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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
What is Geosteering and Why Geosteer?

Simplified case of water-drive reservoir

Producing well improperly placed

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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

Water Injector

Oil Producer

Water Drive

Oil
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)
• What is geosteering? Why geosteer?

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Reactive Geosteering

Objective

Well Landing Build Angle

Reservoir Exit

Drop Angle

Reservoir Exit Build Angle

Reservoir Entry Hold Angle

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

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

Well Landing Build Angle

Objective

?
Presentation Outline

• What is geosteering? Why geosteer?

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Pro-Active Geosteering

- Objective: Well Landing, Build Angle, Imminent Exit, Drop Angle
- Maximum Reservoir Contact

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

Schlumberger Periscope™

Halliburton Azimuthal Deep Resistivity ADR™

Baker Hughes AziTrak™
• 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

1 Ω·m  Shale

10 Ω·m  Oil

1 Ω·m  Water

100  Ohm·m

10  Ohm·m

100  Ohm·m

10  Ohm·m
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
Geosteering with Azimuthal Deep Wave Resistivity Images and Bright Spots

Deep Electrical Image

Bright Spots

Well Path Close to Roof

Up and Down Resistivity


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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

![Graph showing geosignal magnitude vs. distance to boundary with different resistivity values and signal detection threshold.]

- **Shale Cap Rock:** Rt = 1 Ohm-m
- **Oil Reservoir:** Rt = 10 to 1000 Ohm-m

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Geosteering with Azimuthal Deep Wave Resistivity
Real-Time Decisions

- Landing of The Well
- Low Resistivity Above the Well
- Low Resistivity Below the Well
- Crossing the Mid-Point
- Build Angle
- Porosity Log
- Gamma Log
- Primary Target
- Geosignals
- Azimuthal Resistivity
- Drop Angle
- TVD (ft)
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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

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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