Evolution of E & P Risk Analysis (1960-2017)*

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Abstract

Risk Analysis of Petroleum Exploration and Production ventures arose in the 1970s and 1980s to counter chronic underperformance of the Exploration sector; its adoption by the Production sector expanded rapidly after about 1996. Major advances since then depended on use of high-speed personal computers, company-consistent assessment software and practices, training of multidisciplinary professional staff and executives, and management of E & P as a portfolio of uniformly assessed ventures. In practice today it combines long-standing and evolving principles of statistics, economics, and utility theory, with more recent advances in petroleum geology, seismic, petroleum engineering, and cognitive/decision theory. Risk Analysis methods are now routinely applied to exploration plays and prospects, as well as appraisal and development projects, involving both conventional and unconventional reservoirs.

Pioneering work in this emerging field was carried out and published by professional staff employed by Shell, Exxon, Arco, Gulf-Chevron, BP-Amoco, ELF-Total, and Cities Service. Later contributions from professionals at Texaco, Mobil, Unocal, Conoco, Marathon, and Statoil improved our understanding and applications. The key to widespread Industry adoption was development of 1) a sound procedural methodology "friendly" to geoscientists and engineers; 2) easy-to-use software implementing the methodology; and 3) guidance by expert geoscientists and engineers on central coordination teams.

The main function of E & P risk analysis has been to temper unrealistic project expectations caused by industry overoptimism and overconfidence, which are rooted in various forms of cognitive bias that negatively affect our decision behavior. Resulting best practice today detects and limits biased estimates, and links creative geoscience-based prospecting, objective assessment of opportunities, and consistent risk analysis of evolving project stages.

Six practical methods are now routinely used to detect and limit bias in assessing E & P ventures: 1) Probabilistic estimating of constituent project parameters; 2) Reality-checks of parameter estimates; 3) Use of appropriate and documented distribution shapes for reservoir parameters; 4) Employing crowd-sourcing methods for estimating chances of geologic success or failure; 5) Managing E & P as a Portfolio; and 6) Calibrating and improving project evaluations through routine performance-tracking of all significant ventures.

Explanatory Notes for Presentation Slides***

***Users will advance to the corresponding slide with click on each number (of slide) below. Subsequently, a click on the left-directed arrow in upper right of the slide will return user to previous page (in explanatory notes).

Slide

#1. Mr. Chairman, Ladies and Gentlemen: Thanks for the opportunity to review nearly 60 years of the evolution of E & P Risk Analysis. In my allotted 18 minutes, I'll only be able to 'hit the high spots' of this complex field.

#2. Right up-front, I want to acknowledge the help of many Rose & Associates colleagues, plus my good right arm, Elizabeth Sherry – many thanks, guys!

#3. After a brief Introduction,

A. The main part of the talk reviews Concepts, Tools, and Practices over the past Six Decades – focusing on when they widely adopted, NOT when they were first introduced.
B. Then I'll summarize the 9 AAPG Research Conferences, which (over 35 years) promoted the growth of E & P Risk Analysis in our Industry.
C. I'll speculate as to Future Developments and Directions,
D. Then conclude with some "Lessons Learned" over the years.

#4. First, a definition:

A. Risk Analysis is a complex subdiscipline of E&P that integrates Statistics, Geoscience, Engineering, Economics, and Cognitive Science;
B. . . . to generate objective, probabilistic estimates of the key subsurface parameters governing the Expected Net Present Value of E&P ventures;
C. . . . and to develop plans by which such ventures can be efficiently and profitably carried out.

#5. Exploration Risk Analysis arose in the 1980s in response to chronic and widespread underperformance by Global Exploration.

#6. Here is a well documented example, from BP's Deepwater Exploration group: of 125 consecutive exploration targets drilled during the late 1980s and 1990s; the actual recoverable volumes discovered (the green curve) were less than half (45%) of what BP's exploration staff had predicted (the red curve). Such performance was characteristic of BP's competitors, too. *Clearly, Change was Required!*

#7. Here I want to emphasize what subtopics of Risk Analysis I have excluded from this paper: a) Utility Theory & Risk Aversion; b) Resource Endowment Methods; c) Discovery-process Modeling; and d) Formal Definitions of Reserves (Proved, Probable, Possible).

A. Now -- seeing the effectiveness of Risk Analysis methodology in improving Exploration, the Development sector (the 'P' in E&P) began adopting such measures starting in about 2000.

B. Organized Risk Analysis methods are now firmly embedded in most E&P organizations around the world.

#8. The 1960s decade started the transition from Promotionalism ("The Deal") to Professionalism (of Exploration as a Business). What were the common tools and concepts used to evaluate Exploration prospects in the 1960s?

A. We routinely generated Cash-flow Models of candidate prospects, providing estimates of their Net Present Value (NPV) – *if Discovered!*
B. We recognized the natural limits of Basic Reservoir Parameters;
C. Such parameters were expressed deterministically (as single numbers) even though most of us knew they were highly uncertain; and
D. We recognized that most exploration prospects were overvalued – biased – so we developed pragmatic ways to cope with such bias.

#9. For example,

A. The SEC developed strict definitions of reserves categories;
B. Engineers were licensed by states;
C. Management brought in outside experts to review prospects;
D. Many companies pitted Engineers (thought to be conservative) against Geoscientists (thought to be optimistic);
E. Many executives applied their own personal "Rules of Thumb" when screening prospects (many were counter-productive);
F. But the root causes of this chronic overoptimism were not addressed.

#10. So how did we progress during the next decade – the 1970s? Probabilism – the coming view -- began to replace Determinism – the traditional view.

#11. We recognized the concept of the Exploration Play – a trend or family of geologically related fields and prospects.

#12. We realized that oil and gas fields are distributed lognormally in provinces, basins, and plays, which made the lognormal expectation a powerful predictive tool.

#13. To combine probabilistic distributions statistically we began to perform Monte Carlo simulations using Main-frame Computers, which commonly became viewed as "Black Boxes".

#14. Paul Newendorp explained the usefulness of the Expected Value Concept (the Chance-weighted Present Value of a proposed venture), but we were still unsure about how to go about estimating the Chance of Success.

#15. We understood that two essential estimates constituted the geoscientific responsibilities of Exploration Risk Analysis:

A. Prospect Resources, the Estimated Ultimate Recovery in Bbls or MCF;
B. And the Chance of Geologic Success (Pg).
C. These were required geological inputs for calculating Expected Value

#16. We developed early approaches to estimating Pg, by assessing the probability that three independent geologic requirements – Trap, Reservoir, and HC-Charge – had been met in the subsurface, and their product was the chance of encountering recoverable HCs (Pg).

#17. And the first papers were published in the 1970s on the important topic of Cognitive Bias – how we routinely fooled ourselves into thinking that our estimates of critical exploration parameters were objective.

#18. By the 1980s, interest in Exploration Risk Analysis was increasing, especially among the Major Oil Companies. They started using multidisciplinary teams to generate and evaluate Plays and Prospects.

#19. They began accepting the large uncertainties that attend exploration prospects, by estimating geotechnical parameters probabilistically, constrained by known distribution patterns, (mostly lognormal). P90, P50, and P10 values could then be plotted, and the mean calculated.

#20. Smaller companies developed graphical methods to approximate Monte Carlo simulation, by combining distributions of the three constituents of the Prospect Resources Distribution (Area, Average Net Pay, and HC Recovery Factor). This could be done by the working geoscientist or engineer, thus escaping the centralized Main-frame Computer.

#21. Geologists utilized Depositional Models to predict Reservoir trends, and they learned to assess the effectiveness of Caprocks and Seals in preventing escape of reservoired oil and gas.

#22. Work on the Generative Basin led to the Petroleum System concept of Wally Dow and Les Magoon, which expanded and integrated our grasp of the essential geological requirements for oil and gas fields.

#23. In carrying out Risk Analysis of New Exploration Plays, we learned the important difference between Play Chance and Prospect Chance.

#24. Companies began to develop understandable, consistent, scientifically sound, operational protocols for performing Risk Analysis on all their exploration ventures; now the challenge was to embed such concepts and processes throughout the E&P organization.

#25. One of the most widely influential processes for Exploration Risk Analysis was developed and taught by Bob Megill (ex-Exxon), Ed Capen (ARCO), and Pete Rose (ex-Shell, ex-USGS, Independent) from 1984 through 1995. Their evolving course was sponsored by AAPG (of course, many Major companies were also developing their own protocols at the same time). After 1990, Rose also taught it on his own, adding substantial geologic content over the years. This evolving course eventually became the "Flagship Course" for Rose & Associates LLP, and also was the basis for Rose's 2001 AAPG book, *Risk Analysis and Management of Petroleum Exploration*

Ventures, which became an Industry standard. Rose & Associates also used the course to develop PC software, enabling individual professionals, teams, and companies to perform Prospect Risk Analysis as a user-friendly procedure, consistent with the course they had been taught.

#26. The 1990s was the "Tipping Point Decade"for E&P Risk Analysis; it was also technologically revolutionary:

A. The Seismic Revolution reduced exploration uncertainty through widespread use of 3D, amplitude anomalies & other seismic attributes, and Pre-Stack Depth Migration;
B. Work Stations helped integrate geology, seismic, and reservoir science;
C. Personal Computers became widespread among E&P professionals;
D. Monte Carlo simulation became more accessible and efficient through use of Parametric Solutions on our PCs;
E. Play Analysis was refined by mapping Prospectivity as separate geologic components of Pg, using GIS applications . . . .

#27. So-called "Traffic-light Mapping".

#28. Increased understanding of Petroleum Systems led to more discriminating schemes for determining Pg (as shown by this 5-component system), and we defined Pg as "the chance of finding enough reservoired hydrocarbons to sustain flow or more". Some schemes used as many as 12 components.

#29. *Caution! This figure is a hybrid, combining a Cartesian scale for Chance-of-Success, with a Probit scale for Prospect Resource, but it allows me to illustrate an important concept*. Since most wildcat wells wouldn't be completed unless enough production was found to at least pay for well completion and operating costs, we distinguished between Geologic Chance of Success (Pg) and Commercial Chance of Success (Pc), by marrying the Prospect Resource Distribution to Pg, and truncating the distribution below the minimum Resources required to cover well completion (Pc). *This was the "Two-Step Process".* With Truncation, Chance of Success goes Down, but Mean Resources go Up!

#30. Continuing on with Developments of the 1990s Decade: the combined concepts of Expected Value, Decision-Trees, and Value of Information encouraged thinking about E&P as a series of Staged Ventures with reassessment of Expected Value at each successive stage of each Project.

#31. The 1990s decade saw the institutionalization of the Risk Analysis Process in company after company, including: a) Uniform Software; b) Training; c) Use of PowerPoint technology; d) Oversight by experienced, centralized Quality-assurance teams; e) Routine post-audits of all projects, with staff feedback, and archiving of results; and f) Enforced and sustained Management support of the Risk-analysis Process.

A. Companies began to manage Exploration through a Portfolio of Ventures, and
B. They adopted routine measures to detect and counter Cognitive Bias in Exploration ventures before drilling through use of:
    i. Reality-checks,

ii. Constraining parameter estimates by expected distributions (usually lognormal),
iii. Modified Delphi rounds for chance-estimates,
iv. Centralized Quality-assurance teams, and
v. Performance-tracking of all projects.

#32. What were Industry's advancements during the 2000 Decade? Most companies were now fine-tuning a process adopted several years before:

A. They were now incorporating Monte Carlo simulation directly into PC-based Risk Analysis software, using *Crystal Ball* or *At Risk;*
B. Project economics could now be run on different project outcomes (the P90, P50, P10 cases) using different costs and schedules, so as to build a probabilistic expression of Project ENPV for uncertain ventures;
C. We worked out the challenging process for assessing complex traps, involving multiple outcomes and dependencies among the different geological chance-factors;
D. Geophysicists, such as W. A. Fahmy, Mike Forrest, and Rocky Roden, began to quantify the impact of different seismic attributes on the original geological chance of success (Pg) of prospects;
E. We realized that Staged Exploration Projects offered opportunities for applying Bayes' Theorem to evolving project values and decisions;
F. The Development Sector began adopting many of the probabilistic and statistical procedures utilized by the Exploration sector, especially as related to Field Development;
G. . . . and in 2008 we adopted a refined, updated process for defining oil and gas reserves and resources – PRMS – which led to the SEC's official modernization of Reserves Definitions, providing the basis for public investing in the new Resource Plays.

#33. Now here we are, more than halfway through the 2010 Decade: E&P Risk Analysis appears to be a Maturing Technology, with ongoing incremental refinements and applications, but fewer major advancements:

A. We're starting to express the different elements of geologic chance probabilistically – as ranges -- combining them to express Pg as a probabilistic range, rather than a single probability estimate;
B. We're also evaluating the benefits of assessing Pg through carefully constructed questionnaires;
C. The basic concepts and methods of Prospect and Play Analysis have now been adopted for evaluating Resource Plays, such as the Bakken and Eagle Ford plays, in which statistics-based evaluations also employ Type-well curves; as well as . . .
D. Field-size Distribution plots, adapted now as Well-size Distribution plots, used to estimate per-well ranges of production rates and for EURs for wells, sectors, and entire trends.

#34. AAPG has played a substantial role in facilitating the transfer of this new technology throughout the global E&P Sector, sponsoring nine Research Conferences since 1974, each addressing current issues and emerging concepts. These conferences accelerated the development and adoption of Risk Analysis; they demonstrate the importance of Professional Associations in Technology Transfer. Everyone benefitted. I'm proud to say that I attended all but one of these conferences.

#35. So that is how we got to where we are now – what lies ahead?

A. It seems likely that continuing refinements and "tweaks" in Risk Analysis software will make it harder and harder for working staff to use it; this may make Risk Analysis a specialist's job, unfortunately separated from the working prospector; this is "false precision" and should be resisted – strive instead to "get it about right", which expresses a realistic perception of operational accuracy;

B. We will continue to see incremental improvements in existing methodologies, for example, fully probabilistic cash-flow models;

C. And new Seismic techniques will continue to reduce – but by no means eliminate – project uncertainties;

D. But the largest challenge still remains: Overestimation – Cognitive Bias? How can Staff and Management learn to deal with it at the beginning of projects, thus saving a lot of money?

E. We should also anticipate that Firms will improve their ability to build Predictive Portfolios that help them Deliver on their E&P Promises;

F. We will probably see other businesses adopt E&P's now time-tested Risk-analysis methodologies;

G. And we will see increased data-base mining and use of Artificial Intelligence in E&P Risk Analysis.

#36. Winding up, I'd like to offer 30 years' worth of Distilled Learning:

A. Risk Analysis DOES NOT find oil and gas: it enables more good prospects to be drilled with the money not wasted drilling poor ones.

B. Continued management support (and enforcement) of E&P Risk Analysis is absolutely essential to improved portfolio performance.

C. The Key Exploration Decision is NOT which new PROSPECT to drill – it is which new PLAY to enter.

D. *Creative Prospecting* delivers promising opportunities which *Risk Analysis* evaluates and ranks into the *Company Portfolio* – *both functions are essential*; think of them as a Yin-Yang couplet, with some intrinsic tension, which must be accommodated and managed.

E. E&P is a "Repeated-Trials" Game, and a Predictive Annual E&P Portfolio is an Attainable Goal.

F. Cognitive Bias is Powerful and Lurks Everywhere . . . and that will encourage me to conclude with a personal story: *When I first started teaching Risk Analysis as a business in 1990, I figured the market would be saturated within three or four years, as the concepts and methods would be absorbed by client companies, and then I'd need to be looking for other professional opportunities. Well, here it is 27 years later, and Rose & Associates continues to grow and thrive. This is compelling evidence of the power and pervasiveness of Cognitive Bias, the root cause of E&P underperformance. I had not grasped this at the start, but it becomes increasingly clear and compelling*. For the E&P Industry, Cognitive Bias remains the #1 challenge; for Rose & Associates, it is the "*Gift that keeps on Giving!*"

#37. Thank you for your attention.

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EVOLUTION OF E&P RISK ANALYSIS 1960-2017

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. . .Thanks, Friends!

OUTLINE:

1) Introduction
2) Exploration Prospect Evaluation: 1960s , 1970s, 1980s, 1990s, 2000s, & 2010s – Concepts, Tools, & Practices
3) Themes of AAPG Research Conferences
4) Future of E&P Risk Analysis -- Where do we go from here?
5) 30 years of Distilled Lessons Learned

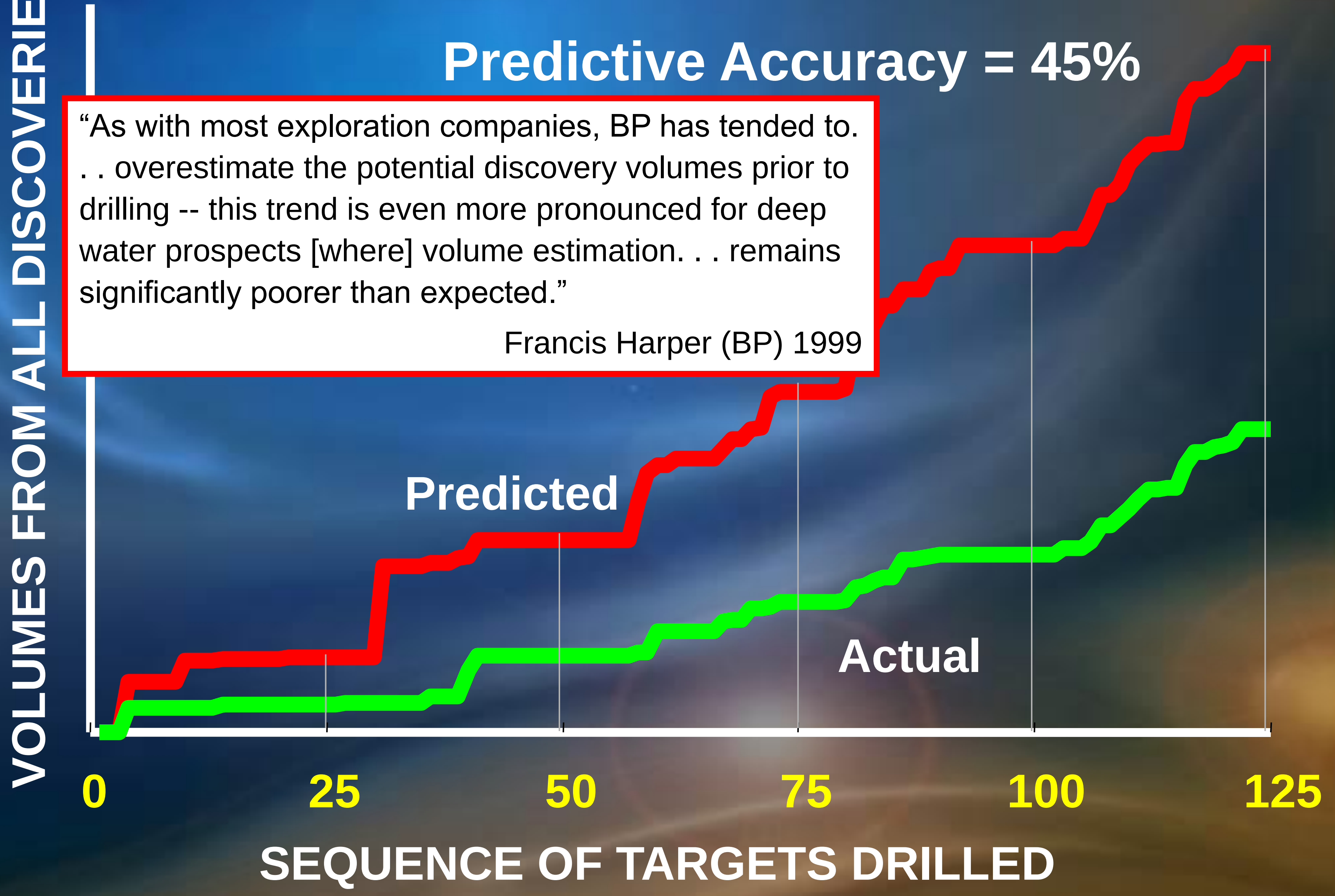
DEFINITION OF E&P RISK ANALYSIS:

- *Integration of Statistics, Geoscience, Engineering, Economics, and Cognitive Science to generate . . .*
- *Objective Probabilistic Estimates of Uncertain, Chance-weighted Monetary Values (ENPVs) of Proposed Exploration and Development Ventures*
- *and to Design Plans by which they can be Efficiently and Profitably Carried Out.*

EVOLUTION OF E&P RISK ANALYSIS:

- Emerged in 1980s in response to chronic underperformance of Global Exploration

GLOBAL DEEPWATER TARGETS



"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

Harper 1999

EVOLUTION OF E&P RISK ANALYSIS:

- **Emerged in 1980s in response to chronic underperformance of Global Exploration**
- **What is NOT included here:** ***Risk-aversion metrics; Resource Endowment; Discovery-process Modeling; Reserves Definitions (PPP)***
- **Methods adopted by Development/Production Sector ~2000.**
- **Now (2017) embedded in operations of most International E&P organizations.**

PROSPECT EVALUATION IN THE 1960s:

- From Promotionalism (“The Deal”) >>>>

  Professionalism (“The Business”)

- Tools and Practices of the Time

  ✓ Prospect Cash-flow Model >>> Project NPV

  ✓ Natural Limits of Basic Reservoir Parameters

  ✓ Prevalent Determinism in Estimating

  ✓ Pragmatic ways to Reduce Bias

EARLY PRAGMATIC MEASURES FOR REDUCING BIAS IN E&P VENTURES

- Reserves Definitions (SEC)
- Licensing/Certification of Professionals
- Use of Outside Experts
- Engineers vs. Geologists
- Individual Rules of Thumb (esp. Executives!)

Underlying Causes & Remedies of Bias Not Addressed!

PROSPECT EVALUATION IN THE 1970s:

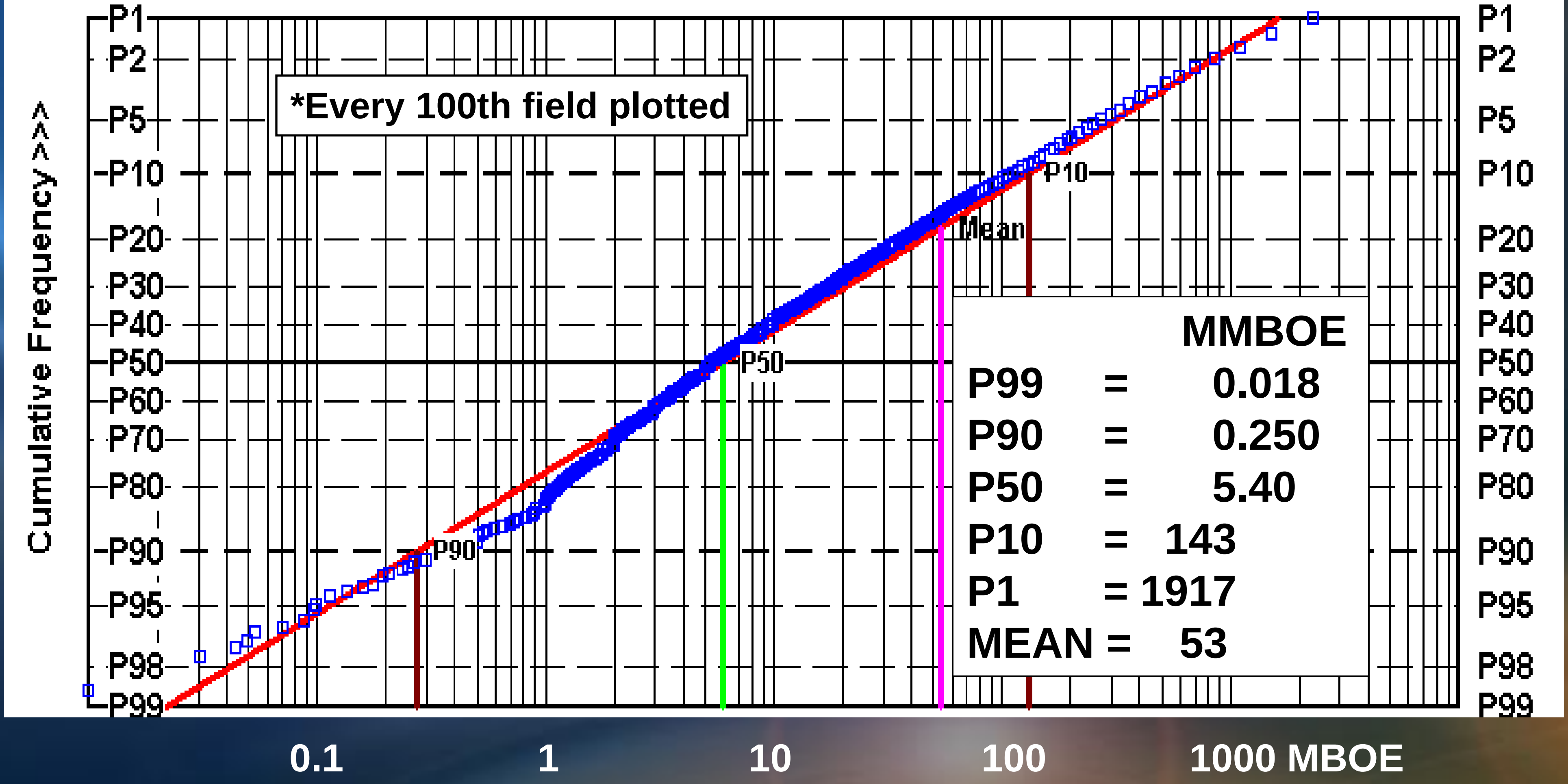
1) Probabilism Begins to Replace Determinism
2) The Exploration Play Concept
3) Oil and Gas Field-size Distribution is Lognormal
4) Monte Carlo Simulation via Main-frame Computers
5) Expected Value of E&P Ventures
6) Geological Elements of E & P Risk Analysis
7) Recognition of Cognitive Bias in Decision-making

EXPLORATION PLAY DEFINITION

A **PLAY** is . . . . . . a family of geologically related leads, prospects, and possibly producing fields; primary elements of similar geologic origin include hydrocarbon charge, reservoir origin, structural style, and seal. Commonality of trap type enables statistical analysis.

Common themes: a physical entity, not a concept;
petroleum systems-common history;
cohesive field size distribution

GLOBAL FIELD-SIZE DISTRIBUTION (n~30,000)*



Source: NRG, IHS

PROSPECT EVALUATION IN THE 1970s:

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WHAT IS A PROSPECT WORTH (CHANCE-WEIGHTED VALUE)?

PV of EUR (-) PV of COSTS = NPV (PROFIT)

(X)

CHANCE OF PROSPECT SUCCESS

(MINUS)

DRY-HOLE COST

(X)

CHANCE OF PROSPECT FAILURE

= EXPECTED VALUE CONCEPT

RISK ANALYSIS: GEOLOGICAL ELEMENTS

- *Project Resources (Estimated Ultimate Recovery = EUR in Bbls/MCF)*
- *Chance of Geologic Success (Pg)*

BASIC INPUTS FOR EXPECTED VALUE - - (= ENPV)

EARLY SYSTEM FOR ESTIMATING GEOLOLOGIC SUCCESS-CHANCE (Pg):

1. *TRAP (Structural or stratigraphic)*
2. *RESERVOIR (Minimum parameters?)*
3. *HC-CHARGE (Source, Oil/Gas, Timing?)*

P trap x P reservoir x P hc charge = $\boxed{Pg}$

COGNITIVE BIAS – FIRST PAPERS:

1974, Tversky & Kahneman, "Judgment Under Uncertainty"

1976, Capen, "The Difficulty of Assessing Uncertainty"

1978, Kahneman & Tversky, "The Psychology of Preferences"

1979, Kahneman & Tversky, "Prospect Theory, an Analysis of Decisions under Risk"

EXPLORATION PROSPECT EVALUATION (1980s):

1) Integrated Multidisciplinary Prospecting Teams
2) Accepting & Managing Pervasive Uncertainty >>> Probabilistic Estimating
3) Generating the Prospect Reserves Distribution – the Lognormal Requirement (P_{10}/P_{90} and Swanson's Mean)
4) Depositional Models
5) Top-seal Analysis
6) The Generative Basin >>> Petroleum Systems
7) Play Pg vs Prospect Pg
8) Systematic operational process for Prospect Risk Analysis

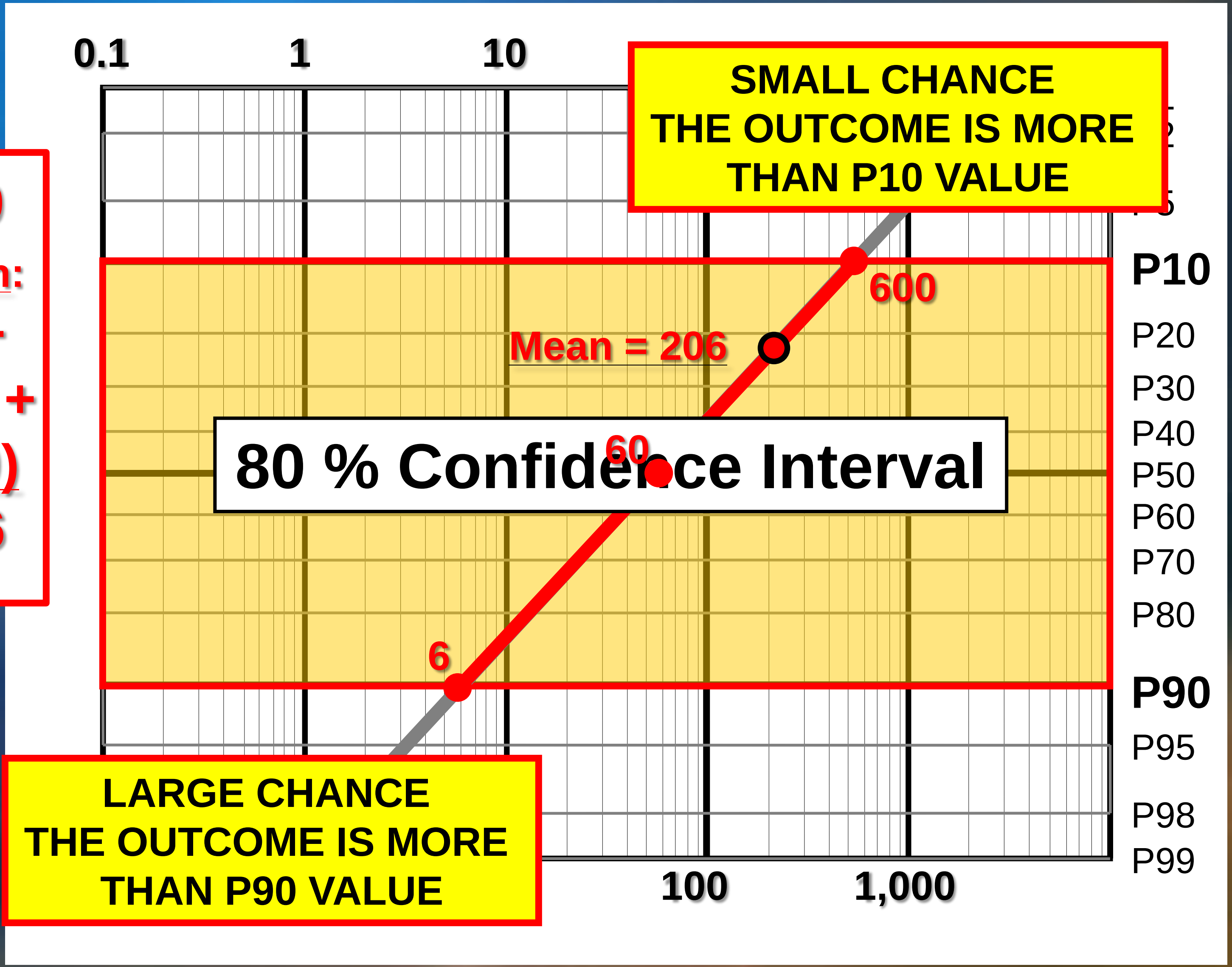
ESTIMATING WITH PROBABILISTIC RANGES

$P_{10}/P_{90} = 100$

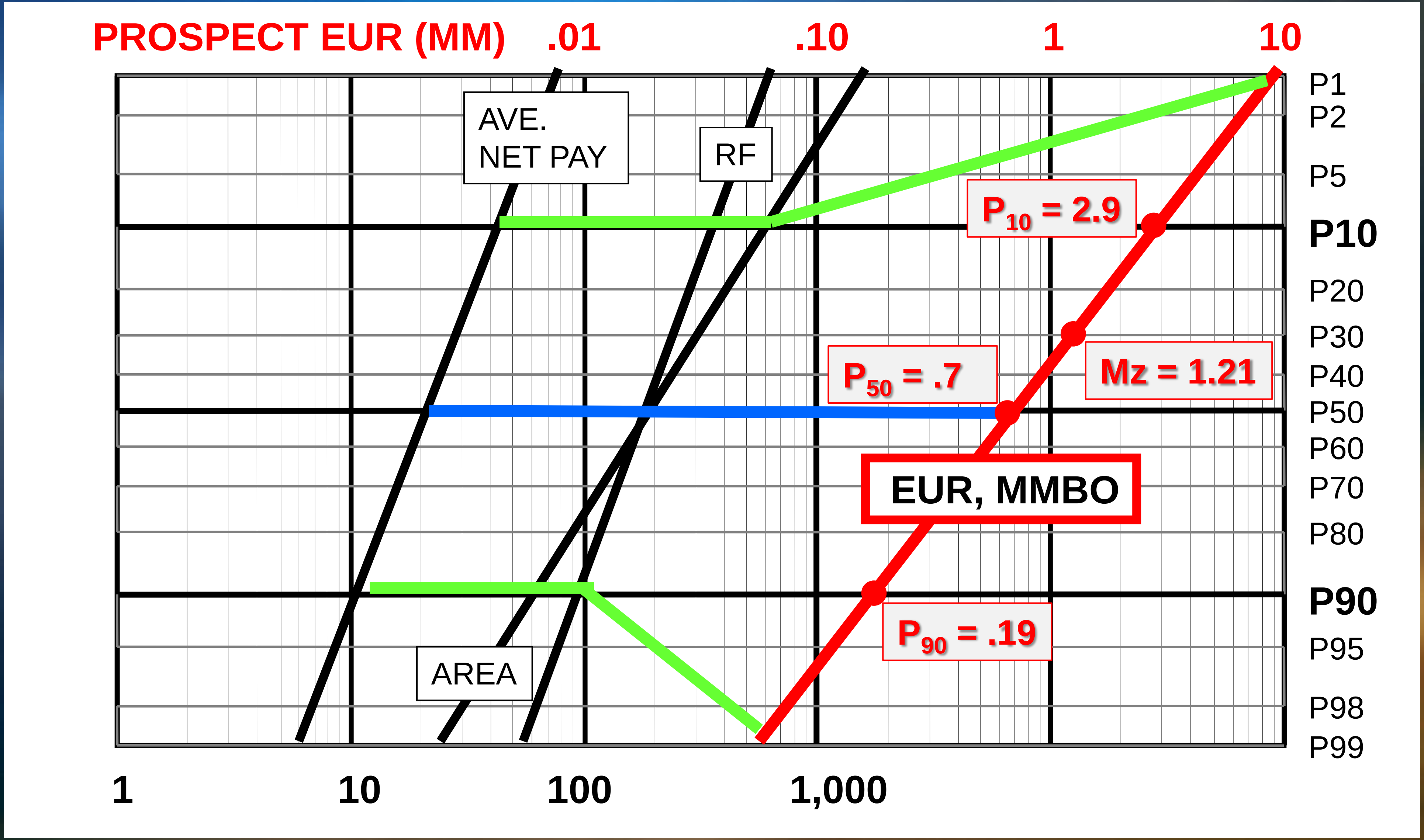
Swanson's Mean:

$.3(6) + .4(60) + .3(600)$

Mean = 206



DISTRIBUTIONS OF AREA, Ave NP, AND RF ARE MULTIPLIED TO YIELD PROSPECT EUR



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ESSENTIAL ELEMENTS OF PETROLEUM SYSTEM

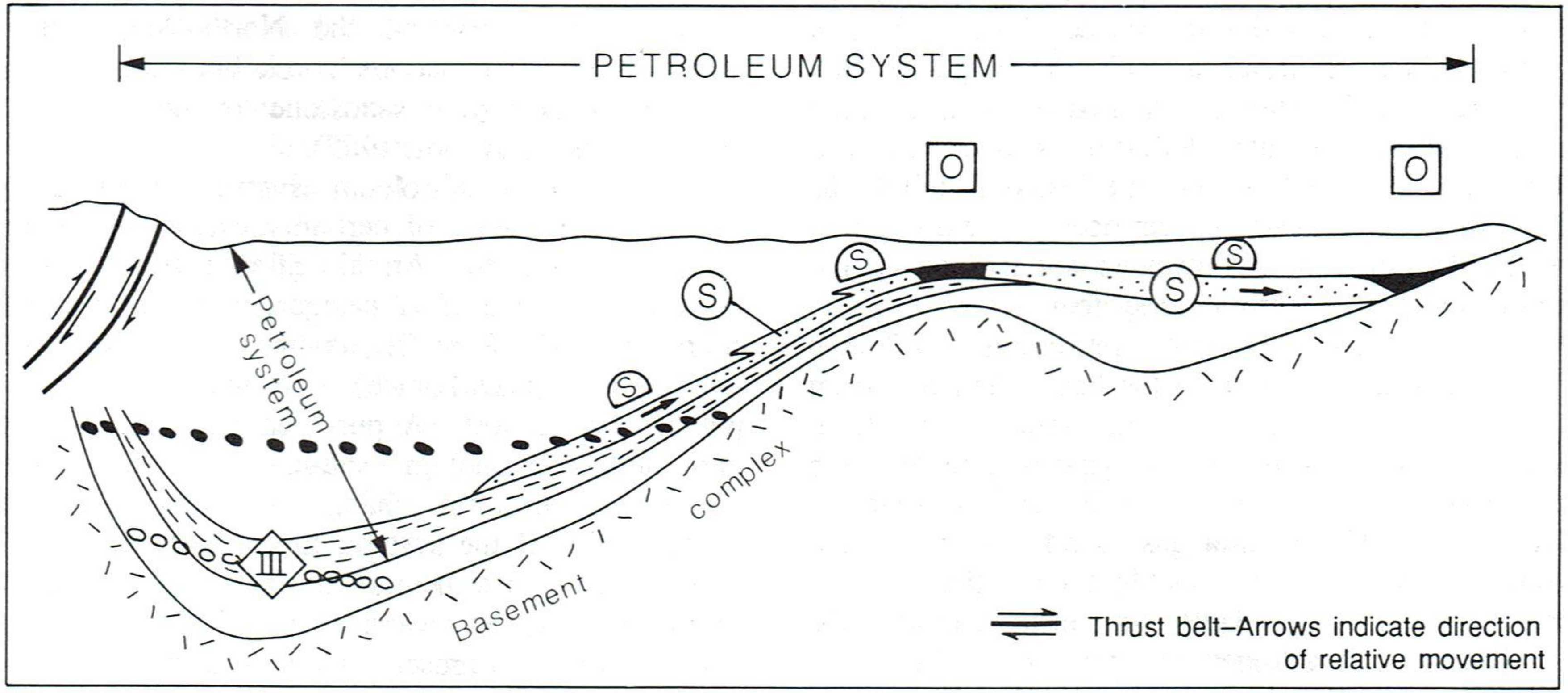


Figure 1. Hypothetical geologic cross section (see fig. 2 for location) of a basin showing the essential elements of a petroleum system. The expanded explanation is appropriate for figures 1–6.

From Magoon, 1988

PLAYS: SHARED AND LOCAL CHANCE

- **Play (Shared) Chance**

  Chance that the play exists, i.e., chance of finding a minimum quantity of hydrocarbons capable of sustained flow in at least one prospect ; dependent factors.

- **Local (Independent) Chance**

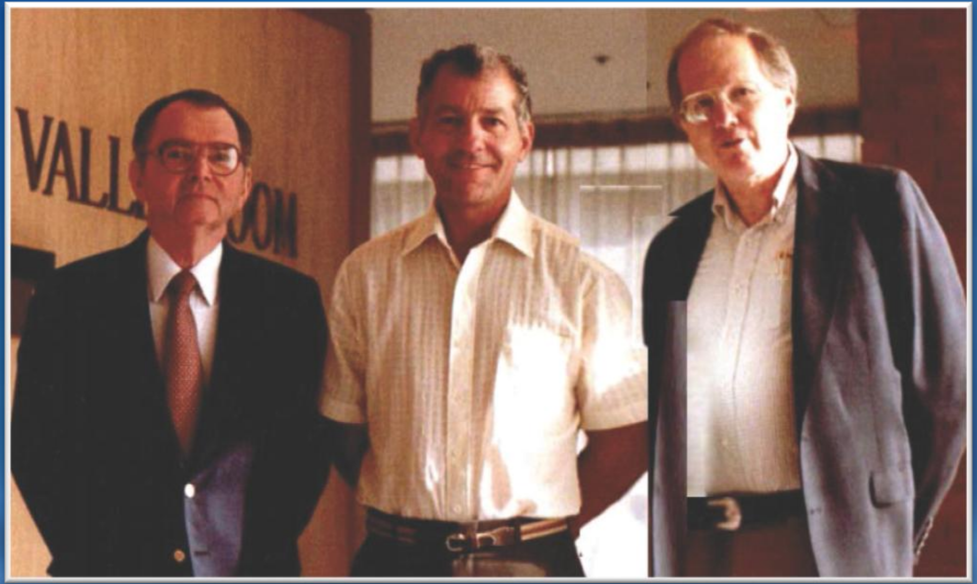
  Given that there is at least one future discovery, the % of undrilled prospects expected to contain hydrocarbons capable of sustained flow, when considering independent factors.

$\boxed{\text{Shared Chance x Local Chance = Average Prospect Pg}}$

EXPLORATION PROSPECT EVALUATION (1980s):

1) Integrated Multidisciplinary Prospecting Teams
2) Accepting & Managing Pervasive Uncertainty >>> Probabilistic Estimating
3) Generating the Prospect Reserves Distribution – the Lognormal Requirement (P_{10}/P_{90} and Swanson's Mean)
4) Depositional Models
5) Top-seal Analysis
6) The Generative Basin >>> Petroleum Systems
7) Play Pg vs Prospect Pg
8) **Systematic operational process for Prospect Risk Analysis**

EVOLUTION OF CONCEPTS & METHODS LEADING TO A SYSTEMATIC OPERATIONAL PROCESS OF RISK ANALYSIS



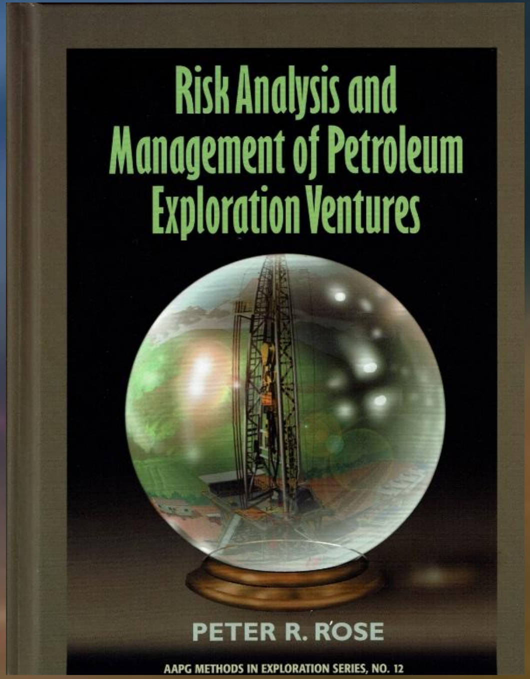
Bob Megill, Ed Capen, & Pete Rose

Major Companies:
Shell, Exxon, Gulf, Chevron, Texaco, BP, Total, ARCO, others

(+ Geoscience)

1984

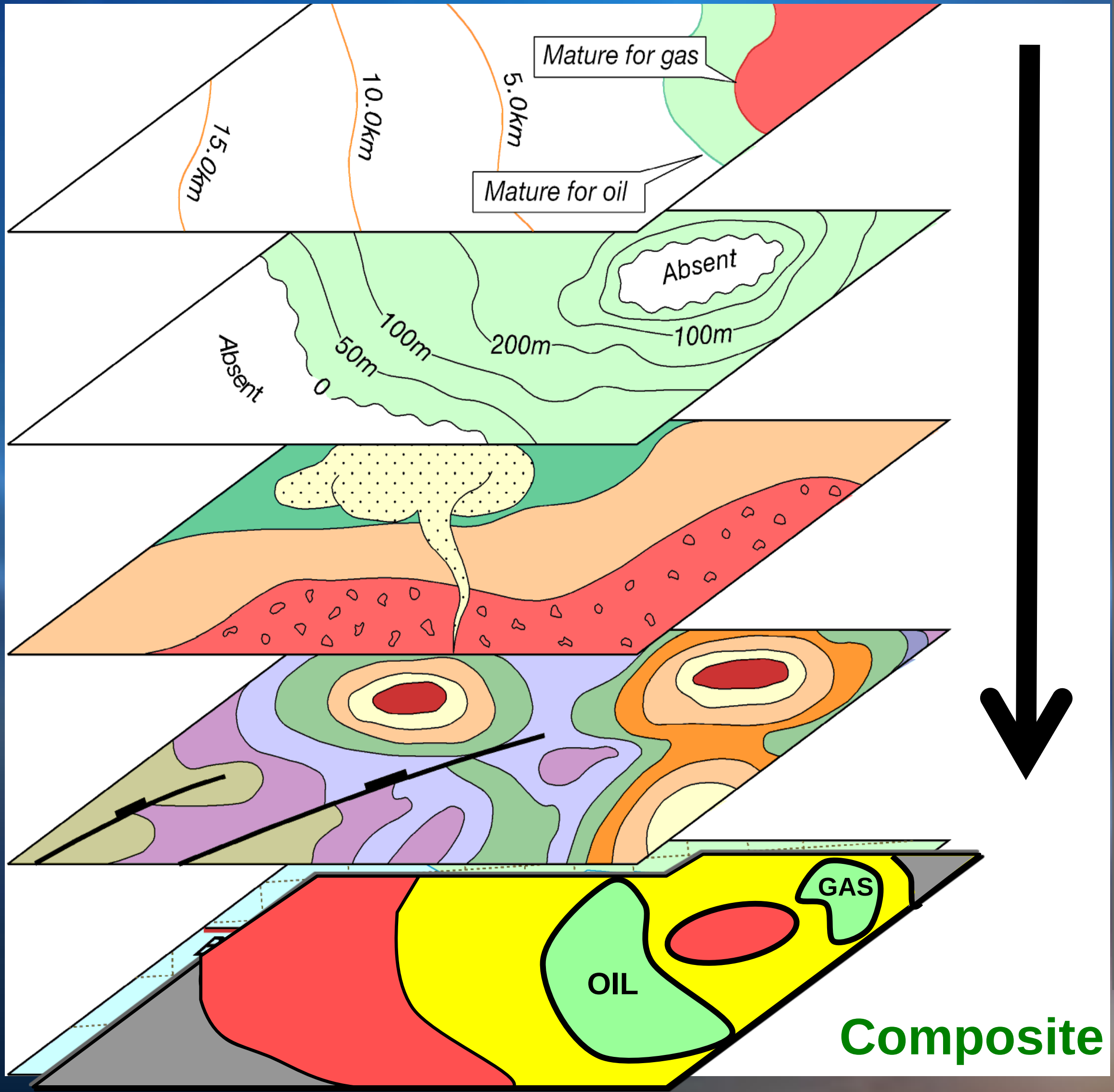
2001



EXPLORATION PROSPECT EVALUATION (1990s):

1) The Seismic Revolution reduces E&P Uncertainty – 3D, Amplitude anomalies, PSD Migration
2) Work stations
3) The PC Revolution
4) Monte Carlo approximations by parametric solutions
5) Mapping Prospectivity (Pg) using GIS applications – “Traffic-light Mapping”

Map Compilation/Integration:



Charge

Ro	Temperature
SR isopach	Orthocontours
SR quality	Inversion

Top Seal

Isopach	Rheology

Pressure/frac gradient

Reservoir

Isopach	Net to gross
Depth	Isoporosity
Provenance	Amplitude

Structure

Velocity/fault analysis
Regional structure

Overlay Maps to find 'sweet spots'- business focus info overlain last. (Source: BP)

PROBABILITY OF GEOLOGICAL SUCCESS

Pg

Five Factors:

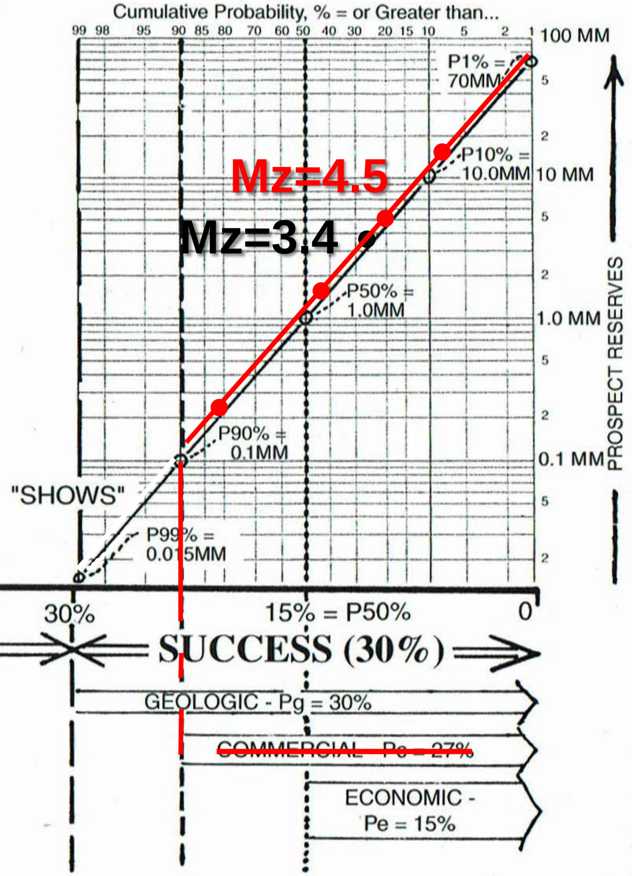
- Hydrocarbon Source Rocks
- Migration and Timing
- Reservoir Rocks
- Closure (Structural or Stratigraphic)
- Containment (Seal, Preservation)

When multiplied, represent the chance of an active HC-system yielding oil/gas in quantities enough to ***sustain flow***; ie, **P99 RESERVES OR MORE**: ***The Chance of Landing on the Prospect Resources Distribution***.

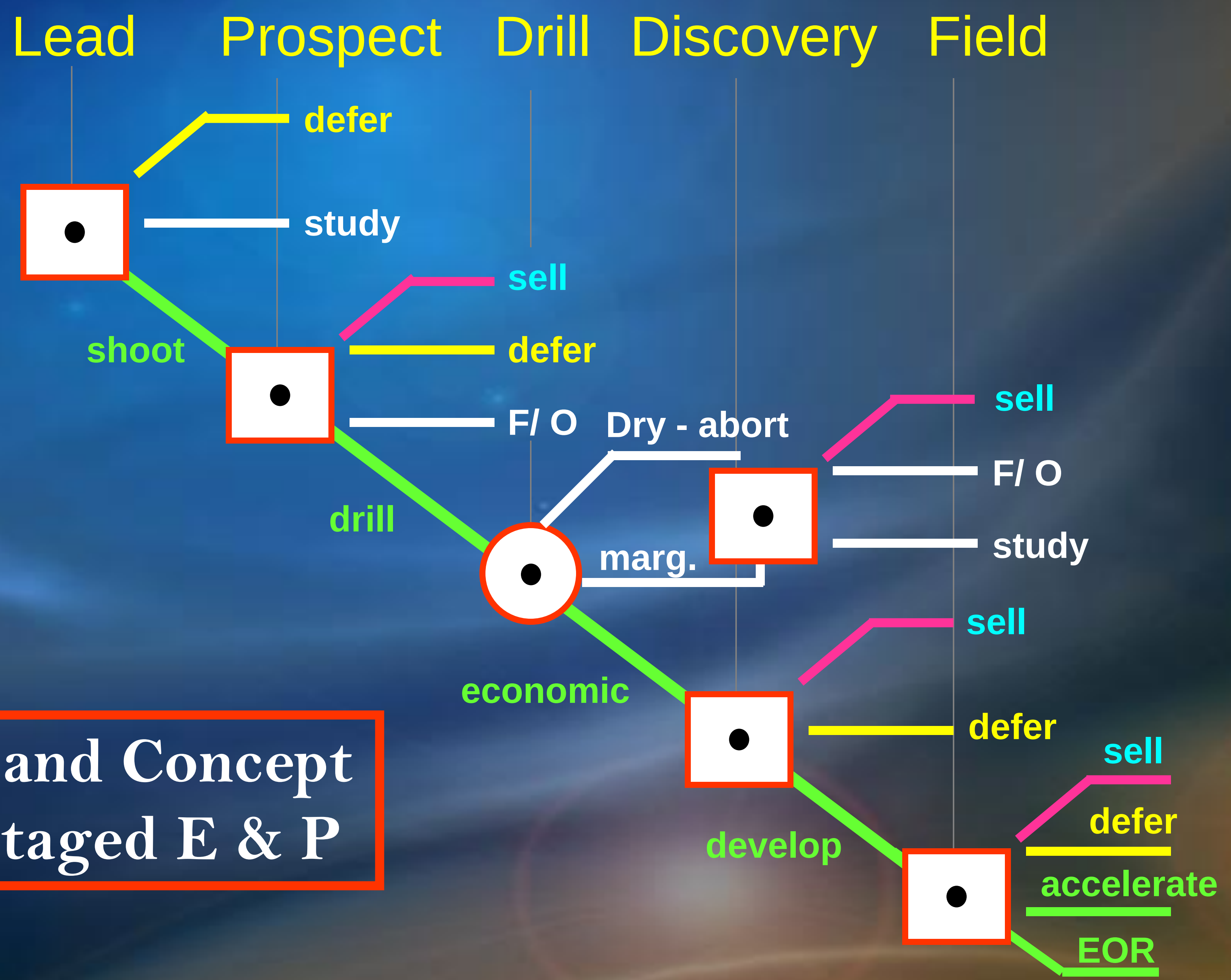
ESTIMATING CHANCE OF COMMERCIAL SUCCESS (Pc) & MEAN OF COMMERCIAL EUR DISTRIBUTION:

For a Prospect with: 1) **Pg = 30%** ; 2) Mean (Mz) of EUR Distribution **= 3.4 MM bbl**; and 3) **EUR of 0.1 MM bbl** needed to cover costs of well completion & operating:

1) Pc = (30% - 03% = 27%), 2) Mean of Truncated Distribution = **4.5 MM bbl**.



COMMERCIAL TRUNCATION EFFECTS:
Chance goes down, Mean EUR goes up.



VoI and Concept of Staged E & P

EXPLORATION PROSPECT EVALUATION (1990s, continued):

8) Value of Information (VoI) and Staged Exploration

9) Institutionalizing the Risk-analysis process: Software → Training → PowerPoint → Oversight by QA teams → Post-audits & Archiving → Sustained Management Support

10) Managing E&P as a Portfolio

11) Predrill Methods for Detecting Cognitive Bias:

Reality-checks
Constrain Estimates by Expected Distributions (LN?)
Modified Delphi Methods for Pg
Centralized Quality Assurance Teams
Performance Tracking of All Ventures

FURTHER ADVANCEMENTS – THE 2000s:

1) Monte Carlo capability incorporated into PC software
2) Probabilistic project NPVs
3) Evaluating Complex Traps
4) Marrying seismic attributes to Prospect Pg
5) Applying Bayes' Theorem to Staged E&P Assessments
6) Adoption of Risk-analysis Methodology to Field Development
7) Adoption of Petroleum Resources Management Systems (PRMS 2006 >>> SEC 2008)

THE 2010s – A MATURING TECHNOLOGY?

1) Probabilistic Estimation of Pg

2) Estimation of Pg using Questionnaires

3) Resource Plays – Statistics-based Evaluations using Production Type-well curves

4) Resource Plays – Field-size Distribution plots >>> per-well values for Rates and EURs

AAPG RESEARCH CONFERENCES: *Sharing Emerging Knowledge*

1) Stanford, 1974: Probabilistic Resource Endowments methods
2) Houston, 1984: Resource Endowment, Plays & Field-size Distributions
3) Snowbird, 1993: Risk Analysis of Prospects
4) San Diego, 1995: Risk Analysis Methods for Prospects & Plays
5) Galveston, 1998: Risk Analysis of Offshore Gulf Coast Ventures
6) Galveston, 2005 (w/SPE): Delivering E&P Performance
7) Colorado Springs, 2006: Status of Global Risk-analysis Practice
8) Washington DC, 2007 (w/SPE): Multidisciplinary Conference on SEC Reserves Definitions
9) Houston, 2011 (w/SPE): Multidisciplinary Resources/Reserves Symposium

WHERE DO WE GO FROM HERE?

1) Creeping Software Complexity Constrains Wide Usage?
2) Incremental Improvement of Existing Methods (fully probabilistic cash-flow models)?
3) New Seismic Techniques Reduce Project Uncertainty?
4) Focus on Cognitive Bias – Education & Predrill Detection?
5) Predictive E&P Portfolio Performance?
6) RA Methodology Adopted by other Businesses?
7) Database mining >> Artificial Intelligence?

30 YEARS OF DISTILLED LEARNINGS:

1) **Risk Analysis DOES NOT find Oil & Gas** – *it allows more Good Wells to be drilled with the $$ NOT WASTED drilling Bad Wells*

2) **Essential for Improvement/Maintenance of Company E&P Performance** -- *Continued Management Support/Enforcement!*

3) **Key Exploration Decision** – *which new Play to enter (NOT which new Prospect to drill)*

4) **Yin-Yang Relationship in E&P:** *Creative Exploration with Disciplined Evaluation of Ventures, in a Portfolio Context*

5) **E&P is a "Repeated Trials" Game** – *a Predictive Portfolio is an attainable goal that promotes Delivering on your E&P Promises*

6) **Cognitive Bias Lurks Everywhere** *(Pre-drill detection saves $$)*

EVOLUTION OF E&P RISK ANALYSIS 1960-2017

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Houston, TX
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