AUTOMATED GEOSTEERING USING A BAYESIAN NETWORK

HUGH WINKLER, Factor Technology

CLAIMS

- Humans can no longer do accurate geosteering interpretations quickly enough: we have to compute them
- The *only* way to solve the geosteering problem is probabilistically
- The Bayesian network approach is the best way to compute an interpretation and automate geosteering.

FACTOR TECHNOLOGY

CLAIM 1

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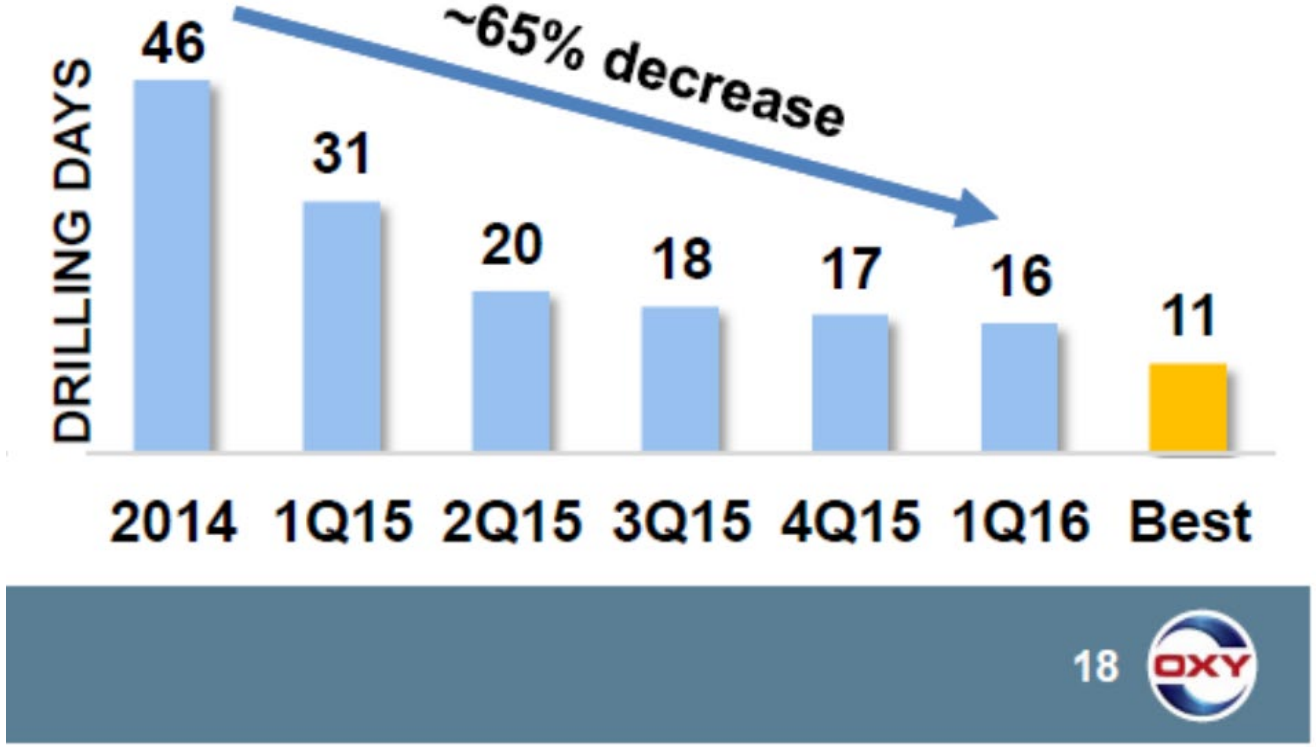
FACTOR TECHNOLOGY

DRILLING SPEEDS HAVE QUADRUPLED SINCE 2014



August 2018:

350 feet per hour

Cyclone Drilling

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GEOSTEERING: A SCIENCE PROJECT EVERY 30 MINUTES

- Used to have 4 hours; now 30 minutes
- Interactively apply judgment
- High Cognitive Load
- Shift Work
- Costly Mistakes
  - Excess Tortuosity
  - Missed Exposure to HC
  - Sidetracks

FACTOR TECHNOLOGY

CLAIM 2

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- The *only* way to solve the geosteering problem is probabilistically

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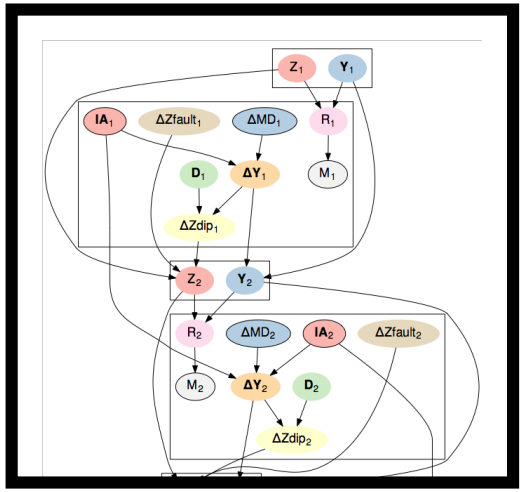
FACTOR TECHNOLOGY

BAYESIAN NETWORKS: A WAY TO AUTOMATE GEOSTEERING

- Modeled it as a Bayesian network
- Leverage 30 years of machine learning development
- Massively parallel GPU computation
- We tell you where the geology (probably) is
- We tell you where the wellbore (probably) is
- Extensible to decision-making



Geosteering by exact inference on a Bayesian network
Winkler (2017) *Geophysics*

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CAN'T WE JUST CORRELATE?

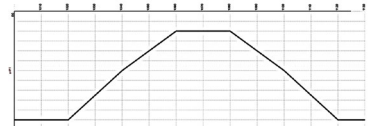
- Interactive software tools help you find structure that maximizes correlation. Can't we just automate *that*?
- No: correlation is least-squares optimization
  - Correct only if all uncertainties are normally distributed
  - Spoiler: they aren't
    - Logs: Inverse mapping of GR -> log depth: multimodal
    - Faults: Change in structure due to faulting : multimodal or power law
    - Angles: Mapping of normally distributed uncertainty in angular measurements to rectilinear: weird

FACTOR TECHNOLOGY

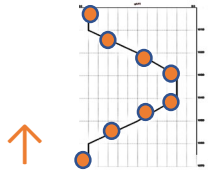
CORRELATION (ALONE) NOT UNIQUE

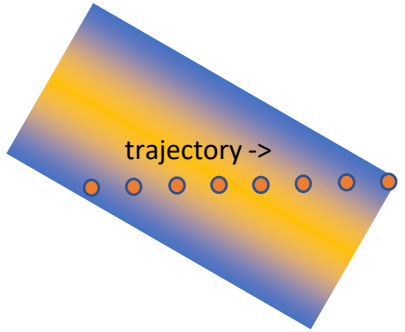
Both of these interpretations explain the LWD equally well

LWD GR



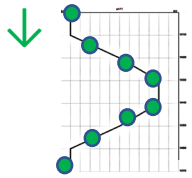
Type log





Interpretation 1:
Dip down 30°

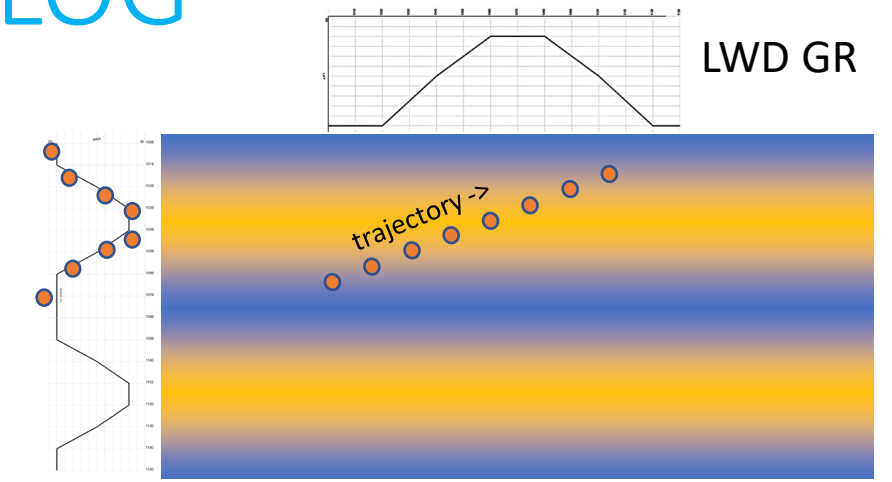
Type log

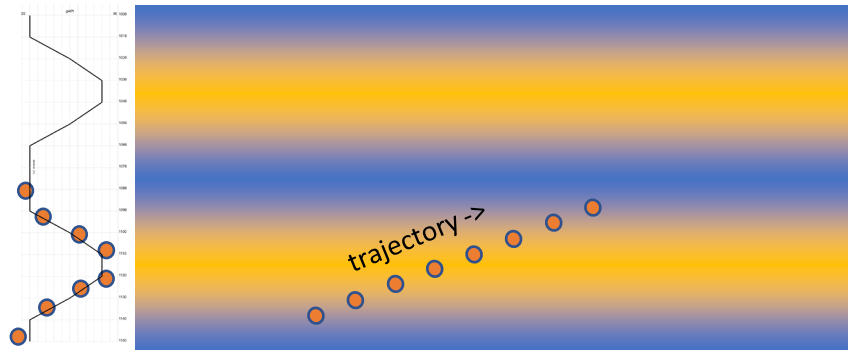


Interpretation 2:
Dip up 30°

CORRELATION (ALONE) DOES NOT RESOLVE AMBIGUOUS TYPE LOG

Both of these interpretations explain the LWD equally well



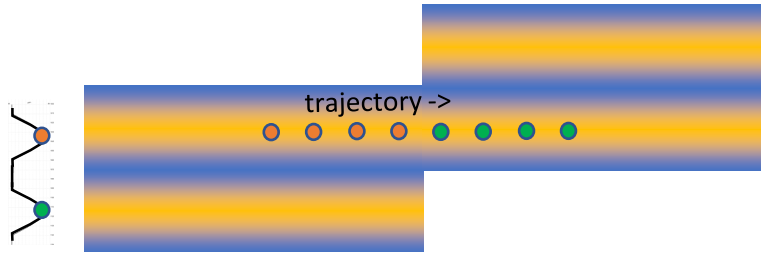


FACTOR TECHNOLOGY

CORRELATION (ALONE) DOES NOT RESOLVE AMBIGUOUS FAULT

Both of these interpretations explain the LWD equally well

LWD GR = constant



Interpretation 1: Fault

Interpretation 2: No fault

HEURISTICS: THE EXTRA INGREDIENT

Geologists usually aren't fooled by correlation pitfalls

They apply heuristics, and override the maximum correlation coefficient

- The dip can only be in some reasonable range for this region
- Faults occur with some regional frequency and throw
- Drill pipe can only bend so much
- Noise in log, depth, and survey measurements allow wiggle room to adjust geologic structure and wellbore position

We model those heuristics as probabilities

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THE GEOSTEERING PROBLEM

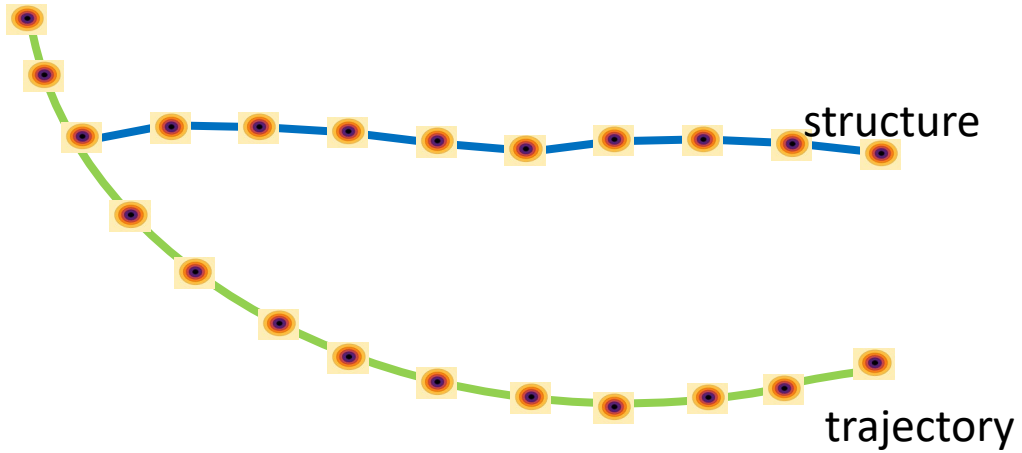
Given

- …That stratigraphy varies laterally by dipping and faulting
- Priors:
  - Type logs (estimate of stratigraphy)
  - Estimate of structure
  - Estimate of fault frequency and throw
- Measurements
  - Along-hole depth
  - Surveys
  - While-drilling log
- Uncertainties for all priors and measurements (i.e. probabilities)

Calculate Posteriors

Geologic structure

True wellbore trajectory



In Bayesian terminology: we'll apply the measurements to update our prior beliefs

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PROBABILITY OF DEPTH GIVEN GAMMA RAY

Consider one point along wellbore

Given a GR reading:

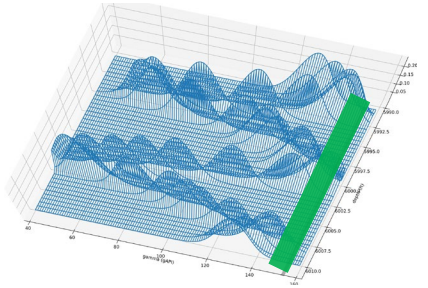
- What is the probability the tool investigated any particular depth? (Remember the GR reading has uncertainty)

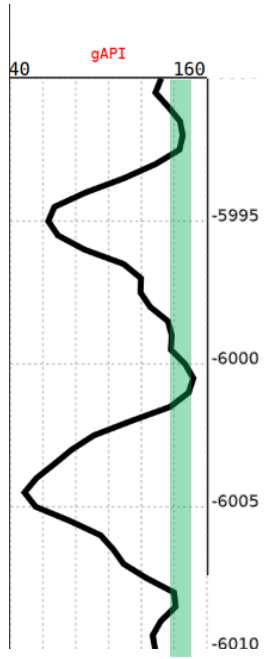
Well logs map:

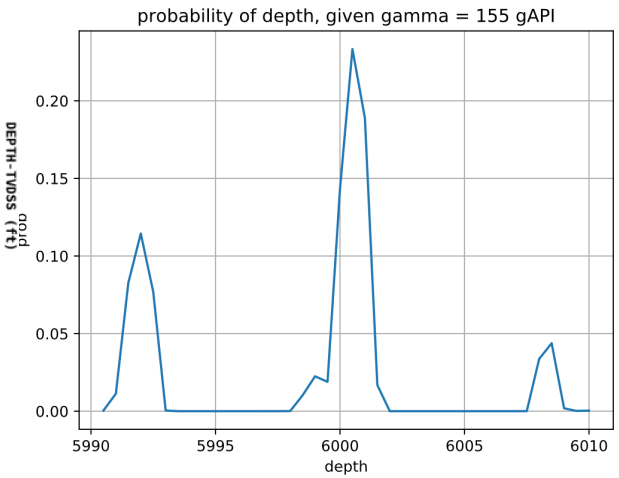
- depth -> GR
- GR -> depth ambiguously

Model as probability

- P(depth | GR)







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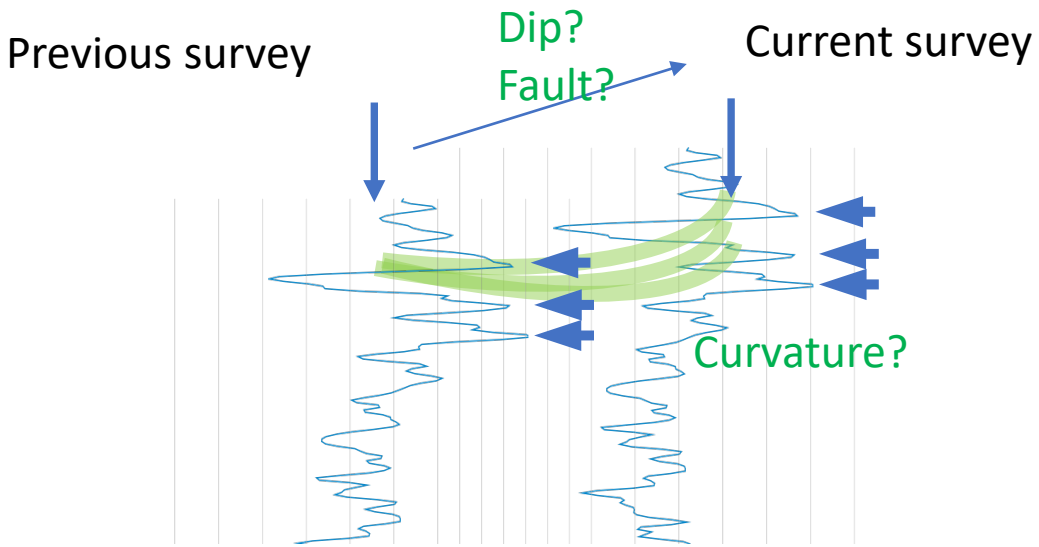
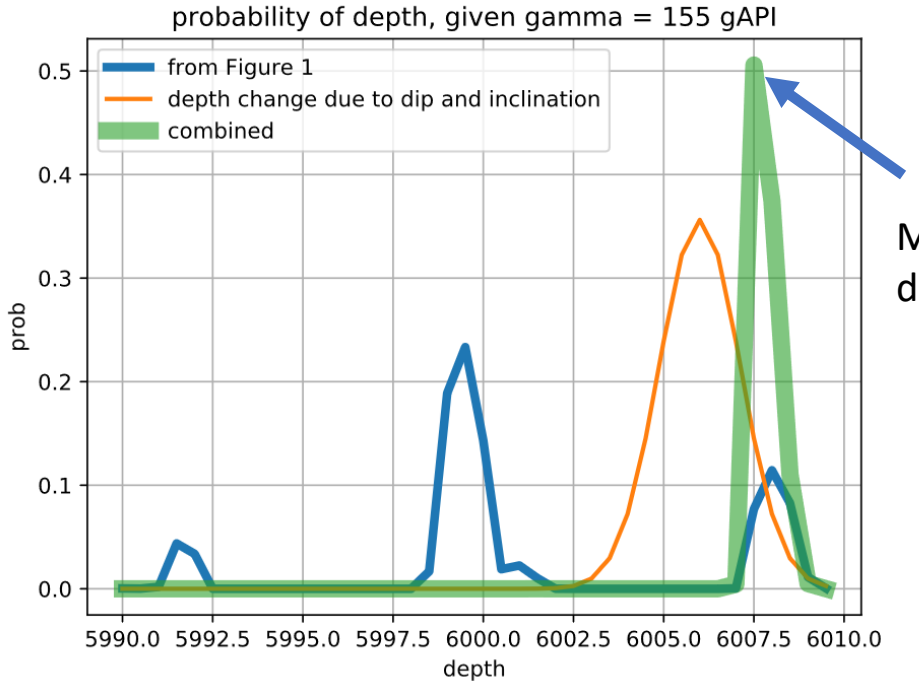
BUT WE HAVE MORE INFORMATION…

- If you had some idea where you were at the *previous* survey location, then
  - What are the chances the earth dipped up or down? How much?
  - What are the chances you crossed a fault? How large?
  - The two surveys define a minimum curvature position estimate. How much might it be off?
  - These are all also probability functions (i.e. random variables)
  - "Wiggle room"
- When you account for the influence of these other factors, modify your probability ("update your priors")





Most likely depth 6007.5'

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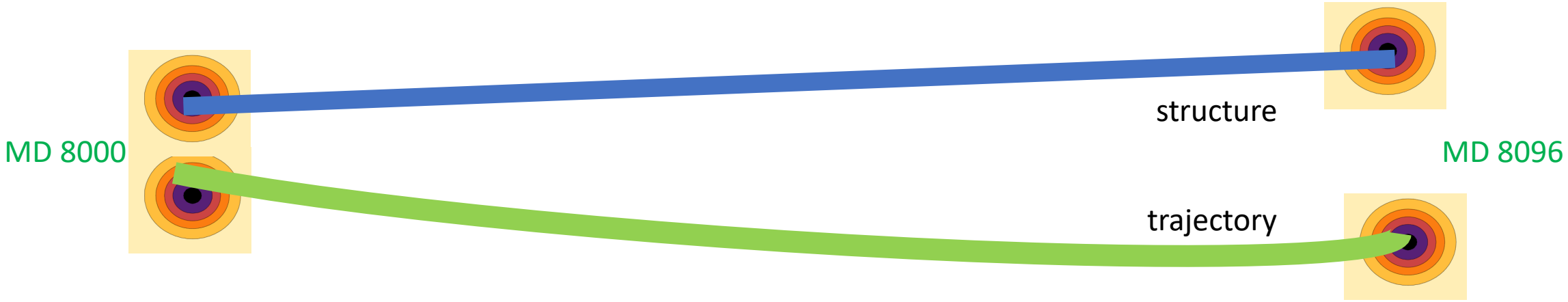
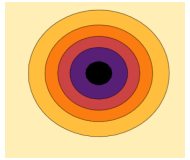
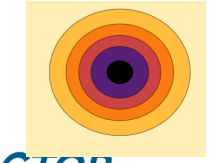
MUTUAL INFLUENCE ACROSS NEIGHBORS



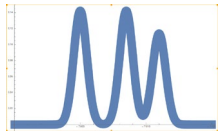
Probability for the structure position at previous location



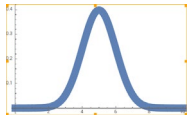
Probability for the wellbore position at previous location



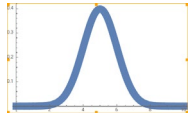
Probability the tool investigated a log depth



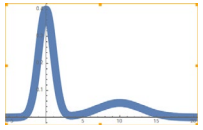
Probability the wellbore trajectory differed from the minimum curvature



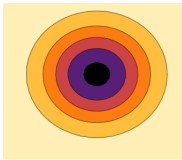
Probability the earth dipped up or down



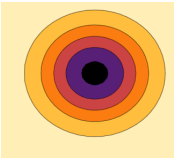
Probability the earth faulted up or down



Probability for the structure position at current location

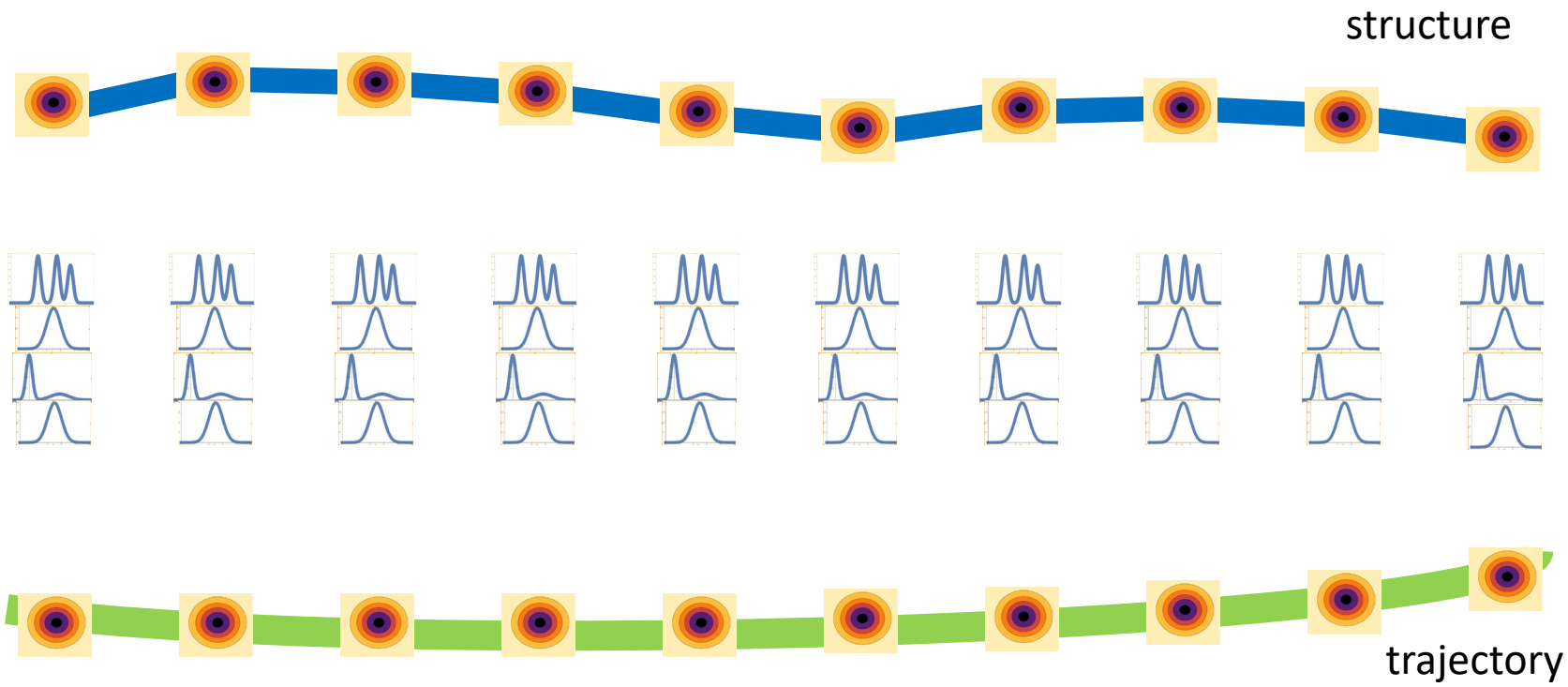


Probability for the wellbore position at current location



“THE ANSWER”

…is the joint probability over **all** these random variables across the whole well



This answer is a function over thousands of dimensions

FACTOR TECHNOLOGY

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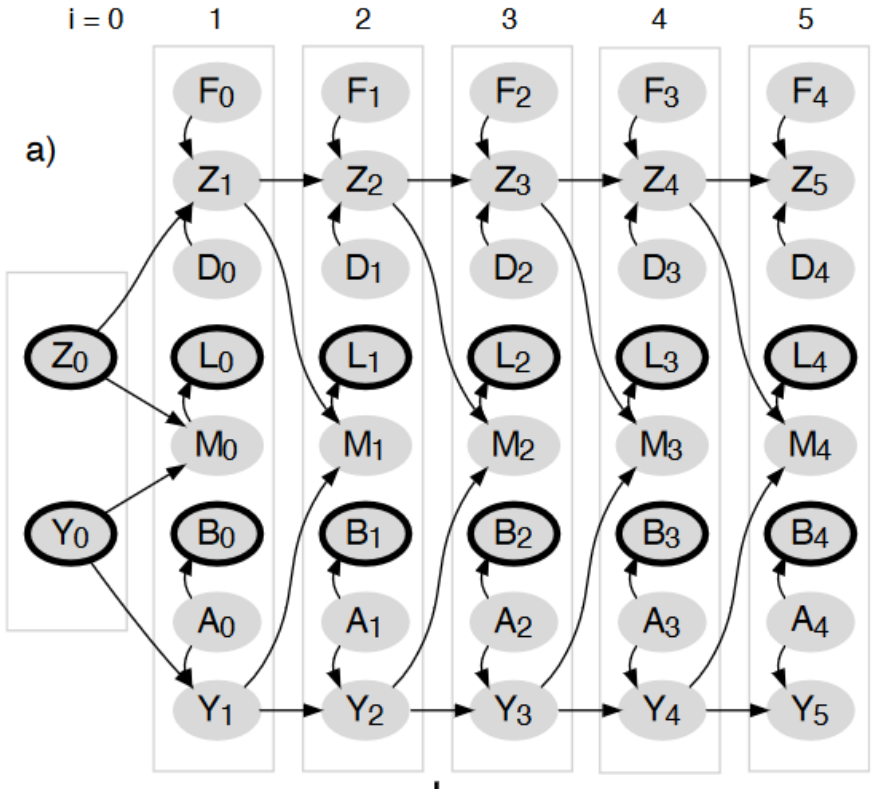
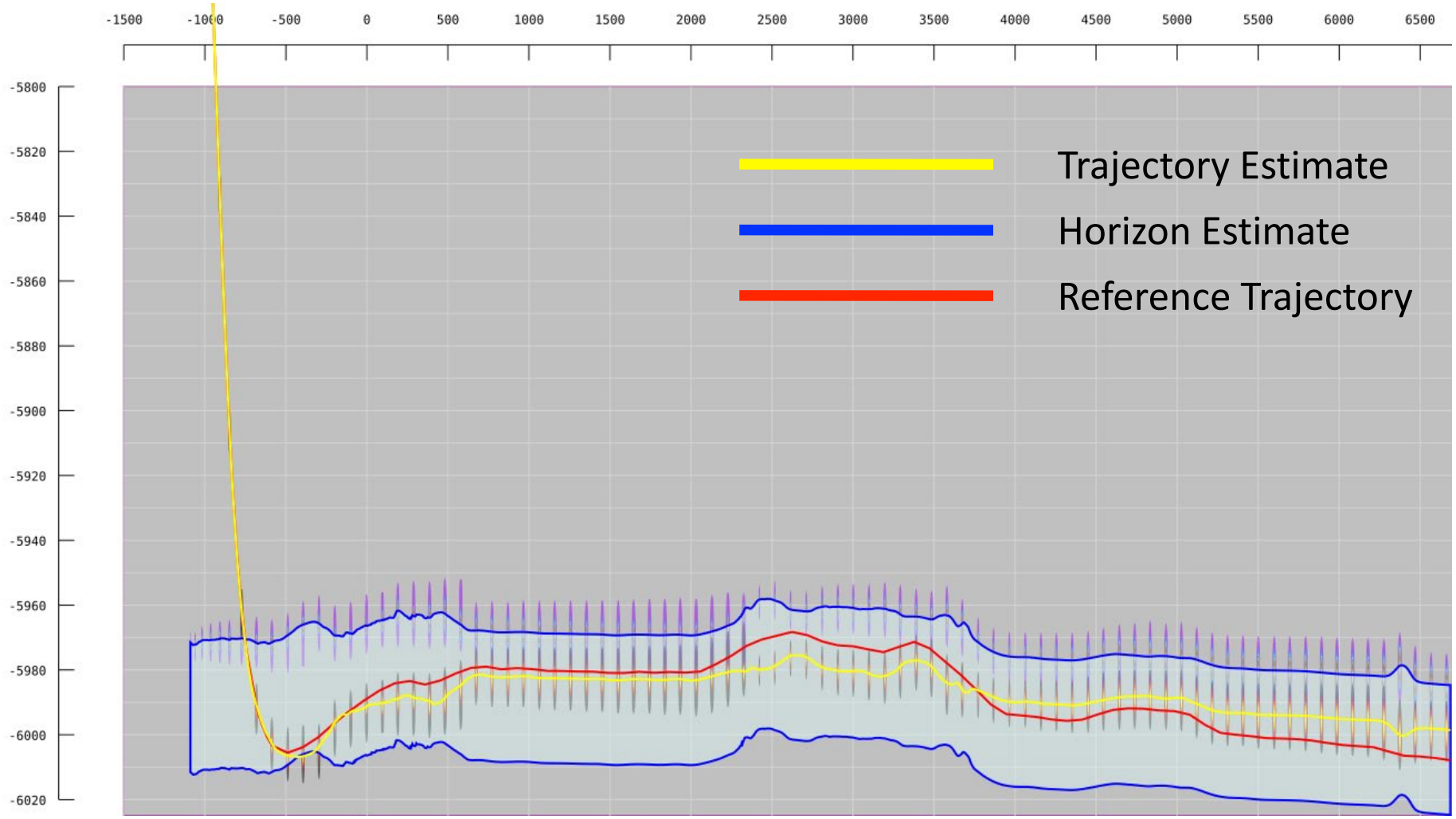
FACTOR TECHNOLOGY

BAYESIAN NETWORK CALCULATES JOINT PROBABILITY

- Naïvely, the joint is the product of all the individual probability functions
  - Would require more bytes of memory than there are atoms in the universe (10^80)
- BN recognizes the conditional relations among the thousands of variables
  - Collapses the problem to a tractable size



COMPUTED INTERPRETATION



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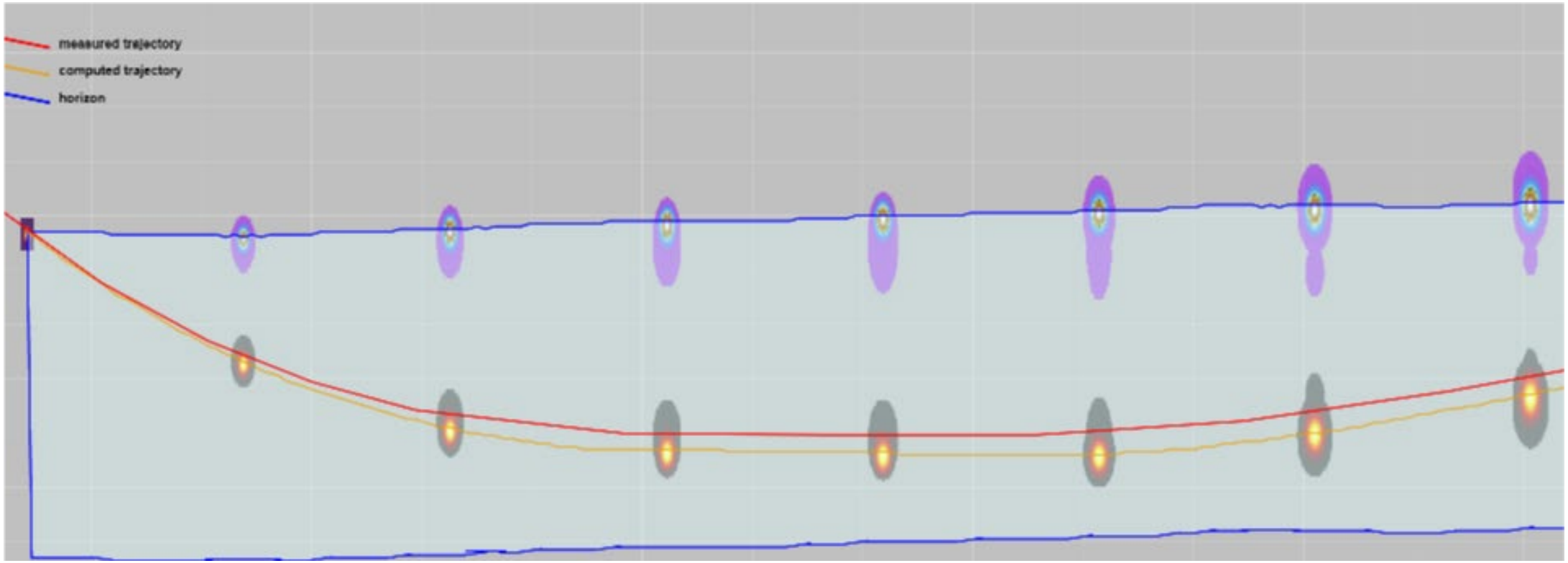
“ELLIPSES” OF UNCERTAINTY



(different well than previous/next)

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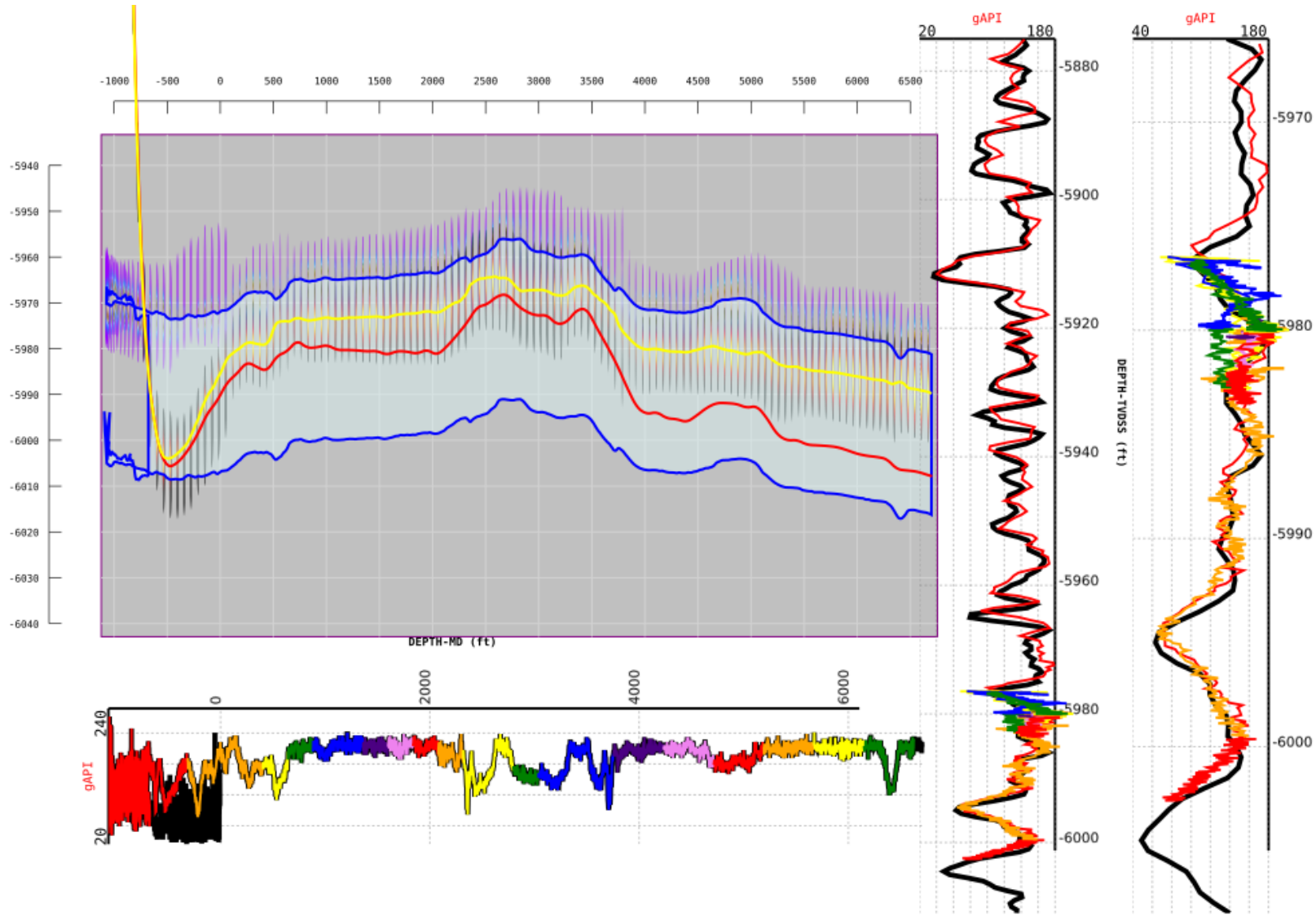
RETROSPECTIVE RESULTS



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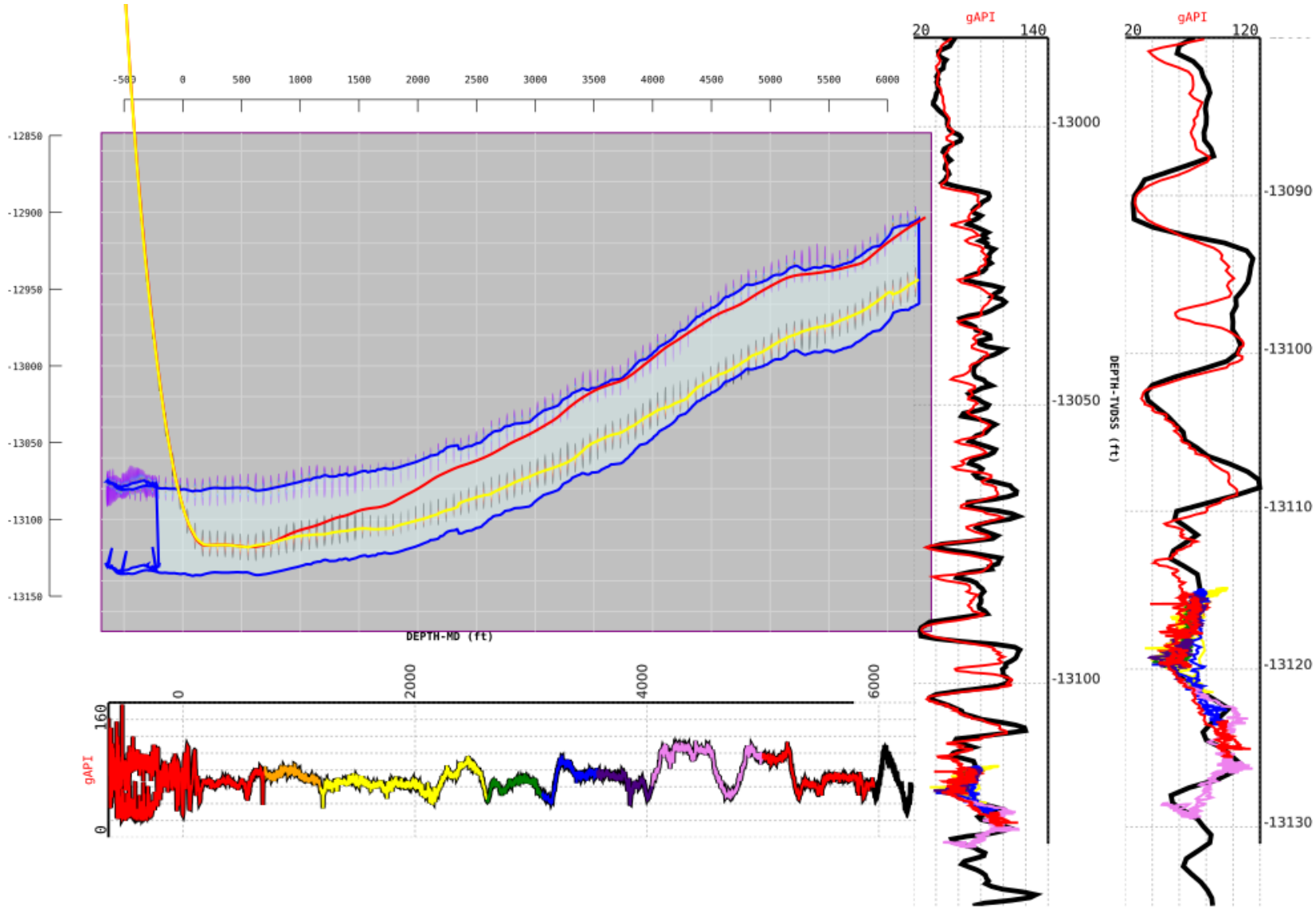

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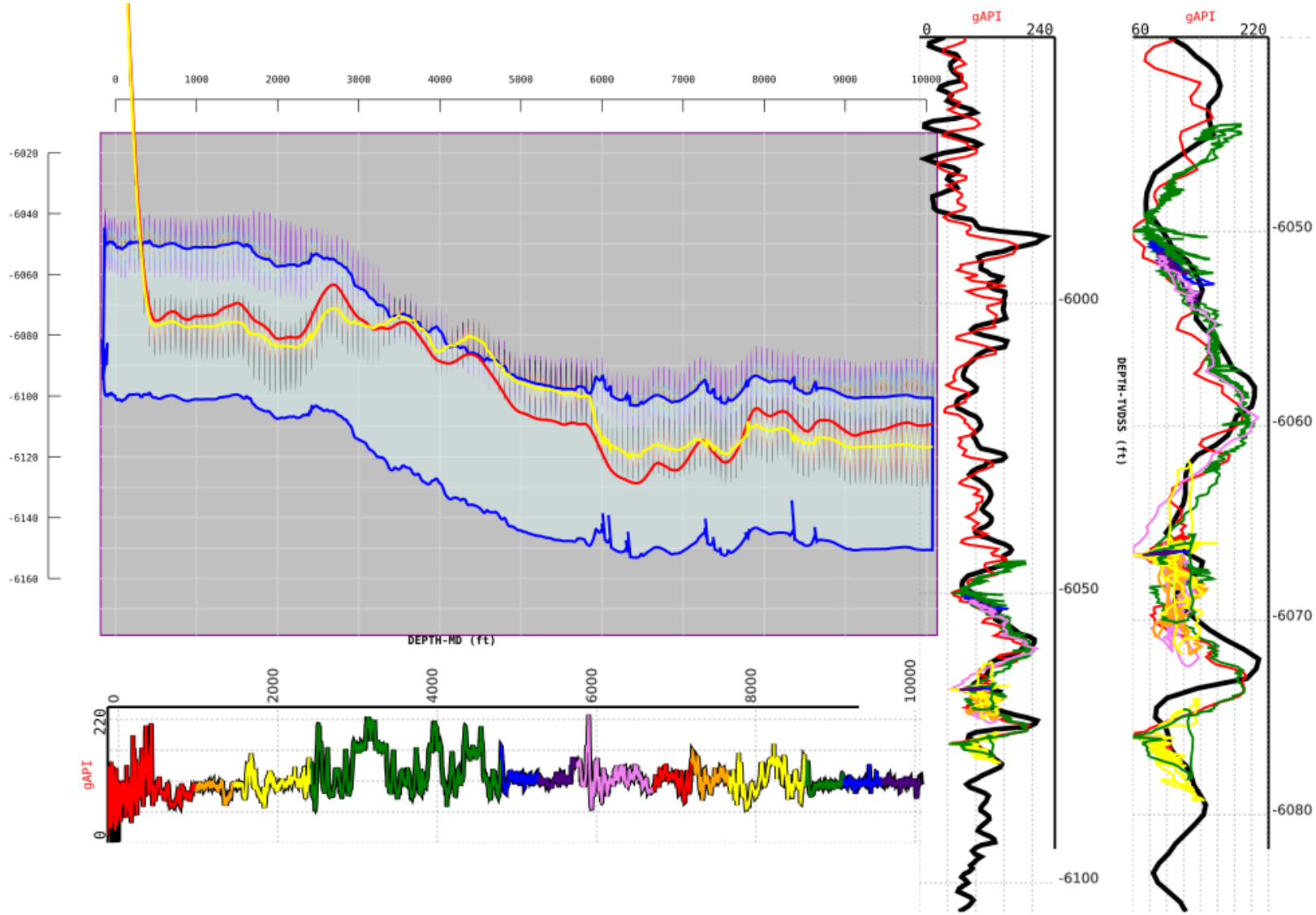

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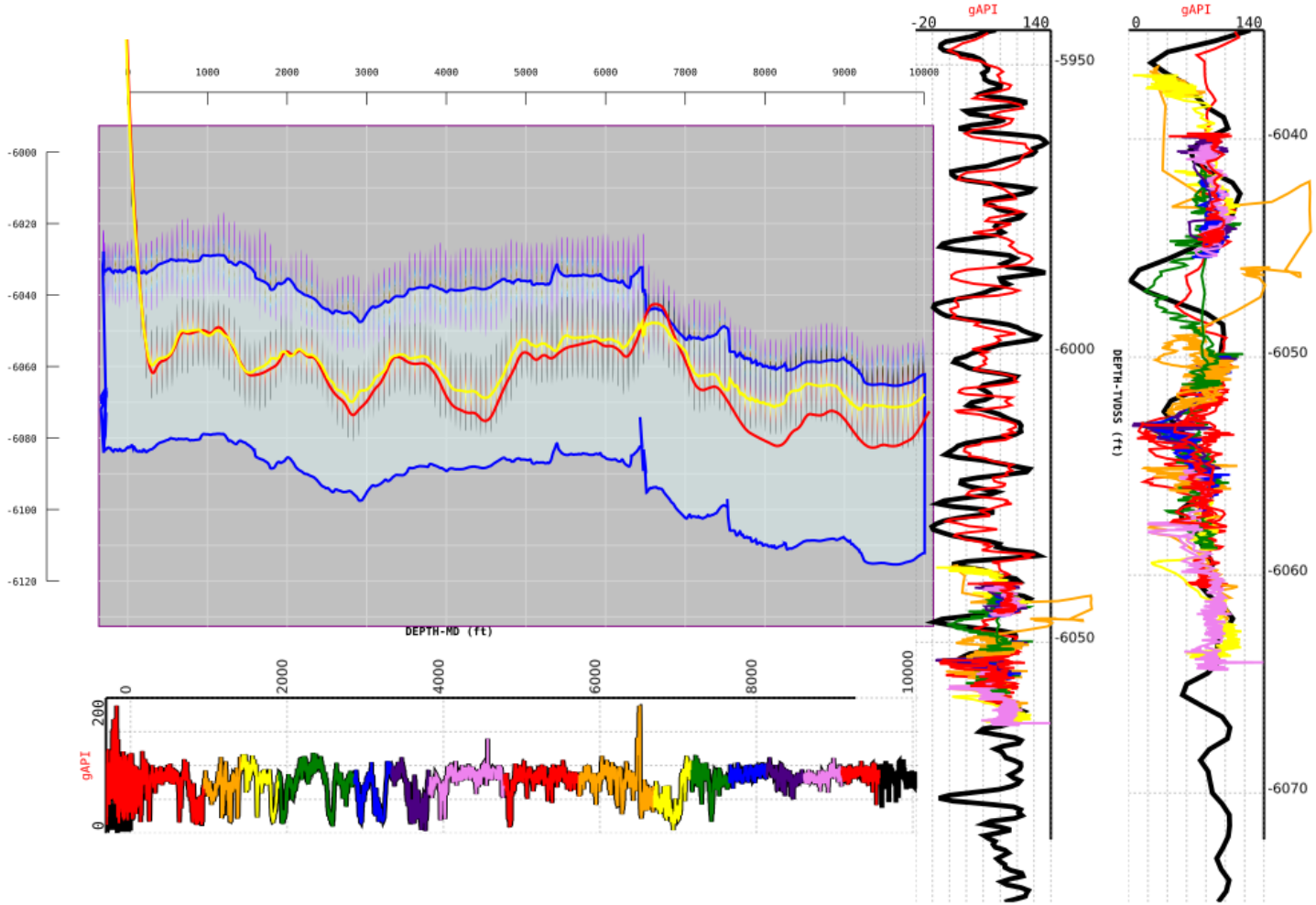
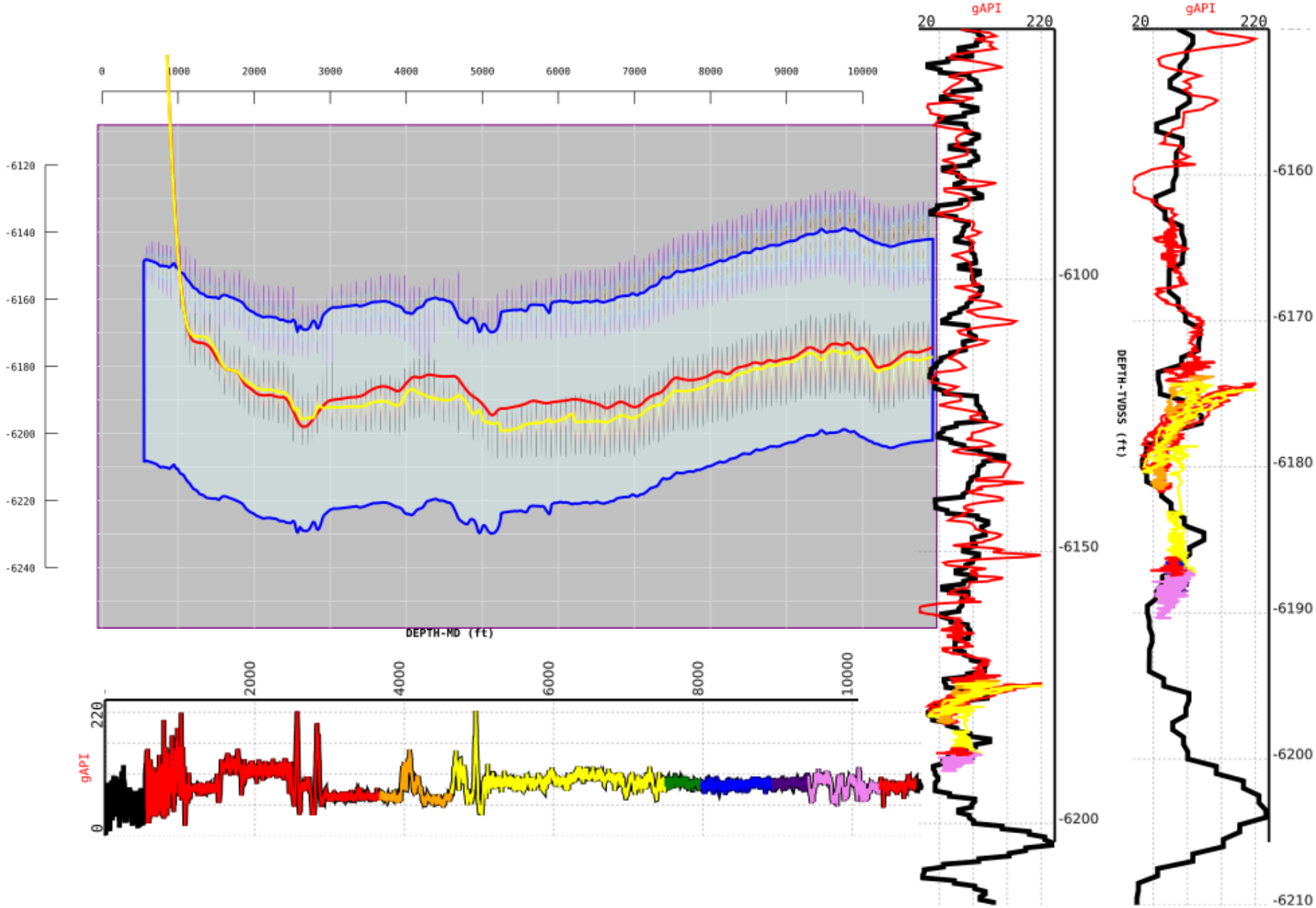
DETECT SUBSEISMIC FAULTS





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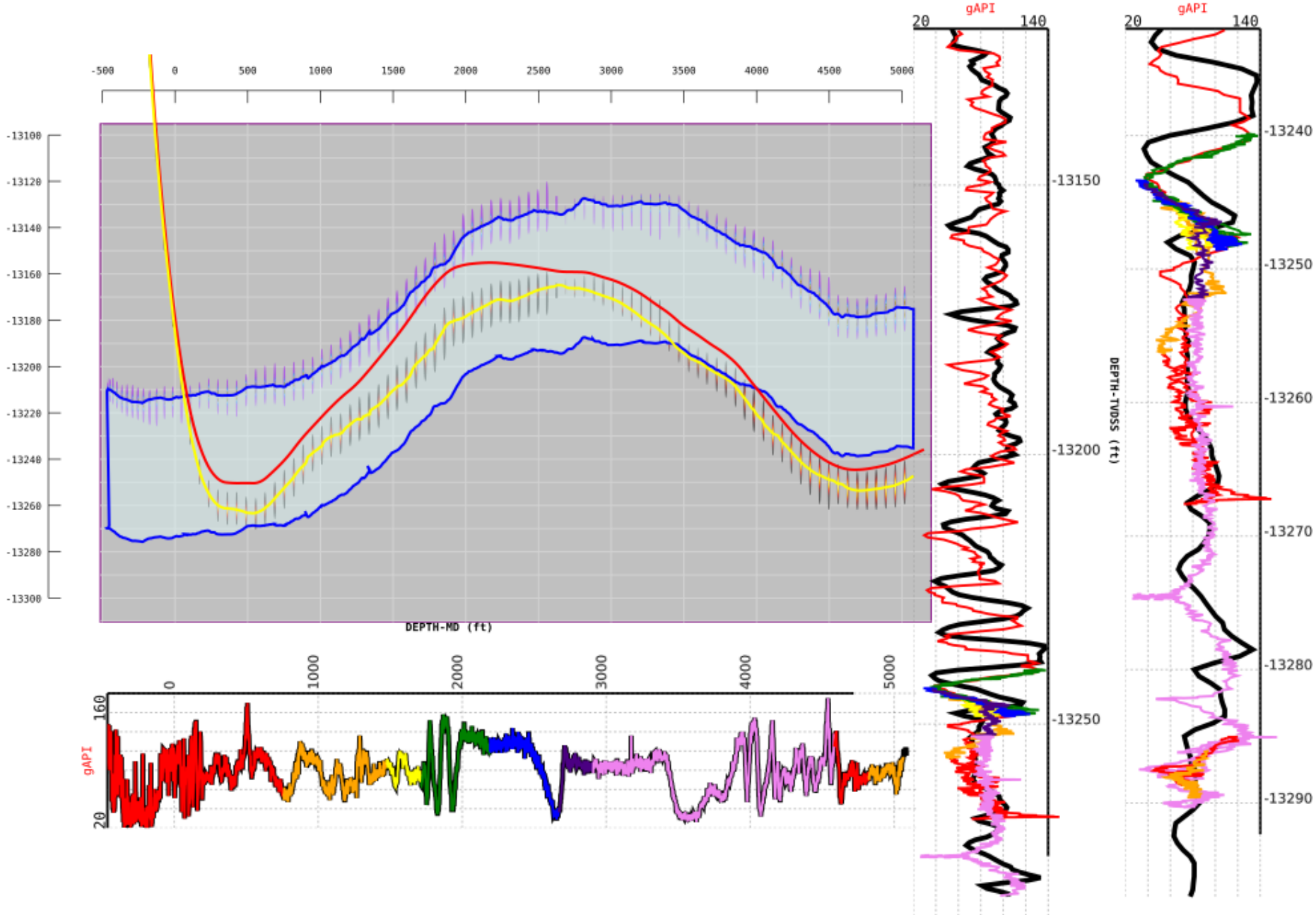

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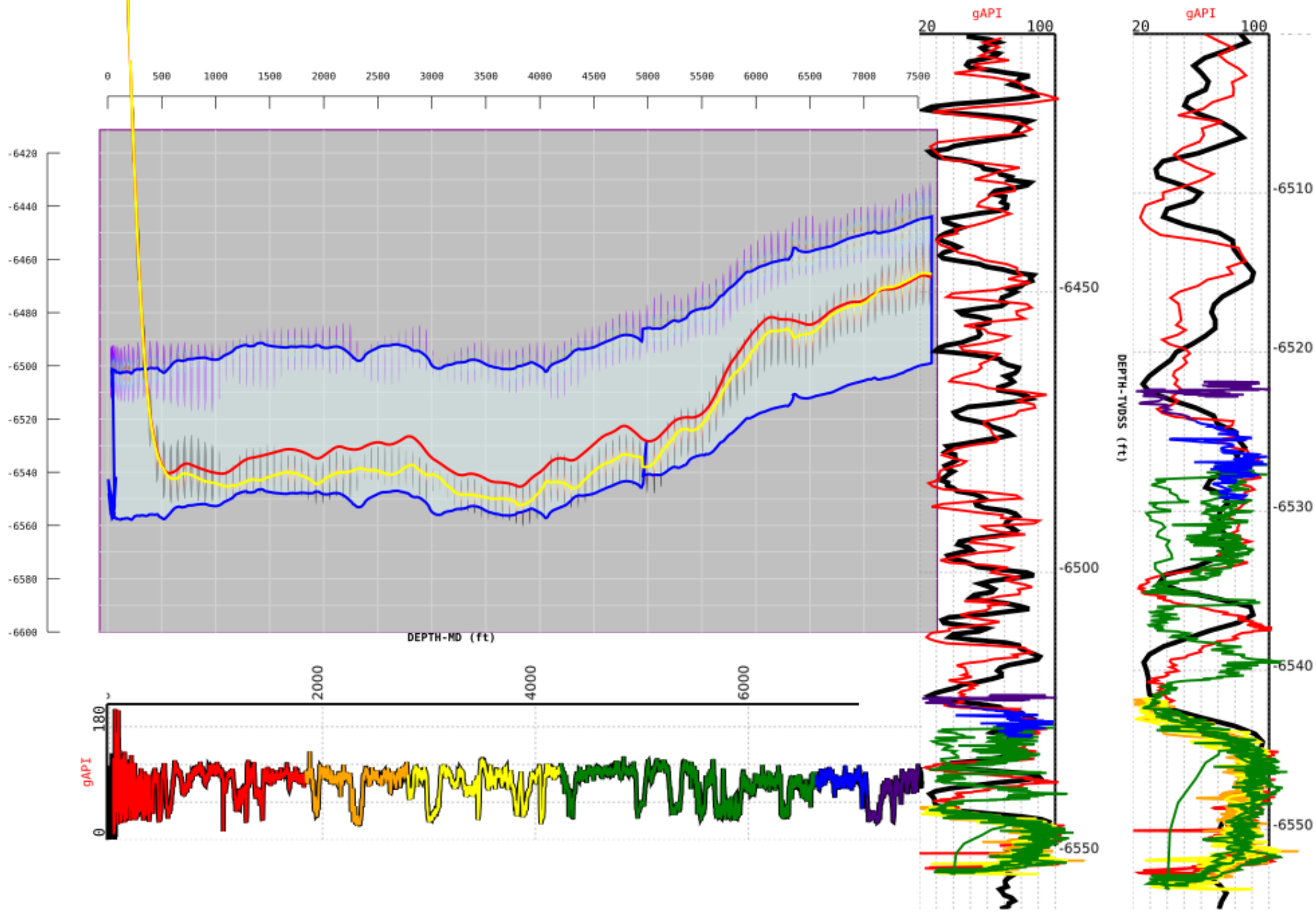

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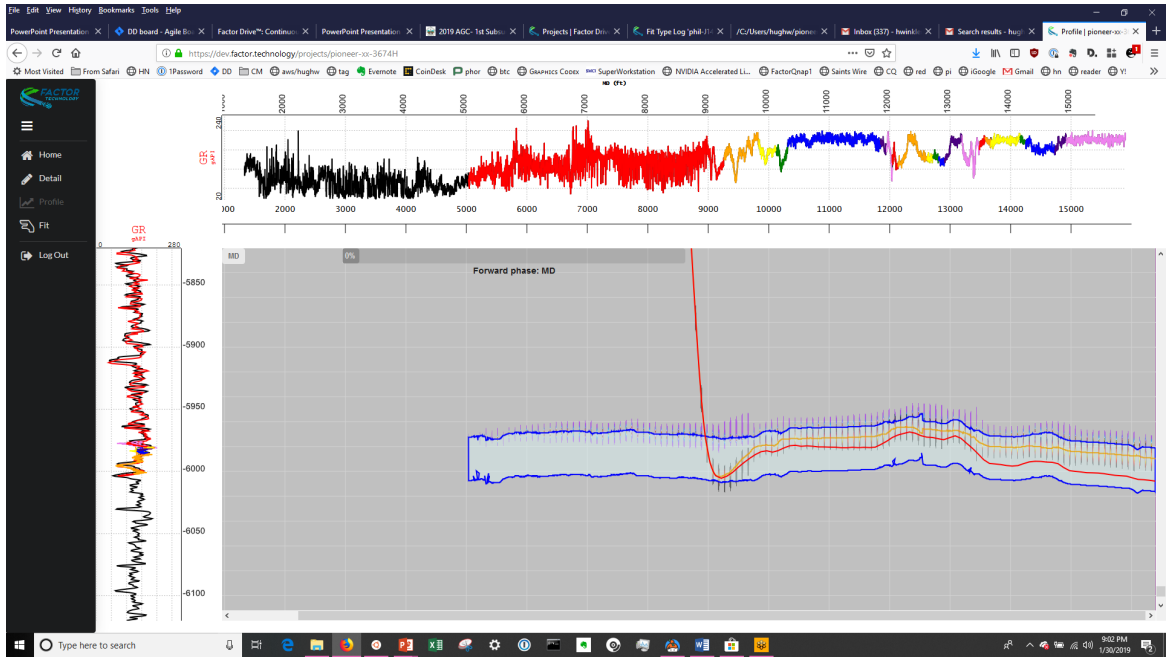
MASSIVELY PARALLEL COMPUTATION

- BN still requires a massively parallel computation on NVIDIA GPU
- ~5000 multiprocessors
- 60 GB -> 2TB RAM
- Results at bit depth in a minute
- Recompute 8000’ lateral in an hour

FACTOR TECHNOLOGY

HOW YOU USE IT: REAL TIME

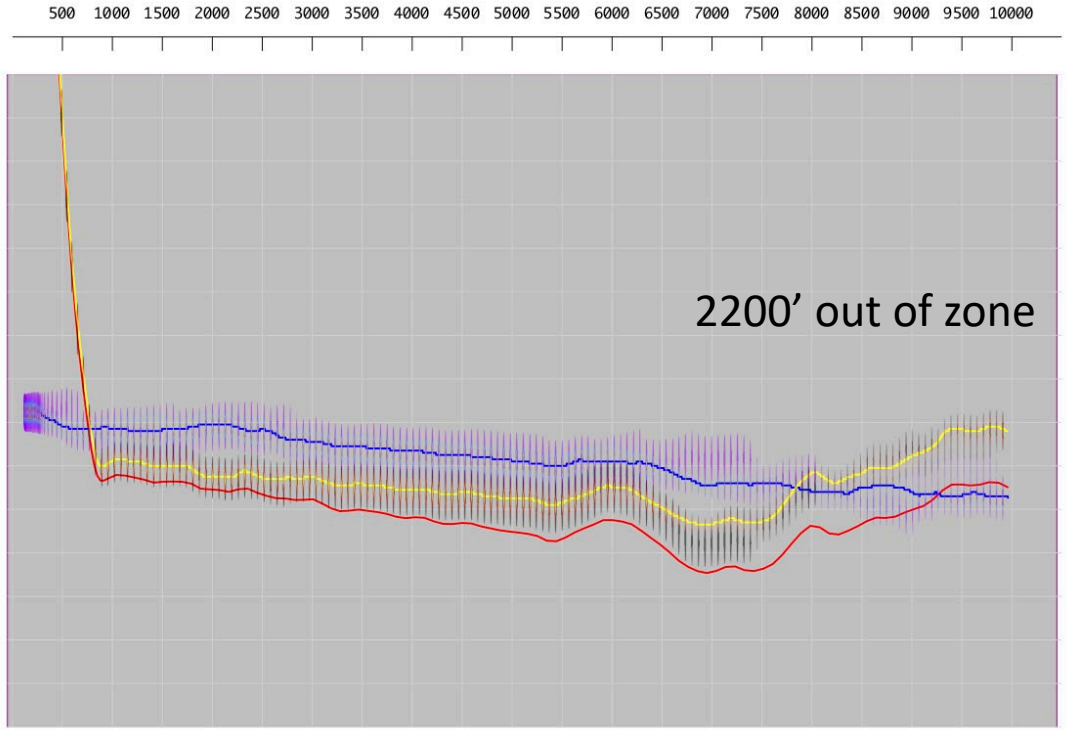
- Enter pre-job parameters, then sit back and watch while they drill the lateral
- Result: an always up to date computed interpretation.



FACTOR TECHNOLOGY

HOW YOU USE IT: RETROSPECTIVELY

- Field or regional studies: bulk resteer old wells
- Collaboration between customer and Factor
- Objectives:
  - Update maps
- Idea: report P10/50/90 feet in/feet out of zone



FACTOR TECHNOLOGY

AUTOMATION EMPOWERS GEOLOGISTS TO DO GEOLOGY AGAIN

- Companies need not “staff up” to handle increased activity
  - Fewer entry level geologists to train, manage, and trust with ops
  - Fewer personnel to let go in a downturn
- Geologists once again “own” their wells
  - No shift work just to manually work interpretation tools
- Development geologists focus attention on extracting oil and gas
- Manage operations by exception with the core team

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