IN SEARCH OF BYPASSED GAS PAYS
IN THE MACUSPANA BASIN WELLS

Leonardo Aguilera Gómez, Carlos Bortolotti Andrade and John S. Sneider.

Introduction.

The Macuspana Basin is located in the Southeast Tertiary Basins Province of south-eastern Mexico. The Yucatan Platform limits the basin to the east, and the Reforma-Akal horst bounds the basin to the west. The Chiapas Foldbelt forms the southern boundary of the basin; the basin opens to the north into the Gulf of Mexico (figure 1).

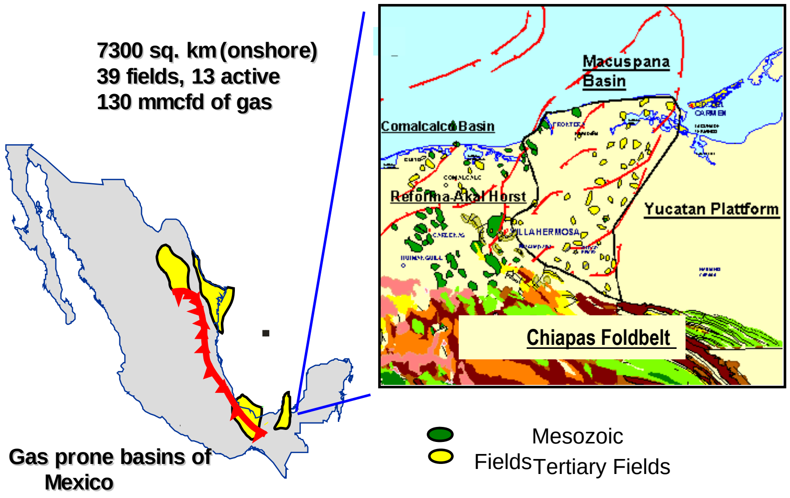


Figure 1. Location Map of the Macuspana Basin.

Exploitation of the basin began in the early 1900's; in the 50's the largest field, the José Colomo, was discovered. Cumulative production from the field is 2,457.6 BCF of gas. The Acachu field, discovered in 1973, was the last of the 36 fields discovered in the basin, and reached a maximum production of 720 mmcfd of gas in 1974. In 1996 after 25 years without exploration activity, a new exploration program commenced to increase gas reserves and production in the basin.

Today 13 of the 39 discovered fields are active. The production from the fields is 130 mmcfd of gas from three different plays: 1) Macuspana limestone of the Middle Miocene, 2) sandstones of Upper Miocene – Lower Pliocene and 3) sandstones and sands of the Pleistocene. The principal hydrocarbons produced are dry and wet gas, but some fields to the south of the basin produce oil with associated gas.

A quick scan of the basin wells indicated that many of the abandoned wells have significant potential for bypassed pay or undeveloped reserves. A review of older dry wells and undeveloped fields in the basin identified wells with strong shows and log responses suggesting hydrocarbons and low resistivity-low contrast (LRLC) intervals producing as one-well fields that have not been developed in other wells in the area.

The target during the earlier exploration phase was oil so many zones with evidence indicating gas were not tested. In other cases, the drilling and completion procedures damaged the reservoir causing inconclusive tests.

There are 24 undeveloped fields. Some of these fields tested gas in LRLC intervals consisting of thinly laminated sandstones and shales. The log evaluation in this laminated section was challenging. In most cases prospective low resistivity intervals have resistivities less than 2 ohmm and where often considered wet or tight. When tested, the production test rates in the low resistivity zones were variable with initial production in the order of 2 mmcfd of gas in wells like the Mangar-1 or as big as 5.6 mmcfd of dry gas in wells like the Jimbal-1.

PEMEX started a project to re-evaluate the geological, geophysical and production data in order to define bypassed pays and to document the opportunities in non-evaluated reservoirs in the basin. Almost all the wells were drilled before 1970 and have older log suites. In order to reduce the risk of re-entering or drilling new wells, a comprehensive well re-evaluation is made including lithology-petrophysical calibrations, rock type-logs calibrations, the analysis of drilling and completion techniques, and the mechanical status of the well.

The integrated work of the multidisciplinary team of wellsite geologists, log analysts, geophysicists and engineers defined potential gas intervals and difficult to identify pays.

Methodology.

The general re-evaluation process can be seen in Figure 2. It begins with the scanning of well logs and drilling histories in search of gas shows and anomalies in the original evaluation of potential gas intervals. This includes a qualitative log analysis and a simultaneous review of the mud log to define zones with hydrocarbon shows, lost circulations, and to get information about the lithology.

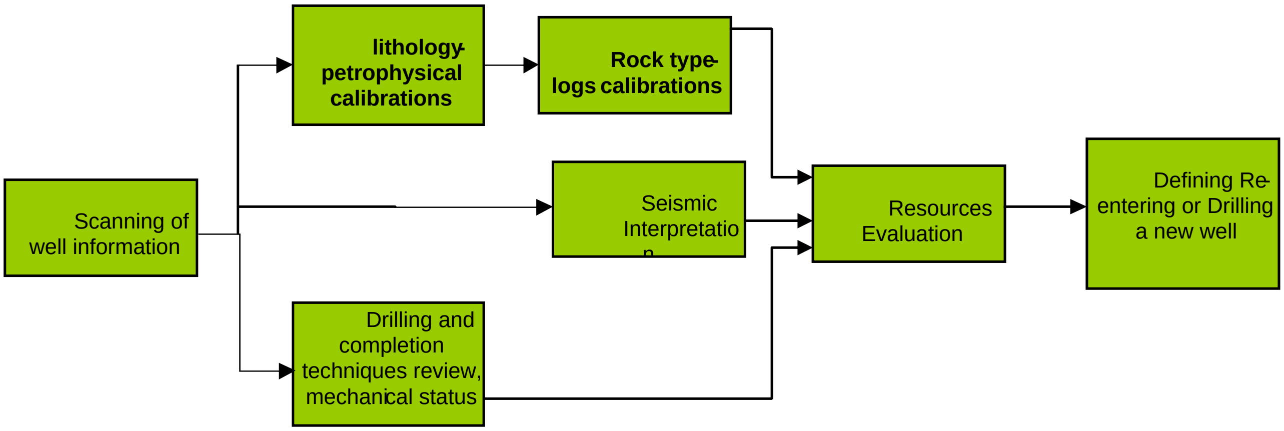


Figure 2. General re-evaluation process applied by the Macuspana team.

At this stage, it's important to review the drilling and completion techniques because many of the techniques used in the 1970's could suppress important gas shows. Some of the documented procedures that suppressed shows or damaged the reservoir include:

- Over-balance drilling conditions, common with heavy oil-based mud.

- Heavy oil-based mud used as a control fluid when perforating.
- Introduction of the packers and tubing after perforating the intervals.
- Short testing times,

In general, these procedures generate formation damage by fluid invasion or by reducing the permeability caused by the swelling of water sensitive clays. Well tests were often inconclusive or misleading because of short testing times and small fluids recoveries related to formation damage caused by the heavy, oil-based mud used during drilling or perforating.

Formation water salinity is a key factor in log evaluation and the most reliable source of information is from the production tests. To confirm the anomalous fresh water zones reported in many zones in the Macuspana basin, salinities reported in well tests are compared to salinities calculated from logs in the same intervals from the SP and Pickett crossplots.

A detailed analysis of the completion operations identifies the mechanical status of the well and helps to determine if is possible to re-enter a well or a new well is required.

Lithological-petrophysical calibrations.

The key to properly evaluating potential intervals is to understand the relationship of lithology petrophysical rock types and to understand the relationships between rock properties and pore fluids (figure 3A). From a petrophysical point of view, a **rock type** is defined by similar **lithologic characteristics** such as grain types and size, sorting, consolidation, clay content, cements and other pore filling material, and **pore space properties** such as pore types, size and size distribution of pores and pore throats and permeability.

A) B)

Figure 3. A. Relationship among fundamental rock and fluids properties of reservoirs and seals (from Sneider, 1999; modified from Archie, 1950). B. Sneider rock types for sand and sandstones (Sneider, 1999)

In 1950, Archie recognized that a rock type has a specific pore geometry with similar porosities, permeability, capillary pressure properties and curves, and has distinct relationships between porosity-permeability and permeability/pore size vs. water saturation. In other words, a specific rock type will have a specific pore size and distribution that control porosity and permeability. If we can define the rock types as they relate to lithology and capillary pressure data, we then understand the relationship between water saturation and the pore system. In the Macuspana Basin project, we use a classification of rock types according to their permeability range made by R. Sneider (1999).

Lithological-petrophysical calibrations in potential intervals use a reservoir characterization study of the Macuspana basin. A Seals and Reservoirs Rock Catalogue was made for the basin from a spectrum of different reservoir qualities and types typical from the basin. Core samples have special core analysis, detailed petrography, SEM, X-ray and water sensitivity measurements. These samples are used to define rock types, to estimate porosity, permeability and Archie "m" in cuttings in other wells in and out of the basin.

The samples in the catalogue are ordered and classified with a numerical system (figure 4) where every digit represent a petrophysically important rock characteristic such as: grain size, sorting, consolidation, clay content, cements and other pore filling material. Estimates of petrophysical properties (porosity, permeability and Archie m) are made with this classification system and with specially designed comparators.

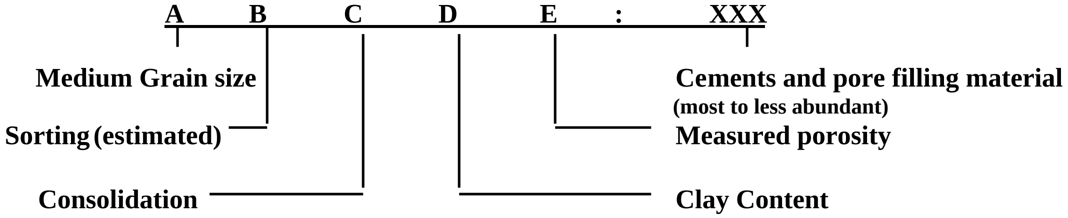


Figure 4. Numerical classification system for sands and sandstone (Sneider, 1999)

This study showed that changes in grain size, sorting, clay content and consolidation make Macuspana reservoirs complex to evaluate. Core analysis in the sand D, the main reservoir in the Jose Colomo field, shows that changes in the lithologic properties greatly impact in reservoir quality; small variations in porosities ranges (22-25%) have a large range of associated permeability (2-1700md) for the same sand body in the same well. This makes predicting reservoir performance difficult (figure 5).

Mineralogy characteristics of Macuspana reservoir also effect log response. The reservoir samples analysed are very fine to medium grained sandstones whose average mineralogy is: quartz 52.2%, K feldspar 10.6%, plagioclase 26%, clay minerals 9%, and 2.2% others such as volcanic rock fragments. The clay content varies from 5 to 17%. An average of 30% of the clay is expansible clays usually illite/smectite and chlorite/smectite mixtures.

Rock-fluids compatibility analysis showed that clayed sandstones are highly sensitive to water and NaCl, usually used like control fluids during perforating, generating permeability lost in some cases up to 90%; because of this, potassium chloride was recommended for future completion operations.

Rock types – log calibrations.

In the Macuspana Basin, pay zones with clean SP or Gamma Ray and high resistivity have easy to identify log responses; however, there are some productive intervals that are difficult to identify in older conventional log suites. The most common of these difficult to identify pay zones is the LRLC pays of some undeveloped fields. The key for identification of these difficult to identify pays is the rock type – log calibrations.

When the logs are calibrated against rock types, we see that changes in log character are closely associated to lithology and tend to mask changes in log response related to changes in fluid content. After calibration of the rock types with logs, the thickness, pay class, movable and irreducible water saturations of potential pay zones can be identified.

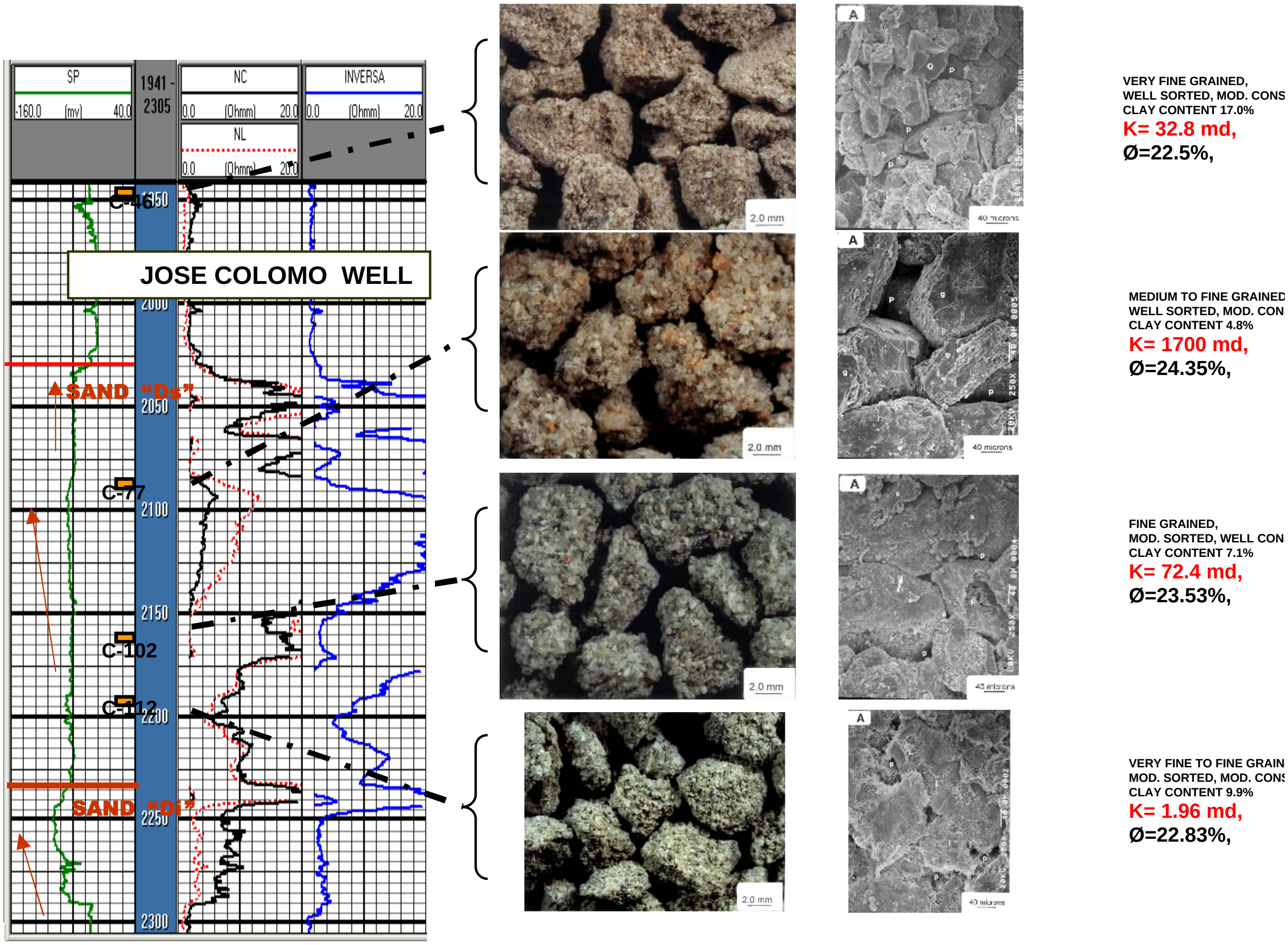


Figure 5. Reservoir quality variations in the sandstone Ds of the Jose Colomo field, like response to grain size, clay content, sorting and consolidation changes.

The detailed lithology analysis in potential intervals allow us to differentiate among decreases in resistivity due to rock type changes and those due to increasing saturation of saline water. We have seen in many potential intervals that resistivity curve gradients can be explained by changes in clay content, reducing grain size or changes in consolidation; simultaneously we can distinguish free water zones from irreducible water zones (Sw vs. Swirr). Using this information we apply different cut-off values for water saturation in log evaluation according to the rock type. This analysis allows us to define and to test LRLC pays.

Applications.

Definition of pay zones and their thickness with this methodology have a large impact in the reserves evaluation, but it's critical when it's applied in LRLC laminated zones of sandstone and shale. In these kinds of reservoirs, mistakes in pay thickness can affect the production rates if the entire pay interval is not perforated completely, and significant volumes of hydrocarbon can remain in the reservoir due to the multiple horizontal flow barriers (shale laminations) present in the reservoir. A good example can be seen in the producer interval of Chunel-1 well (figure 6).

Initially in this well was perforated the interval 1088-1094m producing 849 bpd of oil and 0.17 mmcfd of gas in a sandstone with a estimated permeability between 10 and 50 md. This zone has a clean GR and high resistivity (yellow zone in figure 6).

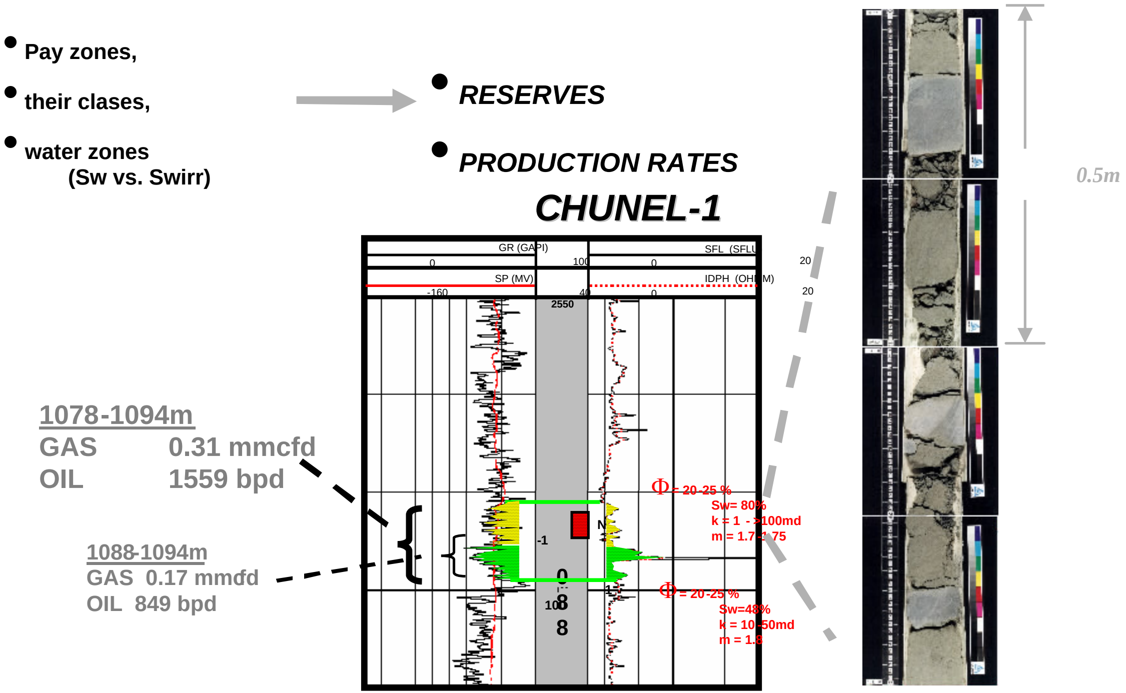
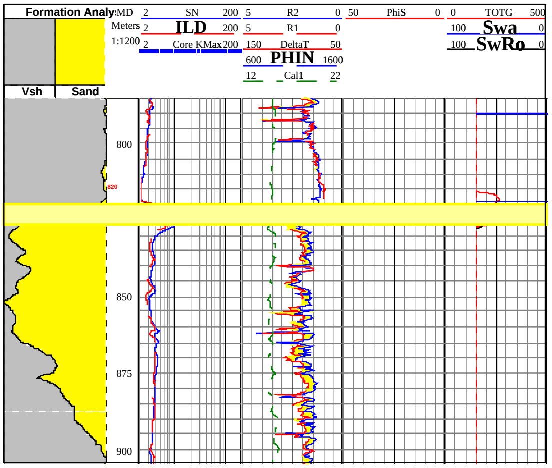


Figure 6

The **lithological-petrophysical calibrations and rock types – log calibrations** of the core 1 in the upper 10 meters zone indicate that the interval is laminated with very good quality sandstones with permeability greater than 100 md (estimated with the rock catalogue, before the special core analysis) alternating with tight and low permeability shales, sandy shales and shaly sandstones (with k < 1 md). The GR has a serrated character and the resistivity drops to 2-3 ohmm. The lower resistivity is explained by the laminated structure, according with core (photograph in Figure 6) and gamma ray response; the water saturation of 80% estimated from logs evaluation was inferred to be irreducible water so the perforation were added to the top of the perforated zone from 1088 to 1078 meters. As a result, the production rate of the interval almost doubled to 1559 bpd of oil and 0.31 mmcfd of gas.

Another good example of the application of this methodology was the tested and produced interval in Macuspana-1B, the first re-entered exploratory well in the basin. The lithological analysis of a big sand body with 50 meter thickness (820-870meter, figure 7) showed a similar rock type throughout the interval of fine to medium grained sandstones. The resistivity drop at 827m was interpreted as the gas-water contact. The upper interval from 820 to 826 m was tested and produced 3.9 mmcfd of dry gas.



820-826 m GAS= 3.9 MMCFD

PWH= 75.9 Kg/cm^2 Shock = 3/8’’

Figure 7. Producing interval of Macuspana-1B, resistivity decreases at 827m corresponding to the gas–water contact.

Conclusions.

The lithologic complexity of the Macuspana basin reservoir rocks requires the integration of logs, lithology analysis, petrophysical data, and in the case of re-entering wells, analysis of the engineering and mechanical well status to reduce the risk

By identifying rock types and then making rock – logs calibrations we can define changes in quality of the reservoirs, identify fluids contacts and recognize different water zones (Sw vs. Swirr); this procedure is the key to find LRLC pays.

Wide permeability ranges from rocks with similar porosity make the Macuspana reservoir performance difficult to predict; therefore, it is necessary to implement a consistent sampling program for conventional and sidewall cores, special core analysis and logging with new tools like the NMR and Imaging tools.

Additional risk must is associated with re-entering wells because of the poor quality information (old wells with old logs, little petrophysical information and mechanical status information) and in many cases with formation damage.

Re-entered wells may not have the best production rates, but they serve as probes for bypassed gas reservoirs in areas without any established production.

References.

Sneider Exploration Inc., PetroTech Associates, PEMEX, Reporte Técnico 1999, ESTUDIO DE CARACTERIZACIÓN DE PROPIEDADES DE ROCAS: Un Catálogo de Litofacies de Yacimientos y Sellos de la Cuenca de Macuspana.

Ed. Moore, D. et al, 1993, PRODUCTIVE LOW RESISTIVITY WELL LOGS OF THE OFFSHORE GULF OF MEXICO, for The New Orleans Geol. Soc. and Houston Geol. Soc.

Kulha, John, 2000, LOW RESISTIVITY LOW CONTRAST PAYS, Curso – Taller, Asoc. De Ingenieros Petroleros de México.

Sneider, Robert M. et al, 1999, WORKSHOP FOR PEMEX: EVALUATION OF RESERVOIRS AND SEALS (Identification of Difficult to Identify Pay), Notas de Taller.