USGS Methodology for Assessing Continuous Petroleum Resources

By Ronald R. Charpentier and Troy A. Cook

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USGS Methodology for Assessing Continuous Petroleum Resources

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Outline

- Principles of resource assessment
- Previous methods of assessing continuous resources
- Methodology issues addressed by the new USGS methodology

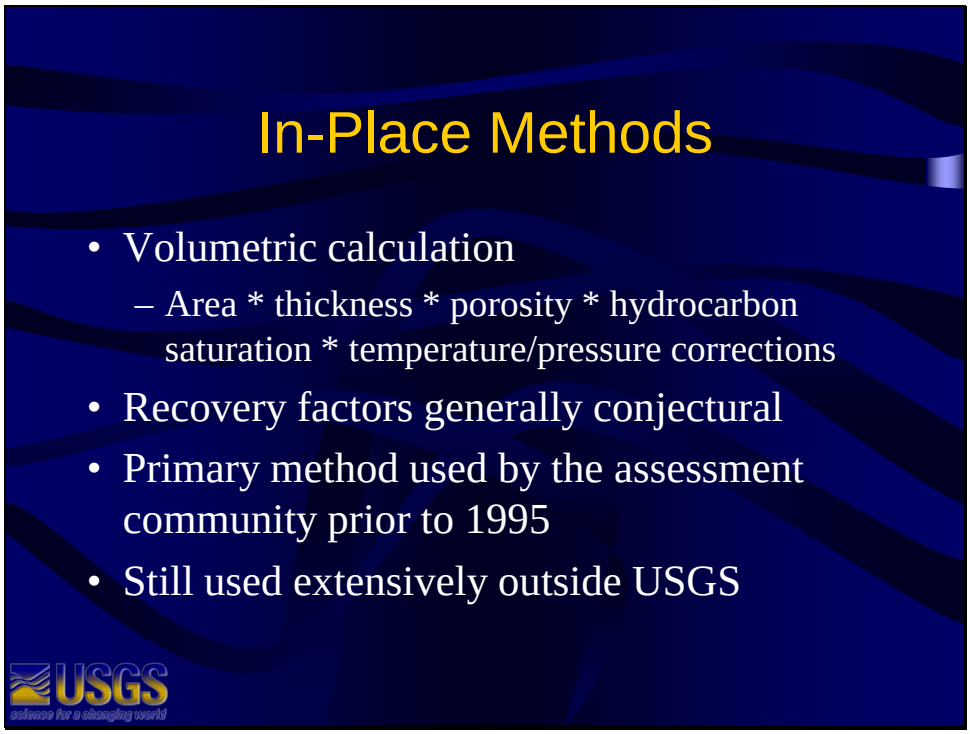
Outline (continued)

- New USGS methodology for assessing continuous resources
  - Defining shale-gas assessment units (AU)
  - Walk through the new USGS methodology
- Applying analog data in data-poor AUs
- Data requirements for shale-gas AUs

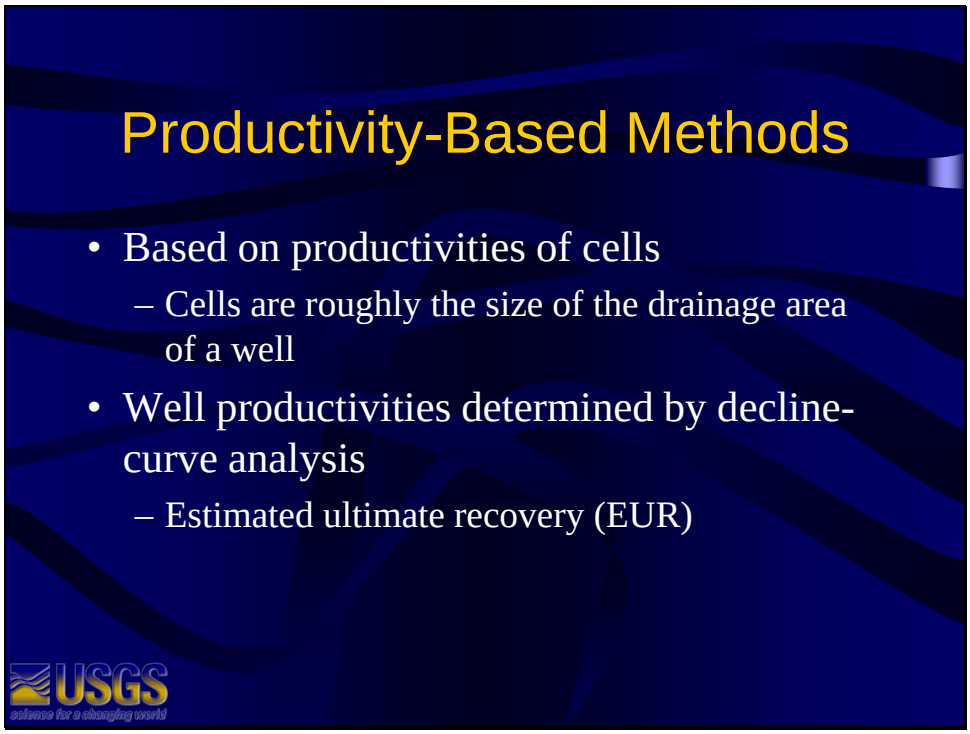
Principles of Resource Assessment

- Resource assessments should be fundamentally based on geology.
- Probabilistic methods should be used.
- Assessment methodology is a means of quantifying geologic hypotheses and uncertainties.

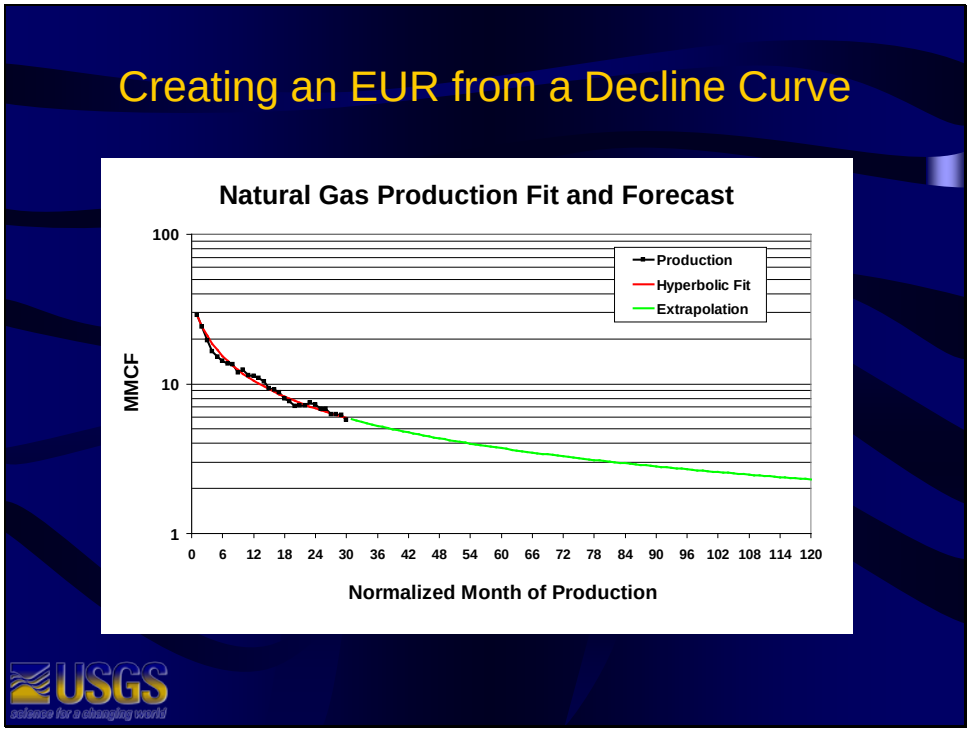
Previous Methods of Assessing Continuous Resources



Commonly, the recovery factors for continuous accumulations have been poorly understood.



Productivity-based methods use drilled wells as “computers” to calculate recoverable resources.



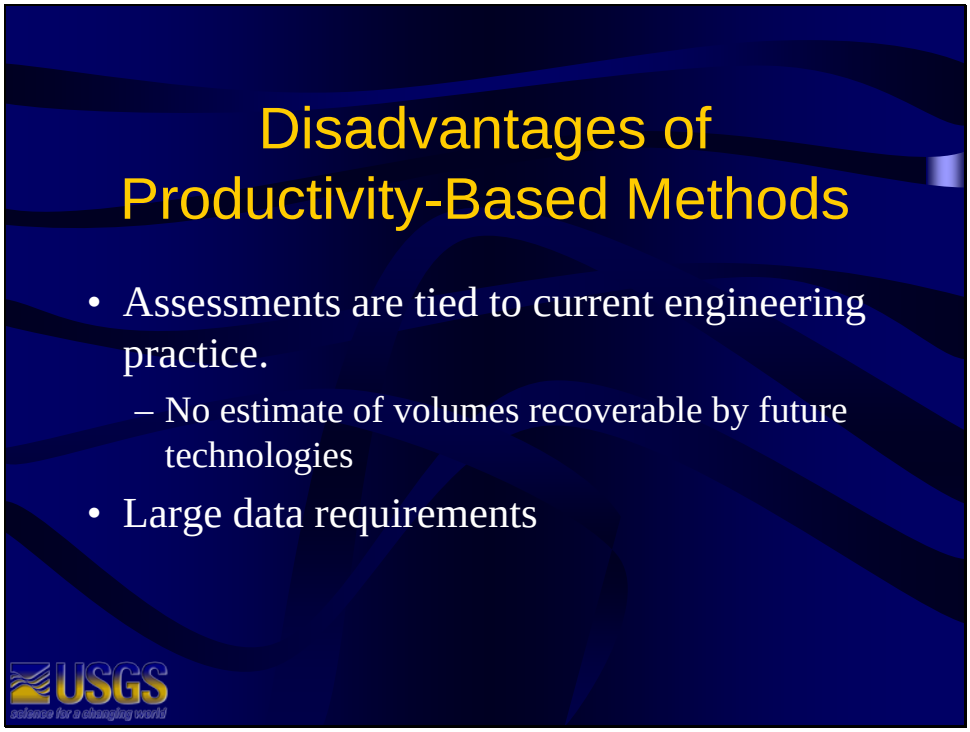
A hyperbolic decline curve was fitted to the mean production decline of six Barnett Shale gas wells. This example demonstrates a calculation of estimated ultimate recovery (EUR) based on a 90-month forecast of the expected decline.

Productivity-Based Methods

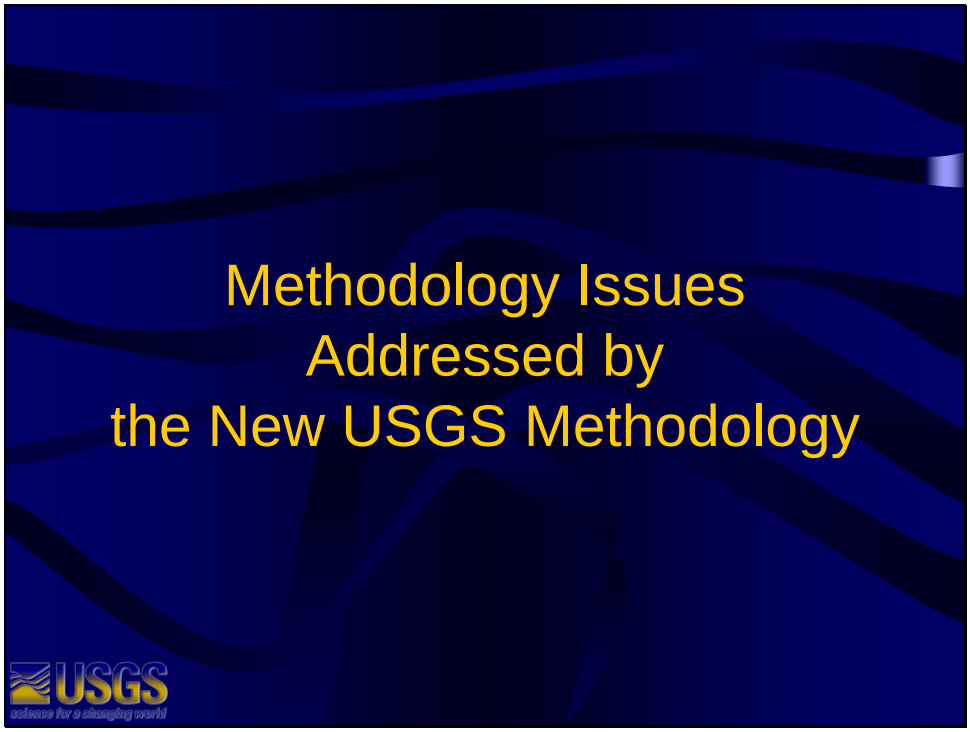
- Estimates of numbers of cells based on:
  - Area of assessment unit (AU)
  - Percent of area already tested
  - Area of a cell
- In USGS methodology, all of these are estimated as probability distributions

Advantages of Productivity-Based Methods

- Well productivities (EURs) make assessments more realistic
- Much more production data available now compared to 30 years ago
  - Many more wells with longer producing histories
  - Many more plays



Some organizations that need to study the effect of radical changes in production technology may wish to supplement these methods with in-place calculations. Although the methods have large data requirements, analog data can be used for areas that are data-poor.


Methodology Issues
Addressed by
the New USGS Methodology
USGS
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Applicable to Frontier Assessment Units (AUs)

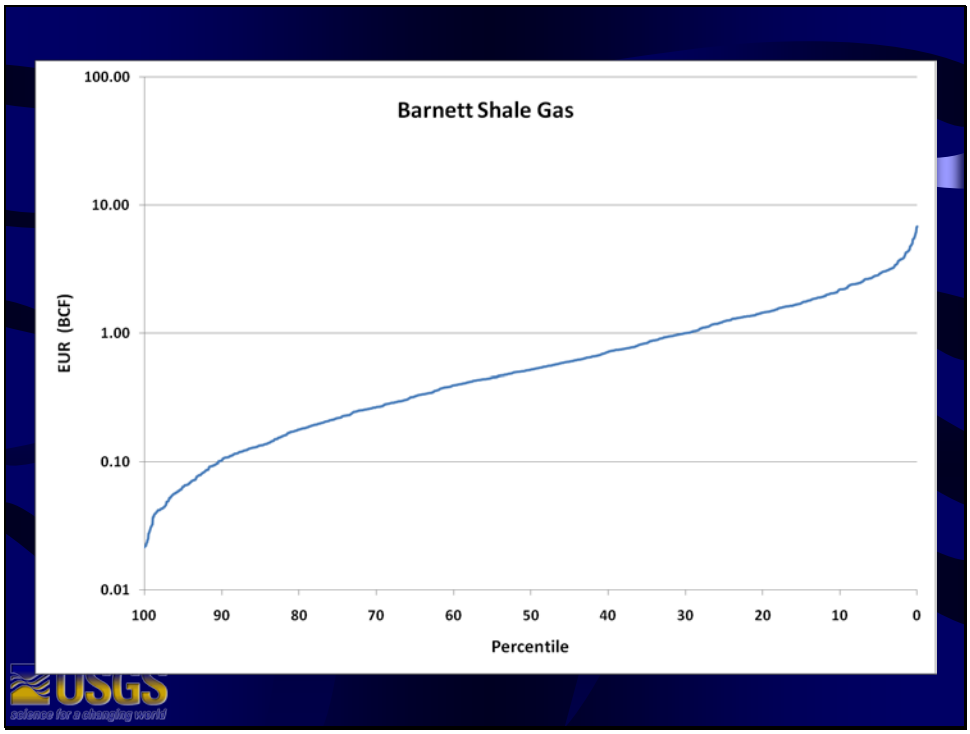
- No or little previous production
- Little information about well performance parameters
  - Success ratios
  - Drainage areas
  - Estimated ultimate recoveries (EURs)
- Possibility of zero potential
- Solved by use of analogs

Accounts for Poorly-Developed Geologic and Engineering Models

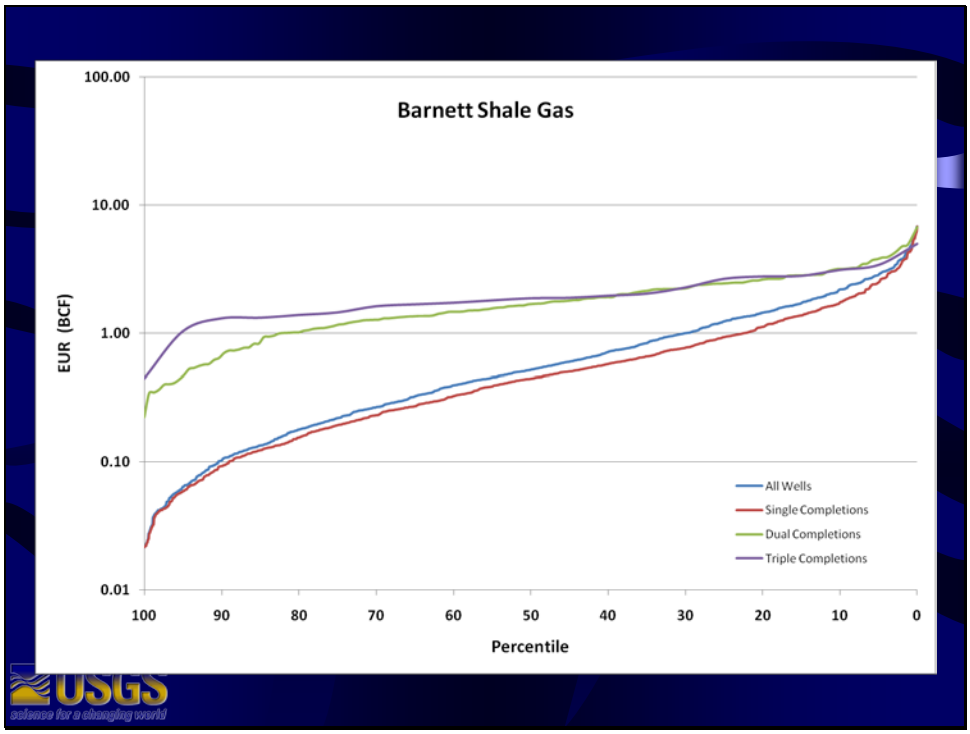
- Understanding of geologic and engineering controls on productivity is not as refined as for conventional petroleum.
- Still very hard to estimate ahead of drilling
- Great improvements in last decade
  - Lots of models giving partial explanations of controls on productivity
- New method is robust.

Better Handling of Complex Historical Information

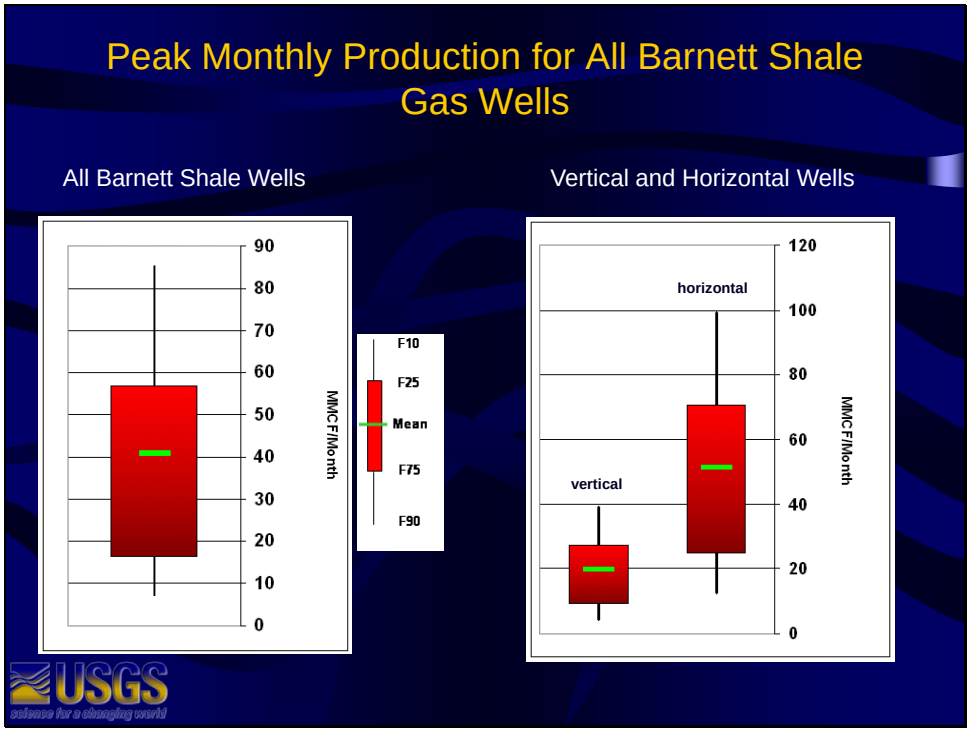
- Complex patterns
  - For example, trends in EUR with time
- Not as "well behaved" as some classic conventional data sets
  - Discovery process models less applicable
- Multiple trends going on at once
  - Analysis and interpretation needed



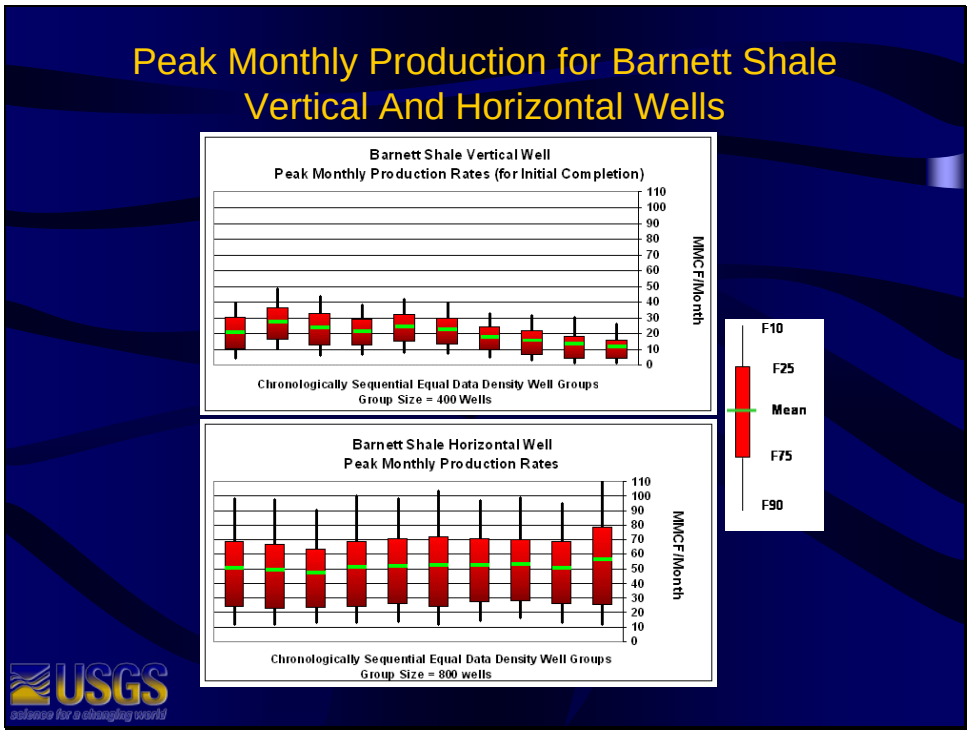
This graph presents the EUR for 1,417 vertical wells in the Barnett Shale as of 2003. It shows the distribution of EURs for those wells with an EUR of at least 0.02 billion cubic feet (bcf). The percentiles indicate what percent of the wells have an EUR of at least the indicated amount. Note that the range of EURs is greater than two orders of magnitude. (1 billion cubic feet = approximately 28 million cubic meters).



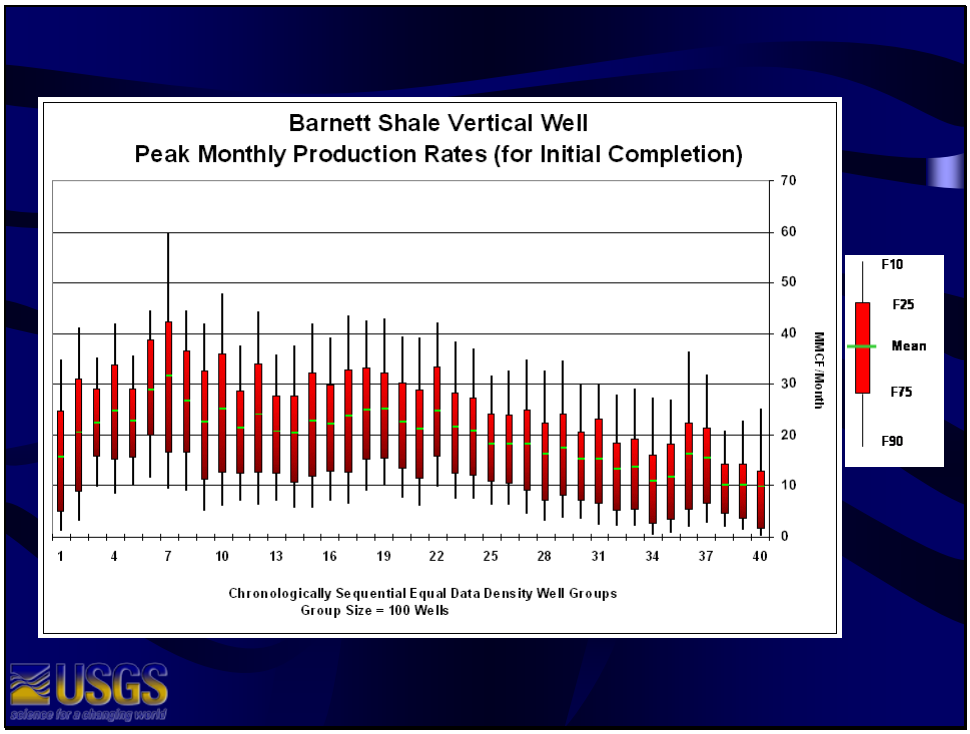
This graph adds lines for those wells used in the preceding graph with single completions (1,240), dual completions (156), and triple completions (21).



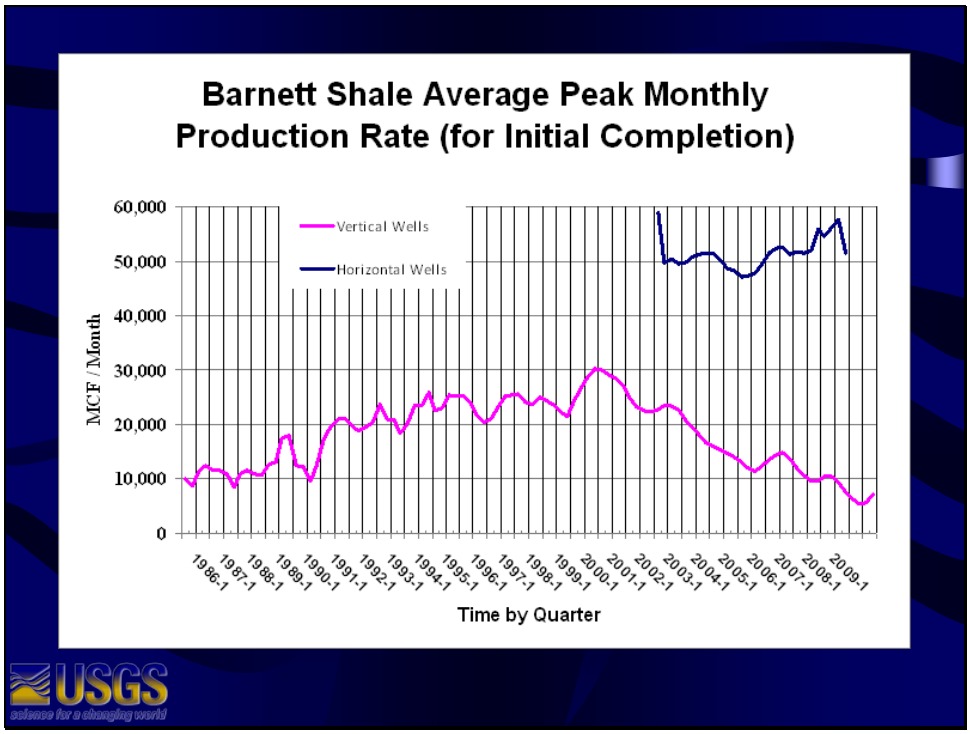
These box-and-whisker plots show the distribution of peak monthly production for Barnett Shale vertical wells as of 2003. Peak monthly production is generally the production value for the first full month of production. Note the increase in information that results when the full distribution (on the left) is broken into two subgroups (on the right) showing much higher peak monthly production values for horizontal wells as compared to vertical wells. The box-and-whiskers plots show the parameters of the distributions: the green line is the mean, the top and bottom of the red box are the F25 and F75 fractiles, and the top and bottom of the lines are the F10 and F90 fractiles. MMCF, million cubic feet.



The same data from the previous slide can be further subdivided to give even more information. Here the wells are divided into subgroups by order of drilling to show trends in peak monthly production with time. Vertical wells show a decrease with time, whereas horizontal wells have had relatively stable peak monthly production with time.



Even more subdivision provides additional information on data trends.



This graph shows trends in the average peak monthly production with time, separately for vertical and horizontal wells. MCF, thousand cubic feet.

Allows Mixture of Sweet and Nonsweet Populations

- Study of <u>some</u> continuous deposits suggests that the productivities within a continuous deposit are a mixture of <u>two</u> populations
  - Most clearly seen in some tight gas sands
  - Not all deposits show this
- How do you define sweet?
  - Are sweet spots just the high end of some distribution, or are they evidence of a mixture?

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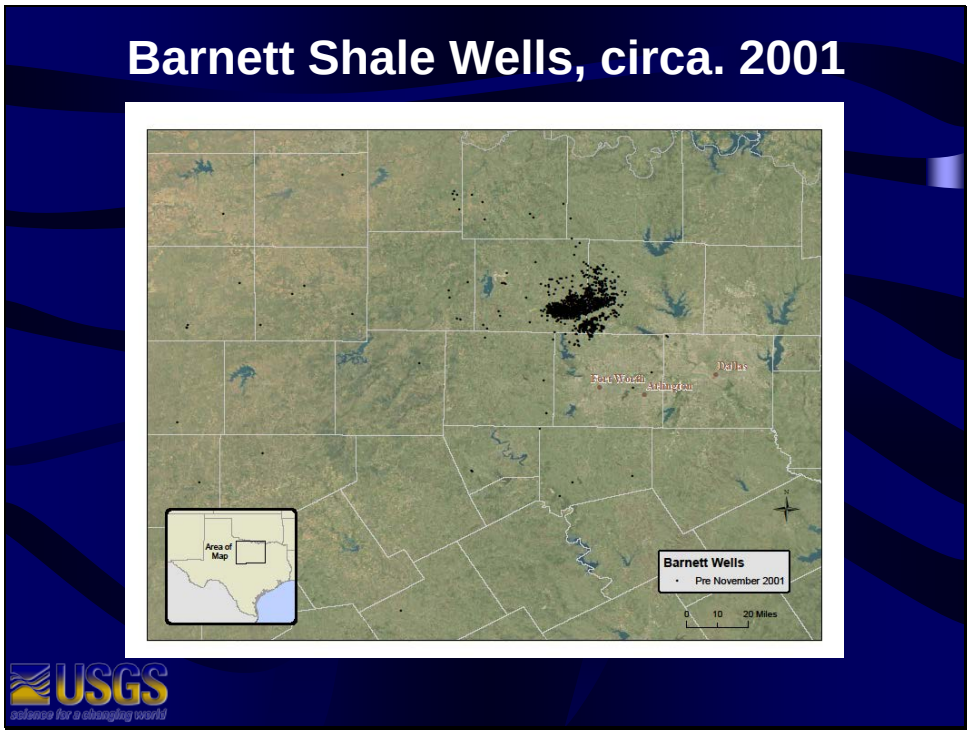
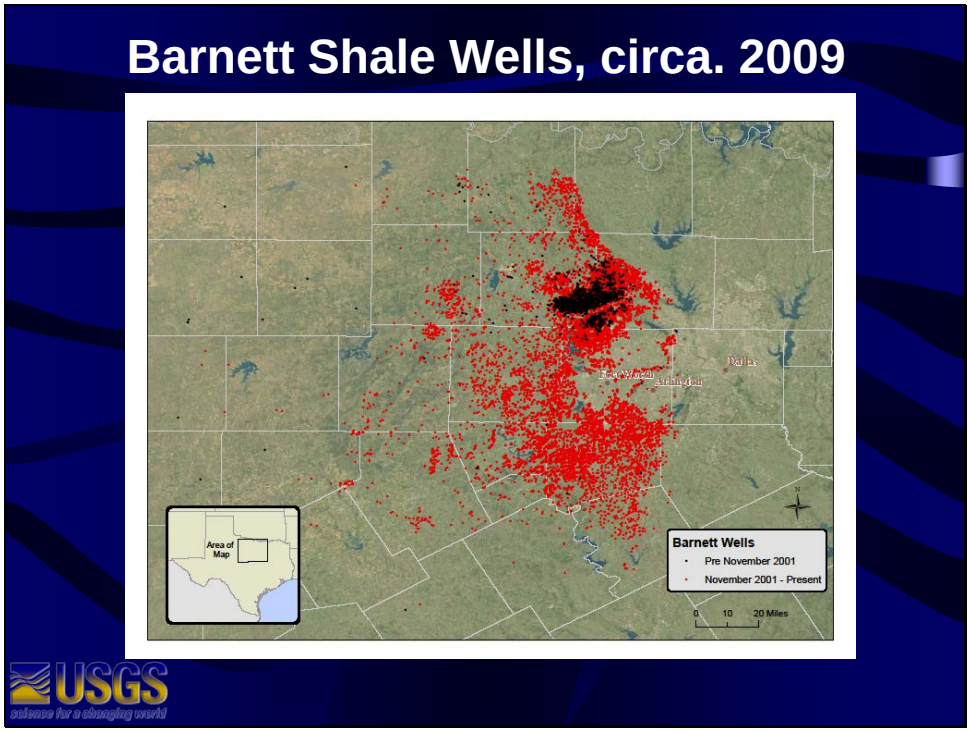
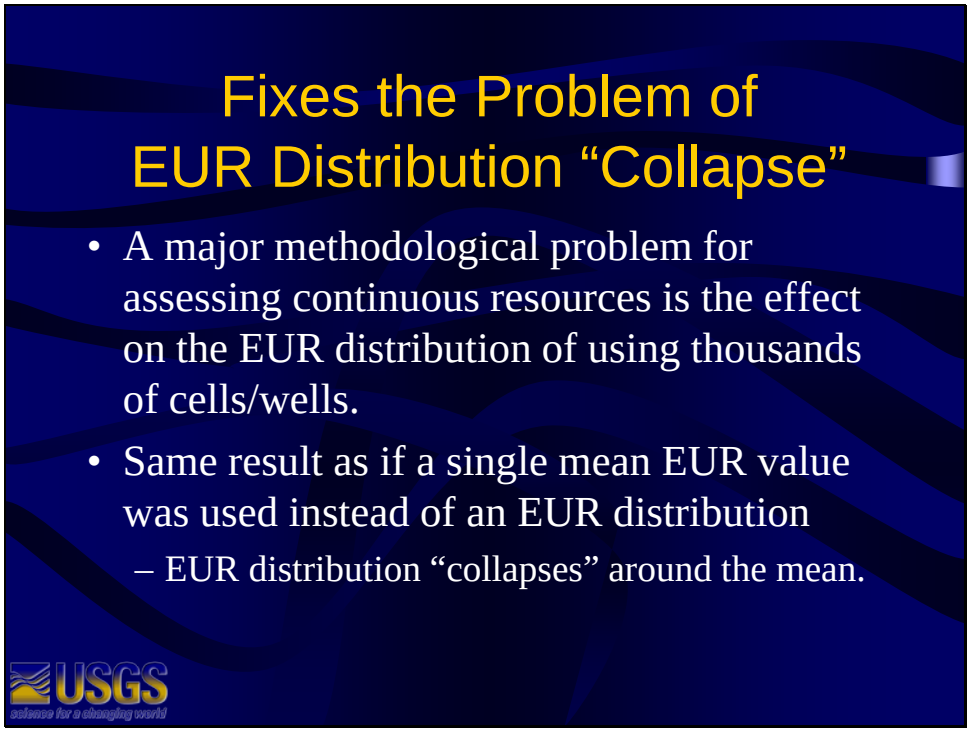


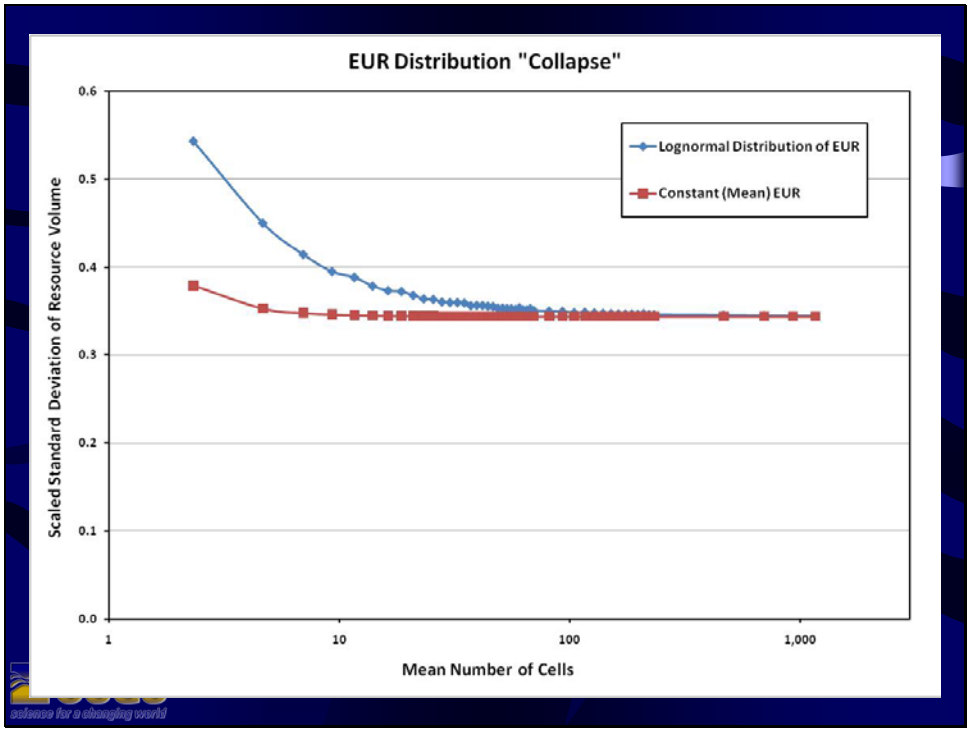
The spatial distribution of well productivity reflects spatial changes in those geologic and engineering characteristics that control the productivity. This map shows vertical wells drilled in the Barnett Shale as of 2001, defining a sweet spot. (20 miles = approximately 32 kilometers).



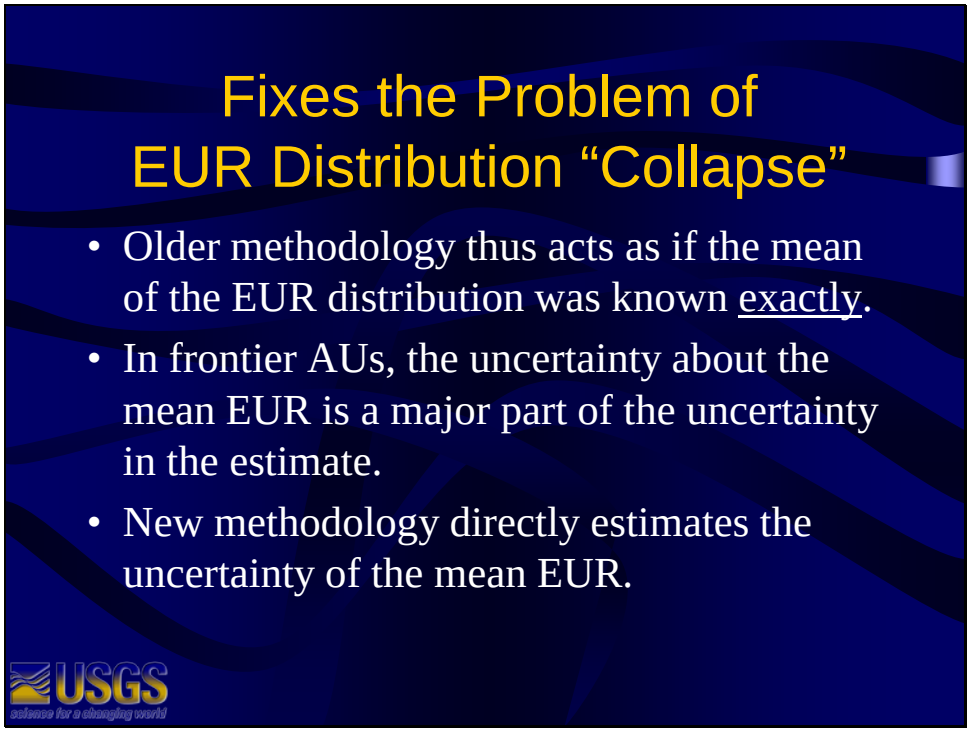
This map shows a great expansion of the Barnett play that took place between 2001 and 2009. Most of the new wells were horizontal wells.



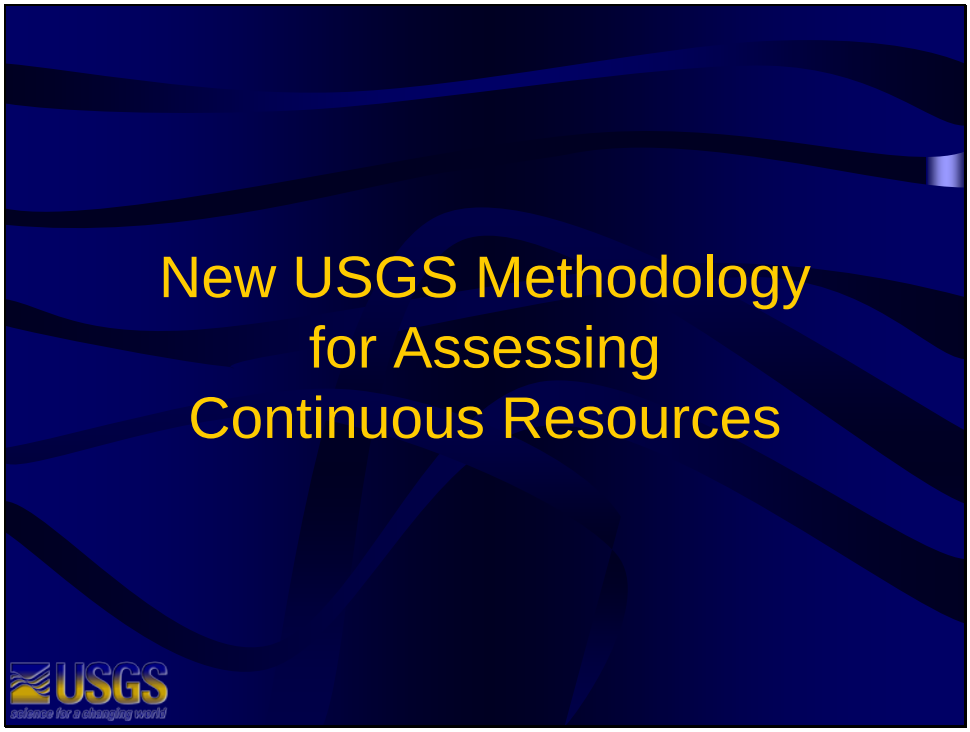
When assessment models aggregate thousands (or tens of thousands) of EURs from an EUR distribution, the result is close to merely multiplying the number of cells by the mean EUR.



This graph shows a comparison of simulations performed with a shifted truncated lognormal distribution of EURs versus simulations with a constant mean EUR. When there are more than 100 cells, the standard deviation of the resulting estimate of gas volume is practically the same whether a variable or a constant EUR is used. Most assessments are for thousands or tens of thousands of cells. This phenomenon is termed EUR distribution “collapse” around the mean.



The older assessment model acts as if the mean were known exactly. This underestimates the uncertainty in the result, especially for frontier AUs where the mean EUR is uncertain.


New USGS Methodology
for Assessing
Continuous Resources
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Features of New USGS Methodology

- Wells instead of cells
- Risk more explicit
  - AU risk, area risk, well risk
- Option to have mixture of two populations
  - Sweet spots and nonsweet spots
- Direct estimation of uncertainty of mean EUR

Robustness of New USGS Methodology

- The new methodology works for both data-rich and data-poor areas.
  - Analogs used for data-poor areas
- The new methodology is not tied to a specific geologic model.
  - As better understanding of geologic and engineering controls develops, this can be accommodated in the assessments.

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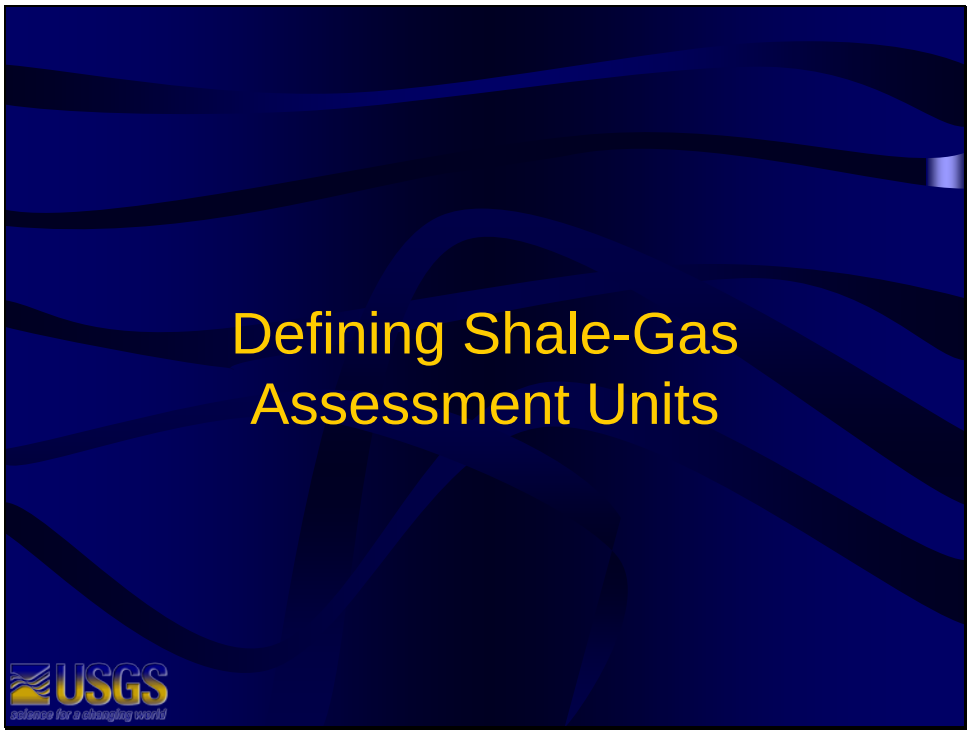
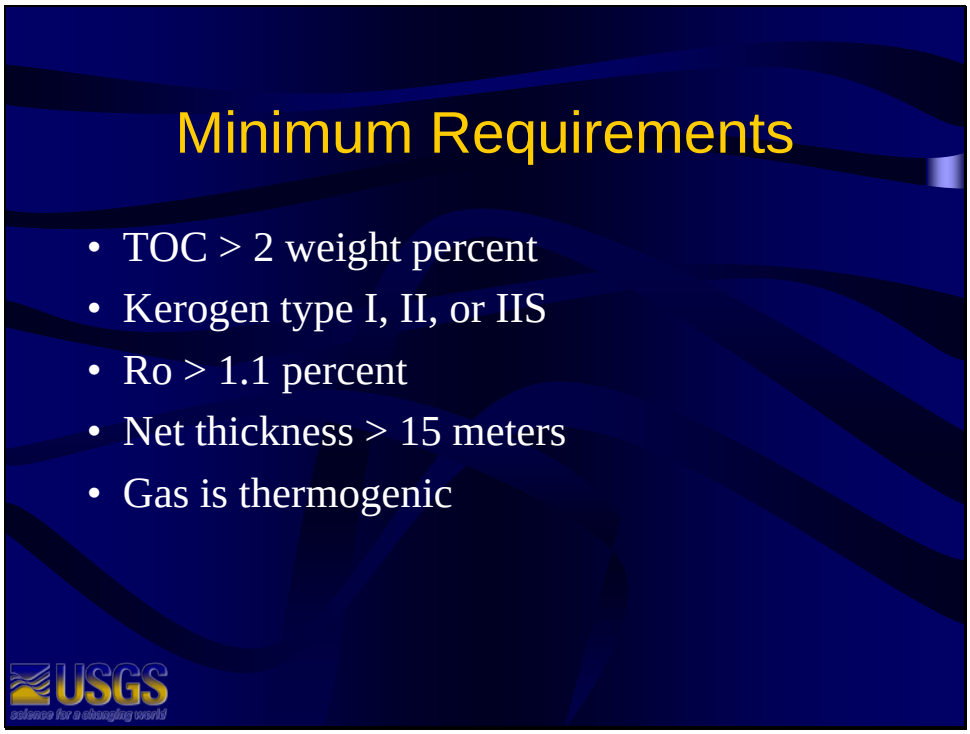


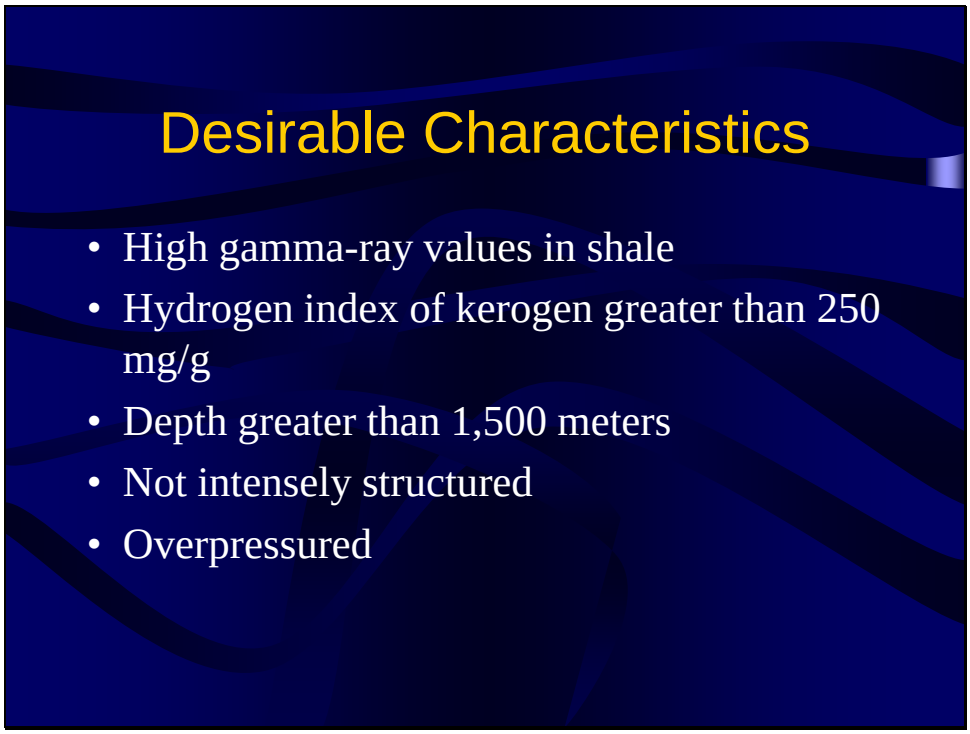
Before conducting a quantitative assessment, one must define assessment units and select which ones will be quantitatively assessed. A set of minimum requirements is needed to determine which proposed units may have significant resources to assess. These criteria are also used in the quantitative assessment itself. As an example, the minimum requirements for shale-gas assessment units are presented here.

Minimum Requirements

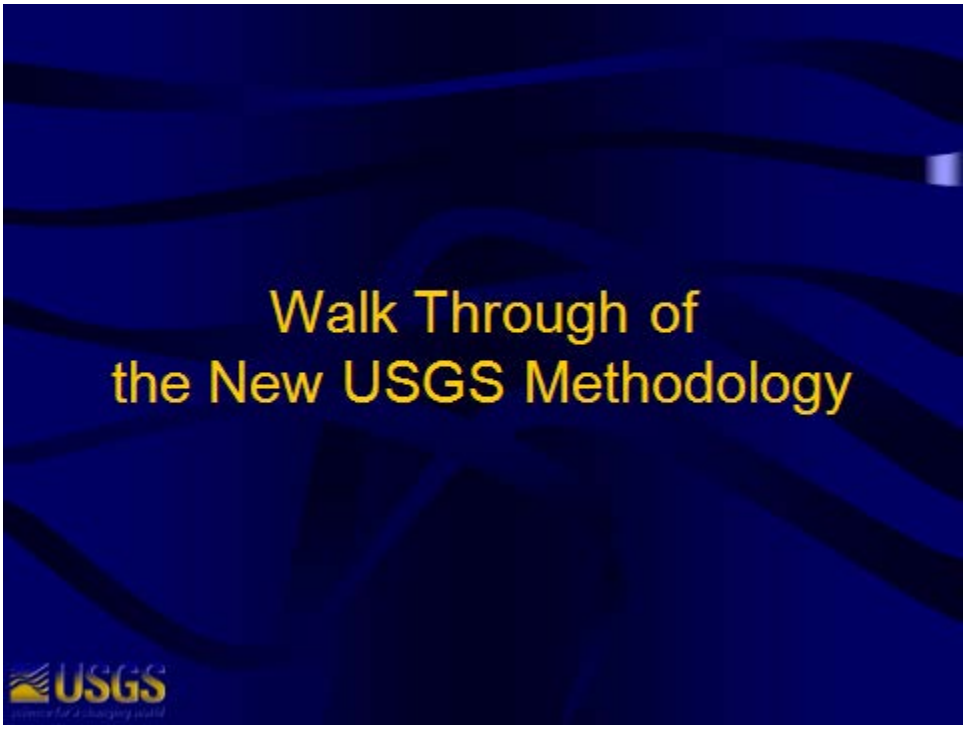
- Based on current USGS thinking of what is needed to have a successful shale-gas AU
- Could change in the future with increased geologic understanding
- This list is specific to thermally generated gas in its source rock.
- Biogenic gas would have different minimum requirements.



TOC, total organic carbon; Ro, vitrinite reflectance.



Mg/g, milligrams per gram.


Walk Through of
the New USGS Methodology
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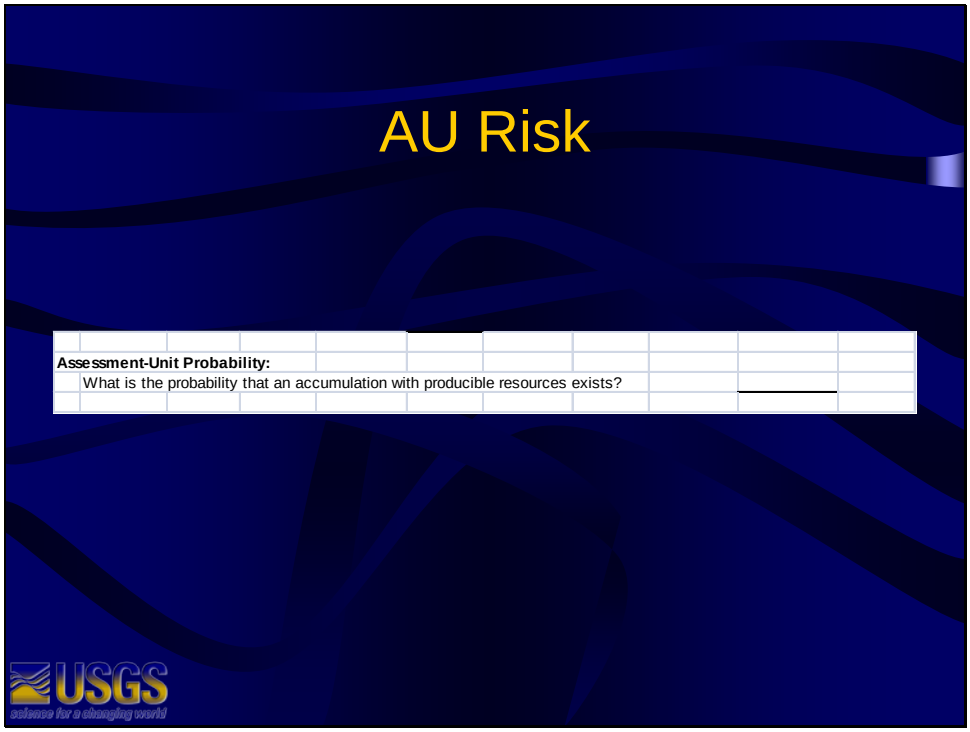
AU Risk

- Based on 5 minimum requirements
- What is the probability that all 5 requirements are met at some place within the AU?
  - This shows the need for mapping the extents of the 5 requirements.

AU Risk – Alternate Questions

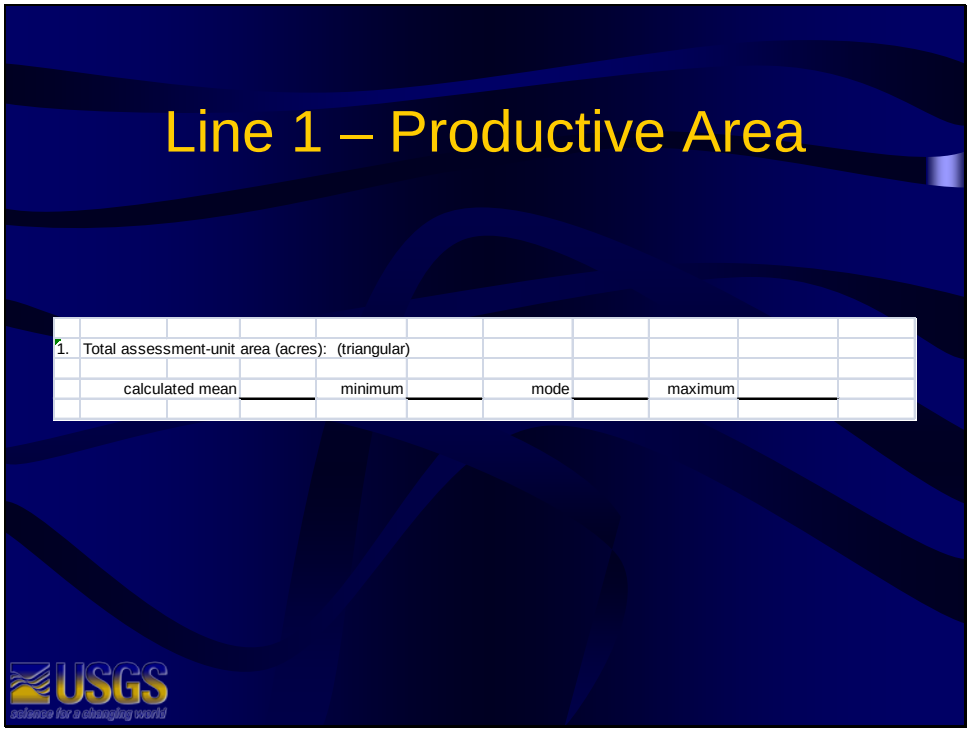
- What is the probability that at least one well within the AU will have production capacity of at least the minimum EUR (0.02 bcf)?
- What is the probability that the petroleum system exists?
- Conversely, what is the probability that the AU will have no producible resources?



This is the part of the official input form that concerns AU risk.

Line 1 – Productive Area

- Again, based on 5 minimum requirements
- How large is the area within the AU where all 5 requirements are met?
  - This shows again the need for mapping the extents of the 5 requirements, and understanding the uncertainties about their extents.



In this line and others, the distribution represents the assessors' uncertainty about a single value that exists in nature. (There exists one correct value of how large an area meets the five minimum requirements.) Distributions in nature are rarely triangular, but this is a distribution within the minds of the assessors. The minimum, mode, and maximum values of a triangular distribution are reasonable values to ask of an assessor to describe his/her uncertainty.

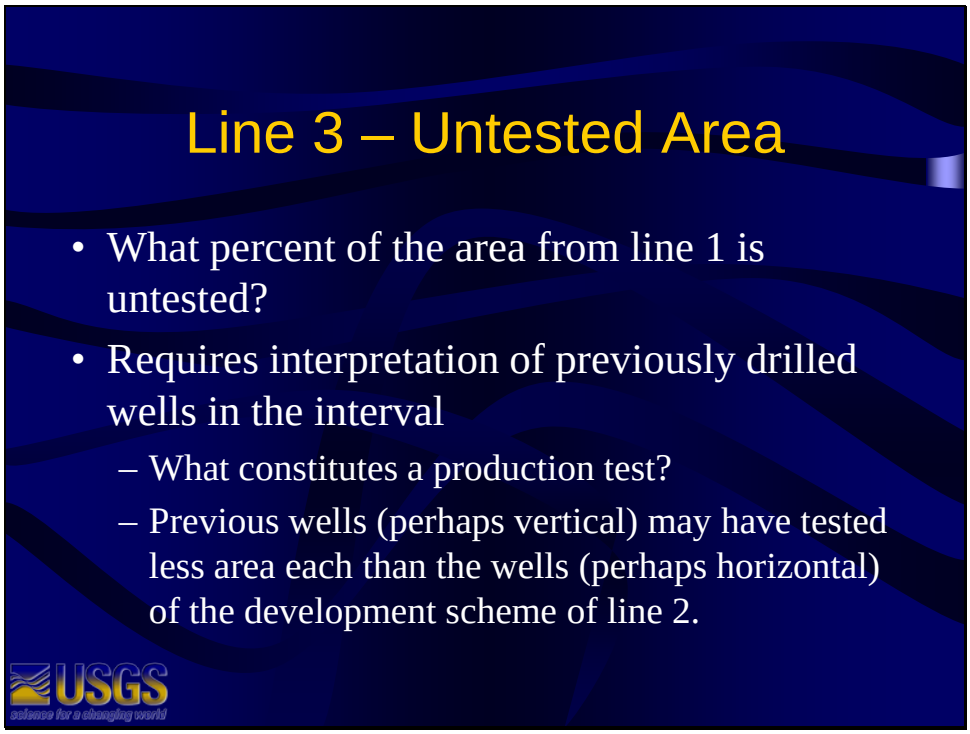
Line 2 – Drainage Areas

- What is the average drainage area of a production well in this AU?
- Uncertainty about a fixed value
- Contingent on a development scheme
  - Horizontal vs vertical wells
  - Development scheme must be consistent with that implied by the EUR distribution

Line 2 – Drainage Areas

2. Uncertainty about average drainage area of wells (acres): (triangular)

calculated mean _____ minimum _____ mode _____ maximum _____



Not all penetrations of a stratigraphic interval are tests of that interval. Interpretation of those wells is needed, but the number of tests may be uncertain. Date of drilling may provide information, in that wells drilled before the recognition of production potential in that interval are unlikely to be tests (especially in an underpressured interval).

Line 3 – Untested Area

3. Percentage of total assessment-unit area that is untested (%): (triangular)

calculated mean _____ minimum _____ mode _____ maximum _____

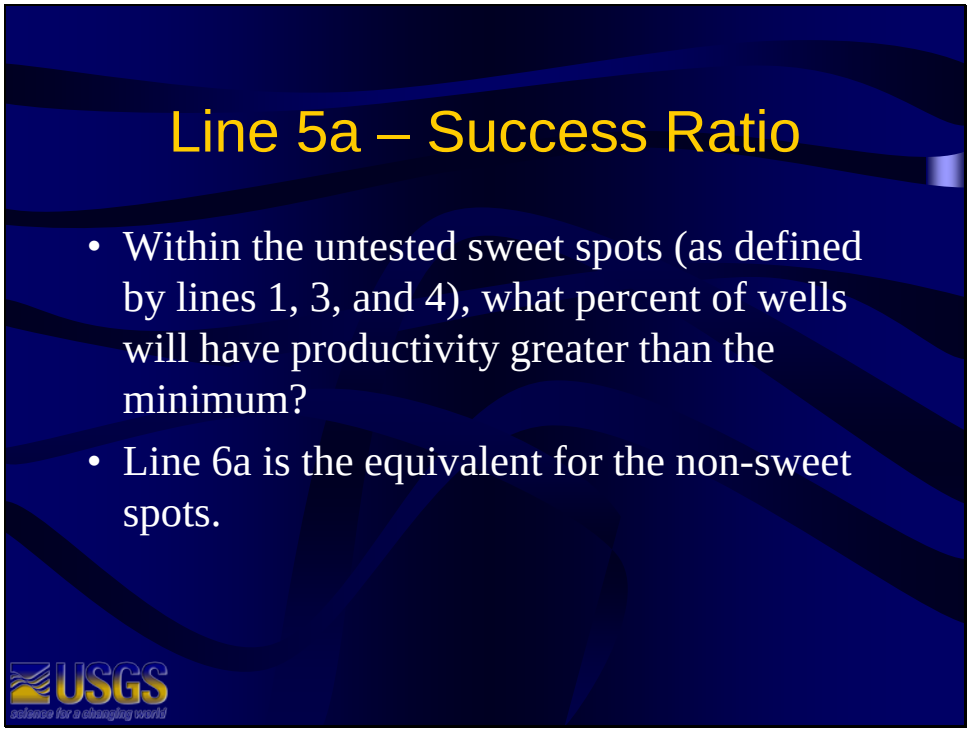
Line 4 – Sweet vs Non-sweet

- Within the untested area (as defined by lines 1 and 3), what percent of the area falls within sweet spots?
- Can be 100 percent if assessors choose to model the accumulation with one population (one success ratio and one EUR distribution) rather than two

Line 4 – Sweet vs Non-sweet

4. Percentage of untested assessment-unit area in sweet spots (%): (triangular)

calculated mean _____ minimum _____ mode _____ maximum _____

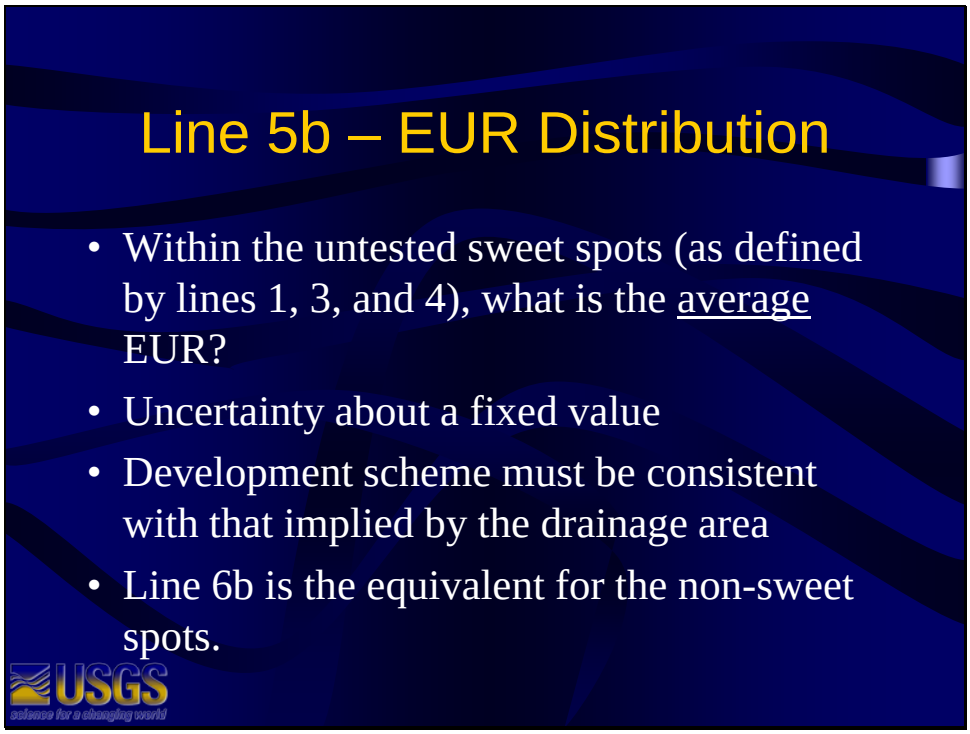


Some of the non-successes would have no or insufficient flow to result in completing the well as a producer. Other non-successes would be completed as producers, but have an EUR less than the minimum.

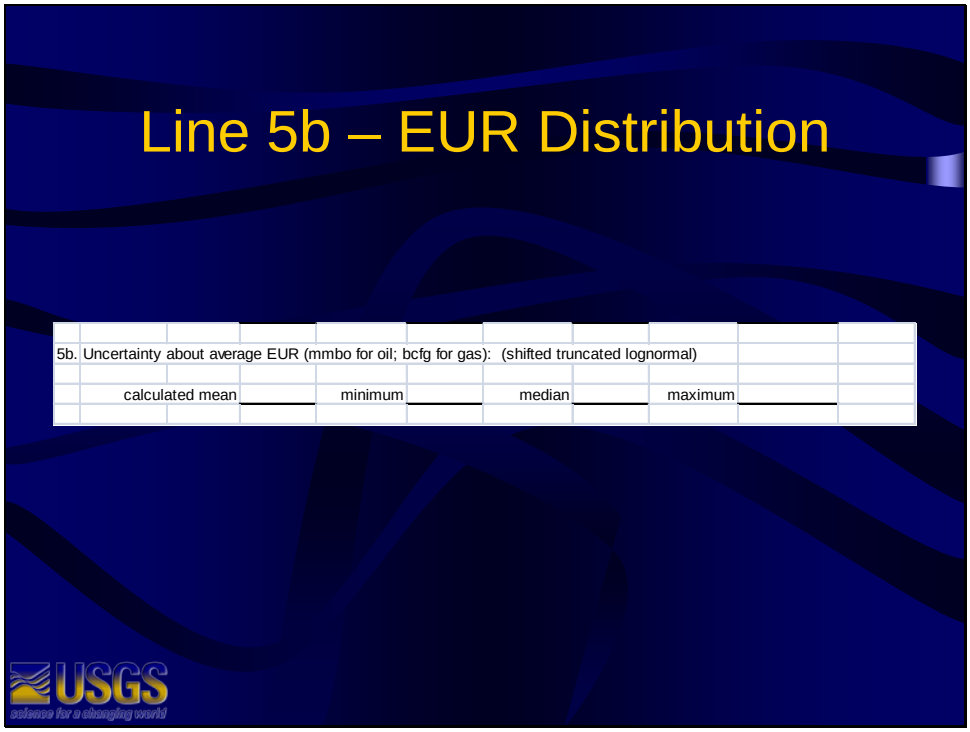
Line 5a – Success Ratio

5a. Future success ratio (%): (triangular)

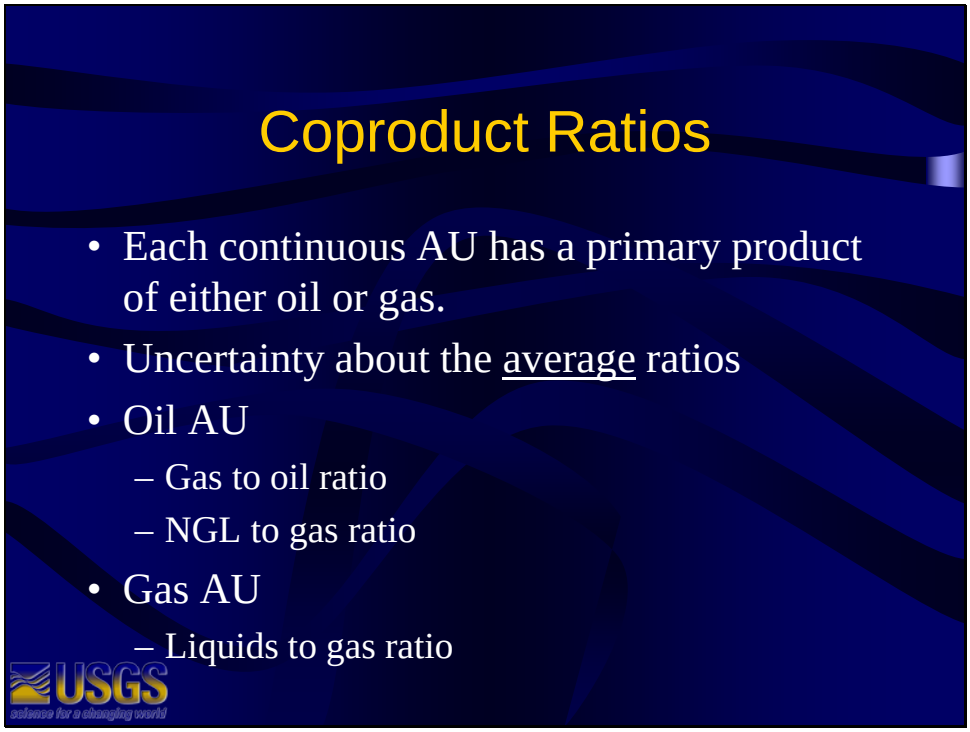
calculated mean _____ minimum _____ mode _____ maximum _____



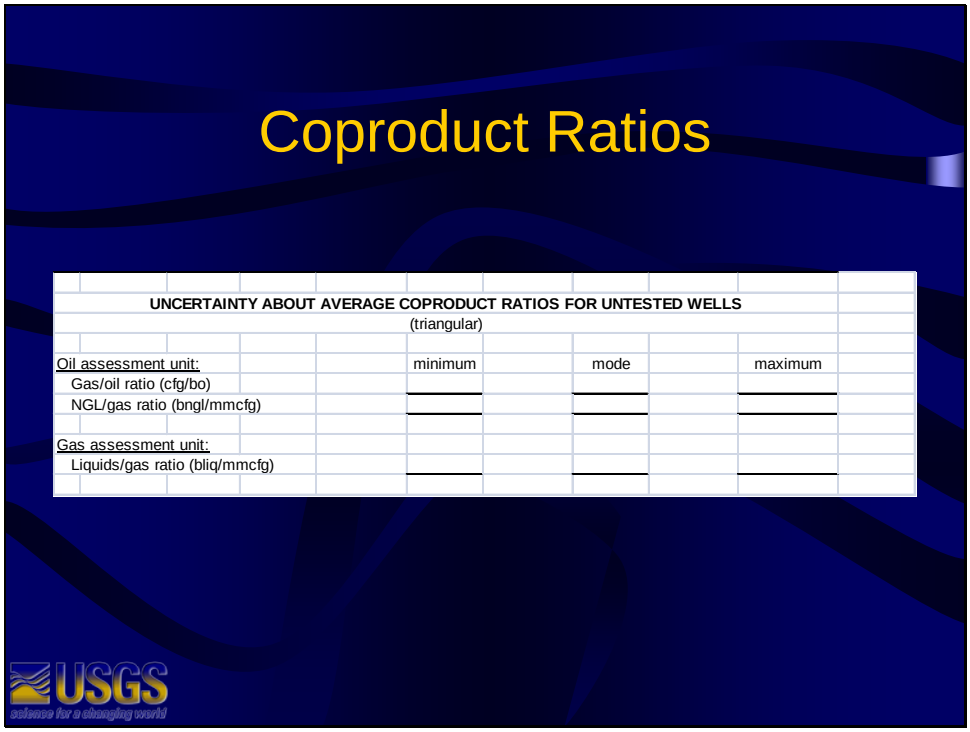
Experimentation with analog data suggested that the uncertainty about the average EUR could be more skewed that can be reasonably represented by a triangular distribution. Thus a shifted truncated lognormal distribution is used here.



mmbo, million barrels of oil; bcfg, billion cubic feet of gas.



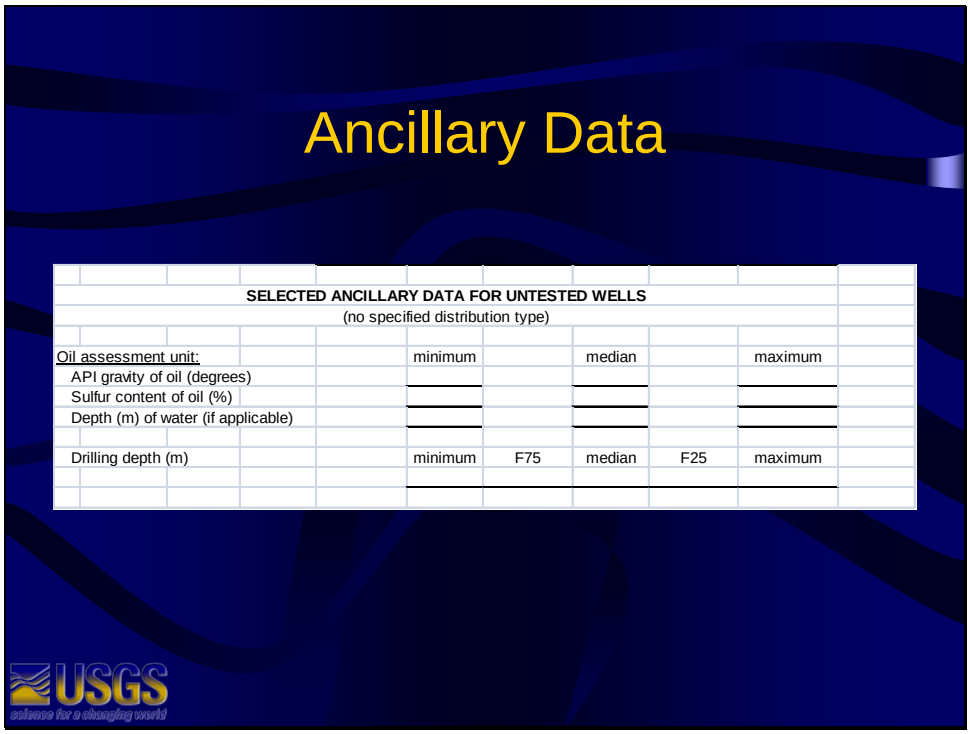
NGL, natural gas liquids.



cfg/bo, cubic feet of gas per barrel of oil; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; bliq/mmcfg, barrels of liquids per million cubic feet of gas.

Ancillary Data

- Not used in the volumetric calculations
- Useful for cost analysis or supply modeling



There is a 75 percent chance of the depth being greater than the F75 value. Similarly, there is a 25 percent chance of the depth being greater than the F25 value.

Allocations

- Commonly need to report by geographic entity (country, state, province; onshore vs offshore)
- Point estimates of percent of resource volume
  - Problems with distributions constrained to add to 100 percent
- Default is to use areal percent determined by GIS

Allocations

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO STATES

Surface Allocations (uncertainty of a fixed value)

1. _____ _____ _____ _____ is _____ % of the AREA of the AU

mean VOLUME % in entity _____

2. _____ _____ _____ _____ is _____ % of the AREA of the AU

mean VOLUME % in entity _____

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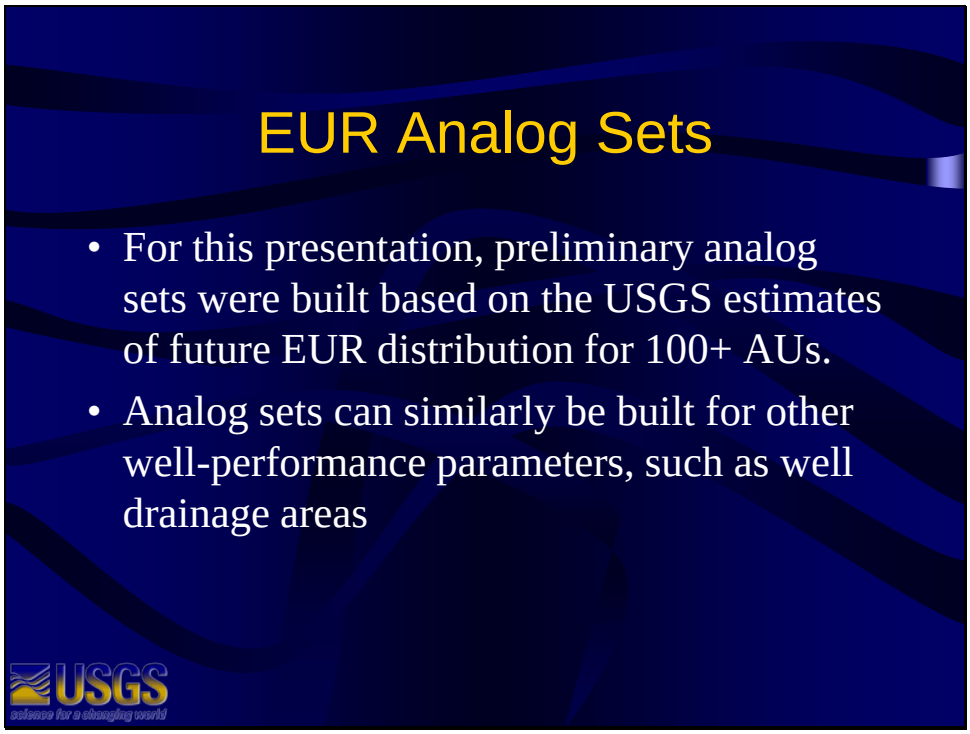
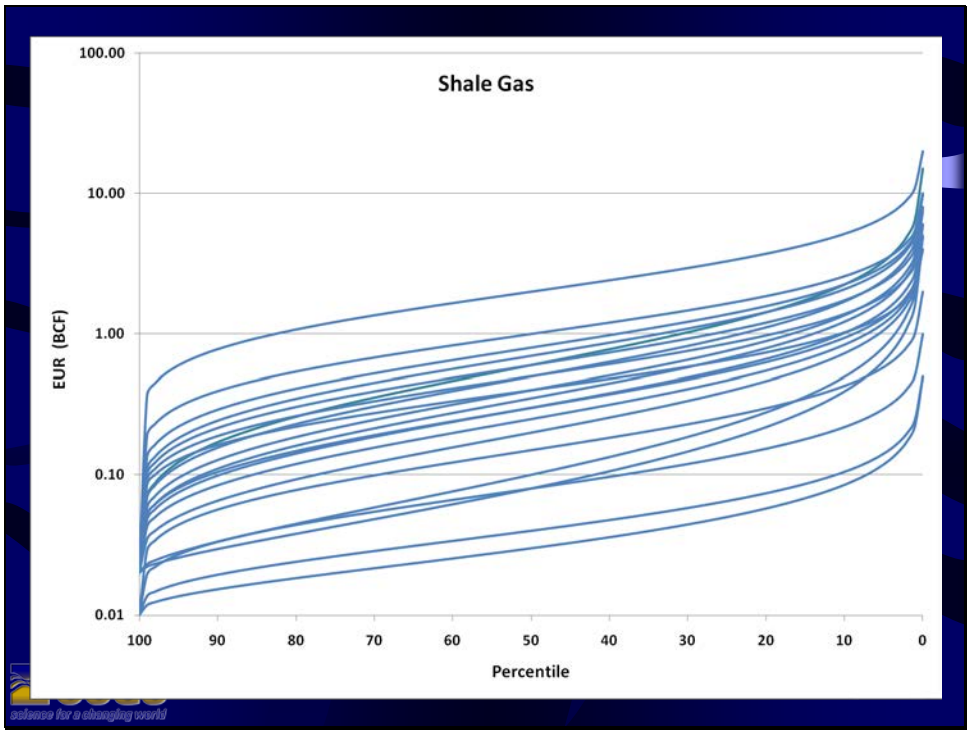
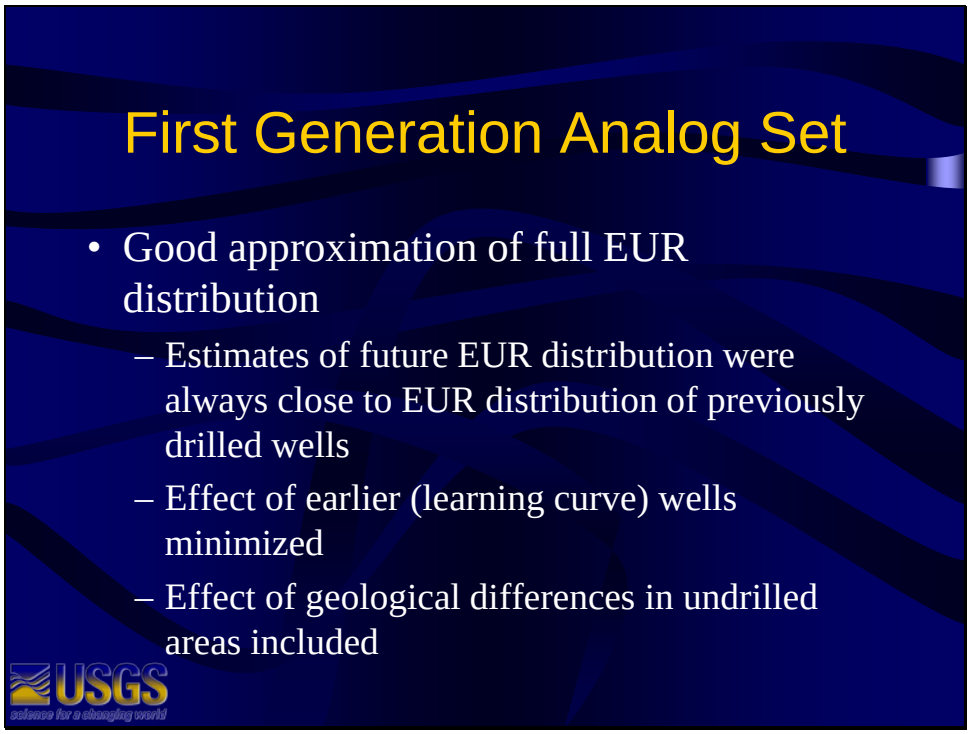
Applying Analog Data in Data-Poor AUs



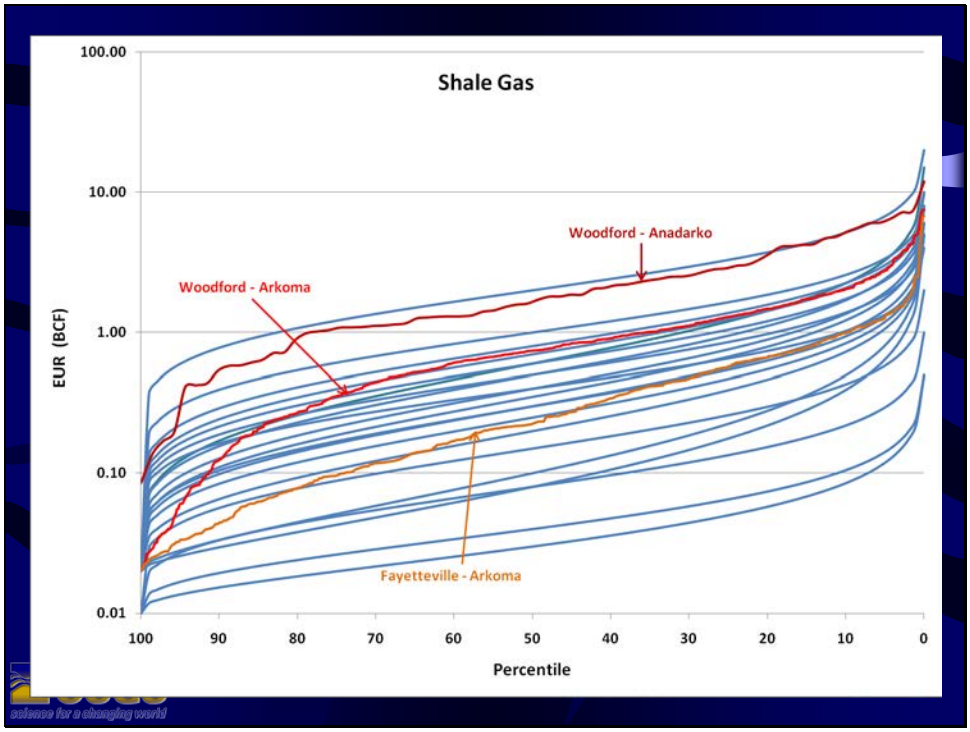
Of the 100+ AUs for continuous oil and gas resources, 21 shale-gas AUs will be used in the following graphs.



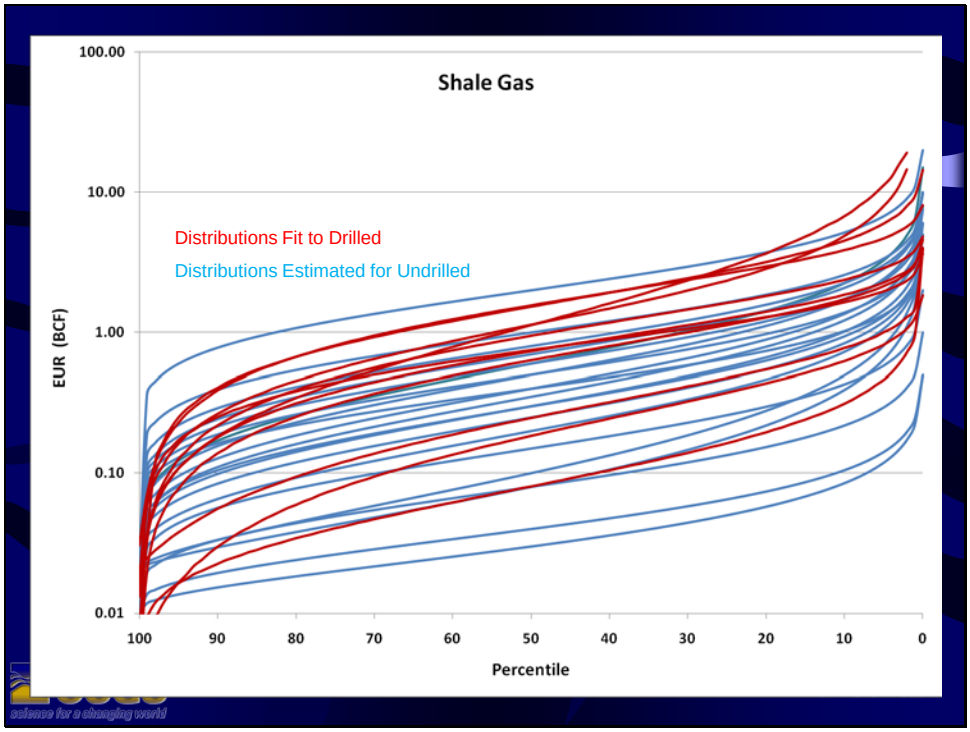
This graph shows 21 shale-gas EUR distributions, based on USGS assessments of undiscovered shale-gas resources. Each distribution is a truncated shifted lognormal, and is therefore a smooth curve. The graph thus represents the "distribution of the distributions." Each distribution is a USGS estimate of the EUR distribution for undrilled productive cells of a particular assessment unit. This graph is termed a "spaghetti plot" which shows how EUR distributions vary for different shale-gas assessment units. The overall area defined by the variation in EUR distributions is termed "the cloud."



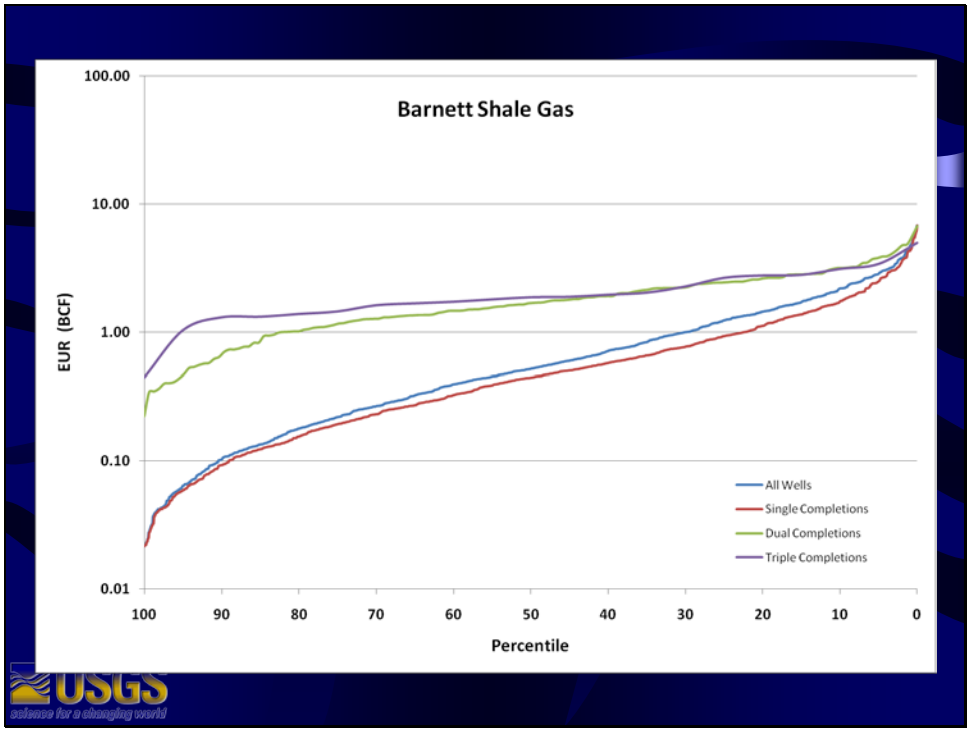
Defining the cloud by using USGS estimates of EUR distributions of undrilled cells gives a good rough approximation of the range of distributions. Assessments have been conducted over the last decade in a wide variety of reservoirs, using a variety of completion practices, and thus the present analog set probably captures much of the range of distributions based on current technology.



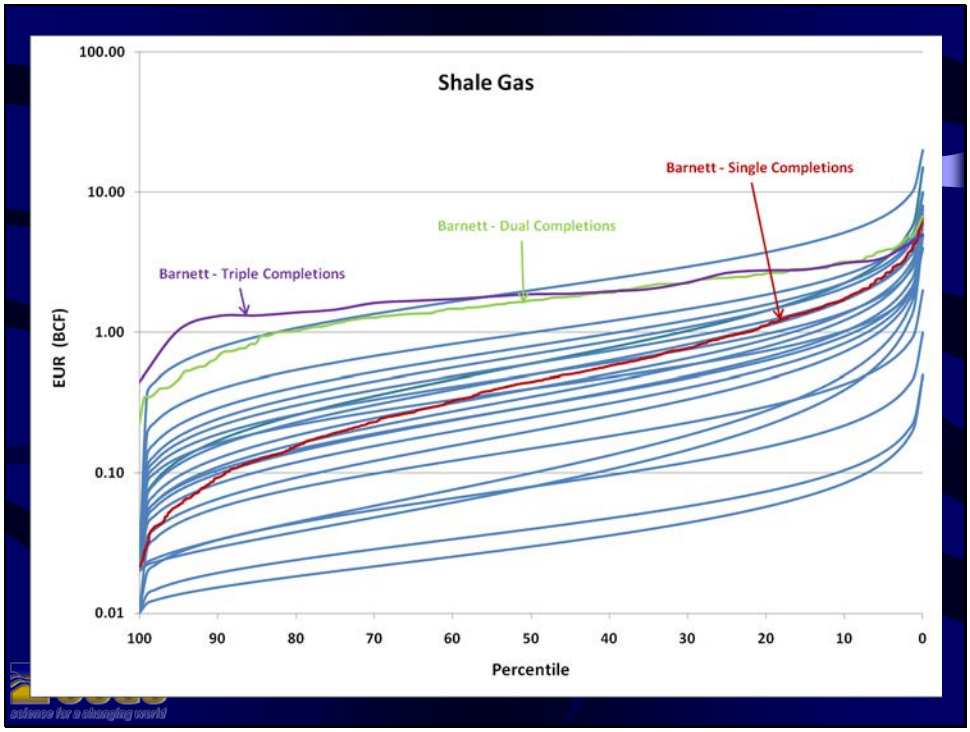
This graph adds the EUR distributions for three recent USGS sets of shale-gas wells, plotted against the cloud shown previously, to put the three distributions in context. The three additional curves are not smooth because they are based on actual well data and not on fitted distributions.



In this graph, the EUR distributions for eleven sets of shale-gas wells are plotted against the cloud to provide context. These red curves are smooth because distributions have been fitted to the data.



This graph presents the estimated ultimate recovery (EUR) for 1,417 vertical wells in the Barnett Shale as of 2003. It shows the distribution of EURs for those wells with an EUR of at least 0.02 bcf. The percentiles indicate what percent of the wells have an EUR of at least the indicated amount. Note that the range of EURs is greater than two orders of magnitude. This graph also has lines for single completions (1,240), dual completions (156), and triple completions (21). (1 billion cubic feet = approximately 28 million cubic meters).



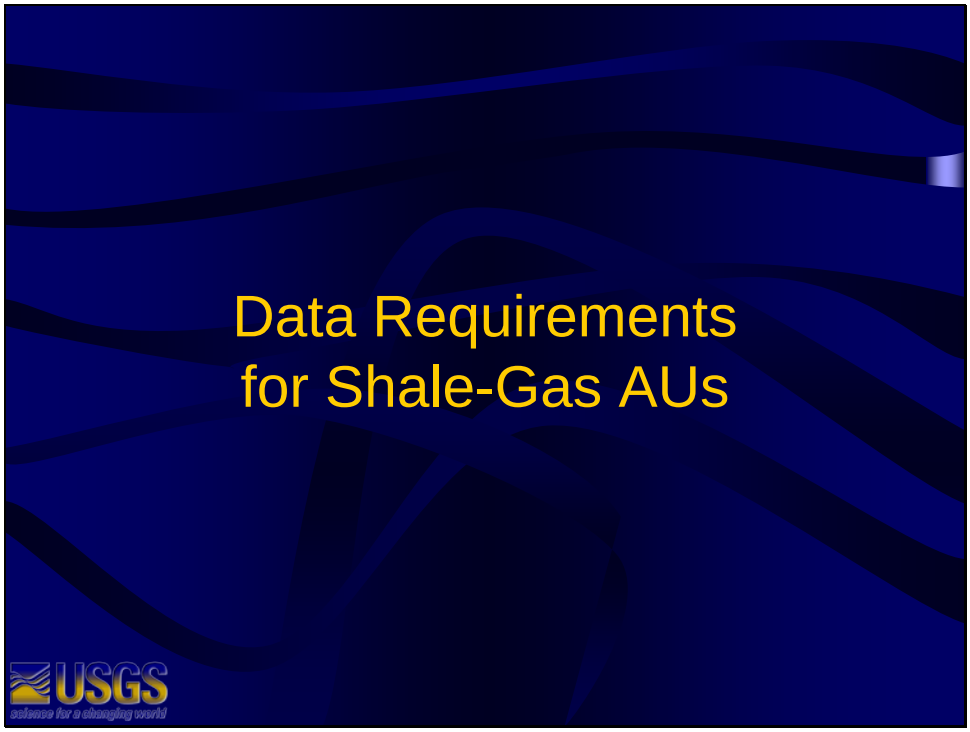
The data from the previous graph is now plotted against the cloud to provide context.

Choosing Analogs

- Use multiple analogs, not just the single "best" analog.
  - Multiple analogs give some measure of variability.
- Analogs for drainage areas and EURs must be based on similar development schemes
  - For example, horizontal versus vertical wells

Modifying Analogs

- Analogs may be modified in such cases as:
  - Increased EURs where the productive section is so thick as to accommodate additional completions



Again, shale gas will be used as an example to show what data should be collected and analyzed as part of an assessment.

Geologic Data

- Where possible, data should be mapped and contoured.
- Uncertainty of data values is important.
- This is not an exhaustive list. Any other data that may be relevant to productivity should be included.
- Geologic data requirements for other continuous resources are similar.

Shale Characteristics

- Extent of shale
- Thickness of shale
  - Gross thickness
  - Thickness of highly organic shale
- Structure maps

Shale Characteristics

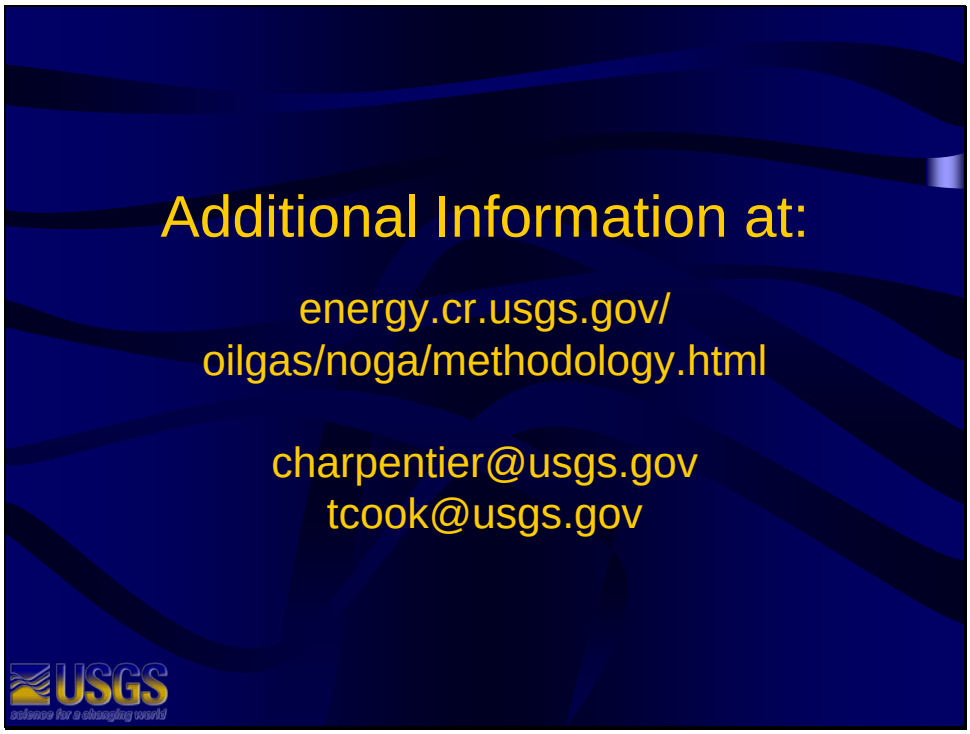
- Lithofacies
- Mineralogy
- Natural fractures
- Regional stress field

Shale Maturation

- Total organic carbon content
- Organic composition
- Maturity indicators
- Thermal history models

Exploration and Production

- Well locations
- Production tests
- Decline-curve analyses based on production histories



This website has links to references concerning the new USGS methodology, as well as references concerning previous methodologies.