SPE Knowledge Forum

10 Rules for Cost Effective Reservoir Management

- RiskGuard™
- FullStream

David Bowling
Business Development Manager
Geoscience and Petroleum Engineering

14 March 2019
Plan for the unexpected

Actinia Oil Rig Blowout

Actinia Blowout, Feb 1993 Vietnam
In the field of observation, chance favours only the prepared mind.

Louis Pasteur, French biologist (1822 - 1895)
Impact of Information on E&P cash flow

Source: The Digital Oil Field – Oil and Gas Investor April 2004
Our Industry Performance – The Hard Facts

Geomechanics Related Incidents

COST OF NPT USD 26B

AN ESTIMATED 25% OF TOTAL DRILLING COSTS

Source of increasing Risk (2011)

KEY FACTORS

POOR ANALYSIS PLANNING

COMMUNICATION BARRIER MONITORING

CHANGE MANAGEMENT

Incident Identification

SOLUTIONS

PRE-DRILLING

GEOMECHANICS ANALYSIS

REAL-TIME COMMUNICATION

LOGGING WHILE DRILLING
Casing and Mud Design – More Realistic

Without Geomechanics (PP/FG Study)

Include Geomechanics in wellbore stability mud weight design

With Geomechanics

Both pore pressure AND collapse pressure needed
Exploration Drilling – loss of investment

Slide 7

Days

Depth

[Graph showing depth vs. days with various sections labeled: ST1, ST2, ST3/ST4, indicating 102 days behind schedule.]

P50 Plan
Actual

P50 59.44 days 15% NPT

102 days behind
Bias

- Availability Bias – prior experience influences concepts
- Confirmation Bias – only use facts that support our decision
- Blinkered mindset – don’t know what you don’t know
- Hindsight Bias – the “I knew it all along” effect
- Overconfidence – believing too much in our own decision competencies and estimates
- The “Not-Invented-Here” bias
- Sunk Cost Fallacy – to continue with a project after money, time and effort already invested
Experience

[Map showing locations around the world with various markers and labels such as Aberdeen, Houston, Beijing, Dubai, Kuala Lumpur, Jakarta, Perth. A legend is also present showing different symbols for different categories such as Wellbore Stability, Fracture Permeability, Fault Seal, Pore Pressure, Sand Production, Real-Time PPFG.]
Integrate and align goals
RiskGuard™
Analysis and risk management solutions
RiskGuard™ Drilling Solution Map

RiskGuard™ Analysis and Risk Management Solution

**RiskGuard Pressure**
- Well Control Mitigation Solution
  - Level 1 requirements
    - Geomechanical model
    - Risk Assessment
  - Gamma/Resistivity
  - RT Geomechanics

**RiskGuard Stability**
- Wellbore Instability Mitigation Solution
  - Level 1, 2 requirements
    - Geomechanical Model
    - Risk Assessment
    - Gamma/resistivity
    - RT Geomechanics
    - Acoustics

**RiskGuard Assessment**
- Risk Identification Solution
  - Geomechanical models
  - Risk Assessment

Sample of Complementary Services and Technologies (depending on risk mitigation requirements)
- High-end Acoustics
- RT Formation Testing
- Look-ahead Measurements
- Optimized FIT/LOT

**RiskGuard Trouble Zones**
- Inaccessible/Undrillable Mitigation Solution
  - Level 1, 2, 3 requirements
    - Geomechanical Model
    - Risk Assessment
    - Gamma/resistivity
    - RT Geomechanics
    - Acoustics

- Casing Liner Drilling Systems
- Performance-based Fluids

**RT Density images**
- Wellbore Strengthening Fluids
- Alarm Detection Systems
- Optimized FIT/LOT
- RT High Res Images
- Advanced Well Engineering

**Advanced Geomechanical Analysis**
- Optimized FIT/LOT
- Advanced Well Engineering
- Advanced Reaming Systems
RiskGuard™ Assessment

- 70% reduction in NPT
- Optimize drilling, faster reaction time. Proactive not reactive
- Optimise completion, larger hole size = more production
- Explore deeper, further

<table>
<thead>
<tr>
<th>Risk No.</th>
<th>Risk/Hazard Category</th>
<th>Risk/Hazard Details</th>
<th>Initial Risk Grade (H, M, L)</th>
<th>Actual or Potential NPT (hrs.)</th>
<th>Actual Cost of Event or NPT ($)</th>
<th>Residual Risk Grade (H, M, L)</th>
<th>Proposed Baker Hughes Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Drilling Success</td>
<td>Uncertainty in the azimuth of S'Hmax effects knowledge of optimal drilling direction</td>
<td>M</td>
<td>24</td>
<td>90 (may have to side-track)</td>
<td>M</td>
<td>RiskGuard Assessment, RiskGuard Stability</td>
</tr>
<tr>
<td>2</td>
<td>LOT Uncertainty</td>
<td>Uncertainty in the magnitude of S'Hmin influences upper bound of MW window</td>
<td>H</td>
<td>24</td>
<td>96 (fighting losses)</td>
<td>M</td>
<td>RiskGuard Assessment, RiskGuard Stability</td>
</tr>
<tr>
<td>3</td>
<td>Fractured Formations</td>
<td>Losses due to critically stressed fracture network or more major faults</td>
<td>H</td>
<td>24</td>
<td>96 (fighting losses)</td>
<td>M</td>
<td>RiskGuard Trouble Zones</td>
</tr>
<tr>
<td>4</td>
<td>Pp Uncertainty</td>
<td>Occurrence of overpressure variation (spatial location and magnitude) across the field</td>
<td>H</td>
<td>12</td>
<td>48 (circulating out gas, raising MW)</td>
<td>M</td>
<td>RiskGuard Assessment, RiskGuard Pressure</td>
</tr>
<tr>
<td>5</td>
<td>Pp Uncertainty</td>
<td>Drilling through and into depleted sandstones or reservoirs</td>
<td>M</td>
<td>12</td>
<td>48 (time for wellbore strengthening)</td>
<td>M</td>
<td>RiskGuard Assessment, RiskGuard Pressure</td>
</tr>
<tr>
<td>6</td>
<td>Dipping Beds</td>
<td>Bedding plane failure due to angle of attack of the well</td>
<td>H</td>
<td>24</td>
<td>96 (time for wellbore strengthening and fighting wellbore failure)</td>
<td>M</td>
<td>RiskGuard Trouble Zones</td>
</tr>
<tr>
<td>7</td>
<td>FG Uncertainty</td>
<td>Uncertainty in the fracture gradient in depleted sandstones</td>
<td>H</td>
<td>24</td>
<td>96 (fighting losses, wellbore strengthening)</td>
<td>M</td>
<td>RiskGuard Pressure</td>
</tr>
<tr>
<td>8</td>
<td>Drilling Success</td>
<td>Tight hole in the formations below the Fairlure Fm.</td>
<td>H</td>
<td>12</td>
<td>48 (reaming operations)</td>
<td>L</td>
<td>RiskGuard Stabiliy</td>
</tr>
<tr>
<td>9</td>
<td>Drilling Success</td>
<td>Blocky and elongated cavings in the Belfast and Fairlure Fms.</td>
<td>H</td>
<td>6</td>
<td>24 (optimising MW, wellbore strengthening)</td>
<td>L</td>
<td>RiskGuard Stability</td>
</tr>
<tr>
<td>10</td>
<td>Drilling Success</td>
<td>Stuck pipe and stuck logging tools in the Waard Fm.</td>
<td>H</td>
<td>12</td>
<td>48 (fighting)</td>
<td>L</td>
<td>RiskGuard Stability</td>
</tr>
<tr>
<td>11</td>
<td>Inflows and Gas</td>
<td>Gas inflow in the reservoir section requires appropriate mud weight and design (to prevent formation damage)</td>
<td>M</td>
<td>12</td>
<td>48 (circulate out gas, raise MW)</td>
<td>M</td>
<td>RiskGuard Pressure, Other Services</td>
</tr>
<tr>
<td>12</td>
<td>Weak, Shallow</td>
<td>Formation experienced tight hole and stuck pipe, possible due to reactive mud</td>
<td>M</td>
<td>12</td>
<td>48 (optimise MW, low reactivity mud)</td>
<td>M</td>
<td>RiskGuard Assessment, RiskGuard Stability</td>
</tr>
</tbody>
</table>

Baker Hughes, a GE company
Integrated RT Geomechanics - saved $30M

- **Background and Challenges**
  - Wildcat deepwater exploration
  - Offset well is 100km away
  - Poor 2D seismic, complex geology
  - Uncertain pressure mechanisms **AND** stress distribution
  - Narrow margin drilling

- **Approach and Solution**
  - Real Time Geomechanics
  - Transition zone deeper, less dramatic
  - Deepened hole section, lower mud weight
  - Drilled faster

- **Results and Benefits**
  - Safely drilled to planned TD
  - Omit un-necessary 6” hole section
  - Reduce well costs by $30M
Well Life Cycle

Drilling

- Information Management
- Drilling Engineering
- Data Mudlogging
- Rig-Site Supervision

Formation Evaluation MWD

Drilling Dynamics

Drilling Fluid Systems

High Performance Bits

Completion

- Completion Fluids
- Pumping, Simulation, Filtration

Completion Fluid Systems

Compaction

Hook-ups

Flow Control Equipment

Packers

Safety Systems

Production

- Automated Production Systems
- Performance Chemicals

D&E, C&P, Pressure Pumping

Packers

Cementing Equipment

Automated Production Systems

Flow Control Equipment

D&E, C&P, Pressure Pumping

D&E, C&P, Pressure Pumping

D&E, C&P, Pressure Pumping
Horizontal well tested validated

- Background and Challenges
  - 1037m horizontal
  - Low-permeability sand
  - Thin reservoir

- Solution
  - Pre-drill modelling
  - Real Time Geomechanics
  - Real Time Petrophysics
  - Reservoir Navigation Services
  - Well efficiency close to 100%.
  - Gas inflow exceeded 1 mm3/d
  - Potential to exceed 3 mm3/d

- Geological uncertainties eliminated: structural plans clarified, gas-water contact location established, resource base defined
- Horizontal well achievable with high flow rates

- Commercial Discovery
Benchmark Asset Performance

- Possible (3P) into Proven (1P)
- Sub commercial (3C) into commercial (1C)
- Explore deeper, further
- Enhanced Recovery and Company Wealth
Country Stress map (Kuwait)
Country Development Plan

BHGE solutions through project life cycle

World’s only fullstream Oil & Gas company ... ~70,000 employees in 120+ countries

Differentiated portfolio ... leading franchises

Oilfield Services (OFS)
- Drilling Services, Logging & Evaluation, Completions & Production, Artificial lift + Industrial Services

Turbomachinery & Process Solutions
- Centrifugal & Reciprocating Compressors + Drivers, (Gas & Steam turbines, Aero derivatives), Aftermarket Services

Oilfield Equipment (OFE)
- Subsea Production Systems, BOPs, Flexible Risers, Wellheads, Subsea Services, Surface Pressure Control

Digital Solutions
- Measuring & sensing technology, software + pipeline inspection

Driving technology synergies

Production Optimization
✓ Optimize reservoir performance,降低成本

Drilling Wells Faster
✓ Faster development through enhanced technology

Digital & Sensor technology
✓ Accuracy, Monitoring and predictivity

Fullstream commercial models; Lower cost of production / increasing industrial yield

Outcome based contracts; transfer global knowledge & experience -Well Delivery

Reduce costs. Increase productivity. Share risk and reward.
Norway: Johan Sverdrup

**Project Details**

- Integrated well construction project
- **Contract:** 6 years (with option to extend to life of field)
- 50 years estimated field life
- A trilateral partnership between BHGE, the operator, and the rig contractor

**BHGE Scope**

- BHGE’s Oilfield Services (OFS) product and services portfolio, including Drilling, Cement, Fluids, Completions, and Wireline
- A dedicated BHGE project management team adding value over pure bundled services

**Challenges**

- Multiservice contract well construction and project management
- Flawless HSE
- Deliver “The Perfect Well”

**Results**

- No serious injuries or incidents to date
- Initial drilling campaign delivered 8 months ahead of plan
- All wells to date have been delivered according to requirements
- A 50% cost reduction
- ‘Moving Perfect’ improved by 25%
- World record 17 ½’ sections
Middle East Region: Shaybah

**Project Details**
- Onshore project in a remote geographical location
- Five-year contract
- BHGE was contracted to deliver 90 multilateral wells

**BHGE Scope**
- BHGE deployed a full project management team to work alongside the customer
- Responsible for management and contracting of multiple drilling rigs
- Leveraged the full breadth of the Oilfield Services portfolio including: tubing running services, wellhead installation, drilling jars, rig and camp moving, waste management, H2S safety systems

**Challenges**
- Extremely tight mobilization schedule
- Lump-sum turnkey project
- 3D, multilateral wells
- Remote location
- Integrate multinational companies into a cohesive, safe and efficient team

**Results**
- Achieved all contractual obligations
- The fastest and deepest drilling in the history of the field
- Substantial increase in feet drilled per day (34% to 167% improvement)
- Zero well control incidents
- Successfully delivered 86 wells to date
- Contract extended due to good performance results
Malaysia, Petronas: D18 Redevelopment

**Project Details**
- Offshore SEA
- Mature field

**BHGE Scope**
- FDP, Project Management, Well Engineering, Logistics and 3rd Party Management, Perforation, Coiled Tubing, Acid Stimulation, Operations Vessel, Slick Line, Noise Mapping, Core Analysis

**Challenges**
- Multiple stacked oil and gas reservoirs with lateral and vertical faults. Highly compartmentalized.
- Decline 21,000 BOPD to 4000 BOPD
- Determine Oil In Place and establish connectivity
- Enhance Recoverable Reserves

**Results**
- **2007 safe man days; 4.1 million man hours w/o LTI**
- Deployed 30+ Petroleum Engineering and Geoscience disciplines for FDP
- **19 new technologies in 2018**
- Doubled production from 4000 BOPD to 8000 BOPD, reaching 15000 BOPD in 2019
- BHGE successfully completed 9 well program (NO LTI, low NPT)
- **Extended field life by 20 years**
What does upside look like for you?

Q: Increase Step Out on Subsea Development Wells?

- Can deviated wells be drilled in all directions?
- How will the reservoir produce?
- Is the reservoir a single connected unit or compartmentalized by the faults or fractures?
- Could increasing the step out eliminate a drilling centre

Potential reservoir reached by a Subsea Drilling Centre
10 rules for project success

- Every Project is Different
- Align project goals
- Start at exploration
- Strategic data acquisition
- Share knowledge between everyone
- Collaborate
- Use analogues (Local, Regional, Global)
- Introduce new technology and update
- Learn from experiences
- Remove Bias
Yes, ma’am, the more I practice, the luckier I get!

in response to a lady who said – “that was a lucky shot!”

Gary Player, Golfer