Statistical Look of the Hydrocarbon Prospectivity of Undiscovered Subsalt Plays at the Mexican Side of the Deepwater Gulf of Mexico Basin

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GCAGS Explore & Discover Article #00207*
http://www.gcags.org/exploreanddiscover/2017/00207_perez_rodriguez.pdf
Posted October 30, 2017.

*Article based on a full paper published in the *GCAGS Transactions* (see footnote reference below), which is available as part of the entire 2017 *GCAGS Transactions* volume via the GCAGS Bookstore at the Bureau of Economic Geology (www.beg.utexas.edu) or as an individual document via AAPG Datapages, Inc. (www.datapages.com), and delivered as a poster presentation at the 67th Annual GCAGS Convention and 64th Annual GCSSEPM Meeting in San Antonio, Texas, November 1–3, 2017.

ABSTRACT

The likeliness and the size of undiscovered subsalt fields in the Mexican side of the deepwater portion of the Gulf of Mexico Basin are investigated and discussed. The continuity of the geological setting from the U.S. side into the Mexican side of the basin and the comparison between the total plays versus the subsalt plays of the whole basin suggests the presence of undiscovered subsalt resources south of the international border. Basinwide, there is a probability ratio of subsalt plays having as much as 1.3 times the volume of hydrocarbon as the above salt ones. Although subsalt Miocene plays have a share of reserves greater than that of subsalt Lower Tertiary plays, spatial distribution of these trends suggests that the latter plays may predominant south of the border. Statistical evidence suggests that there is a chance of finding one subsalt field with a subsalt play for every four fields with plays of any kind that are discovered. The cross plot of the areas of the fields and the distribution of reserves shows a dispersed cloud of points loosely suitable to be analyzed even with the use of confidence bands. The logistic function reduces the uncertainty of this situation and provides a meaningful insight in the connection between the areas and the dimension of reserves of the fields. The cumulative frequency curve of the volume of reserves of subsalt fields in the U.S. side of the basin is applied to constrain the expected volume of reserves in the Mexican side. Between the first quartile and the median size of undiscovered subsalt fields, the sizes could be from one and a half up to two and a half times bigger than the size of the largest above-salt field already discovered in the Mexican side of the basin. However, this promising appraisal is tempered by the analysis of risked probabilities, which shows that the overall odds against a commercial discovery at the basin are 7 to 3.

Originally published as: Perez Rodriguez, S., 2017, Statistical look of the hydrocarbon prospectivity of undiscovered subsalt plays at the Mexican side of the deepwater Gulf of Mexico Basin: Gulf Coast Association of Geological Societies Transactions, v. 67, p. 273–282.

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I. INTRODUCTION

The Mexican side of the deep-water Gulf of Mexico is located offshore northeast Mexico, in water depths ranging between the 500 m and the 3600 m isobaths. It is bounded by the Gulf Coast Basin (GCB) to the north and west, by the Mexican Ridges (MR in Fig. 1) to the south, and by the Sigsbee Abyssal Plain (SAP in Fig. 1) to the east-southeast.
The western part of the Mexican side of the deep-water Gulf of Mexico comprises the southernmost extension of the US Louann Salt Subprovince. Its' eastern part includes the Perdido and the Peripheric fold belts (CNH, 2015). To-date, there are no subsalt discoveries made in the Mexican side of the basin. However, in the US side of the basin there are about 95 fields that have found subsalt reservoirs.

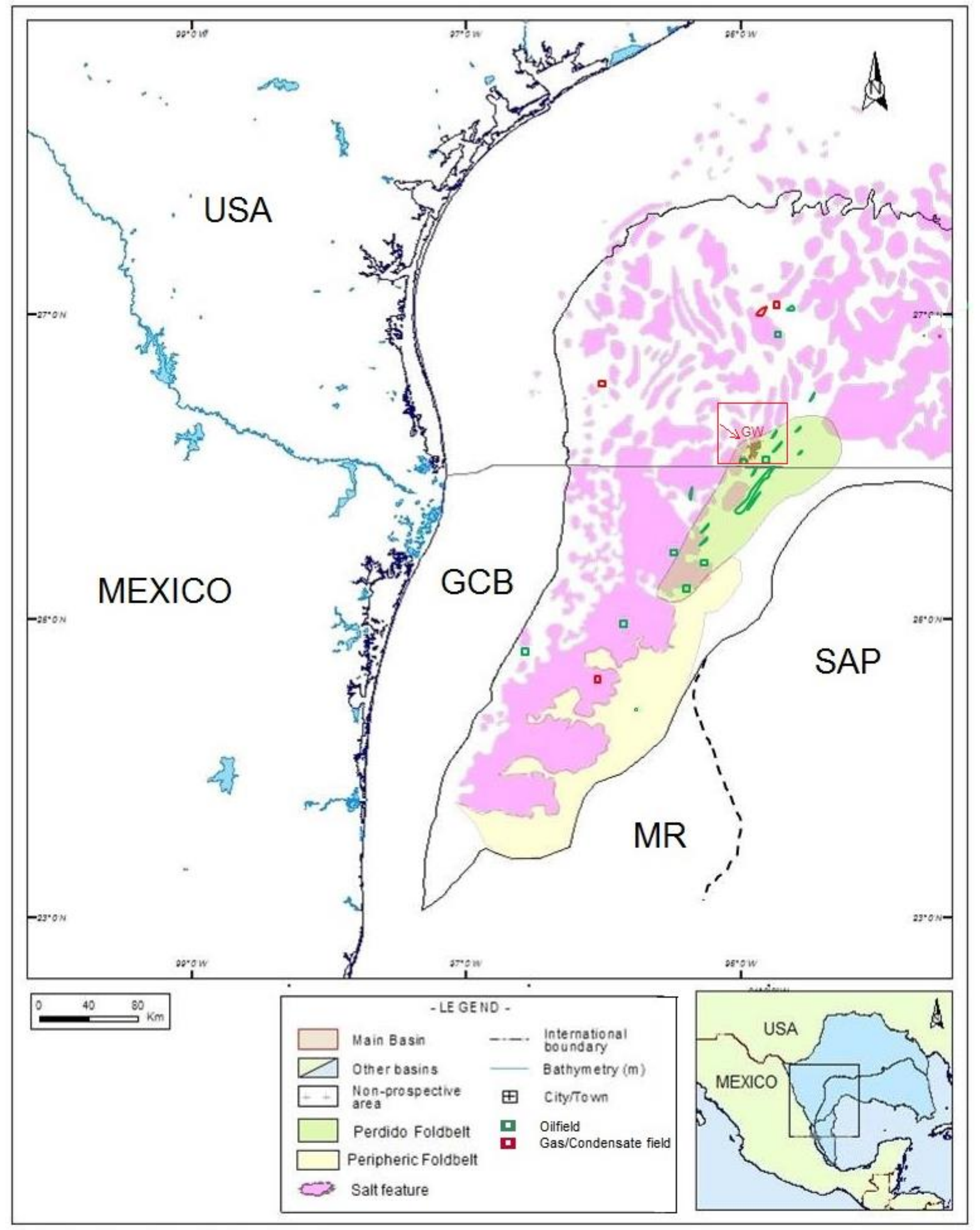

Figure 1. Location map and main features of the DWGoM Basin.

These discoveries includes the very large Great White field near the international border (GW, pointed with a red arrow in Fig. 1.).
Since 2012, after the first commercial discovery in the Mexican side of the deep-water Gulf of Mexico Basin, expectations of finding subsalt reservoirs have increased. Evidence suggests that the current nine above-salt discoveries in the Mexican side of the basin seems to reflect a natural tendency in the local business to avoid risk and to test the most accessible plays rather than an evidence of the lack of potential for subsalt plays. This conservative approach has not been limited to the exploration in the deep-water portion of Gulf of Mexico Basin and is understandable: it is usual that the above salt prospects are less riskier and have lower capital expenditures than the subsalt ones.
It was not until in 2012 that the first subsalt well in Mexico was drilled in the Campeche-Sigsbee Sub-basin (Vallejo et al., 2012).
However, the lack of an associated discovery took luster from the otherwise hallmark achievement. In the near future, the anticipated presence of international operators having subsalt expertise is expected to provide a quantum leap in subsalt exploration of the Mexican side of the deep-water Gulf of Mexico.

II. OBJECTIVES

To present statistically-based assessments regarding the likeliness and the dimensions of undiscovered subsalt resources by field on the Mexican side of the deep-water Gulf of Mexico Basin.

To introduce logistic functions as an alternative to make the statistically-based assessments of expected field sizes.

To compare the application of an assessment of expected field sizes solely based on confidence bands (as presented by Harbaugh et al., 1996) versus assessments based on logistic functions.

III. METHODOLOGY AND RESULTS

Failure of the first Mexican well looking for subsalt objectives points out the need to proceed with caution before dealing with forecasts based on unrisked probabilities. Inspection of Figure 2, showing general exploratory results of New Field Wildcat wells in the deep-water Gulf of Mexico Basin confirms the need of an exhaustive degree of analysis before assuming a lead supports a reliable prospect, either subsalt or not. Around 70% of the exploratory wells in the basin have not found commercial accumulations. With this somewhat grounding knowledge, let's then proceed with the review of the distributions of properties of discoveries that have been made.

A firsthand basinwide comparison of the volumes of hydrocarbons segregated between subsalt plays and others provides an initial view for further analysis. The histogram in Figure 3 shows that for both groups the Miocene plays have the greatest share of reserves. Although there appears to be more Miocene and Lower Tertiary reserves below salt, this is not true for the other plays ranked by age. A calculation of the ratio of partial to total volumes for each group shows that the subsalt plays amount to 56% of the reserves of the province. In other words, the subsalt plays hold almost 1.3 times as much reserve as the above salt plays. Also is of notice that of all the Lower Tertiary the Wilcox Formation/Group and the Frio Formation are the units presenting reserves at the GW discovery.

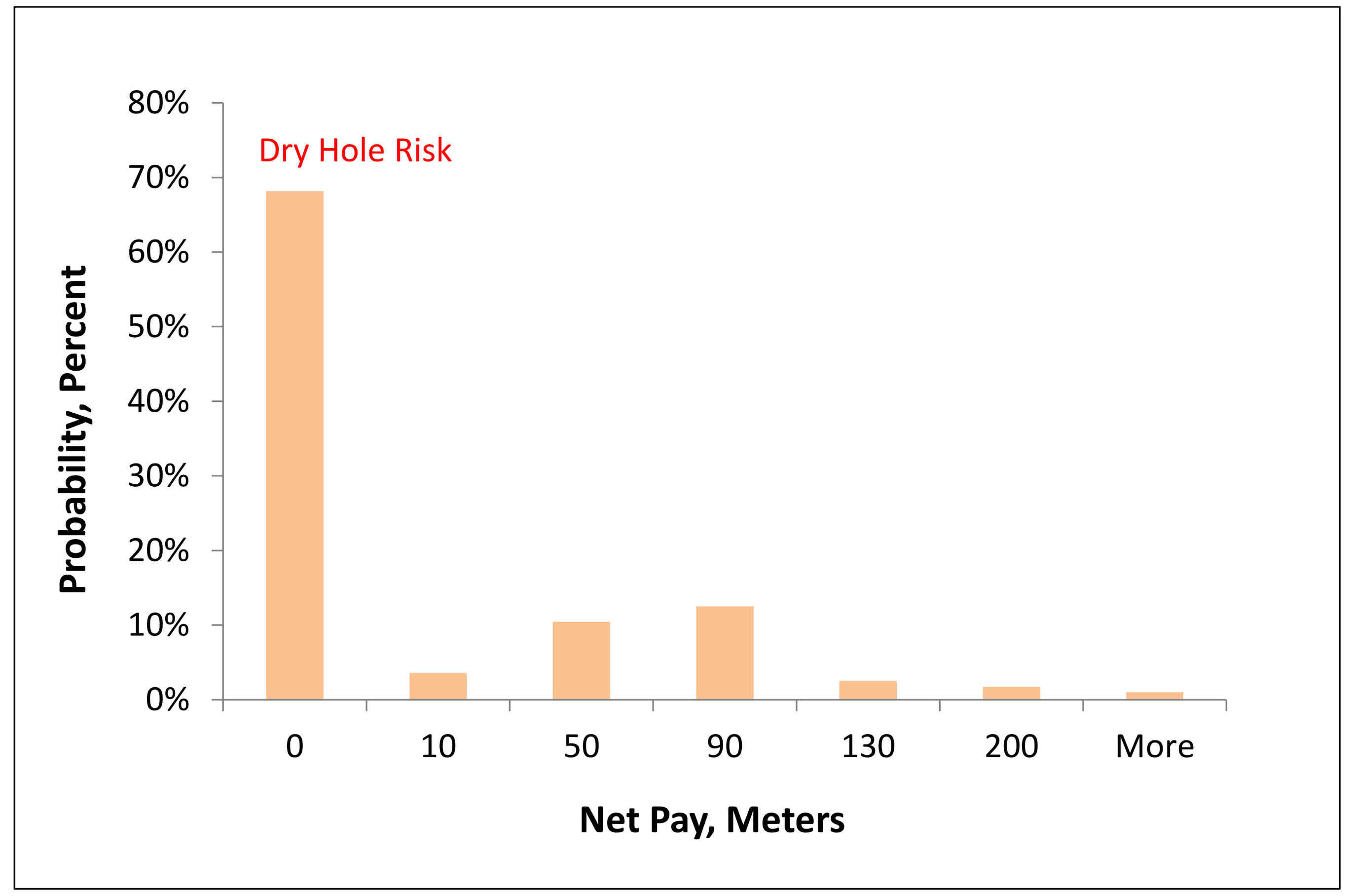

Figure 2. Risked probability distribution showing the relative weight between commercial and non-commercial outcomes at the deep-water Gulf of Mexico Basin.

These initial results fosters the need for gaining further insight in the appraisal of undiscovered subsalt resources in the Mexican side of the basin.

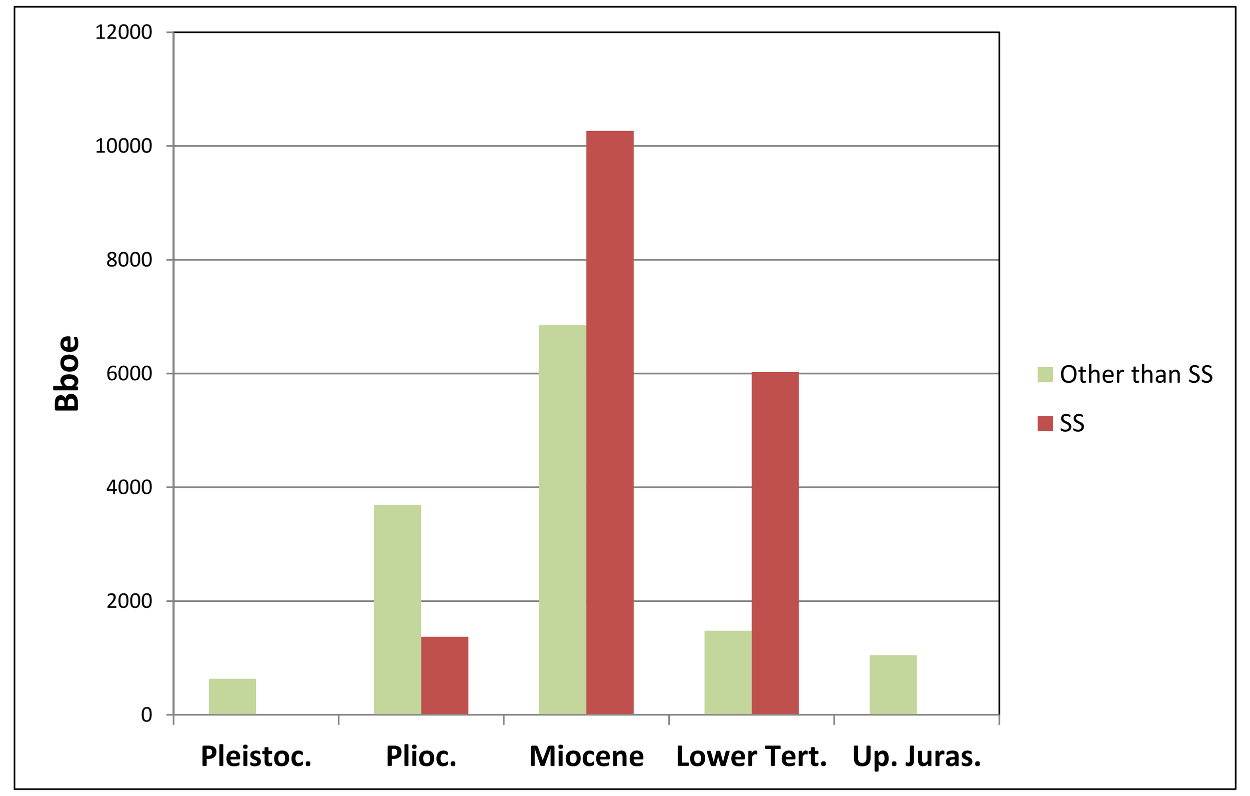

Figure 3. Distribution of reserves of subsalt plays (SS, brown bars) and other plays (green bars).

To that end, the analysis of the plot of hydrocarbon reserves vs the area of the fields, as seen in in Figure 4, is an accepted step in the procedure to grasp essential features of undiscovered resources in a basin (Harbaugh et al, 1996). Approximately one-quarter of all the discoveries are subsalt (SS, brown asterisks in Fig. 4). The average curve for these points (the brown line, Power (SS), what is the Power Law Fit curve for subsalt discoveries) and the respective 90% confidence band are also displayed. The confidence band is contained between the NU and NL curves , that are the upper and lower limits of the band.

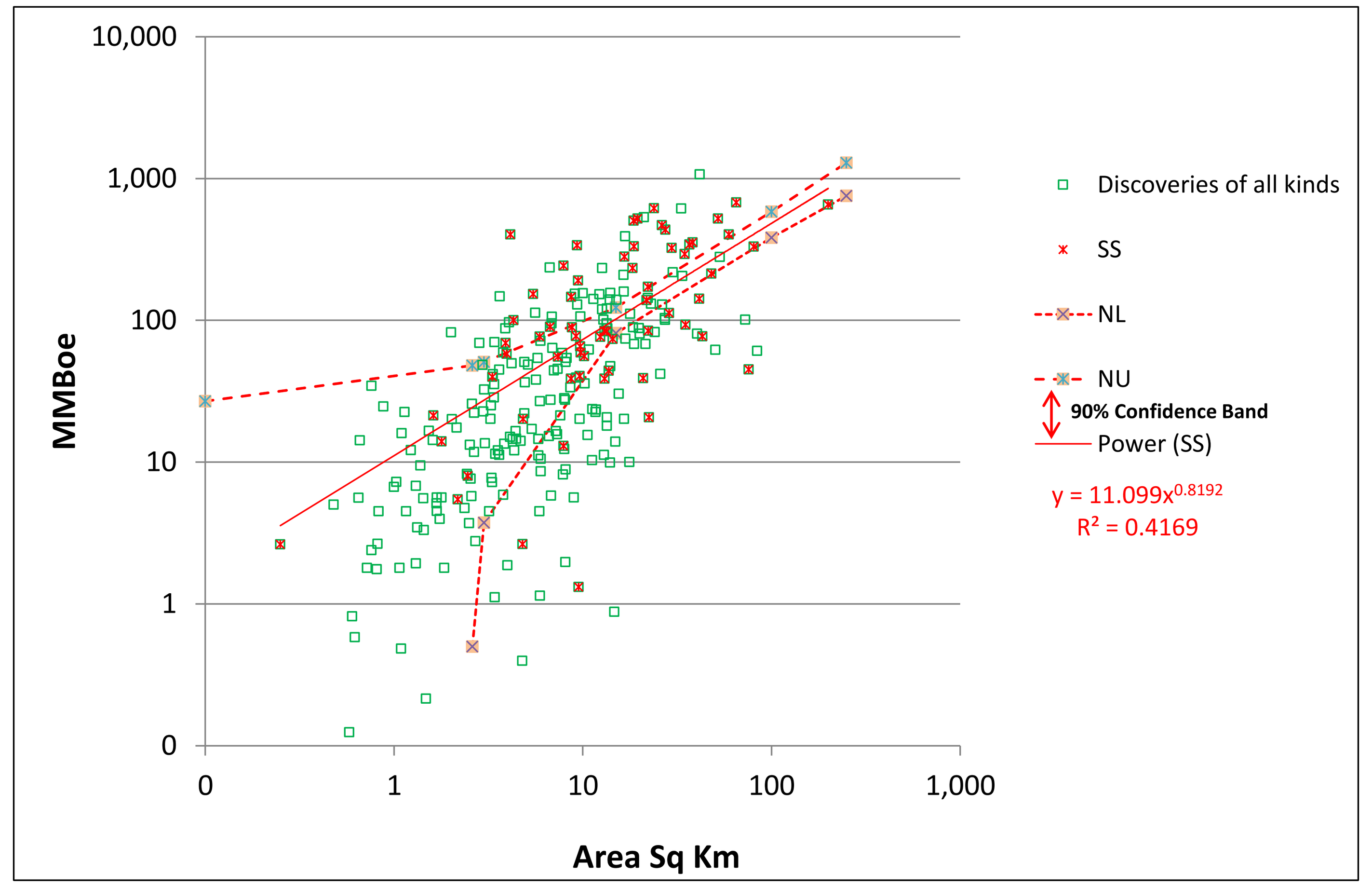

Figure 4. Plot of area versus reserves of fields (SS, subsalt in brown points, other in green squares). Boundary of the confidence band in segmented brown lines, the power law average line is the continuous brown lines.

The histogram in Figure 5 shows that the reserves by field tend to cluster toward large to very large size fields, a hint already suggested in Figure 4.

Furthermore, the inspection of the cumulative frequency curve of the volume of reserves by fields in subsalt plays in the US side of the basin (Fig. 6), shows that there is 90% probability for these fields to not be greater than giant ones (680 MMboe). In agreement with the data shown in Fig. 5, their median (P50) value of 330 MMboe is in the range of very large fields.

This size is between two and a half and three times the dimension of the largest above salt discovery in the Mexican side of the basin. Even the first quartile (P25) of the distribution of subsalt fields is almost one and a half times bigger than the largest above salt field discovered at the Mexican side.

Coming back to Figure 4, the subsalt field sizes in MMBoe are correlated with their areas in sq km with a power law curve (Power SS). However, the dispersion of points gives a low correlation coefficient for the power law curve that fits their distribution. Furthermore, a significant amount of points plot beyond the confidence bands (95%) around the fitting curve.

How can we use such disperse data to gain further insight into likely expectations of the dimensions of the fields in the basin, particularly the subsalt ones?

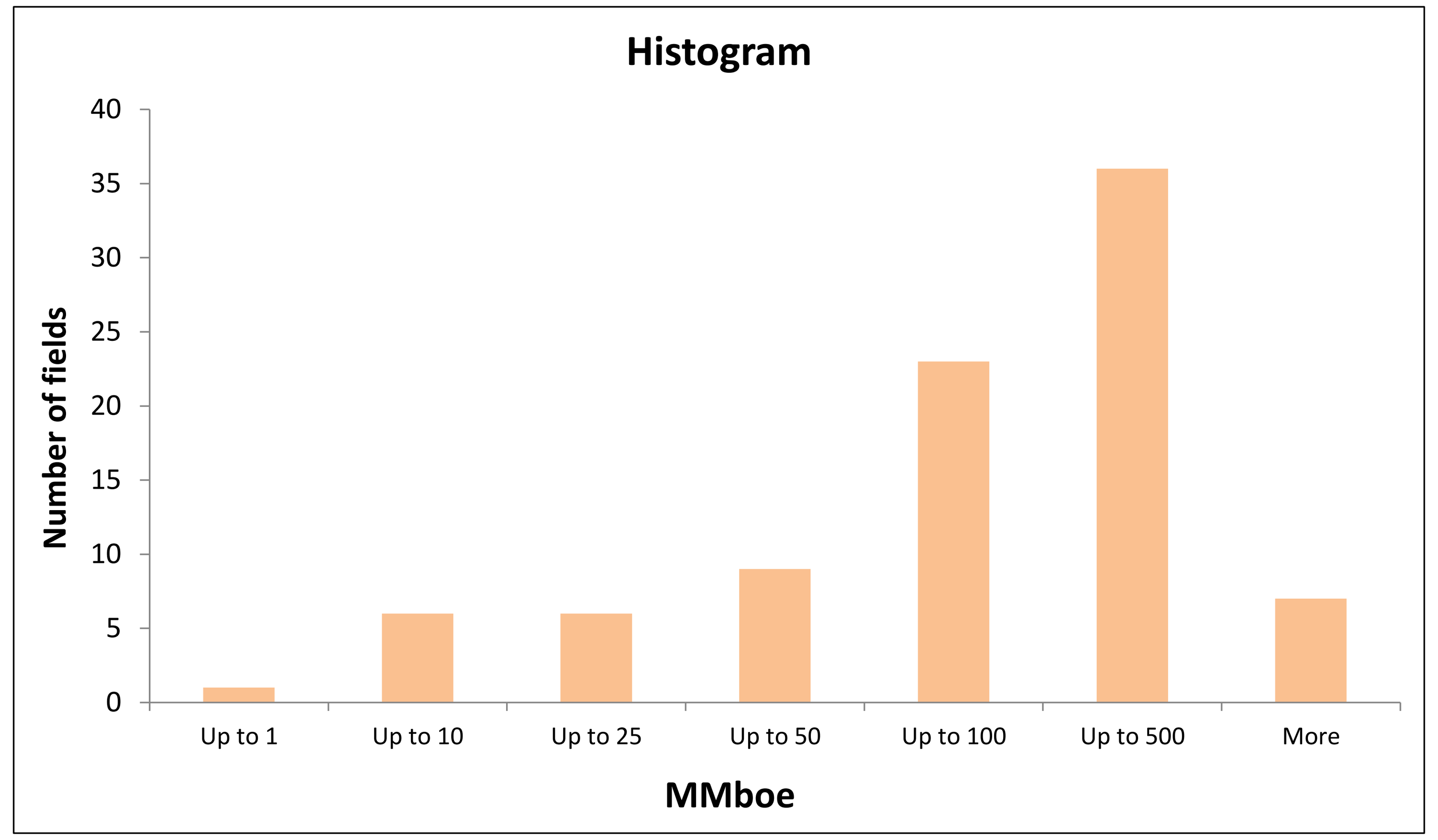

Figure 5. Histogram of the distribution of reserves for subsalt fields

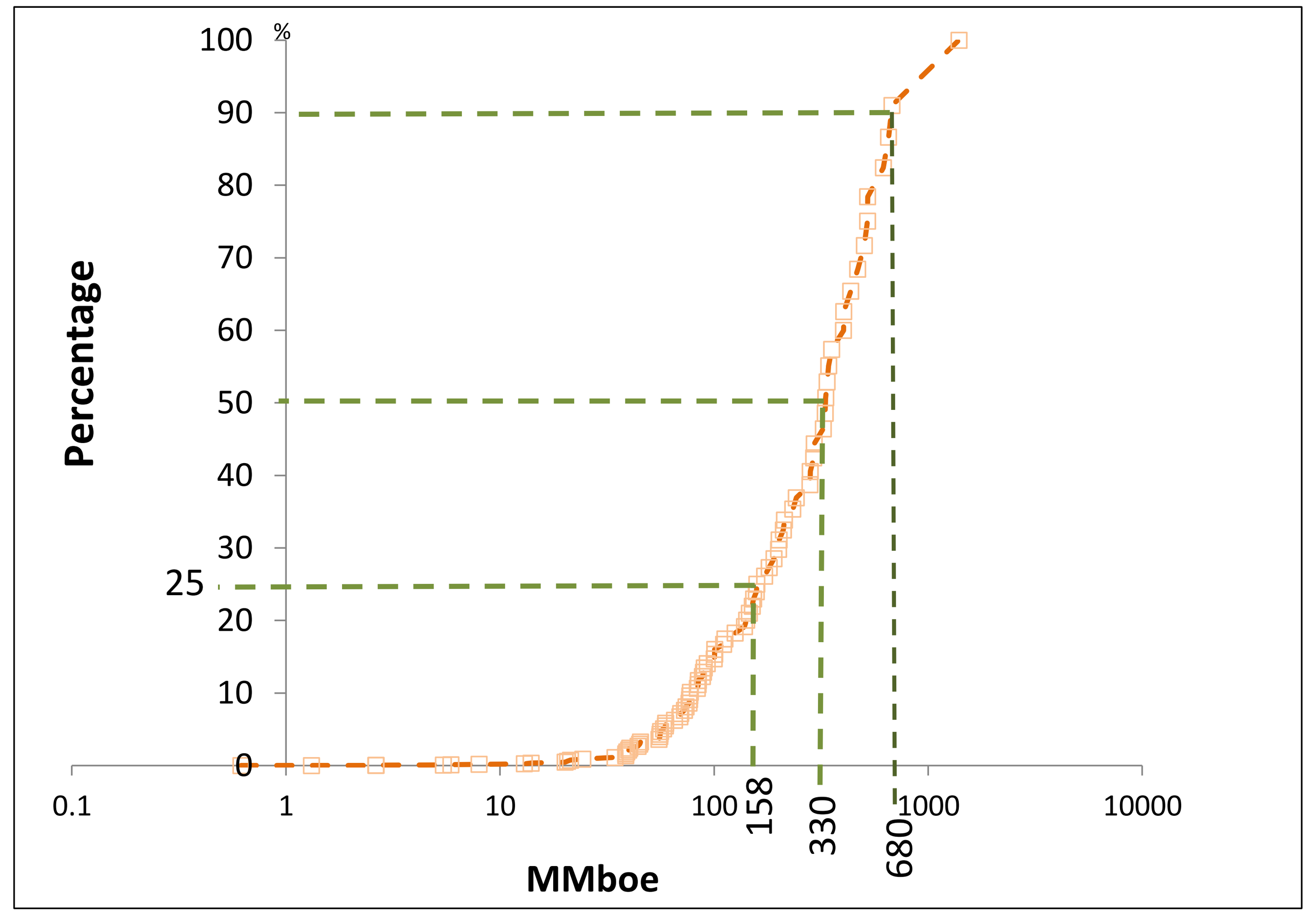

Figure 6. Cumulative plot of the distribution of reserves for subsalt fields.

To that end, let's review a plot of the reserves by area of both fields with subsalt reservoirs and Mexican fields with above salt reservoirs (Fig. 7, in brown squares and blue circles, respectively).

The specific information of fields having subsalt reserves defines an average curve (brown segmented line in Fig. 7) that is above the average curve for all the fields of areas up to 150 sq km (blue continuous line in Fig. 7).

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This means that the expectation of reserves for subsalt fields calculated with this latter curve will give estimations lower than the specific average curve for fields with reserves from subsalt plays. It is also of interest to note that if the average curve for above salt fields is also plotted (green segmented line in Fig. 7), it happens to be close but below the average curve for all fields in the basin (the blue continuous line in Fig. 7). The inclusion of data from above salt discoveries in the Mexican side of the basin (Pemex, 2012, 2013, 2014, 2015) shows that their points (blue circles in Fig. 7) are more fairly distributed on both sides of the average curves for all (blue continuous line) and above salt fields (green line) than at the sides of the average curve for subsalt fields.

As previously noticed in Figure 4 but now using a vertical scale in Bboe (Fig. 7) rather than in MMboe, fields having subsalt reservoirs seem to cluster along an average curve such that an increase in area relates to an increase in reserves.

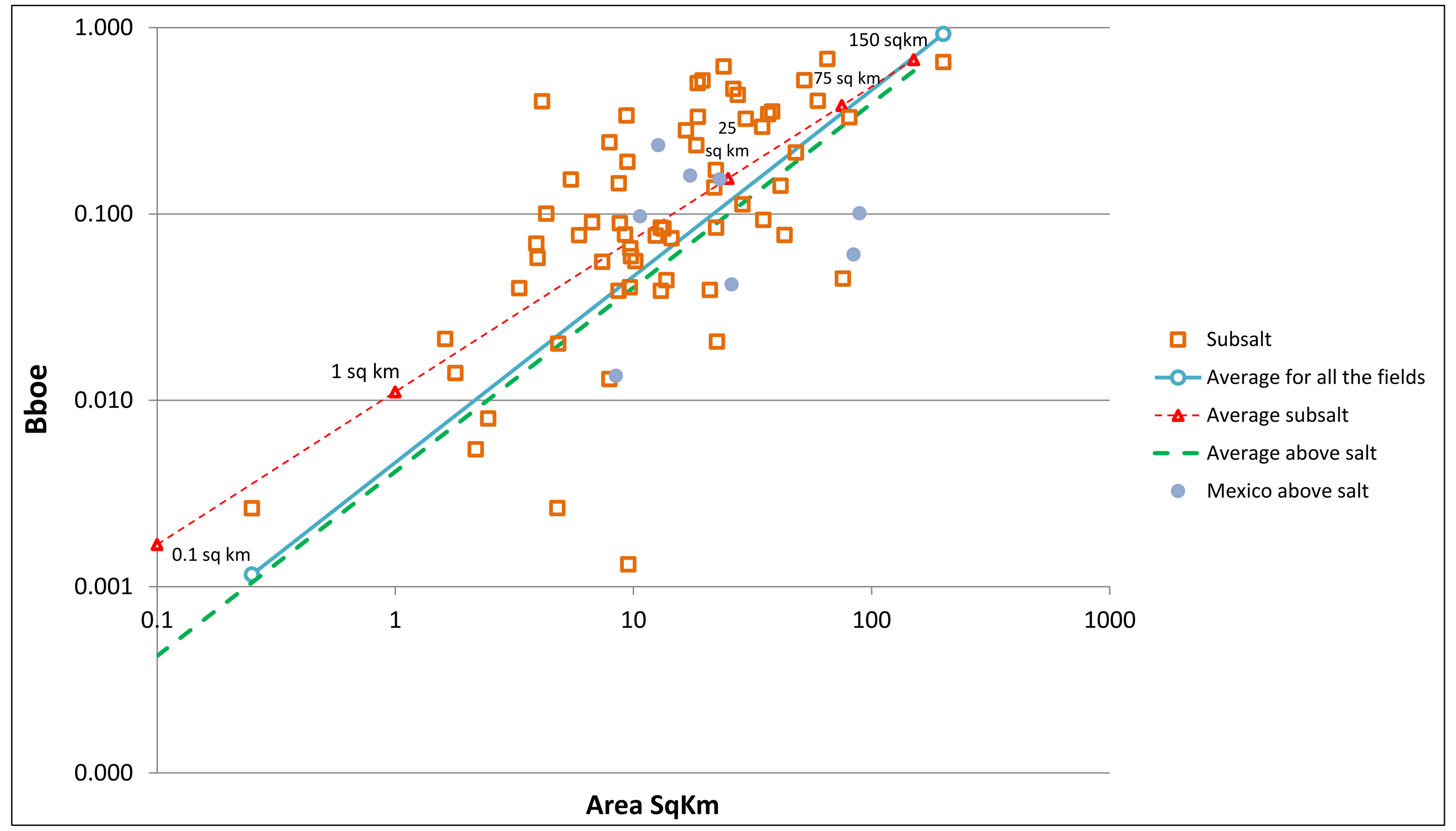

Figure 7. Plot of the average curve for fields with subsalt, other than subsalt and all kinds of reservoirs (red, blue continuous and blue discontinuous lines, respectively).

Given that the power law regression, however low in its correlation coefficient, produces a curve that divides the fields with subsalt reservoirs into those above and those below it, that dichotomy suggests we can use a logistic function to gain insight. A binary coding "1" or "0" for those fields with reserves above or below the average for the given area, respectively, will help to realize patterns in agreement with the combination of the results of Figures 4, 5, and 7. At first glance, it looks like those fields with bigger areas tend to hold bigger reserves, and also the frequency of cases with reserves above average for a given area also appears to increase. Then, a tentative initial sorting by the area of the fields seems one alternative.

One trend that could be elucidated is that if with the increase of field sizes there is also a greater frequency of fields with an above average size for a given area.

The following equations stand for the calculations of the logistic regression (L(X)):

$$L(X) = bo + b1\ X \qquad (1)$$
$$P(X) = e^{L}/(1 + e^{L}) \qquad (2)$$
$$Odds(X) = P(X)/(1-P(X)) \qquad (3)$$

Where:

X is the area of the fields (sq km), while bo and b1 are the decision variables. They are adjusted by the application Solver of Excel during the optimization process that finds the best combination of those two variables that allows the Eq. (2) to accurately predict whether the size of the field will be above or below (codes 1 and 0, respectively) the average curve for a given area (Harmon, 2012).

To speed up the resolution by Excel, the default value of the decision variables is arbitrarily set to 0.1 before the running of the application. The connection between the decision variables and the predictive (Eq. (2)) and the Odds (Eq. (3)) equations comes from the definition of the Logit function (Eq. (1)) that provides the entries for both of them.

As an example to proceed with a generalization, in our study there are 43 subsalt fields with areas between two and four sq km. Of them, 16 have reserves above the average value of reserves for fields of the same area. The other 27 fields have reserves below the average value of reserves for fields of the same area. Hence, the probability that the size of a field with an area between two and four sq km to be above the average would be 0.37. In parallel, a tentative value of the probability as indicated by Eq. (2) for the same area interval is found using tentative arbitrary values for "bo" and "b1" in Eq. (1). Having made the same calculations for the other intervals of areas, the definitive coefficients "bo" and "b1" in Eq. (1) are calculated with the application Solver of Excel as the result of an iterative loop. The iterative loop finds "bo" and "b1" by trials leading to the ending values that maximize the sum of a log-likelihood statistics (Zaiontz, 2013) constructed with the areas and associated probabilities of the presence of fields with sizes above the average.

So, the approach of the model using the logistic function is to address the general likelihood that a field of certain area will be larger than the corresponding average field size. The procedure followed in this case leads one to estimate the logistic regression (L) as a function of only one independent variable (the area).

The procedure is adapted to work with frequencies of the count of fields' sizes above the average by intervals of areas or classes. This generates an output of the logistic regression for each class, where the class is represented by the end member of the class (Zaiontz, 2013). For a more rigorous treatment there is also the option to find the central value of the distribution areas by each class, and then select it as the representative of the class. To find the classes or figures representing intervals of areas (bins) could be, for instance, based on arranging the data in increasing value of the area. Then, the end member of the class could be a field size significantly different than the bin size of the previous class. For instance, all the fields smaller than 2 sq km have less than 80 MMboe. Those between 2 and 4 sq km have less than 400 MMboe, and so on and so forth for the subsequent cases. Other more elaborate alternatives could be used, like intervals defined by the breaks of slope in the plot of the cumulative curve of normalized reserves by field (in MMboe). The result of the logistic regression is summarized in the Eq. (4).

$$L(X) = -0.5830 + 0.0025\ X \qquad (4)$$

The logistic regression (L) can also work as a function of two independent variables (Harmon, 2012). This allows including the data of field size as an additional independent variable, and the area the other independent. This permits the estimation of the likelihood of specific field sizes that are some percentage greater than the average value corresponding to a field of a given a specific area. The presentation of this method is intended to be offered in a later paper.

IV. DISCUSSION

Although not confined to subsalt objectives, the revision of the risked probability distribution in Figure 2 shows a spike which corresponds to the probability of a dry hole that is almost 20% above an even break of 50% . This probability of a dry hole is too high respect to the usually accepted result of a fair (50-50) random chance of success. This provides a valuable warning that will help one to make decisions regarding investment opportunities on the Mexican side of the basin.

The results presented in Figure 3 point out that Miocene Plays, followed by Lower Tertiary plays, are the main candidates for discovery in subsalt reservoirs on the Mexican side of the basin. Although the prominence of the hydrocarbon accumulations in Miocene over other subsalt plays is a long-standing trend since the early stages of exploration in this basin (Montgomery and Moore, 1997), it seems that Lower Tertiary plays will be the main plays to be found on the Mexican side of the basin. This conjecture is based on the trend of the spatial distribution of the Lower Tertiary plays; they have been consistently shown to be present in locations closer to the Mexican border of the basin than the Miocene Plays (Xu et al., 2017). The Miocene plays are predominant in the central and eastern sides of the basin, away from the Mexican border.

The overall basinwide distribution of the size of the subsalt fields, as shown in Figure 4, suggest that subsalt plays could provide a significant proportion of undiscovered resources in the category of large to very large size fields in the Mexican side of the basin.

This assumption is also supported by the average curve for fields with subsalt reservoirs with respect to the average curve for all the fields, and the average curve for other fields with reservoirs other than subsalt (Fig. 7).

The results provided by the analysis based on logistic function add a great deal of information to the outputs based on the area versus field size plot. First, we overcome of the drawback of a low coefficient of correlation for the best-fit curve of the data, since what are important in logistic regression are the counts above and below the curve of reference.

Let's say, for instance, that geological and geophysical analysis indicates a prospect in a subsalt structure has a closure having an estimated area of 50 sq km for the hydrocarbon accumulation. The average value of reserves for a field of such area is large (274 MMboe). The 90% confidence band around the average curve for subsalt fields (Fig. 3) gives a broad expected range between 265 to 282 MMboe.

On the other hand, let's consider the results of the method of logistic regression. Using the Logit equation (Eq. (1)) to calculate P(X) to predict whether the field size will be above or below the average; it is found that there is a 61% chance that, provided a successful discovery, reserves will be greater than the aforementioned average. Also, as P(X) is greater than 50%, the odds in favor of such occurrence are relatively strong. This can be realized from Eq. (3), as Odds(X) = 1.6 ≈ 2, which is approximately a 2 to 1 odds in favor. In this instance, the results of the logistic modeling give more certainty to the likely expectations, supporting an outcome biased toward the upper side of the confidence band above the average curve. This can be also compared with the estimation of reserves given by the geological analysis in connection with the features of the prospect.

V. SUMMARY AND CONCLUSSIONS

A Lower Tertiary subsalt play seems to be the main candidate for the discovery of subsalt reserves on the Mexican side of the basin. The undiscovered resources could be in the category of large to very large size fields with a significant proportion of the fields on the Mexican side of the basin.

However, this promising appraisal is tempered by the analysis of risked probabilities, which shows that the overall odds against a commercial discovery are 7 to 3. In other words, the probability of success is 30%.

Unlike fields having above-salt reserves, the average curve for all the fields is not a good reference for the estimation of undiscovered reserves for fields in subsalt plays on the Mexican side of the deep-water Gulf of Mexico Basin. Better and more reliable results are obtained using the specific average curve for fields in subsalt plays. This curve obeys and depicts the relative advantage of subsalt discoveries (in fields of areas smaller than 150 sq. km.), with respect to other hydrocarbon accumulations in the basin, and hence shows a fair separation above the average curve for fields with plays other than subsalt.

Estimation of expected reserves based on the average curve for fields (with the presence of subsalt plays in our case) accompanied with the traditional 90% confidence band can be further enhanced by appraisal using logistic regression, which indicates the probability to be either in the upper or in the lower side of the confidence band.

ACKNOWLEDGEMENTS

The author thanks IHS Markit for giving permission to present data from its Database.

Special thanks to Vlad Andrus, Tianguang Xu and Didier Arbouille to for the hints to orientate the research and the assistance in keeping high quality standards in the making of this article.

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