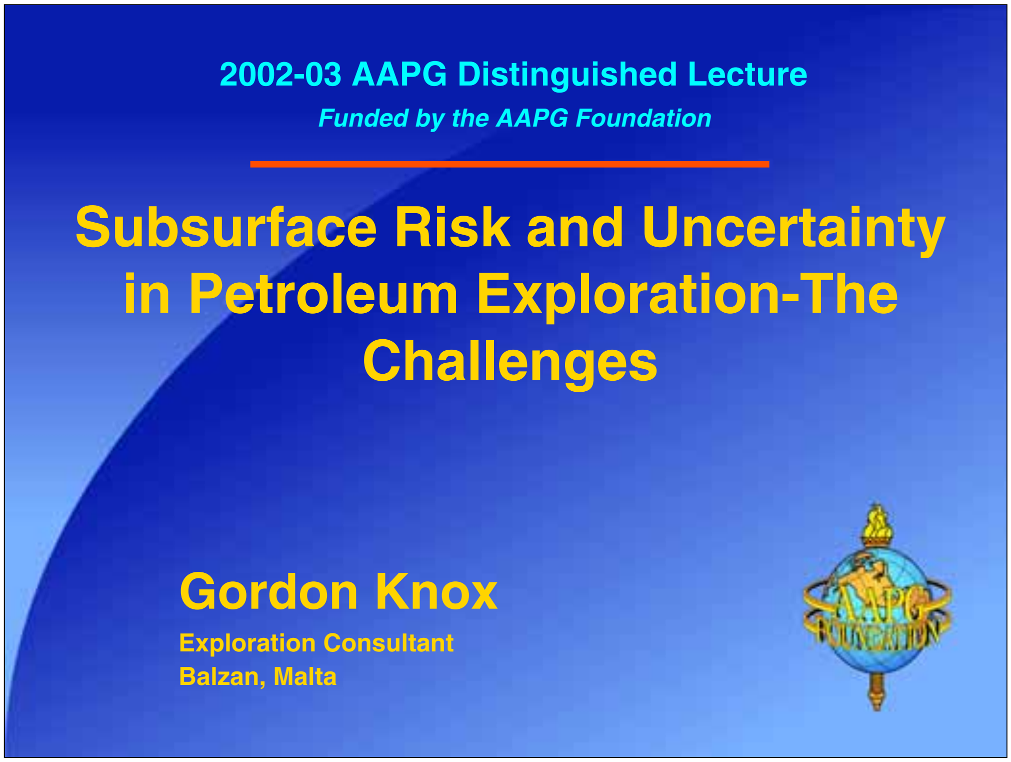


Introduction.

Good Morning (Afternoon, Evening). It is with great pleasure that I find myself here in (LOCATION) as a guest speaker of (LOCAL ORGANISATION). Right at the start I would like to thank the AAPG Foundation for making this International Distinguished Lecture tour possible and for sponsoring my tour through New Zealand, Australia, Thailand, Vietnam, Brunei, Indonesia, China, Japan and South Korea. I would like to also thank the organisations here (LOCAL SPONSORS) who have been involved with the AAPG in sponsorship and the local logistics and arrangements.

When I was first approached by the AAPG to give a lecture tour I was asked if one of the topics could be on risk and uncertainty from the perspective of a working explorer. During my professional career I have experienced the practice of risk and uncertainty from the perspective of an exploration team member, different levels of exploration management and also from being in charge of a group dedicated to providing and developing methods/applications to assess risk and uncertainty in exploration. I have therefore picked a few topics to include in the lecture which reflect this background.

In prospect evaluation we simplify geology into models. However sophisticated the model, it is always a gross simplification. We do this for three reasons:(1) We cannot go to the subsurface;(2) We could not handle all the data even if we could; and (3) If a good model is chosen it can actually be an excellent representation of reality. Some say it is possible to remove bias. I believe it is impossible to remove bias, but what should be done is to try and recognise where and how it arises and to minimise it.

The talk will address the following subjects.

The need: with a brief outline of why we assess risk and uncertainty in exploration.

Definition of Risk & Uncertainty: common usage of the terms in exploration.

Approaches to Risk & Uncertainty: a look at various methods though I shall spend some time on creaming curves.

Bias: various kinds of bias.

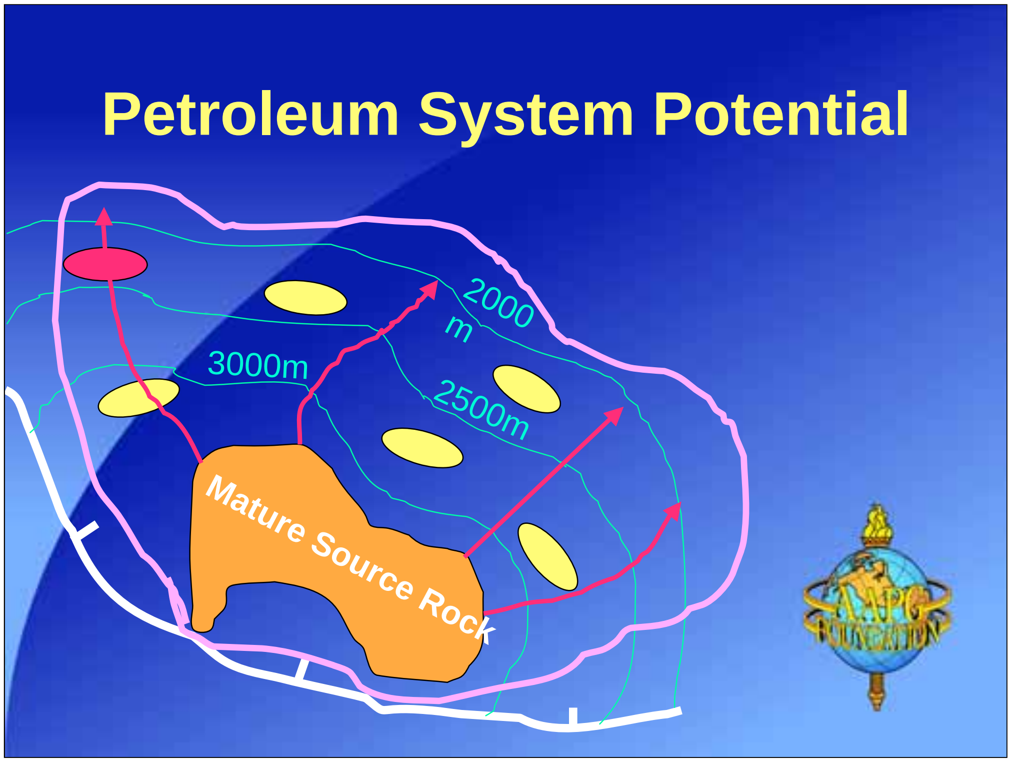
Process: I will close by discussing process.

The Need.

We commonly think of petroleum companies carrying out routine play and prospect analyses and summations of expectations of exploration success over future years, as the primary evaluators of risk and uncertainty assessment. However, it is of major interest to state petroleum companies, government agencies and ministries and to consultants working with private and state industry. In recent years the results of such analyses have become of interest to non governmental organisations.

Each of these players has different interests. The private sector and state petroleum companies evaluate plays and prospects to assess potential volumes in terms of their economic worth and rank as potential drilling opportunities. Private companies are interested in their ability to replace existing equity reserves by long term exploration. State companies and government bodies are interested in national potentials and their possible impact on economic policy and long term government policy making.

Some government surveys, NGOs and consultants aggregate various secondary data sources for regional and global potentials. Various production scenarios are used to postulate everything from imminent shortages to several decades of supply. These in turn are potentially of use in global energy utilisation modeling, and in environmental issues.



Bread and butter prospect evaluation consists of studying data sets to define subsurface models relating to the potential entrapment of petroleum. In other words we seek to define '**the natural petroleum utility**' of an area which may consist of one or more '**petroleum systems**'.

We examine risk and uncertainty pertaining to:

Charge: Source rock, kitchen, expulsion efficiency, migration efficiency.

Reservoir: Gross section, net section, porosity and hydrocarbon saturation and recovery efficiency.

Trap: Structural or stratigraphic closure, quality of map, depth conversion

Sealing formation: Vertical, lithology, thickness. Lateral in fault assisted closures and stratigraphic traps.

Risked estimates are then made of individual prospect volumes. These can then be aggregated according to various classifications to create expectations of exploration finding success for a budget programme, an exploration strategy over several years, specific play, basin or region areas.

Global Potential

Depending on your source the remaining global potential is estimated (since 1950s) to be anywhere between 1 and 4 trillion barrels. Over the years many estimates have centred around 2 trillion barrels.

At the other end of the scale, over the last 60 years, many estimates have been made of the total petroleum reserves potential of the Earth ranging between 1 and 4 trillion barrels of conventional oil. Estimates of security of supply ranges from imminent shortages to several decades of supply at present consumption levels.

Definition of Risk

- To take a risk is to do something you are not sure you are able to do. You are only trying to do it
- Risk-taking means doing something whilst tacitly or explicitly estimating, on incomplete data, ones capacity to do it

Adapted from Cohen & Hansel, 1956

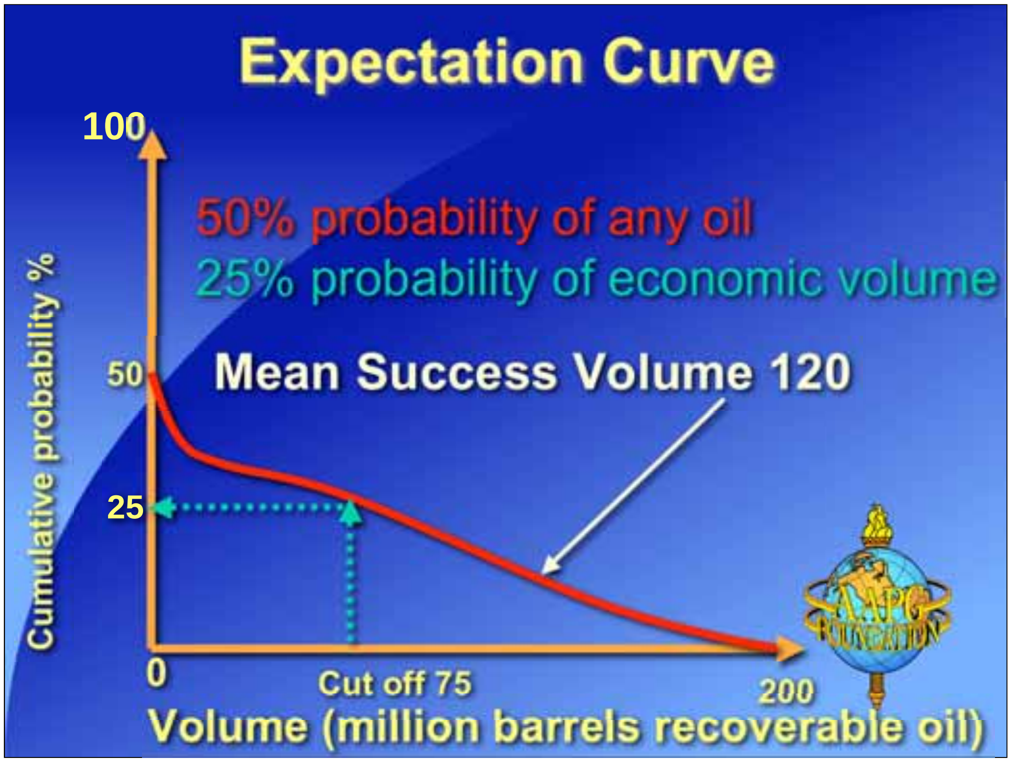
Definition of Risk and Uncertainty.

This is a basic definition of risk taken published in 1956 by Cohen and Hansel.

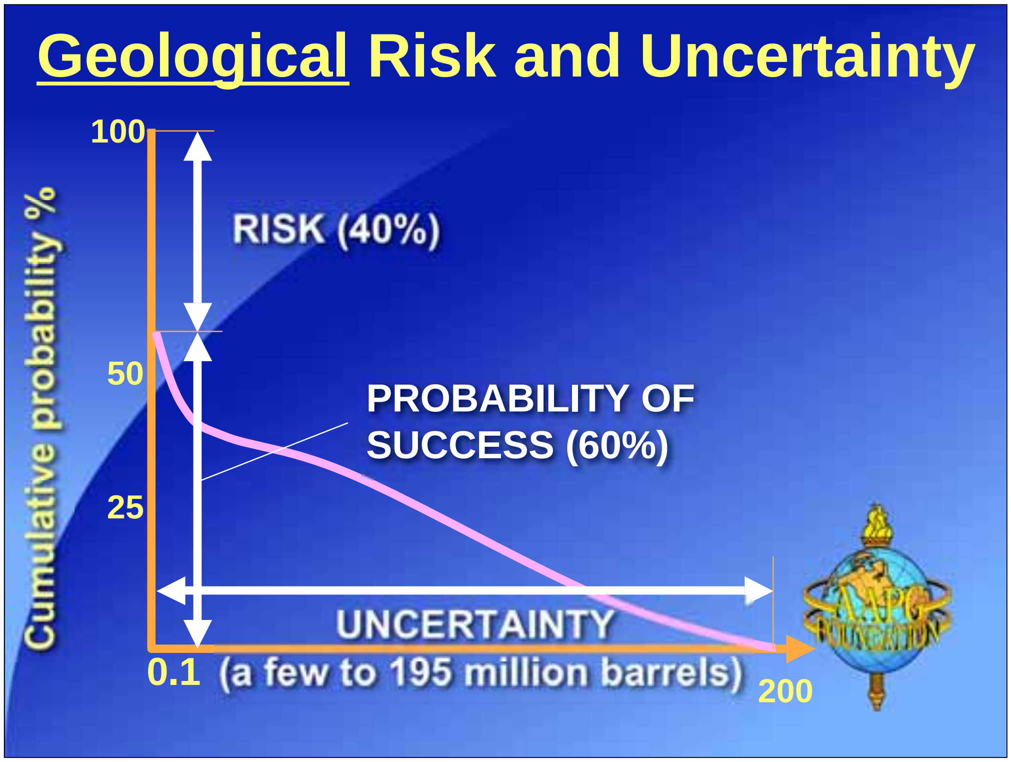
Definition of Uncertainty

- Looking forward, uncertainty encompasses the range of possible outcomes, some of which involve success/gain and others involve failure/loss

Associated with success or with failure are a range of possible outcomes.

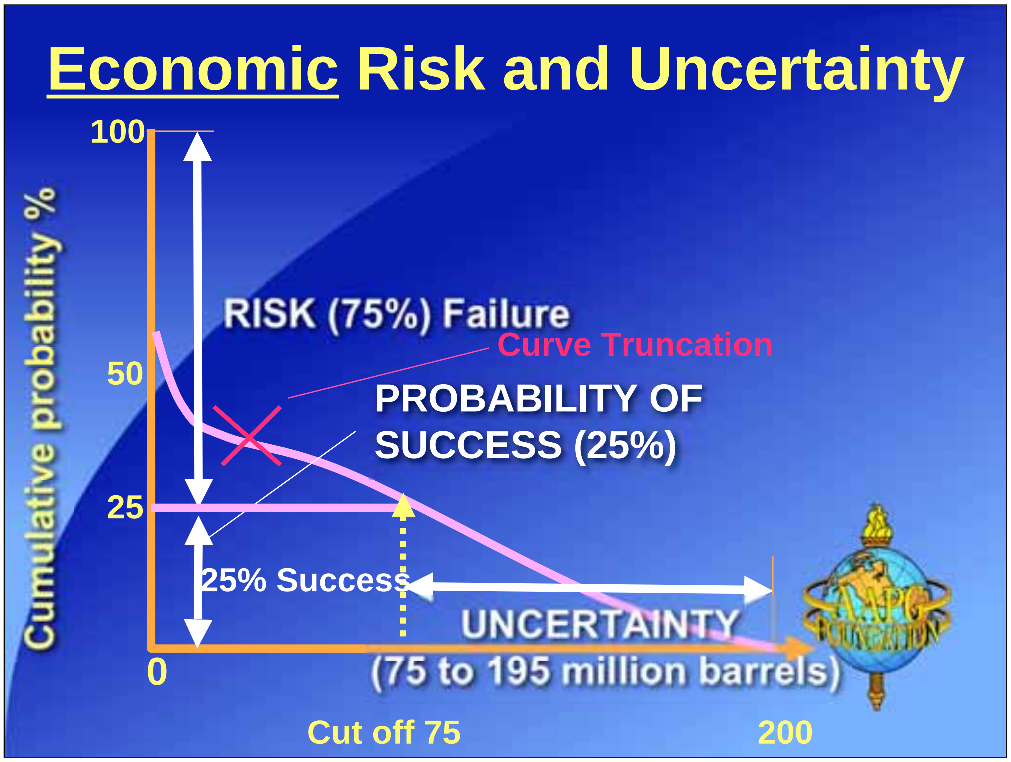


A common convention in exploration today is to to use expectation curves of volume. In this illustration the possible range of discovery is from a few barrels of oil to around 200 million. Using a greater than convention, on this chart, we say that there is a 50% chance of finding a few barrels or greater volume. However, a few barrels are not generally economic and in any area there is a threshold volume at which it becomes economic to develop and produce. In this example the threshold is 75 million barrels and there is a 25% chance of finding 75 million barrels or greater. The threshold volume may change with time.

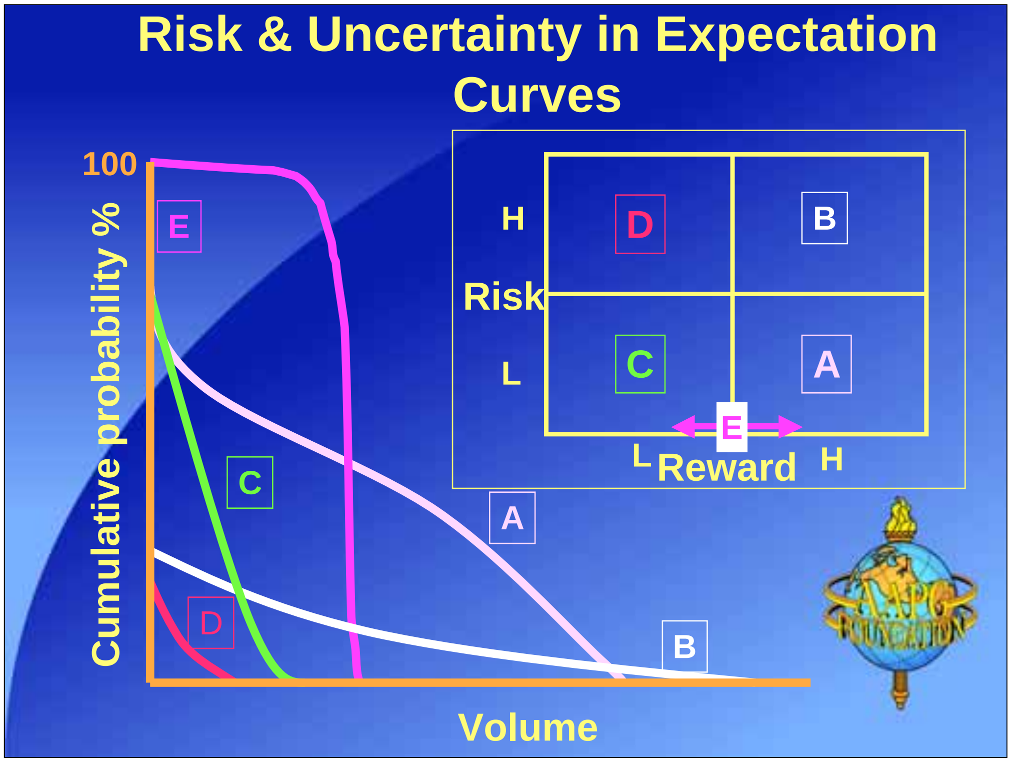


We can translate an expectation curve into geological risk and uncertainty. Thus, on this curve, the risk of failure or not finding oil is 40% and of success is 60%. The uncertainty is represented by the range of potential discovery from a very small volume to 195 million barrels recoverable oil.

However, this is not what we are about as we require an economically viable prospect.



Factoring in the cut off volume of 75 million barrels we then have a 75% risk of failure or not finding an economic deposit. The uncertainty about the range of 75 to 195 million barrels represented by the 25 % chance of success of finding greater than 75 million barrels recoverable oil.



We can deduce different types of risk and uncertainty according to the shape of the expectation curve.

A: is a high reward and low risk. Such prospects are practically unknown in frontier plays.

B: is high reward and high risk, the sort of prospect that industry has been familiar with over the last quarter century.

C: is low reward and low risk and might represent the kind of prospect left in a mature producing basin as a near field prospect

D: is not worth mentioning.

Approaches to Risk & Uncertainty.

Prospect evaluation methodology depends on the data and knowledge available in a basin.

The less there is the more subjective judgments and assessments become. For example, **expert knowledge** is expressed as subjective judgments acquired through experience and incorporation of explicit and intuitive knowledge. Allows the expression of personal statements of probability and value which can differ from expert to expert and will vary with time for the same expert. The Delphi Technique has been used in the past as an assessment method. An example was illustrated during the lecture.

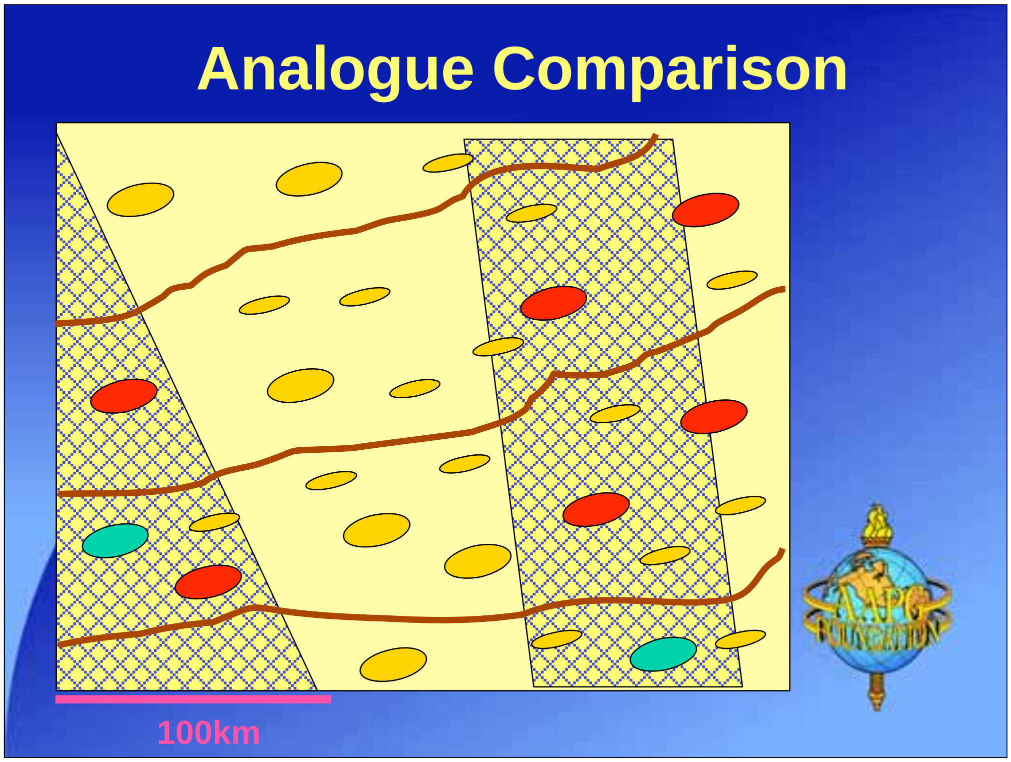
In general, the use of **analogue comparison**, is a very common approach in geology. The problem is to define an analogue that is appropriate to the area under study. Great care has to be taken particularly when using analogues from ‘foreign’ basins.

Historical performance methods are utilised in areas with large numbers of exploration wells and significant numbers of discovered fields. Outcomes can be used to calibrate systematic prospect and play studies where **play/prospect attributes** and their risk and uncertainties are examined and statistically manipulated to create expectation curves.

Analogue Methods

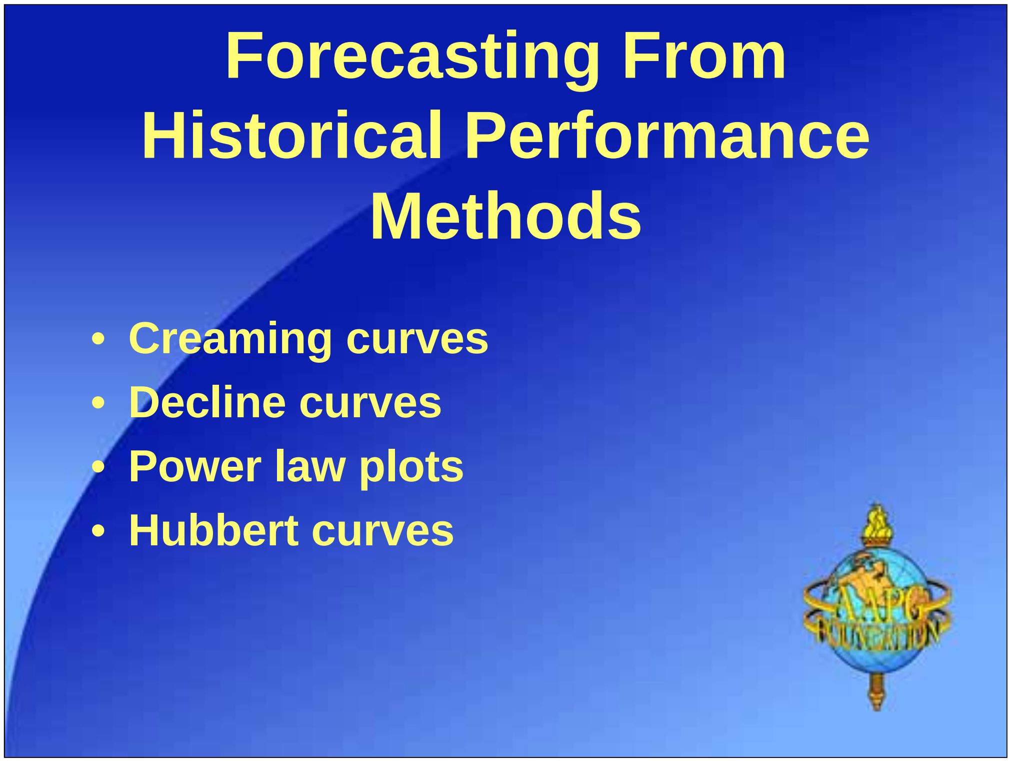
- Area of basin proportional to potential volume of petroleum
- Volume of sedimentary basin proportional to potential volume of petroleum
- Area of oilfield versus area of basin extrapolation
- Tectonostratigraphic basin comparisons
- New technology updates on adjacent acreage

During the early history of exploration in the twentieth century, attempts were made to compare unexplored basin areas with an explored petroleum bearing basin. Such approaches were discredited as the early comparisons were often with prolific Middle East basins. A similar fate befell sedimentary volume comparisons. However, the approach has great value if care is taken with the analogue comparison. Both modern and palaeo sedimentary settings have been used to model environments within a play under study. Geochemistry has provided a multitude of source, expulsion and migration models for petroleum. There is considerable scope for comparing basins or areas of similar tectonostratigraphic style. For instance, comparison of Tertiary basins in southeast Asia or different sectors of modern deltas. The application of newer technology in seismic or drilling in one area may allow ‘What if’? Assessments to similar areas yet to receive such operations. Such approaches may change the potential of an area positively or negatively.



This is a cartoon of a mature basin with many fields and prospects. The brown lines are faults which divide specific prospective trends. The cross hatched areas represent 3D seismic coverage. Comparison of pre and post 3D acquisition showed that prospects' expectations had changed systematically which has been confirmed by several wells. The intervening areas could be expected to change in the same way.

In this example the potential value of the acreage was increased with the application of new technology, not only in the area of application, but by projection into comparable analogue areas. The value may also be decreased.

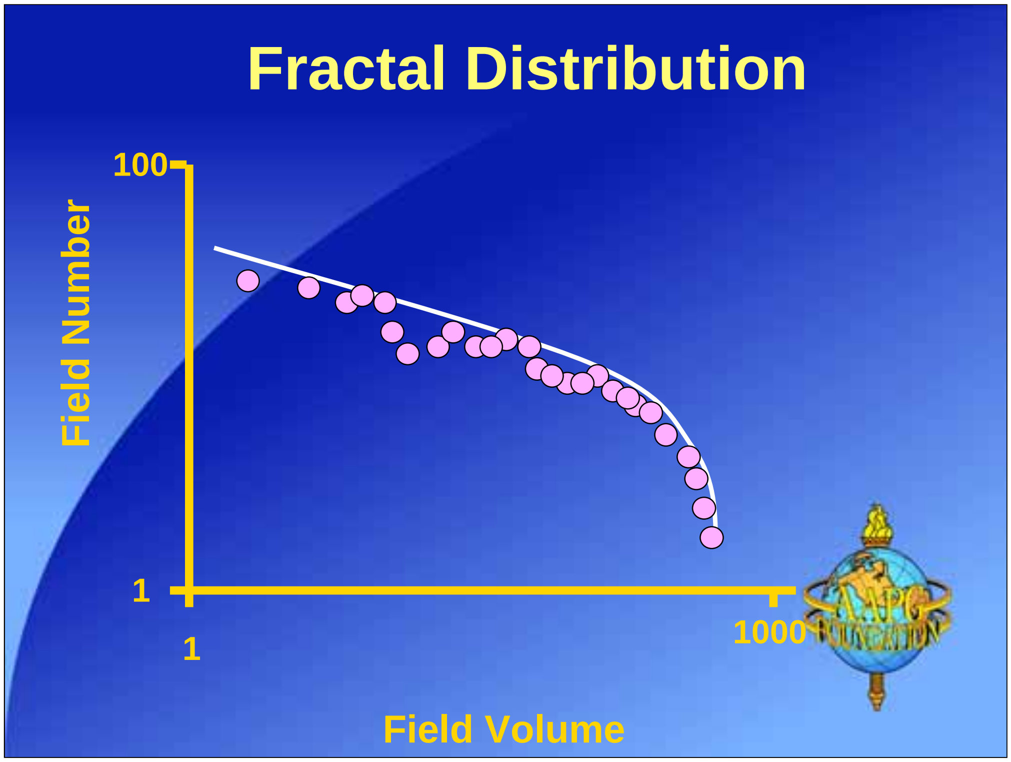


Where the basin has a significant exploration and discovery history, various methods have been employed to project past discovery history as a basis for future prediction. I will talk at some length about creaming curves and briefly about other approaches.

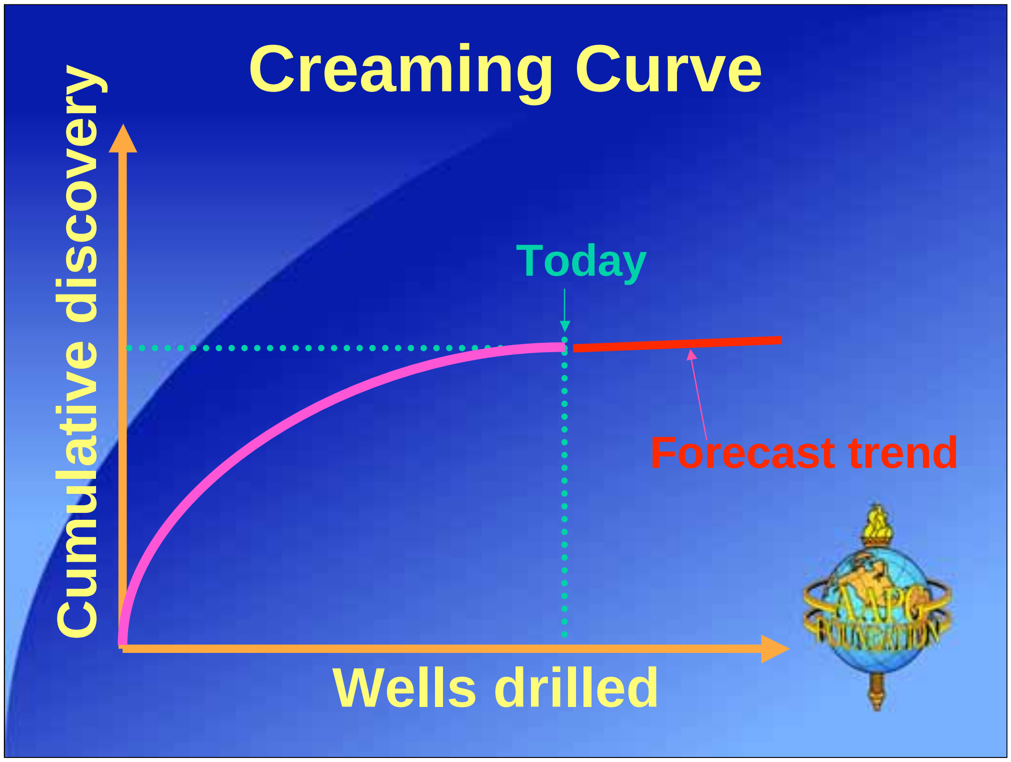
Decline curves and creaming curves are different ways of projecting discovery volumes into the future and are based on the premise that the largest volumes are discovered first and over time the discovery volumes become smaller and smaller. Decline curves look at the fall in discovery volumes over time and creaming curves assess the cumulative discovery volumes over time.

Power law plots assume that petroleum accumulations are part of a dynamic earth system whereby in any play there are few very large fields and increasing numbers of smaller accumulations.

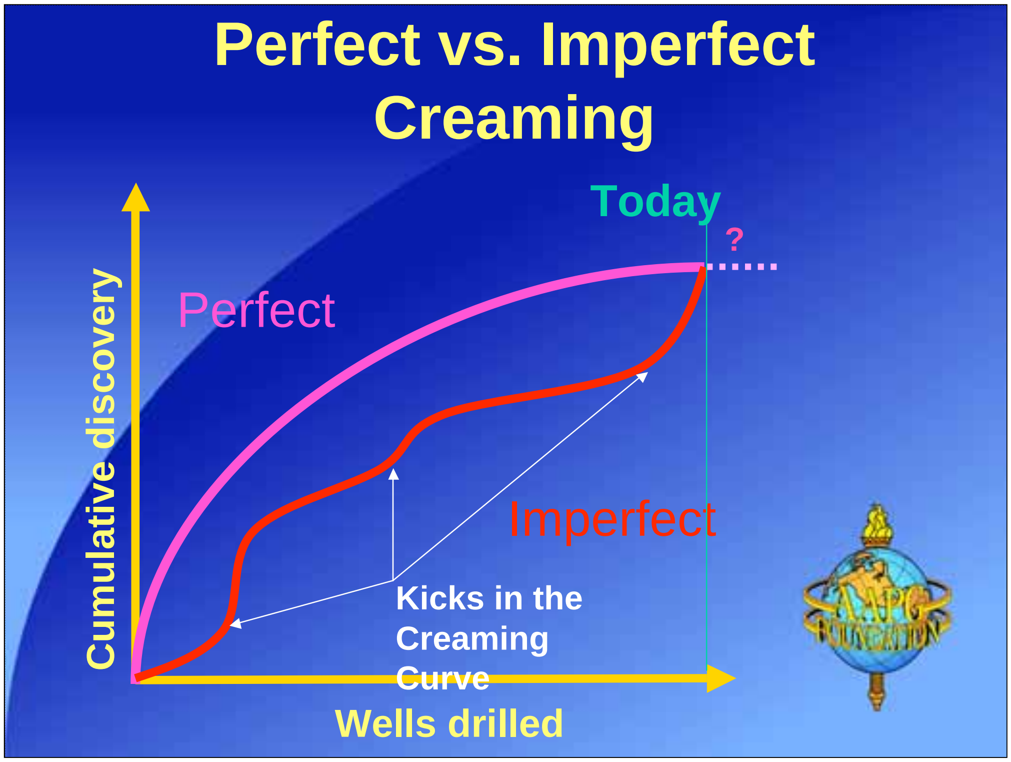
Hubbert curves depend upon production profile scenarios for a basin or area and have particularly been popular in predicting impending shortages of oil in the near future.



The advent of Chaos Theory and Complexity theory has led to experimentation with Power Law Curves. Essentially, the earth and petroleum systems are considered to be in a dynamic critical state. In such a system there will be few giant fields, lots of medium size fields and an infinite number of tiny accumulations. Intuitively, this is correct as every small rumple in a migration path is an accumulation. In fact any accumulations smaller than the economic cut-off are not likely to be quantified. Any that we record are due to a failure of a larger prospect. Because of this cut off any field size distribution tends to be log normal in character. Nevertheless, above the limit of economic cut off it may be possible to interpret missing volumes. An example from Australia is discussed in the lecture.



Creaming curves plot the cumulative discovery volume against cumulative exploration activity or time. The latter may include number of discoveries, number of exploration wells, meterage drilled or years. In principle, a curve builds up in which largest volume discoveries are made first and with time the discovery volumes reduce and the curve flattens. Projecting into the future the curve flattens towards the asymptote with an indication of the likely maximum volume and the number of exploration wells needed to achieve it. Curves plotted against wells or meterage drilled give some idea of the effort involved and also the success rate if all wells are included. Curves published in the literature frequently use time on the bottom axis and it is not easy to project and interpret into the future as the curve may have been affected by slow downs/speed ups in activity. Sometimes petroleum volumes may be plotted as a percentage of the volume accrued to date.

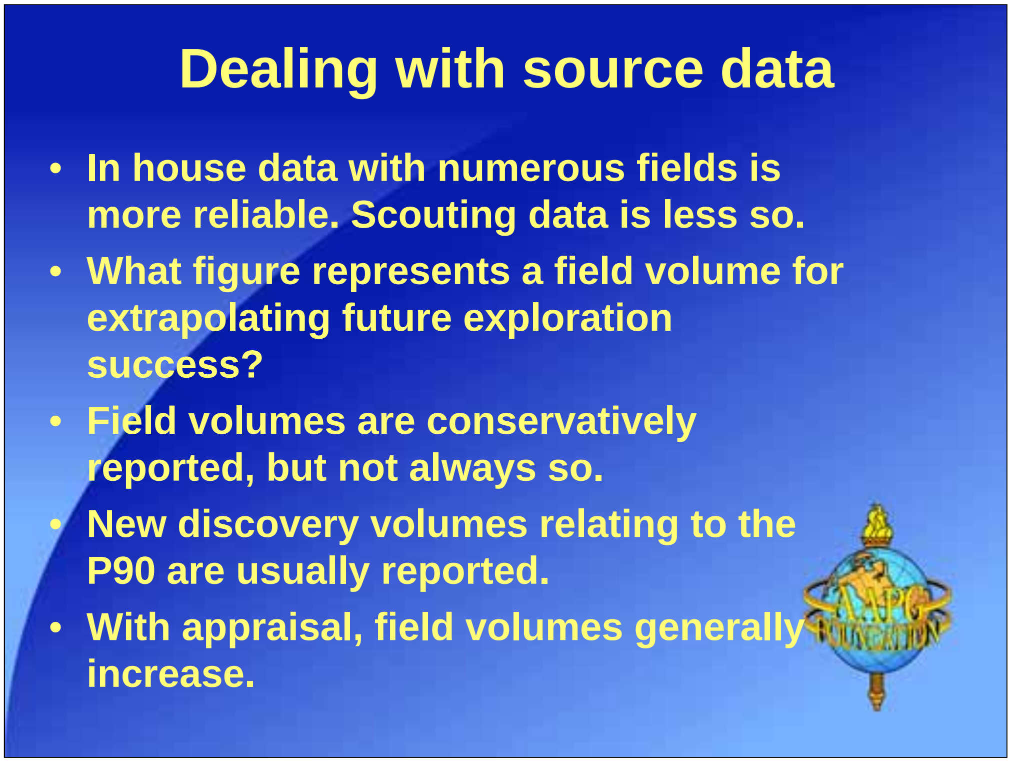


If an exploration outfit were able to pick off the best prospects in order and successfully turn them into discoveries we would call this perfect creaming. Although, some basins exhibit near perfect creaming the reality is that nature does not yield her secrets easily and the creaming is imperfect. An imperfect curve is difficult to project into the future. An imperfect curve will exhibit changes in gradient which reflect variation in rate and amount of accrual of discovery volumes. Repeated innovation in concepts and/or technology is often reflected by changes to steeper gradients (kicks in the creaming curve) followed by a lowering gradients as the particular innovation creams the prospect volumes. A kick will often reflect a new successful idea or application of technology.

During the lecture, examples were discussed from various basins including the North Sea, Bangladesh, Oman and Western Canada to illustrate different types of plots and difficulties of projection into the future.

All curves exhibit some degree of imperfection from small to large. A near perfect curve may lead to overconfidence in understanding of the geology and the failure to realise new or hidden potential which is not represented by the current curve.

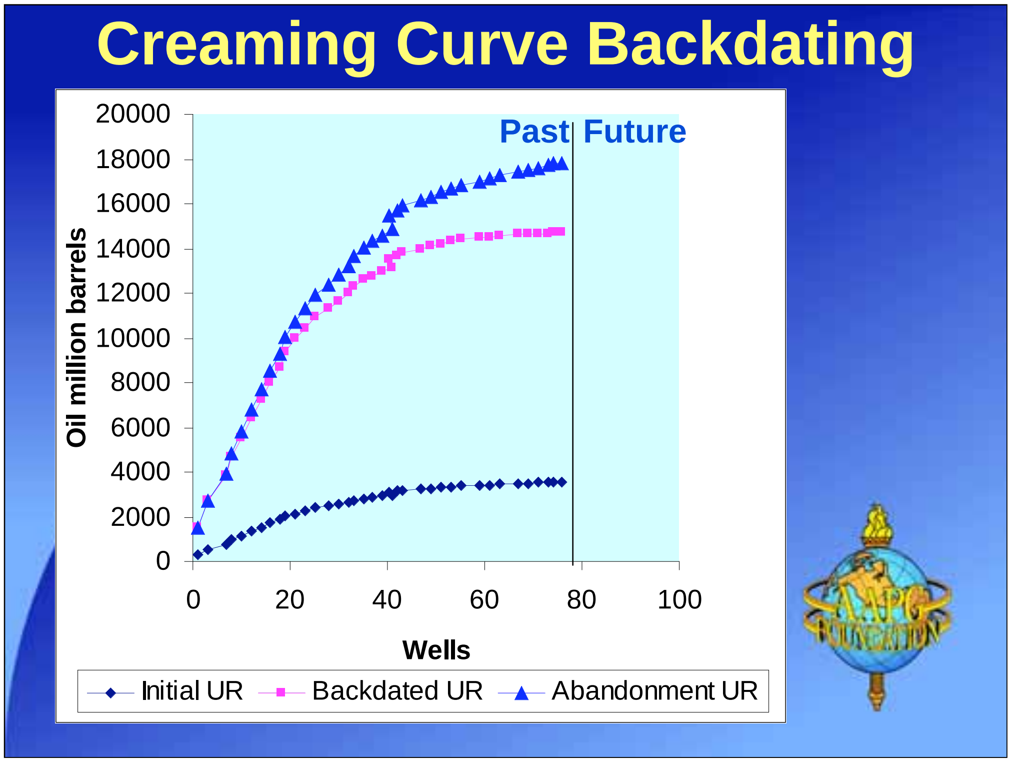
The more imperfect the curve the more challenge there is in elucidating the underlying geology.



Organisations with large field data bases in which they have an equity interest can apply a consistent process for estimation of field and prospect volumes. In such cases, reliable creaming curves may be constructed. Even so, care has to be taken in defining what representation of a field expectation curve is used as a basis for creaming curve construction and prediction of future exploration success. Field volumes may be reported conservatively as the P90 (or P85 volume) or less conservatively for other reasons. In general, with further development/appraisal uncertainties are narrowed and field volumes increase.

Where curves are constructed on the basis of scouting data it becomes more difficult. The underlying methodology may vary from one organisation to another.

It must be emphasised that creaming curves constructed from such data may contain inconsistencies and may be wide of the mark. Published creaming curves should also be examined critically, particularly with respect to curves which show sudden kicks representing rapid accruals of petroleum reserves without apparent innovation or activity.



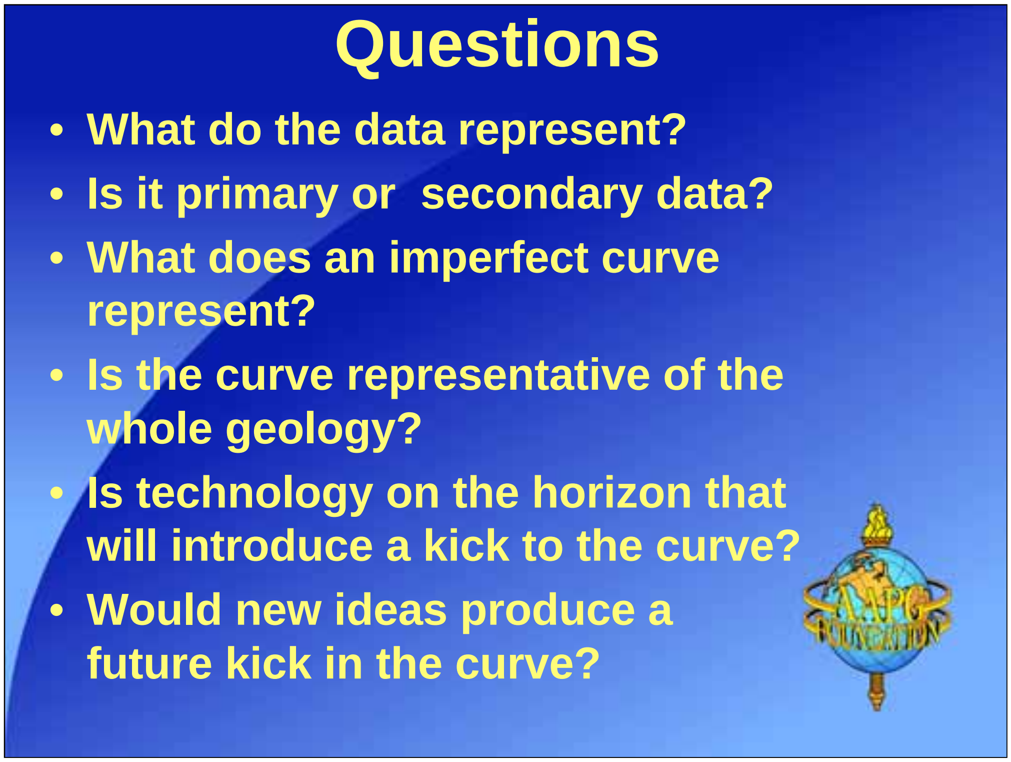
Backdating is a process by which field volume revisions which change with time are plotted with the discovery well.

Here is a fictitious example.

The black curve represents the initial booking of volumes in each field (say P90). It can be seen that the P90 is inappropriate as a measure for creaming curves.

The pink curve represents backdating to the discovery well. In practice, older fields have greater levels of backdating which tends to give the curve a flatter appearance than it warrants to the right. Thus, future creaming would be underestimated.

The blue curve represents the cumulative volumes as at abandonment. Now, volumes at abandonment are, by definition, not known until abandonment. A methodology is required that simulates abandonment volumes being booked to the discovery well, such as the mean volume from a field expectation curve at any moment in its history between discovery and abandonment.



See notes on previous slide.

Having discussed creaming curves which I regard as top down approaches I would like to discuss briefly, prospect play approaches which I regard as bottom up.

Bottom up approaches utilise data from variables within the play, relating to source rock, charge, reservoir, trap geometry and sealing lithologies.

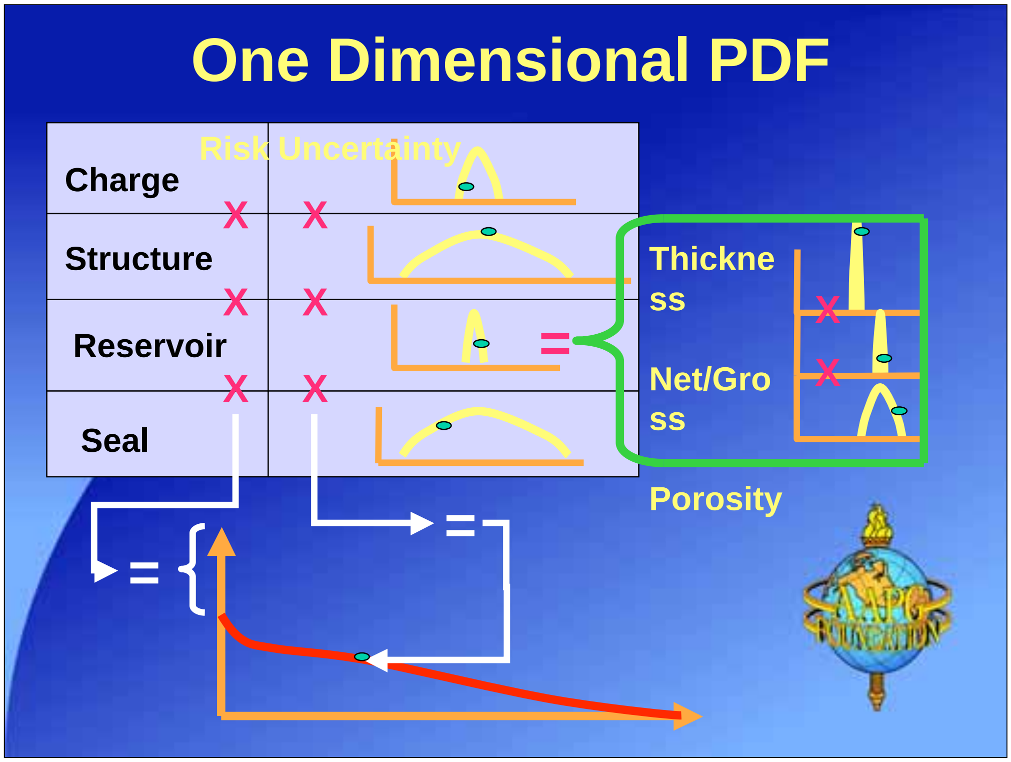
Where little data is available, subjective decision matrices are often developed.

Deterministic approaches take what is considered to be an average figure from each variable and multiply them to get a one figure outcome.

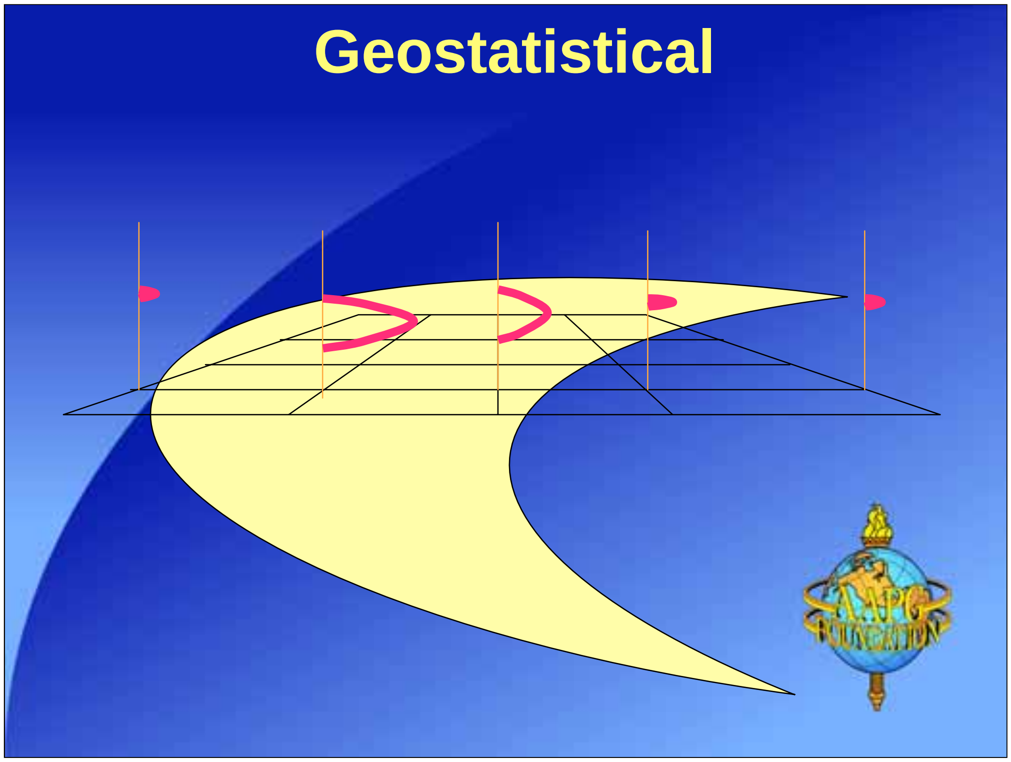
One dimensional PDF methodologies were first developed in the the sixties and became applied in major companies in the 1970/80s. At the same time applications using the Monte Carlo methodology were developed. Today vendors market PC based applications with this capability.

Since the late 80s 3D seismic has become routine, geostatistical techniques, originally developed in the mining industry have been applied to petroleum prospects by exploration companies and some contractors.

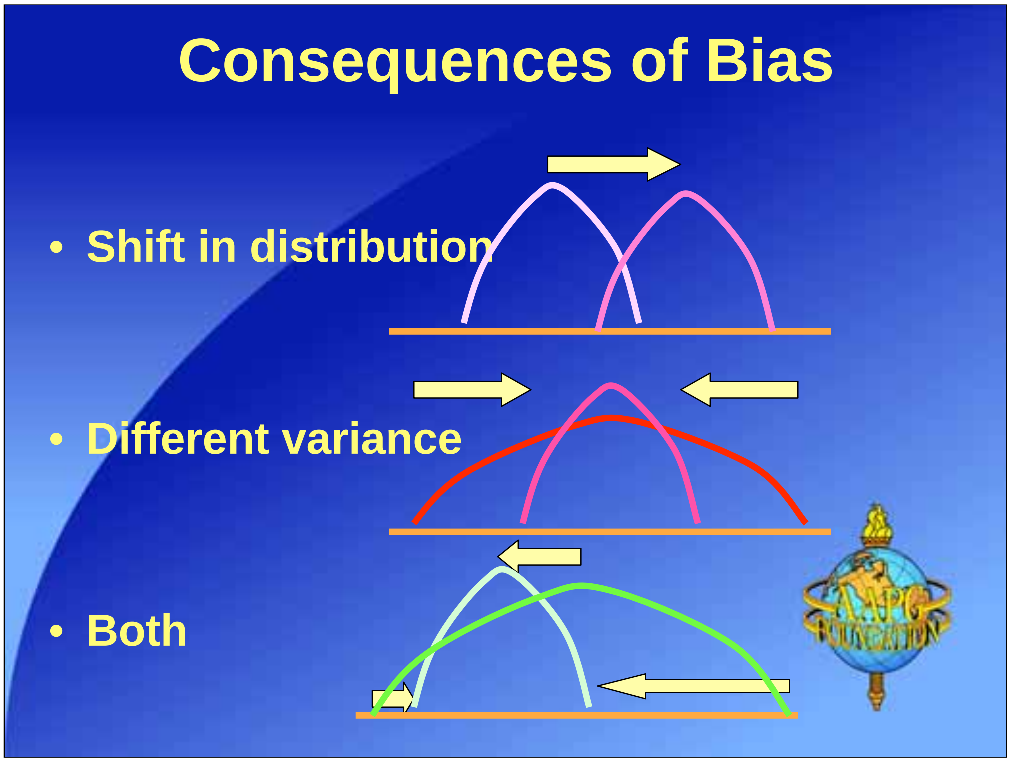
Body mapping involves the mapping and assessment of bodies in 3D seismic space which can be assigned geological attributes relevant to petroleum volume estimations.



In one dimensional PDF approaches the geological variables are sampled singly and in random order and multiplied to get a product. This is repeated at least a thousand times and the result is an aggregation of points to create a log normal expectation curve.



In geostatistical applications the variable is manipulated areally from very large numbers of sampling points, the grid nodes of a seismic survey for example, and results in many realisations of map outcomes. For example as many as 1000 structural maps, each being equally probable, can be created. Some examples were illustrated in he lecture.



Bias.

I would now like to go on to the topic of bias. If we consider any variable and relate the sample to the real population then we may encounter the following types of bias.

Displacement bias where the distribution is shifted.

Tighter variance or more limited range.

Both of the above.

Bias is a major issue. All of us have different biases according to our background and education, and professional development.

Why does bias occur?

The subsurface is complex and inevitably we have to simplify it.

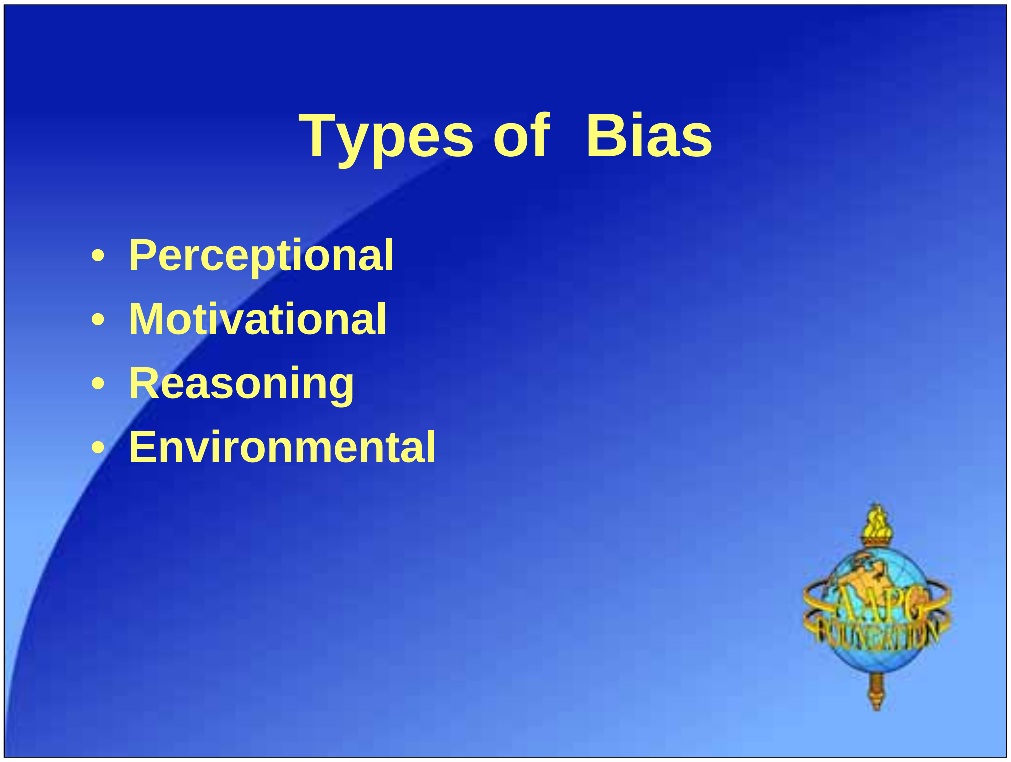
People have difficulty with lots of empirical data.

Subjectivity is a normal human trait.

The working environment and culture affect us.

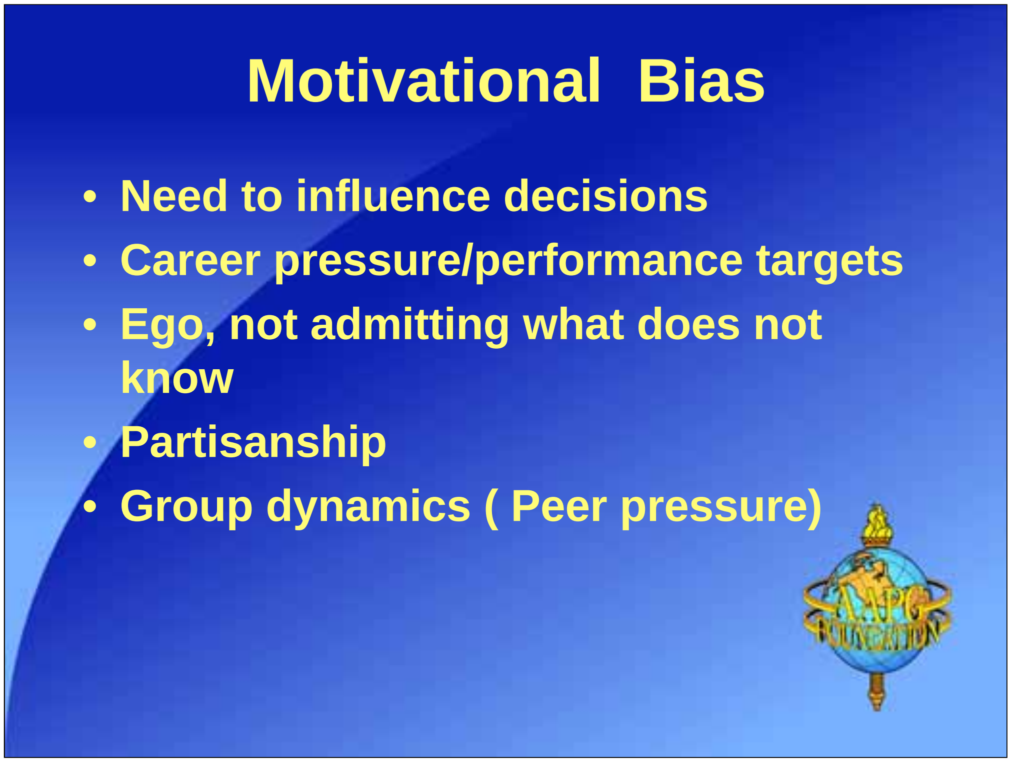
Managements needs may influence evaluations.

Is there enough time to do the job properly?



Perceptional bias relates to the senses. The main sense involved in exploration is that of sight, particularly in observing geology or interpretation of seismic sections. In the 1960s, Robert Ornstein and Roger Sperry made important advances in our understanding of how the brain works. They discovered, in particular, that the brain is divided into two halves, or hemispheres, and that different kinds of mental functioning take place in each. Thus, in most people the left hemisphere operates sequentially and deals largely with 'academic' activities, such as reading, arithmetic and logic. By contrast, the right hemisphere operates holistically and deals more with 'artistic' activities, such as art, music and colour.

Many examples of optical illusions the right brain creates a pattern which is not quite representative of the data. For example, photographic images of topography can appear inverted.



We all like our advice to be taken, there is a fine line before we become stubborn.

Pressure to do well, sell a prospect, be associated with a discovery well.

Not wanting to show what we do not know.

Partisanship: In October 2003, at a Geological Society Petroleum Group meeting in London Iain Bartholomew gave a presentation on an experiment within Amerada Hess where exploration groups across the world were asked rate risk and uncertainty in prospects from different areas of the world. The different groups showed clear partiality to those prospects they knew and rated them higher.

Reasoning Bias

- **Overvaluation-Geological model given more weight than it merits**
- **Accessibility/Neglect-Recent or spectacular data only utilised and other data ignored. Neglect of prior data**
- **Fixity-Being fixed on a starting model. Average map! Being unable to consider other models**
- **Exclusion-Success/Failure cases are left out. Not allowing for significant upsides/downsides**

Reasoning bias relates to models and data being given incorrect or inappropriate value in judgements of prospectivity.

Early in a project, a model may be chosen that in hindsight turns out to be incorrect, whereby newest data is utilised. In the 1980s a company had a limited well control of 18 wells which, they did not know at the time, were drilled in some of the best sands of a play and gave a more optimistic model than warranted of widespread thick and laterally extensive sands. Later 3D seismic and wells showed the sands to be more heterogeneous. Production required an extensive multilateral programme.

In acreage bidding rounds, embargos of particular areas have happened because of attachment to non prospective geological model which in hindsight were proved to be longer viable. The converse has also happened.

On an every day level many of us have experienced: ‘I will not fly because there have been a major plane disaster yesterday. The disaster looms in one’s mind and shuts out the long term safe prior record of the aviation industry. Recent data is ften preferred to older data.

During map interpretation, one map tends to be used as a base case, whereas there may be several structural solutions.

Narrowing the uncertainty in a well depth prognosis may lead to surprises where well reach a target horizon much deeper than expected with attendant cost implications.

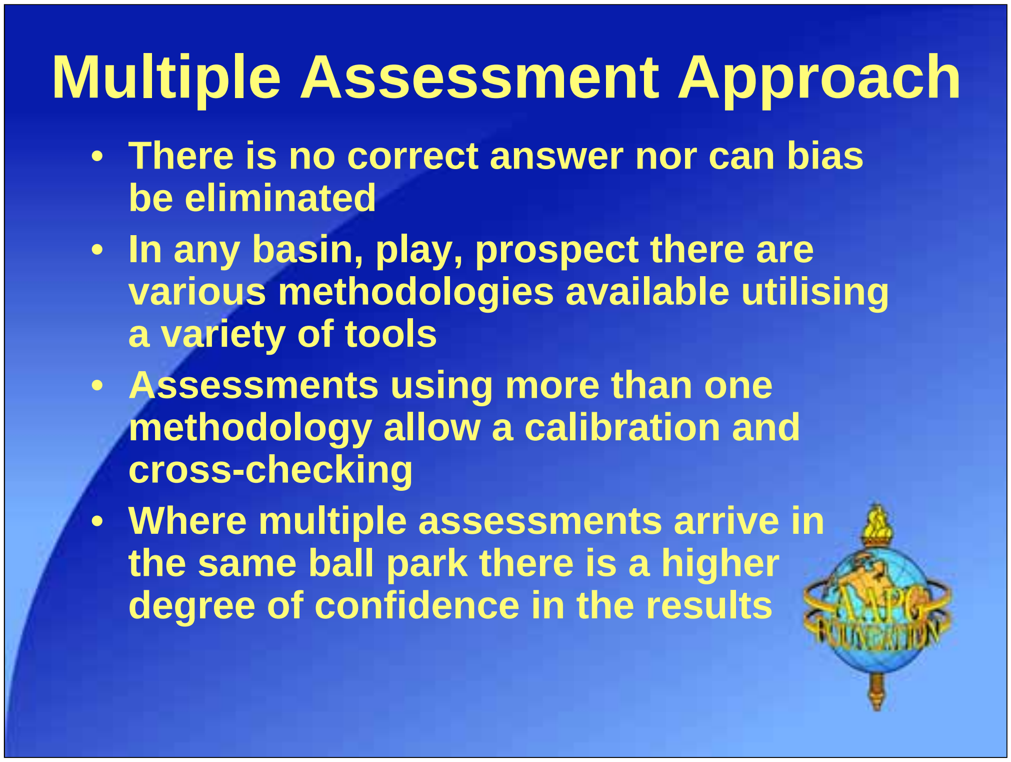
The working environment and culture affects how people take decisions. A company may be risk averse or risk amenable and may even oscillate between the two extremes.

A context dependent mentality can arise which is different if, for example, one is considering a farm in or farm out each with a distinct bias on the prospectivity assessment.

There is a tendency for all levels of exploration to champion prospects in a positive light.

There is a problem of association. A well has taken two sidetracks to get to its objective and has found promising petroleum indications. The test is in doubt because of the well is well over budget. This parallels findings that as individuals we would not buy a second theatre ticket for £50 after losing the first ticket, whereas if we had just lost a £50 note we would happily buy the theatre ticket.

We are all affected by success and failure which affects our attitude to future prospects. Initial success in a play can lead to higher exploration commitments than the play would warrant particularly in a competitive bidding situation.



I have given an outline of the nature of bias and a few examples of its manifestation. I find it difficult to see how bias can be eliminated particularly in the face of human nature. I believe that bias can be minimised if a systematic open process is used for the assessment of risk and uncertainty which is used across the board in an exploration organisation. Such a process may involve more than one methodology with a variety of tools. If the process and data allow the use of both top down and bottom up methods then there is a way of cross checking and calibration. Contrasting methods which arrive in the same order of value may be given higher confidence than those that do not.

The process must be completely open and explicit, owned and accepted by everybody involved in it.

The methods/tools must be shared and applied across the board.

A dedicated team/individual should have ownership of the process and be there to nurture and improve it and act as a champion.

Access to all expertise-part of this is knowing what expertise you have in house.

Framing the requirements of risk and uncertainty assessment is the company strategy and goals. What is your company about?

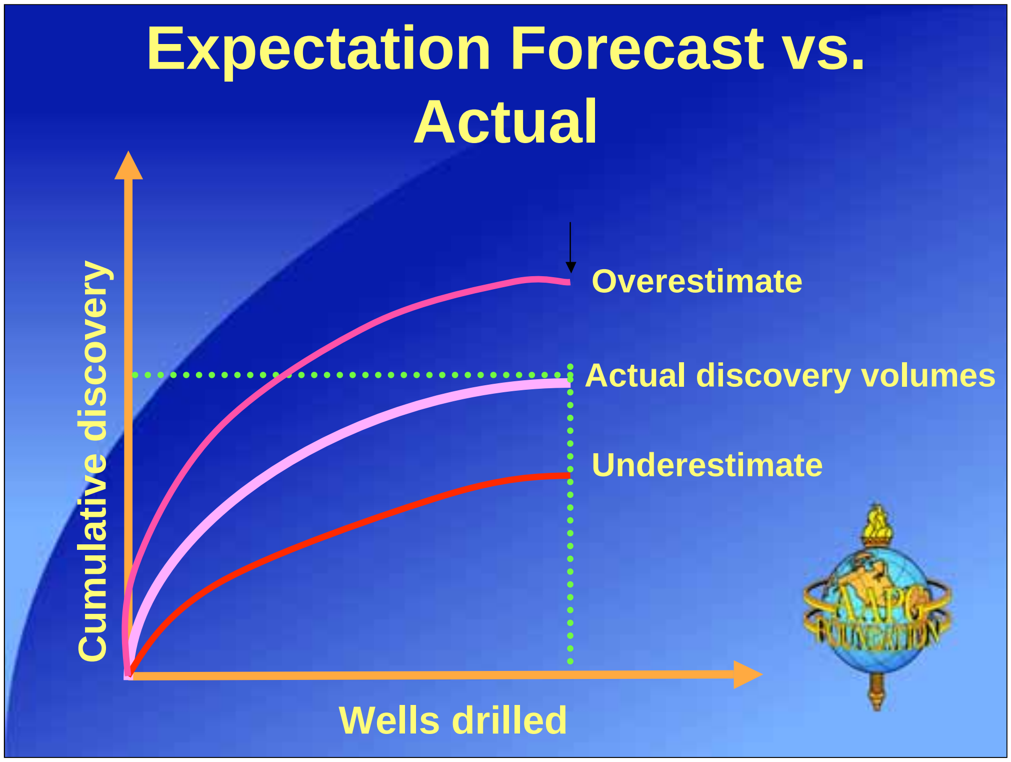
Is it to find a new discovery every year? Is it to document reserves without bringing them on stream? Does infrastructure on declining fields require connectable prospects to be added? Etc?

Rather than a play or basin approach, the Petroleum Systems Approach provides a disciplined and systematic approach to understanding risk and uncertainty. This approach should be intimately linked to the methods/tools for assessing prospect volumes. In addition, the ability to continually learn and update knowledge is vital to enhance performance.

Exploration Performance Criteria

- Finding costs
- Hydrocarbons discovered
- Success Ratio
- Expectation versus discovery volumes
- Trap or reservoir parameters vs. predicted
- Value adding through basins>>petroleum plays; leads>>prospects>>discoveries within a petroleum systems context
- Reducing risk and uncertainty and increasing economic value

Performance can be measured by factors considered important to an organisation. A few are listed here. They are not exclusive and different organisations would pursue different sets.



Just one example of a performance measure. After a period of time an exploration programme can be assessed in terms of its predicted expectation volumes versus actual discovery expectation volumes. The plot would include all exploration wells.

Actual discovery volumes are shown in mauve. Three outcomes are possible: (a) The exploration expectation is close to the actual volume realised in which case the organisation has a good grasp of the nature of the various risks and uncertainties.

(b) The expectations overestimated the discovery volumes.

(c) The expectations underestimated the discovery volumes.

In both (b) and (c) there is a serious problem of risk and uncertainty assessment which requires a systematic investigation of pre and post drilling data and a inspection of the process/methodology.

Risk and uncertainty should be fully and properly acknowledged.

I would like to sum up. I have given a lecture which looks at various aspects of risk and uncertainty in geology in petroleum exploration, from definitions, through approaches to assessment. A brief look at bias and some remarks on process and performance measures and learning. I leave you with the bullet points on the slide above which I should like to emphasise.

I would like to end my lecture by wishing you the best of luck in your prospect evaluations and assessment of risk and uncertainty. Thank you for listening and I would appreciate receiving any questions or comments you would like to ask me.