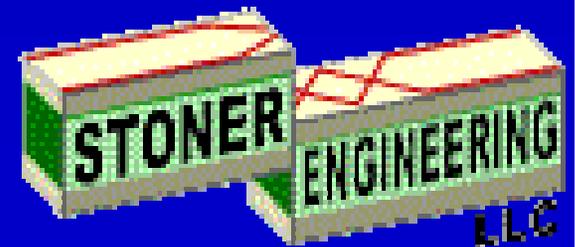


# Geo-Steering Horizontal Wells: Case Studies Demonstrate the Value of Fuzzy Logic Directional Steering Guidance

Sandra Mark, Black Hills E&P, Golden, CO

Michael S. Stoner, Stoner Engineering LLC, Golden, CO

Rocky Mountain Section Meeting AAPG  
Snowbird, UT, October 8, 2007



# Outline

- *Geo-steering fundamentals, the process*
- *Technical Hole Deviation (THD)*
- *Fuzzy Logic for genuine steering guidance*
- *Case studies*

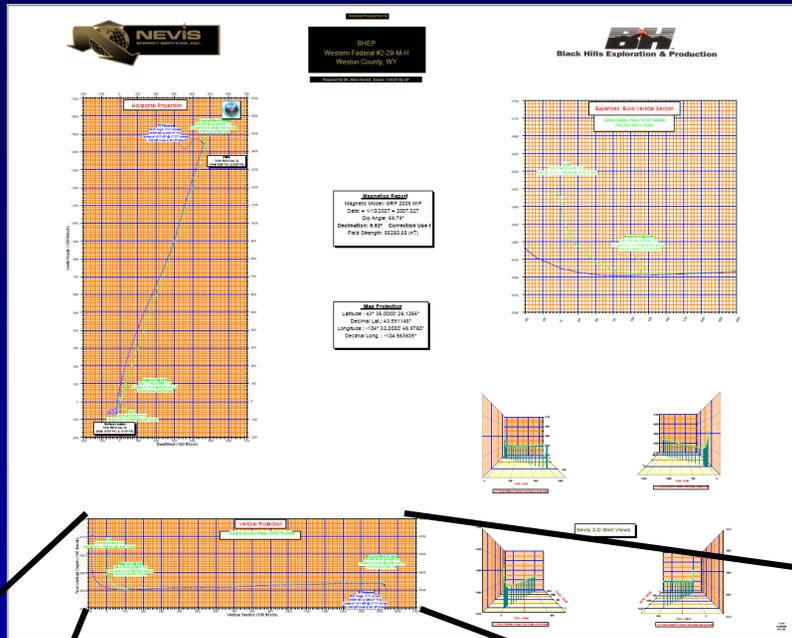
*Geo-steering a horizontal well is geological interpretation at its most stressful.*

The objective of geo-steering interpretation is to describe the stratigraphic location of the wellbore as drilling progresses.

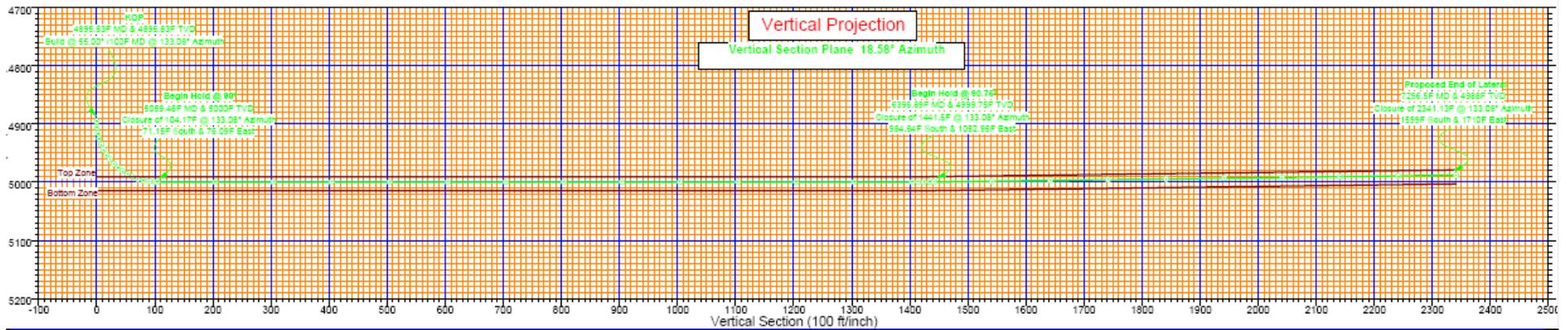
*"Geo-steering is like driving a car by looking in the rear view mirror"*



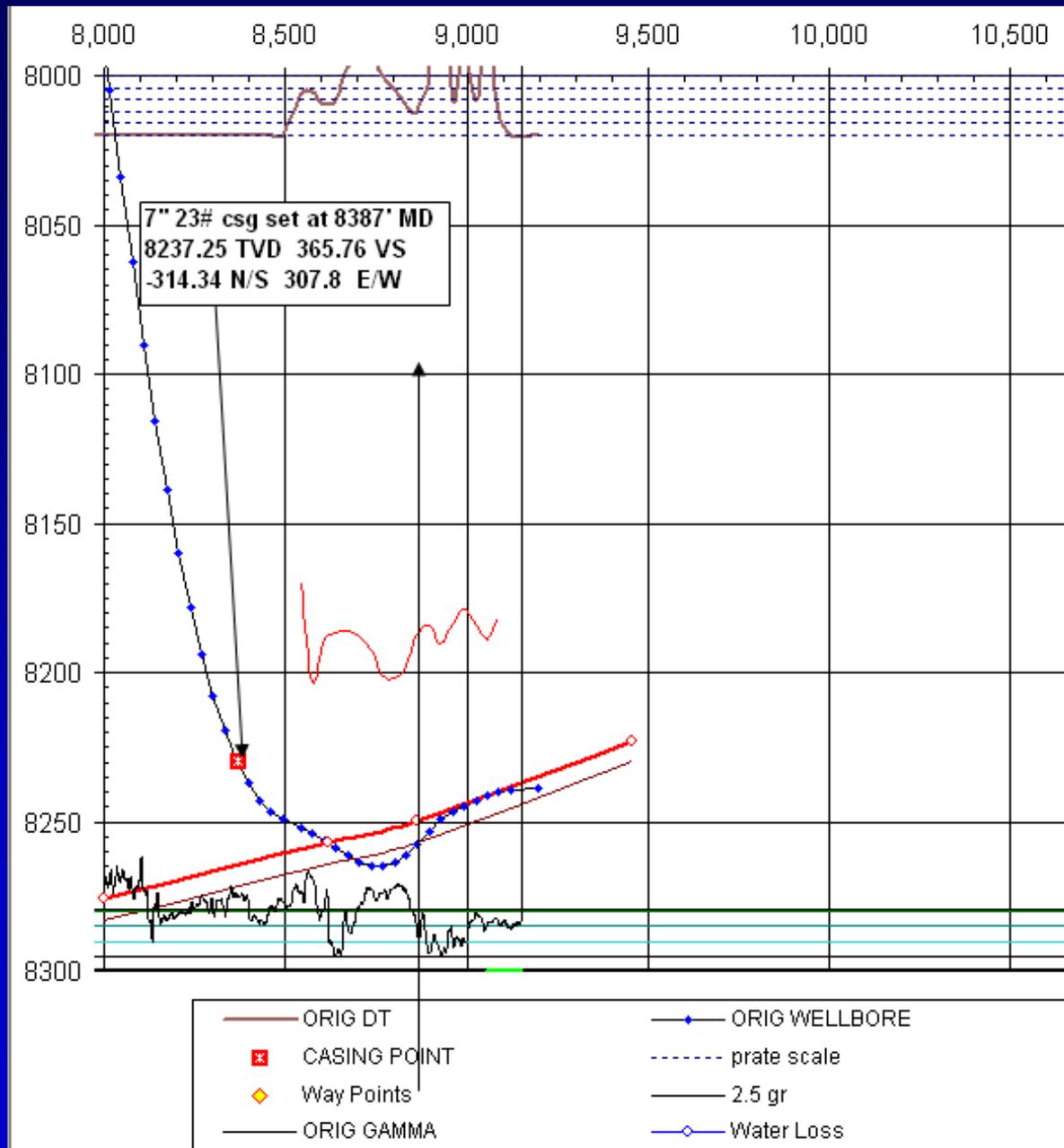
# Directional Drilling Service Company Display – Lacks Detail



Measured Depth FT	Incl Angle Deg	Drift Direction Deg	True Vertical Depth	Vertical Section FT	N-S FT	E-W FT	CLOSURE Distance FT	Direction Deg	Dogleg Severity Deg/100
<b>KOP-&gt; 4887' TVD Begin Build @ 52.00'/ 100'</b>									
4887.00	.00	19.27	4887.00	.00	.00	.00	.00	.00	.00
4897.00	5.20	19.27	4896.99	.45	.43	.15	.45	19.27	52.00
4907.00	10.40	19.27	4906.89	1.81	1.71	.60	1.81	19.27	52.00
4917.00	15.60	19.27	4916.63	4.06	3.83	1.34	4.06	19.27	52.00
4927.00	20.80	19.27	4926.13	7.18	6.78	2.37	7.18	19.27	52.00
4937.00	26.00	19.27	4935.30	11.15	10.53	3.68	11.15	19.27	52.00
4947.00	31.20	19.27	4944.08	15.94	15.04	5.26	15.94	19.27	52.00
4957.00	36.40	19.27	4952.39	21.50	20.29	7.09	21.50	19.27	52.00
4967.00	41.60	19.27	4960.15	27.79	26.23	9.17	27.79	19.27	52.00
4977.00	46.80	19.27	4967.32	34.76	32.81	11.47	34.76	19.27	52.00
4987.00	52.00	19.27	4973.83	42.35	39.98	13.98	42.35	19.27	52.00
4997.00	57.20	19.27	4979.62	50.50	47.67	16.67	50.50	19.27	52.00
5007.00	62.40	19.27	4984.64	59.14	55.82	19.52	59.14	19.27	52.00
5017.00	67.60	19.27	4988.87	68.20	64.38	22.51	68.20	19.27	52.00
5027.00	72.80	19.27	4992.25	77.60	73.26	25.61	77.60	19.27	52.00

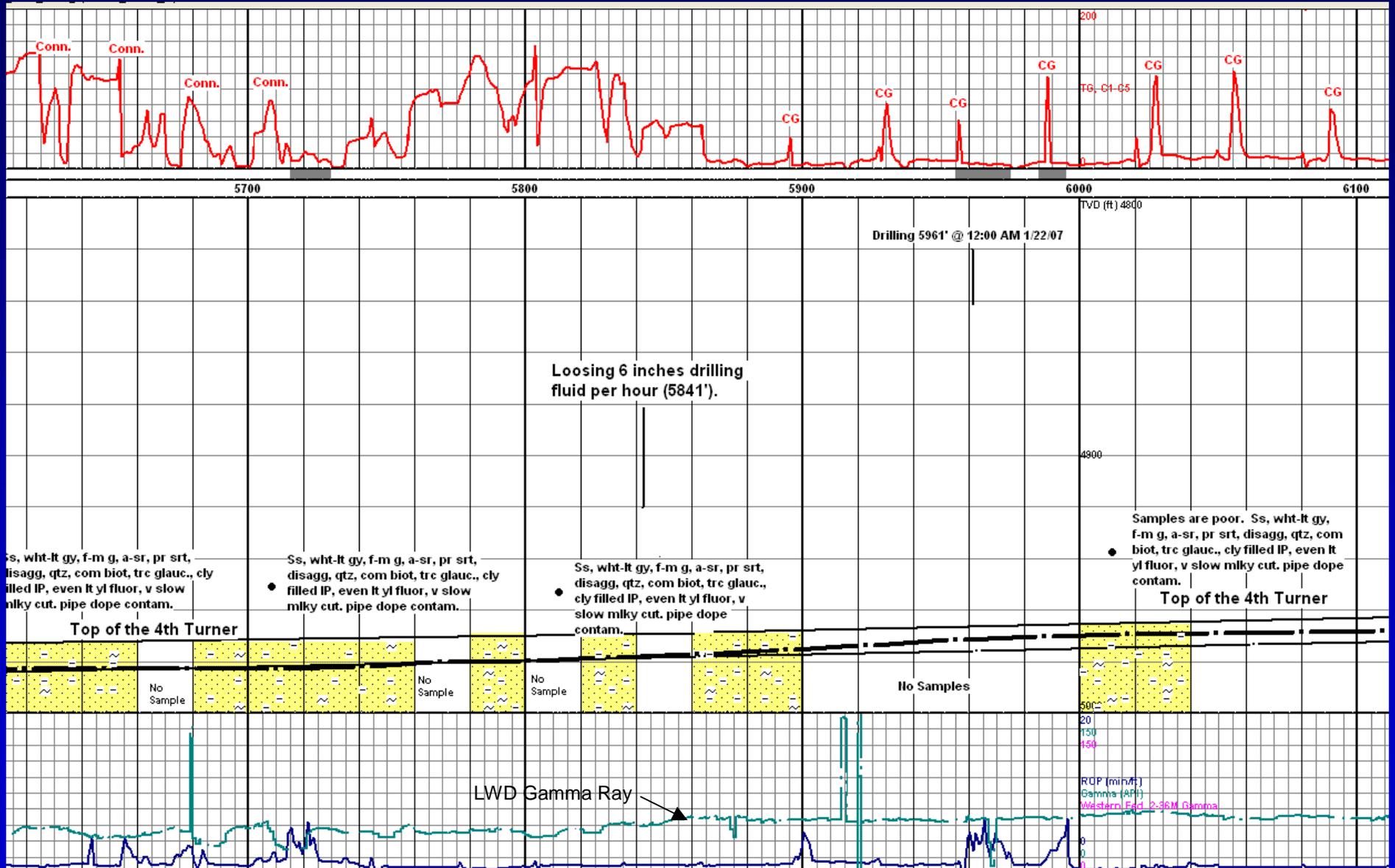


# Spreadsheet-based tools are widely used by industry— largely a drafting tool.



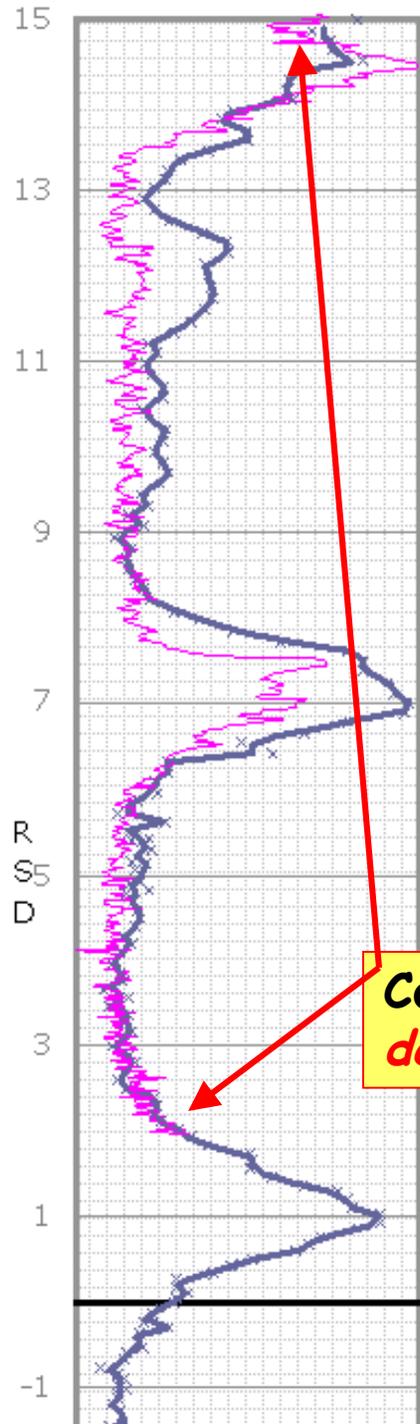
# WellSight Software - Mudlog Display, still a drafting tool

## Sample detail but LWD Gamma Ray difficult to interpret

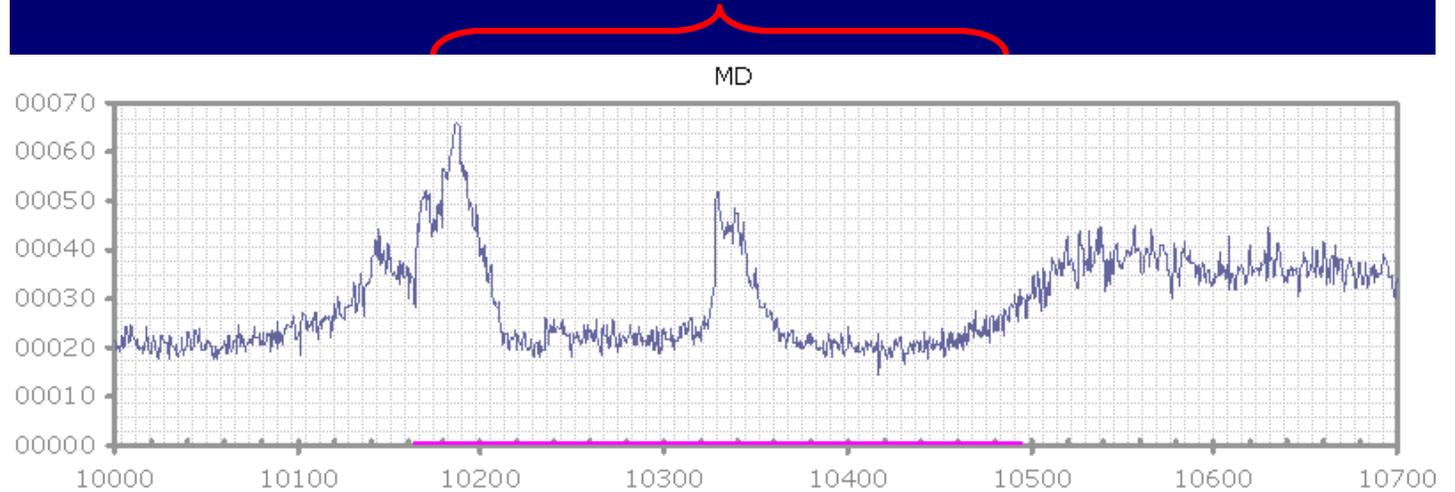


# Geo-steering Requirements

- Depth-accurate formation evaluation measurements acquired with Logging While Drilling (LWD) tools, gamma in the Rockies.
- Type log (digital) from a nearby well or vertical pilot hole.
- Survey data from the directional drilling service company.
- Software that performs the mathematics necessary to allow correlation between type log and LWD data.



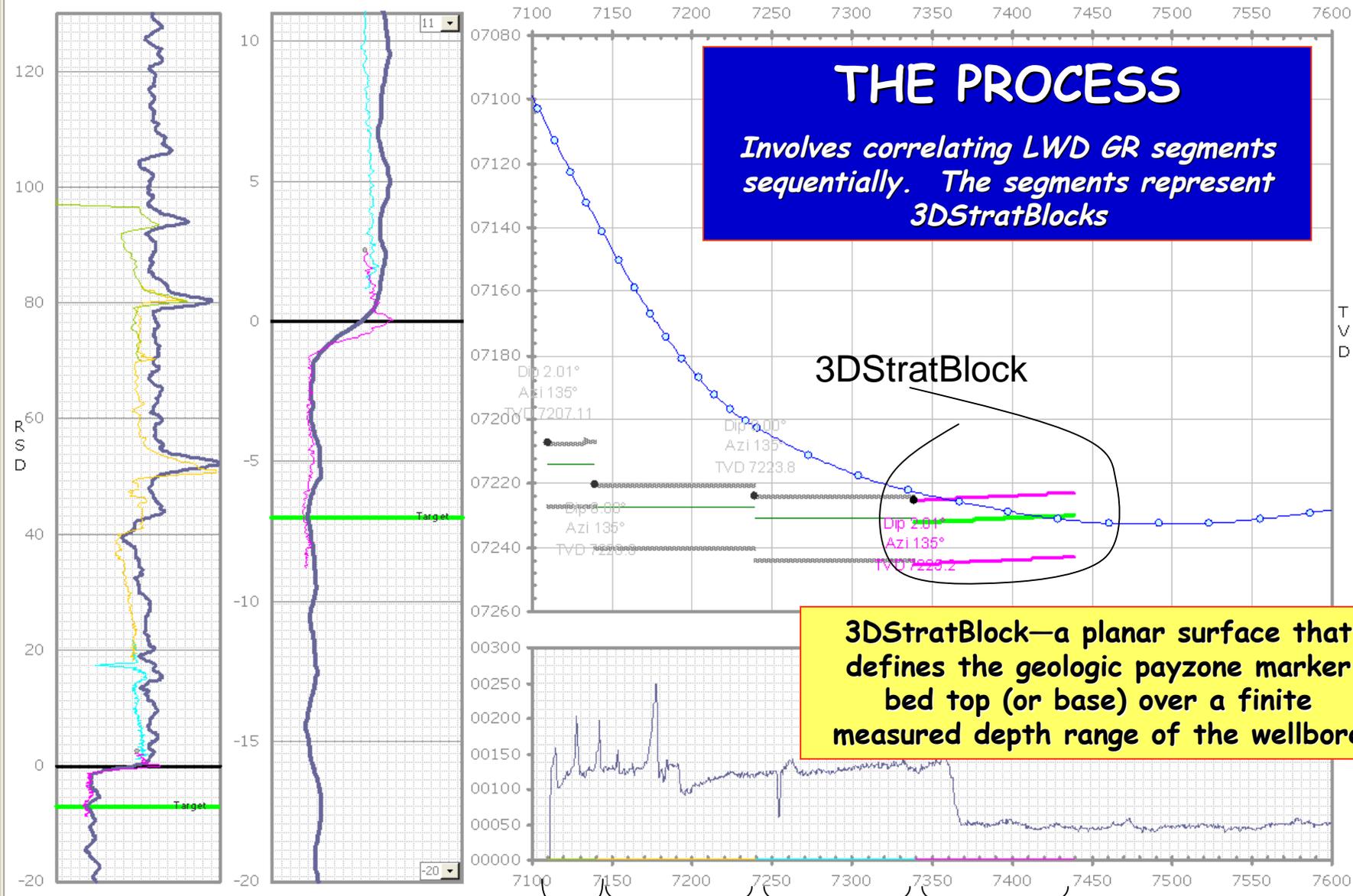
340' of *measured depth* LWD gamma ray data



Correlated to 12' of *relative stratigraphic depth* gamma ray data

Close	?	Current	Initial	Current	Initial	Trans.	1
MD Start	7339.00	7339	MD End	7439.00	7439	Style	Line (thin)
Thick.	20.05	20.05	TVD	7225.20	7223.8		
Dip Azi.	135.00	135	Dip	2.01	0		

MB#2, 3DSB#3...

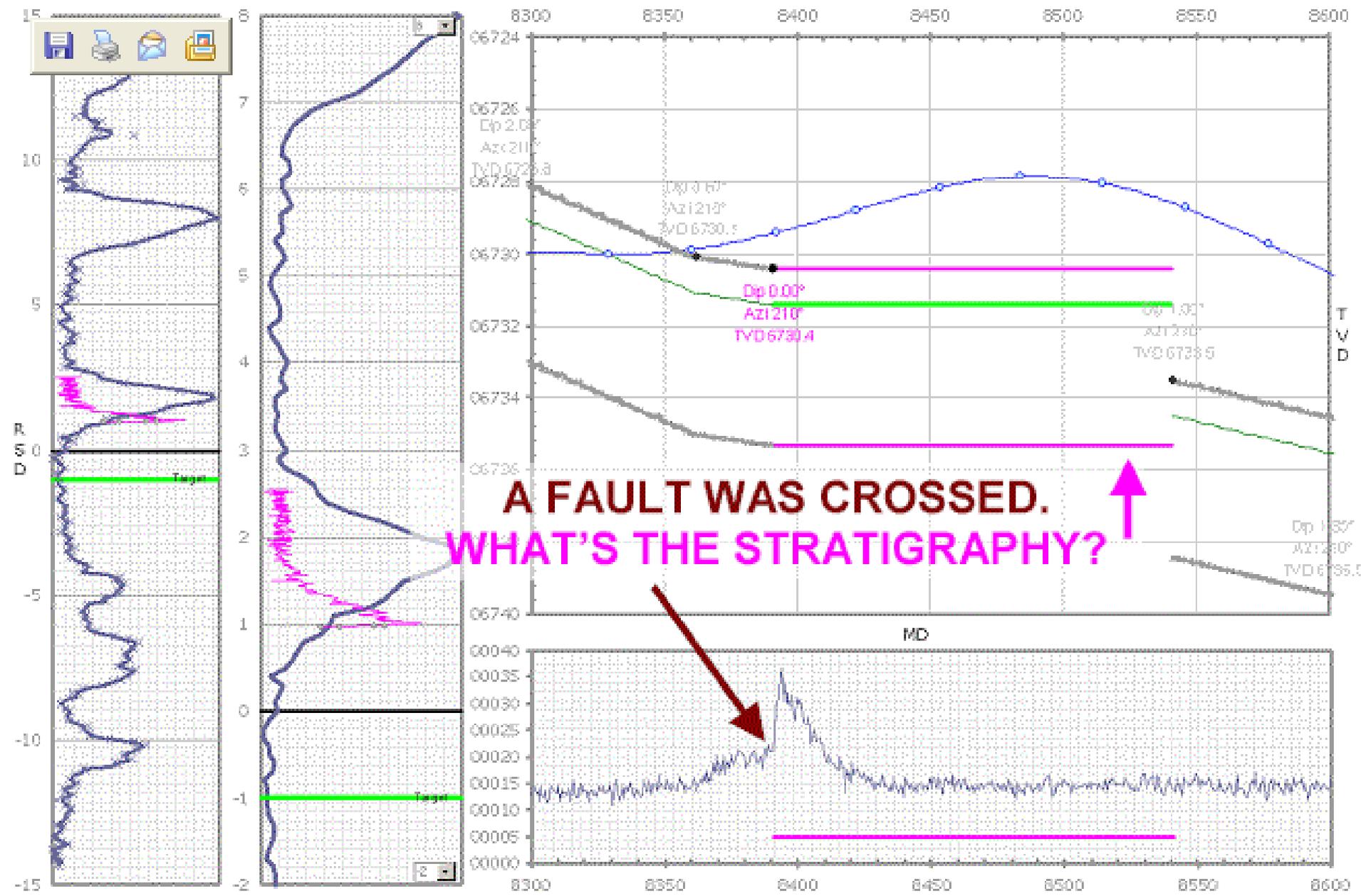


decrease TVD

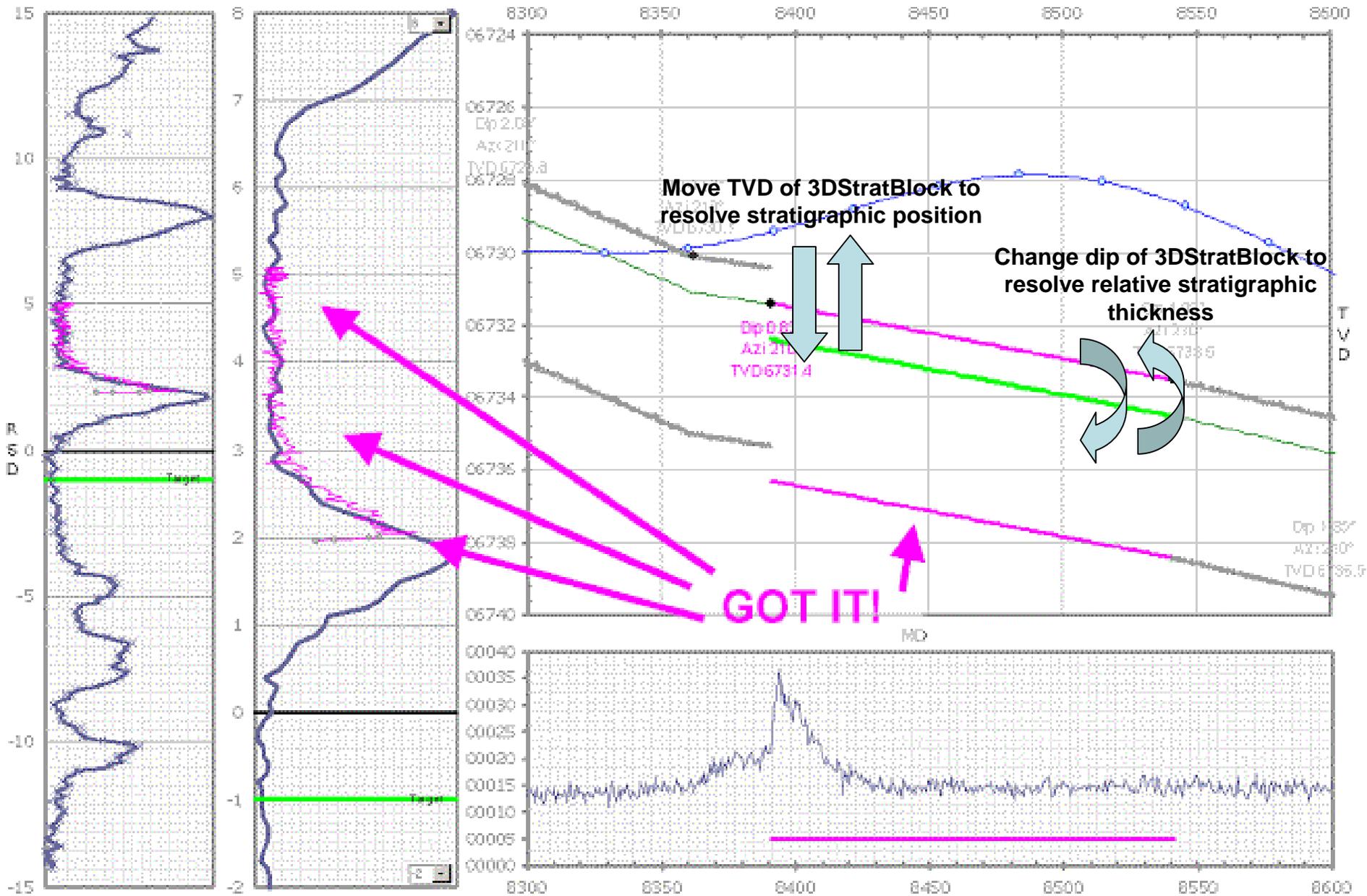
3DStratBlocks







**A FAULT WAS CROSSED.**  
**WHAT'S THE STRATIGRAPHY?**



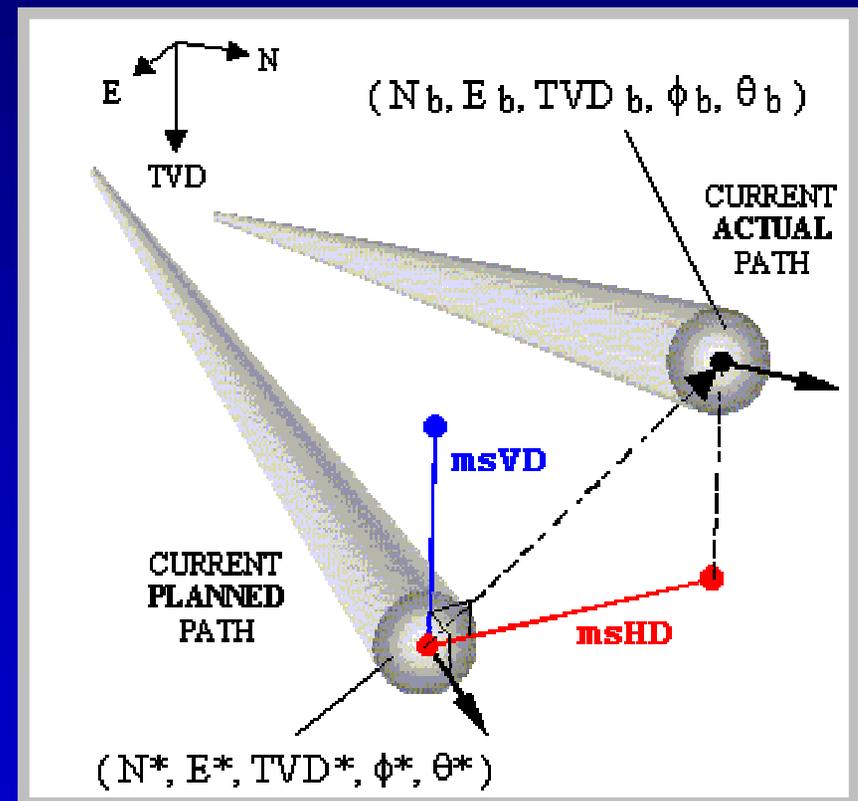
Take the interpretation to a new  
level with Technical Hole  
Deviation (THD)

# Technical Hole Deviation (THD)

- Is the mathematical unification of planned versus actual directional well paths.
- Quantifies how a well path differs from plan (in greater detail than service company)
- When combined with the geo-steering interpretation through Fuzzy Logic processing, genuine steering guidance is provided.

# THD...since 2000

- Technical Hole Deviation (THD)
  - Quantifies how a directional well path differs from its planned trajectory
  - Accommodates any type of directional drilling; any planned well path profile
- Provides Log & Table formats
- Geometry OR Geo-steer
- No distortion like vertical section projection



# THD Components

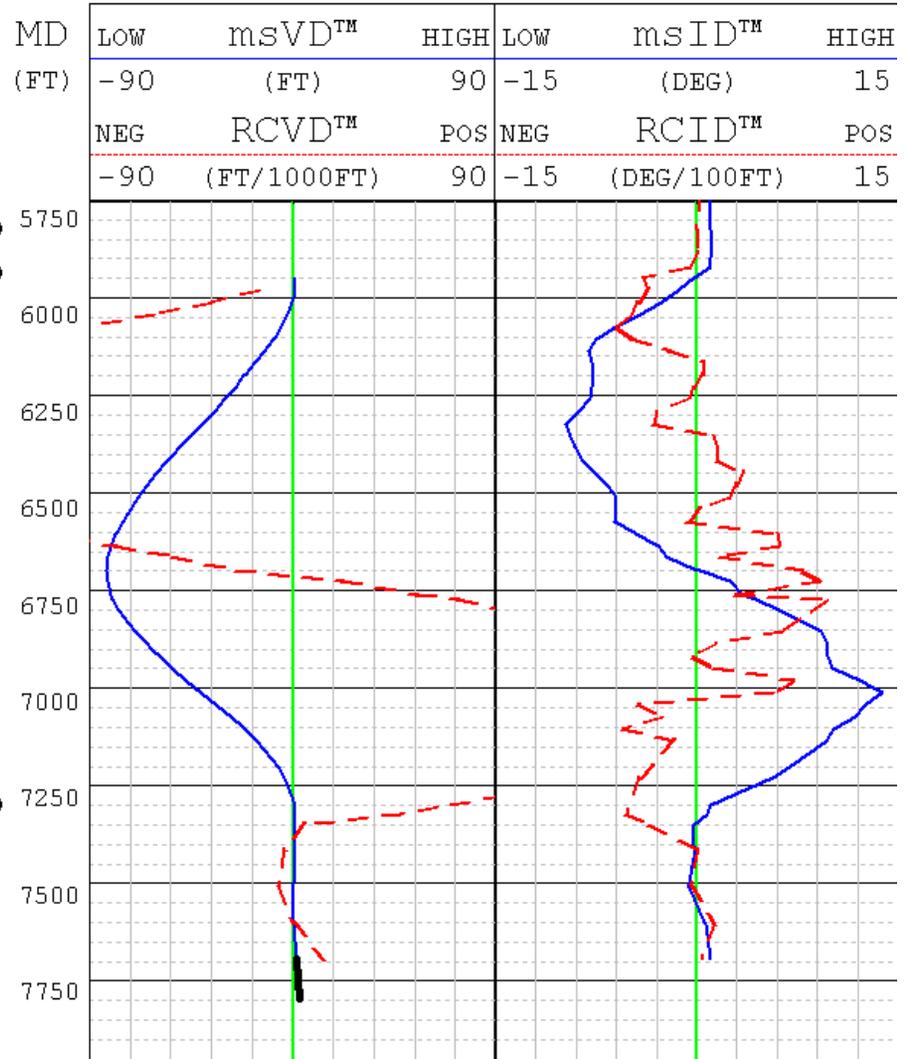
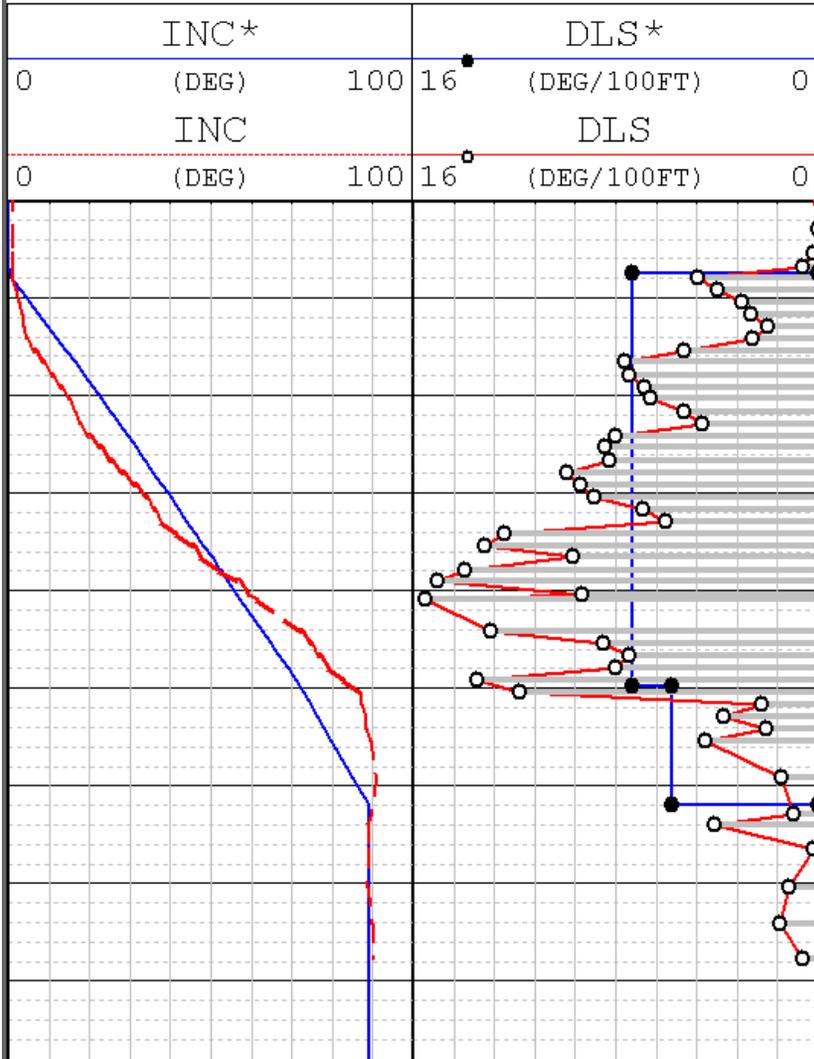
THD Component	Description	Deviation "Sense"	Unit	Order	Lineal Deviation	Angular Deviation	Verbal Descriptor
ms VD	vertical deviation	Vertical	ft or m	1st	x		High/Low
RCVD	relative change in vertical deviation	Vertical	ft/1000ft or m/304.8m	2nd	x		Positive/Negative
ms ID	inclinal deviation	Vertical	deg	1st		x	High/Low
RCID	relative change in inclinal deviation	Vertical	deg/100ft or deg/30.48m	2nd		x	Positive/Negative
ms HD	horizontal deviation	Horizontal	ft or m	1st	x		Left/Right
RCHD	relative change in horizontal deviation	Horizontal	ft/1000ft or m/304.8m	2nd	x		Positive/Negative
ms AD	azimuthal deviation	Horizontal	deg	1st		x	High/Low
RCAD	relative change in azimuthal deviation	Horizontal	deg/100ft or deg/30.48m	2nd		x	Positive/Negative

# VERTICAL TECHNICAL HOLE DEVIATION LOG™

**WELLNAME:**

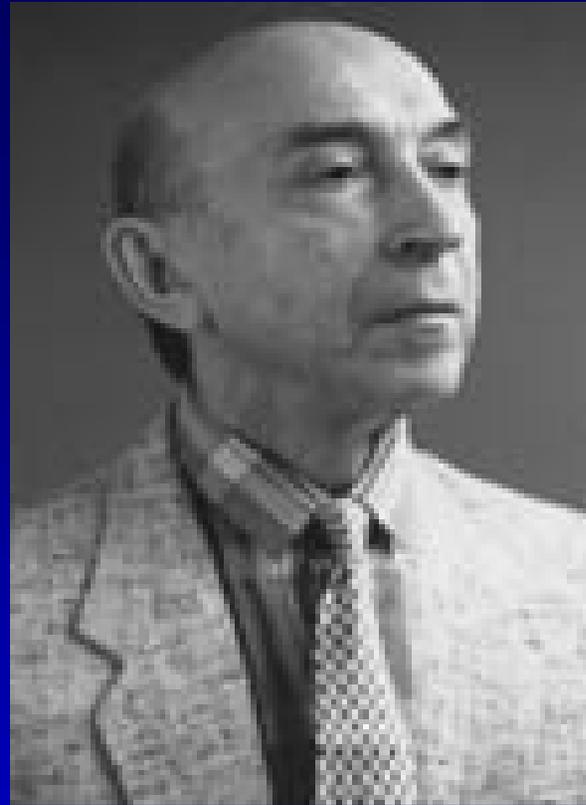
Excess Measured Depth: 81 FT 1.3%  
based on footage of: 6368 FT

Average Absolute msVD: 37.8 FT  
Average Absolute msID: 3.65 DEG  
THD Grid Values (FT~DEG): 18~3



Let's Get Fuzzy....

*Fuzzy Logic, that is*



*Professor Lotfi A. Zadeh*

*University of California, Berkeley*

*Founder of Fuzzy Logic, first published in 1965*

# *Fuzzy Logic*

*A type of logic that recognizes more than simple true and false values. Fuzzy logic works with ranges of values that represent degrees of truthfulness and falsehood; it resembles human logic.*

# *Fuzzy Logic*

*For example, the statement, today is sunny, might be 100% true if there are no clouds, 80% true if there are a few clouds, 50% true if it's hazy and 0% true if it rains all day.*



**What do these  
commercial products  
have in common...**

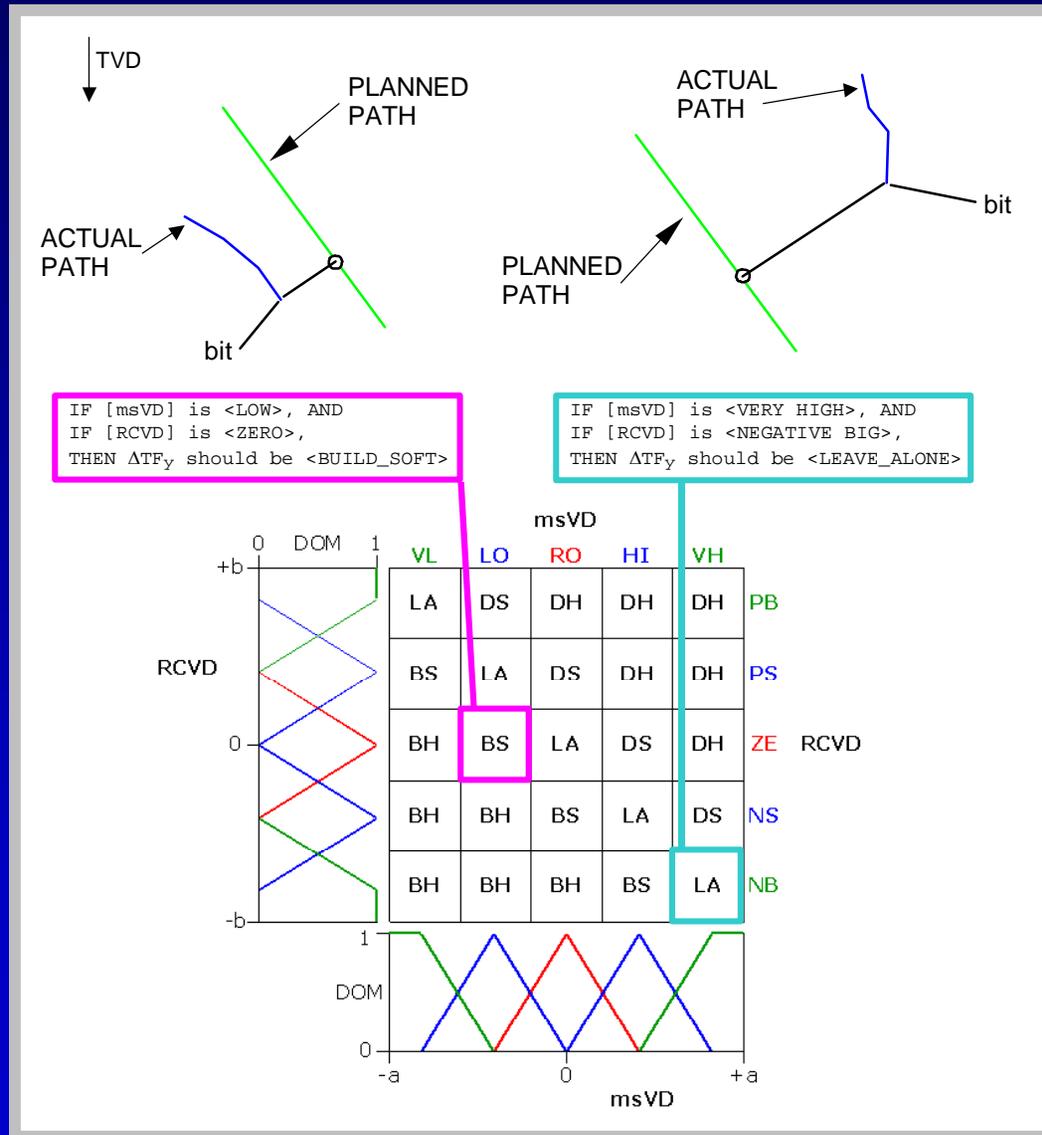




**They all use  
Fuzzy Logic  
controllers!**



# Fuzzy Logic for Steering—Utilizes THD



When THD data are combined  
with the geo-steering  
interpretation through Fuzzy  
Logic processing, genuine  
steering guidance is provided.

# Steering Guidance

Output—Steering Guidance

Input—is THD

MD	Δ High/Low Side	Δ Right/Left Side	VD	RCVD	ID	RCID	HD	RCHD	AD	RCAD
5888.00					1.14	0.1				
5920.00					0.97	-0.5				
5950.00			1.33		-0.23	-4.0				
5981.00	Towards BUILD 80%		0.88	-14	-1.36	-3.6				
6011.00	Towards BUILD 100%		-0.18	-35	-2.67	-4.4				
6043.00	Towards BUILD 100%		-2.12	-61	-4.21	-4.8				
6074.00	Towards BUILD 100%		-4.91	-91	-6.02	-5.9				
6105.00	Towards BUILD 100%		-8.56	-120	-7.46	-4.7	-55.54		6.12	
6135.00	Towards BUILD 100%	Towards LEFT 30%	-12.62	-139	-8.02	-1.9	-55.18	12	8.14	6.9
6165.00	Towards BUILD 90%	Towards RIGHT 20%	-16.80	-143	-7.86	0.5	-54.68	17	6.91	-4.2
6198.00	Towards BUILD 90%	Towards LEFT 30%	-21.32	-142	-7.74	0.4	-54.01	21	6.93	0.1
6229.00	Towards BUILD 100%	NO CHANGE	-25.55	-142	-7.81	-0.2	-53.28	24	6.05	-3.0
6259.00	Towards BUILD 100%	Towards LEFT 40%	-29.72	-145	-7.96	-0.5	-52.39	31	7.87	6.3
6291.00	Towards BUILD 100%	Towards LEFT 40%	-34.52	-158	-8.86	-3.0	-50.90	49	11.83	13.0
6323.00	Towards BUILD 100%	Towards LEFT 50%	-39.95	-180	-9.83	-3.2	-48.76	71	14.55	9.1
6354.00	Towards BUILD 80%	Towards LEFT 20%	-45.41	-189	-9.48	1.2	-46.33	84	13.67	-3.1
6384.00	Towards BUILD 80%	NO CHANGE	-50.47	-182	-9.05	1.5	-43.92	87	12.00	-6.0
6416.00	Towards BUILD 80%	Towards LEFT 50%	-55.61	-174	-8.56	1.6	-41.24	91	11.92	-0.3
6447.00	Towards BUILD 80%	Towards LEFT 60%	-60.20	-162	-7.56	3.5	-38.36	101	11.92	0.0
6479.00	Towards BUILD 80%	Towards LEFT 30%	-64.43	-145	-6.71	2.9	-35.19	109	11.21	-2.4
6511.00	Towards BUILD 80%	Towards LEFT 50%	-68.25	-131	-6.02	2.3	-31.77	117	11.65	1.5
6542.00	Towards BUILD 90%	Towards LEFT 60%	-71.78	-126	-5.97	0.2	-28.07	132	12.27	2.2
6573.00	Towards BUILD 100%	Towards LEFT 40%	-75.35	-128	-6.16	-0.7	-24.15	140	11.97	-1.1
6603.00	Towards BUILD 80%	NO CHANGE	-78.41	-113	-4.53	6.0	-20.42	138	10.49	-5.5
6634.00	Towards BUILD 80%	NO CHANGE	-80.58	-78	-2.79	6.2	-16.97	124	8.23	-8.1
6665.00	Towards BUILD 80%	NO CHANGE	-82.07	-53	-2.28	1.8	-14.18	100	6.03	-7.9
6697.00	Towards BUILD 50%	Towards LEFT 10%	-82.77	-24	0.01	7.9	-11.82	82	5.01	-3.5
6727.00	Towards DROP 60%	Towards LEFT 30%	-82.16	23	2.52	9.3	-9.78	76	4.60	-1.5
6759.00	Towards DROP 60%	Towards LEFT 60%	-80.56	55	3.39	3.0	-7.59	76	4.62	0.1
6771.00	Towards DROP 60%	Towards LEFT 60%	-79.76	74	4.45	9.8	-6.73	80	4.84	2.0
6855.00	Towards DROP 60%	Towards RIGHT 20%	-69.73	132	9.37	6.5	-2.46	56	1.63	-4.2
6887.00	Towards DROP 60%	Towards RIGHT 20%	-64.41	183	9.79	1.5	-1.85	21	0.67	-3.3
6918.00	Towards DROP 40%	Towards RIGHT 40%	-59.15	186	9.74	-0.2	-1.80	2	-0.48	-4.1
6950.00	Towards DROP 60%	Towards RIGHT 20%	-53.63	188	10.14	1.4	-2.08	-10	-0.56	-0.3
6980.00	Towards DROP 60%	Towards RIGHT 20%	-47.83	210	12.16	7.3	-2.40	-11	-0.65	-0.3
7011.00	Towards DROP 60%	Towards RIGHT 60%	-40.88	241	13.83	5.8	-3.01	-21	-1.62	-3.4
7042.00	NO CHANGE	Towards RIGHT 10%	-33.80	244	12.58	-4.3	-3.74	-25	-1.09	1.8
7073.00	NO CHANGE	Towards RIGHT 60%	-27.25	223	11.85	-2.5	-4.50	-26	-1.71	-2.1
7104.00	NO CHANGE	Towards RIGHT 10%	-21.32	200	10.22	-5.5	-5.25	-25	-1.09	2.1



# Case Studies

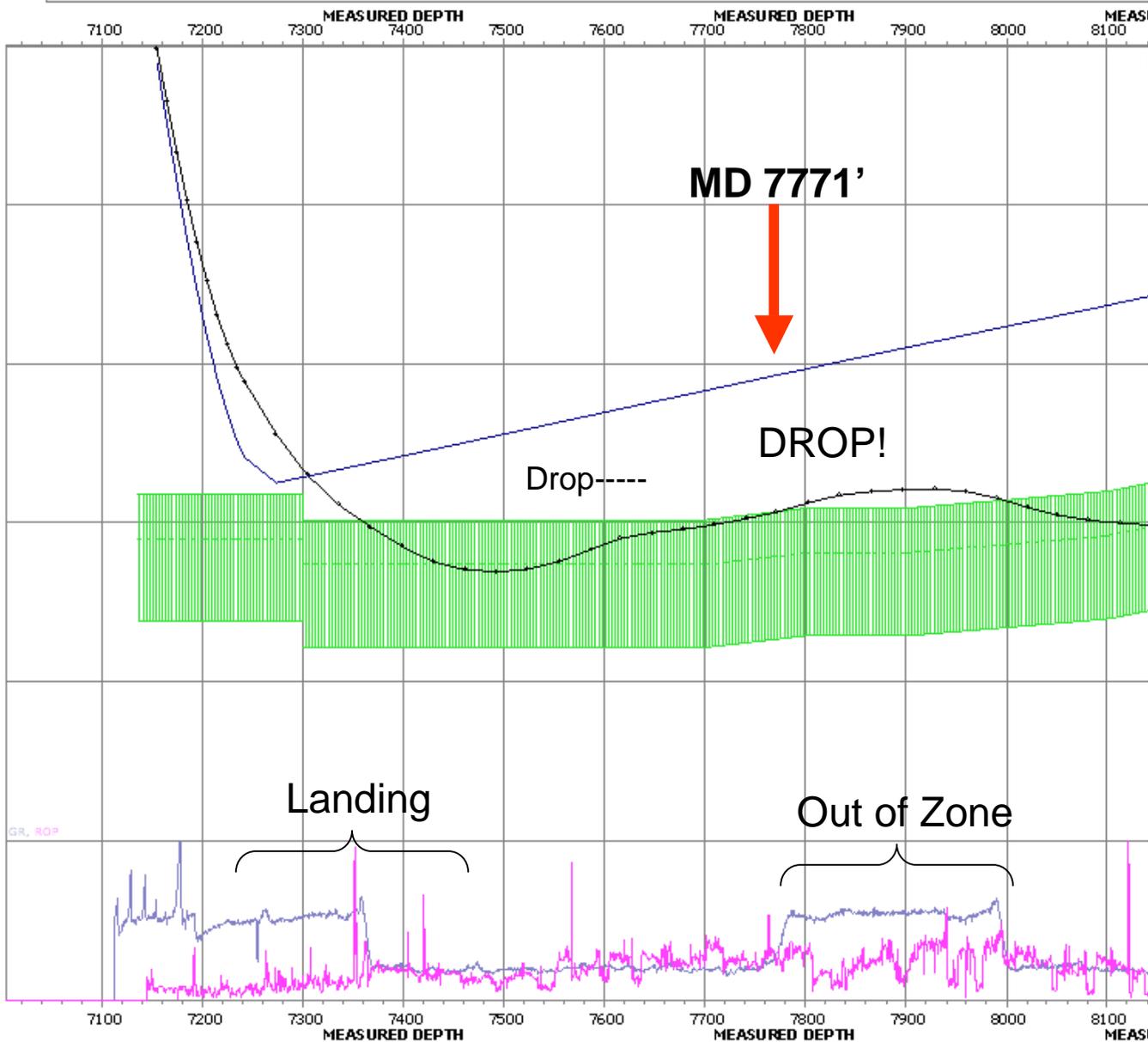
# Before geo-steering software, we were all clueless

Email from wellsite geologist Jan 23, 2007

Good morning,

We bumped the inclination up last night, about 8:30 pm, to 93 deg. The samples showed a drop in fluorescence and cut, which I decided that we were low in zone. Well, low we were not. at MD 7771' - TVD 7223.3' - Incl 92.1 - VS 597.6 , the gamma log reached 140 API units. The samples collected were 95-100% shale indicating that we came out the top of zone. We are sliding on the low side and coming back into zone.

# "Post mortem"



THD, THD Logs, & FDDC Steering Guidance			
<input checked="" type="checkbox"/> Use Marker Bed for Planned TVD	<input checked="" type="checkbox"/> Calculate FDDC Steering Guidance		
Marker Bed	4		
MD	Δ High/Low Side	Δ Right/Left Side	
7194.00	Towards BUILD 30%	Towards LEFT 50%	-
7204.00	Towards BUILD 30%	Towards LEFT 50%	-
7214.00	Towards BUILD 30%	Towards LEFT 50%	-
7224.00	Towards BUILD 30%	Towards LEFT 50%	-
7234.00	Towards BUILD 30%	Towards LEFT 50%	-
7241.00	Towards BUILD 30%	Towards LEFT 40%	-
7273.00	Towards BUILD 20%	Towards LEFT 40%	-
7304.00	Towards BUILD 20%	Towards LEFT 30%	-
7335.00	Towards BUILD 30%	Towards LEFT 20%	-
7367.00	Towards BUILD 40%	Towards LEFT 20%	-
7398.00	Towards BUILD 40%	Towards LEFT 20%	-
7429.00	Towards BUILD 60%	Towards LEFT 20%	-
7461.00	Towards BUILD 70%	Towards LEFT 20%	-
7492.00	Towards BUILD 20%	Towards LEFT 10%	-
7523.00	Towards DROP 40%	Towards LEFT 20%	-
7555.00	Towards DROP 40%	Towards LEFT 10%	-
7587.00	Towards DROP 60%	Towards LEFT 10%	-
7616.00	Towards DROP 60%	Towards LEFT 10%	-
7647.00	Towards DROP 70%	Towards LEFT 10%	-
7678.00	Towards DROP 70%	Towards LEFT 10%	-
7709.00	Towards DROP 70%	Towards LEFT 10%	-
7741.00	Towards DROP 70%	Towards LEFT 10%	-
7771.00	Towards DROP 70%	Towards LEFT 10%	-
7803.00	Towards DROP 90%	Towards LEFT 40%	-
7834.00	Towards DROP 80%	Towards LEFT 90%	-
7866.00	Towards DROP 80%	Towards LEFT 90%	-
7897.00	Towards DROP 50%	Towards LEFT 100%	-
7929.00	Towards DROP 10%	Towards LEFT 90%	-
7960.00	Towards BUILD 60%	Towards LEFT 90%	-
7991.00	Towards BUILD 60%	Towards LEFT 80%	-
8021.00	Towards BUILD 50%	Towards LEFT 80%	-
8051.00	NO CHANGE	Towards LEFT 90%	-
8082.00	NO CHANGE	Towards LEFT 90%	-
8114.00	Towards BUILD 80%	Towards LEFT 80%	-
8145.00	Towards BUILD 90%	Towards LEFT 60%	-
8176.00	Towards BUILD 10%	Towards LEFT 70%	-
8207.00	Towards DROP 20%	Towards LEFT 90%	-
8239.00	Towards BUILD 80%	Towards LEFT 40%	-
8270.00	NO CHANGE	Towards LEFT 60%	-
8301.00	Towards DROP 80%	Towards LEFT 40%	-
8333.00	Towards DROP 100%	Towards LEFT 60%	-
8364.00	Towards DROP 10%	Towards LEFT 30%	-
8400.00	Towards DROP 90%	Towards LEFT 40%	-

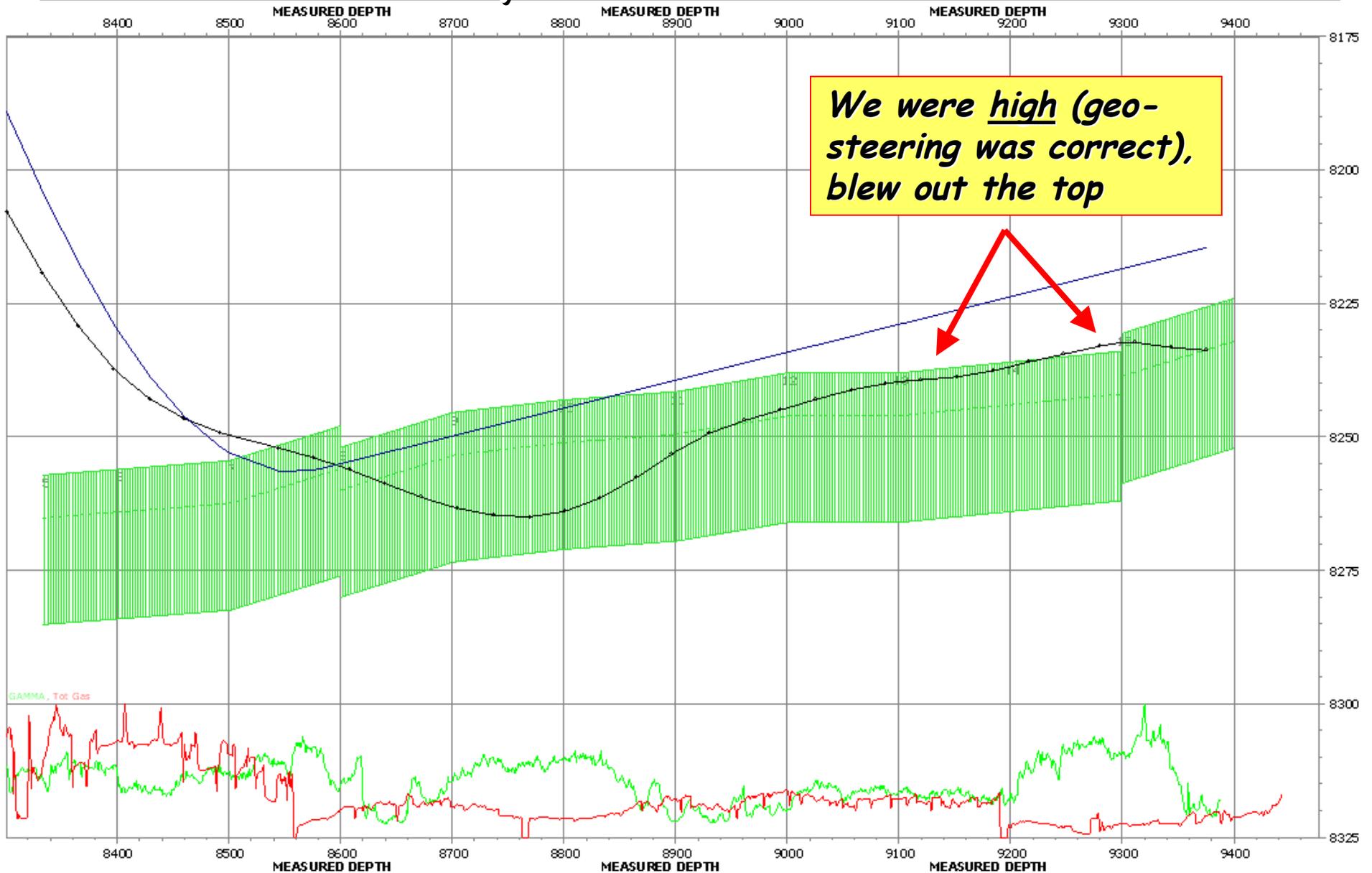
Several months later, same field,  
next well, MD 9100...

We're high!! (technical  
geosteering)

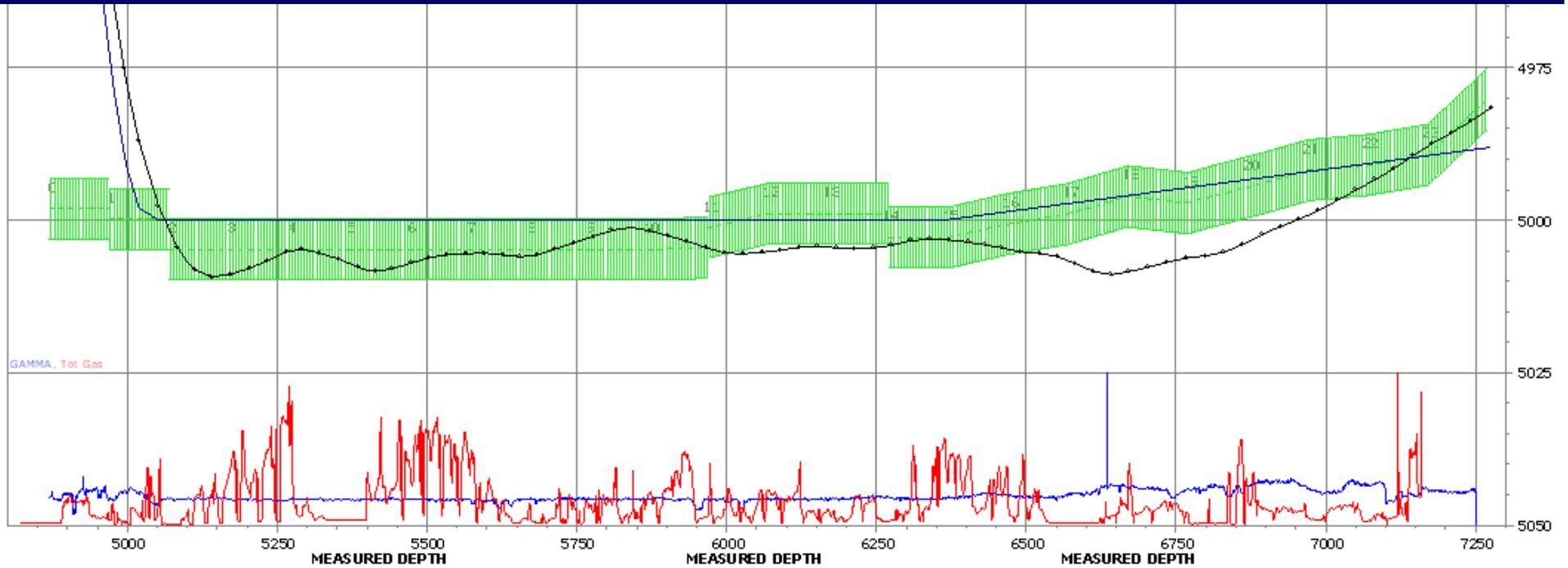
We're low!!  
(eye-balling)



# Same field, several months later...



# Another field -- Gas confirms when in zone



Possum  
belly gate  
open

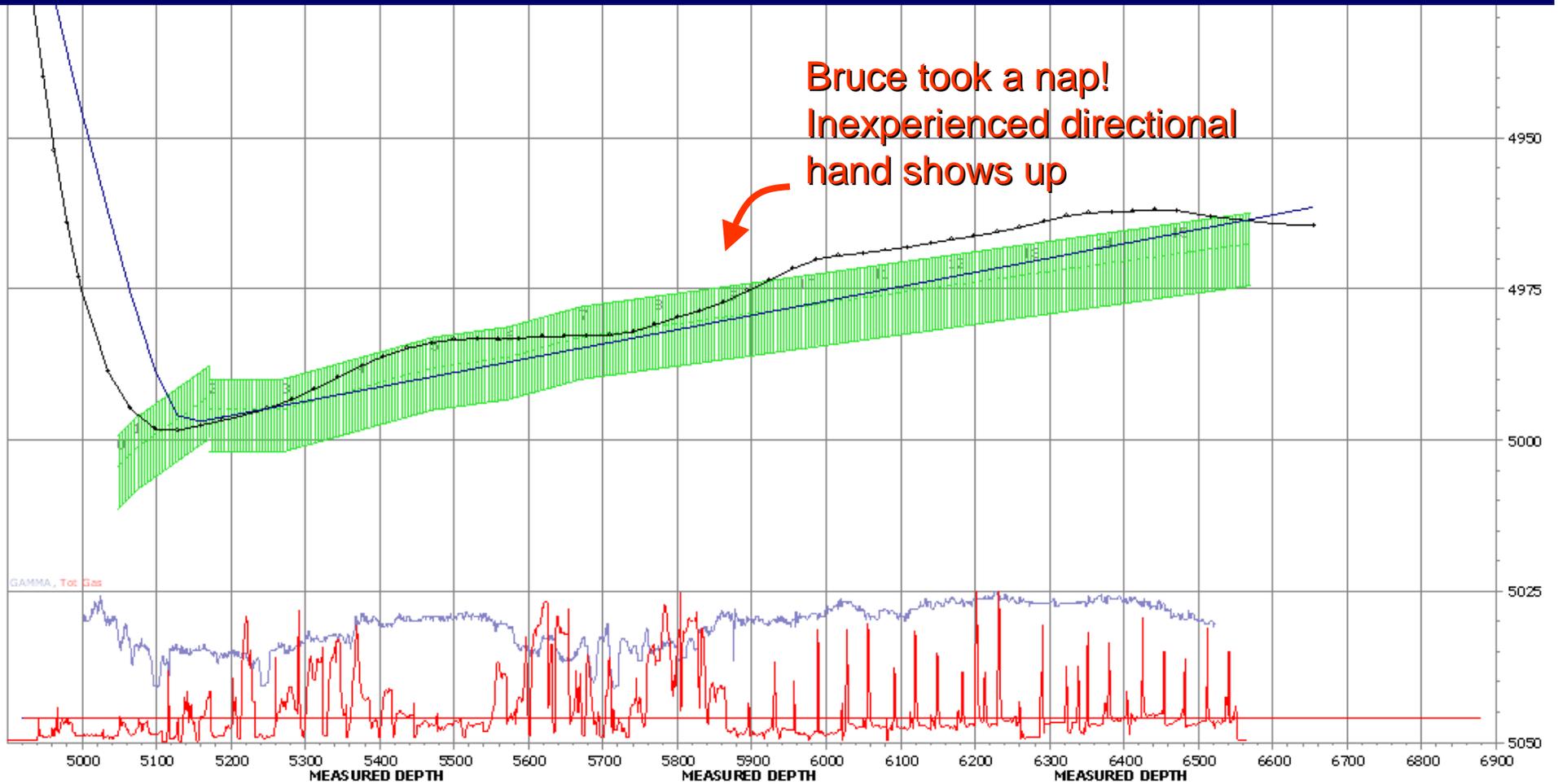


Frozen



Frozen

# Gas confirms when in zone

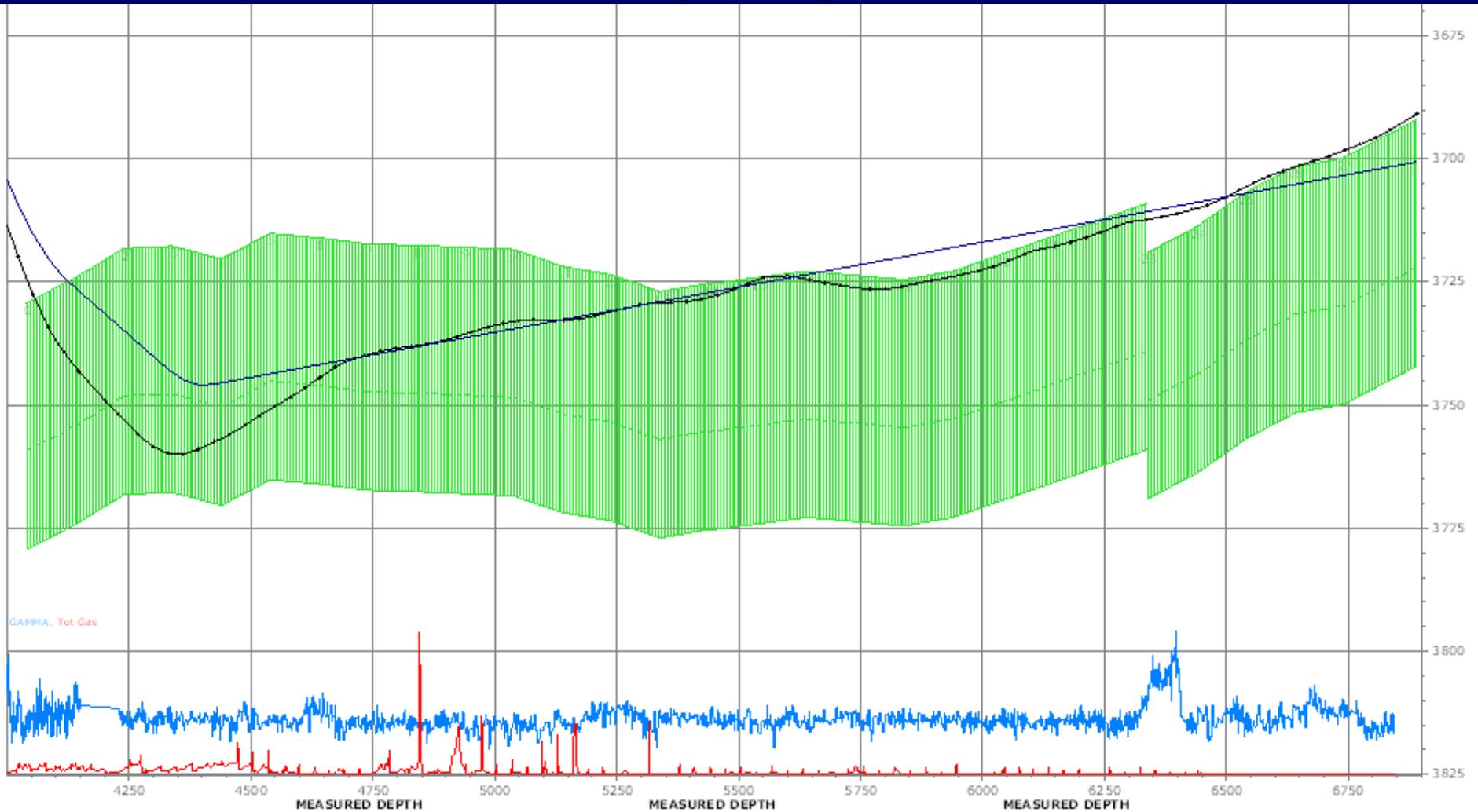


# Recent horizontal drilling program look back

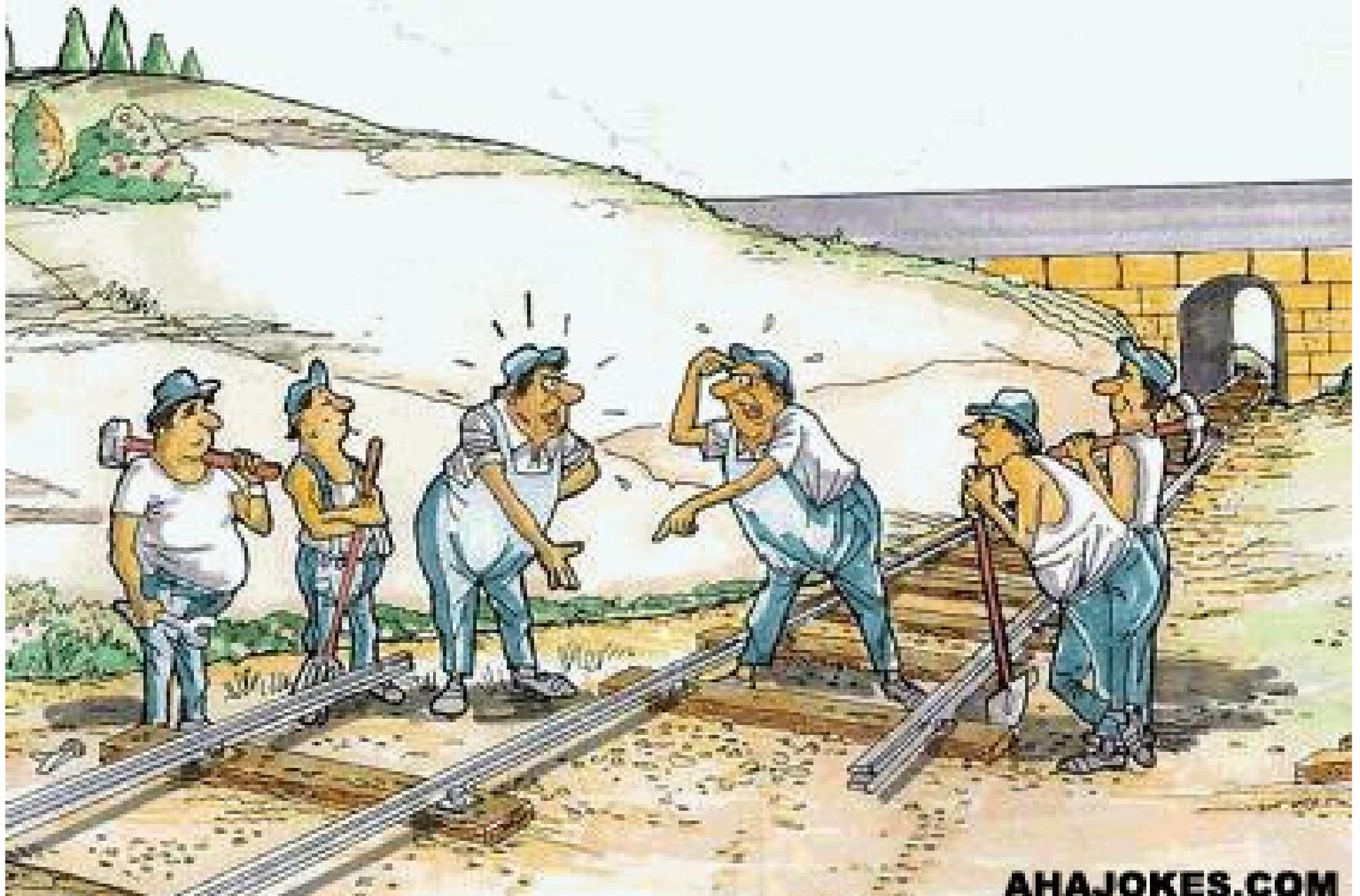
Feet in zone	10 day moving average after frac
825'	43 b/d
1000'	65 b/d
1375'	56 b/d

Photo from Sunburst  
Consulting Report, Robert  
Tilden, 2/3/06

# Yet another field -- Technical geo-steering corroborates wellsite geologist calls



# Team Work



# Acknowledgments

- Co-Author Dr. Mike Stoner  
[www.makinhole.com](http://www.makinhole.com)
- Black Hills Exploration & Production
  - Glen Luebking
  - Amber Buschman

