Welcome

Exploration
Geologic Risk Assessment
And Prospect Evaluation

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In – san – i – ty

Webster:

“Extreme folly or unreasonableness”

Albert Einstein:

“Insanity is doing the same thing over and over again and expecting a different result.”
Risk Analysis:
An integrated project assessment (resources, chance, economics) under conditions of uncertainty.
Utilized for subsequent Decision Analysis.

Risk Management:
The art and science of identifying, analyzing and responding to risk factors throughout the life of a project.

✅ **Uncertainty:** Range of possible outcomes

✅ **Chance:** Likelihood of occurrence

✅ **Risk:** Threat of loss
Expected Value

The basic equation for project evaluation

\[ EV = P_c (PV_c) + P_f (PV_f) \]

Expected Value is the sum of the probability-weighted outcomes

- \( c = \) commercial success outcomes
- \( f = \) geologic and commercial failure outcomes
This part of the Basic Equation is expressed as a cash-flow schedule incorporating net revenue interest (NRI), production decline, time-value of money, and anticipated inflation.

\[ P_c \left( \text{NRI} \times \text{TOTAL EUR WELLHEAD PRICE} \right) = \left( \text{NET FINDING, DEVELOPING, & OPERATING COSTS} + \text{NET TAXES} \right) + \left( 1 - P_c \right) \left( \text{NET AFTER TAX FAILURE COST} \right) = \text{PROJECT EXPECTED NET PRESENT VALUE @ X%} \]

*NRI = Net Revenue Interest = (1 – Royalty)*
This part of the Basic Equation is expressed as a cash-flow schedule incorporating net revenue interest (NRI), production decline, time-value of money, and anticipated inflation.

\[ P_c \left[ NRI \times \frac{TOTAL \ EUR}{WELLHEAD \ PRICE} \right] - \left[ NET \ FINDING, \ DEVELOPING, \ \& \ OPERATING \ COSTS \right] - \left[ NET \ TAXES \times \left( 1 - P_c \right) \right] - \left[ NET \ AFTER - TAX \ FAILURE \ COST \right] = PROJECT \ EXPECTED \ NET \ PRESENT \ VALUE \ @ \ X\% \]

*NRI = Net Revenue Interest = (1 – Royalty)*
Exploration Evaluation Process

- Probabilistic EUR Estimation
- Geologic Chance Assessment
- Engineering, Economics, Com./Econ. Truncation
- Post Drill Assessments, Performance Tracking

Recommend Process Improvements

After Otis & Schneidermann, 1997
Objectives

1. Discuss uncertainty in E&P, its magnitude and effects, and the application of statistics to characterize uncertainty.

2. Discuss fundamentals of estimating prospect resources (EUR) and assessment of chance of success, that lead to accurate calculation of value and better exploration decisions.

3. Convey the importance of assessing geotechnical performance, by comparing forecasts to actual ultimate recovery, critical chance factors, and profitability with actual outcomes.

4. Learn, network and have fun.
Objectives

Statistics and Uncertainty

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Definitions

Event: One of two or more things which can occur, aka, possible outcomes

Outcome: What does occur

Probability: Subjective confidence about the likelihood of an uncertain future event, given repeated trials

Distribution: An orderly portrayal of related data samples selected from a population
Sample and Population Descriptive Terms

• Measures of central tendency
  – Mode – the most frequent event
  – Median – half events are above; half are below
  – Mean – average of all values in the distribution

• Measures of uncertainty
  – Variance – the average of squares about the mean
  – Standard deviation – square root of variance
  – P10/P90 – ratio of the P10 to the P90
Plotting Conventions

• Definitions: % \(\geq\) (‘GE’) or % \(\leq\) (‘LE’)
• Industry standard: % \(\geq\) (‘GE’)
  – Explorers think in terms of large discoveries
  – Consistent with SEC / SPE / WPC / AAPG guidelines
  – Commercial threshold truncations easier to apply
  – Less confusing for decision makers

In a Greater Than convention:
• P10 is the larger number
• P90 is the smaller number
What Are P10 and P90?

• In the GE convention
  – P10 is the value on the distribution for which there is a 10% probability that a random selection from that distribution will be greater than or equal to that value – this is a large number
  – P90 is the value on the distribution for which there is a 90% probability that a random selection from that distribution will be greater than or equal to that value – this is a small number

• In the LE convention
  – P10 is the value on the distribution for which there is a 10% probability that a random selection from that distribution will be less than or equal to that value – this is a small number
  – P90 is the value on the distribution for which there is a 90% probability that a random selection from that distribution will be less than or equal to that value – this is a large number

• These definitions apply to any Pvalue
Distributions

Sums tend to have distributions that are normal-like

Products tend to have distributions that are lognormal-like

Estimates of EUR (Resources) are products: Area x Avg Net Pay x Recovery Yield
Resource Field Size Distribution
North Sea Brent Play

Estimates of EUR are products: (Area x Net Pay x Recovery Yield)
Productive Area Distribution
GOM DW

Estimates of Area are products: (Length x Width)
Avg Net Pay Distribution
Brazil DW

Estimates of Net Pay are products:
(Thickness x N/G)
Most natural processes are products: Why rainfall?
Objectives

Estimation of Resource and Chance

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Critical Success Factors

• Develop and maintain a rigorous, probabilistic process that delivers predictable resources - *Deliver what you promise*

• Focus on high quality technical evaluations of prospects and plays - *Strong focus on fundamentals*

• Improve assessment of prospect chance, volumes and risk through calibration with actual results to allow better portfolio decisions – *Active performance tracking*
Prospect or Play Evaluation

- Do we have a **Source** of hydrocarbons? What kind – oil or gas?
- Can we **Migrate** the hydrocarbons from the source to the trap with the right **Timing**? When and how much?
- Do we have a **Reservoir** to store the hydrocarbons? What are its characteristics?
- Is the a **Closure** to trap the hydrocarbons in the reservoir? How big is it?
- Is there a seal that will **Contain** the hydrocarbons to the present day? How efficient is it?
Five Independent Chance Factors Multiplied Together Yields Pg

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Five Independent Chance Factors Multiplied Together Yields Pg

- **Source**
  - Source presence
  - Source quality
  - Generation history
  - Migration pathways
  - Migration shadows
  - Preservation

- **Timing & Migration**

- **Reservoir**
  - Reservoir presence
  - Reservoir continuity
  - Porosity
  - Permeability
  - Diagenesis

- **Closure**
  - Data quality
  - Data control
  - Structural complexity
  - Velocity variations
  - Depth variations

- **Containment**
  - Seal lithology & continuity
  - # of seals necessary
  - Fault gouge
  - Pore pressure

Focus on Fundamentals
Van Krevelen Diagrams - Oil or Gas?

- Indicates kerogen type which impacts whether source rock is oil prone (Type I), gas prone (Type III) or both (Type II)
- What is Fm 4?

Plot hydrogen and oxygen indices obtained from pyrolysis
**Figure 7.** Burial-history curve at the Currant Creek location. Data used to construct the curve are presented in table 2. Location shown in figure 1. Fm., Formation; Sh., Shale; Gp., Group; L. Cret., Lower Cretaceous rocks.
Petroleum-System Events Charts

<table>
<thead>
<tr>
<th>Time (Ma)</th>
<th>Geologic Time Scale</th>
<th>Petroleum System Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>400-300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200-100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100-0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paleozoic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D  M  P  P</td>
<td></td>
<td>Source Rock</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reservoir Rock</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Seal Rock</td>
</tr>
<tr>
<td>Mesozoic</td>
<td></td>
<td>Overburden Rock</td>
</tr>
<tr>
<td>T  J  K</td>
<td></td>
<td>Trap Formation</td>
</tr>
<tr>
<td>Cenozoic</td>
<td></td>
<td>Generation-Migration-Accumulation</td>
</tr>
<tr>
<td>P  N</td>
<td></td>
<td>Preservation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Critical Moment</td>
</tr>
</tbody>
</table>

From Magoon & Dow, 1994
Maps, Cross Sections, Well Logs
Armada Field, North Sea

<= Structure Map
Summary Log =>

Cross Section =>

Data from Abbotts, 1991
Seismic Data Quality

What is the chance of structural closure, faulting, good velocity control?
Geological Probability of Success

Chance Factor Adequacy Matrix

<table>
<thead>
<tr>
<th>Confidence level</th>
<th>Quality</th>
<th>Quantity</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Poor</td>
<td>Limited</td>
<td>Bad News</td>
</tr>
<tr>
<td>High</td>
<td>Good</td>
<td>Lots</td>
<td>Good News</td>
</tr>
</tbody>
</table>

“Coin Toss”
Resource Estimation

• Do we have a **Source** of hydrocarbons? What kind – oil or gas?
• Can we **Migrate** the hydrocarbons from the source to the trap with the right **Timing**? When and how much?
• Do we have a **Reservoir** to store the hydrocarbons? What are its characteristics?
• Is the a **Closure** to trap the hydrocarbons in the reservoir? How big is it?
• Is there a seal that will **Contain** the hydrocarbons to the present day? How efficient is it?
Estimation of Resource

Source
- Hydrocarbon type
  - Oil or gas or both?

Timing & Migration
- Fluid properties
  - GOR
  - Wet or dry gas?

Reservoir
- Depositional Environ.
- Reservoir thickness, continuity & temp.
- Porosity
- Permeability
- Water saturation

Closure
- Structural or stratigraphic trap?
- Productive area
- Spill point
- HC column height
- Depth of burial

Containment
- Hydrocarbon column
  - Shale or Evaporite?
  - Cataclasis?
  - Capillary pressure
  - Overpressure?
  - Temperature

Focus on Fundamentals
Maps, Cross Sections, Well Logs
Armada Field, North Sea

<= Area, Column, Trap Type
Depositional Environment, Porosity =>

Depth, Burial History, Temperature, Pressure =>

Data from Abbotts, 1991
Porosity Depth Plots

• Porosity normally decreases as depth increases
• Porosity-depth plots illustrate the uncertainty associated with specific depth intervals

From Taylor, et al, 2010
Gulf of Mexico Shelf, MMBOE

GOM shelf data from MMS

GOM Shelf
Gulf of Mexico Shelf and Deepwater. MMBOE

The P99 is typically driven by economics
The P01 is typically driven by geology.
The P99 is typically driven by economics.
Reality Checks
Drivers of Uncertainty

Downside potential is similar
What drives the upside difference?
Reality Checks
Drivers of Uncertainty

Avg Net Pay is similar in all three plays
Reality Checks
Drivers of Uncertainty

Prod. area is a key driver
Why the separation in the Campos Basin?

GOM DW
Campos Basin
West Africa

Prod. Area (acres)

Derived from Cossey & Associates, Inc. Deepwater Database
Focus On Fundamentals

1. Obtain a thorough understanding of the geologic, geophysical and engineering aspects of the opportunity

2. Using well founded statistical methods, develop an estimate of the distribution of resource volumes – focus on reality checks

3. Once the resource distribution is documented, assess the chance that an active hydrocarbon system can provide the range of volumes
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Simply put, the end goal of performance tracking is to provide assurance to our stakeholders that we can \textit{deliver what we promise}!

Our stakeholders want to be assured that, if they invest capital and trust in our projects, we will deliver, with a high degree of confidence, the agreed performance targets.

What performance metrics do you use? What metrics do your stakeholders use?
Global Deepwater Targets

Predictive Accuracy = 45%

"As with most exploration companies, BP has tended to... overestimate the potential discovery volumes prior to drilling -- this trend is even more pronounced for deep water prospects [where] volume estimation... remains significantly poorer than expected."

Francis Harper (BP) 1999

What is this gap of cumulative under-delivery called?
"As with most exploration companies, BP has tended to... overestimate the potential discovery volumes prior to drilling -- this trend is even more pronounced for deep water prospects [where] volume estimation... remains significantly poorer than expected."

Francis Harper (BP) 1999
Pre and Post Drill Estimates
Norwegian North Sea

Evidence for motivational bias?

Norwegian Petroleum Directorate, 1997
Pre and Post Drill Estimates
Norwegian North Sea

Evidence for motivational bias?

Norwegian Petroleum Directorate, 2008
Percentile Histograms

- Plot a histogram of where the post drill outcome falls on the pre drill distribution
- If the post-drill result from each pre-drill distribution is random, over time, the result will be a uniform distribution

Otis and Schneidermann, 1997
Diagnostics

Heavy on the downside – too optimistic

Heavy on the upside – too pessimistic

Heavy on both up - and downsides – need to widen ranges

Uniform distribution - acceptable

Otis and Schneidermann, 1997
Percentage of Discoveries at Forecast Percentile

Chevron International

Otis and Schneidermann, 1997

1989 - 90
n = 22

P80
P60
P40
P20

50%
40%
30%
20%
10%
0%
Percentage of Discoveries at Forecast Percentile – EUR Parameters

1989-1990 parameter percentile histograms

Otis and Schneidermann, 1997
Percentage of Discoveries at Forecast Percentile

Chevron International

1993 - 94
n = 34

Otis and Schneidermann, 1997

1989 - 90
n = 22

Otis and Schneidermann, 1997
EUR Estimating Pitfalls

Most common cause of poor estimation of EUR:

Low-side (P99) estimates

Too High!
Calibration of Pg or Pc

Amoco 1990-1993

Low: <15%
Mod: 15% - 35%
High: >35%

Success Rate

Low
Mod
High

Actual
Predicted

Chance Category

From McMaster, 2008
Calibration of Pg or Pc

From McMaster, 2008
Critical Success Factors

- Develop and maintain a rigorous, probabilistic process that delivers predictable resources - *Deliver what you promise*

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Experience is Inevitable, Learning is Not!
Thank You
For Your Attention