Remaining Hydrocarbon Potential in the Subandean Basins: A Regional Perspective

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ABSTRACT

Over 40 BBOE were discovered in the Subandean Basins of western South America. However few large discoveries have been made during the last five years, thus rising concerns about the future prospectivity of the area. This study analyzes the remaining potential of Subandean Basins based on the fractal analysis of discovered fields as well and on the geographical distribution of the accumulations. Thus, the reserves of Subandean Basins were combined in latitudinal segments from Tierra del Fuego to Lake Maracaibo with the assumption that given a common petroleum system, segments of reserves should have an even distribution. Deviations from this pattern could indicate negative aspects of maturity, absence of source rock, lack of structures (or timing), or that hydrocarbons remain to be found or have migrated to other areas.

The remaining potential of the basins based on latitudinal distribution is compared against fractal analysis giving both approaches similar results. A total of 43.5 BBOE of remaining resources are identified for the Subandean Basins, with the Madre de Dios, Llanos-Barinas, and Chaco expected to be the most prolific. A second tier of basins are the Neuquen, Marañon and Oriente, all of which may still contain important reserves. Several areas with irregularities in the distribution of hydrocarbons are identified. Future discoveries are expected to be in technically challenging areas, particularly in the foothill areas or in more elusive stratigraphic traps on the flanks of basins. However as exploration is extended into more sensitive areas, important socio-political and ecological challenges remain in order to unravel the potential of these basins

INTRODUCTION

Exploration in the Subandean Basins of Latin America (Fig. 1) resulted in the impressive discovery of over 40 BBOE during the last 30 years. However since the year 2000 only 2.8 BBOE of reserves were added, of which more than half belong to the Chaco Basin in Bolivia. This fact may raise a question about the future prospectivity of these basins. Thus, this work attempts to make predictions about the remaining potential of the area based on the patterns of latitudinal distribution of discovered reserves as well as on fractal analysis on the basis of commercially available IHS data.

***Figure 1**. Location of Subandean Basins*

SUCCESFUL STRATEGIES DURING THE LAST 30 YEARS OF EXPLORATION

Overall the greatest numbers of reserves added during the last 30 years in the Subandean Basins were discovered in the foothills areas (Macellari, 2001). These discoveries to a large extent were the result of better seismic imaging and techniques to properly position reflectors, better structural models, and also technical advances in drilling. Examples of these discoveries are the El Furrial trend in Venezuela, the Cusiana-Cupiagua fields in Colombia, Camisea in Peru, and the San Alberto, Margarita and related fields in the Chaco Basin. The second largest volume of discoveries were made in the extensions of existing plays into new areas. Examples are the La Victoria, Guafita fields in Venezuela extending from Caño Limon in Colombia, and the Libertador, Guanta and Ishpingo fields in Ecuador extending the play from the earlier discoveries in the Putumayo basin of Colombia. The third source of discoveries is related to new play concepts. Examples of these are the San Francisco and Guando fields in Colombia, the Boomerang Trend in Bolivia, Loma de La Lata and Estancia Vieja in Argentina among many others. Finally exploration in new areas accounts for important discoveries, such as Caño Limon in Colombia, and the offshore discoveries of Tierra del Fuego such as Carina and Ara.

Volumetrically however, a very large number of reserves were added by "re-exploration" and development of existing fields. In fact, when comparing an IHS data set from 1990 with another from 2005, the sum of fields discovered before 1989 experienced an increase in reserves of over 50 BBOE. Even if we consider some possible inaccuracies in the numbers utilized in the data base, this increase in reserves is greater than the reserves found by exploration during the last 30 years! Re-exploration and maximization of the recovery factors of existing fields has played a key role in realizing the full potential of these basins.

The main lessons learned during this period is the importance of foothills exploration, the development of new play concepts and the unbiased utilization of the information, including the in many instances forgotten field geology. Many new discoveries during this time had been made by challenging preexisting paradigms. When looking in retrospective many fields were found in fairly obvious areas (i.e. San Francisco Field) but were not investigated before due to preconceived ideas. Persistence has been a key ingredient in the successful discovery of important fields (i.e. Colombian foothills) and finally, the role of exploring near exiting fields can not be overemphasized as a key ingredient for success.

PREDICTING THE FUTURE, METHODOLOGY

It is almost a rule that any prediction about the future of oil discoveries is destined to failure. However considering the mature level of exploration achieved in the area, we may have accumulated enough statistical data in order to be able to make a meaningful guess about the future potential of these basins.

There are several methods to predict the remaining reserves of a basin, including creaming curves and fractal analysis. The problem with creaming curves is that they do not account for new play concepts, which are a very important driver in the discoveries of new reserves. Fractal analysis is based on the assumption that the largest fields are discovered early and the smaller fields are discovered later in the process of exploration (Fig. 2). Over time, the average field size declines since the parent population is being sampled without replacement. Ultimately, if and when all fields are discovered, they tend to form a fractal distribution, which is represented as a straight line on a log-log plot of field size (x-axis) versus field number (y-axis), when the data is sorted from largest to smallest field. The slope of this straight line is called the fractal dimension, and usually has a negative 45 degree slope, or-1.0 (i.e. Kauffman et al., 1975 among others).

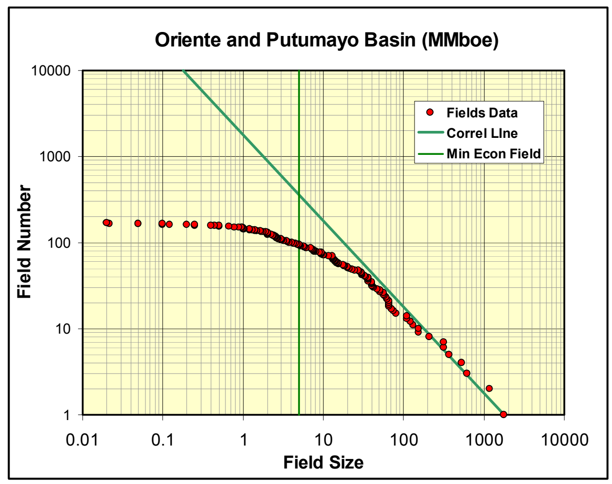

Figure 2. *Example of a fractal analysis, Oriente and Putumayo Basin.*

A third approach is the geographic analysis of the distribution of oil accumulations with a common petroleum system (Macellari, 1992). Because western South American basins are arranged in a north/south trend, field data can be clustered in latitudinal segments without much longitudinal variation. IHS data for all fields from western Venezuela to Tierra del Fuego were compiled and grouped at latitudinal intervals (Figs. 3, 8, 9).

The assumption is that given a common petroleum system, segments of reserves should have an even distribution. Deviations from this pattern could indicate negative aspects of maturity, absence of source rock, lack of structures (or timing), or more interestingly, that hydrocarbons remain to be found or have migrated to other areas. Thus this method can be used as a first pass predictive tool to identify prospective areas that may have been overlooked. The fractal and latitudinal analysis were combined to "predict" the reserves to be found in each basin, and in some cases to identify areas that merit additional attention.

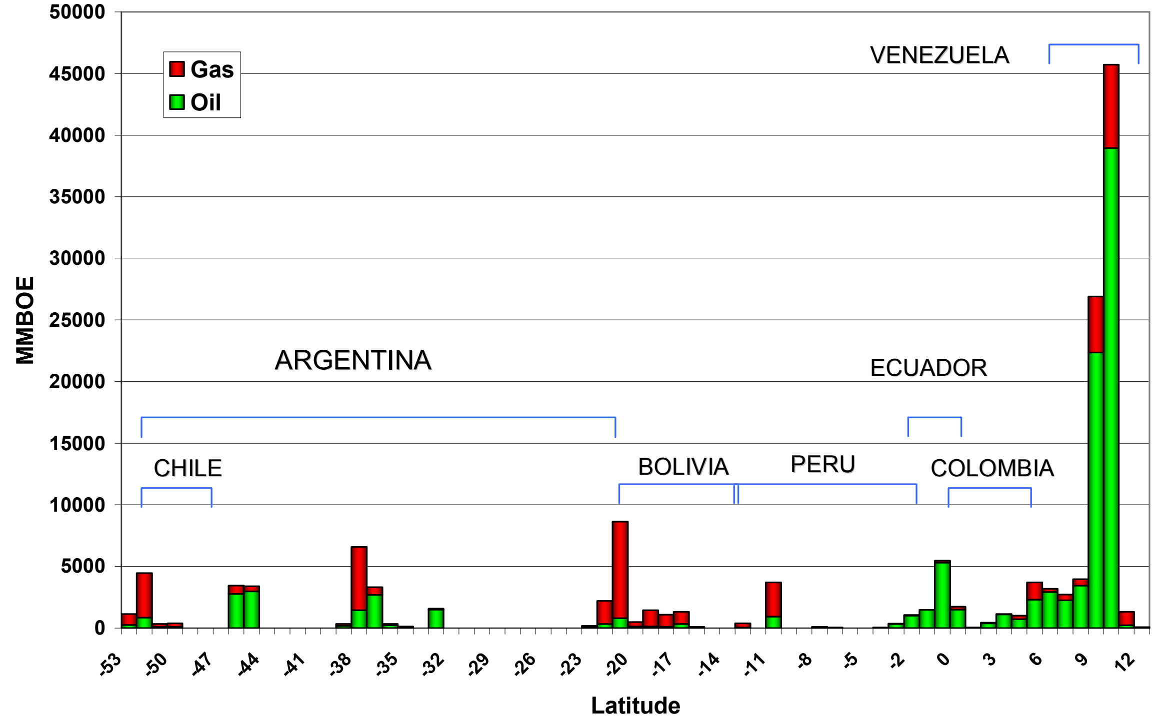

Figure 3. *Latitudinal distribution of hydrocarbon discoveries in Western South America. Data from IHS.*

A comparison between the results of fractal analysis and latitudinal distribution of hydrocarbons in the Subandean basins indicates that both methodologies yield very similar results considering the large uncertainties inherent to both approaches (Fig. 4).

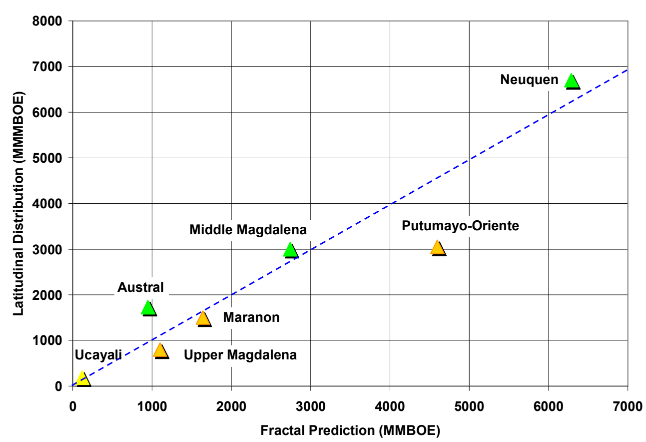

Figure 4. *Comparison of estimated remaining reserves (MMBOE) between the Latitudial distribution method and the Fractal analysis. A good correspondence between the two methods is observed.*

SOURCE ROCKS AND RICHNESS OF A BASIN

The main underlying factor controlling the ultimate recovery of a basin is the quality of its petroleum system. In general it can be observed that source rocks in the Subandean Basins display a roughly symmetric distribution with an increase in age from north to south up to the Chaco Basin, and a general decrease in age again to the south up to the Austral Basin (Aleman et al., 2003, Benavides, 1991, Brisson et al., 2003, DeCastelli, 1984, Illich, et al., 1981, Palmer and Russell, 1988, Talukdar et al., 1985, Valderrama and Cordoba, 1985, Zumberge, 1984 among many others) (Fig. 5).

A "richness" for each basin was calculated by dividing the total area of a basin by the number of discovered reserves plus the predicted remaining potential of the basin. The Marcaibo Basin stands outside the range of all the other basins by an order of magnitude (1.7 MMBOE per Km2) vs. a range of 0.19 to 0.002 MMBOE per Km2 for the rest of the Subandean Basins. A question that remains unanswered is the reason for the very large difference in reserves in the Maracaibo Basin with respect to the rest of the Subandean Basins. A possible explanation may be related to the upwelling characteristics controlling the deposition of La Luna source rock (i.e. equatorial upwelling in Venezuela vs. coastal upwelling in the rest of western South America) (Macellari and deVries, 1988) but this needs to be better understood.

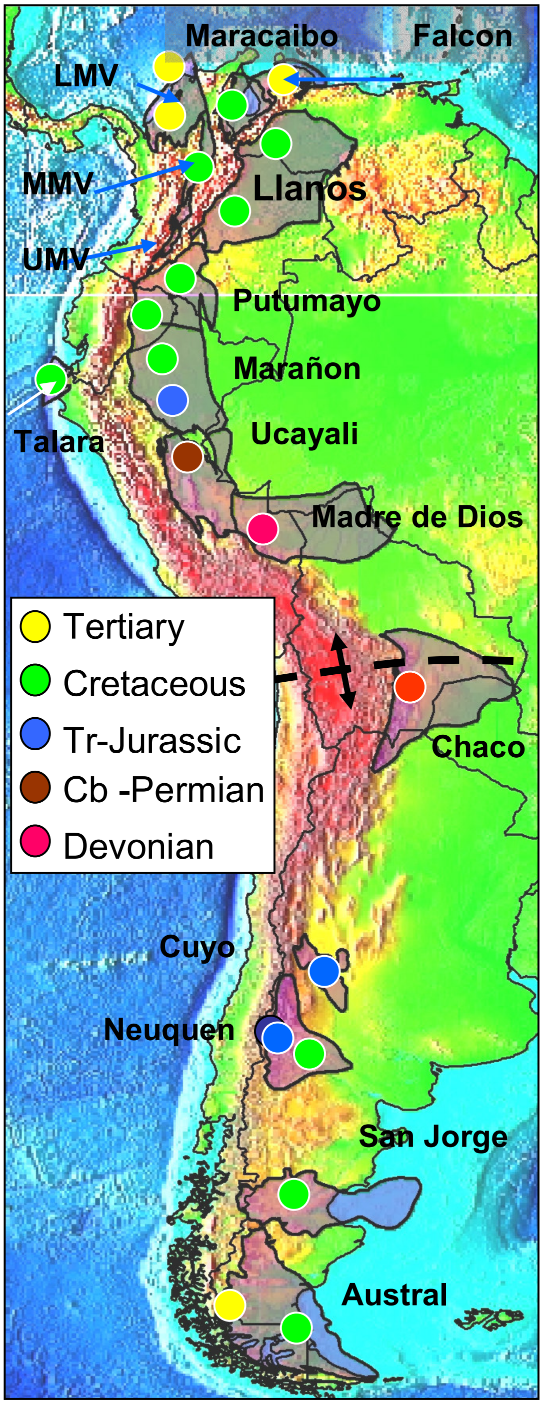

Figure 5. *Age of the main source rocks for the Subandean Basins.*

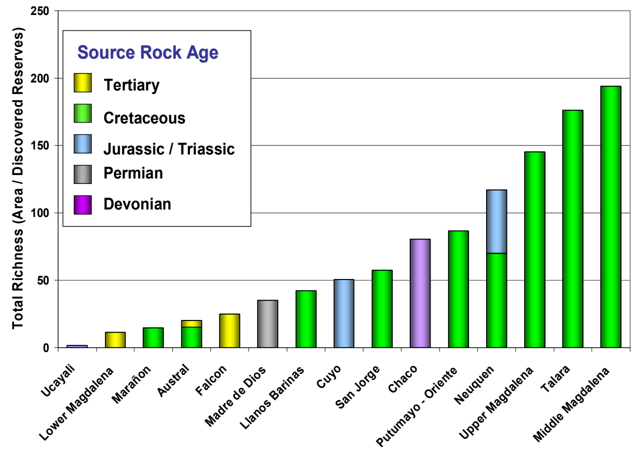

Figure 6. *Calculated "richness" of the Subandean Basins (in MMBOE per 1000 Km2). The Maracaibo Basin, with a "richness" of 1716 is excluded from the chart.*

REMAINING RESERVES

A total of 43.5 BBOE of remaining resources to be discovered are estimated for the Subandean Basins, excluding Maracaibo which has a potential for additional 33 BBOE. An estimation of the maturity of the basins can be made by computing the ratio between discovered and predicted hydrocarbon reserves. Basins were ranked according to different parameters including maturity and largest field size remaining to be found (Fig. 7). According to these parameters the most attractive basins are the Madre de Dios, Llanos-Barinas, and Chaco. A second tier of basins are the Neuquen, Marañon (and south Oriente), and Putumayo (and north Oriente). Exploration in these areas has the potential to yield material results with large field sizes.

It is proposed that irregularities in the latitudinal distribution of hydrocarbon discoveries could possibly indicate overlooked reserves. The Neuquen Basin of Argentina and the Llanos Basin of Colombia are discussed as examples. In the case of the Neuquen Basin, the largest number of reserves is found near the center of the basin. However there is a low north of 38 S (Fig. 8). This may indicate the presence of oil accumulations underneath a volcanic cover that has precluded the effective exploration of this part of the basin. The Llanos Basin of Colombia displays an erratic distribution of reserves (Fig. 9). This could indicate the presence of a yet undiscovered heavy oil belt along the eastern flank of the basin, or possibly the existence of yet undiscovered reserves in the foothill areas north of Cusiana.

The fractal analysis of the reserves indicates that the largest number of reserves to be found is in fields expected to be in the range of 10 to 50 MMBOE (Fig. 10). However it is estimated that large discoveries in the range of 500 MMBOE also remain along the trend. Thus the Subandean trend is expected to provide an adequate "diet" for the different appetites of the companies exploring in the area in the years to come.

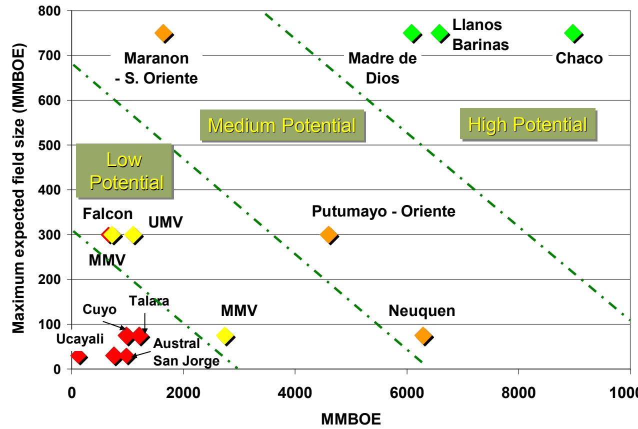

Figure 7. *Graph showing the relation between maximum expected field sizes estimated from fractal analysis vs. remaining hydrocarbons reserves in a basin.*

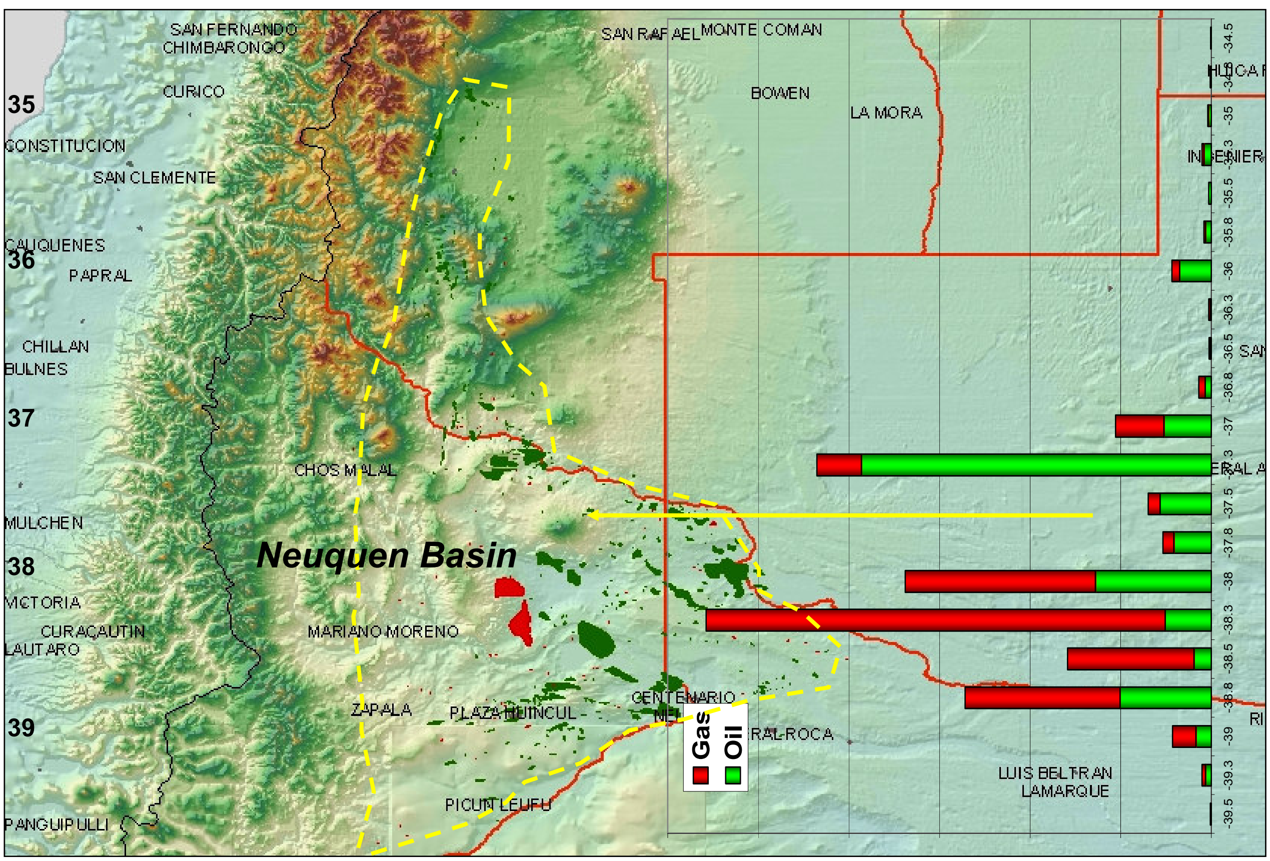

Figure 8*. Latitudinal distribution of reserves in the Neuquen Basin and location of main fields.*

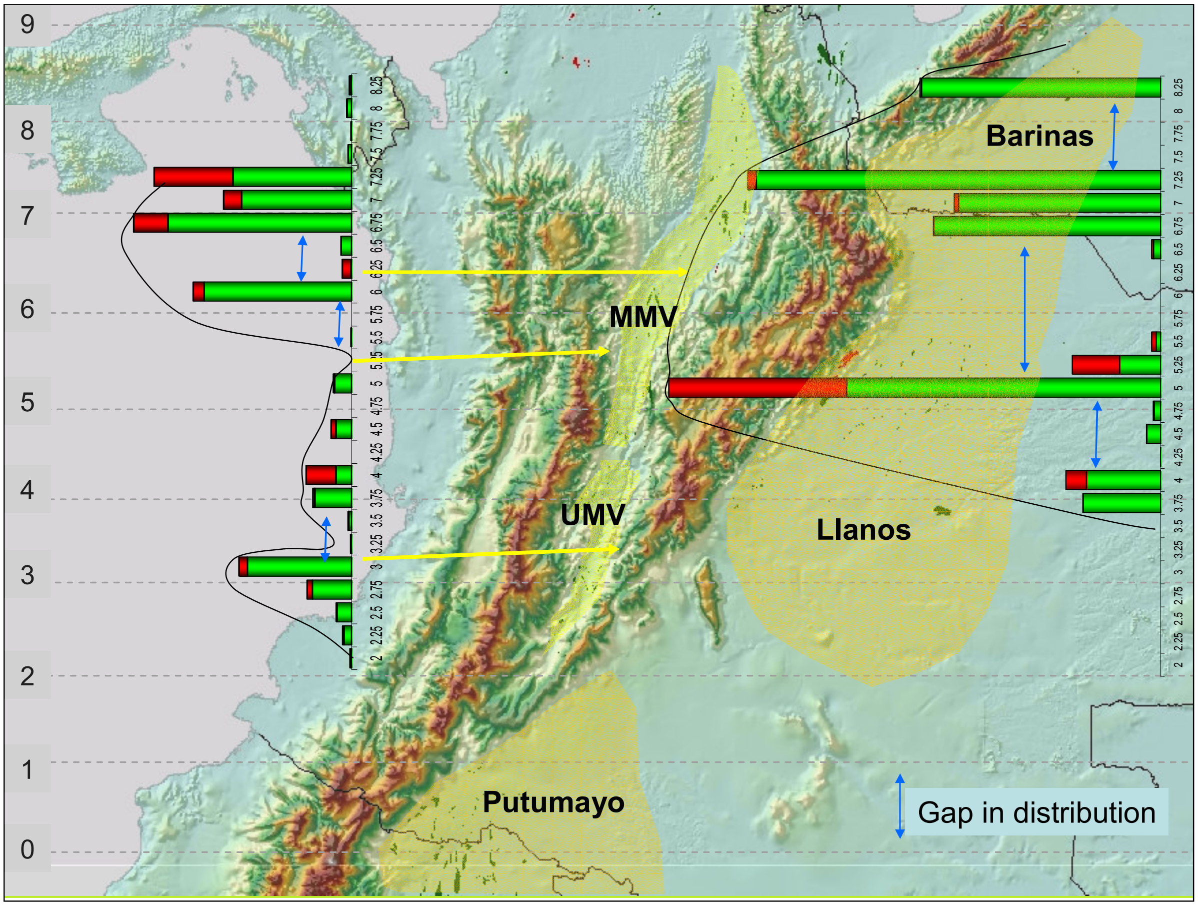

__Figure 9__. Latitudinal distribution of discovered reserves in the Upper and Middle Magdalena basins and in the Llanos and Barinas basins.

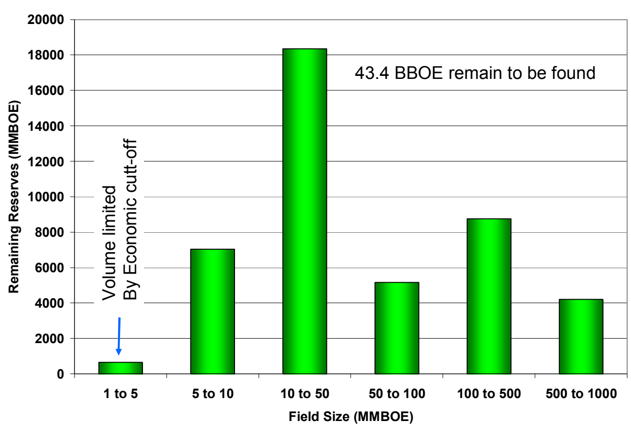

__Figure 10__. Graph showing the relation between Maximum expected field size estimated from fractal analysis vs. remaining hydrocarbons

LOOKING TO THE FUTURE

Despite relatively low exploration success rate during the last years, it is estimated that the Subandean Basins still contain very substantial reserves to be found. Many of these reserves are located in technological and or socio political challenging areas. As it was during the past few years, the foothill areas have the potential to yield additional large discoveries. Further advances in seismic acquisition and imaging are key factors to the success of these activities. Of particular interest is the Madre de Dios Basin that is still fairly immature as well as the Chaco and Colombian Piedemonte areas. As exploration continues to move into sensitive areas, many of the challenges will not only involve technical, but also socio-political and ecological aspects. Our technology will need to contemplate these elements. There are probably still large stratigraphic traps in the flanks of the Subandean Basins containing in many cases heavy oil. The main challenge here is the high-grading of these areas by some remote sensing technique that may allow the identification of areas for further 3D seismic analysis.

It is estimated that even though the main expected field sizes to be discovered are relatively small, with a peak at 10 to 50 MMBOE, the area still offers attractive to Majors and Large Independent companies to encounter fields within their “materiality” range.

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