EVALUATING THE SHALY SAND OIL RESERVOIRS OF EL TORDILLO FIELD, ARGENTINA, USING MAGNETIC RESONANCE LOGS*

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Introduction

El Tordillo field was discovered in 1932 and was operated by YPF (the national oil company) from 1932 until 1991. In 1991, the Consortium El Tordillo, in which Tecpetrol S.A. is the operator, assumed operations.

The field is situated on the north flank of the San Jorge Basin in Chubut Province, Argentina. It is approximately 50 kilometers from the town of Comodoro Rivadavia and 1500 kilometers south of Buenos Aires (Figure 1). More than 1200 wells have been drilled in the field, and production is spread over approximately 57 square kilometers.

Three Cretaceous units produce the numerous fluvial sand bodies that structurally and stratigraphically trap hydrocarbons in the field. Relevant geological, geophysical, and engineering observations from studies performed within the field can be found in Muruaga et al. (2001) and Taboada et al. (2001). See also Fitzgerald et al. (1990).

The main objectives for running MRIL logs in El Tordillo field were:

- Identification of water vs. oil zones
- Determination of porosity
- Evaluation of permeability to help identify reservoir quality zones
- Determination of variations in oil viscosity, if any

Petrophysical Properties of the Reservoirs

Both Comodoro Rivadavia and Mina El Carmen formations consist of feldspathic shaly sandstones with volcanic tuff and conglomerates. A summary of the reservoir characteristics is presented in Figure 2. Additional information can be found in Stinco et al. (2001).

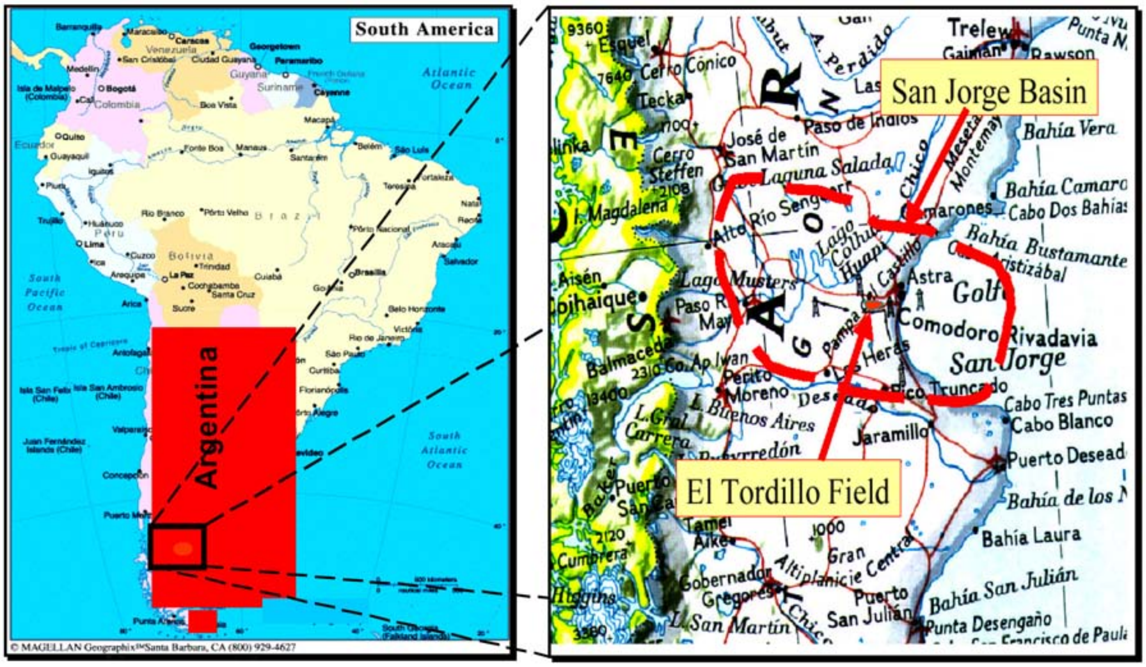

Figure 1. Location map

Formation	Comodoro Rivadavia	Mina El Carmen
Lithology	Feldspathic shaly sand w/ volcanic tuffs, v. f. sand & congl. w/ chert	Feldspathic shaly sand w/ volcanic tuffs, sandy & conglomeritic
Porosity	12 – 25 %	5 – 20 %
Permeability	5 – 150 mD	1 – 90 mD
Temperature	180° F	210° F
Fm. Water Sal.	6000 – 18000 ppm Cl	
Factor “m”	1.7 – 2.05	
Exponent “n”	1.95 – 2.05	
Main Petrophysical Problem	High variability in lithology and matrix (depending on the concentration of volcanic tuffs) affects resistivity and porosity logs response which make log analysis and interpretation very challenging and inconsistent	

Figure 2. Summary of reservoir characteristics.

MRIL Technology

Magnetic Resonance Imaging Logging (MRILPrime ®) service measures several key factors that influence the ability of a well to produce commercial quantities of oil or gas.

One of the fundamental measurements of the MRIL-Prime tool is total fluid-filled porosity. MRIL in general is a fluids-only measurement as the rock matrix is invisible to the tool; therefore, it is unaffected by matrix effects that can influence conventional logs. In fact, the total porosity measurement is the sum of clay-bound water, irreducible water saturation and free fluid volumes — all of which are measured separately by the tool. These measurements are utilized to predict hydrocarbon production reliably. They are critical in identifying low-contrast and low-resistivity pay, where high immovable water volumes or fresh formation water may cause overlooking productive zones when evaluated solely with conventional logs.

In addition, the MRIL tool derives a permeability measurement and is able independently to determine fluid type, pick fluid contacts, and detect changes in oil viscosity.

MRIL Porosity and Permeability

Coates et al. (1999) provide a thorough explanation of the theory and the procedures for determining MRI-based porosity and permeability.

It should be noted that, in general, the MRIL permeability should be used initially to compare good-quality from poor-quality reservoirs in a relative fashion. When calibrated to MRI core analysis, MRIL permeability can be used in its absolute form. See Marschall et al. (1999) for discussion.

MRIL Analysis and Interpretation Models

In order to achieve the objectives of the study, different models of analysis and interpretation were used. They are:

- MRIAN Analysis
- Enhanced Diffusion Method (EDM)
- Time Domain Analysis (TDA)

Refer to Coates, et al., (1999) for explanations of these individual methods.

Evaluating The Shaly Sands Oil Reservoirs Of El Tordillo Field

The main problem to solve when dealing with these reservoirs is that the responses of conventional logs do not always indicate fluid types. These shortcomings have been documented by post-logging well testing.

Pre-Job Planning

A job plan for acquiring MRIL data in El Tordillo field wells was made in this study, based on specific parameters from the well design and anticipated formation and hydrocarbon characteristics (Fam, 2003). The plan was designed to acquire MRIL data that would provide the best opportunity of meeting objectives.

MRIL-Prime Interpretation Compared to Testing Results

Figures 3 and 4 illustrate the powerful capabilities of MRI logging. A good match is seen between the MRIL prediction of light oil (or high GOR oil) and a test that produced light oil or with some gas (Figure 3).

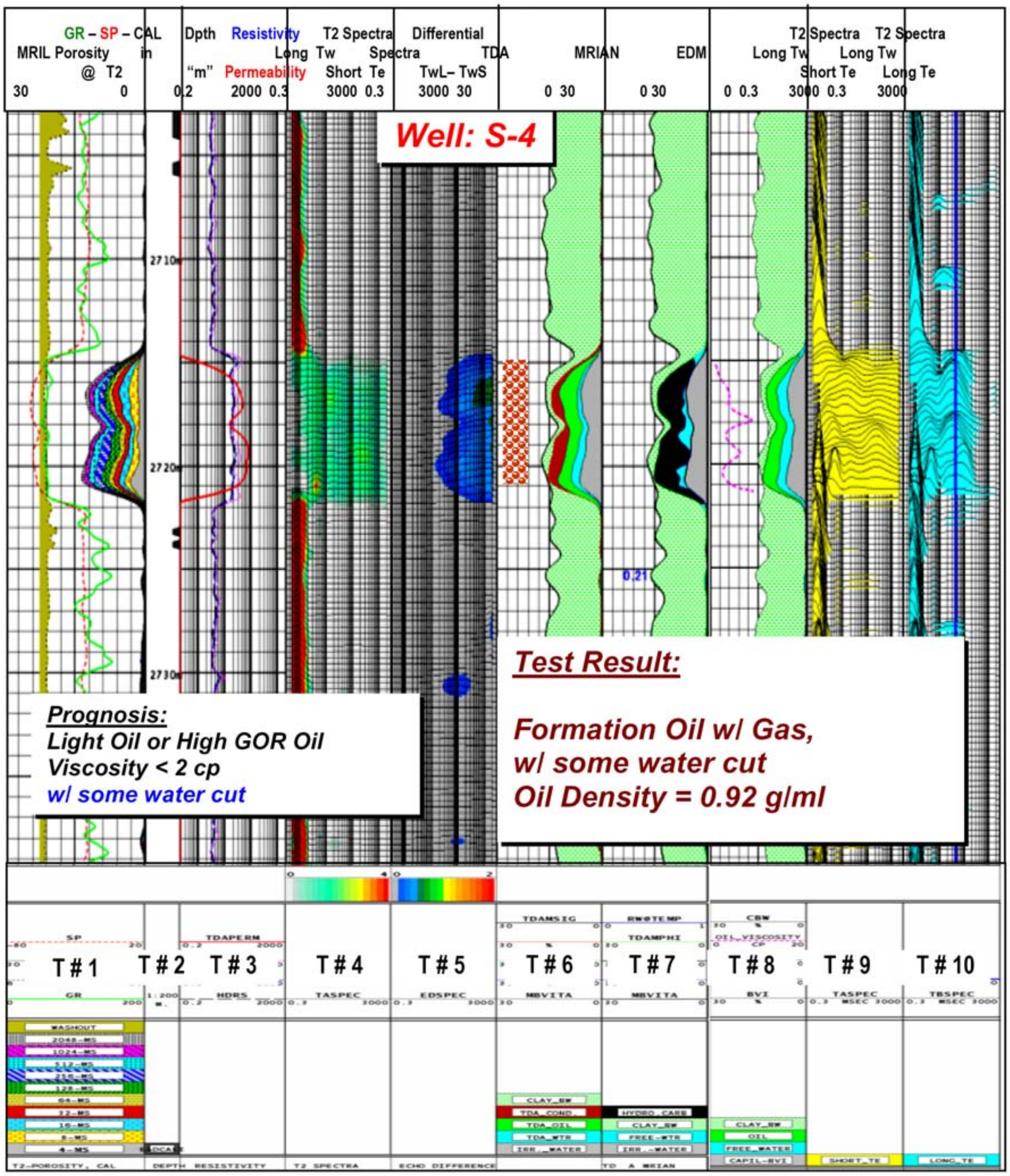

Figure 3. MRIL results, example 1. For track explanation, see Appendix.

Figure 4 shows a different situation. Here the MRIL prognosis called for oil with some water for the two zones shown on the figure. The test results confirmed the prognosis.

As a consequence of these good matches between forecasts and the test results, a high level of confidence was achieved for forecasting fluid types using MRIL logging in different intervals for the Comodoro Rivadavia and Mina El Carmen formations.

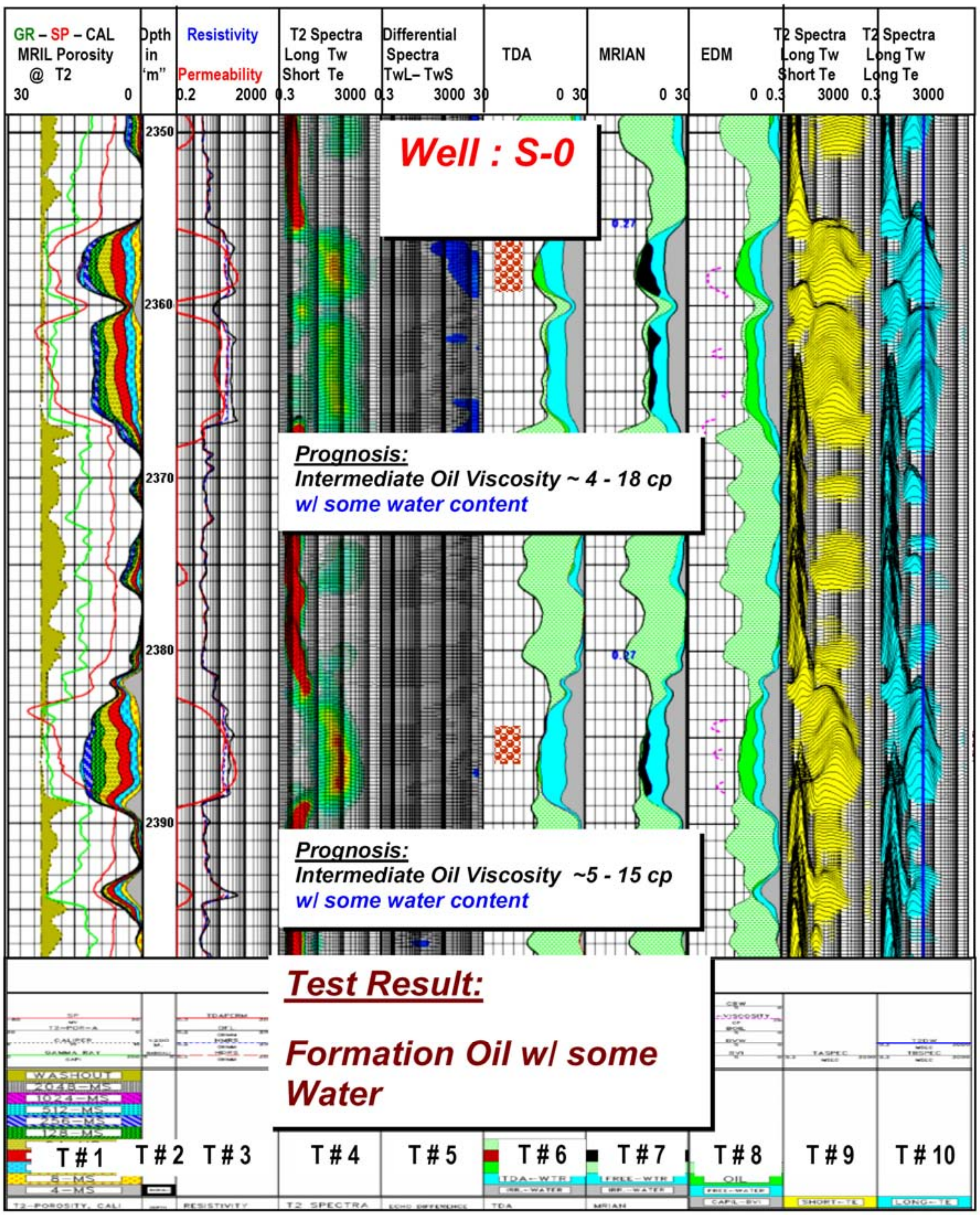

Figure 4. MRIL results, example 2. For track explanation, see Appendix.

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Appendix

Track # 1 displays the GR curve in green, SP in red, and Caliper shaded yellow from bit size. Also presented are 10 raw MRIL porosity curves on scale 30 – 0 %. The shading between these porosity curves present the corresponding T2 times associated with that porosity curve. The T2 relaxation time ranges from 4 - 1024 msec.;variation of porosity value at different T2 relaxation time depends on fluid type and pore size.

Track # 2 is the depth track displaying the depth in meters and a bad hole flag in black shading.

Track # 3 shows the deep resistivity curve in dashed black, medium resistivity curve in dotted blue, and the shallow curve in solid magenta. Permeability curve is presented in solid red. All curves are presented on logarithmic scale from 0.2 – 2000.

Track # 4 displays the raw *T2* spectra from the data acquired with long wait "*Tw*" and short inter-echo spacing '*Te*". The color indicates porosity such that the brighter the color the higher the porosity. The lateral logarithmic scale presents the *T2* relaxation time on scale 0.3 – 3000.

Track # 5 displays the differential *T2* spectra (the difference between the *T2* spectra of the long *Tw* and the short *Tw*). Again the color indicates porosity such that the brighter the color the higher the porosity. The lateral logarithmic scale presents the *T2* relaxation time on scale 0.3 – 3000. In general the differential *T2* spectra signal in this track presents either light hydrocarbon or water in large pore size.

Track # 6 displays the final MRIL porosity, on scale 30 – 0 %, after applying the Hydrogen Index and the *T1* corrections. This final MRIL porosity is obtained after processing the data using the Time Domain Analysis "TDA" technique. The dashed light green shading indicates clay bound water 'CBW"; the red shading indicates condensate or gas; the solid darker green shading indicates light oil; the blue shading indicates free water; and the gray shading represents bulk volume irreducible water "BVI". This interpretation is within the MRIL-Prime tool's depth of investigation, which is about 2.5 – 3 inches in the formation.

Track # 7 displays MRIAN analysis, which is based on the "Dual Water Model" using the deep resistivity curve and the MRIL porosity from TDA. The green shading presents the clay bound water "CBW" porosity; the black shading shows the hydrocarbon volume (based on a known *Rw*); the blue curve presents free water; and the gray shading presents bulk volume irreducible water "BVI". This interpretation indicated presence of hydrocarbon within the deep resistivity depth of investigation, which is about 90 inches into the formation.

Track # 8 displays the Enhanced Diffusion Method "EDM" interpretation directed towards intermediate oil viscosities ranging from 2 – 50 cP. The dashed light green shading indicates clay bound water 'CBW"; the solid darker green shading indicates intermediate oil; the blue shading indicates free water; and the gray shading presents bulk volume irreducible water "BVI". This interpretation is within the MRIL-Prime tool's depth of investigation, which is about 2.5 – 3 inches in the formation. Also displayed on this track is the oil viscosity as the dotted red curve on scale 0 – 20 cP.

Track # 9 displays the raw *T2* spectra from the data acquired with long wait "*Tw*" and short inter-echo spacing '*Te*". The yellow color indicates porosity such that the higher the amplitude of the yellow shading the higher the porosity. The lateral logarithmic scale presents the *T2* relaxation time on scale 0.3 – 3000.

Track # 10 displays the raw *T2* spectra from the data acquired with long wait "*Tw*" and long inter-echo spacing '*Te*". The blue color indicates porosity such that the higher the amplitude of the blue shading the higher the porosity. The lateral logarithmic scale presents the *T2* relaxation time on scale 0.3 – 3000. The dark blue vertical line presents the *T2DW* (*T2* diffusion of water), which is expected to be the maximum *T2* value of the water signal. In other words, a signal found to the right side of the *T2DW* indicates that signal would be an indication of oil.