LEADING A RESPONSIBLE ENERGY FUTURE™

GEOSTEERING 101

PPDM DATA MANAGEMENT SYMPOSIUM

HOUSTON, TX

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MARCH 26, 2014

OUTLINE

- Horizontal well drilling
- Deviated well terminology
- Directional wellbores
- Wellbore surveying
- Targeting
- Geosteering

HORIZONTAL WELL DRILLING

Going Horizontal:

Steps in Horizontal Drilling

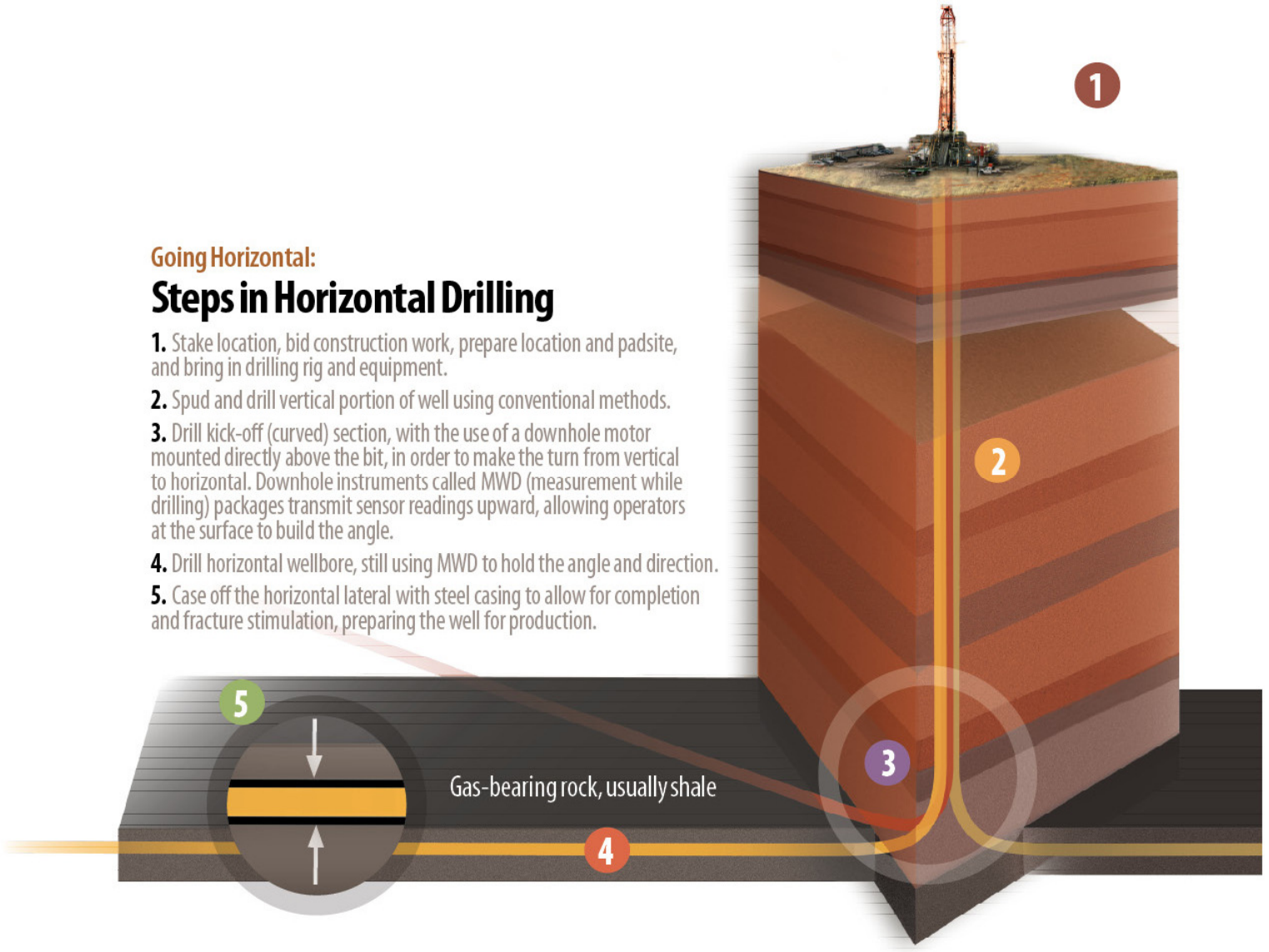
1. Stake location, bid construction work, prepare location and padsite, and bring in drilling rig and equipment.

2. Spud and drill vertical portion of well using conventional methods.

3. Drill kick-off (curved) section, with the use of a downhole motor mounted directly above the bit, in order to make the turn from vertical to horizontal. Downhole instruments called MWD (measurement while drilling) packages transmit sensor readings upward, allowing operators at the surface to build the angle.

4. Drill horizontal wellbore, still using MWD to hold the angle and direction.

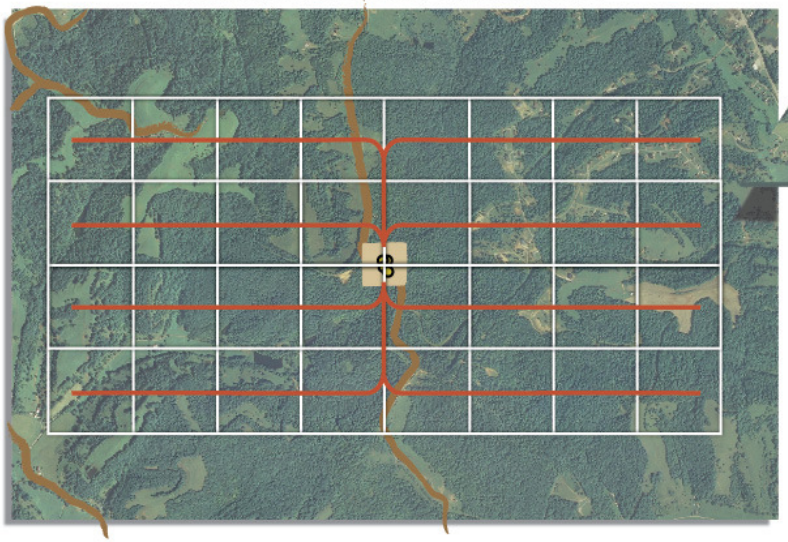
5. Case off the horizontal lateral with steel casing to allow for completion and fracture stimulation, preparing the well for production.

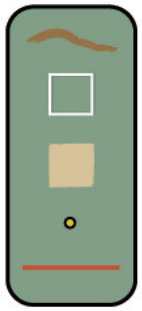


HORIZONTAL WELL DRILLING

Area shown is 1,280 acres

Idealized Horizontal Well Spacing





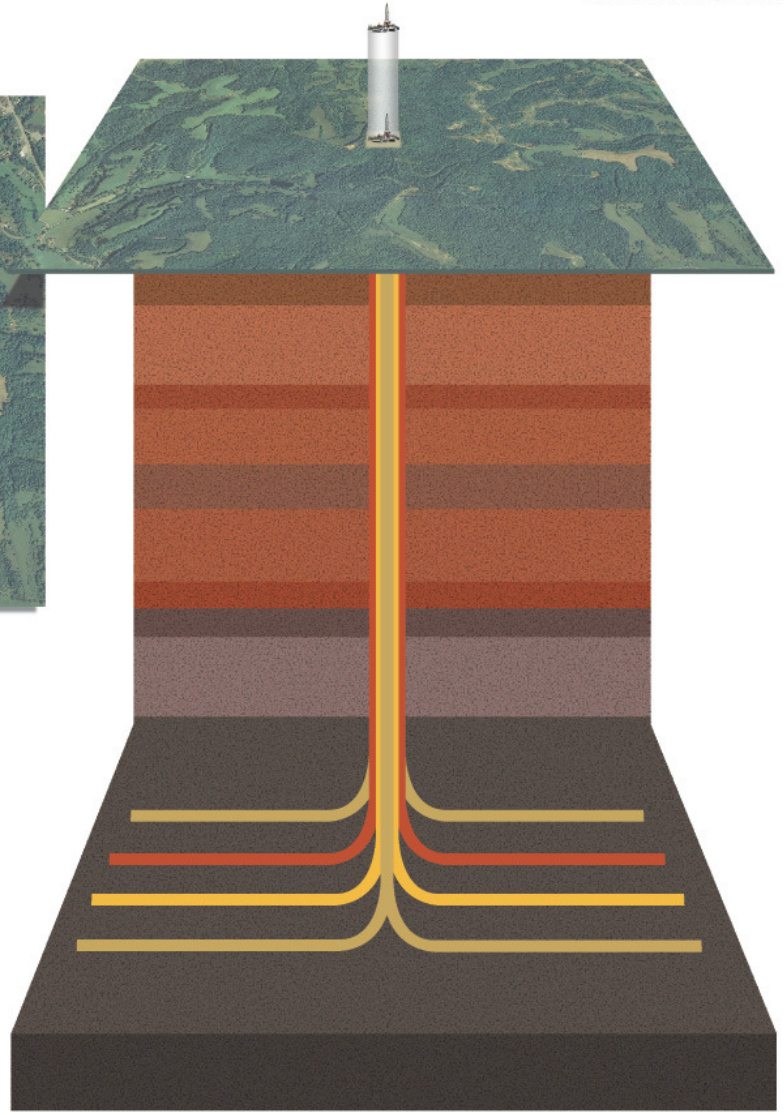
Existing Road

40 Acre Grid

Padsite

Gas Wells

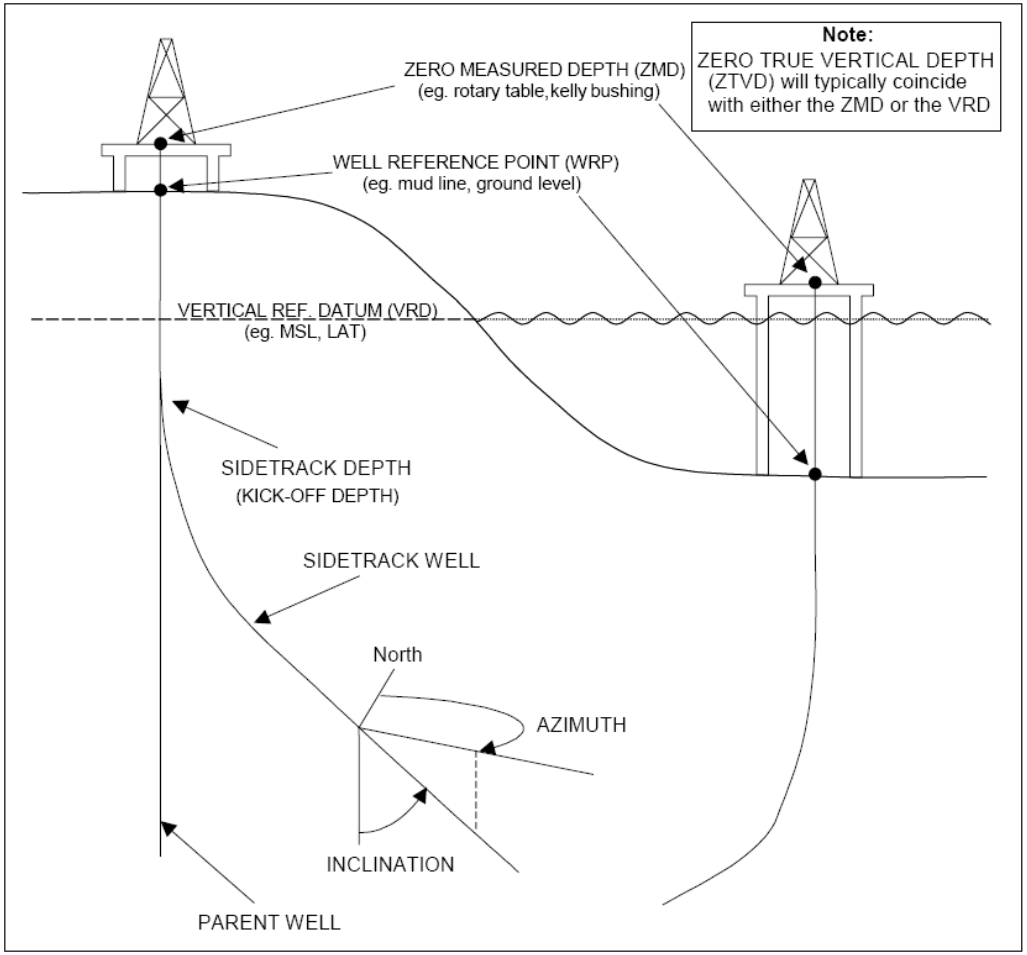
Wellbore



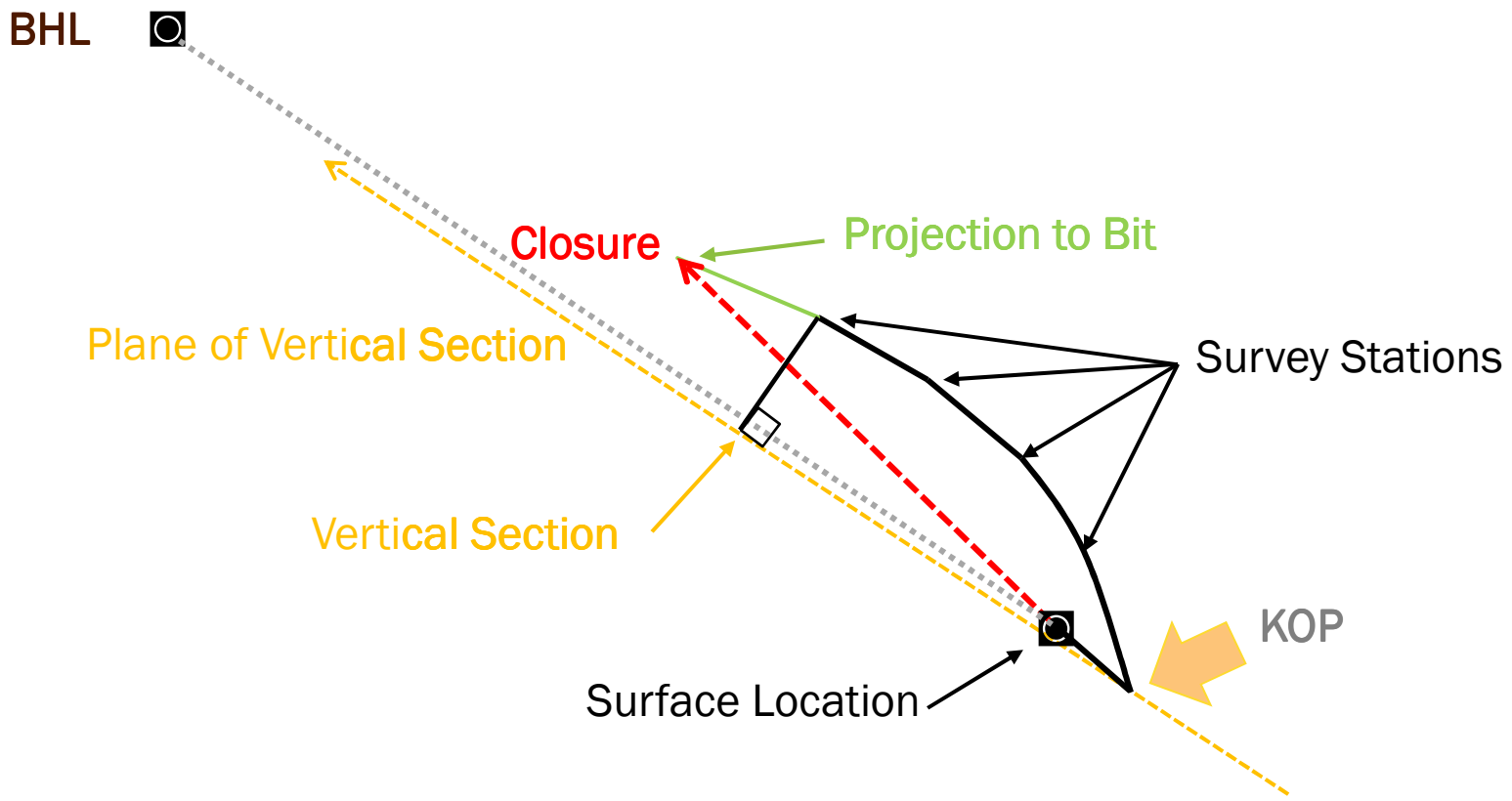
Well spacing can vary due to a number of factors including state regulatory requirements, location and formation characteristics.

DEVIATED WELL TERMINOLOGY

Depth datum

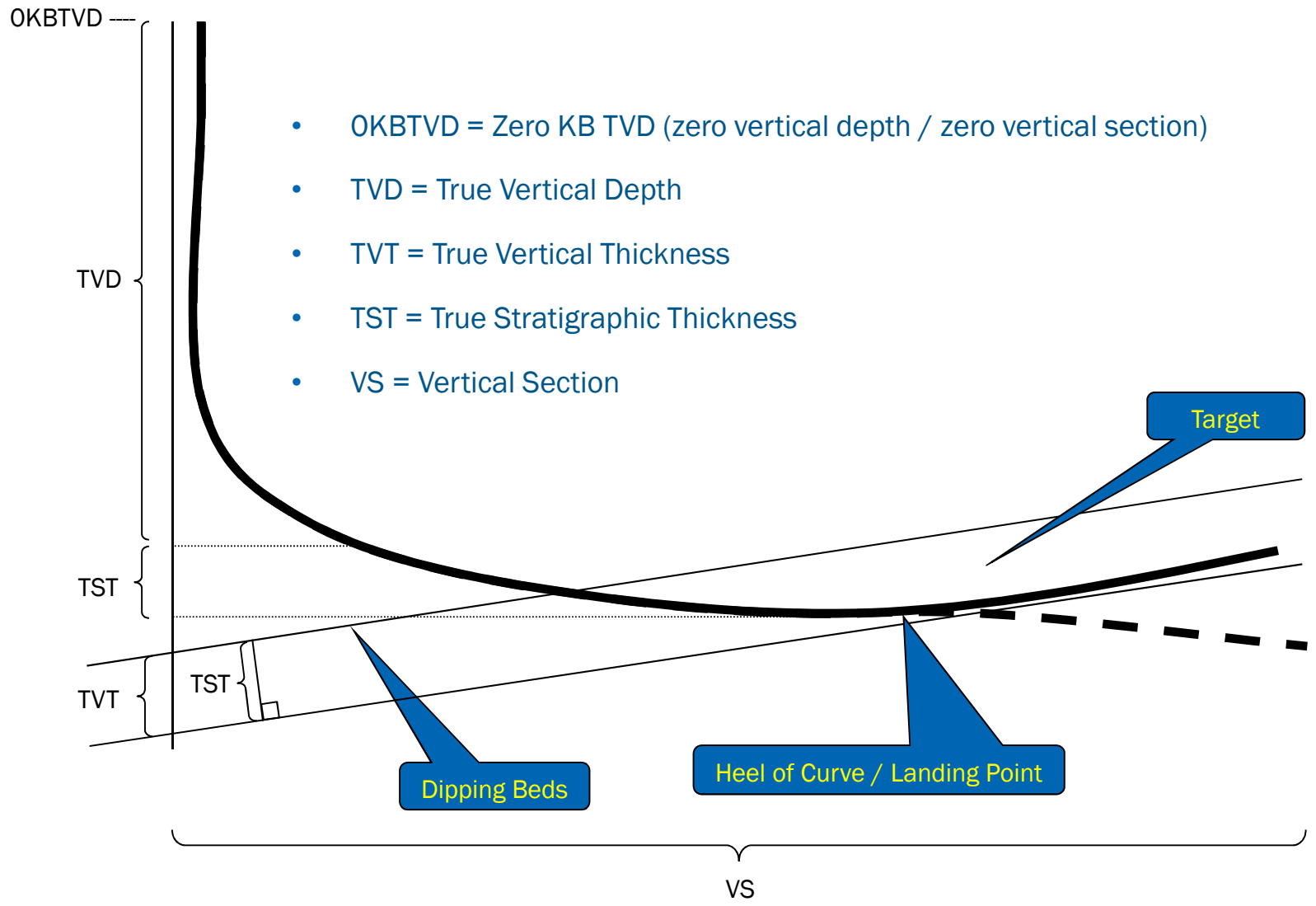


DEVIATED WELL TERMINOLOGY

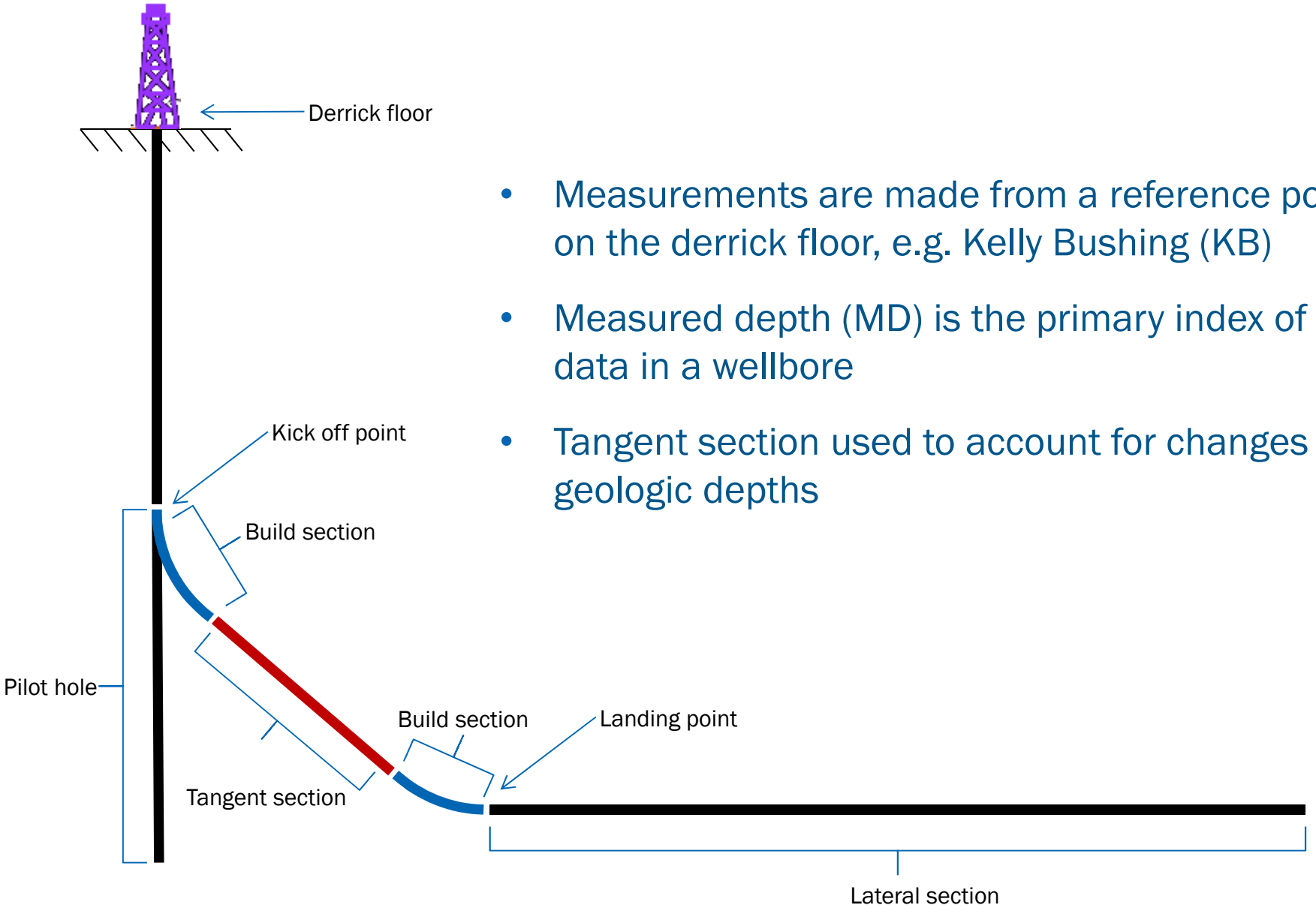


DEVIATED WELL TERMINOLOGY

- 0KBTVD = Zero KB TVD (zero vertical depth / zero vertical section)
- TVD = True Vertical Depth
- TVT = True Vertical Thickness
- TST = True Stratigraphic Thickness
- VS = Vertical Section

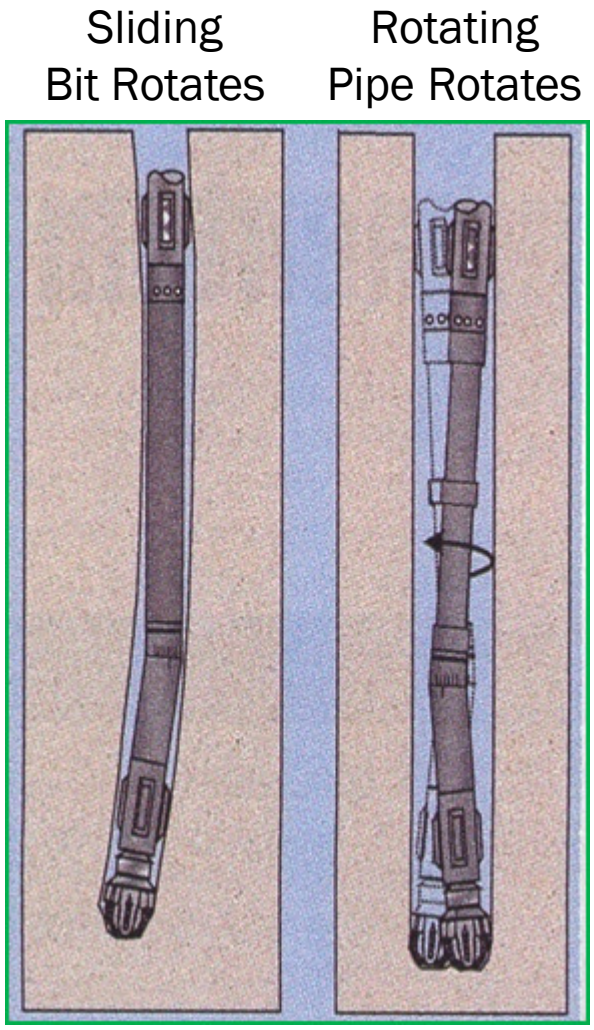


DIRECTIONAL WELLBORES

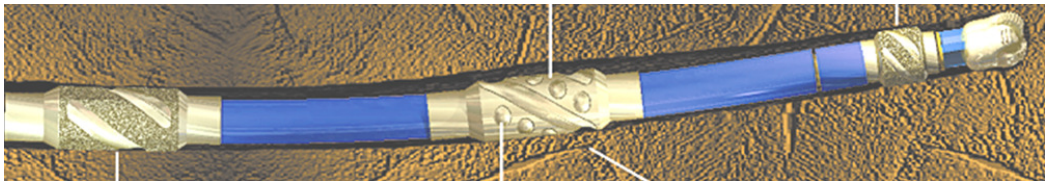


- Measurements are made from a reference point on the derrick floor, e.g. Kelly Bushing (KB)
- Measured depth (MD) is the primary index of data in a wellbore
- Tangent section used to account for changes in geologic depths

DIRECTIONAL WELLBORES

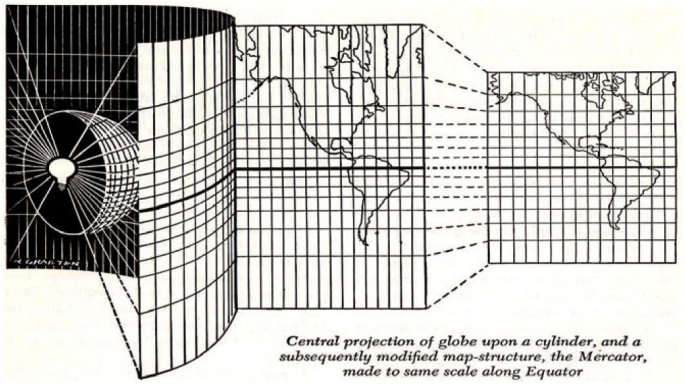


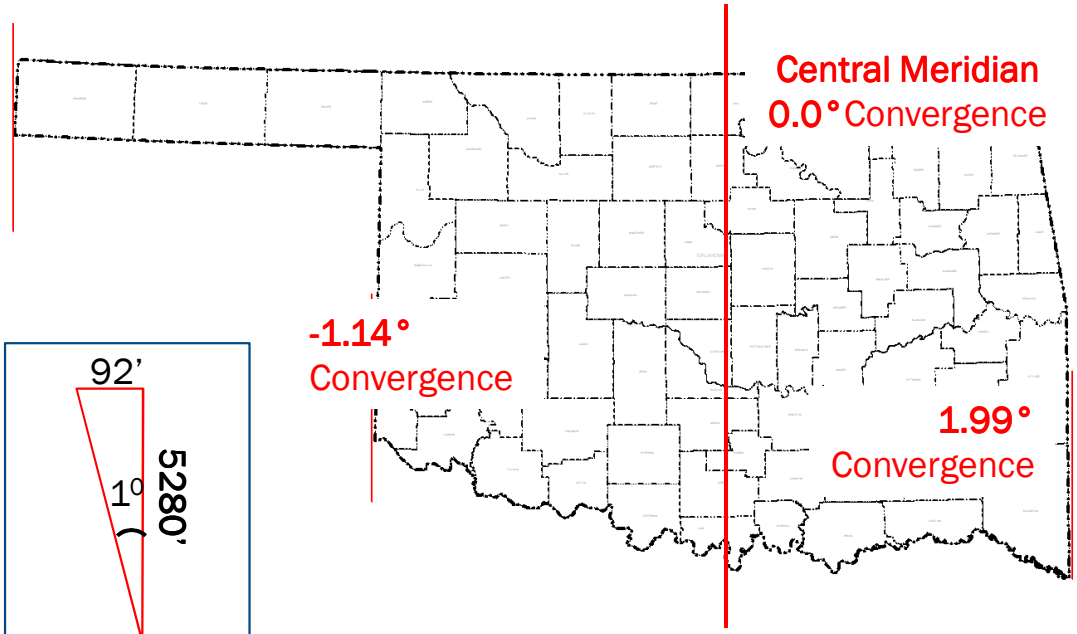
- Sliding causes wellbore to curve
  - > Drilling mud forced through drill pipe up the annulus causes bit to rotate
  - > Drill pipe does not rotate
- Rotating drills straight wellbore sections
  - > Drill pipe is rotated topside
  - > Both pipe and bit rotate
- Amount of bend in the bottom hole assembly determines the amount of wellbore curvature



Images courtesy Oklahoma Geological Survey

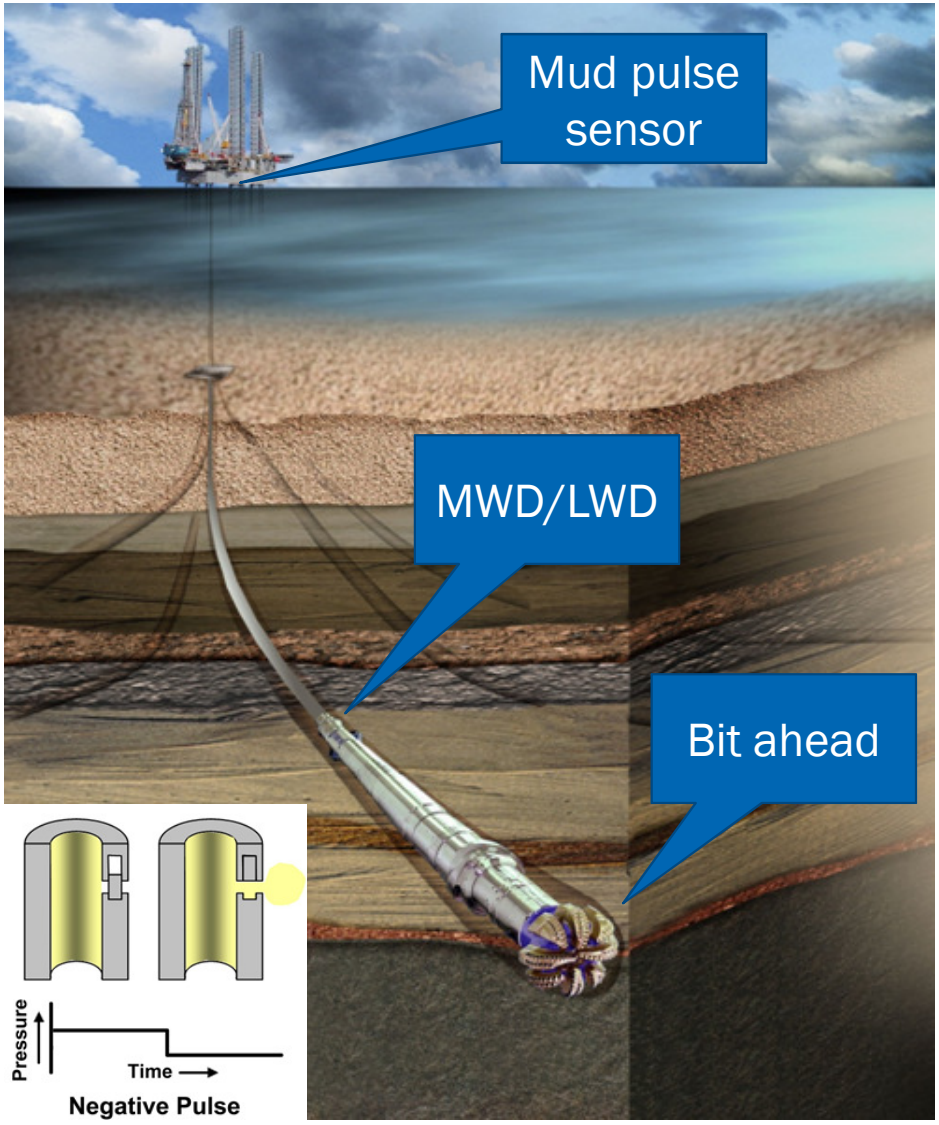
WELLBORE SURVEYING





- Location
  - > Latitude / Longitude
  - > Must have a datum
    - – NAD27 / NAD83
- Grid Convergence
  - > True north vs. grid north

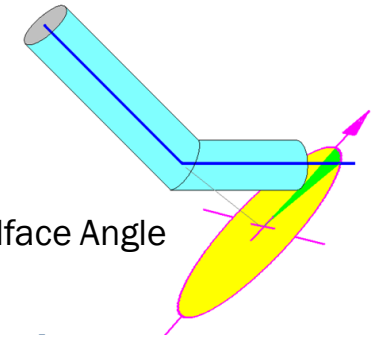
WELLBORE SURVEYING

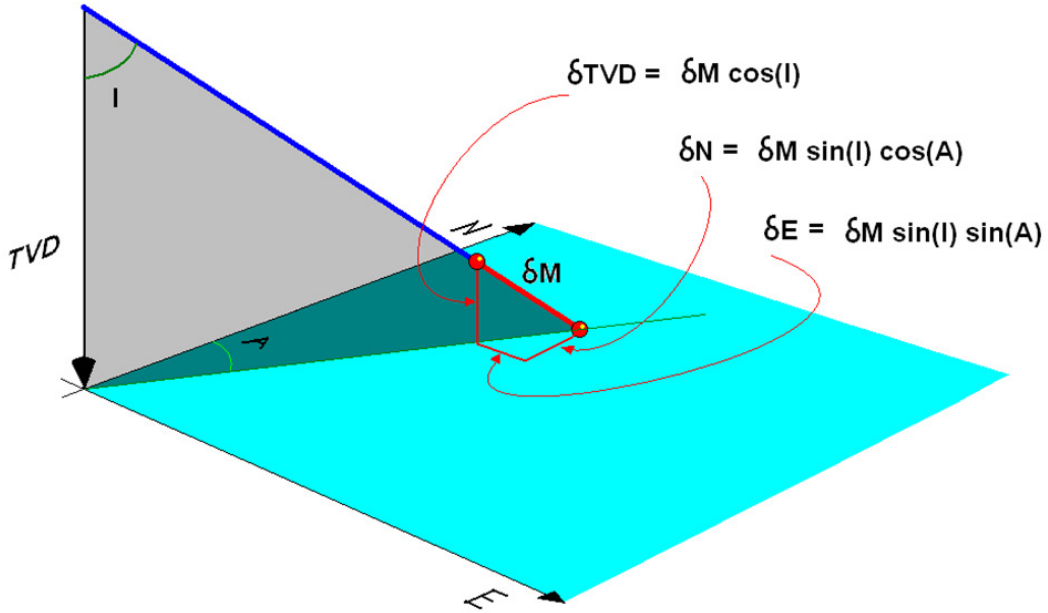


Images courtesy of Angus Jamieson and Oklahoma Geological Survey

- MWD – Measurement While Drilling
  - > Toolface (TF), Azimuth (AZ), Inclination (INC), Gamma Ray (GR)
- LWD – Logging While Drilling
  - > Resistivity, density and acoustic, etc.
- Mud Pulse Telemetry
  - > Down hole data is encoded in mud vibrations and decoded topside
- Bit Depth Deeper Than MWD/LWD
  - > Data recorded where the bit has been, not where it is.
    - – The data is lagged because sensor is behind the bit
  - > Data at bit must be estimated

WELLBORE SURVEYING

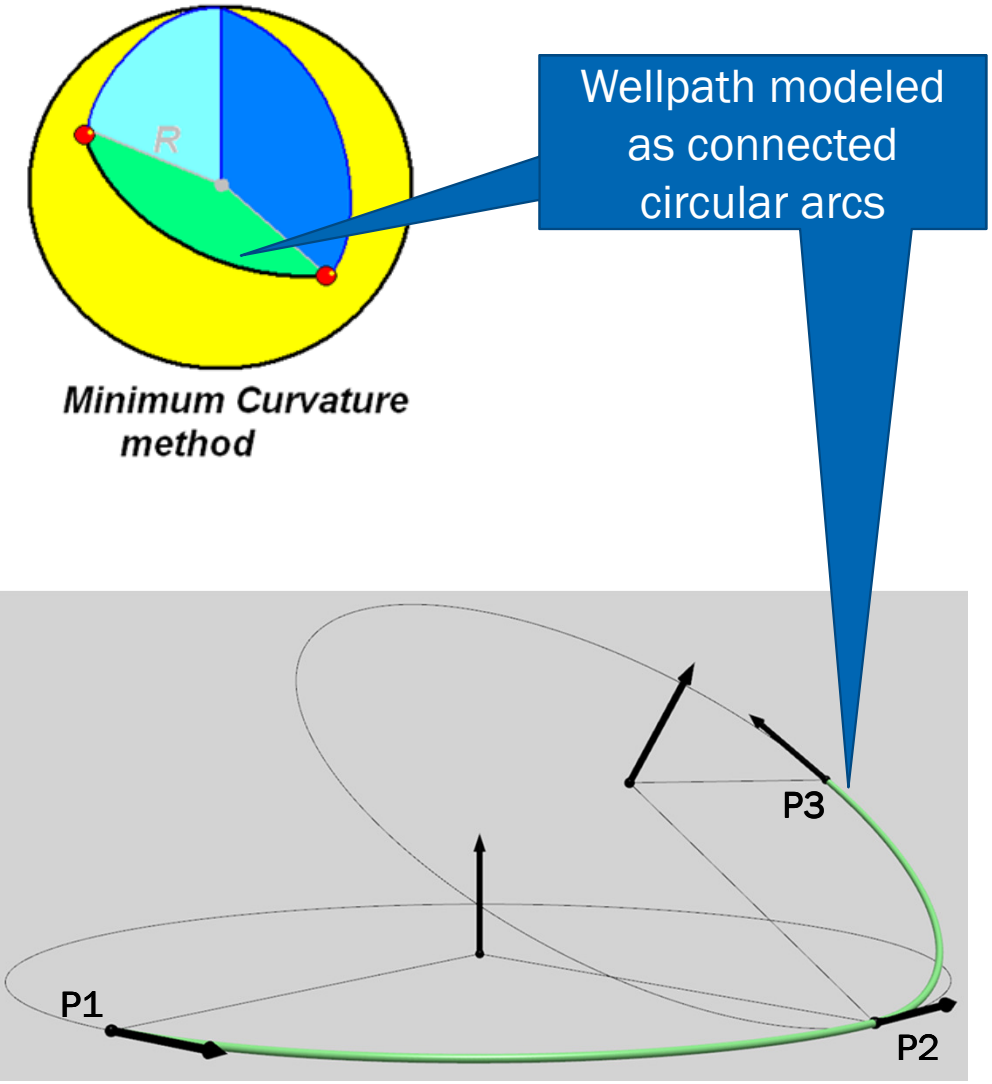




- Basic MWD Orientation Data
  - > Measured depth (MD)
    - Location index of MWD
  - > Toolface Angle
    - Determines the BHA orientation
    - The direction the bit will travel
  - > Inclination (INC)
    - The deflection from vertical of wellpath
  - > Azimuth (AZ)
    - Compass direction of wellpath
    - Adjust for grid convergence
- Calculate Position
  - > Northing, Easting and Vertical (TVD)

Images courtesy of Angus Jamieson

WELLBORE SURVEYING



- Minimum Curvature
  - > Curved wellpaths well modeled by circular arcs
    - – Circular arc segments are connected to complete wellbore
  - > Azimuth + inclination = direction vector
    - – Direction vectors at segment ends are tangent to circular arc
  - > Arc length + direction delta = arc path
    - – Arc length = MD delta
    - – Direction delta = angle between vectors
  - > position 1 + arc path = Position 2
    - – Position 1 is tie-in point
    - – Northing, Easting and Vertical (TVD)

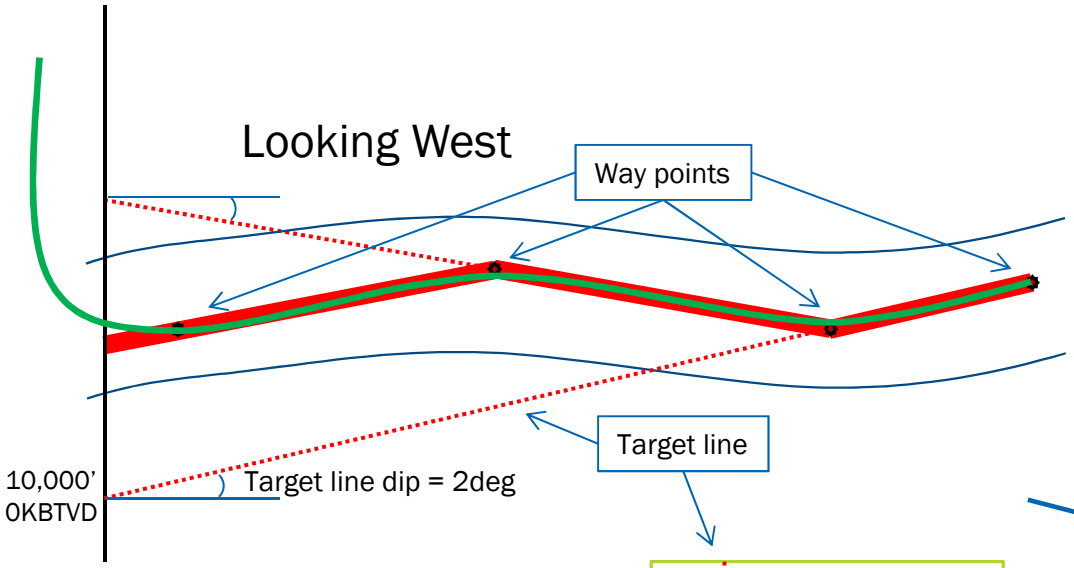
Top Image courtesy of Angus Jamieson

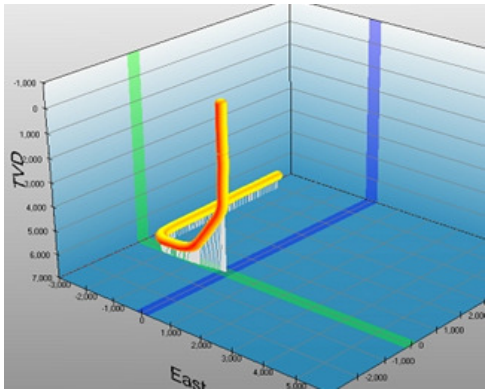
TARGETING

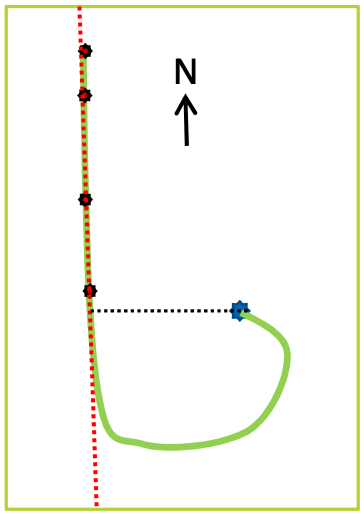
- Directional Drilling vs. Geosteering
  - > Directional drillers place wellbore at a position in 3D space
    - – Fixed point, way points or target lines
  - > Geoscientists estimate geology based on MWD/LWD data
    - – Targets are adjusted as geologic interpretation is updated
- Position Control
  - > Optimize reservoir placement for maximum hydrocarbon recovery
  - > Hazard avoidance
    - – Faults, geologic structure, water contacts, etc.
    - – Hard lines – lease and unit boundaries
    - – Anti-collision
- Target Options
  - > Drilling plan
  - > Fixed point
  - > Way points
  - > Target lines

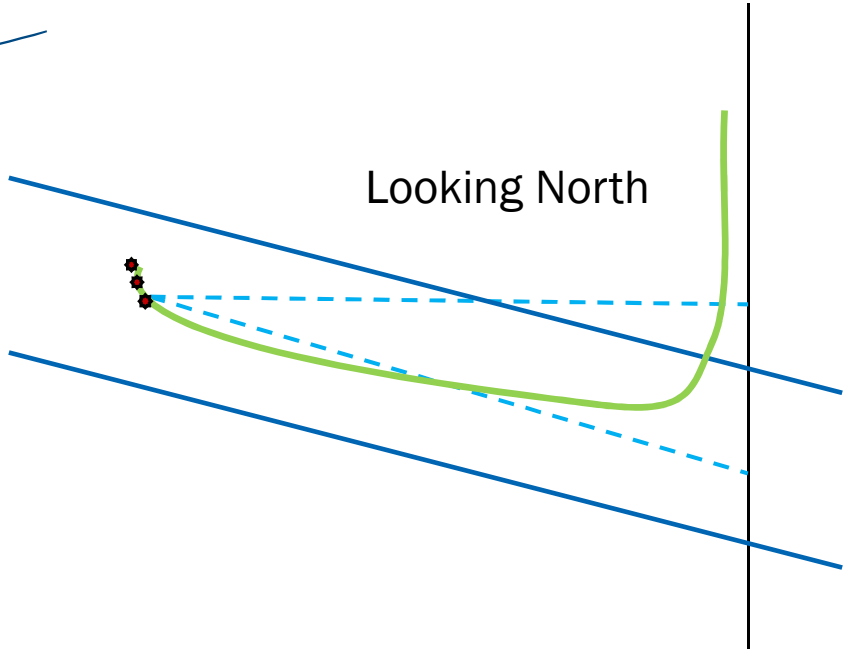
TARGETING

- Target Lines
  - > 0KBTVD, dip and Azimuth
- Way Points
  - > 3D target points in space









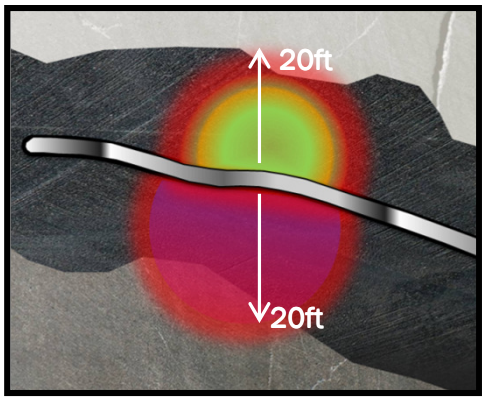
GEOSTEERING

- Three Primary Methods for Geosteering
  - > Direct measurement (LWD)
  - > 3D Forward modeling
  - > Inverse or true stratigraphic thickness method

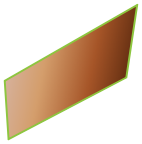
GEOSTEERING - DIRECT

- Direct Measurement
  - > Logging while drilling
  - > Down hole tools measure bed proximity directly
  - > Bed boundary mapping
  - > Proprietary technology
  - > Thin bed targets and complex geology
  - > Can be expensive

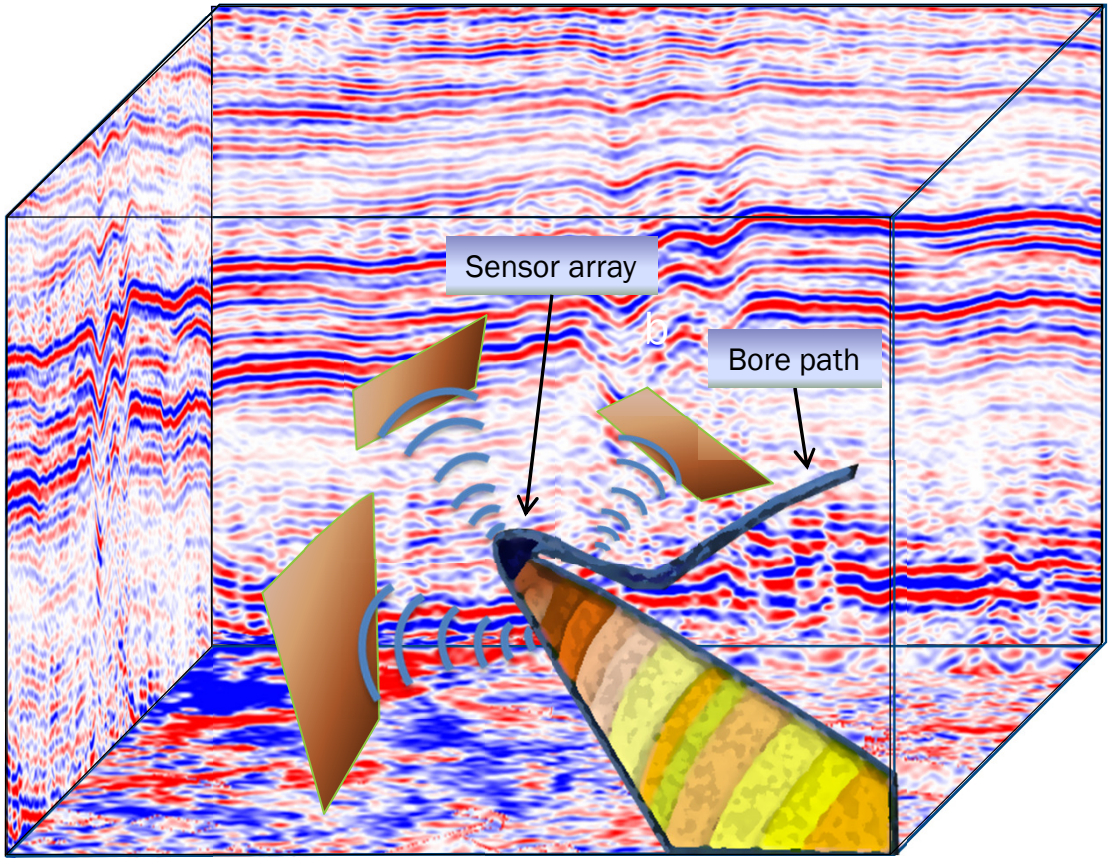
GEOSTEERING - DIRECT



Down hole logging tool can directly sense beds and other discontinuities

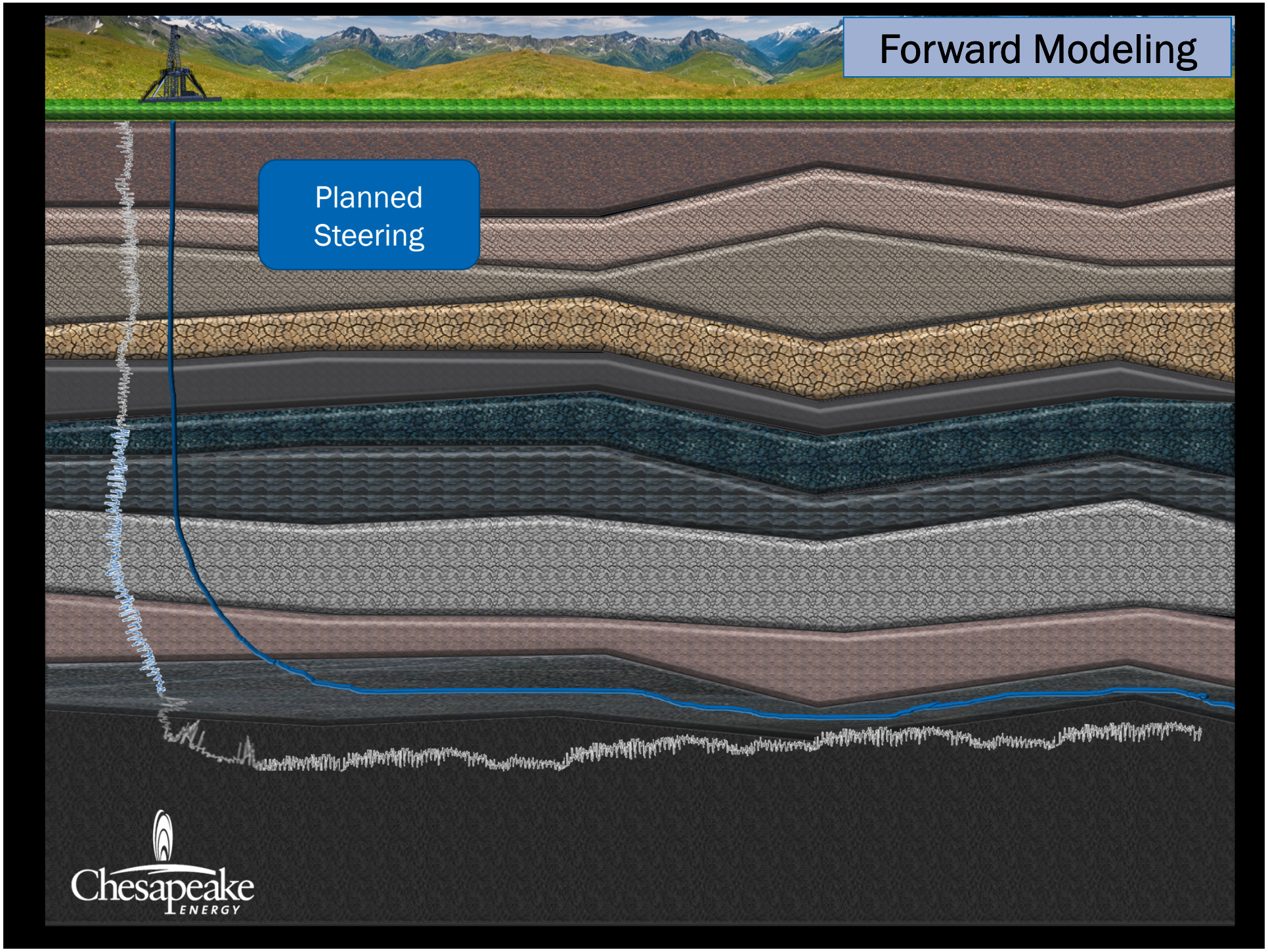


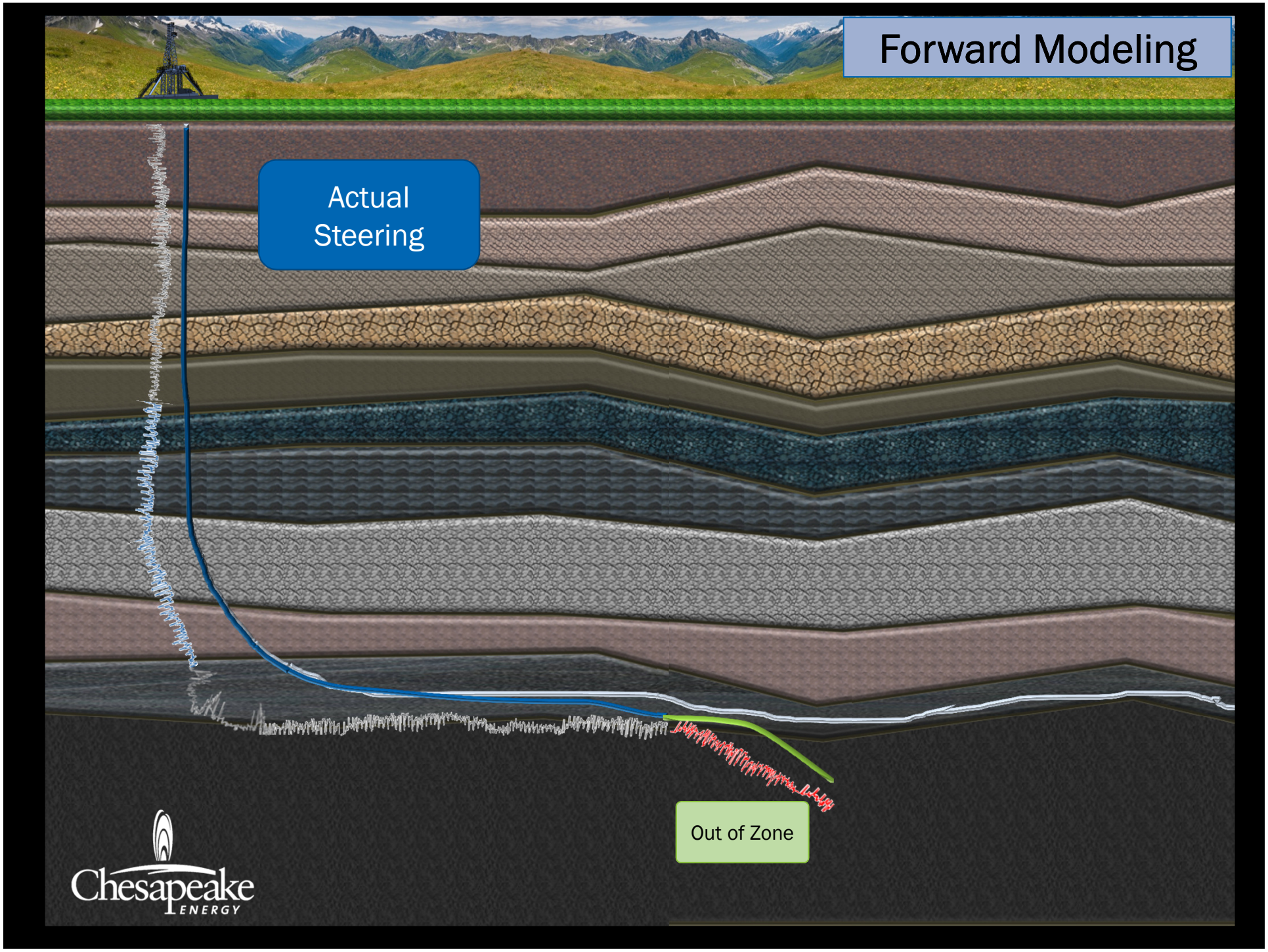
Bed boundaries

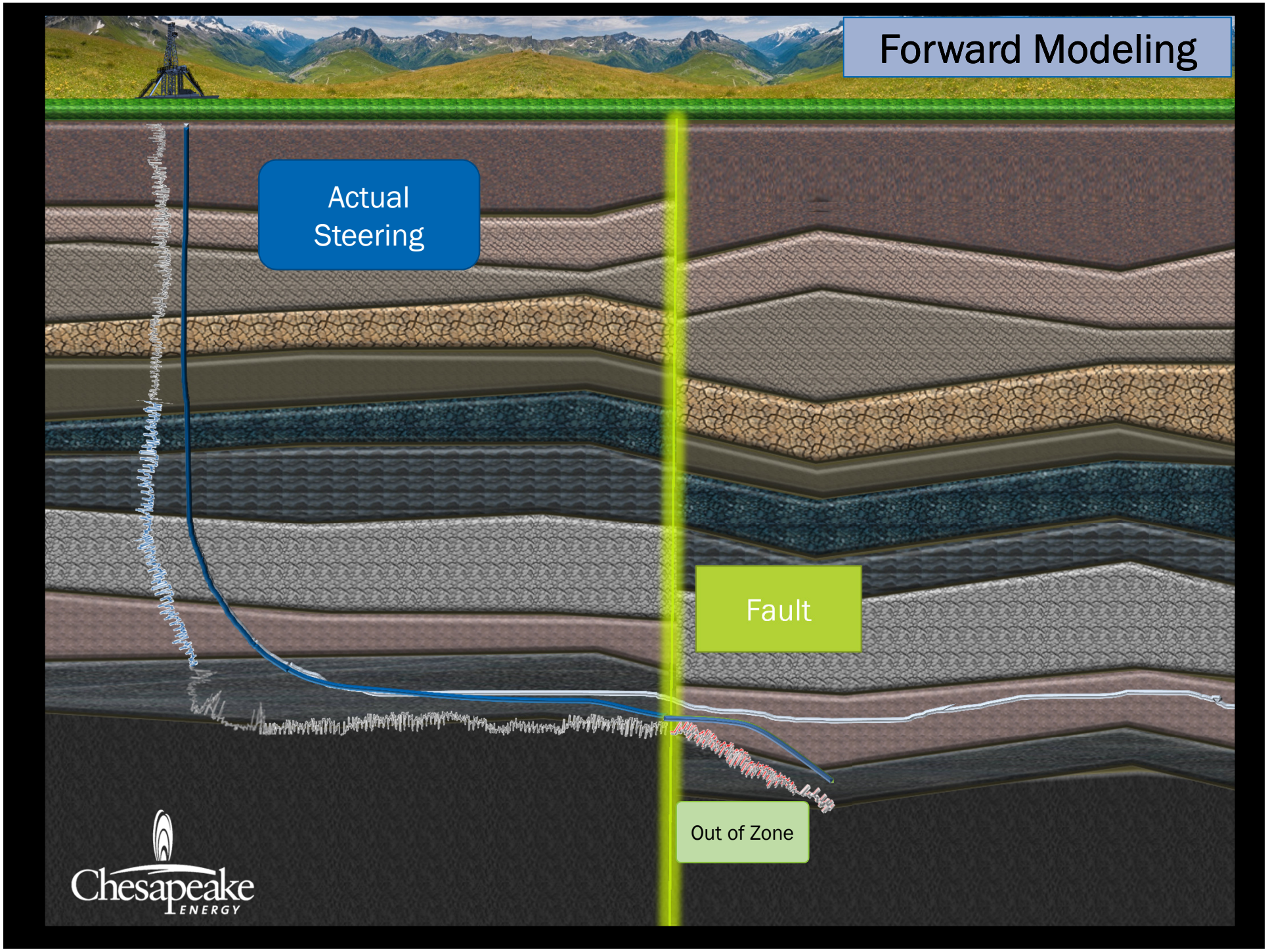


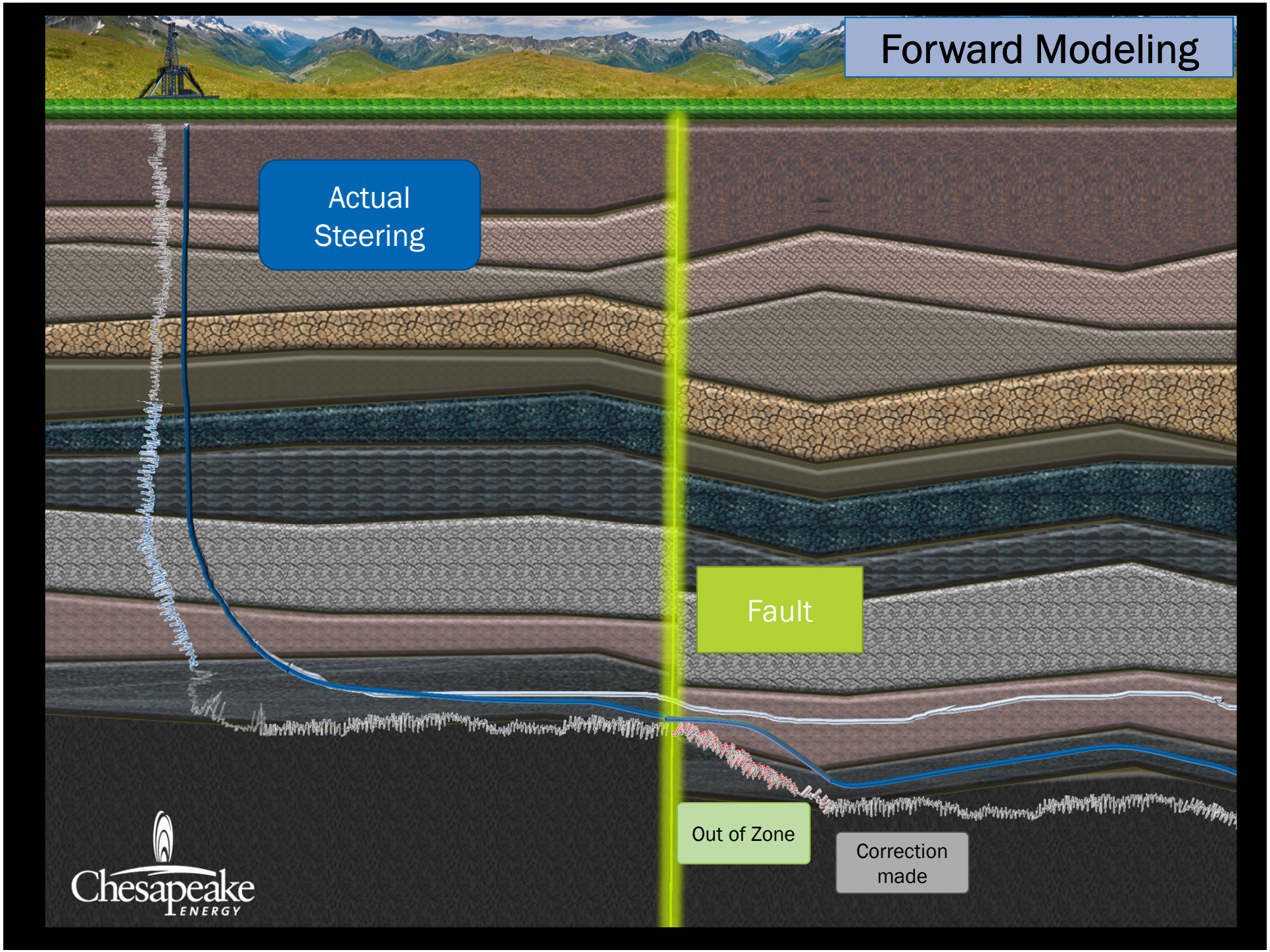
GEOSTEERING – FORWARD

- 3D Forward Modeling
  - > Model based
    - – Assumes a pre-defined Geologic model
    - – Estimate wellbore path
    - – Extract log signature from model
    - – Compare after section is drilled
    - – Adjust geologic model to fit found drilled log pattern
  - > Robust 3D estimation
    - – Can model bed thickness changes
    - – Can model facies changes
  - > Not always practical for real-time geosteering
    - – Model generation hard in real-time


Forward Modeling
Planned
Steering
Chesapeake
ENERGY


Forward Modeling
Actual Steering
Out of Zone
Chesapeake ENERGY

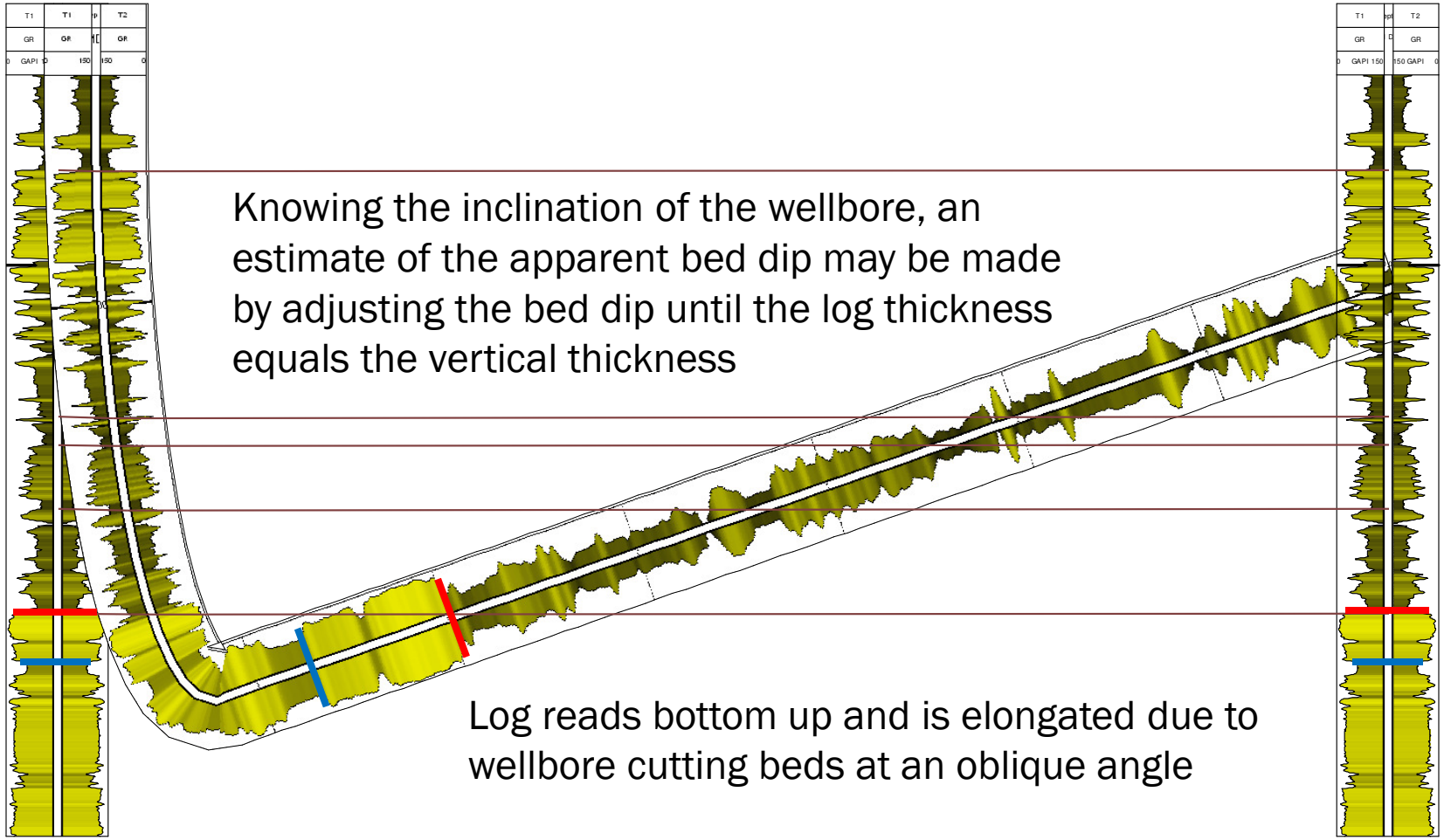

Forward Modeling
Actual Steering
Fault
Out of Zone
Chesapeake ENERGY


Forward Modeling
Actual Steering
Fault
Out of Zone
Correction made
Chesapeake ENERGY

GEOSTEERING – INVERSE (TVT)

- Inverse or True Stratigraphic Thickness Method
  - So-called Gamma ray steering
  - First developed at UPRC in the Austin Chalk
  - Most common method
  - Use pattern matching to estimate dip along the lateral wellbore path
  - Only estimates apparent dip
  - Assumes a flat earth, constant model
    - Does not account for stratigraphic thickness changes
  - Fast estimate of apparent dip
    - Only a 2D estimate
  - A local estimate of relative position in the target formation
    - Vertical positioning not subject to wellbore path uncertainty

GEOSTEERING – INVERSE (TVT)



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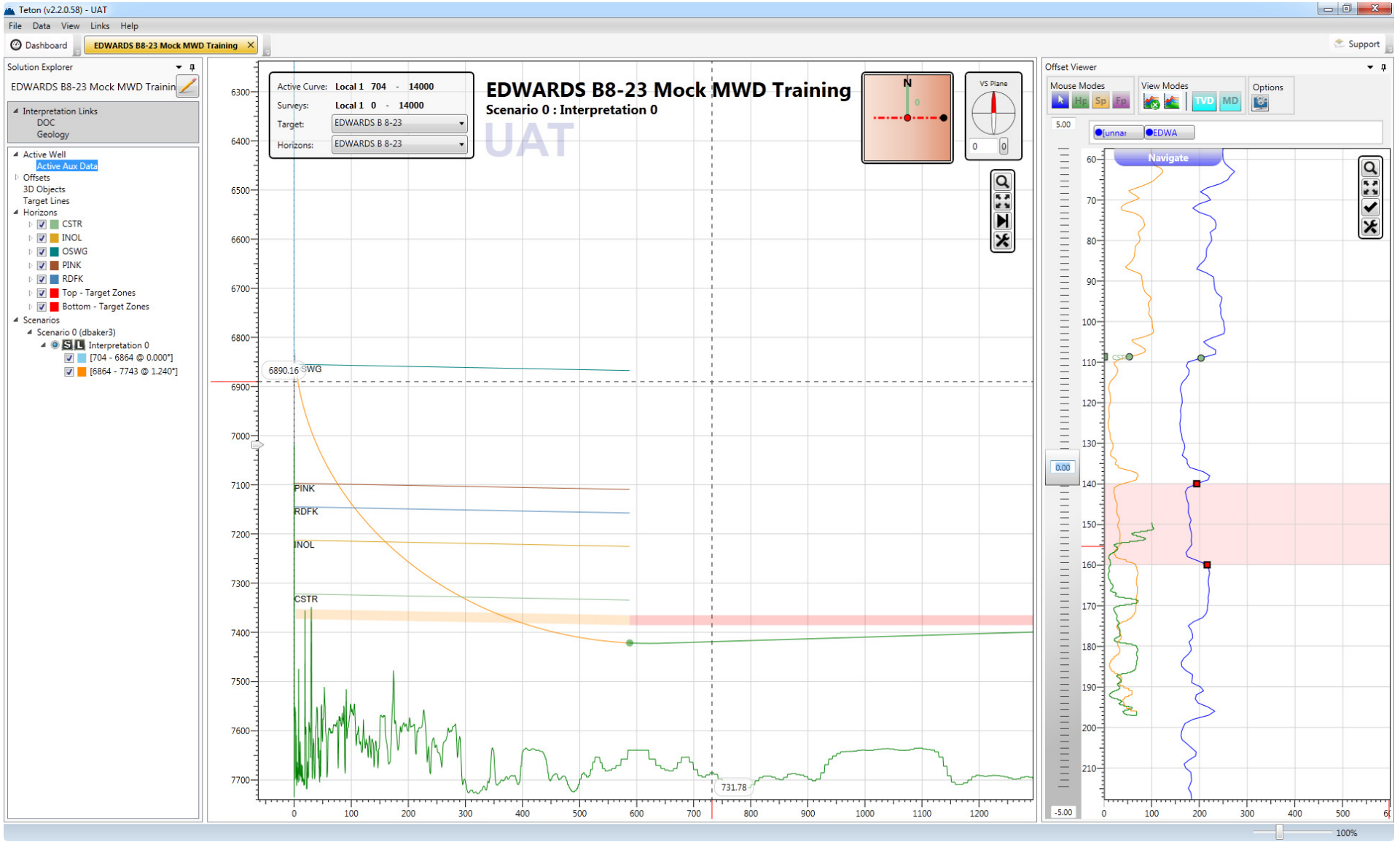

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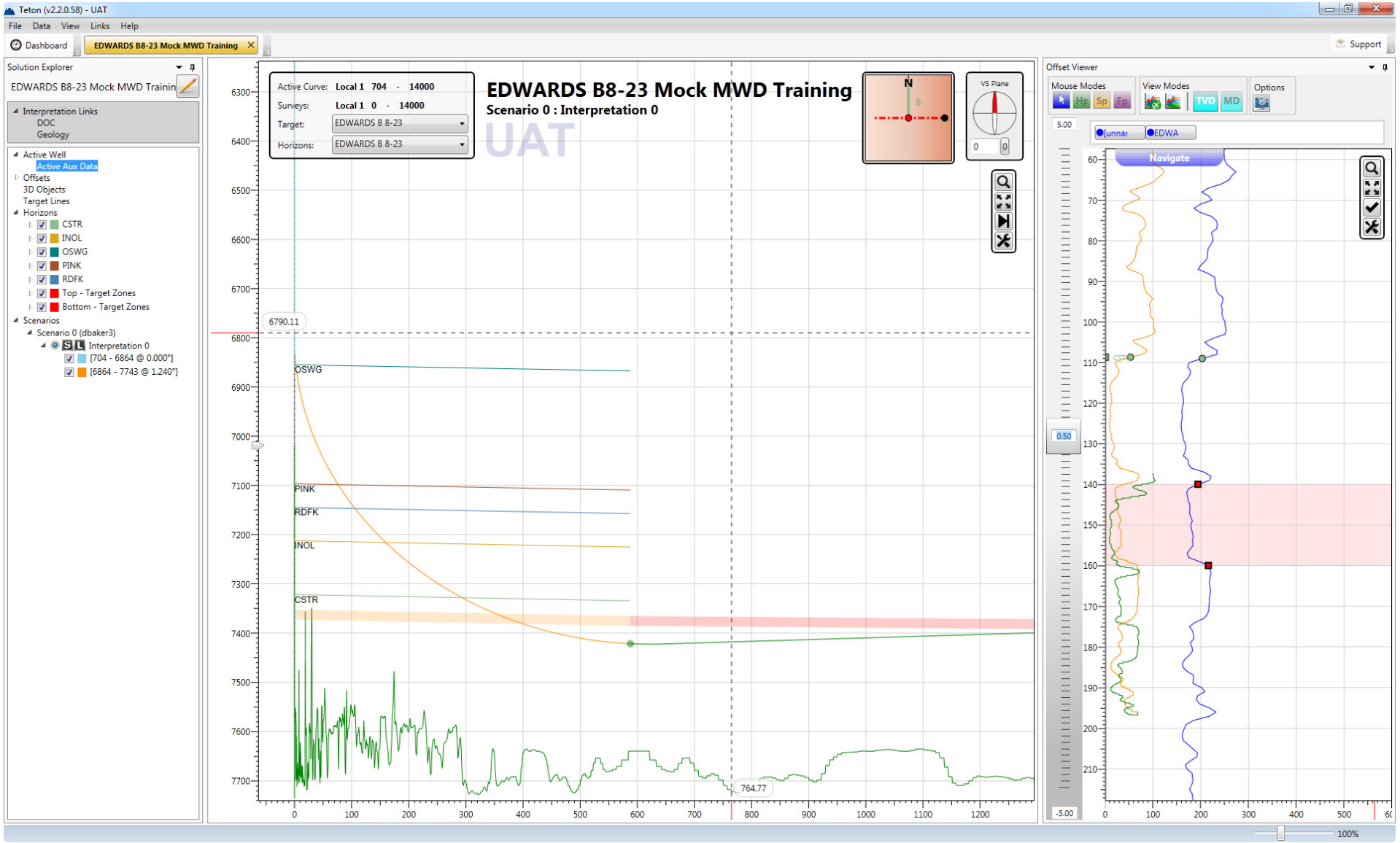

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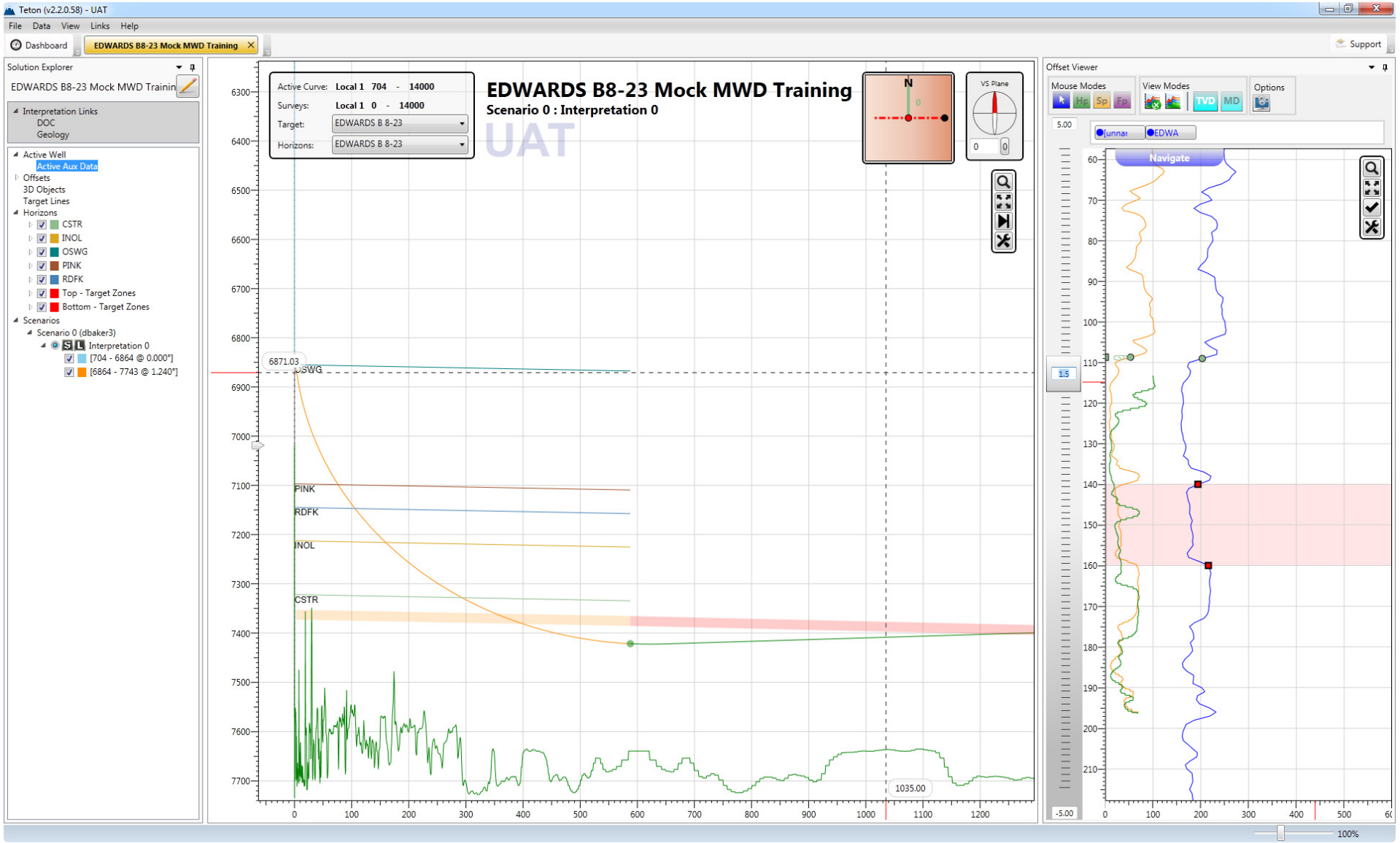

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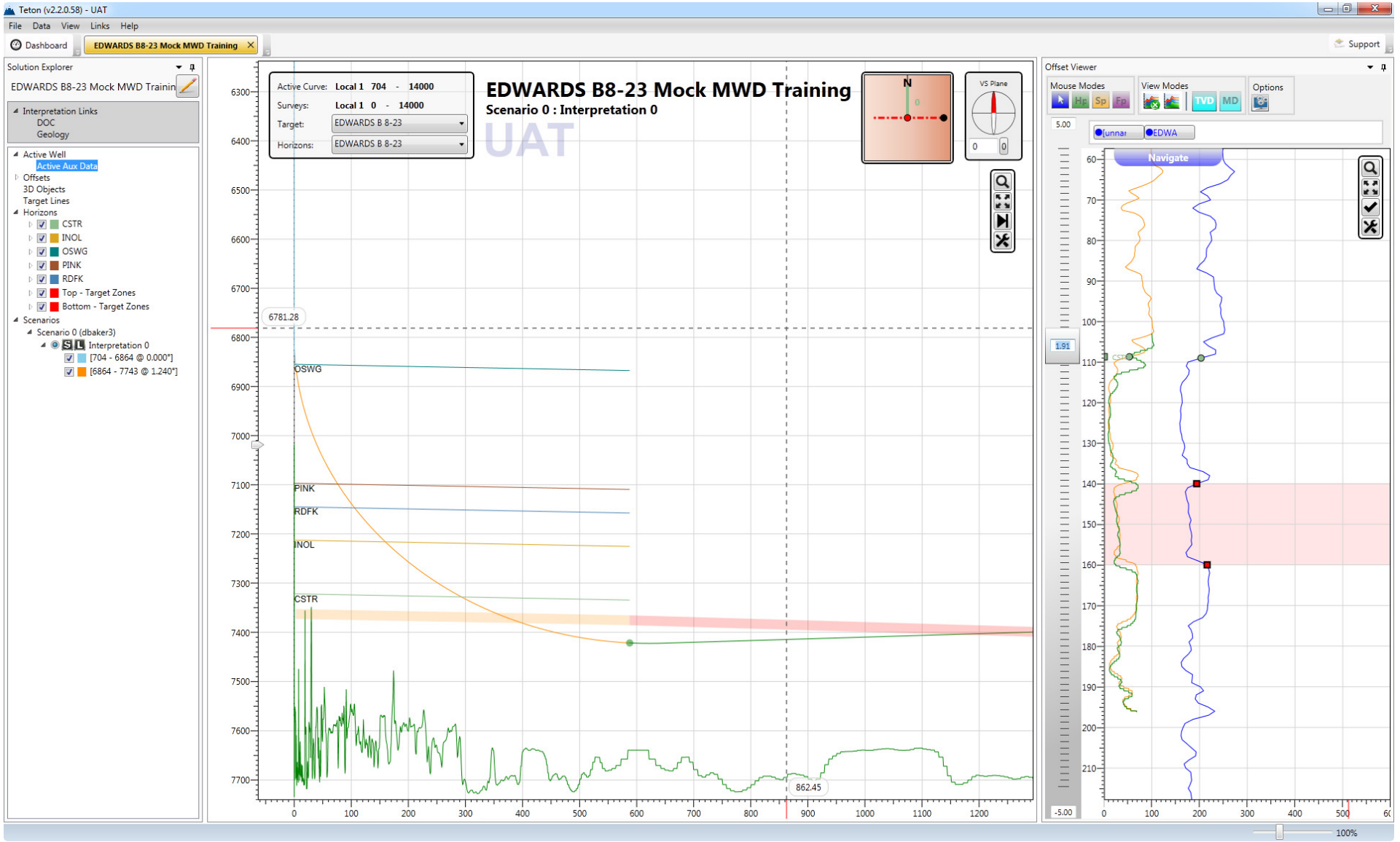

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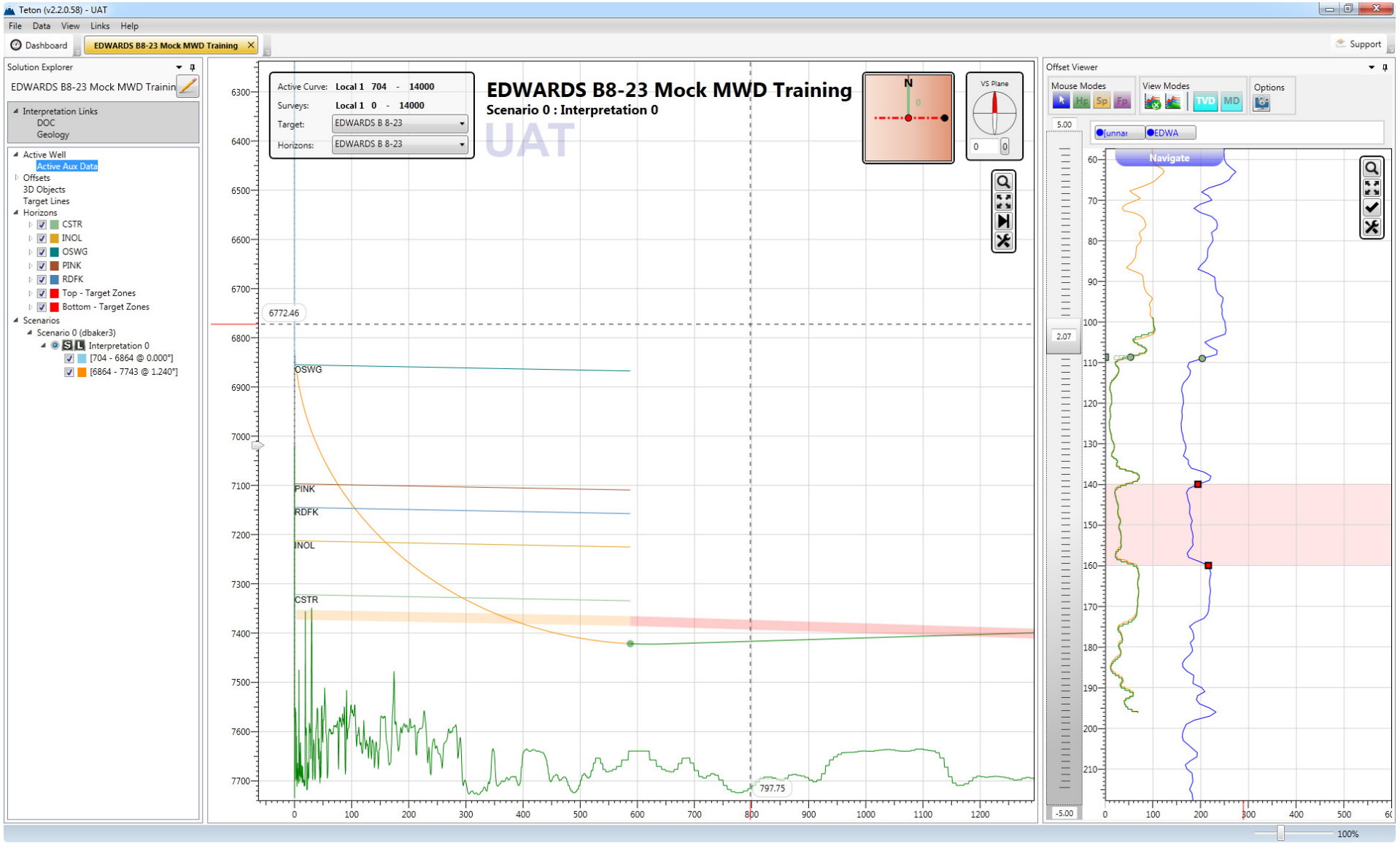

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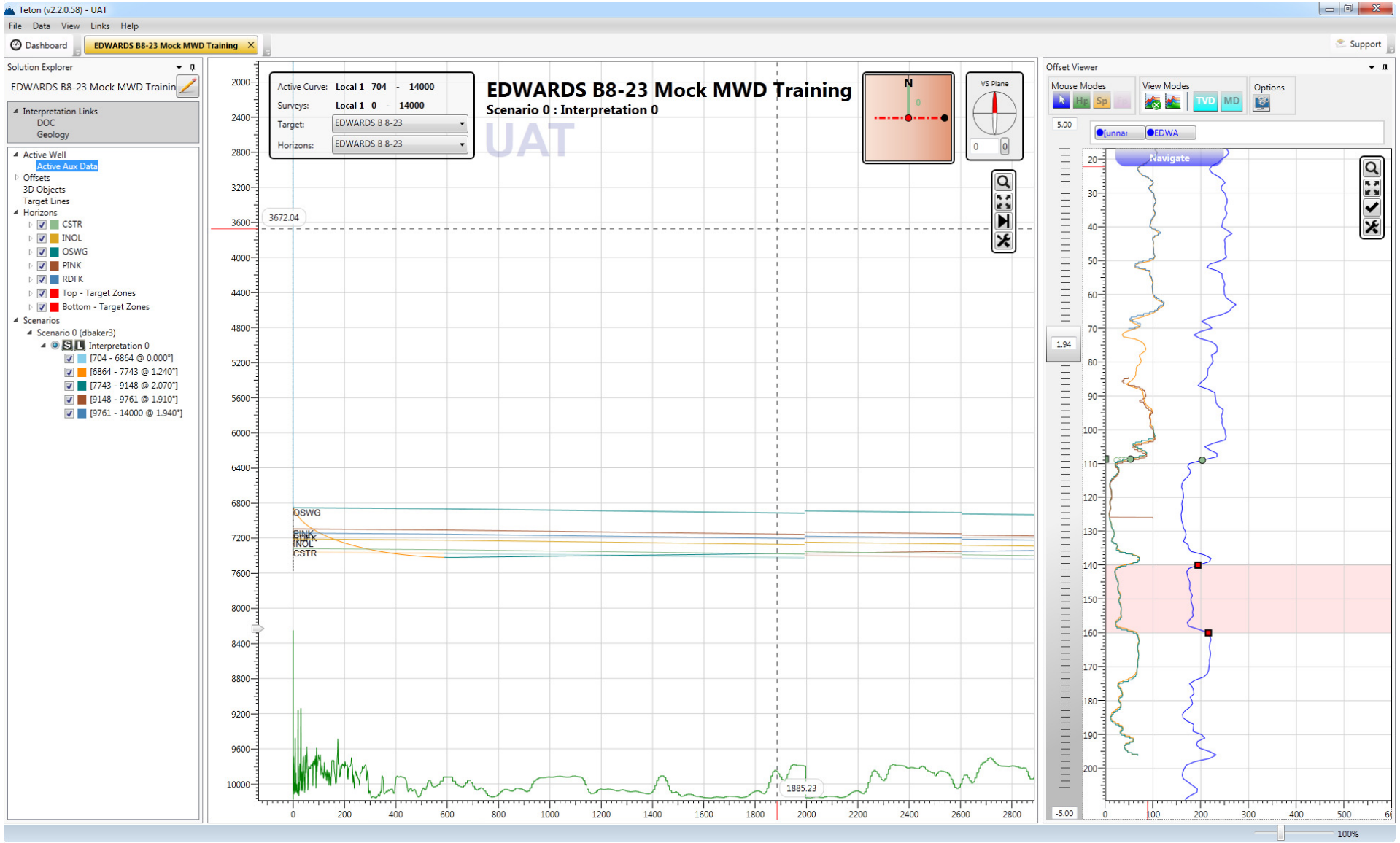

Questions?