QUALITATIVE EVALUATION OF EXPLORATION MATURITY AND UNDISCOVERED TARGET POTENTIAL BY USE OF A REGIONAL SCREENING TECHNIQUE†

E. C. DAHLBERG*

"At present, only a tiny part of the geologically favorable rock in the earth's crust has been explored by drilling. The amount of exploratory footage drilled in the United States dwarfs the total footage in the rest of the world, but even in the United States there is 'room' in the geologically favorable rocks for more than six times as much exploratory drilling as has been done so far."

T. A. Hendricks (1965)

Introduction

The method described and demonstrated herein is one which involves the statistical estimation of the size distribution of "unexplored areas" (blind spots) in regions of petroleum exploration interest. The technique provides explicit quantitative answers with associated probabilities to the basic question of:

"How big a target could still exist in this area and not have been discovered by being hit (discovered) by one or some number of pre-existing or yet-to-be-drilled wells?"

The answers can be inferred from graphs showing, for a given area with a particular well density and configuration (with respect to number and location of wells), the odds and likelihood that a pool of a given size could still be present somewhere within the cumulative, irregularly-shaped well interstices.

This is a flexible technique which allows the user to evaluate the effects of any regional orientation in the existing drilling pattern, as well as vary the "radius of information" of some or all of the local wells depending upon the complexity or trendiness of the local geology, etc. Furthermore, the user may vary the conditions for pool discovery and recognition at his discretion by basing it on intersection by more than one well. Thus, regional seiving may be utilized as an exploration strategy tool in several different ways as will be demonstrated.

One particularly useful application, for example, includes the addition of some number of *proposed* wells to an area and then determination of the extent to which they have reduced the undiscovered target likelihood. In this way a search-wise optimal drilling program and strategy may be probablistically formulated.

Other applications include comparison of several different regions with respect to degree of drilling maturity, as well as documenting quantitatively the increase in target potential with depth in particular areas.

One basic theoretical assumption underlies the method; that is that a target (oil or gas pool) can exist with equal or some stated likelihood anywhere in the area concerned. It is also assumed that a target pool is recognized when intersected by the particular type or number of wells or device (geophysical traverse, etc.) that the user designates.

A particular advantage of this method over the conventional methods of estimating unfound target potential in terms of calculated well densities (four wells per township, eight wells per township, etc.) is that it does not assume an isotropic distribution in regions where the well density is definitely not uniform!

The four cells in Figure 1 illustrate unrealistic examples of the ambiguity involved when dealing

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*Department of Geology, Rensselaer Polytechnic Institute, Troy, New York, 12181, U.S.A. Now at the Institute of Sedimentary & Petroleum Geology, Calgary, Alberta.

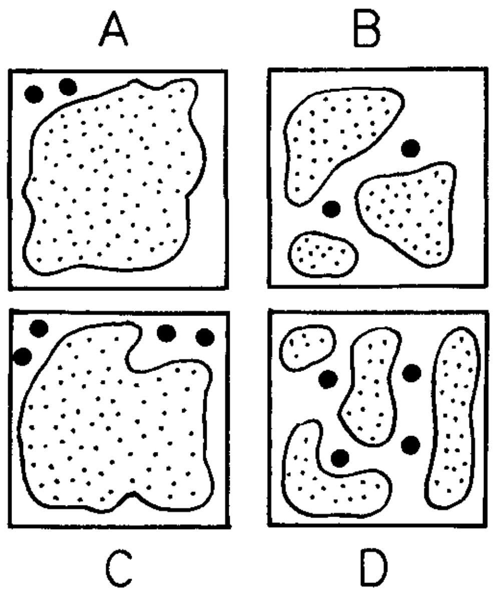

Fig. 1. Townships A and B both have a two well-per-township drilling density but the target potential of A greatly exceeds that of B. Townships C and D would be described by a four well-per-township drilling density. However, the target potential of C exceeds both D and B.

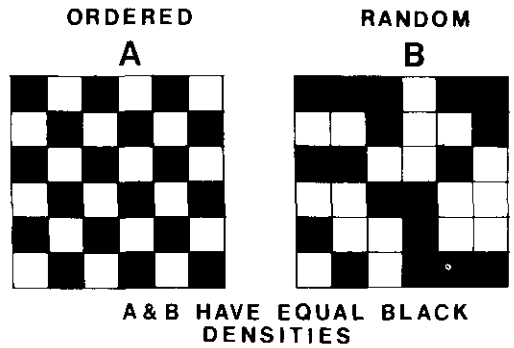

Fig. 2. Two model townships with 18 well-per-township density (black "sections"). Target potential of B greatly exceeds that of A although difference attributable to arrangement is not reflected in the density value.

with "per unit" well density figures. A and B would be described by the same "two wells per township" estimate but would be obviously incomparable with respect to the occurrence potential for targets of an optimal size. The same applies in the case of C and D; in fact C with four wells has more potential for a sizeable undiscovered target than does B with two!

The regional screening technique is addressed to the problem of irregularly sized areas of non-constant shape (which the open spaces between well sites are) in a manner independent of any arbitrary cellurizing.

Models of Well Density and Interstitial Spaces

Figure 2 illustrates two patterns representing spatial mixes of black and white squares. The first A is regular, highly ordered and can be described as isotropic with respect to the locations of the black squares. If we look at these as drilled square mile sections we note that there are no undrilled holes of a size any greater than a single square mile. The area is thus essentially "drilled out" at this level with no future potential for a significant new discovery. The well density in this case would be described as "18". The well density figure for square B would likewise be eighteen. However, due to randomness, irregularity and clustering there are several sizeable "clumps" of white (undrilled) sections. Thus, the potential for an economically attractive discovery in this square would be greater than A due to the existence of the relatively larger open spaces. To effectively reflect this important aspect, an estimator of the size distribution of the "interstitial" white areas with associated probabilities of occurrence, is required.

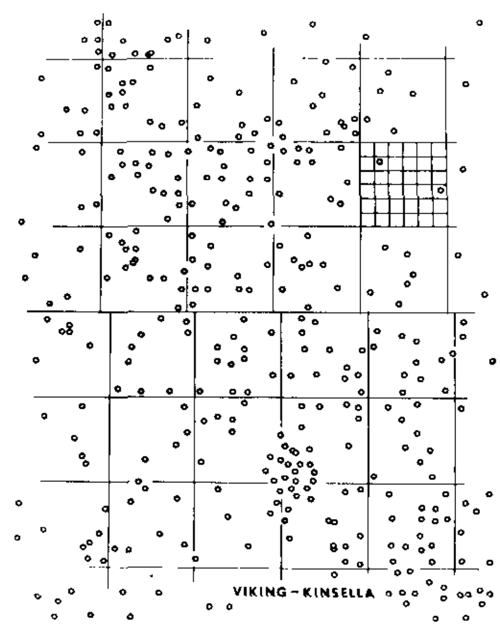

Fig. 3. Approximately thirty townships in Alberta showing the surface drilling pattern.

Figure 3 shows a drilling map of approximately thirty townships in Alberta, Canada. It is apparent that wells tend to be distributed in a clustered fashion similar to that of the black squares in Model B. The following technique can be used for assessing the relative sizes of the undrilled holes and therefore the unexplored potential of the area.

Blind Spots

It is easy to recognize from a map that the drilling in an area is "dense" though difficult to quantitatively express how dense. Yet, in assessing the maturity of the exploration effort in a particular area this factor is extremely significant. The nature of a drilled hole in an area is such that while it contributes information on the existence or non-existence of a deposit, it at the same time reduces the undiscovered potential of the originally virgin area.

Thus, from this point of view (which could be erroneous), an area with no wells has more exploration potential than one with two or three dry holes. It depends on the individual's philosophy whether an area is presumed wet until "proven" dry and, if so, what degree of drilling constitutes drilling "proof." In other words, when is an area drilled out to such an extent that for all intents and purposes there remains nothing of economic interest? The regional seiving technique is addressed to providing conditional answers to these particular questions.

On the typical and traditional map with drill sites the viewer's attention is drawn to "known" areas as clusters of small circles, when it is really the unknown areas and their extent in which explorationists should be most interested. Figure 4 shows the same area, but this time the unknown areas or "blindspots"* are accented by (1) blacking them in and (2) making their borders convex so that they are truly "spots". Figure 5 shows the drilling pattern for the same area but at the deep Paleozoic level below the surface. The average size of the "blindspots" and thus the potential for undiscovered hydrocarbons is naturally larger than that at the shallower levels, since any hole which tests a particular formation must by necessity pass through those which overlie it. For this reason a glance at a surface drilling map provides a very misleading estimate of the underground resource potential of an area.

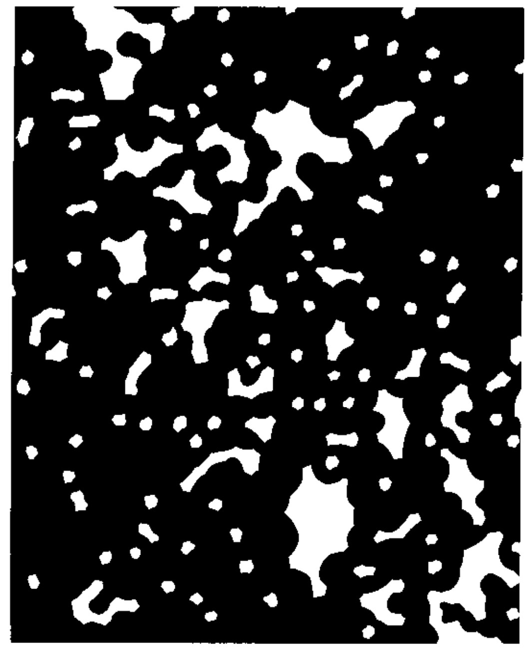

Fig. 4. "Blindspot" areas at the surface level in the locality shown in Figure 3.

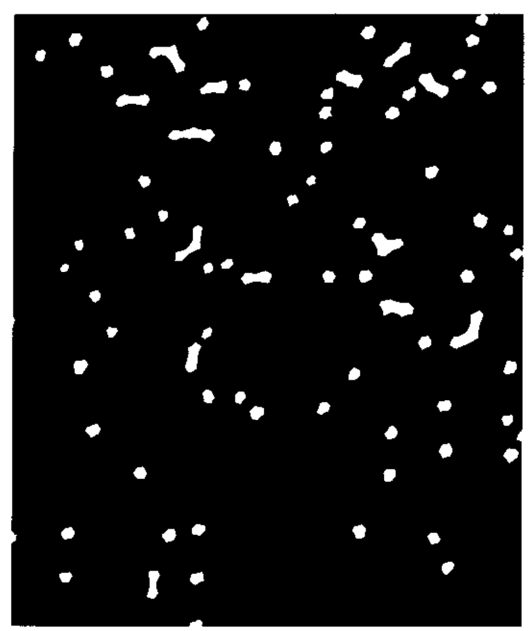

Fig. 5. "Blindspots" in the same area but at Paleozoic depth.

*not to be confused with the geophysicists' "brightspots." These are areas or volumes within the earth's crust where nothing is explicitly known.

Drilling Maturity

The complete exploration of a petroliferous (or non-petroliferous) sedimentary basin has been postulated by A. D. Zapp of the U.S.G.S. (1962) as necessitating a minimum well density of not less than (at least) one well per two square miles (a square 1.41 miles on a side) drilled either to crystalline "basement" rocks or to 20,000 feet. This value can for the present be taken as the limiting case, beyond which we are willing to declare the area "fully" explored, but up to which there can still exist (in terms of space but independent of "geology") a potential for exploration. This potential is proportional to the relative size of the "blindspots" or unexplored holes. The blindspot equivalent of this limit is illustrated in Figure 6. Some degree of clustering attributable to random locations within the two square mile sites is apparent but the "blindspots" are small, homogeneously scattered and rarely larger than two or three square miles.

In order to estimate quantitatively the overall undiscovered target potential of an area in terms of size and probability for purposes of resource evaluation and comparison, their statistical distribution must be assessed. To accomplish this, the regional seiving or screening procedure is employed.

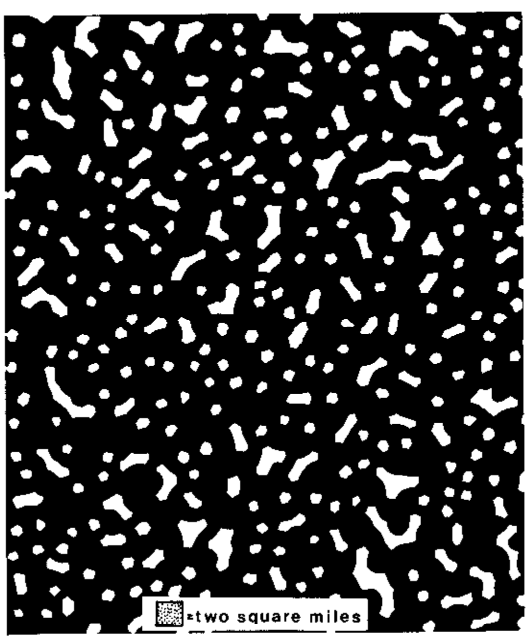

Fig. 6. Hypothetical limit "Blindspots" from a "totally explored" area.

Fig. 7. Shotgun pellet distribution with potential targets.

Concept of Regional Screening

The conceptual basis for the method is illustrated by analog in Figure 7 which shows a buckshot pattern frozen in mid-flight (the spots represent the individual pellets). A very small target object such as a house fly, passing through the pattern would survive with a comfortably high probability, say .95 or 19 to 1 odds. The butterfly would likewise survive with a high degree of certainty though slightly less than the fly, say .90 due to its larger size. The bluejay would be less likely to survive the pellet pattern with a probability of say .55 which means slightly more likely than not. The turkey buzzard, on the other hand, would most likely not escape being hit by at least one pellet — his odds for survival would be, say, 1 to 19 or very slim. In this case, the probability of not being hit would be heavily exceeded by its probability of being hit.

In the exploration setting, the "pellets" become the sites of the wells drilled in an area of interest and the sizes of potential targets are the birds. We then seek to quantitatively estimate the associated probabilities of "survival" over a range of varying sized targets with respect to the local drilling pattern. In a well explored area, the pattern will be "tight" and "dense" with survival probabilities low. In less mature areas survival probabilities will be higher. Since in most exploration regions the drilling pattern is quite variable, the usual case will be a combination of high and low densities located and oriented in varying ways — thus any resulting probabilities will be unique to the drilling pattern of the analyzed area.

The drill sites obviously constitute a "seive" of sorts — a regional screen. The curves representing the distribution of the size of the holes (interstices or "blindspots") which have passed through the "seive" are derived in the following manner.

Method

The area to be evaluated is first "sampled" by locating at random on a properly scaled map some adequate number of times (usually 100 to 200) a series of "trial targets" and recording the number of drill holes that are intersected each time at each location. The targets should cover an appropriate size range as shown in Figure 8 and can be any shape, but generally ellipses are adequate (even lines would do). It is possible to integrate the effects of orientation into the results by recording "hits" for each of several different orientations of the targets, and then constructing a curve for each. Figure 9 shows target ellipses located at various places in the sample area presented earlier. The target centers are located by random number pairs and reference X and Y coordinates. In Figure 9 Target A has zero hits, B is intersected by two drill holes, C by one, D by zero, and E by three. By recording the number of hits at a large number of random locations for each target and reducing the data to histograms, the probabilities of intersection by zero, one, two, at *least* one, at least two, etc., wells can be determined for each sized target, for as many as desired, depending upon the size range concerned. Although in the present case, the sampling was done physically, using transparent ellipses as trial targets, the algorithm can be programmed for a computer and executed with digitized well site locations.

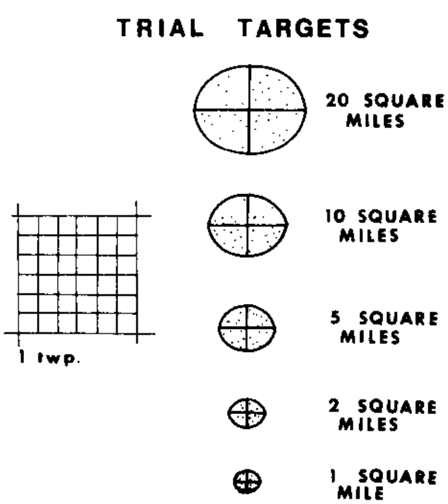

Fig. 8. Elliptical trial targets for generating data for drilling maturity curves.

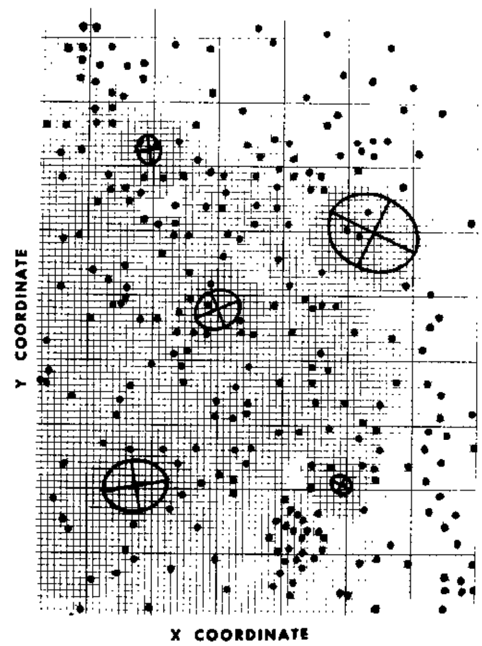

Fig. 9. Example of trial targets superimposed at random locations over the drilling pattern of the sampled area.

In the present example the regional screening was accomplished for the well patterns represented by the three "blindspot" maps of Figures 4, 5, and 6 which show drilling penetration at the Viking (Lower Cretaceous) and Sub-Paleozoic levels of the sample area. The limiting case is also included.

The respective drilling maturity curves appear in Figure 10 which is essentially a plot of potential target area versus the probability of a given sized target not having been intersected by at least one* well, for each of the stratigraphic intervals. The associated "odds" are likewise included for those who prefer to approach the concept of risk in those terms.

*Similar curves for two wells or more can likewise be constructed if it is deemed that more than one well is required for "discovering" a target. This renders the results relatively more conservative.

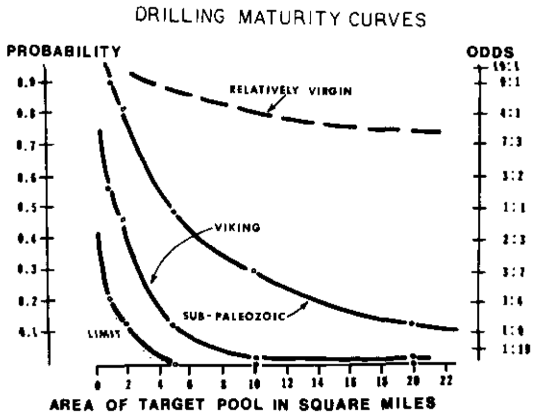

Fig. 10. Drilling maturity curves for the samples area.

The "limit" curve indicates that at the one well per two square mile "saturation" level the probability that a *two square mile target* could still be present, not having been drilled is about one tenth or odds of 9 to 1 *against*. The likelihood of an undetected five square mile target at this level of drilling is close to zero, thus almost impossible. One could therefore reasonably assume that this area at near surface depths is "drilled out" with respect to targets this large or larger.

At the Viking level, the odds of a five square mile target not having been intersected is about a tenth (still small), but at the deeper Devonian horizon the chances are fifty-fifty that a target this size could still be present and not have been "found" by the existing configuration of drilled wells. Any target smaller than this is more likely to have *not* been found (thus could still be present) than to have been hit at the sub-Paleozoic level as shown in the maturity curve. Since in most areas more wells are drilled to test shallower zones than the deeper ones, the maturity curves for different stratigraphic horizons within the same area will be nested in this manner with those representing the deeper zones overlying the shallow zones on the graph. The dotted curve represents an ideallized, relatively undrilled horizon at which the likelihood of undetected targets of almost any size is close to certainty (with respect to available space, at least!).

AN EXAMPLE

Figure 11 is a map of a well known part of the Alberta "oil patch", in which numerous wildcat wells and several oil pools occur. This is an area of about a hundred townships. The "blindspot" map for this area appears in Figure 12. Note that at the Beaverhill Lake level (Devonian) the amount of unsearched area is fairly considerable, but how much is "considerable" in terms of oil and gas pools? To answer this in terms of numerical probabilities the regional seiving procedure is applied as follows.

The base map (Figure 11) is gridded into 0.1 inch squares numbered consecutively from zero in the lower lefthand corner. Elliptical trial targets with areas of 1.7, 5.4, 20.9, 27.4, and 51.8 map square miles are then each centered a hundred and fifty times at grid intersections assigned by successive random number pairs. At each centering, the ellipse is oriented in four positions, NW, N-S, NE and E-W and the number of well site points falling within the boundary of the ellipse recorded. The data are summarized in table 1.

Table 1

Target Area		**1.7**	**5.4**	**20.9**	**27.4**	**51.8**	**(Square Miles)**
	(0)	118-124	80-87	14-27	8-10	0-4	
Number of	(1)	12-20	40-47	38-43	34-37	6-12	
intersections	(2)	11-12	20-23	37-42	61-72	117-120	
150 trials	(2)	1-2	3-5	45-51	36-42	20-21	

The ranges in the value represent the effects of orientation differences, none of which appears to be too great. These data expressed as probabilities are shown in Table Two.

Table 2

Target Size

	k	**1.7**	**5.4**	**20.9**	**27.4**	**21.8**	**(Square Miles)**
Probability of	(0)	.78-.82	.53-.58	.09-.18	.05-.06	.00-.02	
"k" intersections	(1)	.08-.13	.26-.31	.25-.28	.22-.24	.04-.08	
with TARGET	(2)	.07-.08	.13-.15	.24-.28	.40-.48	.78-.80	
	(2)	.01	.02-.03	.30-.34	.24-.28	.13-.14	

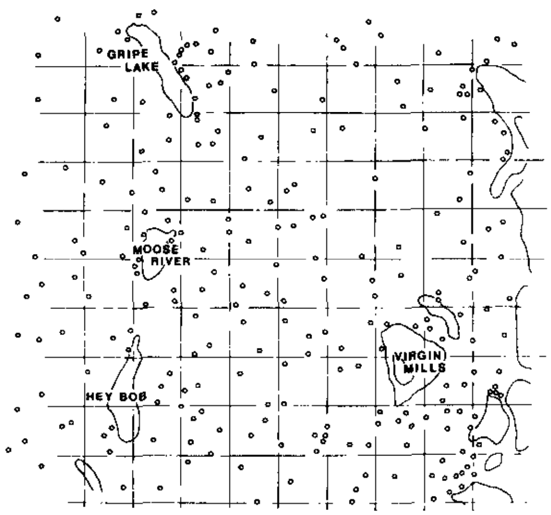

Fig. 11. An area in Alberta to be "screened."

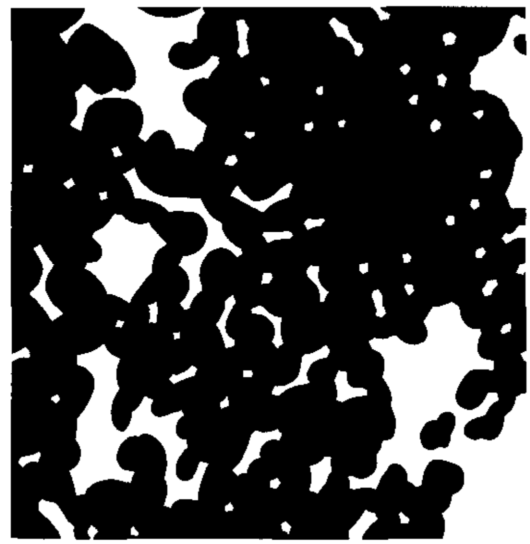

Fig. 12. "Blindspots" at the Beaverhill Lake level of the area shown in Figure 11.

The probabilities in Table 3 reflect target likelihood factors related to the area concerned. They include, for each target size, the probabilities of zero intersections (non-discovery), at least one intersection (one minus the probability of zero intersections), at least two intersections (one minus the probability of zero plus one intersection), etc.

Table 3

Target Size

	1.7	**5.4**	**11.5**	**20.9**	**27.4**	**51.8**	**(Square Miles)**
P (zero hits)	.78	.53	.33	.14	.05	.01	
P (at least one hit)	.22	.47	.45	.86	.95	.99	
P (at least two hits)	.09	.16	(.07)*	.58	.73	.92	
P (greater than hits)	.02	.03	.15	.30	.25	.14	

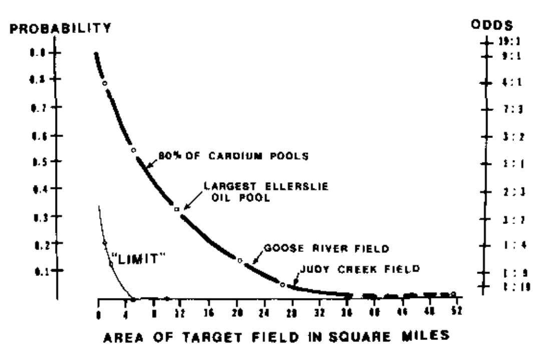

Fig. 13. Maturity curve at the Beaverhill Lake level for the Alberta example. Note the curve for the hypothetical "drilled out" limit.

*statistical discontinuity

The drilling maturity in Figure 13 has been constructed from the data in the first curve row of the data matrix (Table 3) since the probability of non-discovery (the likelihood that a pool could still be present in the area and not have been hit or "discovery by no wells") is what we seek to relate as a function of target size. This curve is interpreted in the same way as those of Figure 10. It reflects the fact that the area is fairly well explored at this stratigraphic level. For example, the likelihood of an additional township-sized field (36 square miles) is less than 0.05 (odds below twenty-to-one against). The turnover point where the odds that a given sized target could be present exceed the odds that it is not, is around six square miles. It might therefore be said that this area has not yet been exhaustively searched for five or four square mile targets.

The relative areas of some well-known western Canadian fields are noted on the graph for purposes of comparison. For example, the likelihood of another Judy Creek-sized pool still being present in the study area is small — around .07. Thus, the existing drilling pattern, though far from regular in terms of spacing has effectively screened the region for all Judy Creek-sized fields.

A Second Example

Figure 14 pictures an exploration area (the stippling) in which there has been some drilling as represented by the black dots and within which a small oil pool shown by the black spot has been discovered. It is desired to estimate the probability that *another* pool of the same size could still be present in the chosen area and not have been "discovered" by the collection of wells drilled up to this time. The stippled area represents a supposed trend along which the geology is favorable to the occurrence of the same kind of pool as that shown. In this case, therefore, a potentially favorable geological environment prescribes the sample area. It is, of course, possible to include sub-areas of differing degrees of favorability in the "regional seiving" of a region. The random sampling scheme is merely weighted in such a manner that the trial targets are *more* likely to be located in the comparatively favorable sub-areas than the others so that the drilling pattern in these parts becomes more critical to the overall probability of occurrence than that in those less favorable.

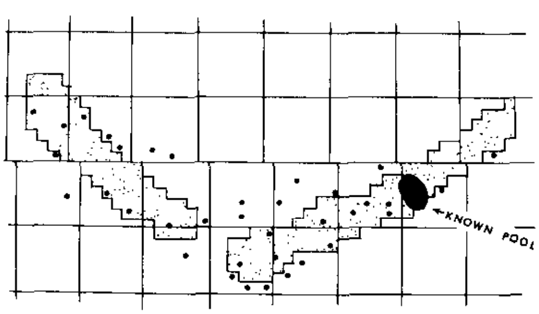

Fig. 14. Evaluation of the target potential of a limited sized area and a specific target size.

The screening method for this problem is the same as in the other examples though limited to just the stippled area; the hypothetical target is identical in size and shape to the known pool, but it wouldn't necessarily have to be in all cases. Recorded in this application are merely the number of intersections of the randomly positioned target and their distribution. The result of three hundred estimates is shown in Figure 15. The probability of non-detection in this case is around 30 per cent (.3). However, if one cares to specify a *two* well requirement for a discovery, the likelihood of the presence of an additional target is considerably higher (P(zero hits) + P(one hit) = .3 + .4 = seventy per cent) = 1.0 − P(at least two hits).

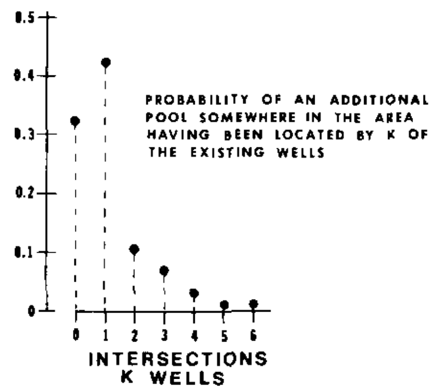

Fig. 15. Probability curve for the area and target shown in Figure 14.

The effectiveness of proposed drilling programs designed to maximize the likelihood of encountering an additional target field in the sample area can be evaluated by adding the additional well site locations to the map in some pertinent way (based on geology, trendology, geophysics, land availability, partnerships, etc.), and running through the screening procedure, using an appropriately sized target. The number of wells, locations, potential target size, spread in target sizes, favorabilities of particular subsurface environments, etc., can all be taken into account in generating the desired probabilities. The variety of the possible applications of the basic area screening method is limited only by the creativity of the user.

Applications

A few examples of some routine uses include the following.

(1) Estimation of occurrence probabilities in risk-type calculations and models in which such input is required. These values are oftentimes "guesstimated" by geologists or approximated from local success ratio values which are generally pretty unstable. For example, in the basic expected

value formula EV = p(V) − (1 − p) (E + WC + L); "p", the probability of achieving a value (V) is a critical parameter in the equation. (E, WC and L represent Exploration Cost, Well Cost and Land Cost respectively). The ultimate accuracy of similar regional probablistic models is likewise dependent upon the relevance of "p", an estimate which can be supplied using the regional screening procedure.

(2) Comparisons of the exploration potential of several different plays of varying geology depth and area of control and economic threshold size. Such information can be summed up on a table of the sort shown below and utilized *along with* the traditional types of play support material by management in allocating funds, accepting or rejecting deals, etc.

Table 4

Comparative Exploration Potential of Several Plays

Play	Threshold Economic Size	Probability
Area A	3200 Acres	.35
Area B	12,200 Acres	.90
Area C (Cret.)	7,200 Acres	.15
" " (Dev.)	1,000 Acres	.83

(3) Estimations of occurrence likelihoods for use in discussions and decision-related conversations. An example — "The likelihood that another Leduc D-3 sized pool could still be present in the Fairway area and not have been discovered by at least one well is seventy per cent." Such information is useful for informal comparison of the potential of several regions.

(4) Assessing the efficiency of the geophysical coverage in some area of interest with respect to some or a spectrum of target sizes *and* the existing drilling and/or coring pattern. The likelihood that a particular shooting pattern (either actual or proposed) is successful in intersecting targets of a particular size, shape, and/or orientation can be evaluated and optimal patterns for future surveys which will maximize the likelihood of discovery by minimizing the exploration uncertainty can be designed and evaluated.

(5) Assigning prices for land leasing and bidding by basing them on degree of exploration uncertainty in terms of the available geologic and geophysical information.

(6) The accuracy of resource evaluation information and estimates is largely dependent on the spatial density of drill sites, traverses, etc. Thus, weighting factors based on maturity curves and associated probabilities may be assigned to estimates of undiscovered oil and gas, potential for geologic structures, etc.

Conclusion

The "regional seiving" technique described above is a useful tool for estimating undiscovered target potential in areas of exploration interest. The resulting graphs can be consulted by individuals involved in strategic exploration planning activities such as allocation of funds and effort.

As those individuals who are associated with searching for, estimating and evaluating mineral resources hidden in the Earth's crust will attest, there is only one thing that is certain. That is that almost all of the future major discoveries will be found in volumes of rock which have as yet not been much searched, i.e., generally between or deeper than the presently existing holes and fields. The "blindspots" of today will be the sites of the giant fields of tomorrow.

Acknowledgements

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