EVALUACION GEOLOGICA Y GEOFÍSICA:
CUENCA MARAÑON
AN EXECUTIVE SUMMARY

by
PARSEP

Proyecto de Asistencia para La Reglamentación del Sector Energético del Perú

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INTRODUCTION

The Marañon Basin Technical Report was conducted approximately over a two-year span by PARSEP, “Proyecto de Asistencia para La Reglamentación del Sector Energético del Perú” which is a joint venture between the governments of Peru and Canada. The objective of this study was to reexamine the geological and geophysical data from within the archives of Perupetro and produce a final report on the future hydrocarbon potential of the Marañon Basin. Due to the immense quantity of data and limited time and resources, a decision was made early in the study to handle the well and seismic data in only a digital format so interpretation could be done using computer workstations.

Almost the first year of the project was spent on data collection, quality control and review. LAS files for all new field wildcats were gathered and when not available, well curves were digitized. Standardized composite well logs were made for all from this data set, which were utilized to create a cross-section grid tied to seismic across the Basin. Seismic SEGY data collection and quality control was considerably more problematic. As much of this study was seismic driven, it was difficult to make any forward progress in the project until a reasonable amount of seismic data was loaded on the workstation. Of the more than 50,000 km of data in the Marañon Basin it took at least one year to locate just over 12,000 km of data and get it loaded. Seismic SEGY data collection is an ongoing process and at the time of the this report, over 30,000 km of 2D seismic lines and nine 3D seismic surveys have been loaded for the Marañon Basin. Within the context of this report, however, as there were time constraints, a cutoff date of December 1, 2001 was set after which no new data was be utilized in the interpretation. By this date, 22,723 km (777 lines) from approximately 30 different seismic surveys had been loaded and constitutes the SEGY data set included in this report. It was proposed that any data acquired after that date be utilized in future studies when a much more detailed evaluation of Marañon Basin could be completed.

To supplement the work of PARSEP Group, four additional studies were conducted by outside consultants who are considered to be experts in their field. The four studies are all included as Appendices in this report, and were as follows,

1. Geochemical: by Hans Von Der Dick, ChemTerra International Ltd.
2. Tectonics: by Tony Tankard, Tankard Enterprises
4. Magnetic and Gravity: by Erwin Ebner, ELS Consulting
Marañón Basin Evaluation

Interpretation

The Marañón Basin is a large sub-Andean Basin extending north from the Ucayali Basin, through Peru into Ecuador and Colombia where it is known as the Oriente and Putumayo Basins respectively. The Basin’s evolution begins in the Late Permian to Early Triassic with a major extensional event that dissected the underlying Paleozoic platform and basement rocks into a series of roughly northwest-southeast grabens and half grabens. In the western extremes, deep rift basins were formed containing sequences of synrift continentally derived sediments that are overlain by a Triassic to Jurassic-aged marine to transitional (sabkha) unit dominated by carbonate deposition and evaporites. This in turn is overlain by regressive continental red beds of Jurassic age.

The eastern Marañón is very different with the remnants of the Late Permian to Early Triassic extensional event being persevered only as a series of half grabens that contain a preserved section of Paleozoic rocks within the lows with early Cretaceous peneplanation stripping off most if not all, of the intervening sediments. In the eastern Marañón the amount of preserved Paleozoic rocks beneath the Cretaceous decreases considerably from south to north to the point where the Cretaceous is seen overlying rocks of only basement affinity as the border with Ecuador is approached.

With this difference it is easy to divide the Basin into two distinct regions, the western and eastern Marañón Basin divided by a major hinge zone. This hinge zone is supported with both magnetic and gravity data. It represents the line of flexure separating the stable Marañón ‘platform’ in the east from the subsiding Basin to the west during the Basin’s thermal sag phase from Late Triassic to Jurassic (+Cretaceous?) time and the rapidly subsiding Marañón foredeep during Tertiary time.

The Marañón Basin started to take on its present-day configuration through a sequence of tectonic events that spans the Tertiary and culminated in the Miocene to near Recent with the highly deforming Quechua orogeny. The present day western margin was formed through a complex combination of wrench related high angle faults, basin inversions and thin-skinned deformation fronts that now separate the Marañón Basin from the Santiago Basin to its northwest and the Huallaga Basin to its southwest.

To standardize the Cretaceous stratigraphy of the Marañón Basin, nine regional cross-sections were constructed across the Basin and datum just above the Chonta Limestone, which is close to the maximum flooding surface during the Cretaceous. When possible, this data was tied to seismic. The data was exported to a database from which a series of maps were generated. These maps were found to support previous interpretations provided in literature on the Basin. When seismic data was integrated into the stratigraphic interpretation, however, several important issues surfaced that were not evident with just well data.

1. The significance of the Marañón Hingeline across which there are major changes in stratigraphy within the Cretaceous
2. The Hingeline fault system was intermittently active through geological time and affects more of the geological column than just the Cretaceous
3. A significant Upper Cretaceous to Early Tertiary WNW-ESE trending wrench related extensional event can be documented in the northwestern Marañón and Santiago Basins that greatly effect the stratigraphy of the Cretaceous section
4. The presence of a Chonta-aged patch reef, which nucleated on the Chonta Limestone. These features significantly affected later depositional patterns in the overlying Chonta and Vivian sections.

Geochemical studies in the Basin have recognized two significant petroleum source rocks that have generated the hydrocarbons found in the Cretaceous reservoirs of the Marañón Basin. These are, the Cretaceous Chonta/Raya Formations and the Triassic/Jurassic Pucará Group. A third less known source rock for the Marañón Basin is also present within the Devonian Cabanillas sequence. It, however, is confined exclusively to southeastern portion of the Basin. The Chonta and Pucará source rocks in the Basin and neighboring areas are sufficiently rich enough to have generated the commercial amounts of hydrocarbons presently found in the oil fields of the Marañón Basin in addition to a sizeable amount of as of yet, undiscovered reserves. A long-range migration from these source rock kitchen areas to reservoir is implied for the accumulations found to date.
Three major episodes of HC generation and migration can be documented in the Basin. The first event occurs during Carboniferous/early Permian time with the generation of hydrocarbons from the Devonian Cabanillas and Ordovician Contaya Formations. The survival of this early hydrocarbon generation phase due to tectonics and over-maturity is questionable, however. The second event occurred in late Jurassic time, which triggered Pucará hydrocarbon generation. The third hydrocarbon generation event occurred during Neogene time and affected the Mesozoic and partially the Tertiary sequences. It generated a second pulse of mature oil and gas from the Pucará where Pucará hydrocarbon generation had not terminated. Chonta HC generation and migration, however, is an ongoing process that has continued through to the present.

Exploration models in the Marañón Basin for last 20 years have been more or less driven by the same concepts. This is quite evident when one examines literature and reviews the NFW wells drilled in the Basin between 1990 and 2000. The critical criteria for defining Cretaceous exploration targets historically in the Marañón Basin, was the presence of paleo-structures. The logic behind this is sound in that the paleo-structures needed to be in place in the Early Tertiary, to catch the primary and principal pulse of Chonta generated oils. This is a philosophy that has dictated exploration in Marañón Basin for quite some time despite the numerous accumulations with,

- No paleo-structure
- Paleo-structures too small to account for the amount of presently trapped oil
- Present day structures with well developed paleo-structures that are dry or with insignificant oil columns.

With these inconsistencies there are clearly other mechanisms at work. Where oil has been found in younger structures, the explanation is one utilizing the remigration of oil from an older breached or tilted accumulation. This is widely accepted and in this report, one of the most critical aspect for future oil exploration in the Marañón Basin. The shortcomings of the paleo-structure hypothesis are that it misses two very important issues, large-scale paleo-stratigraphic traps and paleo-structures that are no longer closed. As long as traps of both these styles were in place and proximal to the later developing Andean Late Tertiary aged structures, the remigration from these paleo-accumulations into younger aged structures is far from difficult to imagine. Obviously, some of these paleo-traps would be coincidental with the younger structures and others not. The key to exploration in the Marañón Basin is in the definition of paleo-traps, not just structures, and in the remigration route of that hydrocarbon during the Quechua deformation.

The other shortcoming concerning past exploration activities in the Marañón Basin has been its focus on Cretaceous reservoirs. In this and a previous PARSEP study in Huallaga Basin and surrounding area, it became evident that carbonates of the Pucará Group represent viable exploration targets in western Marañón Basin. In the south half of the Marañón Basin for example, there are only four penetrations into the Pucará and all are located in the southwestern most corner of the Basin. Of these, three intersected the Pucará in a non-prospective supratidal to continental facies and the one well, Shunusi 1X, which intersected the Pucará in a prospective facies encountered gas bearing porous carbonates. Our current model has the Shanusi 1X well penetrating a high-energy intratidal carbonate along a paleo-high trend created by the late Permian to early Triassic rifting event. This is a potentially productive fairway that may be extrapolated to both the north and south of the well.

The remaining significant under-explored section in the Marañón Basin is that of the Paleozoic. Although studied little in this investigation, it is acknowledged that just to the east across the border in Brazil, a similar section is productive and that similar potential may exist in the Marañón Basin of Peru.

Exploration Concepts Marañón Basin

As mentioned previously, almost all exploration in the Marañón Basin in the past has been for Cretaceous reservoirs. Exploration success within the Cretaceous has progressively diminished in the last 30 years since the first discoveries by Petroperu and Oxy. In the context of this study, the Cretaceous has been studied with this in mind and the focus was to introduce new concepts (logic is perhaps a better term) on how to better, or differently, explore for these reservoirs.

Cretaceous

Where oil has been found in younger structures, the explanation is one utilizing the remigration of oil from an older breached accumulation. This is widely accepted and in the context of this report, one of the most critical aspect for future oil exploration in the Marañón Basin. The shortcomings of the paleo-
structure hypothesis as previously interpreted, are that it misses two very important issues, large-scale paleo-stratigraphic traps and paleo-structures that are no longer closed. As long as traps of both these styles were in place and proximal to the later developing Andean Late Tertiary aged structures, the remigration from these paleo-accumulations into younger aged structures is far from difficult to imagine. Obviously, some of these paleo-traps would be coincidental with the younger structures and others not. The key to exploration in the Marañon Basin is in the definition of paleo-traps, not just structures, and in the remigration route of that hydrocarbon during the Quechua deformation. Examples are given below.

**Paleo-Stratigraphic Traps**

In exploration, it's a well-accepted fact that stratigraphic traps are much harder to define than structural traps for obvious reasons. Looking for paleo-stratigraphic traps is even more difficult still. One thing that is presently known, however, is the importance of a stratigraphic trapping component to a number of Marañon producing fields.

With this in mind, it is not hard to imagine the presence of large-scale stratigraphic traps and perhaps their dominance over structural traps, in pre-Quechua time when the Basin was structurally much simpler. Despite the difficulty, there is still seismic evidence to suggest that conditions in the Cretaceous during pre-Quechua time would be conducive to the development of stratigraphic traps.

It is obviously difficult to ascertain, but one logical explanation for the concentration of oil fields along the Marañon Basin Hingeline is that several large scale stratigraphic accumulations were trapped against the Hingeline due to significant stratigraphic changes from one side to the other. With the hydrocarbon kitchen area being down dip to the west and the pinchout up dip to the east, conditions were ideal for such a development. Significant tectonic reorganization during Quechua deformation would have breached some of the paleo-stratigraphic traps while leaving others intact. Oil from breached accumulations would then have remigrated, probably just a short distance into the nearest structure be it Quechua or older in origin, or have been redistributed within the containing sand body reflecting its structurally modified trapping conditions.

To further emphasize the importance of the Hingeline and its effect on Cretaceous stratigraphy, one other interval needs to be discussed, the Chonta Limestone. The eastern limit of the Chonta Limestone out of the Basin defined both geologically and geophysically, coincides roughly with the Hingeline area and the Marañon productive trend.

Clearly when one examines the evidence, the Hingeline area is one of important stratigraphic changes within the Cretaceous section and one in which numerous stratigraphic traps may have existed. Any breaching of a paleo-stratigraphic accumulation in this area would result in the remigration of hydrocarbons into the nearest trapping geometry, which to some degree may account for the concentration of oil accumulations in this region.

Although the above discussion has focused on Chonta generated oils, the same logic can also be applied to Pucará generated oils in the more southern reaches of the Basin.

**Paleo-Structural Traps**

Unlike its counterpart in this section, paleo-stratigraphic traps, paleo-structural traps are much easier to identify. Of these, there are two types, 1) paleo-structures with a present day structural component which have been the focus of attention in the Marañon Basin for the last 20 years, and 2) subtle but a really large paleo-structures that no longer have closure.

In a Pozo to Base Cretaceous isopach (Figure 2) of this the area, there is no apparent significant, coincidental paleo-structure associated with these wells. It should be noted that Pastococha, does, however have a minor paleo-drape component, as it sits over a pre-Mitu, rifted horst block but it is beyond the resolution of the contour interval of the map. What is significant, however, is the sizable paleo-structure north of the Pastococha well, which is also very evident on the flattened (Pozo) seismic section shown in Figure 3, at Base Cretaceous and younger levels. Present day structure, a result of later Quechua deformation, over this location is non-existent as shown in Figure 4. Based on the above analysis, it is speculated that the paleo-structure defined north of the Pastococha well once reservoird a large accumulation. With Quechua downwarping, this oil then migrated up dip into other structures that were forming contemporaneously with this deformation. Structures such as Yanayacu and Samiria Sur were filled as a result of oil remigration from this ancestral accumulation.
This being the case, other proximal structures such as the ones defined in this study as the Nutria Prospect (figure 10) and Majaz (Figure 13) would have to be considered as being favorably located to receive a charge of remigrated oil in late Tertiary time.

**Figure 2:** Pozo to Base Cretaceous Isochron showing the presence of a large paleo-structure just north of the Pastococha well. The seismic line highlighted is shown in Figures 3 and 4

**Figure 3:** Seismic Line PHI-10 flattened on the Pozo showing the presence of a sizable paleo-structure that existed in the Pastococha/Samiria area in early Tertiary time

**Figure 4:** Present day time section of Seismic Line PHI-10 showing how the high as mapped in Figure 2, has disappeared.

**Conclusions**

From the examples discussed above, it becomes evident prospective structures do not necessarily have to have an ancestral component. By focusing on prospects with a young, Quechua-aged structural evolution that were in a favorable position to receive a charge of remigrating oil from breached paleo-stratigraphic and structural traps may open up new areas of exploration in the Marañon Basin.
Hydrodynamic Study
Through the hydrodynamic study sponsored by PARSEP, it was possible to identify areas where hydrodynamic tilting occurs. Tilts are expected to be very severe in the western Marañon Basin where high hydrologic heads can be mapped within the Cretaceous section, near the highly elevated recharge areas in the fold and thrust belt of the western Basin margin. The effect diminishes to the east and southeast across the Basin and the measured data fits closely with what is observed in the fields. Tilted oil/water contacts have only been found in the productive area of the northern Marañon Basin (Block 1AB Area) and not in the southern production area (Block 8 Area). Hydrodynamics are clearly an important component to understanding the dynamics of the petroleum systems operative in the Basin.

New Prospects and Leads
The Marañon Basin Study was intended to be a regional work, integrating as much data as possible within the Basin to investigate whether new exploration concepts, exploration fairways, etc., could be defined. It was not intended to be an exploration exercise where the ultimate goal is in defining drillable prospects. However, prospects and leads did emerge and identified as the a) Picuro Vivian Prospect (figures 5,6), b) Picuro Pucará Prospect (figures 7, 8), c) Nutria Prospect (Figures 10 to 12), and d) Majaz Prospect (Figures 13 to 14). The later two have multiple objectives within the Cretaceous section.

a) The Picuro Prospect is one developed along the western margin on the Marañon Basin (Figure 5) and was interpreted utilizing paper copies of the Amerada and Oceanic seismic data sets. Objectives are a large, 44 km² four-way dip closure in the Vivian (Figures 5 and 6) and a linear series of four-way dip closures within the Pucará Group (Figure 7).

The Vivian closure is located in the Marañon foredeep and is a broad, gentle structure with no associated faulting. From the hydrodynamic study done for PARSEP it is know from well control that to the north and south of this area that this is a strong easterly hydrologic flow within the Vivian due to the highly elevated recharge area to the west in the fold belt. Reservoir quality is a risk as burial depths are considerable in this area. However, in the Huasaga 1X well in the north-central Marañon Basin, the lower Vivian sandstone at 4087m was fresh water wet (salinity 11200 ppm NaCl) and when tested flowed formation water to the surface at an estimated 1340 bwpd. Clearly this well demonstrates two important factors in the deep Marañon, the connectivity of the Vivian to the western recharge area and hence it’s blanket nature, and the ability of this Vivian sandstone member to maintain excellent porosity and permeability at relatively deep depths of burial. Because of the high hydraulic head in this area, any accumulation is expected to have a strong easterly tilt.
above which there is no structural closure. Overlying and sealing any possible Pucará accumulation is the postulated regional sabhka evaporitic facies which is in conformable contact with the Pucará intratidal facies that represents the potential reservoir unit. Unlike siliciclastic reservoirs carbonates are not as susceptible to porosity occlusion due to burial diagenesis.

**Figure 7:** TWT Structure Map on top of the Pucará

Contour Interval = 50 ms

Closures from N to S (Colored Yellow)
- D = 2.8 km$^2$
- C = 34.3 km$^2$
- B = 8.8 km$^2$
- A = 5.0 km$^2$

**Figure 8:** Seismic Line AH73-1 (Figure 7) through the east verging fault trend that creates the series of closures at Pucará level, colored yellow in Figure 7
b) The Pastochocha/Samiria Area is located in the southern Marañon Basin (Figure 9) south of the Yanayucu Oil Field which is currently producing from the Vivian Formation, and to the west of the Bretaña Discovery, which tested 807 bopd of 18° API gravity oil, also from the Vivian Formation. A block with the configuration as shown in Figure 9 is being recommended to Perupetro to put out for tender.

The Nutria Prospect is the northernmost structural culmination along the Samiria Fault (Figure 10), northwest of the Samiria Sur 1X oil discovery made on the southern culmination. With the data at hand, it appears that the Samiria 1X well was drilled off structure on the NW-SE seismic line PHI-29 and the actual closure, the Nutria Prospect, PHI-13, remains untested.

Figure 9: Location of the recommended Block in the Pastochocha/Samiria area

Figure 10: TWT Structure Map on the Pozo. Note the structural elevation of the Nutria structure relative to the one tested by the Samiria Sur 1X well. Highlighted seismic line displayed in Figure 12
c) The Majaz Prospect located just to the northwest of the productive Yanayacu oil field, is a prospect that fell out while doing an analysis on the Diana Mae 1X well. For the PARSEP evaluation only the newer Great Western seismic lines were used due to the serious misties seen in the Prakla (PK) data set of which PK8-54 is an example (Figure 13). This critical line ties nothing and there is a belief that it may be reversed as well as poorly located in manner similar to several other PK lines we have encountered.

The problem with the Diana Mae location is two fold. The first is in the subtlety of the structure, which has a maximum of 8 ms of closure on the top of the Vivian along a well-defined southwest, plunging structural nose. The saddle defining the counter regional dip to close the Diana Mae structure is poorly defined and additional seismic may show this closure to be even less than currently mapped. There is no faulting associated with the Diana Mae structure (Figure 11 to 13).
Downdip from the Majaz Prospect the Cuinico S 1X Well Tested oil - 18.8° API from a Chonta Sandstone Interval

Figure 13: The maximum size of the structure when mapped on the top of the Vivian if closed at the 2655ms level as indicated above, is approximately 100 km²

Figure 14: West to east seismic line GW95-Q4 across the Majaz structure

Southwest Marañon Pucará Prospects

Shanusi 1X Offset

The mapping at Chonta level (PARSEP, 2002) indicates that the Shanusi 1X well tested the Cretaceous structural culmination of the feature drilled. With the original well having discovered gas, an offset to this well will probably generate little interest unless some method of marketing the gas in this region can be established. This discovery does, however indicate, that hydrocarbons are migrating through the system and that perhaps the gas represents a late generative phase from the Pucará source rocks. Basin modeling shows the Pucará in the very top of the main gas-generating window at this location.
Figure 15: Shanusi area time-structure map on top of Pucará. The Shanusi 1X well tested gas on a small satellite structure that opens up to a much larger feature to its SE.

Yurimaguas Structure

Approximately 25 km north of the Shanusi well is the huge Yurimaguas structure, which was drilled by Texaco in the 50’s. The well was TD’d in the Cushabatay after encountering all the Cretaceous reservoirs to be fresh water wet. The Pucará Group on this structure remains untested. As this structure appears to be on trend with the postulated Pucará reservoir fairway, it remains as an attractive prospect.

On a somewhat speculative note, one might hypothesis that oil once reservoired in the Shanusi structure was displaced further updip into the Yurimaguas structure by a late gas charge.

Figure 16: Subsea structural map on Top Vivian showing the relative structural relationship of the Yurimaguas well to that of the Shanusi 1X well. Highlighted area is potential reservoir fairway trend of the Pucará identified in the Shanusi well.
CONCLUSIONS

Exploration in the Marañón Basin has been focusing primarily on one type of trap for the last 20 years and consequently the well sampling has become somewhat biased in recent years not necessarily reflecting the true potential of the Basin. With the attention in the Basin on structures with ancestral growth, drilling targets have progressively gotten smaller as the most of the obvious targets within the production fairways have been drilled. To enhance this progressively dwindling supply of ‘drillable structures’, companies have moved to depth conversions to add closure to structures that have little to no closure in time introducing another variable into the risk. As a result exploration success along with size of the remaining structures has diminished as well. This velocity variable (issue) is obviously much less important in the more robust structures that were drilled early in the exploration of the Marañón Basin, which could survive a rigorous velocity analysis and conversion to depth. In other words, a 5 ms (or its depth equivalent) change one way or the other will not have much of an impact whether a well gets drilled or not.

It has long been accepted that there has been remigration of hydrocarbons in the Basin that was initiated by the Quechua deformation. Block 64 in the northeast Marañón and the fields of the southern Marañón Basin are such examples. It is naïve to believe that in the past, that only structures, and structures that remained intact after Quechua deformation are the only traps that could have harbored any significant hydrocarbon accumulation. We believe the importance of remigrated hydrocarbons their migration route during the Quechua deformation has greatly been underestimated and significant reserves remain to be found proximal to areas where large stratigraphic accumulations once resided. The same holds true for closed broad gentle structural features that lost closure due to the effects of the Quechua deformation.

Exploration in the Marañón Basin must in the future consider the above as well as new reservoirs in the Chonta Limestone (patch reefs), Pucará and the Paleozoic sections, which this study has attempted to emphasis the importance of. The effects of hydrodynamics are also a component in understanding the hydrocarbon potential of the Basin as indicated through the study sponsored by PARSEP. Finally, an issue as mundane as data verification/qualification may also lead to prospects in a Basin where the seismic data can be fraught with navigational errors. Whether the prospects defined by this study by questioning the data, will hold up under further scrutiny, remains to be seen. It is a starting point, however, for future evaluations.

Upon the completion of this report, it was only to obvious to all involved that to fully understand the idiosyncrasies of the Basin, a detailed examination must be conducted utilizing all available seismic, 2D and 3D, and development wells, but only after an effort to clean up the navigational problems of the seismic data is completed. As the results of this study, PARSEP is leaving a tied data set comprising of almost 23,000 km of 2D seismic lines, over 100 composite LAS files of all exploratory wells, and an Access Database upon which future studies can expand.

SELECTED REFERENCES

NOTE: As an attachment to this report is an Excel spreadsheet of the data pertinent to this study area in the PERUPETRO archives which is included on the CD accompanying this report as Appendix 11 “Perupetro Marañón Basin Archived Files”

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