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THE GEOLOGICAL CHANCE OF SUCCESS FOR PROSPECTS WITH SANDSTONE DEPENDENCIES, CRITERIA FOR THEIR EVALUATION[1]

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Resumen

A través de un sistema de ecuaciones se deconstruye el modelo propuesto por JA Murtha, en un marco dependencia de areniscas (situación del Subandino Sur de Bolivia donde se encuentran los megacampos gasíferos). Las consideraciones, los supuestos y los criterios fueron plasmados con el objeto de conocer los fundamentos e instrumentos analíticos que suponen cada rama o resultado del árbol de decisión de un usual prospecto exploratorio de hidrocarburos. De esta manera se balanc ea el éxito exploratorio en términos estrictamente técnicos desde la perspectiva de localización y condiciones en términos probabilísticos. Asimismo, considera cada escenario que deviene del consecuente análisis de sistema petrolero con sus respectivas volumetrías e inversiones concomitantes. De este modo se obtienen los criterios básicos para la comprensión estructural para la toma de decisiones y los criterios de exposición de la información resultante, tanto a las Directorios de las empresas E&P como a instancias regulatorias y de planificación energética de los Estados.

Abstract

Using a system of equations, the model proposed by JA Murtha is deconstructed within a dependency framework model defined for sandstones (situation in the Sub-Andean South of Bolivia where the giant gas fields are located). The considerations, assumptions and criteria were expressed in such a way as to define the fundamentals and the analytical tools represented within each branch or result of the decision tree for a typical exploratory prospect. In this way the exploratory success for each scenario is weighed in probabilistic terms, these terms being derived from the analysis of petroleum systems, their respective volumetrics and the capital investments. In so doing, the basic criteria for the structural understanding of the decision making process and for exposing the resulting information is obtained; this is as relevant for the E&P business executives as for the regulatory authorities and the States´ energy planning criteria.

Keywords

Geologic success methodology, conditional probabilities, petroleum system, conditional sandstones, Expected Net Present Value.

[1] I want to give thanks to Frederic Shneider, an expert petroleum systems specialist with whom diverse methodological aspects were debated; his most important contribution was sharing relevant information about the essential importance of the dependencies within sandstone geology.

1. Introduction

In April of 1995, JA Murtha published the article Estimating Reserves and Success for a Prospect With Geologically Dependent Layers in which a methodology was formulated for evaluating probabilities in the context of the dependence between sandstones and hydrocarbons. The work presented here is an analysis that models the geological circumstances for which there exists possible interdependencies in petroleum systems and announces their exploratory success as the basis upon which the other factors contributing to exploratory risk and analysis is defined (Wang 2002, Skates 2003, Rasheva & Bratvold 2011 and others). Nevertheless, the possibilities of success for the events (the results of the decision tree) imply a variability in the possible successes associated with prospective volumes, a situation from which diverse scenarios for the necessary investment are derived. Therefore, the objective for this analysis is based upon deconstructing the above-mentioned methodology and demonstrating possible options for exposing information in reference to geological success, prospective volumes and necessary investments in order to establish, support and understand the decision criteria in exploratory activities.

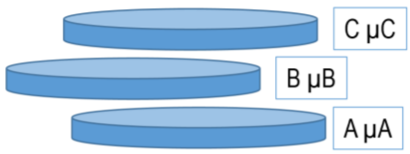
2. Theoretical Structure

The occurrence of geological phenomenon like: the formation of the parent rock, maturation, migration and entrapment, just like all other events that cross over different geological eras, exhibits the possibility for having petrological systems that are dependent. Because of this, it is the accordance between the technical analysis of the basin is with the hard data (seismic, well logs geochemistry, etc.) and the simulations of the components of petroleum systems that define the possibility of interdependence between the sandstones in question. In general, and as a matter of principle, the analysis of petroleum systems is the essential basis for the probabilistic analysis for evaluating a multi-prospect development given that without a rigorous study of the dependencies and independencies for the factors of the petroleum systems insufficient information is being provided in order to make decisions.

Hence, the presented analysis is adopted in the following example:

Figure 1: *Characteristics of reservoirs in sands*

3 Sandstones	Geological Chance of Success	Distribution of Resources (mean)
Sandstone C	P(C)	μC
Sandstone B	P(B)	μB
Sandstone A	P(A)	μA



The core of the analysis is detailed in the decision that lays the groundwork for the perforation of exploratory wells in a setting where there are multiple opportunities for exploration (various sandstones). For this reason, three different sandstones are considered representing three objectives to be tested for drilling an exploratory well. It is assumed that the geological chance of existence has been defined prior to the analysis of the petroleum system. Likewise, an analysis of the reservoirs defines the distribution of resources for each sandstone and represents them as the mean of the mentioned functions.

It is very important to distinguish the differences between the independences and the dependences among the sandstones.

The fundamental theoretical criteria are the following:

Table 1: *Probability criteria as a function of type of dependence*.

Assigning probabilities when the sandstones are independent features:	Assigning probabilities when the sandstones are dependent features:
Element 1 - When the events A, B, C are independent: P(ABC) = P(A)P(B)P(C) In terms of a conditional probability between two events A and B, the behavior will be the following: P(A\B) = P(A). In summary, there should be no definite increase or decrease in the chance of A given the success or failure in sandstone B. Element 2 – In all cases where P(AB) = P(B) P(A\B) Because there is no defined dependence between the sands P(AB) = P(A)P(B). The combined probability of success is represented by the multiplication of the two probabilities.	In all cases where P(A\B) > P(A) In terms of a conditional probability between two events A and B, the behavior should be the following: P(AB) > P(A)P(B) In general, there should be a definite increase or a decrease in A given the success or failure in sandstone B. In this case, the probability of combined success is greater than the probability of success if the sandstones were to be considered independent.

The conclusions that follow from defining whether the sandstones are dependent or independent is summarized in the following statements:

1. All sandstones with dependencies among them will always have a higher probability for success than among independent sandstones;
2. The probability for a dry well when there exists a dependency between sandstones is always greater than the probability of a dry well in independent sandstones.

Hence, methodologically, it is possible to assign probabilities for occurrences by considering whether the sandstones are dependent or independent. The present analysis outlines how to define the probability of occurrence when the sandstones are dependent. There will be 8 possible combinations defining the possibilities of success and failure in the three sandstones (C, B, A). For each sandstone, there are 2 possible results (1 = success; 0 = failure). This means that for the 3 sandstones (C,B,A), there are 2^3 = 8 possible combinations; which equate to the 8 equations and 8 scenarios shown in figure 3.

Figure 2: Proposed lineal equations for the 8 undefined variables

Equations	p1	p2	p3	p4	p5	p6	p7	p8	Event	Equations/Undefined Variables		
1	1	1	1	1	0	0	0	0	P(A)	p1+p2+p3+p4		p1
2	1	1	0	0	1	1	0	0	P(B)	p1+p2+p5+p6		p2
3	1	0	1	0	1	0	1	0	P(C)	p1+p3+p5+p7		p3
4	1	1	0	0	0	0	0	0	P(A&B)	p1+p2	X =	p4
5	1	0	1	0	0	0	0	0	P(A&C)	p1+p3		p5
6	1	0	0	0	1	0	0	0	P(B&C)	p1+p5		p6
7	1	0	0	0	0	0	0	0	P(A&B&C)	p1		p7
8	0	0	0	0	1	1	1	1	P(No A)	p5+p6+p7+p8		p8
Descriptions	Success A,B,C	(A,B) not C	(A,C) not B	A not (B, C)	(B,C) not A	B not (A,C)	C, not (A,B)	None				

M R X

M*X=R, leaving out the cases where X = M (TRANSPOSED)*R

Mathematically, it is possible to solve for the proposed undefined variables using these lineal equations and in this way discover how possibilities are allocated for each proposed scenario. Nevertheless, the essential input is represented by the vector R, which is the outcome produced when evaluating the petroleum system in conformity with the characteristics of dependence among the sandstones.

Figure 3: *Vector R*

	Trap	Reservoir	Seal	Charge	Probability	Event
A	0,70	0,60	0,90	0,60	**22,68%**	P(A)
B	0,70	0,60	0,90	0,60	**22,68%**	P(B)
C	0,70	0,60	0,90	0,60	**22,68%**	P(C)
A if B	0,90	0,60	0,90	0,80	**38,88%**	P(A\B)
A if C	0,90	0,60	0,90	0,80	**38,88%**	P(A\C)
B if C	0,90	0,60	0,90	0,80	**38,88%**	P(B\C)
A if B&C	0,90	0,60	0,90	0,80	**38,88%**	P(A\B&C)

R =

P(A)	P(A)	**22,68%**
P(B)	P(B)	**22,68%**
P(C)	P(C)	**22,68%**
P(A&B)	P(A\B)*P(B)	**8,82%**
P(A&C)	P(A\C)*P(C)	**8,82%**
P(B&C)	P(B\C)*P(C)	**8,82%**
P(A&B&C)	P(A\B&C)*P(B&C)=P(A\B&C)*P(B\C)	**3,43%**
P(Not A)	1-P(A)	**77,32%**

In the current case, the calculation for the petroleum system is performed starting with the application of the BECIP-Franlab algorithm (See Appendix I), which considers four different factors, the product of which represents the formulation of probability for each sandstone or combination of sandstone dependencies. It should be stressed that the vector R is a result of the multiplication of probabilities in accordance with the Bayes´ Theorem. Therefore, the vector R is, without doubt, the most important outcome from this technical analysis because it represents the structural and regional geology, as well as the petro-physics and geochemistry, among with other specialties that contribute to the definition of the possibility horizon for any exploratory stake.

Once the technical aspects have been configured and the algorithm applied, the unknown variables that arose in the development of the combinations define outcomes in probabilistic terms. The results give probabilistic frequencies of combined success as a product of the measurements for the sandstone petroleum systems and their dependence relationships. In the above case, dependence never reaches values of 100%, but it may give success values of 90% in the trap and 80% in the charge. This is because conservative criteria should be normalized so that the decisions made leading to the construction of portfolios for exploratory opportunities be correct and consistent.

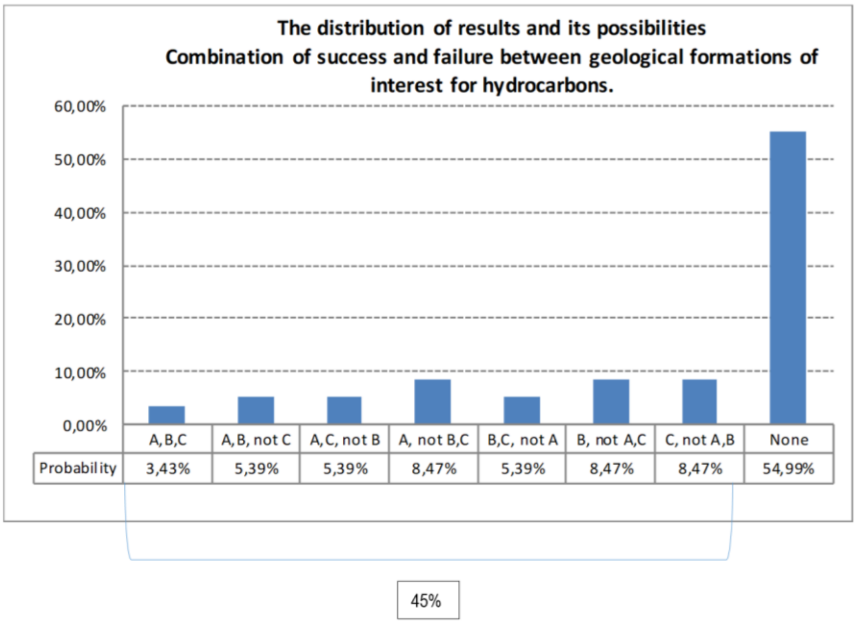
Figure 4: *Results of the lineal equations*

X = M(transposed) R

X		M								R		X	Scenario
p1	=	0	0	0	0	0	0	1	0	28,80%	=	3,43%	A,B,C
p2		0	0	0	1	0	0	-1	0	31,36%		5,39%	A,B, not C
p3		0	0	0	0	1	0	-1	0	33,60%		5,39%	A,C, not B
p4		1	0	0	-1	-1	0	1	0	19,06%		8,47%	A, not B,C
p5		0	0	0	0	0	1	-1	0	19,22%		5,39%	B,C, not A
p6		0	1	0	-1	0	-1	1	0	23,23%		8,47%	B, not A,C
p7		0	0	1	0	-1	-1	1	0	14,12%		8,47%	C, not A,B
p8		0	-1	-1	1	1	1	-1	1	71,20%		54,99%	None

It is important to stress that each scenario corresponds to a possibility in terms of the probability of occurrence for said event. In this way, the combination of scenarios occur in a frequency for which the possibility that each well would come up dry is usually greater than the subset combinations where at least one successful sandstone is found. Nevertheless, it stands out that there is a greater than 40% chance that at least one sandstone of the three sandstones will be successful, as is the usual case in multiprospect developments. Rose (1992) shows that an the economical evaluation of multiobjective prospects should proceed with caution, given that the incentive exists to view the elevated geological chance as no more than the sum of the combination of success possibilities from marginal sandstones that in themselves may not be attractive.

Figure 5: *Scenarios of interdependence in petroleum system and their exploratory success*



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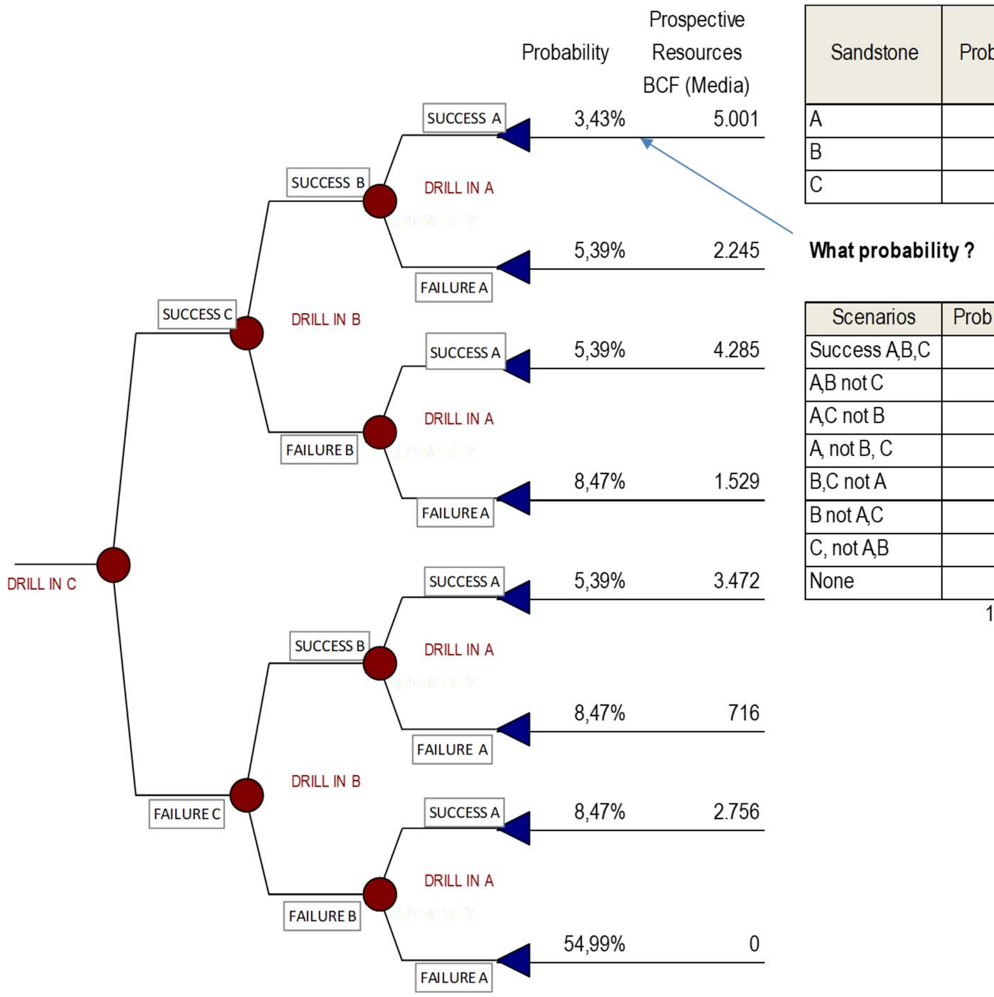
3. Discussion

Let's take into consideration an example (a prospect in southern subAndean Bolivia). Here, the probability obtained for the geological chance of success in at least one sandstone was 45%. This number comes from the sum of the given scenarios in the above graph. This means to say that there is a 45% chance that the geological chance of success is high; this cannot be considered as an economic evaluation alone given that it is assumed that each and every sandstone presents sufficient reserves to be profitable. In practice, this isn't always the case, given that some of the combinations cannot reach the economical thresholds defined under the guidelines, Minimum Economic Field Size (MEFS). In this sense, the 45% success rate may not projects where the scenarios are not profitable. Therefore, it is important to unweave the snarl of interactions between the possible combinations and the prospective resources like has been depicted in the following figure, following the leading thread for the given example:

Figure 6: *Scenarios showing interdependence in petroleum systems and their exploratory success in the decision tree.*



Sandstone	Probability	Prospective Resources BCF (Media)
A	22,68%	2.756
B	22,68%	716
C	22,68%	1.529
		5.001

Scenarios	Prob = M(X)	
Success A,B,C	3,43%	
A,B not C	5,39%	
A,C not B	5,39%	
A, not B, C	8,47%	45%
B,C not A	5,39%	
B not A,C	8,47%	
C, not A,B	8,47%	
None	54,99%	
	100,00%	

Note the extreme cases in the previous table - 5 TCF reserves[2] with no results. Just like tossing a coin, where the coin comes predisposed to land on the exploratory failure side. In this sense, it should taken into consideration that, until now, an innocent trend has commonly existed in which a momentous event stops the important decision making process, even though it may be an unfavorable result of a coin toss. This is what we may expect to have occurred, at least in the southern sub Andean region of Bolivia, for most cases with 5 TCF reserves or for total failures with around 100MM invested in USD.

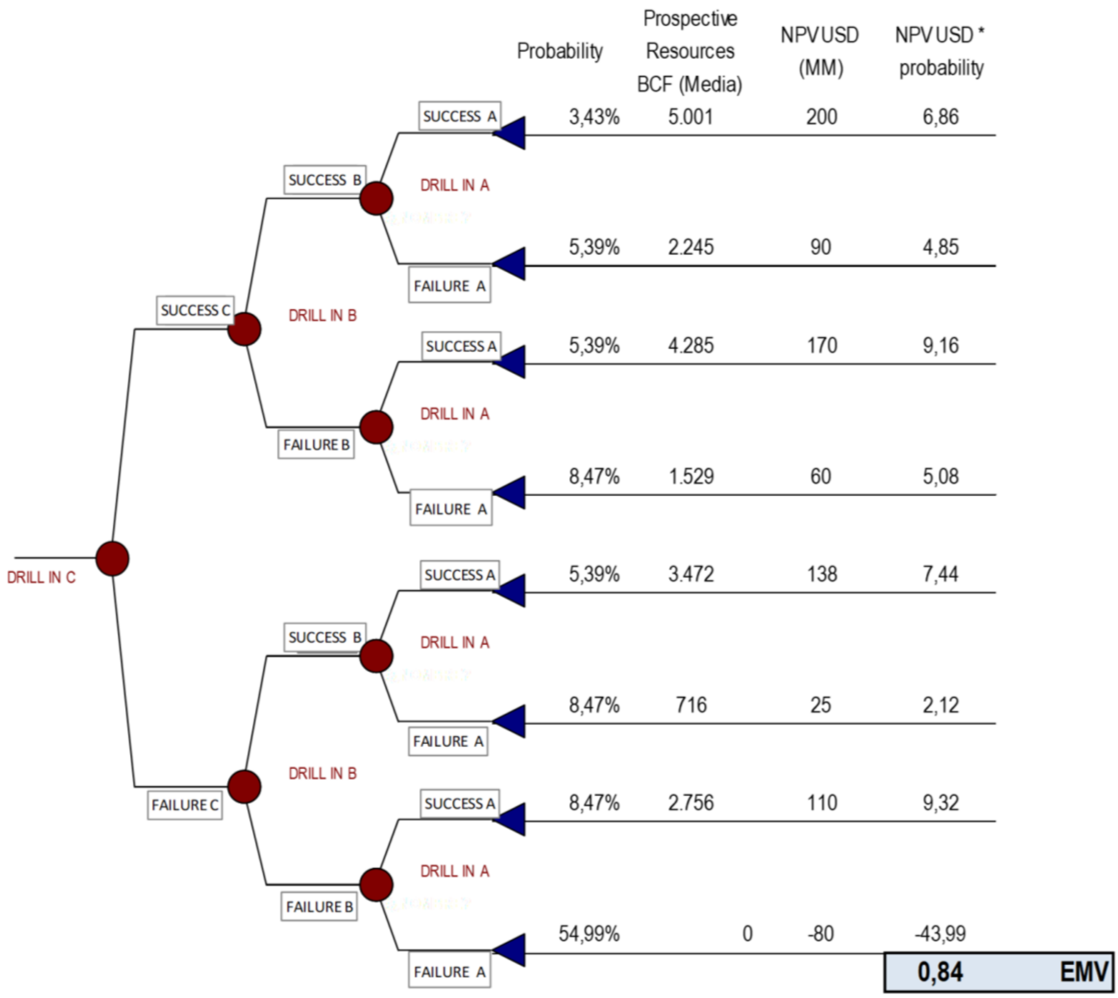
Now, the 5 TCF reserves shown above are located within the context of a 3.43% probability of success and a 54.99% chance for exploratory failure. The relationship between the two probabilities is 1:16, which means that failure is up to 16 times more probable failure than success in discovering a 5 TCF reserve. This example is so extreme that the 3.43% probability is found as an extreme statistic that conventionally would be discarded when the statistical functions with lower than a 5% probability are thrown out. Therefore, it is reasonable that the rest of the scenarios would be considered over the possibility of a dry well.

For this reason, there remains two methods that are used indiscriminately by various E&P companies. The first one involves the selection of the scenarios in conformity with MEFS; in other words, the scenarios that are not profitable are dismissed in accordance with the size of the prospective resource. In this way, those scenarios valued under the economic threshold given by MEFS are eliminated. Nevertheless, this situation forcibly truncates the aggregate distribution function, thus also modifying estimates for the prospective resources defined by their mean and changing the geological chance of success into a general economic input chance of success, which determines the expected Expected Monetary Value (EMV) (Rose 2015)

Another decision-making method is defined by weighing up each scenario considering their Net Present Value (NPV). In other words, for the discovered resources, the corresponding production runs are carried out in taking into consideration their typology, the depth of the sandstones, the investment required and the corresponding development costs in case of success. In other words, it must first be established that it is indispensable to carry out each of the runs with the required technical support in the conceptual development for each scenario. Following this, each one of the results for each economic run is weighted according to their corresponding probabilistic frequency value. In this way, the EMV is the result of the sum of the VPN values weighted by their frequency; or, better said, is the product sum operation as seen in the following graph.

[2] All proven prospective resources by statistical convention are represented by log normal distribution functions and the statistical value of the given representation is assumed to be the mean value. Therefore, it should be noted that the prospective resources should be added up. This is because of the statistical property that it is only possible to add mean values. This characteristic cannot be depicted by the average, represented by P(50) (see PRMS_Guidelines_Nov2011), which is also the principal value recommended by industry practice for calculating hydrocarbon resources. This gap in appraisal values has its roots in the fact that P(50) is a log normal distribution that corresponds to a principal value that is more conservative than the mean.

Figure 7: *Scenarios showing interdependence in petroleum systems and their exploratory success in the decision tree and EMV*



Considering what has been mentioned, it is possible to include a project with the mentioned characteristics and include them in a pre-investment portfolio and then make the decision to drill or not to drill. Nevertheless, much depends upon the point of view and perspectives involved in presenting the information, especially regarding projections for the future. Here a dilemma arises. Which scenario is next to be presented to the company associates and the state organizations for energetic planning and included in long range budget planning for the State? It is clear that in the given example, there was a moment in which no exploratory well had yet been drilled, but there existed 8 scenarios with the possibility of coming up with a dry well.

It is important to remember that it would be wrong to consider the geological chance of success as proportional to the sum of the positive scenarios, because the only thing it reflects is the probability that at least one combination with success may be found. Associated with the 45% probability, there is also a value for prospective resources that does not necessarily relate to the three sandstones, but to a lesser resource. Sometimes, this is revealed by the mentioned values (the sum of probabilities for the positive scenarios and their associated resources), which then are considered in the decision making process and for disclosure in different instances: corporate, contractual and regulatory.

In case of any doubt, a potential solution involves establishing groupings of information. Now, in these cases there continues to exist the point of view of the actors, those to whom the information will be revealed. It is not necessary that the greatest recuperation of hydrocarbons is the more profitable scenario from the point of view of a particular party. The aforementioned is reflected clearly in what is called the Unit Technical Costs (UTC), a highly used indicator for decision makers used in performing preliminary estimates3 when analyzing upstream projects, where the utilitarian reasoning takes precedence because, in concrete terms, it represents greater profits for the lowest possible investment in money and time. On the contrary, although they may not comply with the interests of the E&P companies, the Nation States are the ones that take out the greatest amount of compensation from the hydrocarbons in each scenario for tax reasons and/or needs of the energy economy. In spite of all that, the concept of using grouped information when exposing information about this type of prospect is the best option available given that in these cases the deterministic option from any perspective would be full of biases that could easily be manipulated thereby completely rendering the aforementioned rigorous analysis banal.

4. Conclusions

The geological dependence or independence is a matter of high importance and in principle should not be trivialized by deciding instances. The data collected for the basins; including regional geology, geochemistry, stratigraphic data taken from well logs, seismic data and all other data collected and used as a backbone of information and in simulations for the analysis of petroleum systems; gives scientific base to the definition of exploratory opportunities. Therefore, the dependence and/or independence of these given factors in a petroleum system will be sustained and substantiated by the specialists. With this input, one can make distinctions among scenarios, the associated probabilities and the associated investments for each scenario.

However, the objective of the present analysis was centered upon deconstructing the method - the calculation of probabilities that come from the underlying geological fundamentals. All of the geological knowledge, all of the debated and contradictory science, in the end, comes down to probabilities and their prospective volumes linking them together and creating a profile for the scenarios from which subsequent decisions will be made regarding the risk capital for exploration, income and long-term costs for the future. Without doubt, the importance of knowing how to interpret the numbers in order to give input to the decision tree is fundamental and of central importance.

The explanation lies within the use of matrix mathematics, the theorem of probabilities, the laws of statistics and how to express the speculative information. These are all tools that should be understood by the planners, the E&P company executives and, above all, by the executive branch and the ministers of the State. Nevertheless, the experience shows that short-term political yields for prospects with long-term geological promises, above all in economies with greater sectorial importance in hydrocarbons, are subject to opportunistic interpretations, an aspect which dilutes any effort to make better decisions on the base of technical principles.

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APPENDIX I – CRITERIA FOR EVALUATING THE PROBABILITY OF GEOLOGICAL SUCCESS

DEFINITIONS

Petroleum System: Includes all elements and processes essential to the recuperation of hydrocarbons from nature.

Play: A geographical area defined by a conceptual model that shares a common history regarding the generation of hydrocarbons, their migration, the development of reservoirs and the configuration of traps over a stratigraphic interval such that the critical factors that control the occurrence of hydrocarbons are more or less constant over the defined area.

Lead: Represents the petroleum exploration opportunity associated with an accumulation potential implicating possible saturated hydrocarbons and requiring further collection of geological data and/or their evaluation in order to be classified as a prospect.

Prospect: Is a defined trap with sufficient potential accumulation to represent a viable objective for drilling.

Exploratory Project: Are all related exploration activities coordinated with their respective quality controls, budgets and chronograms with the goal of performing an exploration, a study and/or a geological evaluation of the surface and subsurface using data from remote sensing, topographical studies, gravimetry, magnetometry, magnetotellurics, seismic studies, geochemical analysis, data from well logs and any other studies with the objective of determining the existence of hydrocarbons in an area or geographical zone

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ELEMENTS OF A PETROLEUM SYSTEM USED IN CALCULATING GEOLOGICAL SUCCESS

Lead / **Prospect**	**XXX**	
Area: **XXX**	Country: **Bolivia**	Date: **XXX**
Reservoir / Stratigraphy: **XXX** Lithology / Facies: **XXX** Type of Trap: **XXX**		
Geological Factors	**Probability of Success**	**Commentaries**
TRAP = P(1)=T	**0,6**	
Confidence in mapping	0,6	
Confidence in Trap Model	0,7	
RESERVOIR = P(2)=R	**0,7**	
Presence	0,9	
Quality	0,7	
SEAL = P(3)=S	**0,7**	
Top	0,8	
Lateral	0,7	
Base	0,9	
CHARGE =P(4)=C	**0,7**	
Expulsion	0,8	
Migration	0,8	
Synchronization	0,7	
Preservation	0,9	
Probability of Geological Success "PG":	**0,21**	**Greatest Risk: Trap**

As shown here, the probability of geological success (PG) is the result of the following products contemplating the lowest probabilistic values in each one of the considered four subsystems:

$$PG = \prod_{k=1}^{4} P(k)$$

Or in other words: PG = PT*PR*PS*PC

Parameters evaluated in the determination of the probability of geological success

TRAP

This is a measurement of confidence as a function of the certainty in the geometrical definition of the geological object that can accumulate hydrocarbons (the trap), whether this be formed by sedimentary, tectonic or mixed processes.

Confidence in mapping - This is an estimated value produced as a product of an analysis of the quantity and quality of available information in order to define the trap. The uncertainty in the definition of the trap model decreases with greater quantity and quality of necessary information.

Confidence in the Trap Model – The trap model is defined in function of the information available; therefore, the confidence in the model is associated with the degree with which the data can represent the trap. It is a result produced as a qualification of the uncertainties in the quality of information, employed methodologies in the interpretation and/or the coherence with geological concepts.

RESERVOIR

It is the level of confidence given as a function of the certainties in the existence of a rock unit and its petro-physical qualities as a reservoir, from the moment of migration to the present day.

Presence – It is the level of confidence given for the existence of the rock units considered as the hydrocarbon reservoir.

Quality – Assuming that a rock unit that can be considered a reservoir exists, it is the level of confidence that this unit has the minimum necessary petro-physical qualities in order to be able to deliver a yield.

SEAL

This is the level of confidence given as a function of the certainty of the existence of a rock unit and its capacity to oppose hydrocarbon migration in order to act as a seal from the moment of migration to the present day.

Top – It is the level of confidence that there exists a rock unit, stratigraphically located over the reservoir, that can be considered a seal for having a sufficient capacity to oppose hydrocarbon migration (in terms of its thickness and petro-physical characteristics).

Lateral – It is the level of confidence that there exists a rock unit, stratigraphically considered a facial variation in the reservoir walls or the product of a structural discontinuity, that can be considered a seal for having a sufficient capacity to oppose hydrocarbon migration (in terms of its thickness and petro-physical characteristics).

Base - It is the level of confidence that there exists a rock unit, stratigraphically located at the base of the reservoir, that can be considered a seal for having a sufficient capacity to oppose hydrocarbon migration (in terms of its thickness and petro-physical characteristics).

CHARGE

This is the measure of confidence as a function of the certainty in:

Expulsion – It is the level of confidence that a rock unit exists in sufficient quantity and quality (in terms of TOC and IH concentrations) to have reached sufficient thermal maturity for the production and the expulsion of hydrocarbons to the fetch area.

Migration – It is the level of confidence that the generated and expulsed hydrocarbons had the possibility to move via defined drainage systems in the fetch area from the parent rock to the trap.

Synchronization – It is the level of confidence that the formation of the trap occurred within a timeframe such that it was possible to accumulate hydrocarbons.

Preservation – It is level of the confidence that in the time period following the entrapment of the hydrocarbons, no processes occurred that may have altered conditions allowing for the accumulation of hydrocarbons and causing the quality of the hydrocarbons or their permanence in the reservoir to be jeopardized.

Considering that the permanency of hydrocarbons in a reserve could be due to the quality of the seal and the the reservoir itself, these factors do not need to be considered in the evaluation of this parameter given that these effects have already been considered in the evaluation of the Seal and Reservoir parameters.

RANGE OF REASONABLE VALUES FOR THE COMPONENTS OF THE PETROLEUM SYSTEM

0.1 – 0.39 = Elevated risk with sufficient information that exploratory activities should not be allowed to continue.

0.4 – 0.59 = Elevated uncertainty in confirming the certainty of geological success. There is a necessity to realize other exploratory activities in order to confirm the presence or absence of required elements of a petroleum system.

0.6 – 0.9 = Sufficient certainty for the existence and functionality of a petroleum system in order to define an exploratory prospect.