70 YEARS OF CREATING TOMORROW

Los Alamos NATIONAL LABORATORY

Ultra-deep Water Risk Assessment

DV Rao

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Summary of Phase-I (1st-yr) Analyses

Risk-ranking of candidate technologies

Model Baseline and Data

- Generic ultra-deep water drilling operation in GoM with MODU
- Overpressure Drilling consistent with IADC and API guidance.
- Class VII BOP with 1 BSR and 1 CSR (BOP Controls API-RP 53).
- End-to-end probabilistic risk assessment (APET and FT)
- Well dynamics modeling for blowout time scales and flow rates
- Reliability data from 3rd Party (SINTEF) and from JIP efforts

Ranked list of technologies

1. Real-time data from the bottom-hole
2. VSP (see also No. 9 below)
3. Automated kick detect (with 1 above)
4. Human performance improvement:
   - MWD alerts during swabbing, fishing, etc.
   - Rotating control device
   - 'quick-response' BHP control (closed cycle)
5. Inline DP BOP/Check-valve
6. Reliable LMRP & Emergency Containment
7. Improved BOP
   - Casing, Collar and DP locator
   - Larger choke/vent lines and higher capacity mud-separator
8. Sub-salt 3-D seismic after setting shoe
9. Well dynamics modeling (1-d ➔ 3-d)

OTC Abstract submitted summarizing results

Summary of Phase-II (2nd-yr) Analyses

Driver: How can we achieve orders of magnitude improvement?

Project goal: Identify risk-important technologies and their TRL for Ultra-deep Paleogene
Technical Approach: Systems and risk modeling to estimate risk management

Uncertainties and Knowledge-Gaps

- Peleogene Wilcox formations in ultra-deep-waters of GoM
- Dynamics of salt movement
- Drilling window is small and very high uncertainty (fewer off-set wells)
- Increased probability of ballooning, mud losses and well-control issues.
- Multiple sands
- High Pressures and potentially High Temperatures
- Ocean dynamics (RPSEA-1402 Data)

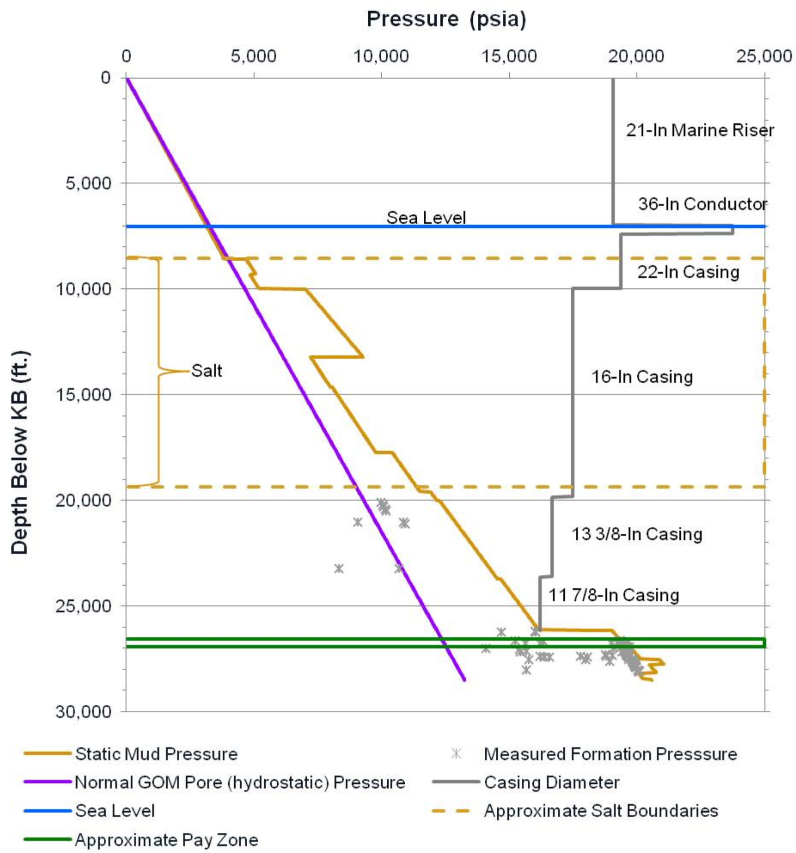
Model Baseline and Data

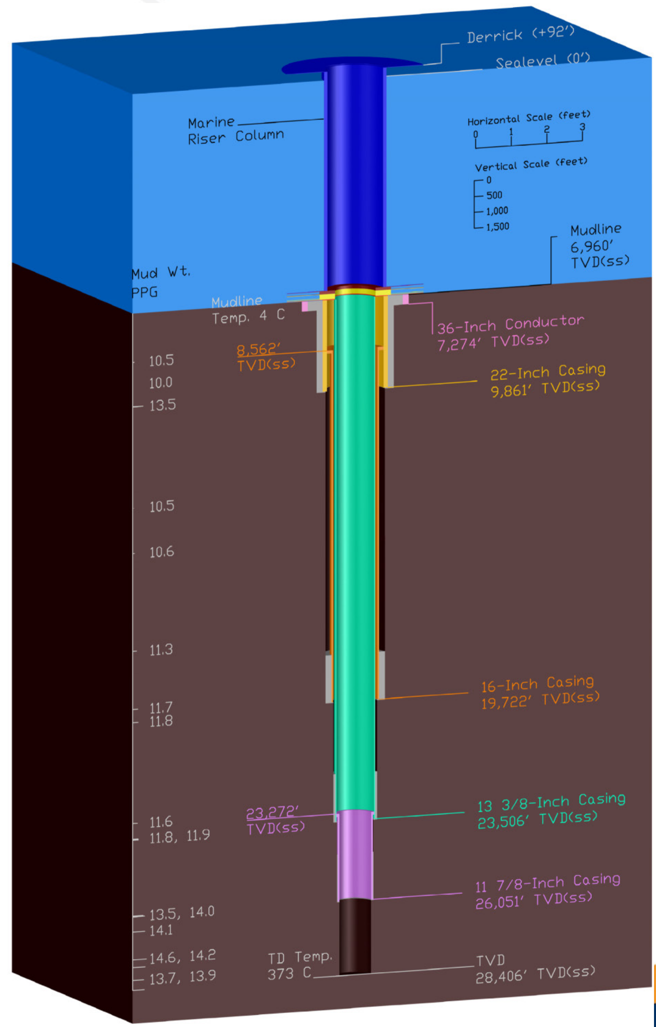
- Generic well in GoM[1]
- Lithology data from multiple sources [2-3]
- Closed Loop Drilling[4-6] (or Managed Pressure Drilling)
- MWD suite of sensors[6] + Coriolis flow meter

References
[1]IHS database
[2] Dessenberger et al;
[3] RPSEA 2501-12 Knowledge Reservoir
[4]JPT Survey.
[5] D. Hennegan, Weatherford (OTC-24097)
[6] Bob Judge, GE Oil & Gas
[7]See Slides 6 and backup slides.

Generic Well Model for Simulations

Variations from the base-case will be considered





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Candidate MWD Technologies for Simulations

Information using Bayesian Inferencing

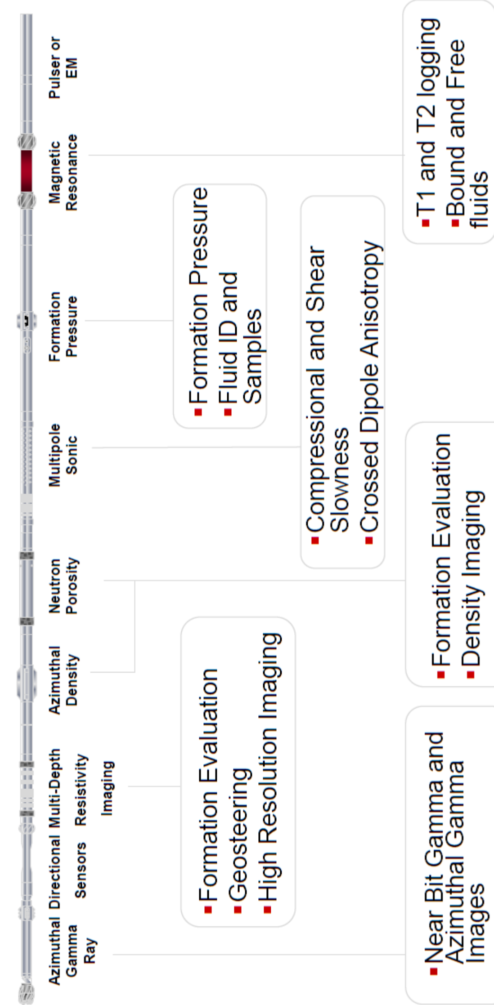
- Vertical Seismic Profile (S_1)
- Coriolis Mud Flow Meter (S_2)
- Annular Pressure & Temperature (S_3, S_4)
- Resistivity At The Bit + Gamma Ray (S_5, S_6)
- Sonic (S_7)
- Rate of Penetration (S_8)
- Shock & Vibration at the bit (S_9)

$$p(E \mid S) = \frac{p(E) \times p(s \mid E)}{p(E) \times p(S \mid E) + p(NE) \times p(S \mid NE)}$$

$$p(S \mid E) = p(S_1, S_2, S_3, S_4 \mid E)$$

$$\cong p(S_1 \mid E) \times p(S_2 \mid E) \times p(S_3, S_4 \mid E)$$

Picture from Schlumberger Used for illustration



Human performance assessed based on p(E|S).
NRC/FAA Data.

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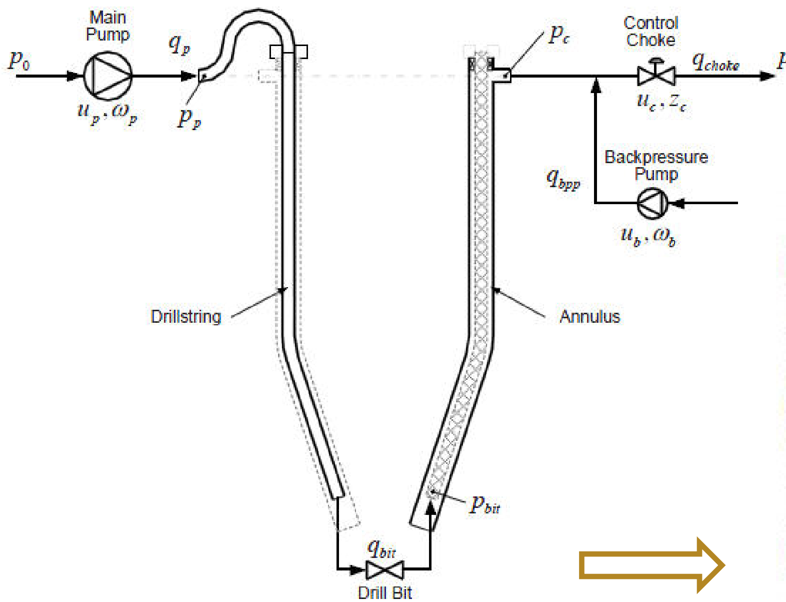
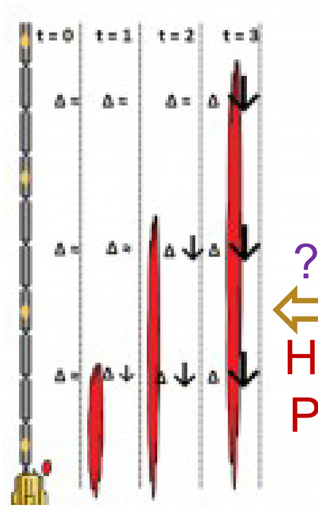
Computational Well-Dynamics Model

To provide data on false negatives and false-positives?



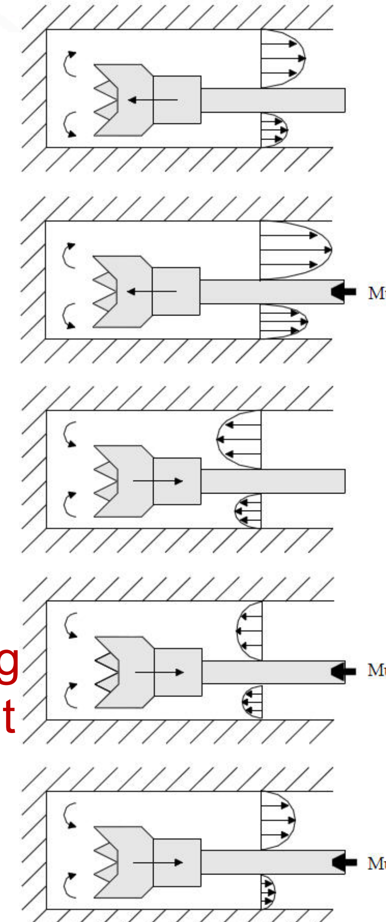
Heaving Isolated



Kick Progression

????

Heaving Present



Ocean Heaving

Picture from Chin and Zhuang, Stratamagnetic Software used for illustration of Swab-Surge Modeling

- Multi-phase CFD Model
- Closed Loop System
- Uncertainty Analysis

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Anticipated Results

- Technical Report Summarizing Risk Assessment.
- Brief to Industry and Stakeholders

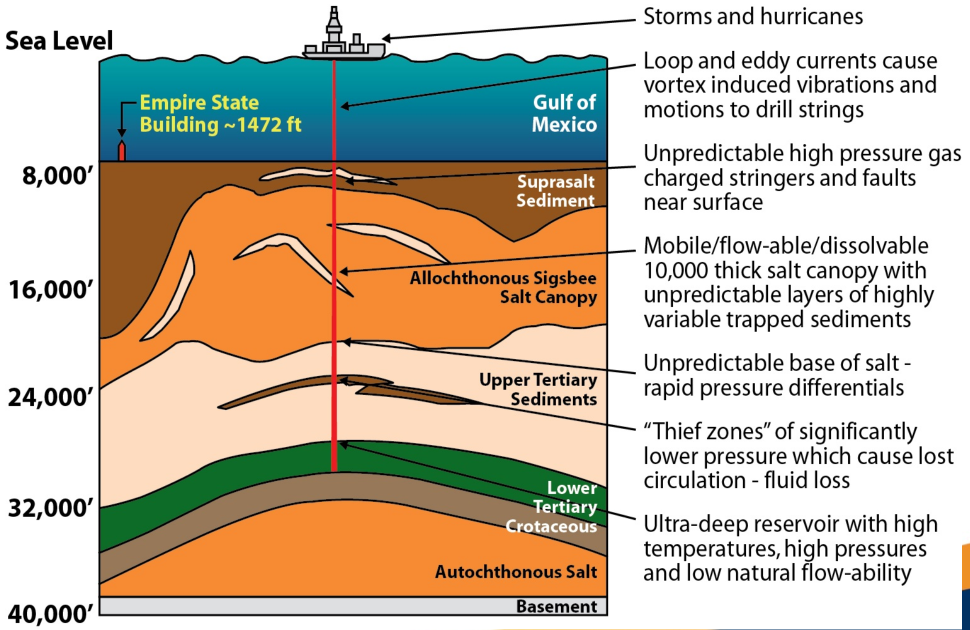
BACKUP SLIDES

Stratigraphy and Heterogeneity impact on UDW Drilling

- Ultra-deep water plays have unique characteristics different from the past history.
  - Reservoirs are often at greater subsea depths and have HPHT (>15,000 psi & >180°F)
  - Seismic imaging of subsalt reservoirs is often poor
  - Reservoirs are consolidated, cemented and have low rock compressibility. They often have lower porosity and permeability but with local seismic fault regions that could have very high permeability
  - Lower overburden significantly lowers window between pore pressure and formation fracture pressure in the target region; some times window less than ½ pound-per-gallon (or 200 – 300 psi)

Parameter	Units	Upper Tertiary	Lower Tertiary
Total Vertical Depth	ft	16, 500	27, 500
Water Depth	ft	4, 200	7, 800
Reservoir Thickness	ft	35	210
Porosity	%	28	17
Water Saturation (Sw)	%	25	30
Permeability	mD	500	16
Rock Compressibility	µsips	12	3
Reservoir Pressure	psia	11, 000	19, 500
Reservoir Temperature	F	186	230
Saturation Pressure	psia	5, 000	1200
API Density	API	32.0	29.0
Gas-to-Oil Ratio	Scf/stb	1, 000	300
Oil FVF	Rb/stb	1.61	1.14
Oil Viscosity	cp	1.5-2.0	3-4
Absolute Open Flow Potential	Stb/d	33, 000	6, 500
Peak Oil Rate	Stb/d	6, 000	6, 000

Phenomenological description of the challenges (Chevron)



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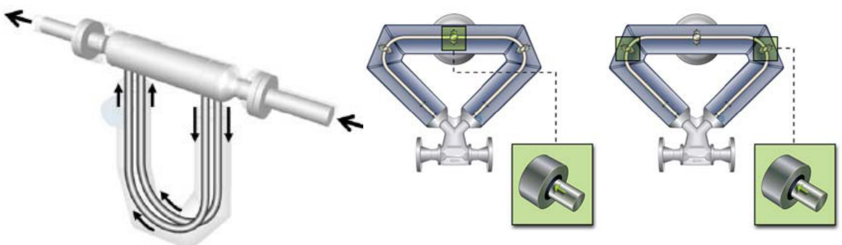
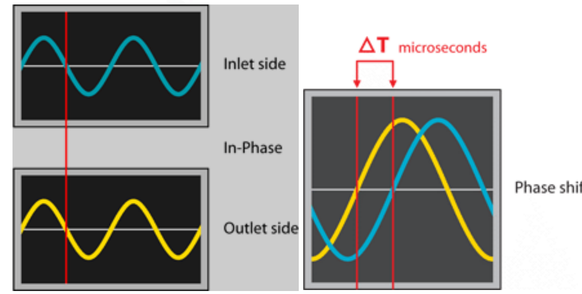
Coriolis Mud Flow Meter

Excess mud flow out of the well = Kick

Coriolis sensors are classified as a ultivariable sensor, as they provide a measurement of mass and volume flow rate, density and temperature. The mass flow rate accuracy is 0.05 to 0.1% of rate. The sensor consists of a manifold which splits the fluid flow in two, and directs it through each of the two flow tubes and back out the outlet side of the manifold.



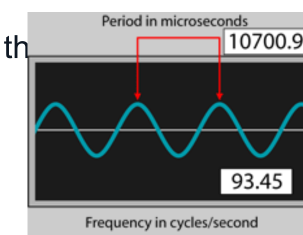
A drive coil is mounted at the center of the two flow tubes geometry to vibrate the process fluid and tubes at a natural harmonic frequency. A magnet and a pickoff coil are located on the inlet and outlet side of the flow tubes and provide the means for measuring the Coriolis effect.
Because of the vibration, the coil moves through the magnetic field and generates a sine wave proportional to that motion.



When the tubes are full of process fluid and at a zero flow condition, the sine waves from the inlet and outlet pickoff coils are in phase. Under flowing conditions, the tubes twist due to the Coriolis effect and the two sine waves shift apart. The time differential between the two signals is directly proportional to mass flow rate.

Measuring the frequency of the tube vibration provides a direct measure of the density of the tubes.

The fluid volume flow rate at operating conditions is determined by dividing the mass rate by the measured density. An RTD measures temperature of the flow tubes.



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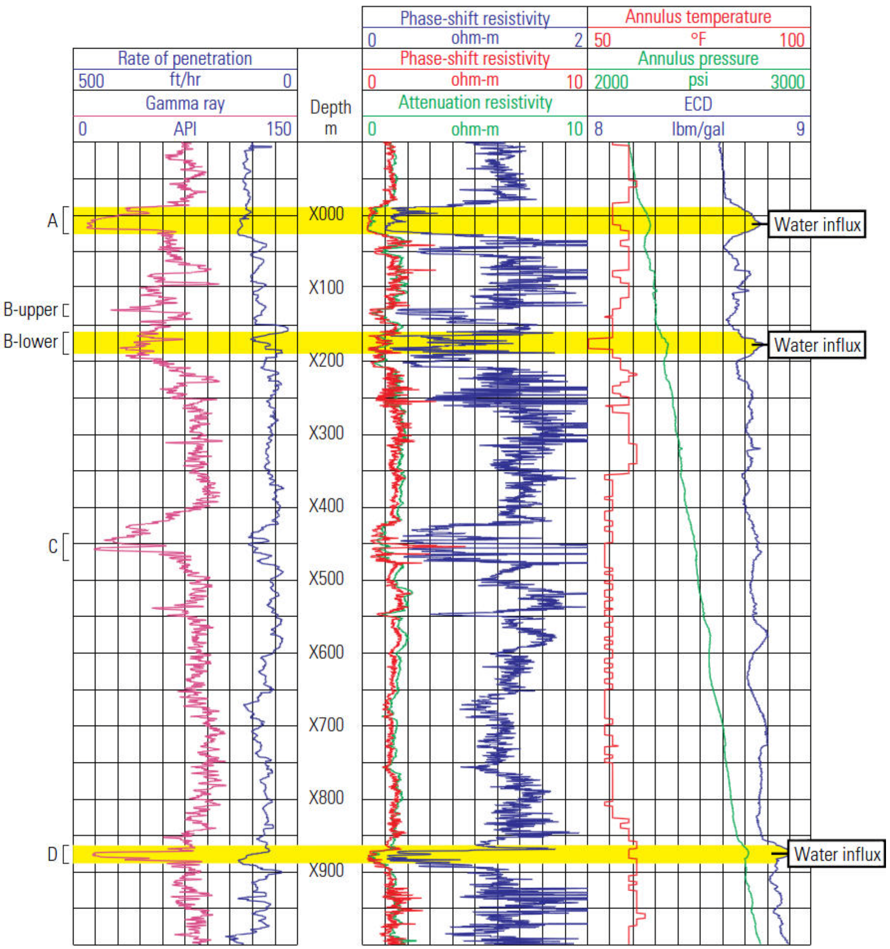
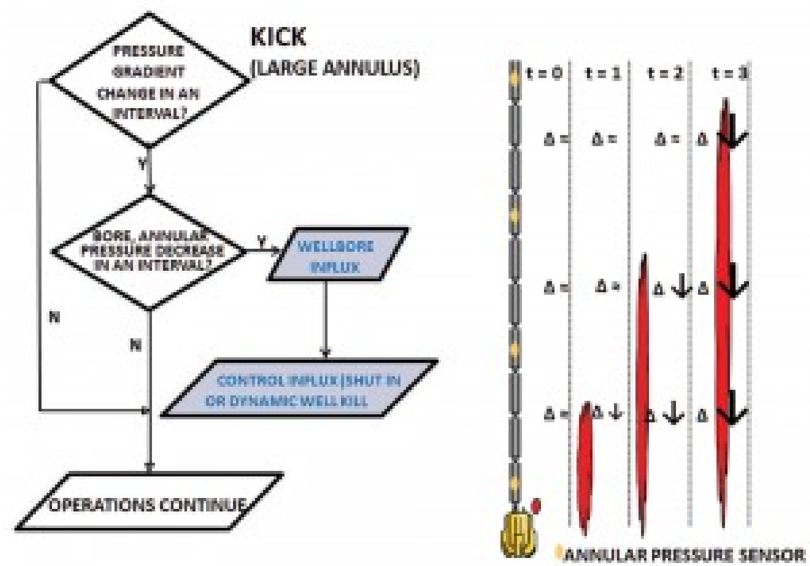
Slide 10

Annular Pressure & Temperature



Annular Pressure & Temperature measurements distributed up the drill string provide real-time data that can monitor the progress of an expanding kick volume in the annulus.



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Slide 11