SPE Distinguished Lecturer Program

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Advanced Geosteering for Optimal Exploitation of Hydrocarbon Reserves

Roland Chemali

Chief Petrophysicist

Halliburton Sperry Drilling

Society of Petroleum Engineers
Distinguished Lecturer Program
www.spe.org/dl

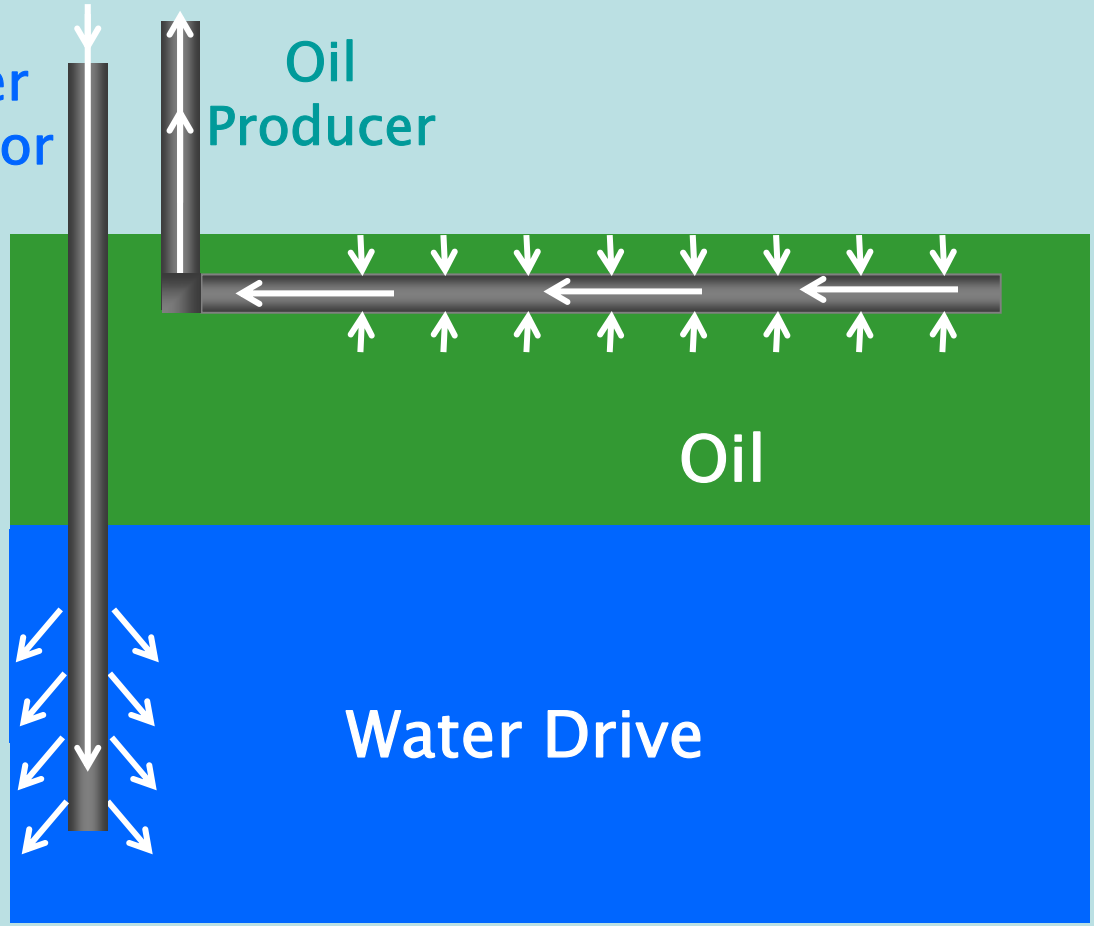
HALLIBURTON

Presentation Outline

- What is geosteering? Why geosteer?
- Reactive and proactive geosteering
  - Wellbore images
  - Azimuthal wave resistivity
  - Other: formation pressure, seismic while drilling
- Summary and conclusion

What is Geosteering and Why Geosteer?

Simplified case of water-drive reservoir



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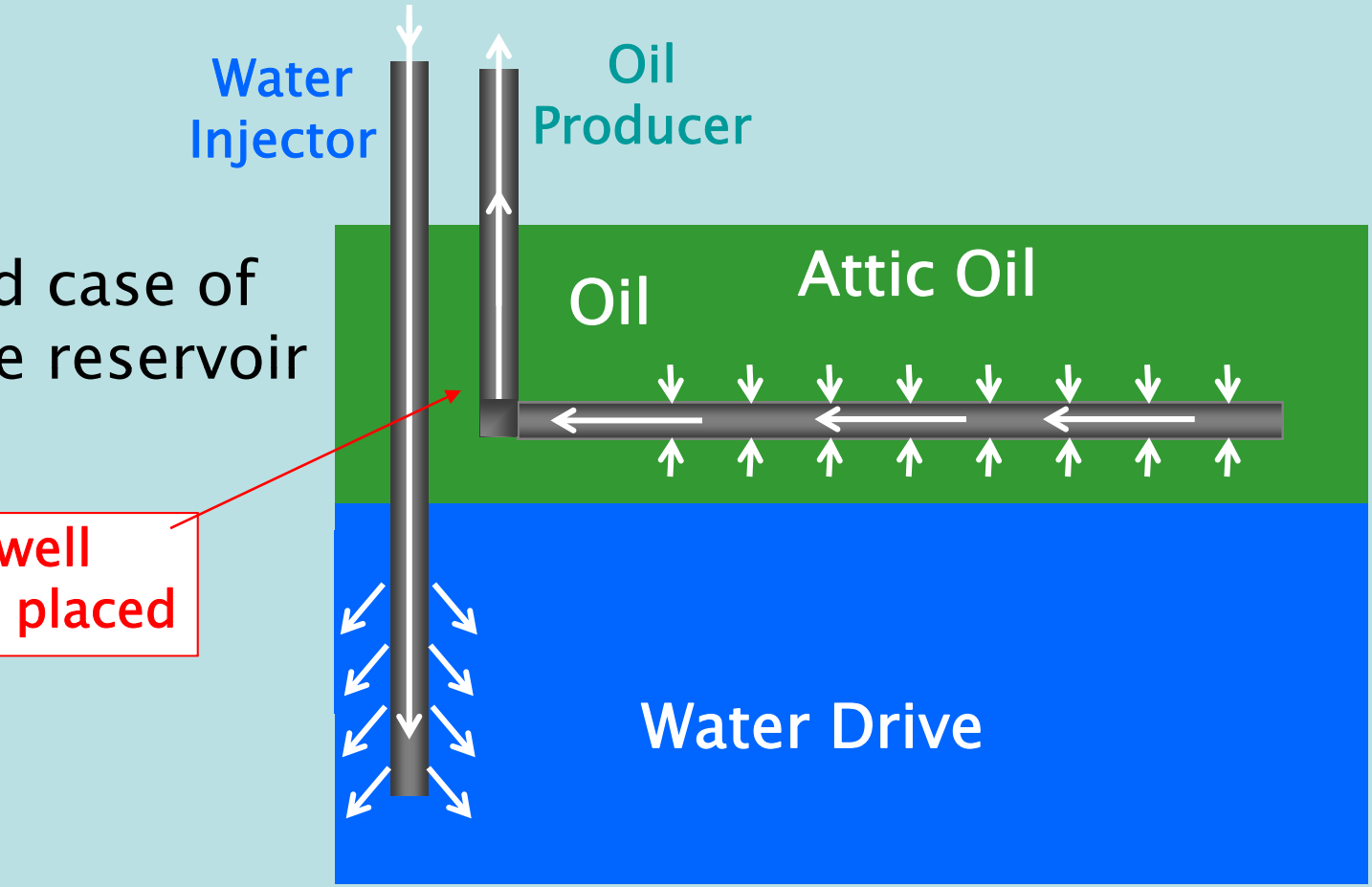


The Value of Accurate Well Placement

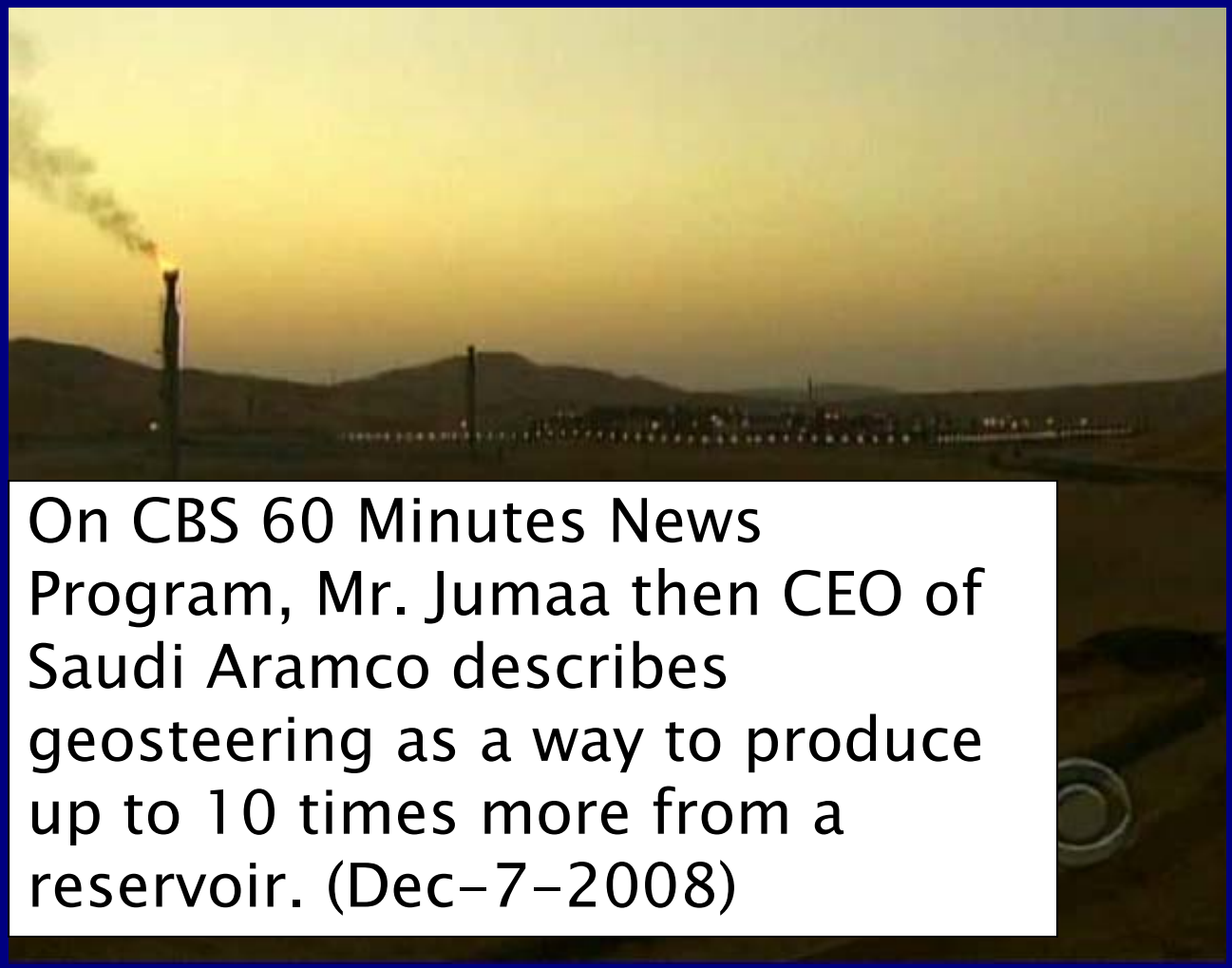
- StatoilHydro Troll field: 2.4 b$

  (Based on OTC-17110)

- Chevron Alba (John Hampson) 225 M$ of additional production in 3 wells

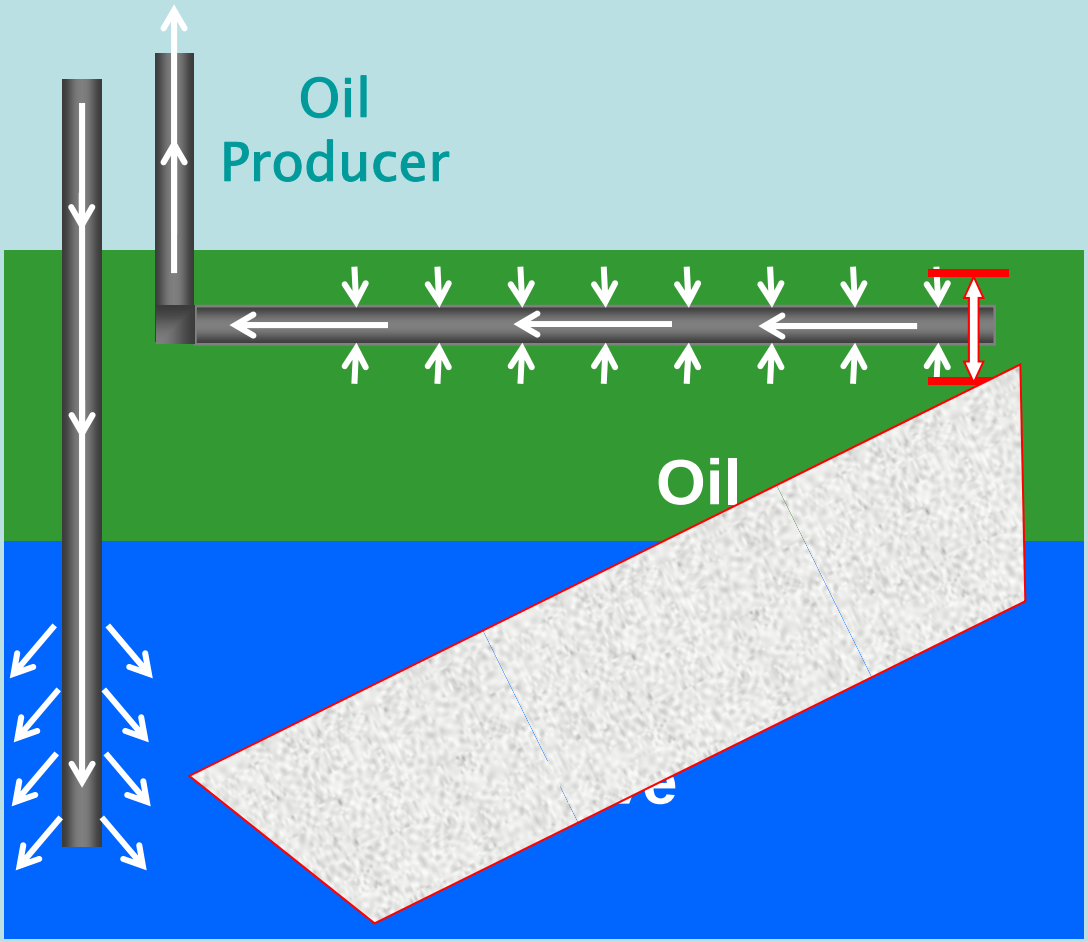
- CBS 60 Minutes; Saudi Aramco CEO interviewed by Leslie Stahl Dec-07-2008

From CBS 60 Minutes The CEO of Saudi Aramco



On CBS 60 Minutes News Program, Mr. Jumaa then CEO of Saudi Aramco describes geosteering as a way to produce up to 10 times more from a reservoir. (Dec-7-2008)

Simple Geometrical Placement ?



Inclination error > 5 ft / 3000 ft = 375000 Bbl/Oil

Uncertainty on OWC

Uncertainty on geology

Sub-seismic events

Definition of Geosteering

- Steering with reference to geological markers

Or

- Planned interactive use of real-time geological and directional information to precisely place the position of each section of the well while drilling (Ed Stockhausen, 2008)

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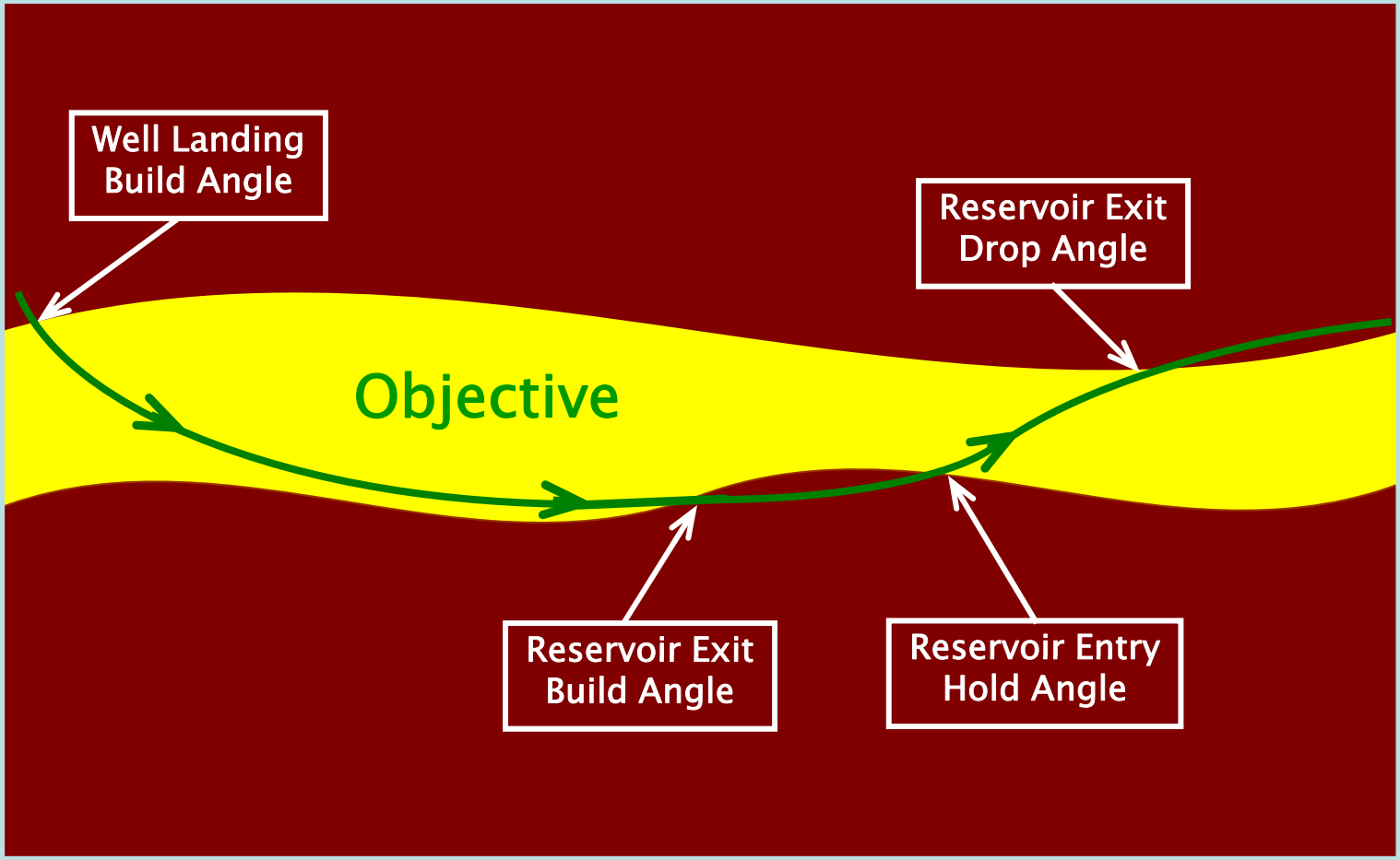
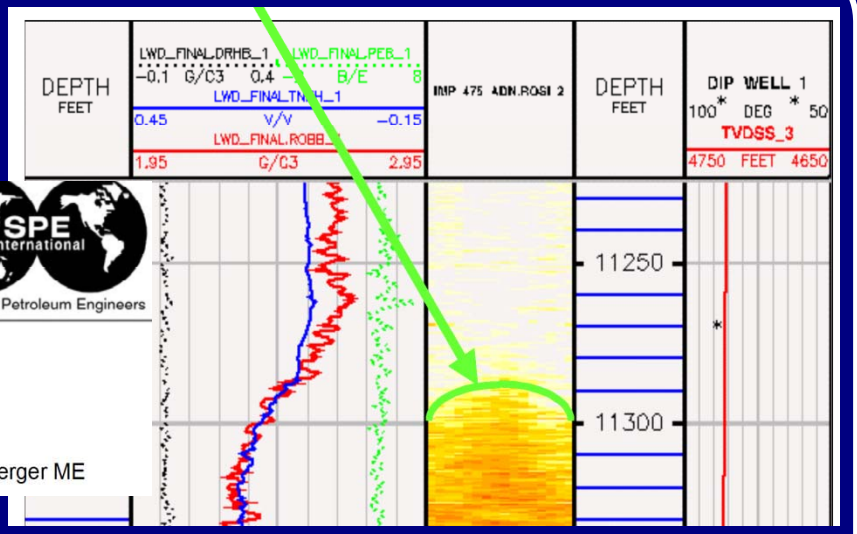
Reactive Geosteering



Steps for Reactive Geosteering

1. Recognize reservoir entry – exit
   - Gamma ray, resistivity, density, etc
2. Determine angle of entry – exit (relative dip)
   - Well bore image by micro-resistivity, density, gamma
3. Change well course accordingly



IADC/SPE 72282

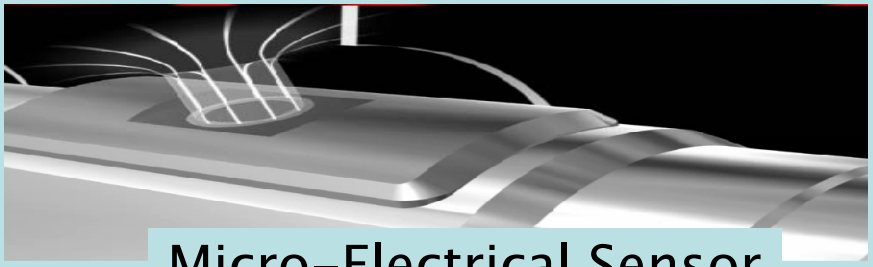
In the Driver's Seat with LWD Azimuthal Density Images

Gene Ballay*, Hussein Al-Ali*, Scott Amos* and Bob Dennis** / * Saudi Arabian Oil Company, **Schlumberger ME

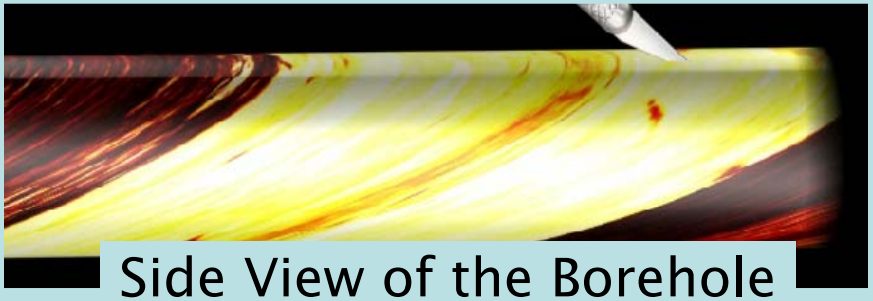
Society of Petroleum Engineers

Ballay, G., (2001) – SPE 72282

Borehole Imaging for Reactive Geosteering Angle of Entry & Exit (Relative Dip)



Micro-Electrical Sensor

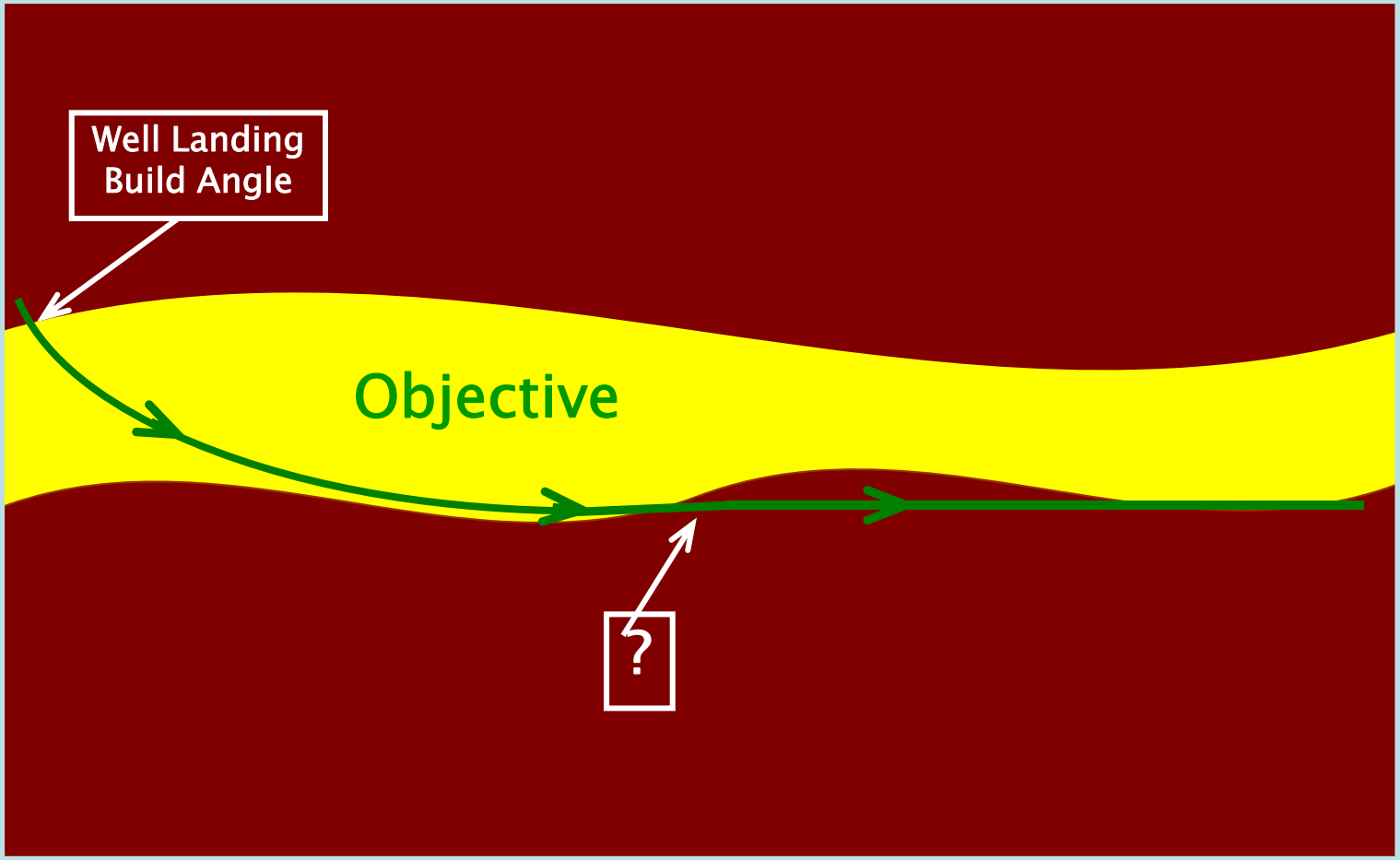


Side View of the Borehole

Unfolded Image of
The Borehole Wall

1. Borehole wall image is acquired while drilling
2. Geosteering engineer looks for sinusoidal patterns
3. Sinusoids are converted to relative dip
4. Geological model is updated
5. Geosteering decision is made

No Geosteering
Geometrical Steering



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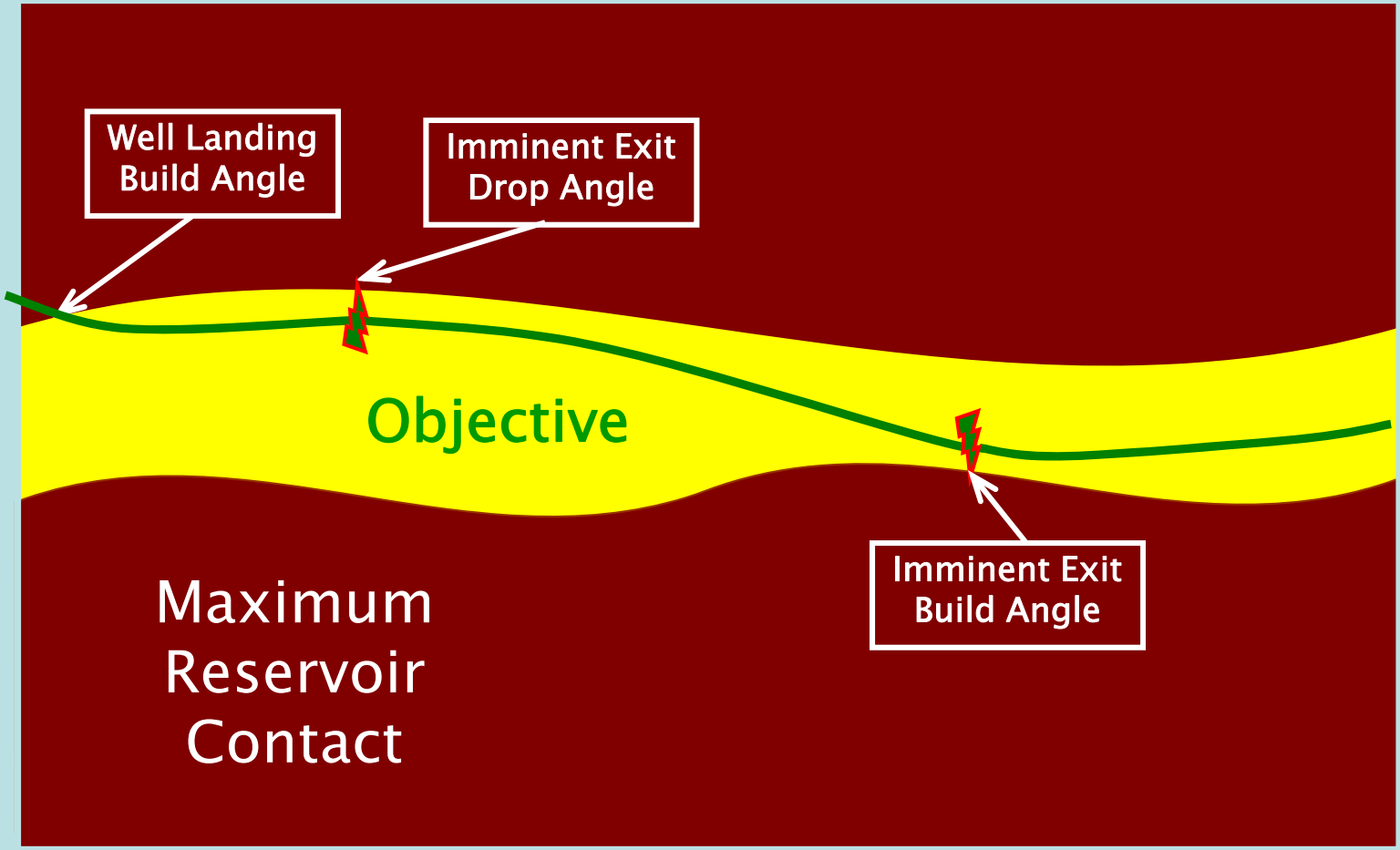
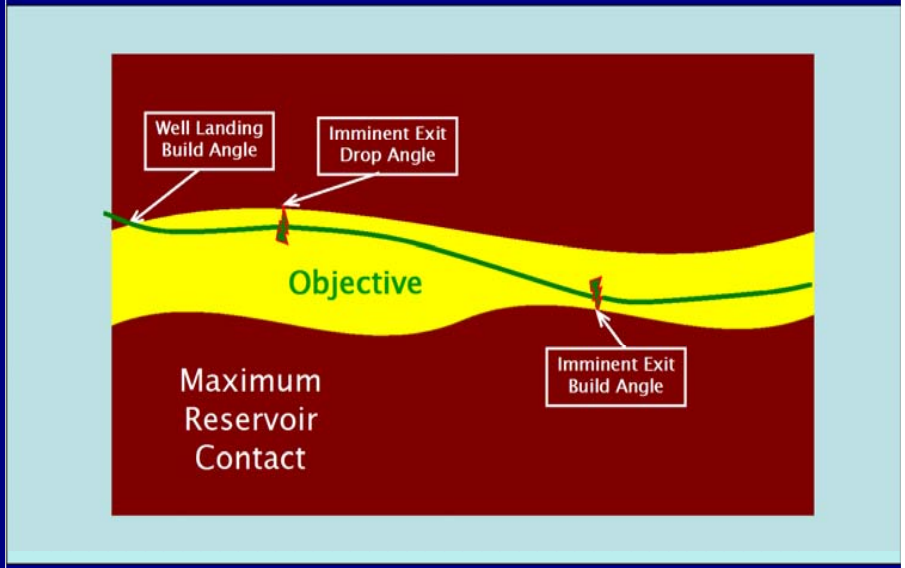
Pro-Active Geosteering



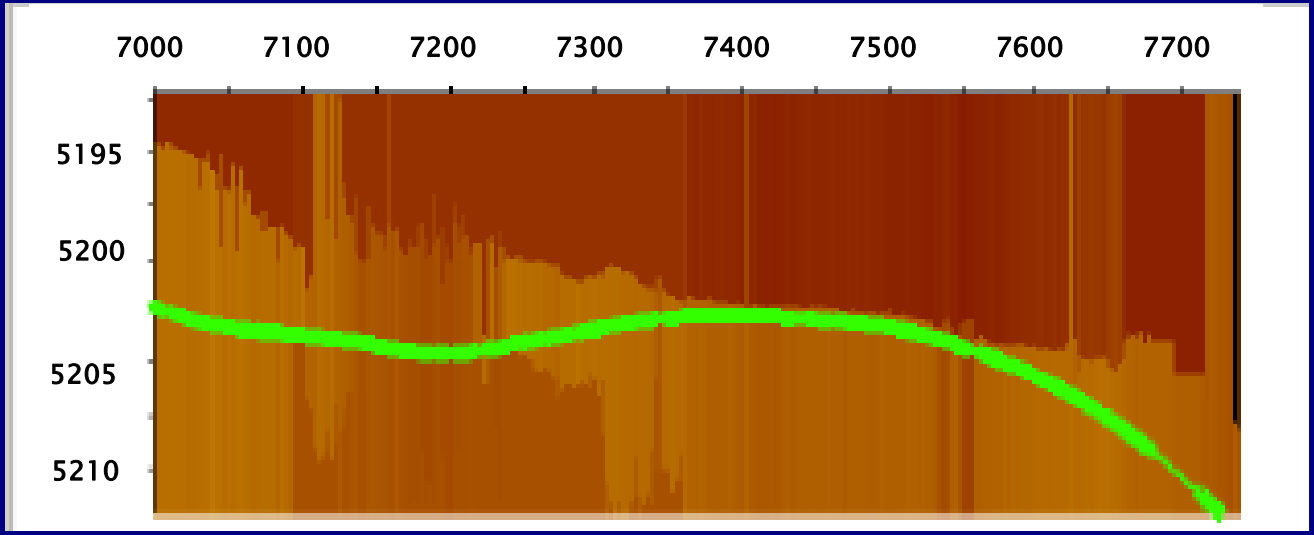
Pro-Active Geosteering
Who Benefits?

1. Drillers
   - No sidetracks
   - Less stability issues
2. Completion Engineers
   - Fewer doglegs
3. Early Production
   - High reservoir contact
4. The Environment
   - Fewer wells for given production
5. Cumulative Production
   - Less oil left behind
   - Higher cumulative production
   - High reservoir contact



Steps for Pro-Active Geosteering

1. Anticipate reservoir entry or exit, long before they occur
   - Deep Wave Resistivity
2. Determine direction of approach
   - Azimuthally sensitive wave resistivity or educated guess
3. Change well course accordingly



Omeragic, D., (2005) – SPE 97405

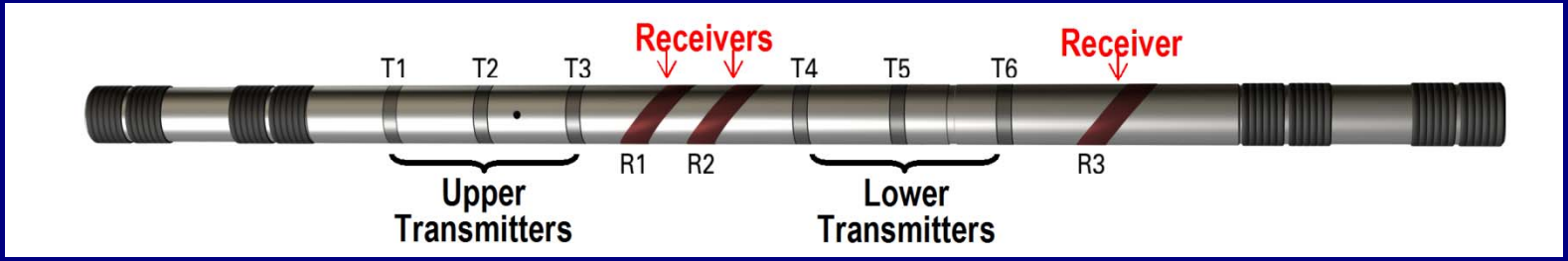
Pro-Active Geosteering With Azimuthal Wave Resistivity Logging While Drilling (LWD)

Schlumberger Periscope™

Halliburton Azimuthal Deep Resistivity ADR™

Baker Hughes AziTrak™

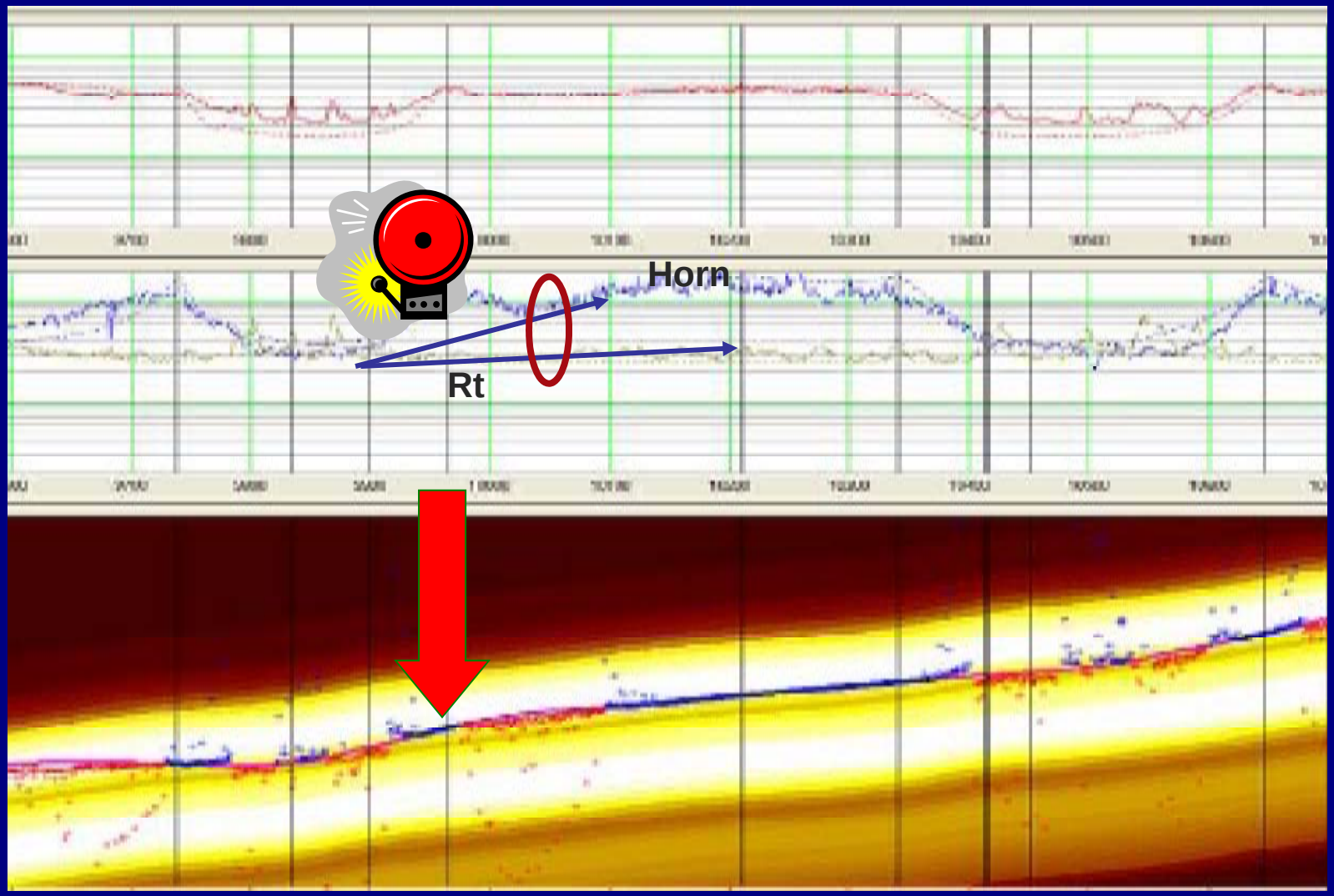
Pro-Active Geosteering With Azimuthal Deep Wave Resistivity LWD



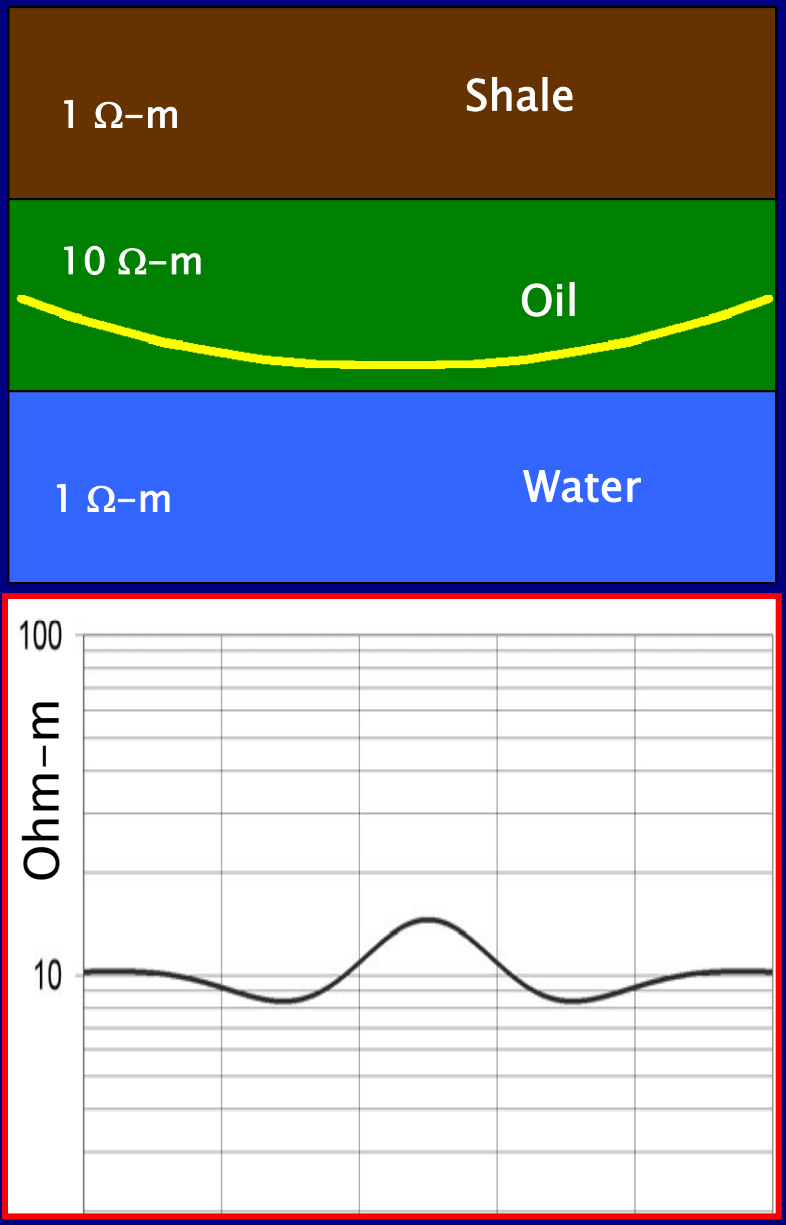
- Geosteering with up-down resistivity
- Geosteering with resistivity images
- Geosignal and distance to bed boundary
- “Depth of first detection” for azimuthal deep resistivity

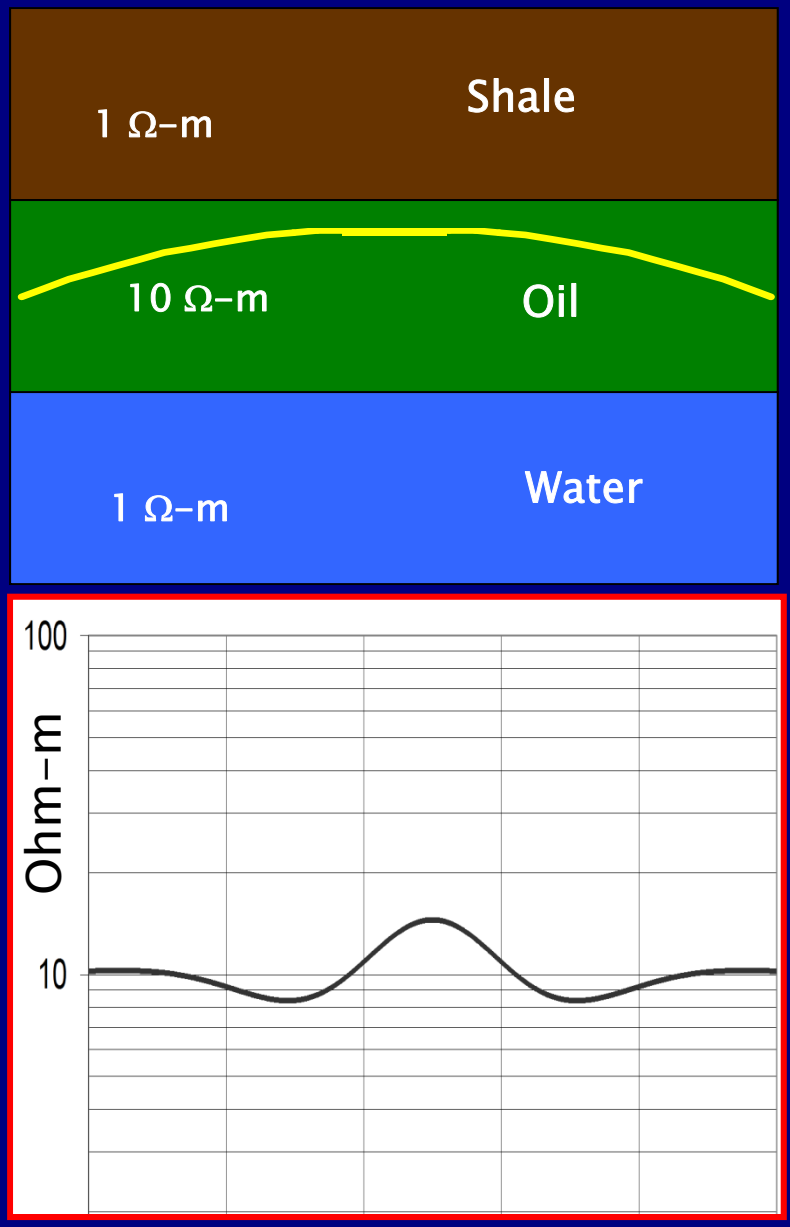
Geosteering with Up-Down Resistivity

Azimuthal Wave Resistivity LWD

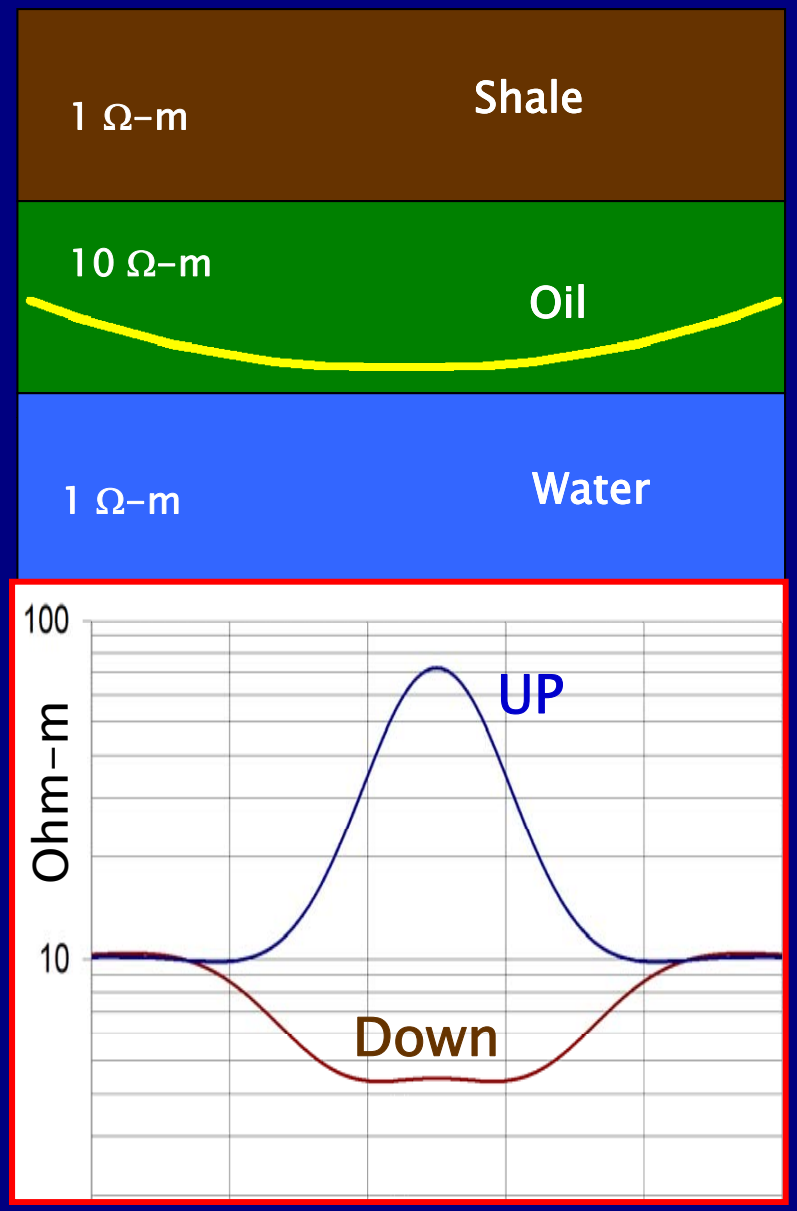


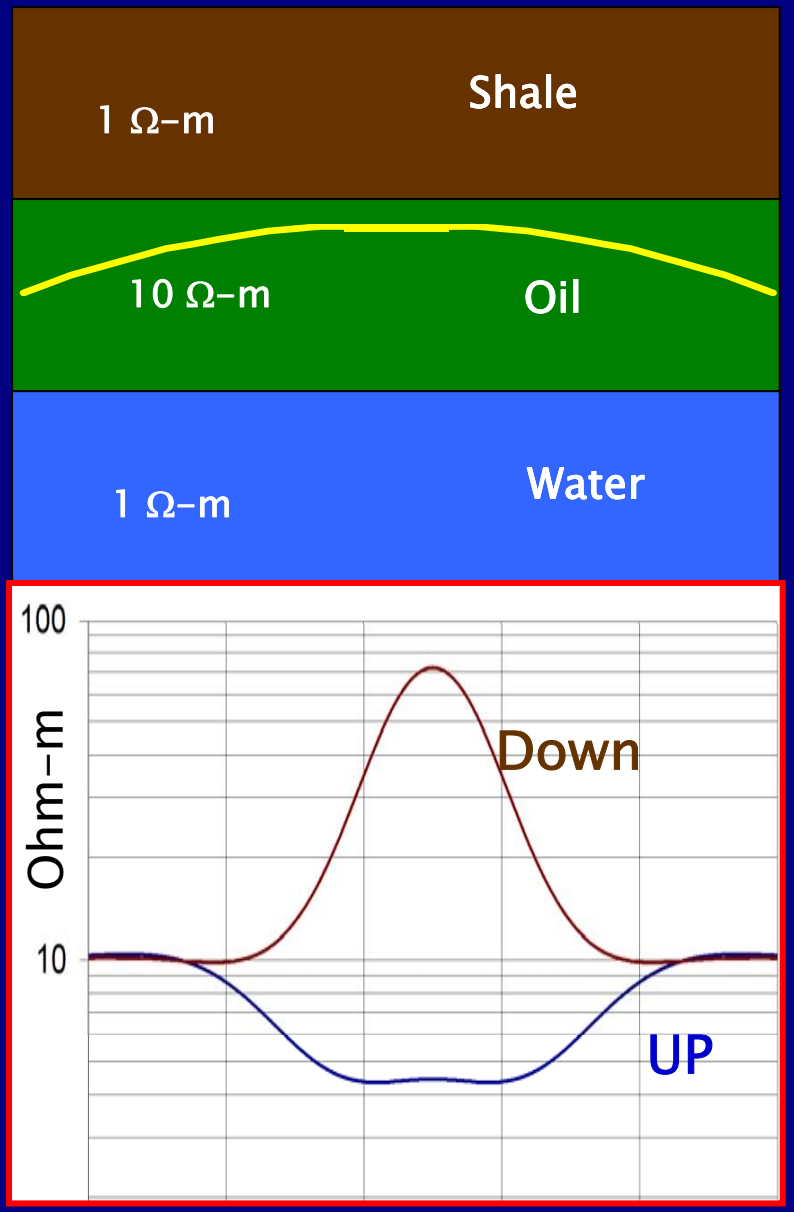
Geosteering with Non-Azimuthal Wave Resistivity





Geosteering with Azimuthal Deep Wave Resistivity ; Up-Down Resistivity

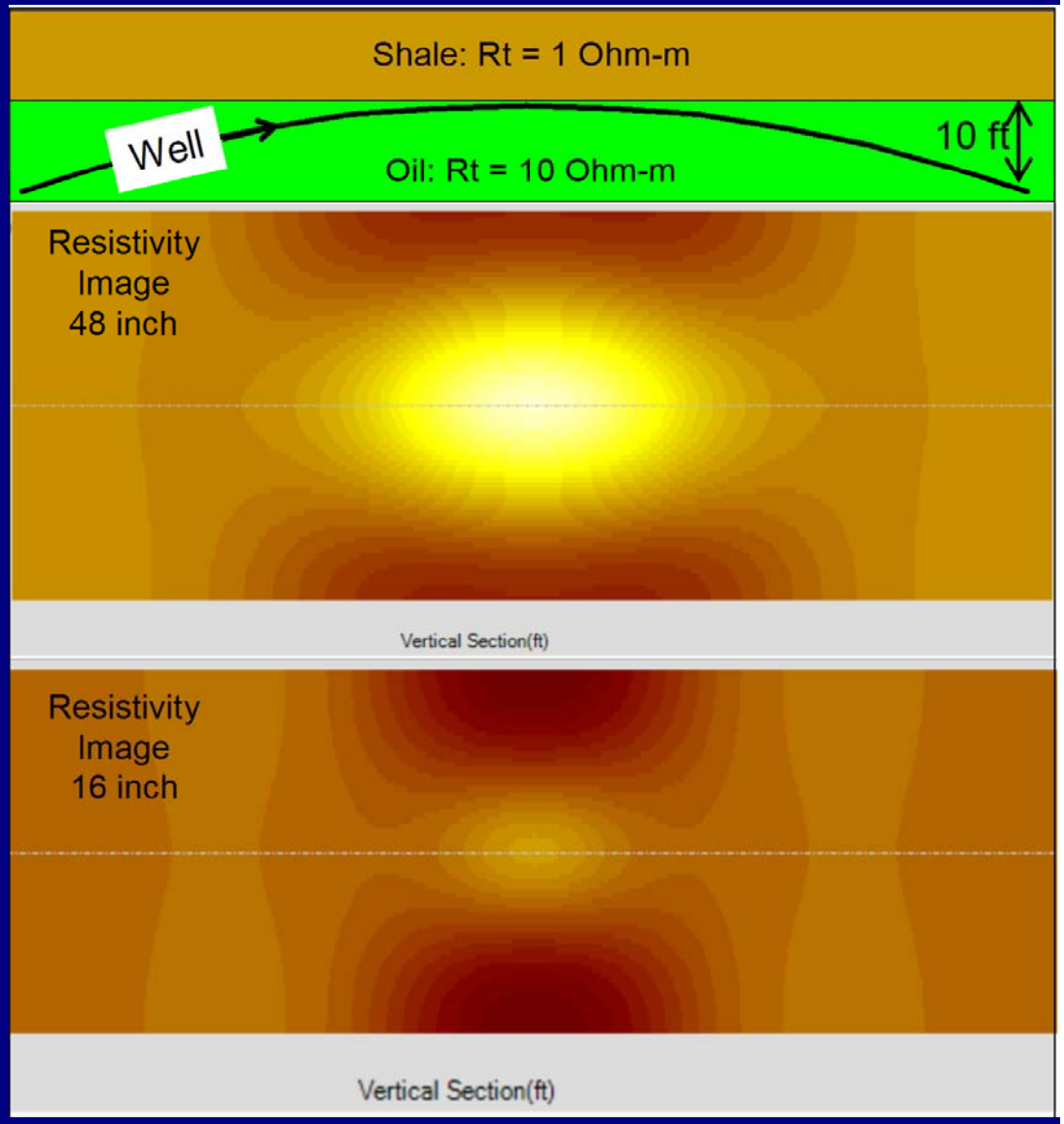




Geosteering with Azimuthal Deep Wave Resistivity Images and Bright Spots

Bright spot near boundaries

Deeper image sees bright spot before shallower image



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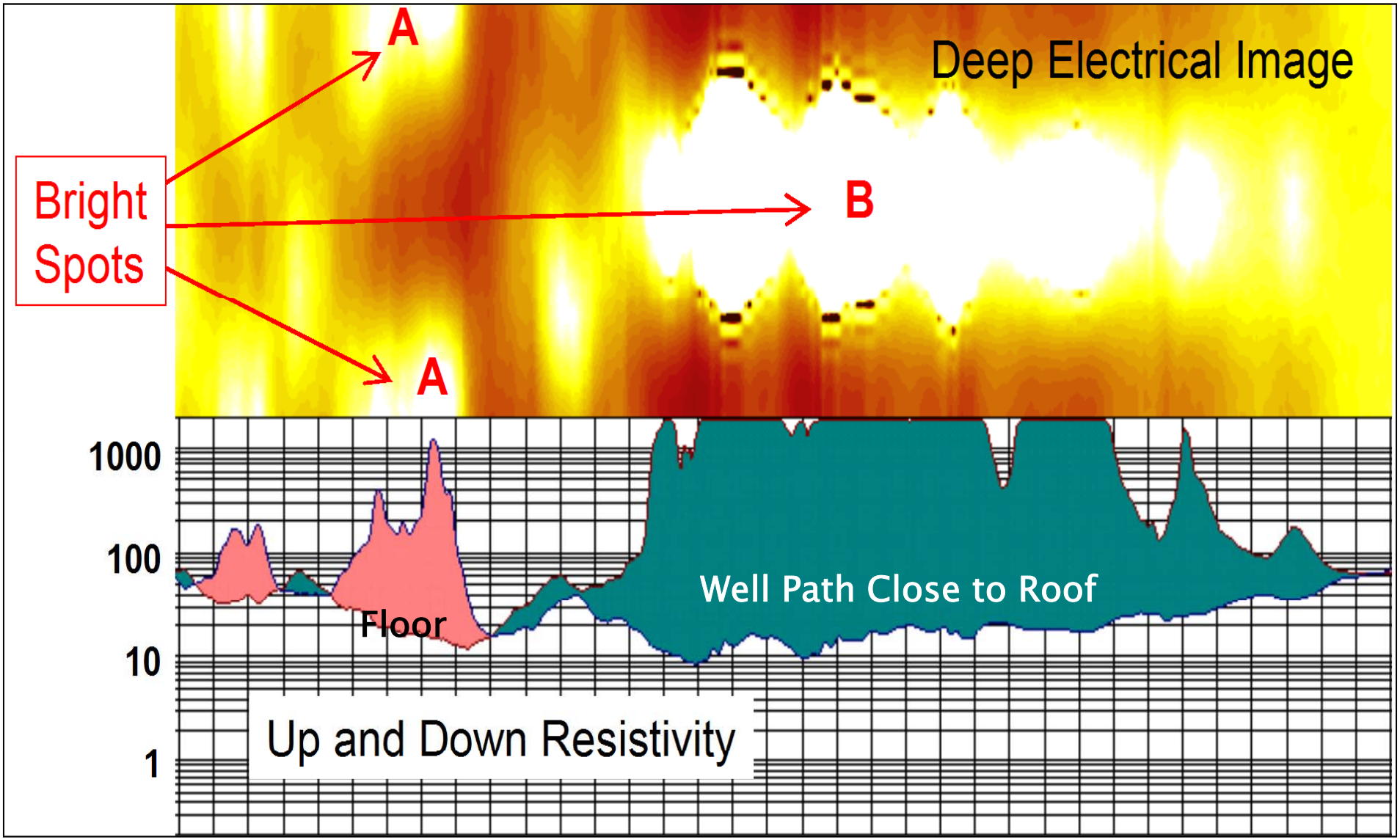
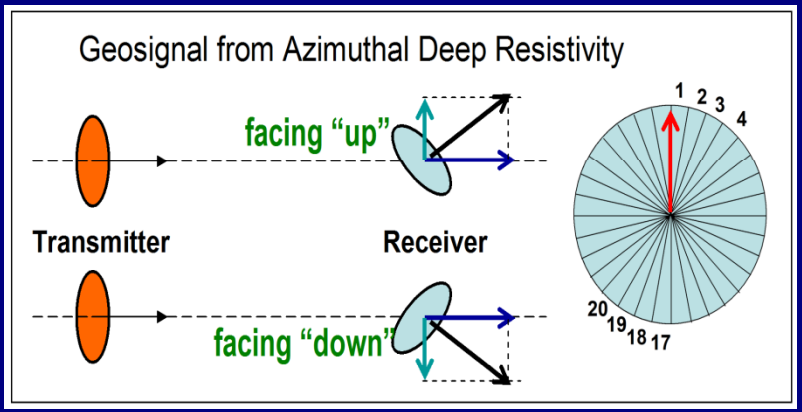
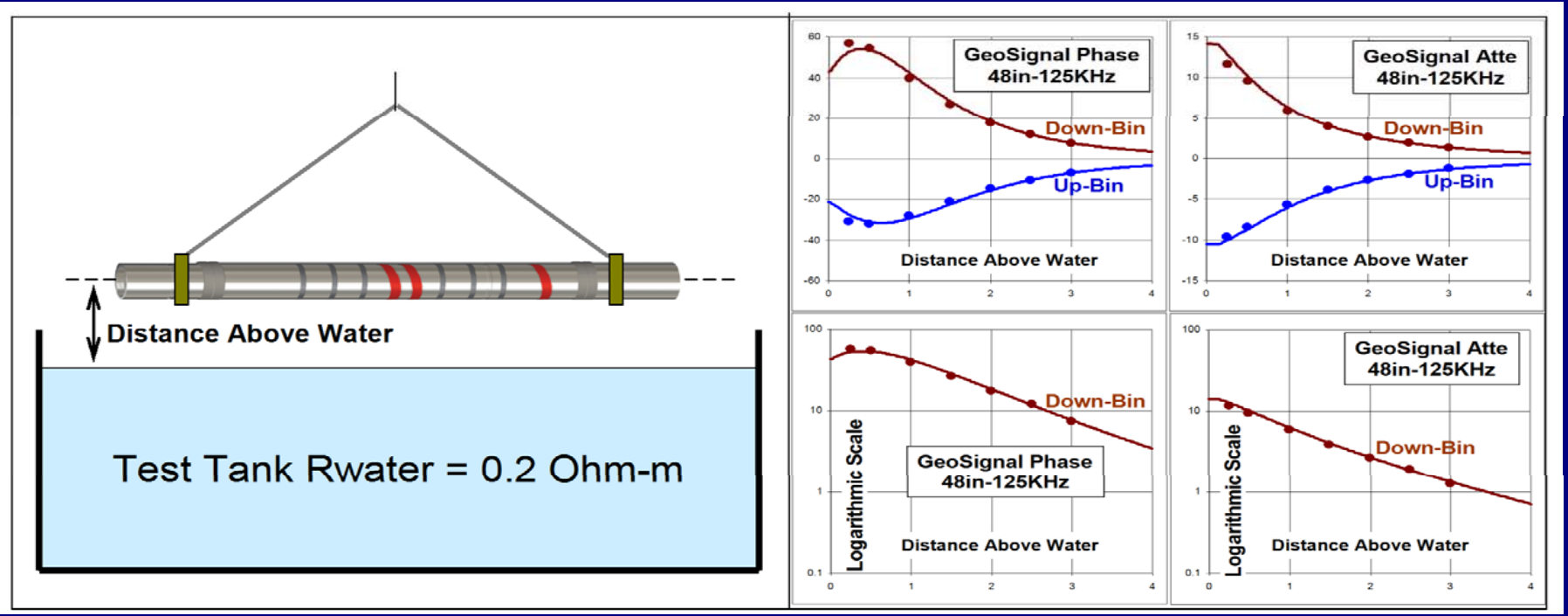


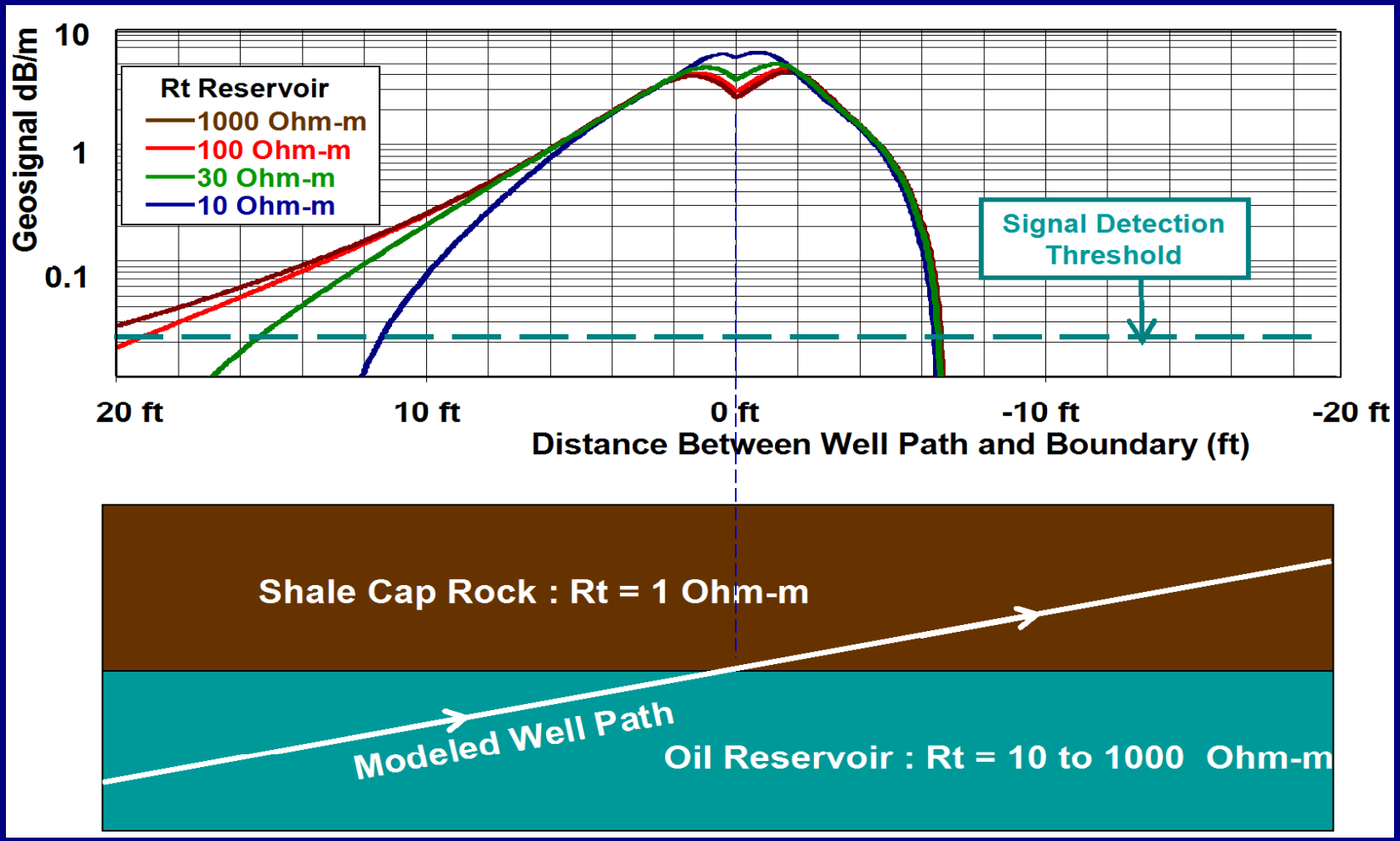
The Geosteering Signal or Geosignal Helps Determine Distance And Direction of Boundary

In general the geosignal points towards the less resistive formation

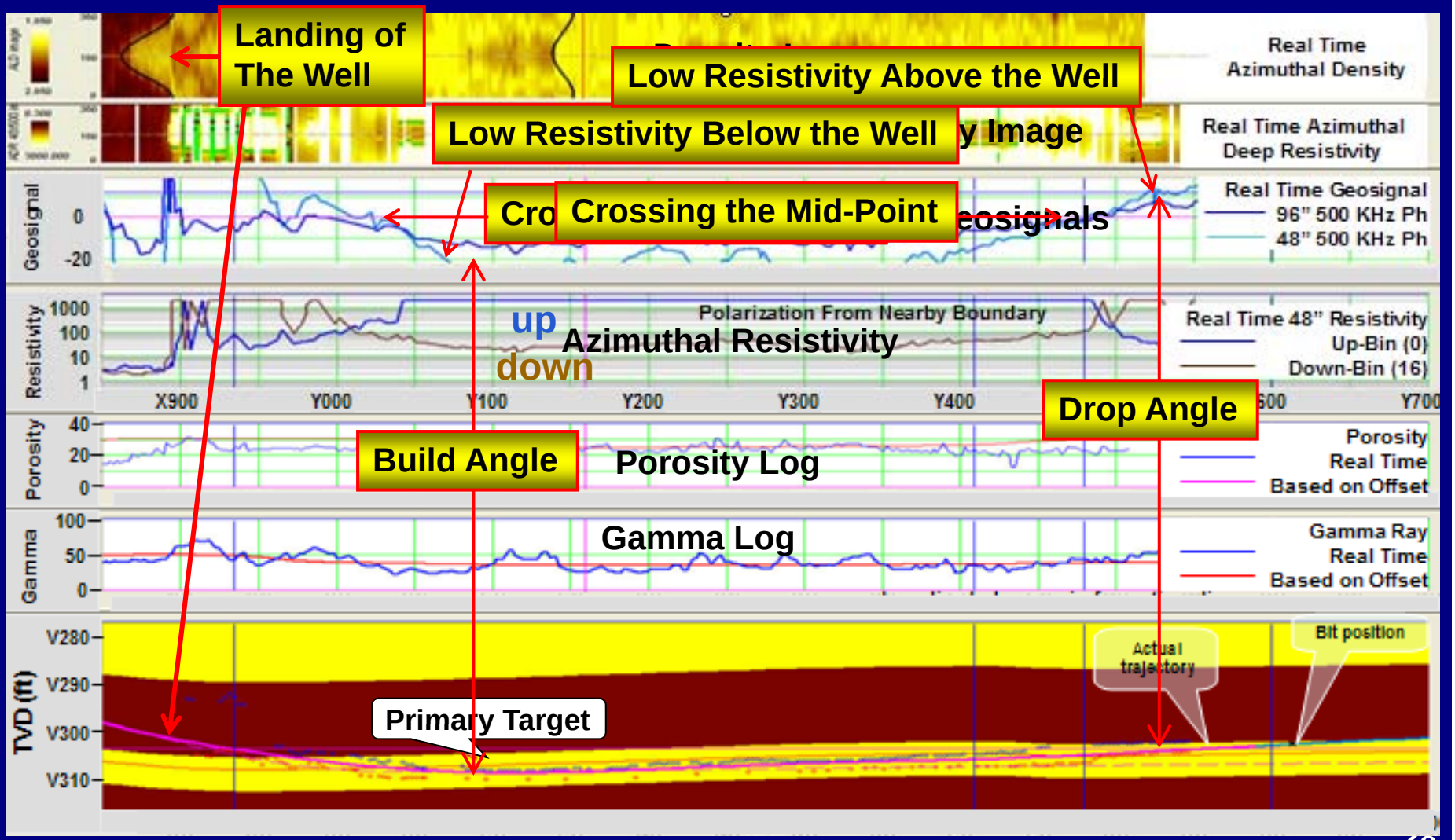




Geosignal Magnitude vs. Distance to Boundary Azimuthal Deep Wave Resistivity



Geosteering with Azimuthal Deep Wave Resistivity Real-Time Decisions



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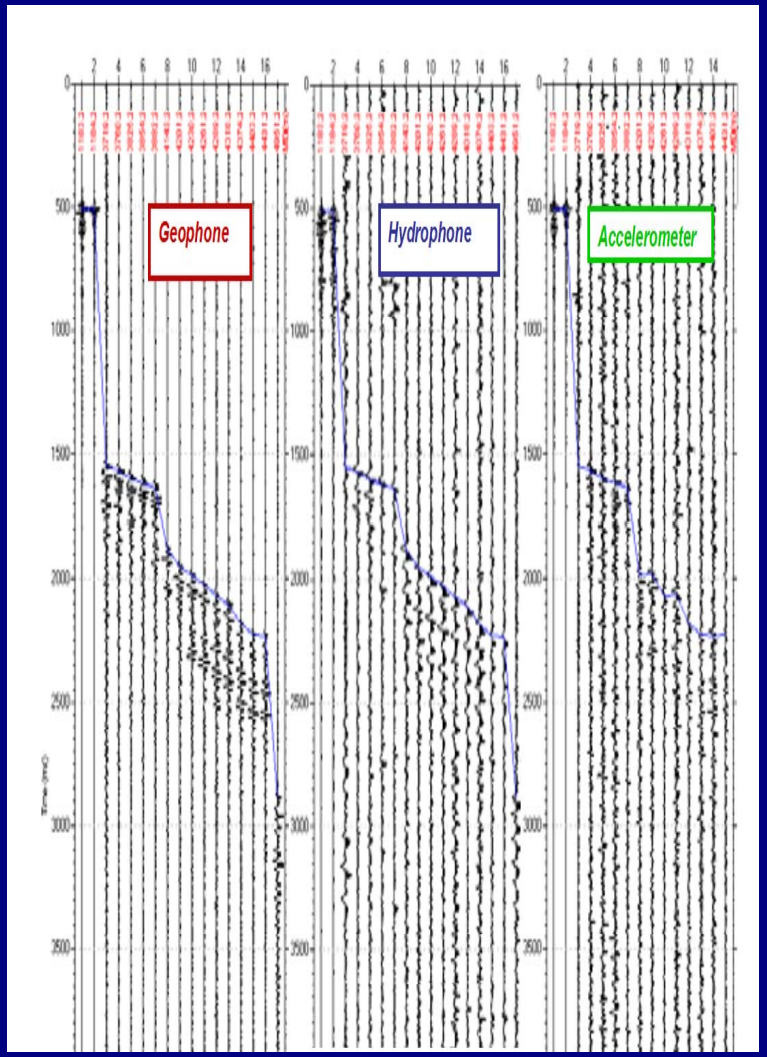
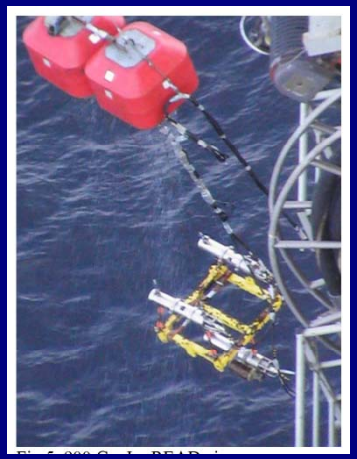
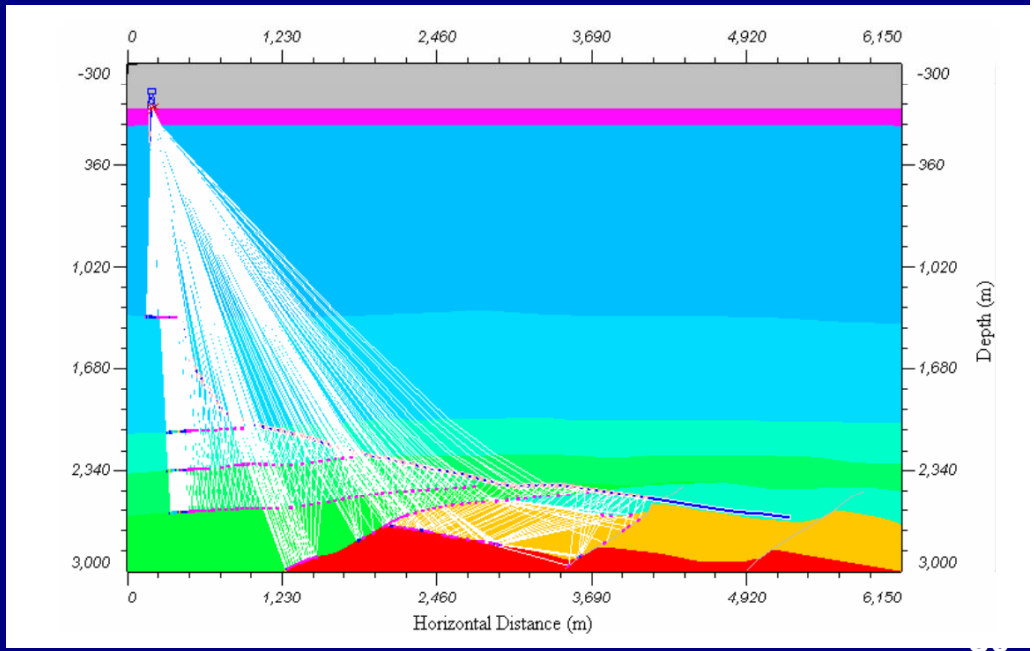
Geosteering with Seismic While Drilling

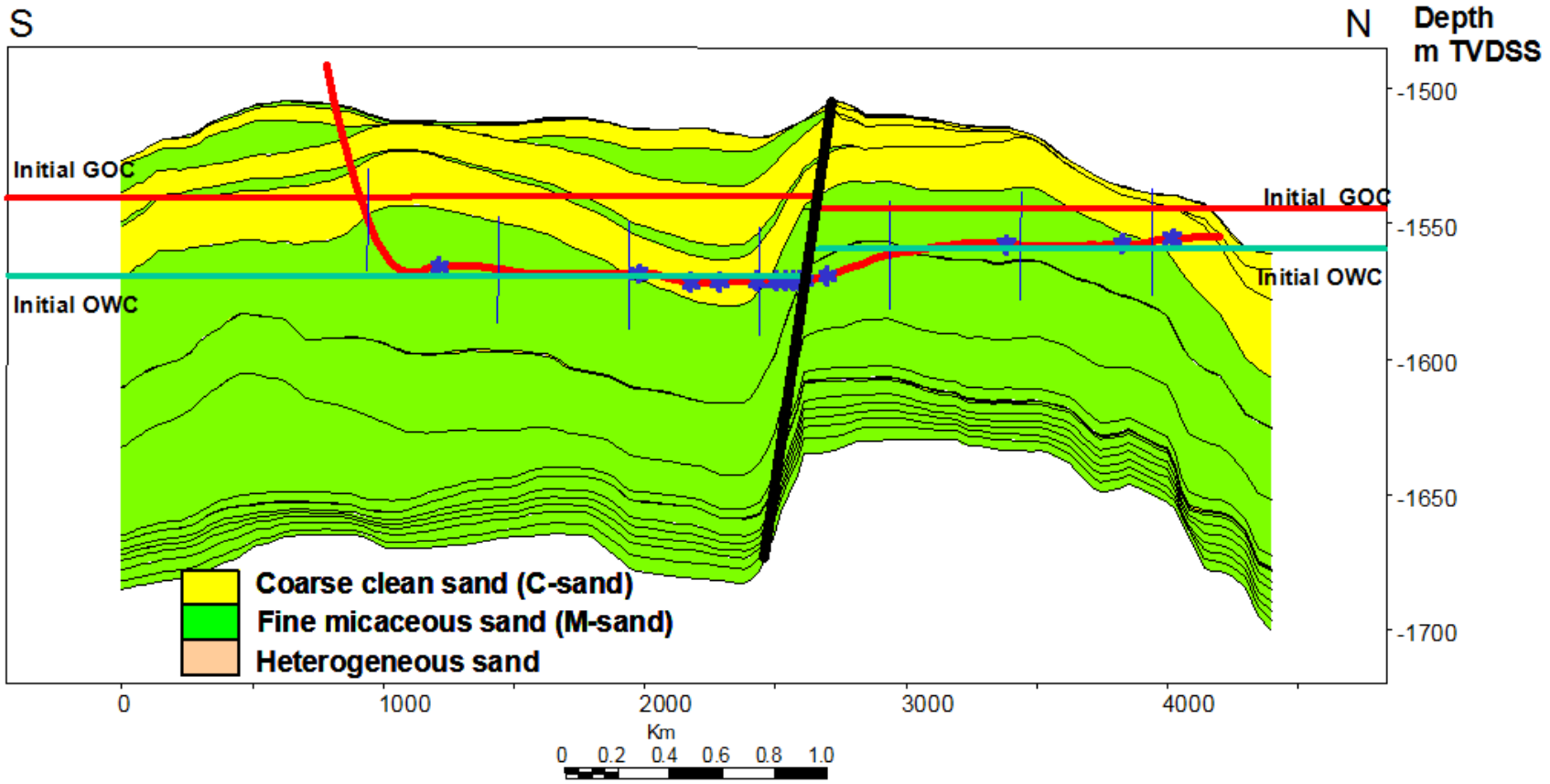






Geosteering with Formation Pressure

1. Reservoir compartmentalization or connectivity by pressure and fluid ID
2. Pressure gradient for long distance well inclination



Buysch, A., (2005) – SPE-93229

Summary and Conclusion

- Reactive geosteering: react to boundaries
  - ✓ Wellbore images
- Proactive geosteering: anticipate boundaries
  - ✓ Deep azimuthal resistivity
- Geosteering enhances early production by maximizing reservoir contact
- Geosteering optimizes sweep efficiency and ultimate oil recovery thru the life of the field

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