	11.558	**72.1**	**6.2**
24	C_SH	0.002	Not Tested	1
25	C_LM	0.089	Not Tested	1

* Not representative

** Not a very representative value

May not need a multiplier

Pi = 460 psi (196 bcf), ff = 6 for all other P wells (ff = 2 at PTrot24)

P wells fractured – Jan 1, 1960

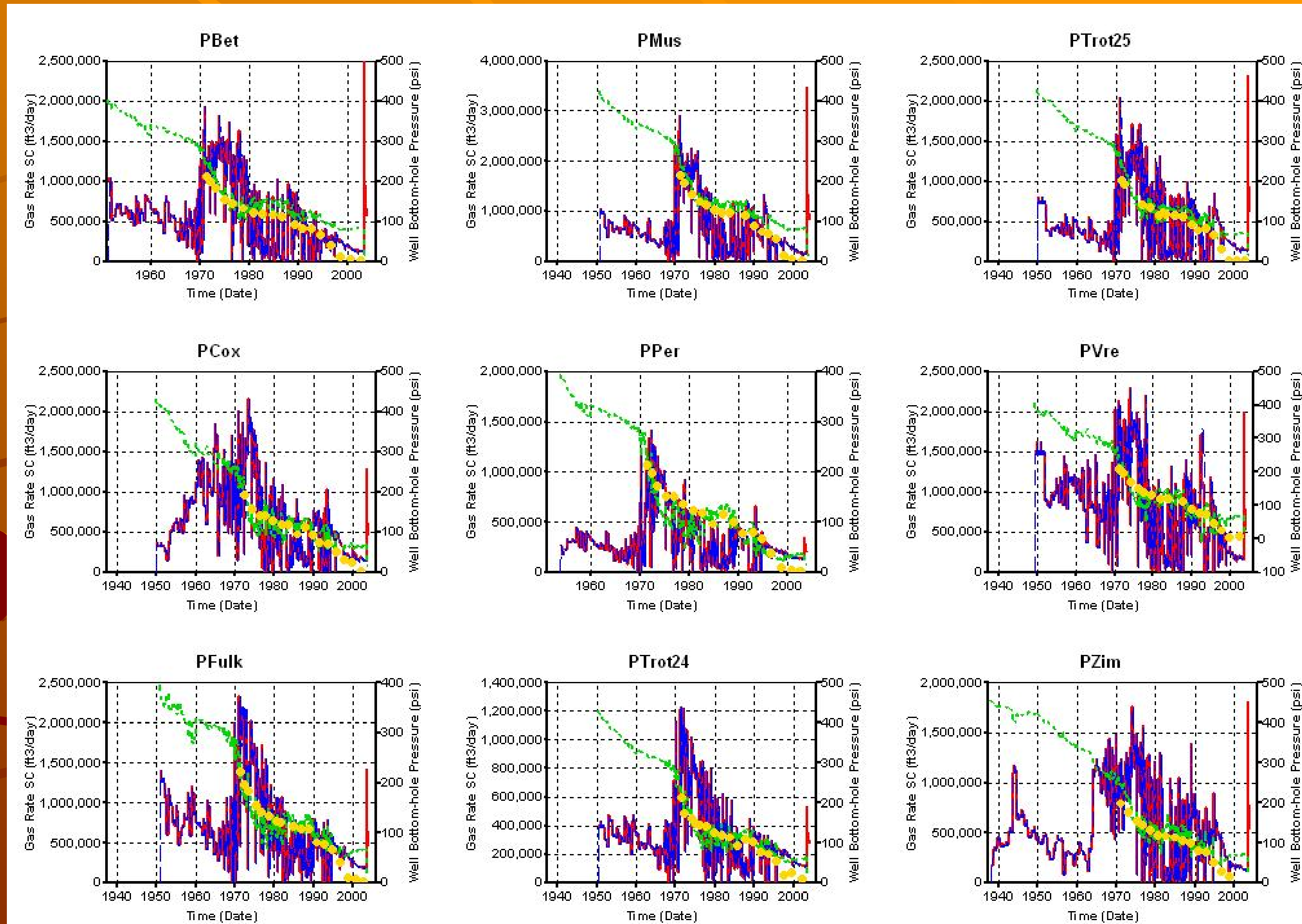
History match - Chase Parent wells

Red – Sim Qg

Blue – His Qg

Green – Sim FBHP

Gold – His FTHP



Prod matched in all CH P wells. Sim cal BHP close to WHFP and follows trend closely. Prod spike from Jul 2003 in most wells - presence of excess flow capacity.

Pi = 460 psi (196 bcf), ff = 6 for all other I wells

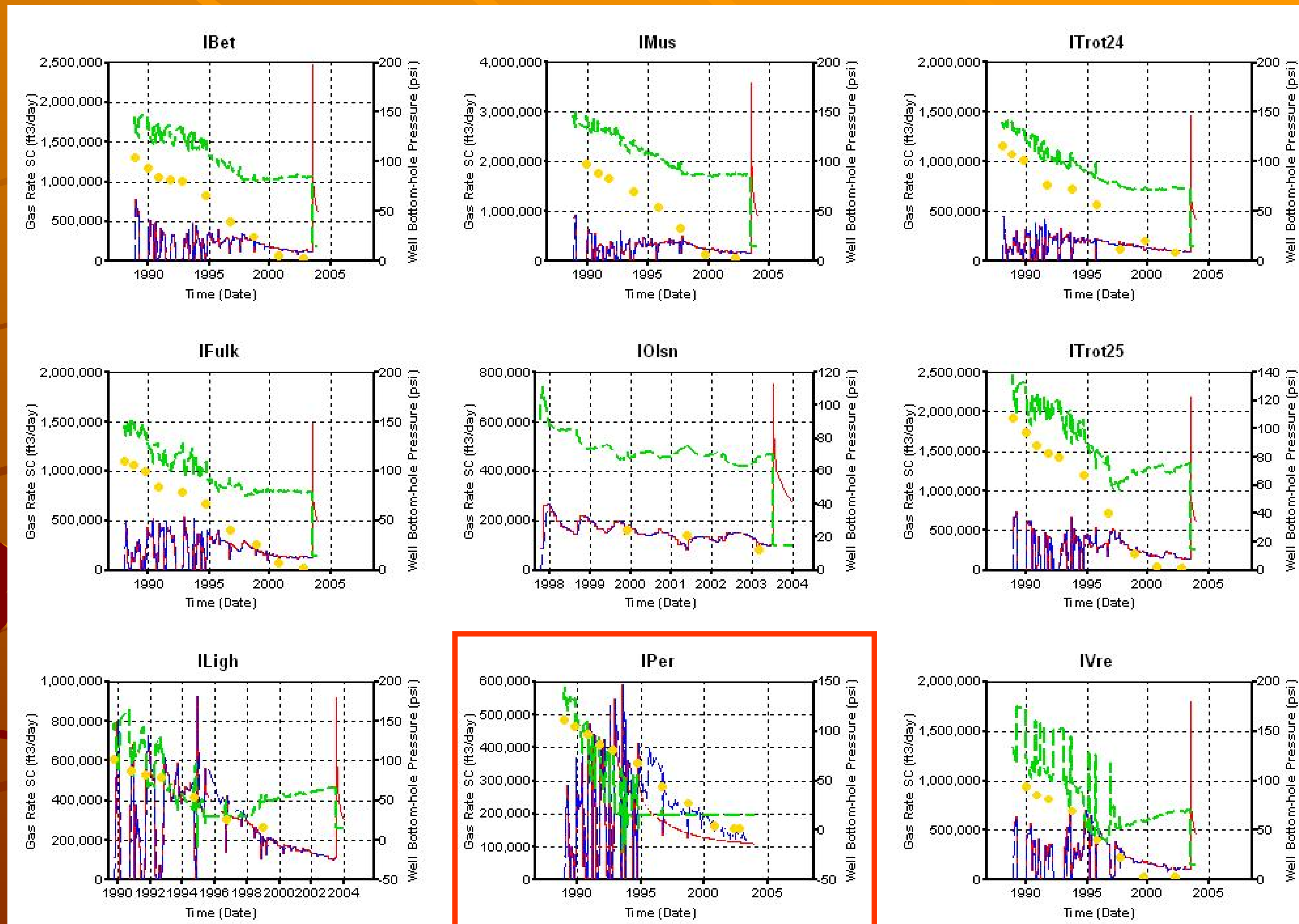
His Match of CH I wells

Red – Sim Qg

Blue – His Qg

Green – Sim FBHP

Gold – His FTHP



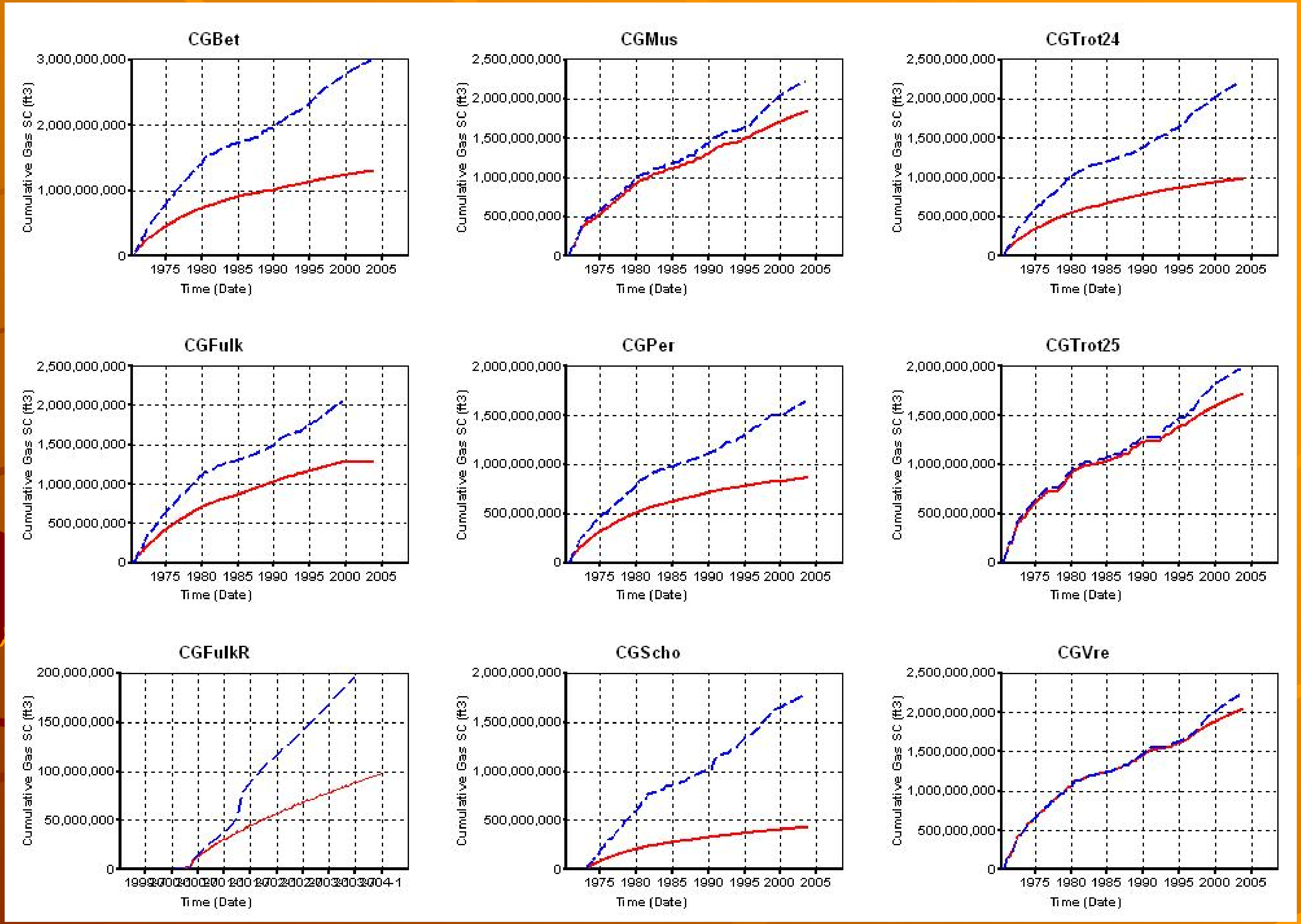
For most wells - Prod matched in all except (IPer – a border well). Prod spike from Jul 2003 in most wells indicating excess flow capacity at wells. Sim cal BHP greater than WHFP significantly (compared to CH P).

Pi = 460 psi (196 bcf), ff = 6 for all other CG wells

His Match of CG wells

Red – Sim Qg

Blue – His Qg



Prod could not be matched for any well

Increased layer K and Sw multiple times – unable to obtain production match

Pr distribution as of Jan 1970 – just before CG wells came online

Initial SI pressures at all CG wells upon completion converge to around 265 psi.

Is it indicative of communication between CG wells and CH gas?

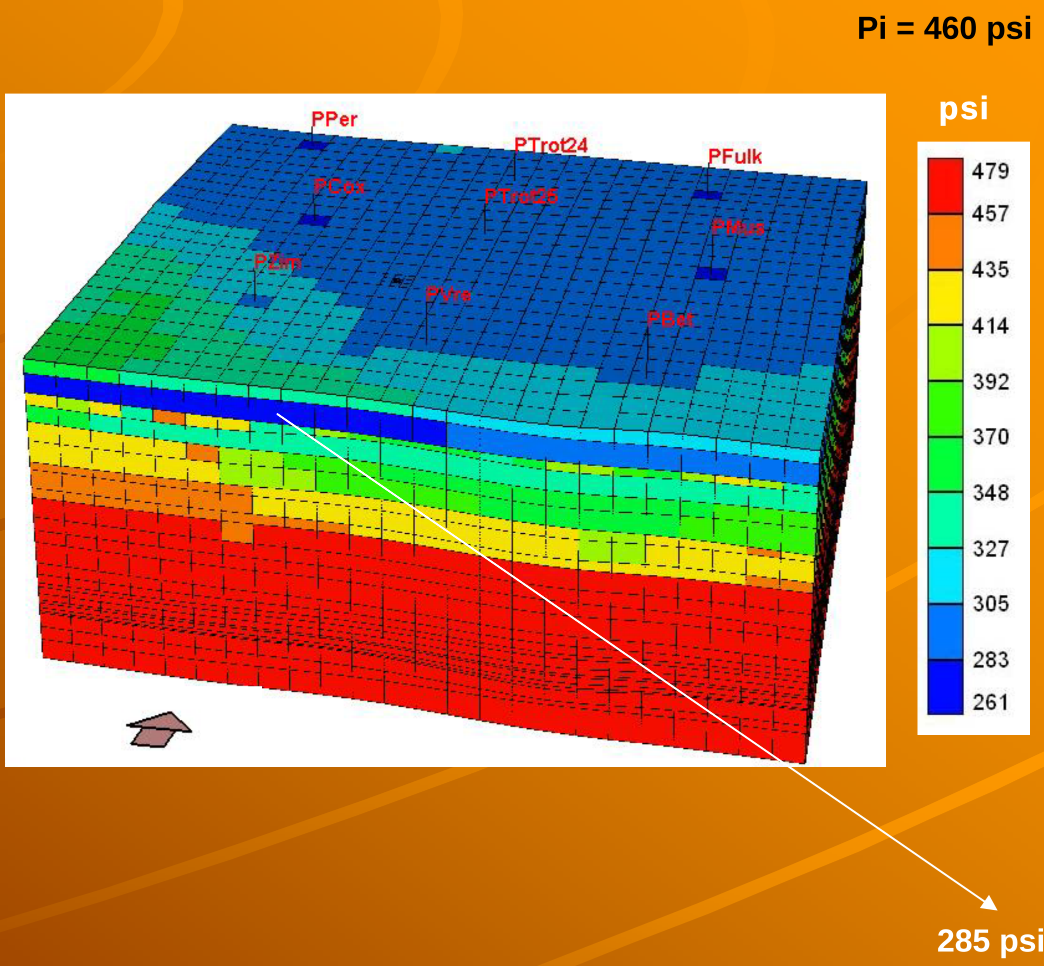
If communication were to exist then till what layer into CH?

May be till L2 (at 285 psi)

<u>Test Assumption</u>

What is simulator calculated SI pressure a CG well upon completion?

Can production history be matched at CG wells?



Pi = 460 psi., ff = 2 for PTrot24 & ff = 6 for all others CH P wells

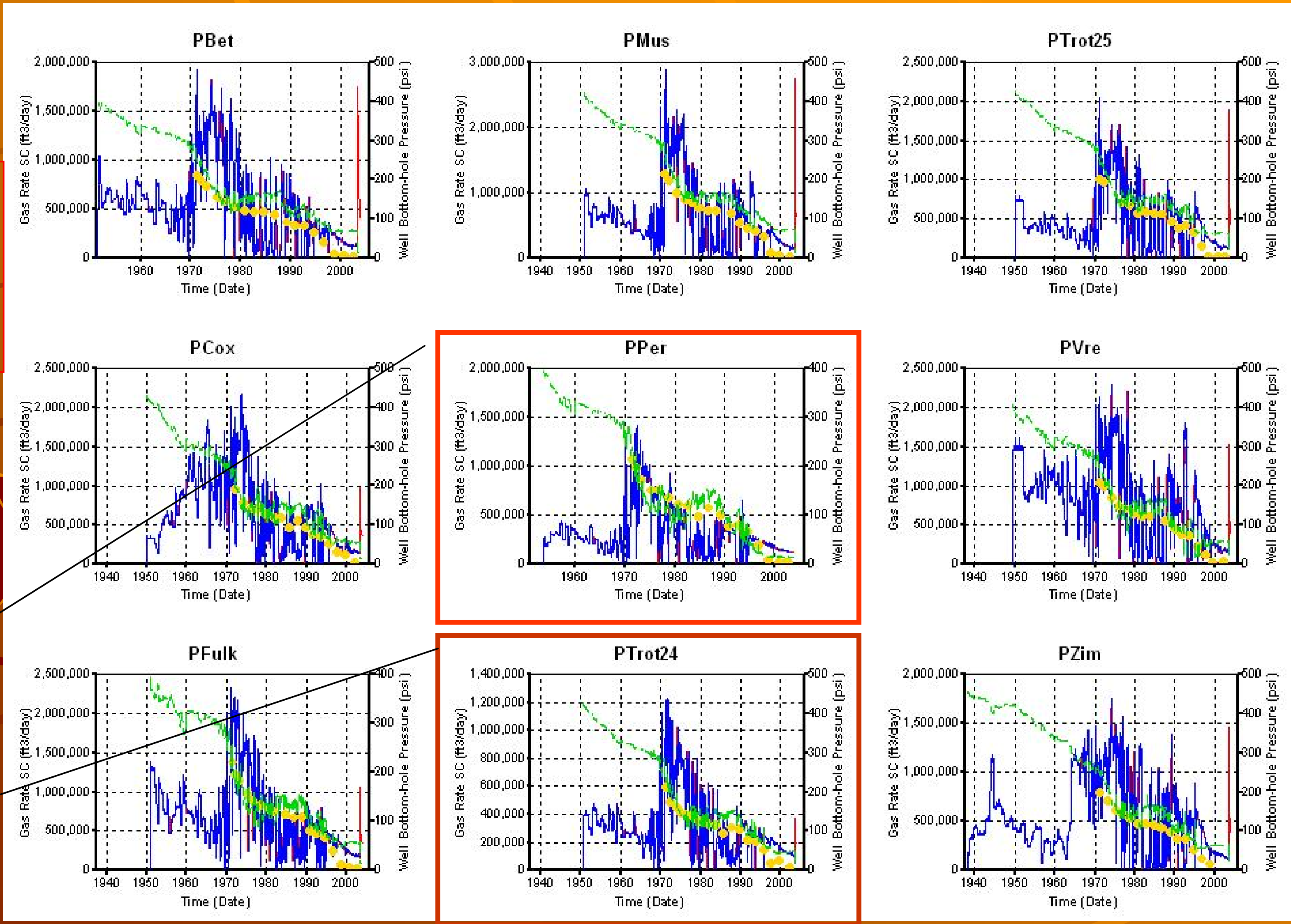
CH P history matches (prod rate) when CG Fractures extended to L2

Red – Sim Qg

Blue – His Qg

Green – Sim FBHP

Gold – His FTHP



No Prod spike

ff=2.0

Production and pressure decline matched at all wells. Most wells show a production spike – excess flow capacity. May be ff and/or OGIP is too high.

Pi = 460 psi., ff = 6 for all CH I wells

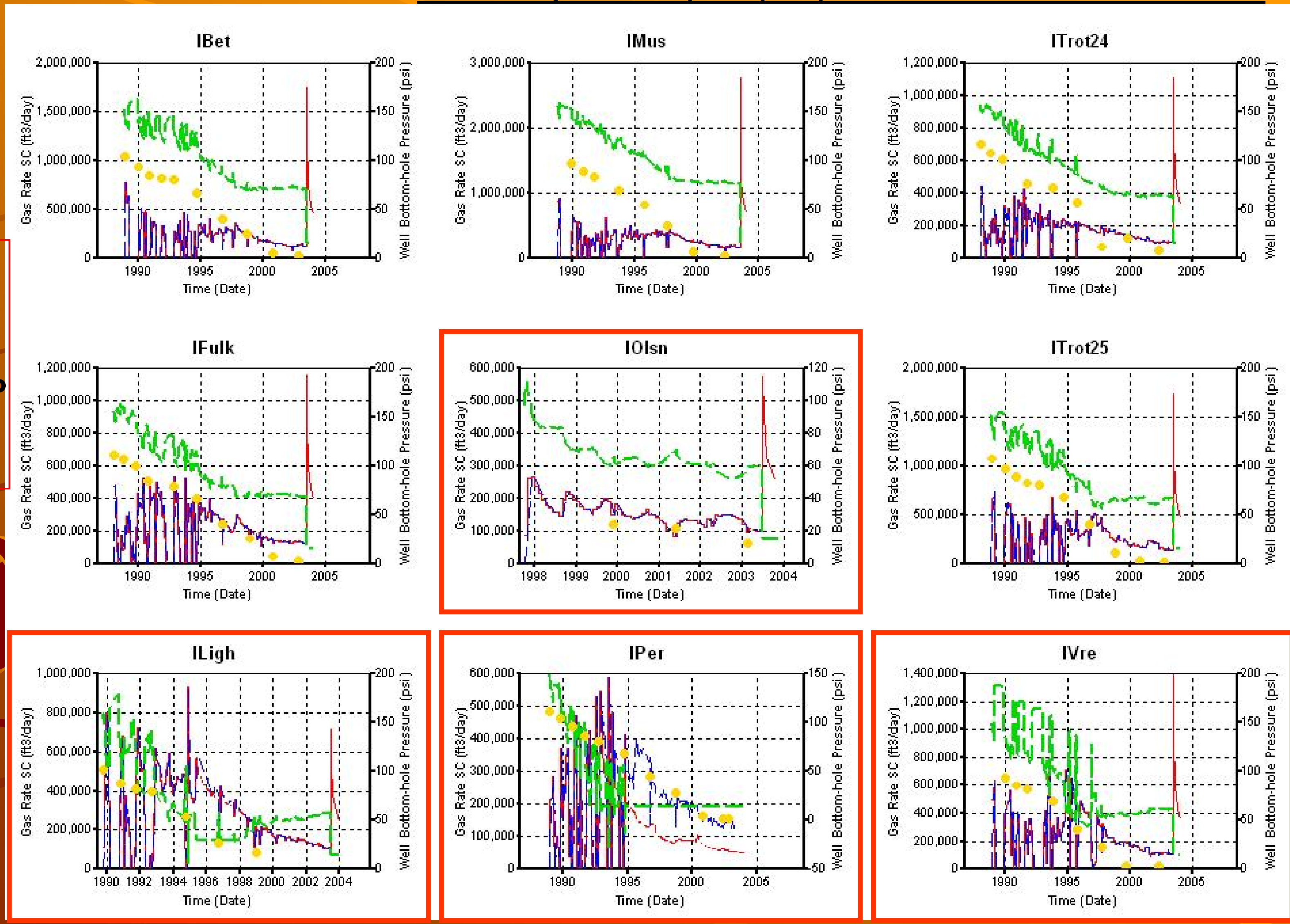
CH I history matches (Cum prod) when CG Fractures extended to L2

Red – Sim Qg

Blue – His Qg

Green – Sim FBHP

Gold – His FTHP



Cum production matched in all wells except IPer - extreme border well. Extending CG fractures to L2 did not throw off CH I matches. BHFP > WHFP in most non-border wells. BHFP trend similar to WHFP initially before flattening during later period - excess flow capacity. May be ff too high and/or excess gas.

Pi = 460 psi, ff = 6 for all CG wells

<u>CG history matches - CG completions extended to L2</u>

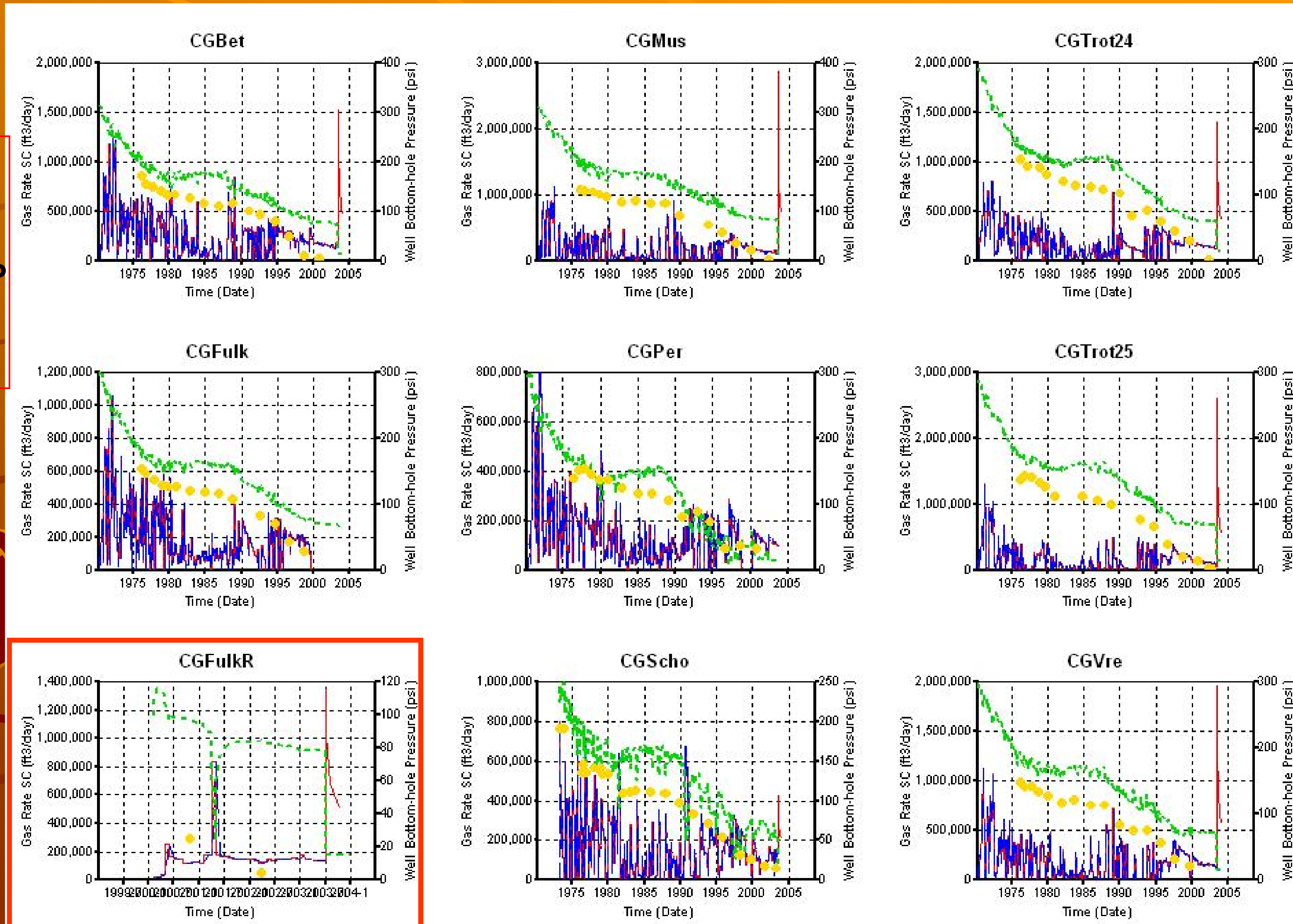
Red – Sim Qg

Blue – His Qg

Green – Sim FBHP

Gold – His FTHP

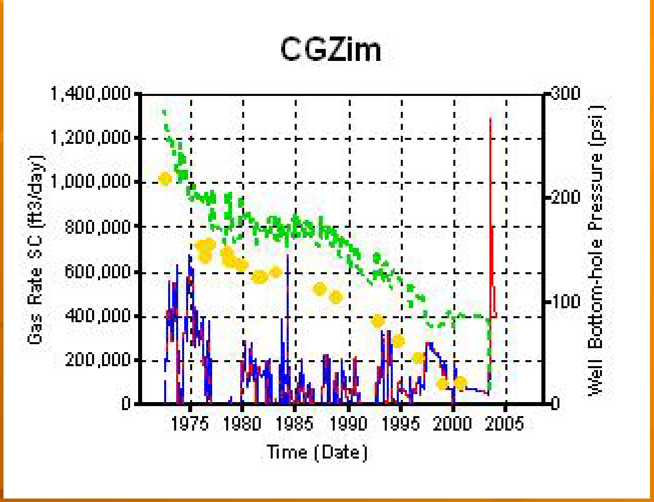
Replacement well



Production matched in all CG wells. The BHFP slightly > WHFP in most wells. BHFP trends are similar to WHFP initially before flattening during the later flow period. May be lower ff and/or OGIP.

Pi = 460 psi, ff = 6 for all CG wells

CG history matches - CG completions extended to L2



It appears that ff = 6 is too high - for most CH P&I and CG wells

- production spike in Jul 2003
- flattening of the BHP in the later part of the flow period.

Selective reduction in ff was carried out in most CH P wells.

- Significant production spikes – ff = 3 or less in many CH P wells
- 1> ff <2 – means minimal improvement in productivity by hydraulic frac

May be OGIP of 196 Bcf (cal at Pi = 460 psi) is too high.

So OGIP reduced by lowering Pi.

- Final Pi = 423 psi - OGIP of 179.5 bcf.

Pi = 423 psi, OGIP = 179.5 bcf

Ff for CH P wells adjusted around 6 (between 5 and 9)

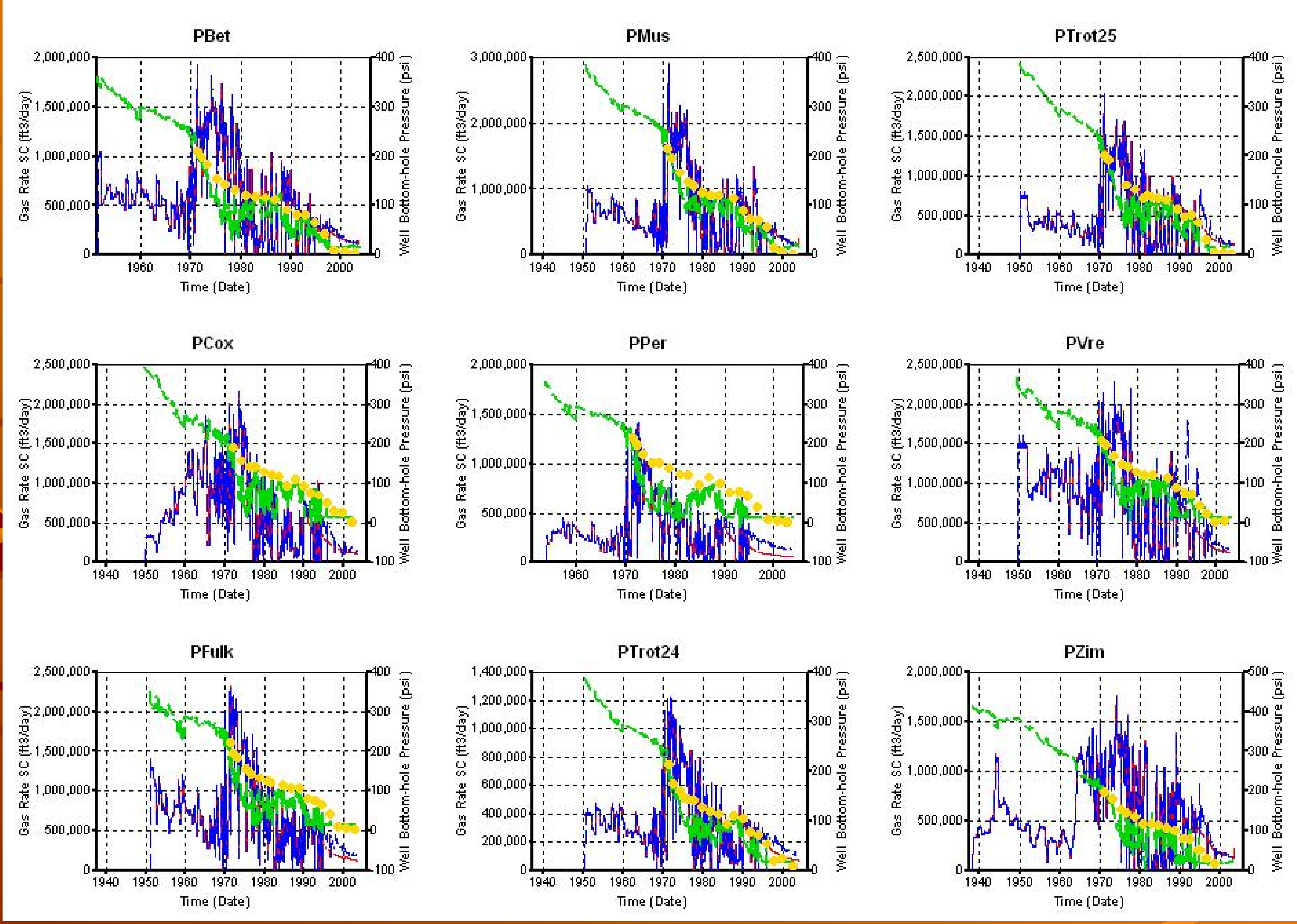
CH P history match - CG completions extend to L2

Red – Sim Qg

Blue – His Qg

Green – Sim FBHP

Gold – His FTHP



Rate production history matched at all CH P wells and prod spike problem significantly reduced. BHFPs and WHFPs are close and lie on same decline trends.

Pi = 423 psi, OGIP = 179.5 bcf.

Ff for CG wells adjusted around 6 (between 3 and 8)

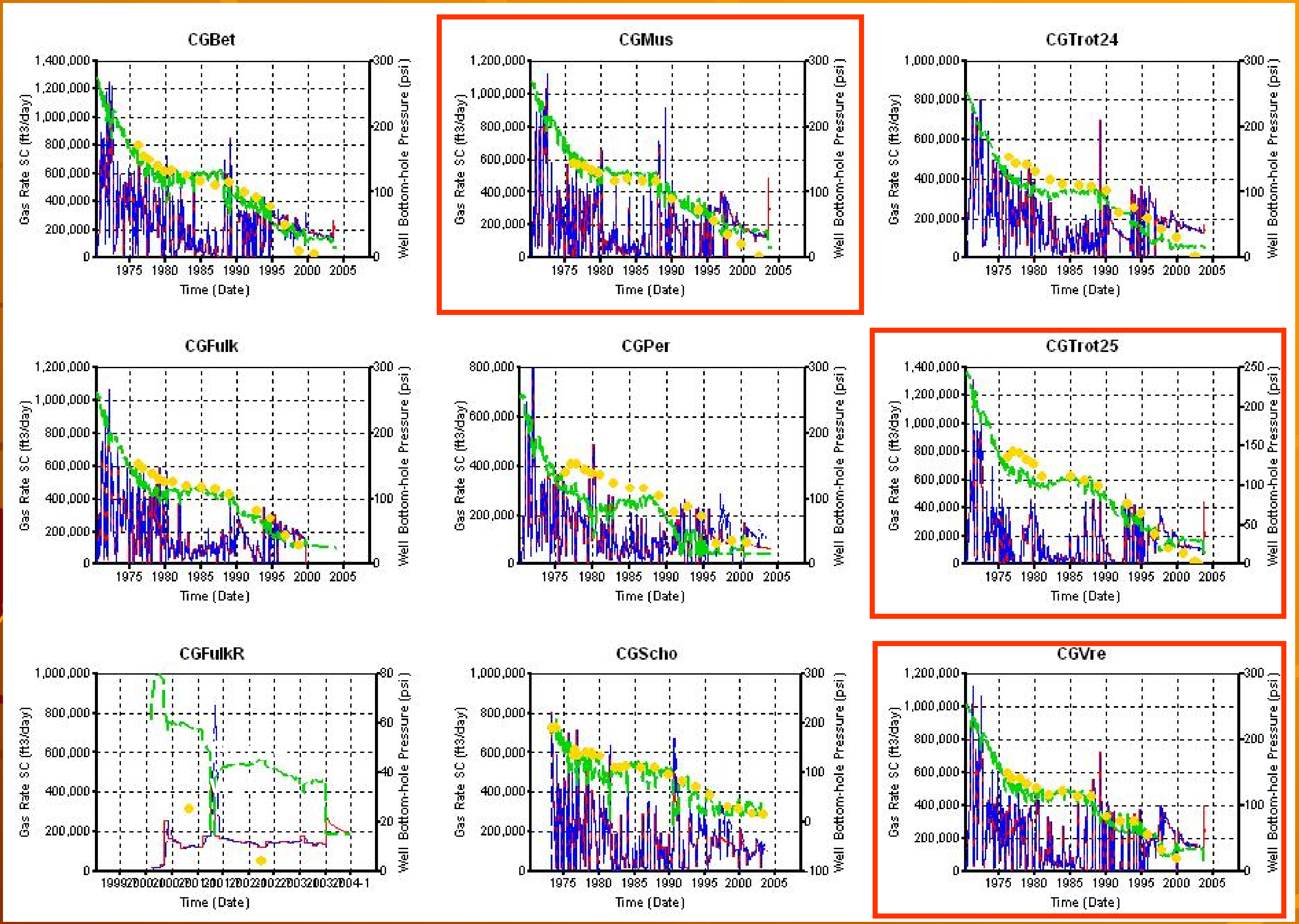
<u>CG history match - CG completions extend to L2</u>

Red – Sim Qg

Blue – His Qg

Green – Sim FBHP

Gold – His FTHP



Pi = 423 psi, OGIP = 179.5 bcf.

Ff for CG wells adjusted around 6 (between 3 and 8)

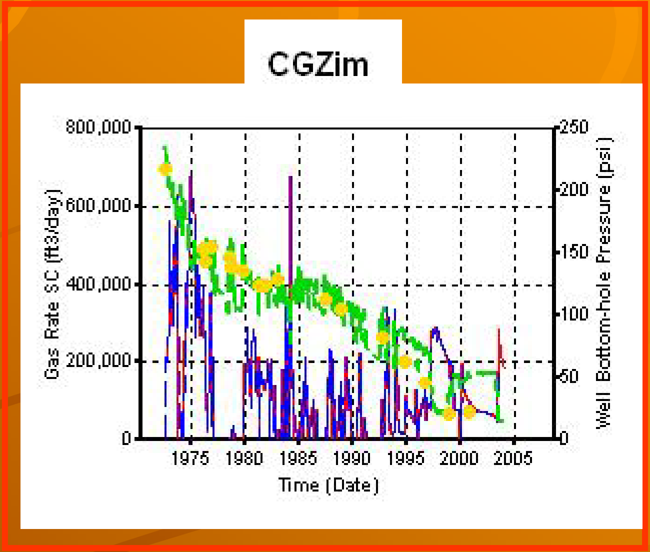
<u>**CG history match - CG completions extend to L2**</u>

Red – Sim Qg

Blue – His Qg

Green – Sim FBHP

Gold – His FTHP



Rate prod matched at all CG wells. Some wells still show a production spike. Remaining production spikes are less than those obtained in previous runs.

BHPs and WHFPs are close and lie on same decline trends.

Pi = 423 psi, OGIP = 179.5 bcf.

Ff for CH I wells adjusted around 6 (between 5 and 9)

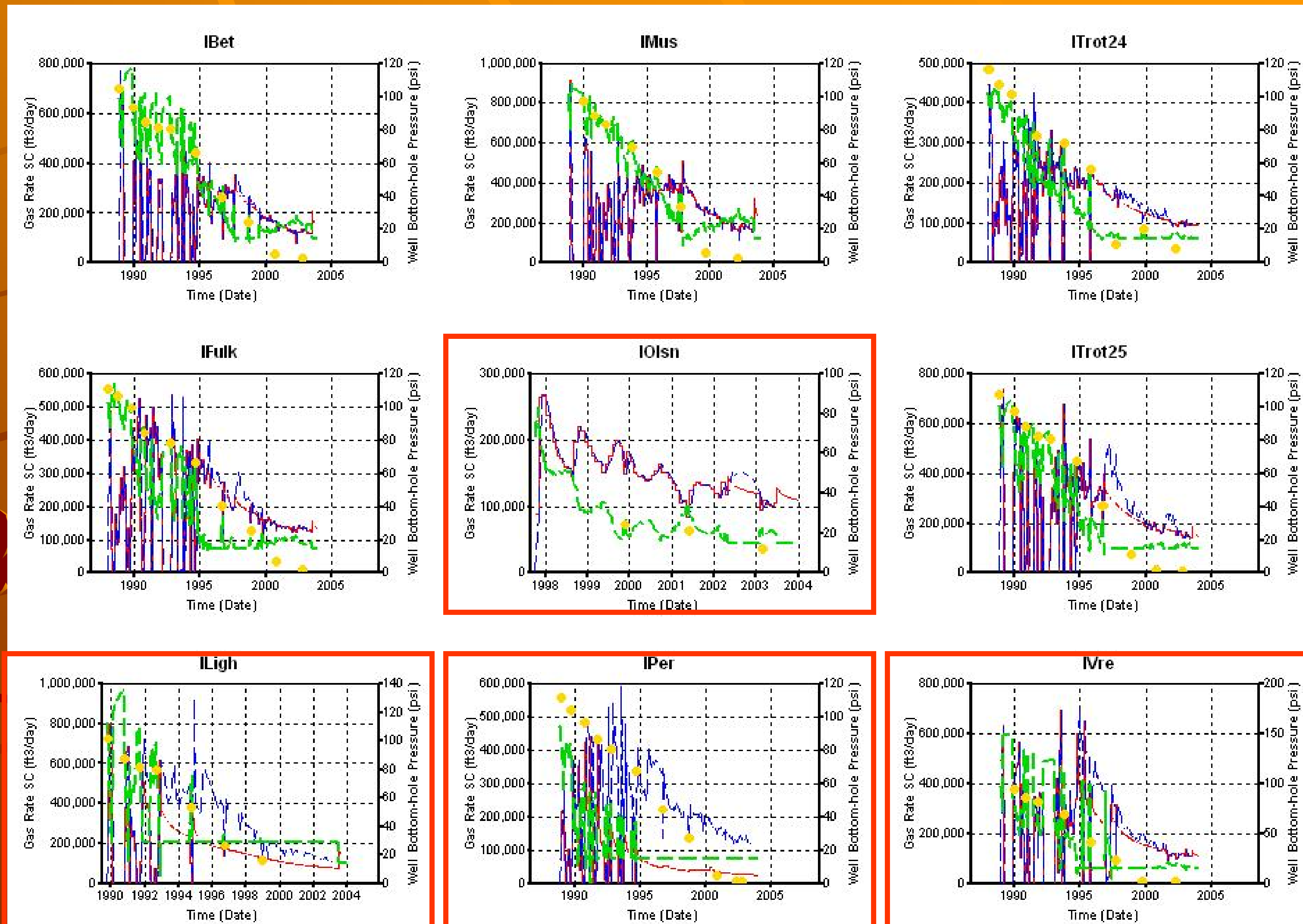
<u>CH I history matches - CG completions extend to L2</u>

Red – Sim Qg

Blue – His Qg

Green – Sim FBHP

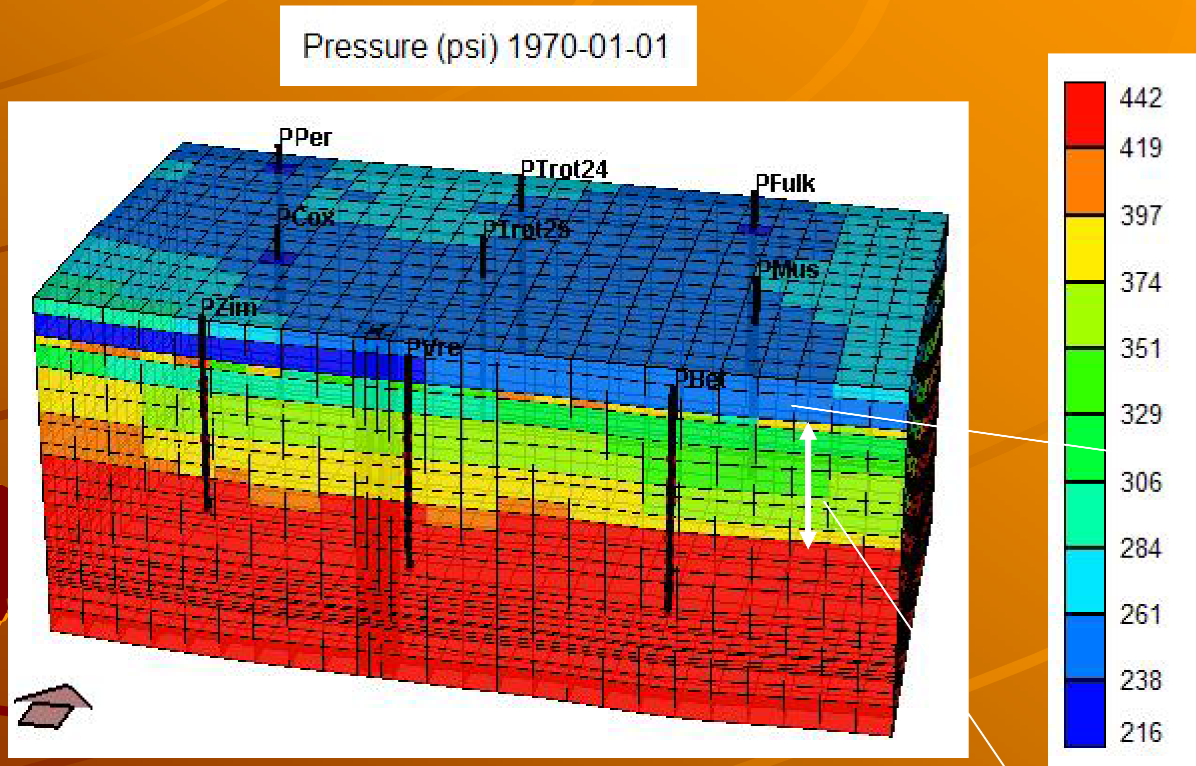
Gold – His FTHP



Production matched in non-border CH I wells. Drainage area of BORDER wells extends outside the simulation area. Also, no significant production spikes in non border wells.

Pi = 423 psi, OGIP = 179.5 bcf.

Res Pr distribution as of Jan 1, 1970 – before CG wells were drilled
CG completions extend to L2



250 psi

(L2 – Krider)

Other CH layers

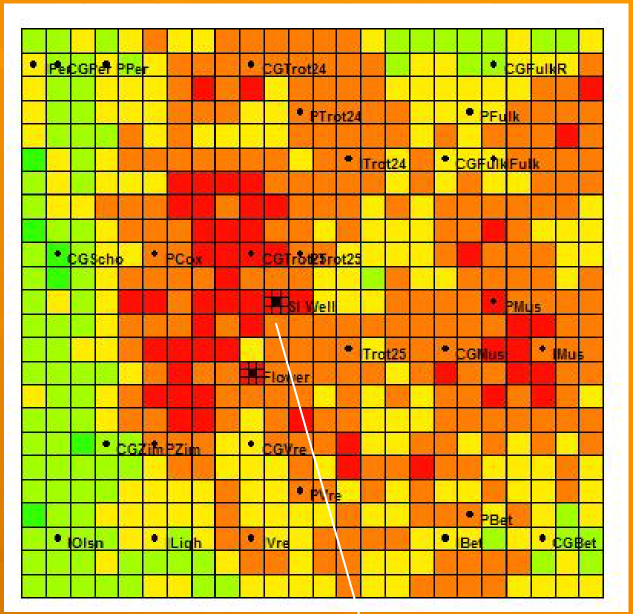
350 to 380 psi

Pi = 423 psi, OGIP = 179.5 bcf

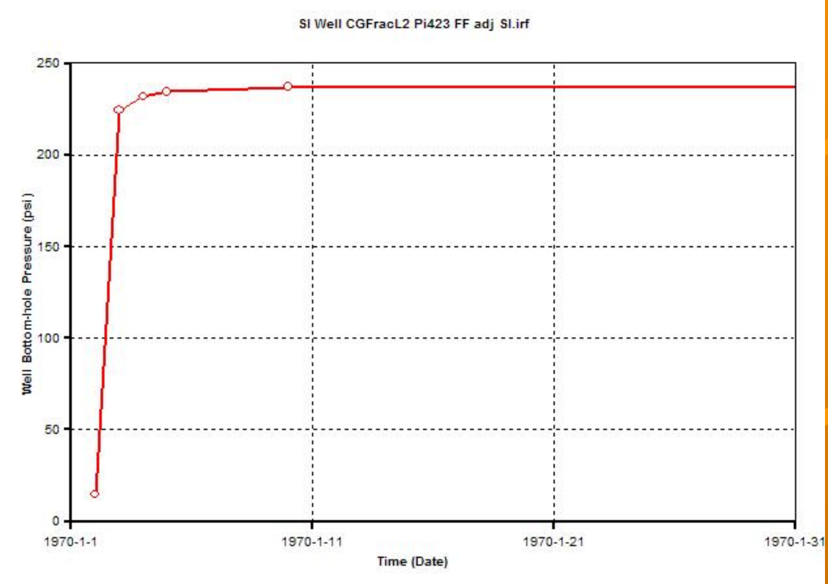
Test well – "SI Well"

- Completed on Jan 1, 1970.
- Refined grids locally
- Completed from L2 to L23.
- SI Well flowed for 1 day.
- SI BHP = 238 psi (ff = 1.0)
- SI BHP = 236 psi (ff = 6.0)

This is close to what has been typically recorded at CG wells upon completion in the study area.



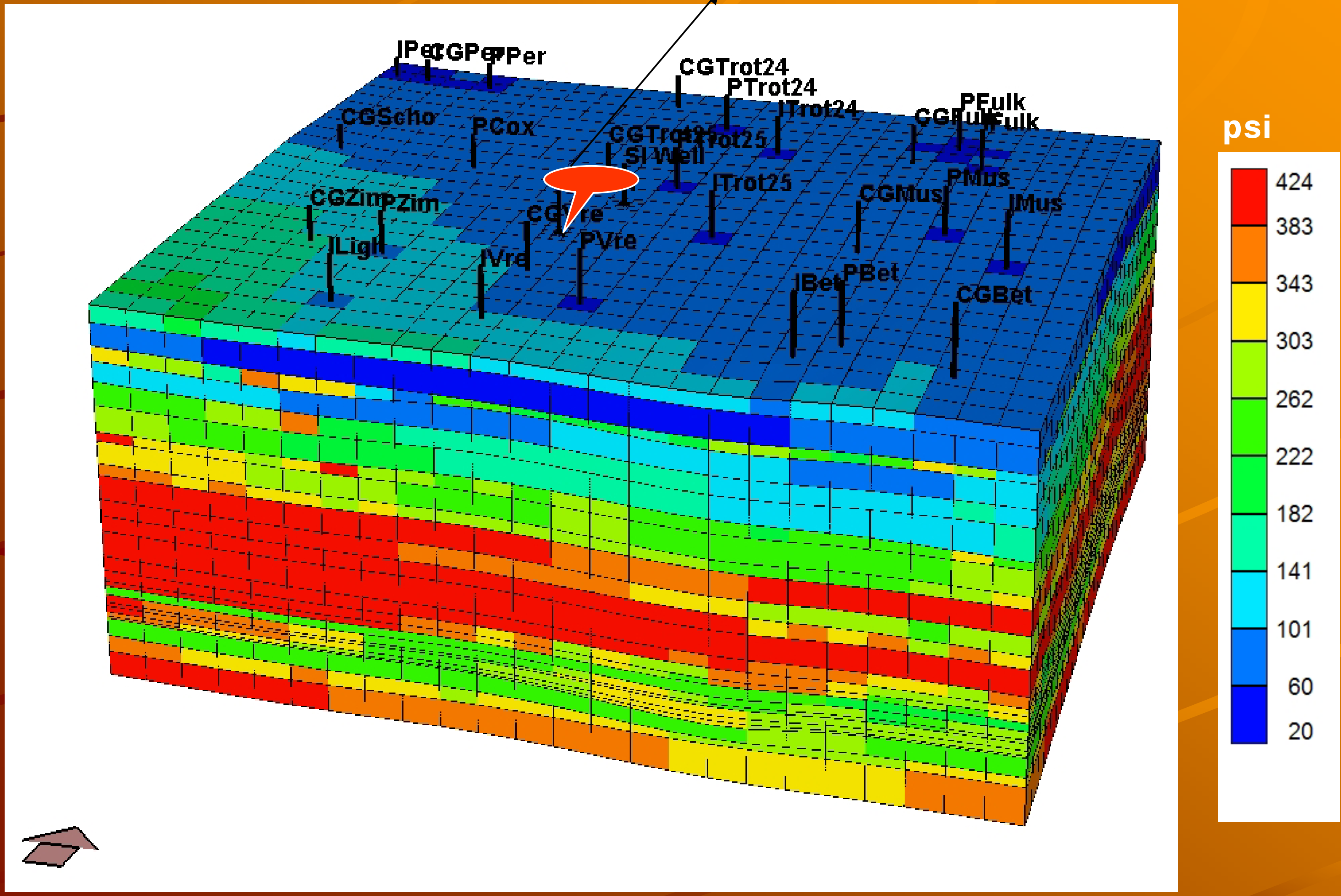
SI pr at a hypothetical CG well – Jan 1970



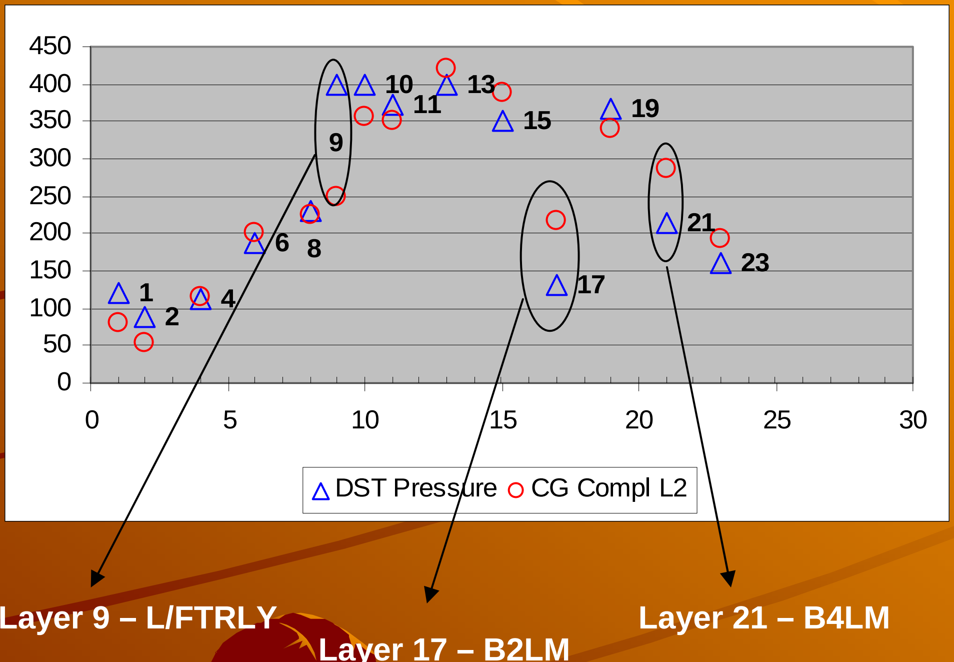
Pi = 423 psi, OGIP = 179.5 bcf

CG completions extend to L2

Pr distribution Jan 5, 1995 – Science well test date



Pi = 423 psi, OGIP = 179.5 bcf



Compare Layer DST data at SCIENCE Well on Jan 5, 1995

	Layer	DST	CG Compl L2
Hrngtn-Paddock	1	120.3	81
Krider	2	87.9	53
Odell	3		
Wnf SS			
Wnf LS	4	113.4	116
Gage	5		
Towanda	6	187.0	201
B/TWND	7		
FTRLY	8	229.9	224.4
L/FTRLY	9	400.0	249
B/FTRLY	10	398.4	356
WREFORD	11	372.4	350
A1_SH	12		
A1_LM	13	400.0	420
B1_SH	14		
B1_LM	15	350.0	389
B2_SH	16		
B2_LM	17	130.6	217
B3_SH	18		
B3_LM	19	368.0	339
B4_SH	20		
B4_LM	21	215.0	286
B5_SH	22		
B5_LM	23	159.5	194
C_SH	24		
C_LM	25		

Despite matching CG production histories, B2LM and B4LM have not drained to the extent that the layer DST data indicate.

Is gas being drained from these layers by non-CG wells because prod from CG wells have already been matched in most cases?

Is there hydraulic communication that connect CH wells to CG layers?

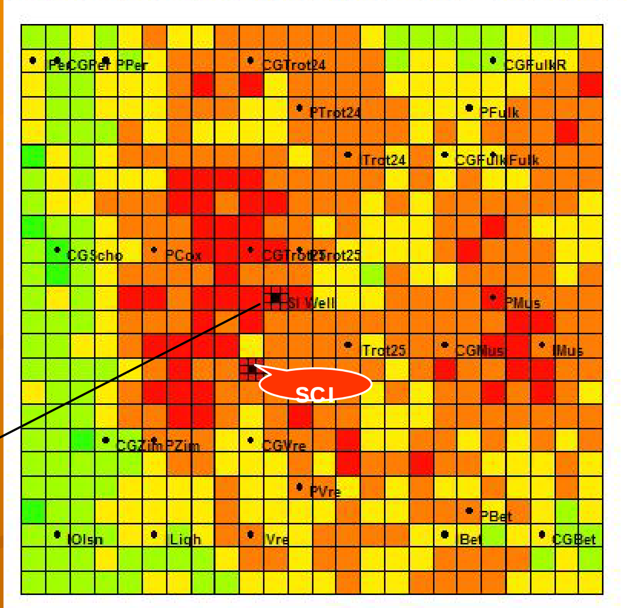
Pi = 423 psi, OGIP = 179.5 bcf

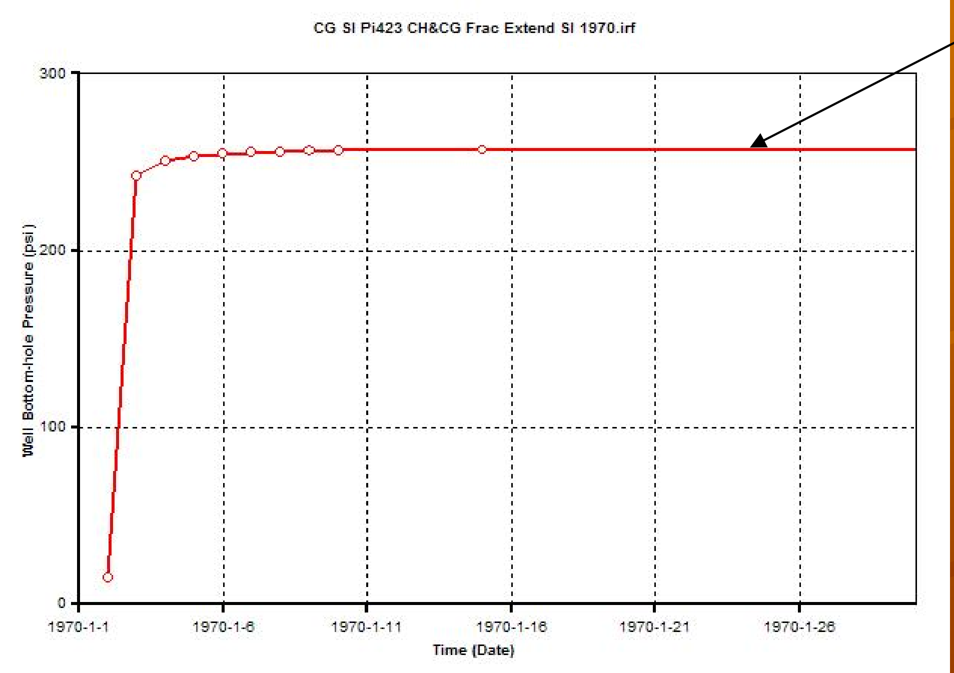
SI pr at a hypothetical CG well – Jan 1970

CH well (P&I) completed to L23 (B5LM) and CG completed to L2 (Krider)

ff factors unchanged

Production and pressure matches at CH wells (P&I) and CG wells remain largely unchanged.





SI BHP = 256 psi

SI pressure closer to 265 psi – the initial pressure recorded at CG wells

(SI BHP = 238 psi when CH well completed in Chase)

Pi = 423 psi, OGIP = 179.5 bcf.

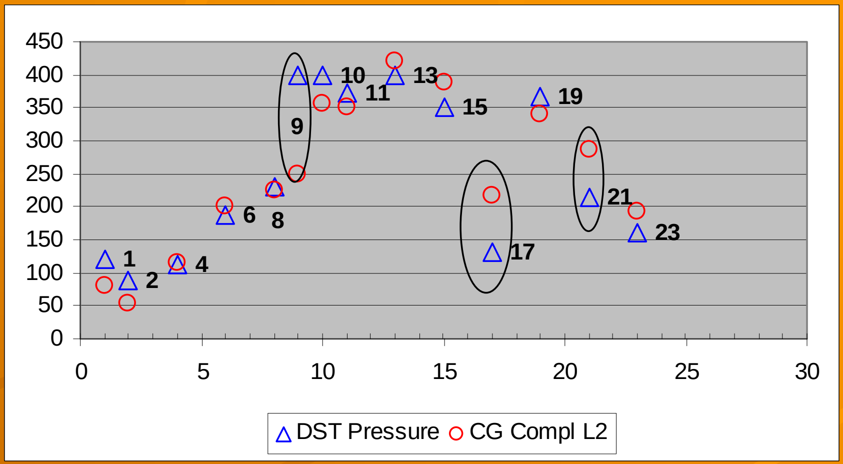
CH well (P&I) completed to L23 while CG completed to L2

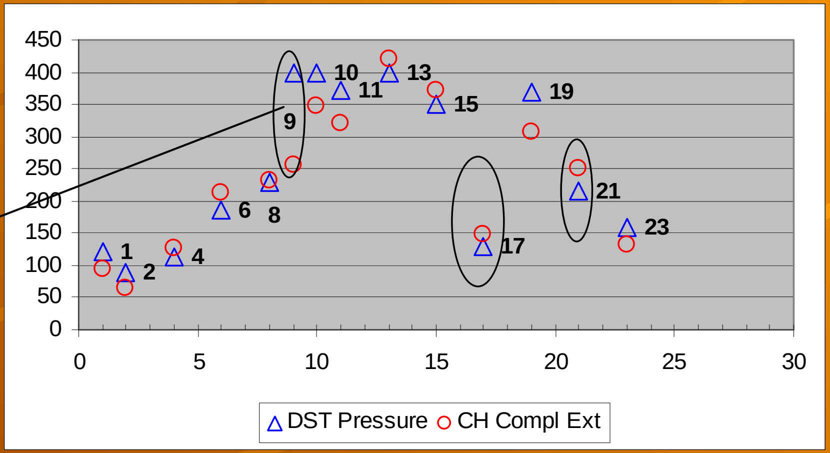
ff factors unchanged

	Layer	DST	Run 6 CG Compl L2	Run 7 CH Compl Ext
Hrngtn-Paddock	1	120.3	81	93.6
Krider	2	87.9	53	64
Odell	3			
Wnf SS				
Wnf LS	4	113.4	116	126.9
Gage	5			
Towanda	6	187.0	201	212.1
B/TWND	7			
FTRLY	8	229.9	224.4	232.2
L/FTRLY	9	400.0	249	255.2
B/FTRLY	10	398.4	356	347.7
WREFORD	11	372.4	350	320.3
A1_SH	12			
A1_LM	13	400.0	420	419.7
B1_SH	14			
B1_LM	15	350.0	389	371
B2_SH	16			
B2_LM	17	130.6	217	149
B3_SH	18			
B3_LM	19	368.0	339	308.4
B4_SH	20			
B4_LM	21	215.0	286	250.3
B5_SH	22			
B5_LM	23	159.5	194	131
C_SH	24			
C_LM	25			

Layer 9 is L/FrtRly – simulator calculates a lower pressure at this zone

Compare Layer DST data at Science Well on Jan 5, 1995





Extending CH completions into CG appear to a) improve layer pressure matches at the Science well, b) better simulate initial SI pressures at CG wells upon completion, and c) enables production and pressure history matching at CH (P&I) and CG wells.

Pi = 423 psi, OGIP = 179.5 bcf.

CH well (P&I) completed in Chase (L9 & L11) and CG completed to L6

ff factors unchanged

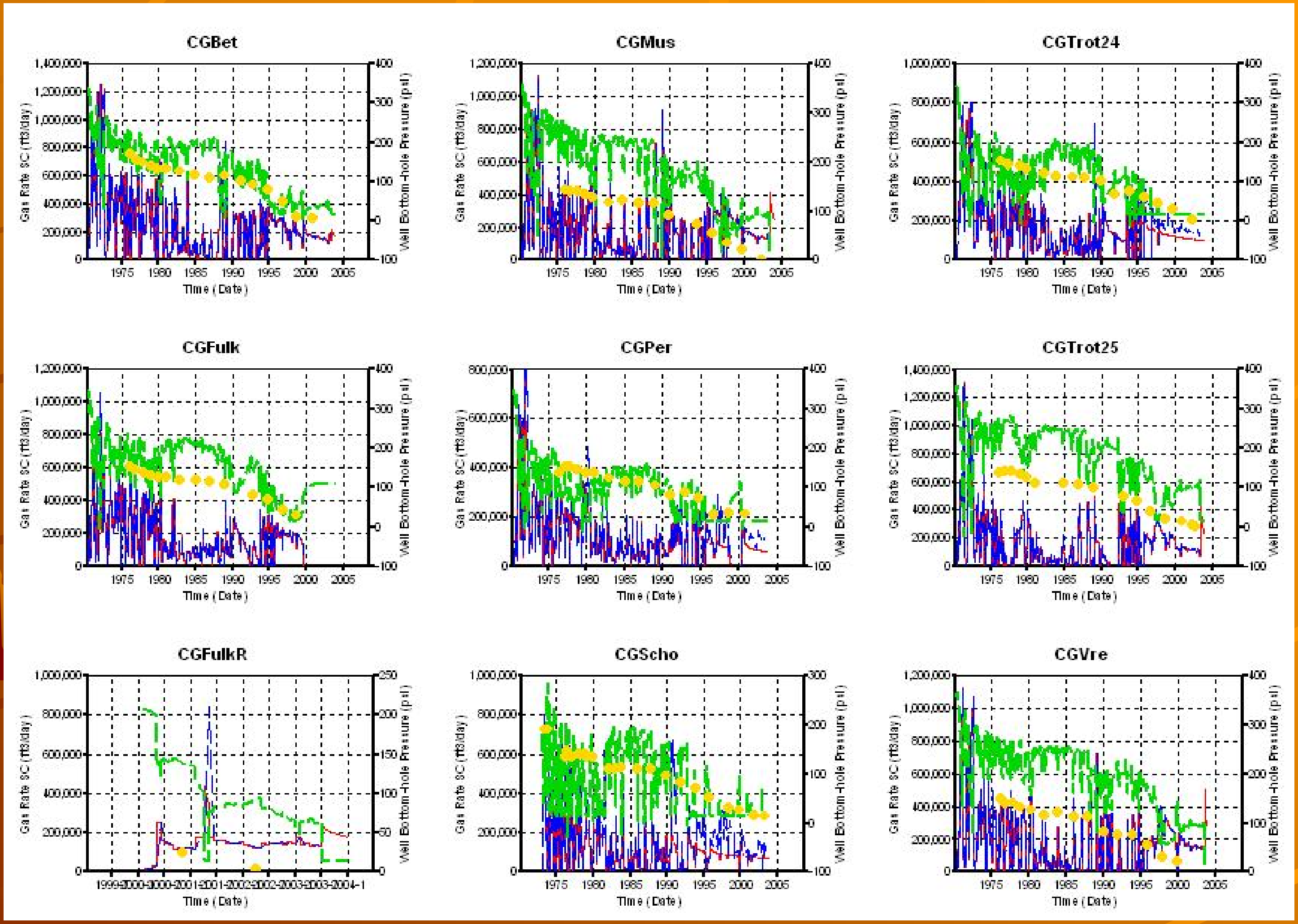
What happens if CG wells completed to Towanda (L6)?

Red – Sim Qg

Blue – His Qg

Green – Sim FBHP

Gold – His FTHP

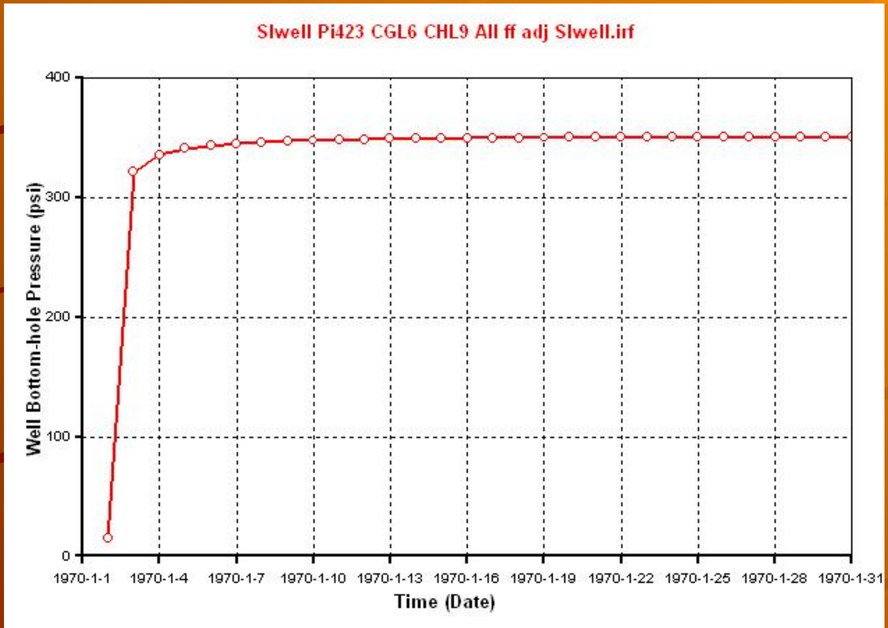


Production matches in CH P&I wells - problem of production spikes surfaces. Production matched at most CG wells. BHP match deteriorates.

Pi = 423 psi, OGIP = 179.5 bcf.

CH well (P&I) completed in Chase (L9 & L11) and CG completed to L6

ff factors unchanged

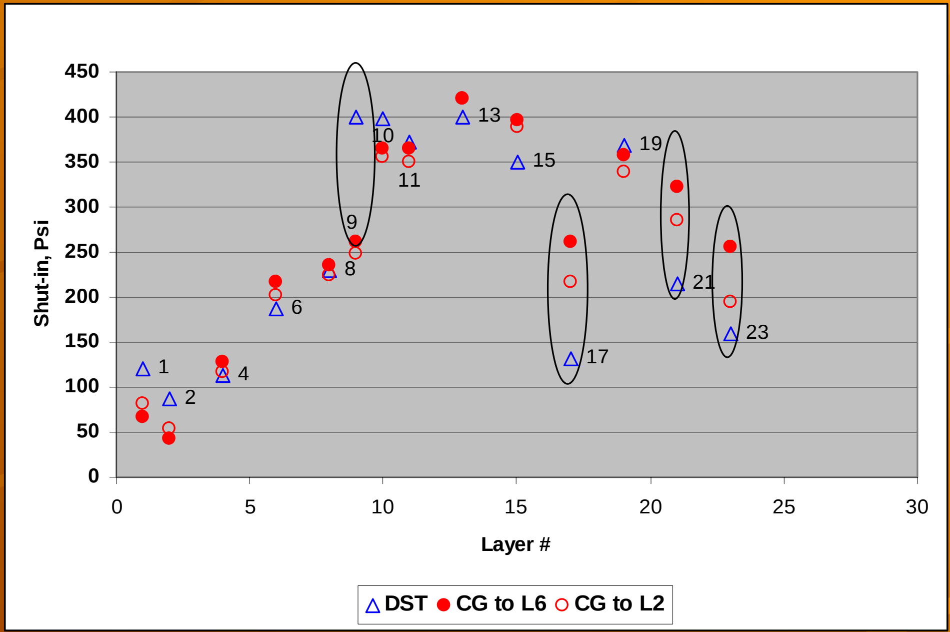


SI BHP stabilizes at 349 psi

What happens to:

a) **Bottom hole shut in pressures at a CG well after completion in Jan 1970?**

b) **Layer pressures at Science Well as of Jan 1995?**



CH layer pr matches unchanged
CG – Pr match deteriorates – B2LM (L17), B4LM (L19), and B5LM (L23)

Summary

- Based on geomodel input (where layer K matches DST K at SCIENCE well), OGIP increases in CG within petrophysical constraints does not result in production matches at CG wells
- Production history match achieved when CG wells communicate with CH gas
  - OGIP around 180 bcf (sufficient); ff between 3 to 9
- CG wells completed to L2 (Krider)
  - Production histories matched at CH P, CG, and non-border CH I (4/9) wells
    - Minimal production spikes when wells freed from rate constraints
    - Current production decline rates - 6 to 8% (Decline rates fall below 2% after around 30 yrs)
  - Close match between FTHP and FBHP at CH P, CG, and non-border CH I wells
  - SI BHP = 238 psi at a CG well completed in Jan 1970 – located in center of study area
  - Close match between simulator calculated layer pr and DST data at SCIENCE well
    - Exceptions - L9 (L/FTRLY), L17 (B2LM), and L21 (B4LM)
- CG wells completed to L2 & CH wells completed to L23 (B2LM) – 1st 2 as above
  - SI BHP = 256 psi at a CG well completed in Jan 1970 – located in center of study area
  - Match between simulator calculated layer pr and DST data at SCIENCE well improved
    - Especially at - L17 (B2LM), and L21 (B4LM)
- CG wells completed to L6 (Towanda)
  - Production history matched at CH P and non-border CH I wells – prod spikes visible
  - Production history matched at CG well – pressure match deteriorates in CG layers
  - SI BHP = 349 psi at a CG well completed in Jan 1970 – located in center of study area

Acknowledgements

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