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Geologic Field Number and Size Assessments of Oil and Gas Plays[1]

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ABSTRACT

Assessments of undiscovered oil and gas potentials for a group of geologically related, untested prospects can be effectively made from an estimate of the possible ranges in number and size of potential fields, assuming that the play exists, coupled with an evaluation of geologic risks that it might not exist. Field-size distributions are constructed from known-field reserves in geologically similar plays, from assessments of representative prospects in the play, or from simulations of distributions of the play's prospect areas, reservoir parameters, and potential hydrocarbon relations. The field-size distributions are truncated at both ends, at a practical minimum and at the largest size reasonably expected in the play. The possible range of numbers of potential fields is estimated from counted and postulated numbers of untested prospects in conjunction with a success ratio, or from look-alike field densities. The chance that the play exists is the chance that there is at least one field of at least the minimum size assessed. The final assessment curves, developed in a Monte Carlo simulation, portray exceedance probability versus the range of possibly recoverable hydrocarbon potentials.

INTRODUCTION

A straightforward way to assess regional undiscovered oil and gas resources is to estimate geologically the number and size distributions of potential fields in exploration plays. A play is a group of field prospects with geologically similar source, reservoir, and trap controls of oil and gas occurrence. In its simplest form (Figure 1), the method, as pioneered by Atwater (1956), is to multiply a prospect count by an assumed success ratio to estimate the number of potential fields; this number times the potential average field size in ultimately recoverable barrels gives a single-valued oil assessment. Belov (1960) and Semenovich et al (1977) reported similar approaches. Ivanhoe (1976), Nehring (1978), and Momper (1979) have illustrated how effectively counts and sizes of fields can be used in assessments.

The Geological Survey of Canada (Roy et al, 1975; Energy, Mines, and Resources Canada, 1977; Procter et al, 1982) made significant advances in methodology by using ranges of values for both prospect numbers and field sizes and then combining these ranges in a Monte Carlo simulation to produce the assessment. Ranges are important for showing the uncertainties inherent in any such assessments and for producing the final probability curves (White et al, 1975). Building on the Geological Survey of Canada model, L. P. White (1979) incorporated marginal as well as conditional probabilities along with the analyses of prospect-number and field-size distributions. Our own very similar approach, developing since 1972, is outlined in this paper.

The field-size play assessment method is appealing because it deals directly with the natural units of petroleum exploration—prospects and fields—in a versatile way useful for both geologic and economic analyses. The ideal method of assessing a play is to aggregate all the individual prospect assessments (Gehman et al, 1975, 1980). Lack of time or data, however, commonly dictates use of the shortcut play approach, which essentially is a form of prospect summation.

The requirements for this play assessment method, as discussed in the next sections, are geologic estimates of (1) the likely field-size distribution, in potentially recoverable barrels or cubic meters, with specified minimum and maximum cutoffs; (2) the numbers of potential fields, generally based on counts of undrilled prospects taken together with postulated field success ratios; and (3) the chance of the play's existence (i.e., the chance of occurrence of at least one field of minimum size). The basic decisions are geologic, and this method is quite distinct from the approaches that depend on statistical extrapolations of field numbers and sizes. These latter methods are very useful where abundant data exist, and they provide instructive examples of field-size distributions. Although not further discussed here, a few examples are the extrapolations of Arps and Roberts (1958), Cozzolino (1972), Kaufman et al (1975), Menard and Sharman (1975), and Drew et al (1982).

In practice, the geologic play assessment procedure involves two steps. First, the assessor assumes that the play exists and models what it would be like in terms of numbers and sizes of fields. Second, the assessor must judge the chance that this model is basically right—that the play really does exist.

PLAY DELINEATION

A critical beginning is to outline the play geologically. Typically, the delineated prospects form a group areally, have the same basic trap type and the same reservoir facies objective, and presumably have the same hydrocarbon source. Thus, they share some common elements of risk relating to the possible occurrence of oil and gas. Lumping distinctly different prospect types can cause serious prob-

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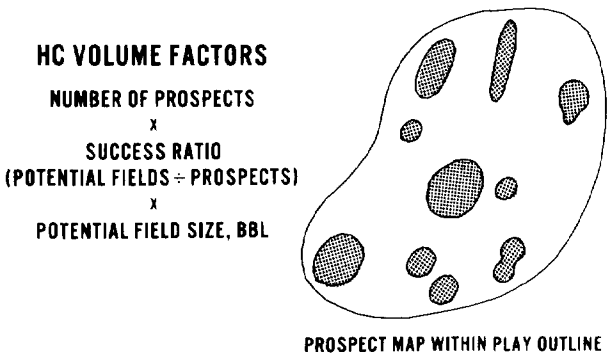

Figure 1—Play assessment from field number and size distribution. Prospect outlines are shown within mapped boundaries of play (from White and Gehman, 1979).

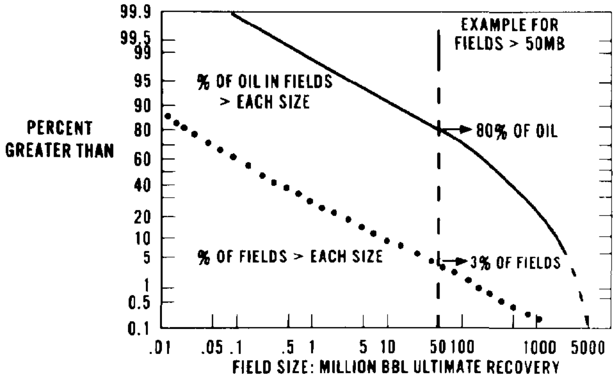

Figure 2—Field-size distribution for 13,985 oil fields of conterminous 48 states. Lower curve shows percentage of fields greater than each size, and upper curve shows percentage of total oil volume in fields greater than each size. As an example, major fields of 50 million bbl or more, which represent only about 3% of fields, contain 80% of total oil.

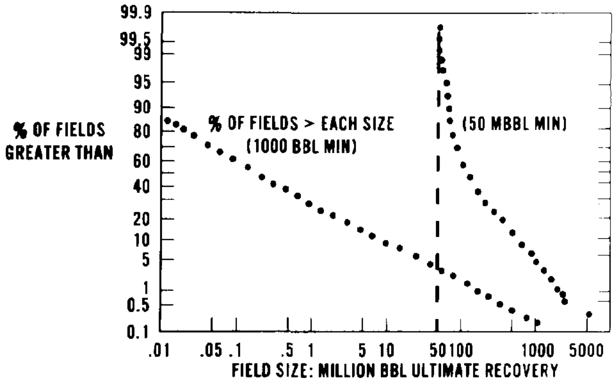

Figure 3—Field size distribution for 13,985 oil fields greater than 1,000 bbl in conterminous 48 states (lower curve), with a truncated distribution of 440 major oil fields of 50 million bbl or more each (upper curve).

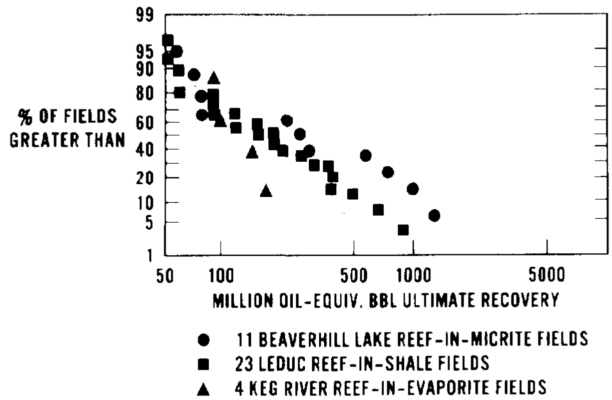

Figure 4—Field-size distributions of three Devonian reef plays, Alberta basin.

lems in the later sizing and risking steps. Wherever a significant areal change in geologic controls is anticipated, it may be best to define a new play. Needless to say, such judgments should be based, where possible, on exploration maps of trap anomalies, reservoir facies distributions and characteristics, seal thicknesses, source rock qualities and maturations, and hydrocarbon shows.

For practical purposes, a large geologic play area may be broken for separate assessments along arbitrary lines such as concession blocks, international boundaries, or bathymetric contours. The resulting subplay assessments will have interdependent risks that should be allowed for if the results are aggregated (Gehman et al, 1975, 1980). Different trap types that are areally interspersed can likewise be assessed as separate plays and then aggregated.

Estimates of field numbers and sizes can be used for assessments at every knowledge level. If assessments are required of areas where data are minimal, the estimates, even though little more than guesses guided by experience, serve to document current thinking in a way that can be scaled and compared with other assessments and known field populations. The initial postulates can easily be revised as new data arrive. The method is most readily applicable where potential structural traps are seismically identifiable. Stratigraphic traps are much more difficult to assess than structural ones, but this is true for any approach.

FIELD-SIZE DISTRIBUTIONS

For compelling practical reasons, we use field-size distributions truncated at both ends and plotted on log-probability graphs (Figures 2-5). The importance of selecting practical minimum and maximum values has been emphasized by Ivanhoe (1976). Klemme (1971, 1975), for a long time, has pointed out the overwhelming significance of the larger fields.

The distribution of about 14,000 United States oil fields (Figure 2)—a partial sample of those in the lower 48 states—illustrates the importance of the larger fields. The sample includes almost all larger fields as known about 1970 and excludes many tiny fields as well as all of the more recent discoveries. The lower dotted line is made of 13,985 points representing the fields ordered according to increasing reserves size. Only 440 fields, or about 3%, are major ones larger than 50 million bbl. The upper curve tracks the percentage of the total oil volume occurring in fields greater than each size. From this curve, we read that the major fields, constituting only 3% of the total number, contain 80% of the total oil. Obviously, in this type of distribution one can account for the bulk of the oil by assessing the larger field possibilities only.

Selecting an effective minimum field-size cutoff is very important, because it affects every major factor in the assessment—the prospects to be counted and the success and risk levels, as well as the average field size. Normally, the minimum size is taken at or just below the assumed economic minimum for the area. This approach ensures that all prospects of real interest are included. It also avoids getting bogged down in hundreds or thousands of fields that are inconsequential to early exploration stages. Furthermore, the comparative data base for assessing subeconomic fields is very weak, as the true sizes of these fields have rarely been scaled. If desired, one can assess the small fields by statistical extrapolation or by estimating a lump-sum proportion from a volume curve like that of Figure 2.

Economic limits always truncate the lower ends of observed field-size distributions (Arps and Roberts, 1958; Kaufman et al, 1975; Grender et al, 1978; Drew et al, 1982; Vinkovetsky and Rokhlin, 1982). In nature's distribution, numbers of deposits probably increase progressively in successively smaller sizes down to droplets and molecules; such a distribution is not lognormal. But we deal exclusively with artificially truncated distributions whose plots almost invariably curve upward near the low-side truncation point (upper curve, Figure 3). Our United States distribution (lower curve, Figure 2) has no data below 1,000 bbl, and many of the data points below 10,000 bbl, where the graph ends, are questionable. If the plot were continued to the left, it would ultimately curve upward at the point of economic truncation beyond which there are no data.

We use the computational convenience of the lognormal distribution, appropriately truncated, but would not argue that this scheme is better or worse than other computational ones for strongly right-skewed distributions that have many more little fields than big fields. Some investigators (e.g., Ivanhoe, 1976; Folinsbee, 1977; Coustau, 1980) plot field size bilogarithmically against rank order. For our assessment approach, we must normalize field numbers at this stage by plotting "percent greater than" against log size. Depending on purpose and data, we may express field size as recoverable volumes of oil or of gas, or of oil plus gas on an energy-equivalent basis.

Plays differing geologically, commonly have different field-size distributions (Coustau, 1980). Of the three different Alberta basin reef plays (Figure 4), the Keg River has the steepest distribution line, reflecting smaller fields and relatively uniform sizes within the truncated range. The Beaverhill Lake has the flattest distribution, reflecting larger fields and more diverse sizes. Coustau (1980) classed these as dispersed and concentrated habitats, respectively. We call them "splitters" and "lumpers," the latter lumping greater proportions of oil and gas in the largest fields.

Plays differing geologically may also have virtually identical field-size distributions. Figure 5 compares Albertan Paleozoic carbonate thrust-belt and Mesozoic sandstone pinch-out fields. Their size distributions are very similar, with the exception of the giant one-of-a-kind Pembina sandstone field with ultimate reserves of about 2 billion bbl. Such one-of-a-kind giants that do not fit the distribution of the other fields are best assessed as individual prospects.

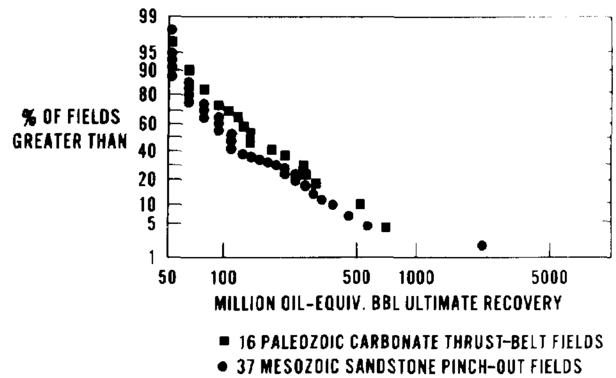

Figure 5—Field-size distribution of Paleozoic carbonate thrust-belt fields compared with that of Mesozoic sandstone pinch-out fields, Alberta basin.

Field-size distributions for play assessments can be built in at least three ways. First, a look-alike known play can be selected and its fields plotted, as in Figures 4 and 5. Second, representative prospects in the play can be assessed, and the mean assessments plotted as before. Third, the distributions of prospect areas, reservoir parameters, hydrocarbon-fill fractions, and recovery factors can be combined in a Monte Carlo simulation to produce a distribution of possible field sizes (Roy et al, 1975; Energy, Mines, and Resources Canada, 1977; Procter et al, 1982). This last approach is more time-consuming but has the advantage of providing many of the detailed data on prospects required for thorough economic analyses.

The ultimate key to selecting any distribution is that it should be tied to the largest field anticipated in the play, as emphasized by Ivanhoe (1976). The best way to do this is to identify and assess the largest prospect in the play. Obviously it will make a big difference in the assessment whether the largest field is going to be 600 or 2,000 million bbl in a sandstone pinch-out play (Figure 5), or 200 versus 1,100 million bbl in different reef-play models (Figure 4). The distribution should not be cut short of the largest reasonably foreseeable size. On the other hand, it should not be extended far beyond this size, or serious overestimates may result. Nature truncates all distributions ultimately by limiting effective closure space or source rock capabilities. The assessor should judge these factors and truncate accordingly. Where data are limited, this truncation may have to be based only on look-alike experience and judgment.

FIELD-NUMBER DISTRIBUTIONS

Where data permit, potential field numbers can be estimated from counted and/or postulated untested prospects

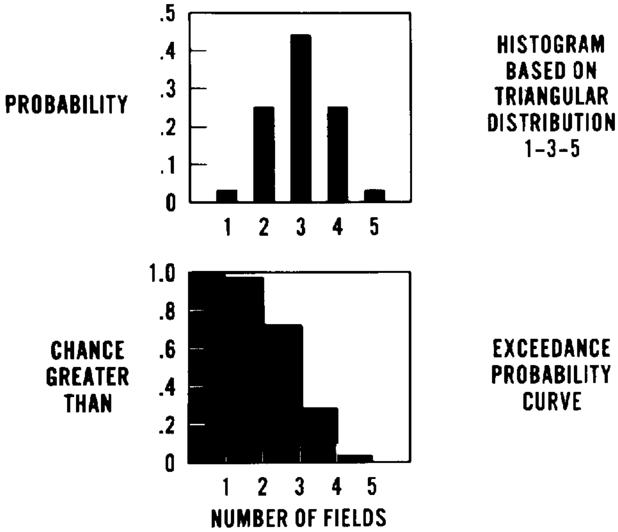

Figure 6—Triangular field-number distribution shown as histogram and exceedance probability curve.

in conjunction with success ratios (Atwater, 1956; Energy, Mines, and Resources Canada, 1977; White, 1979). The only prospects to be counted or postulated are untested ones large enough to hold the minimum size selected for the assessment's field-size distribution. Prospect densities (i.e., numbers of prospects per unit area) from known look-alike plays can be helpful in postulating.

The success ratio equals the expected number of fields of at least minimum size divided by the number of prospects capable of holding that size. Success ratios, which can be drawn from known look-alike plays, reflect the independent geologic risks among prospects. For example, some prospects in the group may have locally poor reservoirs, and various others may have broken seals or may have been flushed. These are prospect-specific attributes conditional on the play's existence (White, 1979). They reflect the almost universal observation that, even in richly productive plays, not all prospects of adequate size contain adequate fields. These success ratio attributes must be treated here separately from the play chances or marginal probabilities, which reflect play-specific risks that could wipe out productive chances for the group as a whole (White, 1979). It is not always easy to sort the independent and group risks geologically without hitting the same risk twice, but it must be done to preserve realistic hydrocarbon volume versus probability relations in individual as well as aggregated assessments.

Success-ratio levels are relative. If a high-graded play includes only the best prospects, the success ratio is likely to be high. If an area is not high-graded and includes many poor prospects, the success ratio probably will be low.

Where it is not realistically possible to estimate numbers of prospects and a success ratio, the assessor can estimate numbers of fields directly by using look-alike field densities—numbers of fields per unit area (Grossling, 1977). Oddly enough, this method finds use not only in virgin frontiers but also in highly mature areas where the now very small prospect objectives cannot be identified and mapped on a play-wide scale.

Computer programs can calculate the binomial distribution of the number of prospects and the success ratio (Roy et al, 1975; White, 1979). Alternatively, field-number distributions can be input in a variety of ways.

PLAY CHANCES

The chance that a play exists is the chance that there is at least one field of at least the minimum size of the field-size distribution. This is the second-step judgment about whether the first-step assumptions of field numbers and sizes are right or not. The assessor decides on a value between zero and one, based on an analysis of the group or marginal geologic risks that could deny the existence of any fields whatsoever. For example, the regional hydrocarbon source, migration path, timing, or reservoir facies may be inadequate or lacking throughout the play area.

The total play chance should recognize risks related both to the regional geology and to the number of prospects, if that number is limited. The regional chance alone would be the play chance given an unlimited number of opportunities. Where prospects are few, however, there is an additional risk that, even if the possible regional problems do not materialize as the play develops, all available opportunities could prove unsuccessful, owing to an unlucky combination of prospect-specific factors. Lee and Wang (1983) discuss using the binomial distribution to calculate risk related to limited opportunities.

The play chance is tied specifically to achieving at least the minimum single-field potential. It may be taken as 1.0 in active productive plays where one more discovery is essentially assured. The principle of "risking the minimum" is pointed out by Roy (1975) and Gehman et al (1975, 1980). White and Gehman (1979) further discussed risking mechanics, and White (1980) summarized play-chance studies for more than 1,000 major-field plays in 80 basins. Play chances are relative, varying not only with the geology but also with the size of the chosen minimum field.

As noted by White (1979), the average prospect chance for the play equals the success ratio (independent or conditional probability) times the regional chance (group or marginal probability). Keeping this key relation straight can make the results of play assessment compatible with those achieved by summing individual prospect assessments.

PLAY ASSESSMENT EXAMPLE

In this simplified example, we are assessing potential field numbers, sizes, and chances in a small offshore area on a delta whose stratigraphy and structure remind us of south Texas. Minimum assessed field size here is to be 50 million bbl. (Any practical minimum size can be chosen.) Look-alike field densities suggest the most likely possibility of three fields. A reasonable range for uncertainty gives a 1-3-5 triangular distribution, which can be converted to a histogram and an exceedance probability curve (Figure 6). The minimum at one field shows that at this point we are assuming that the play exists. In this example, the direct estimate of field numbers bypasses explicit determination

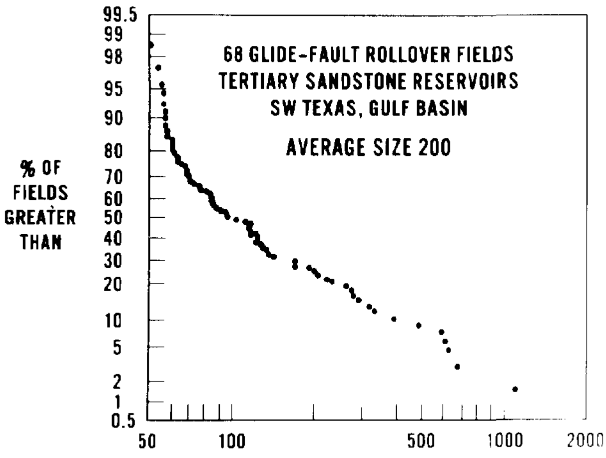

Figure 7—Field-size distribution of rollover traps at down-to-basin faults, south Texas, Gulf basin. Units are oil-equivalent barrels.

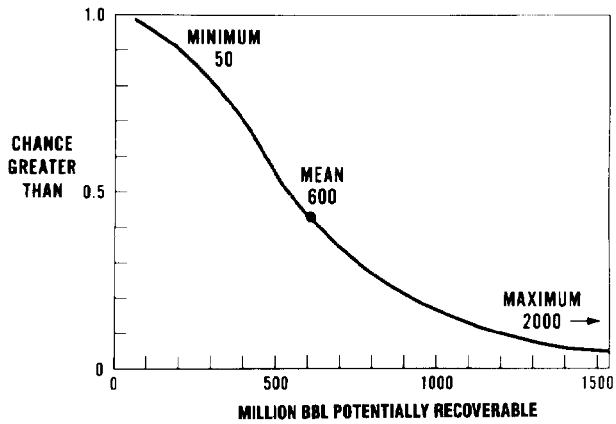

Figure 8—"Unrisked" assessment probability curve derived by Monte Carlo simulation from field number and size distributions of Figures 6 and 7.

GEOLOGIC CONTROL	CHANCE OF ADEQUACY
• TRAP CLOSURE, SEAL, TIMING	.9
• RESERVOIR THICKNESS, POROSITY	.8
• SOURCE QUALITY, QUANTITY, MATURATION MIGRATION, PRESERVATION, RECOVERY	.7
OVERALL CHANCE = .9 x .8 x .7 =	.50

Figure 9—Estimation of play chance for assessment of Figures 6, 7, and 8.

of a prospect count and success ratio.

For the field-size distribution (Figure 7), we plot the estimated ultimately recoverable reserves of 68 south Texas fields. These fields all are on anticlinal rollovers associated with down-to-basin faults, the same trap type anticipated in our new play area. We also expect that the largest field in the new area could approach but probably not exceed 1,000 million bbl, about the same size as south Texas' largest field. The average reserves size of all the south Texas fields is 200 million bbl.

The field-number distribution and the field-size distribution (truncated at 50 and 1,000 million bbl) are entered in the computer for a Monte Carlo simulation. For each of 5,000 trials, the computer at random selects a potential number of fields from our specified distribution from one to five (Figure 6). If it selects three, the most likely value, the computer then randomly samples three different field sizes from the truncated field-size distribution (Figure 7). The computer adds the three values and stores the results as one possible assessment, going on then to repeat the process in the next trial.

The "unrisked" assessment curve (Figure 8) is simply the result of all 5,000 trials plotted proportionately from smallest to largest. It shows, for example, that about 70%, or 3,500 trials, assessed more than 400 million bbl. Typically, the computer picked the most likely three fields, which commonly averaged about 200 million bbl each, the average of the whole field-size distribution. Thus the average assessment is three times 200, or about 600 million bbl. Occasionally, the computer picked the minimum of one field, and at least once it assigned the smallest possible size to that one field, giving the minimum assessment of 50 million bbl. Occasionally the computer picked the maximum of five fields, and one group of five sampled mostly from the large end of the field-size distribution, and gave the maximum assessment of 2,000 million bbl. The minimum-mean-maximum range of Figure 8 thus gives a picture of what the play might contain, if it exists and if our field number and size assumptions are correct.

Next we judge the play's chance of having at least one field with potential reserves of at least 50 million bbl (Figure 9). Assumed chances are 0.9 that the faulted structures as a group will have adequate seals, 0.8 that they will have adequate reservoirs, and 0.7 that they will have adequate access to a mature source. ("Adequate" for this assessment specifically means capability of source, reservoir, and seal for respectively generating, storing, and holding at least 50 million bbl.) The overall play chance for at least 50 million bbl is the product of these individual chances, or 0.5, which is essentially the regional chance. For this example, we assume there are enough prospects so that the element of risk related to limited opportunities is negligible.

The assigned play chance says that, if there were 100 plays like this one, only 50 would be productive, and the other 50 would be effectively dry. As half the final "risked" results are zero, the "risked" curve (Figure 10) shows that the probability of exceeding any given amount of barrels is cut in half relative to the "unrisked" curve. The "risked" mean includes all the zeros and is therefore half the "unrisked" mean.

The "unrisked" curve is used for economic modeling of the play's rewards if it succeeds. The "risked" curve is used for aggregating play assessments into basin assessments,

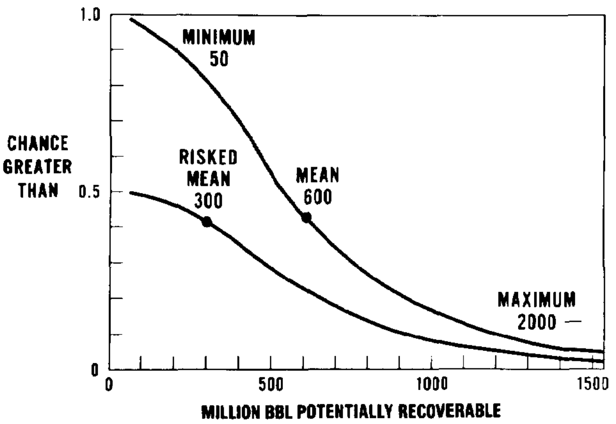

Figure 10—"Risked" and "unrisked" assessment probability curves for assessment of Figures 6, 7, 8, and 9.

care being taken to handle any dependencies correctly (Gehman et al, 1975, 1980).

SUMMARY

Geologic estimates of possible field sizes and numbers provide a natural basis for play assessment, and the results can closely approximate summations of individual prospect assessments. Key points in the procedure are the following.

1. First, modeling the play as if it exists, and then estimating the chance that this model is right.
2. Delineating the play as a geologically coherent group of prospects.
3. Establishing a practical minimum field size (in terms of recoverable oil and gas) to be included in the assessment, thereby de-emphasizing multitudes of insignificant fields and emphasizing the fewer large ones that contain most of the hydrocarbons; the excluded small fields can always be assessed separately as a lump sum.
4. Constructing field-size distributions from populations of known look-alike field reserves, from representative prospect assessments in the play, or from simulations of distributions of the play's prospect areas, reservoir parameters, and hydrocarbon proportions.
5. Plotting the field-size distribution on a log-probability graph truncated not only at the selected minimum size but also at the largest size reasonably expected in the play.
6. Estimating the possible range of numbers of potential fields from counted and postulated numbers of untested prospects in conjunction with a success ratio, or from look-alike field densities.
7. Assigning the play a chance that there is at least one field of at least the minimum size in the assessed field-size distribution, keeping in mind that the average prospect chance equals the success ratio (conditional probability) times the play chance (marginal probability).
8. Computing in a Monte Carlo simulation the final assessment curves portraying probability versus the range of possibly recoverable hydrocarbon potentials.

The whole approach focuses on the geology of the play itself, and look-alike data are carefully selected and appropriately modified to fit. The postulated numbers and sizes of fields can readily be compared with those of productive plays elsewhere, providing a judgment check on the results. The requirements are fundamentally simple and direct, and the method can be used at any knowledge level. The risk-related probabilities can be guided by experience but will always have an unavoidably subjective cast. As a result, it is still possible to get the wrong answer with the right method, just as the right answer occasionally comes from the wrong method. The worst danger for any assessment is that a new play possibility will be overlooked entirely. On balance, field-size play assessment seems capable of giving a better tie with reality over the long term than other commonly used approaches to regional assessment, and it contains the basic components needed for economic screening.

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