PETROLEUM SYSTEM EVALUATION OF A COMPRESSIVE STRUCTURE:

THE EXAMPLE OF MADREJONES (BOLIVIA)

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Introduction

This paper is a synthesis of a study carried out to understand and quantify the petroleum system related to the Madrejones structure, located in the leading edge of the Subandean Thrust Belt, in the Southern sector of Bolivia. In particular, the overpressure regime was an important issue of the study.

The work flow used to understand this complex geological feature was: (1) structural analysis and cross-section balancing, (2) reconstruction of the thermal regime, (3) calibration of the overpressures and (4) evaluation of the hydrocarbon migration.

Known elements of the petroleum system

The existence of gas accumulations in the Palaeozoic reservoir proves the existence of a petroleum system in the area. This petroleum system is characterised by more than one source rock, at least two reservoir levels and various seals.

The proven source rock in the area is Los Monos (Mid-Devonian). Two other probable source rocks are Icla (Low-Devonian), and Kirusillas (Silurian). The kerogen is a marine type II/III and the TOC is around 1 wt%.

The reservoir levels involved in this study are the Devonian sandstones of Huamampampa and Icla and the Low-Devonian – Up Silurian sandstones of Santa Rosa.

The thick shale section of Los Monos is the main regional seal, which contributes to create and preserve the overpressure observed in this area. The shale layers of Icla and Kirusillas are also good local seals.

The construction of the 2D balanced cross-section.

The 2D structural cross-section was built from a 2D seismic line extracted from a 3D seismic cube. This section is perpendicular to the axis of the structure and almost parallel to the direction of the regional compression (Fig. 1).

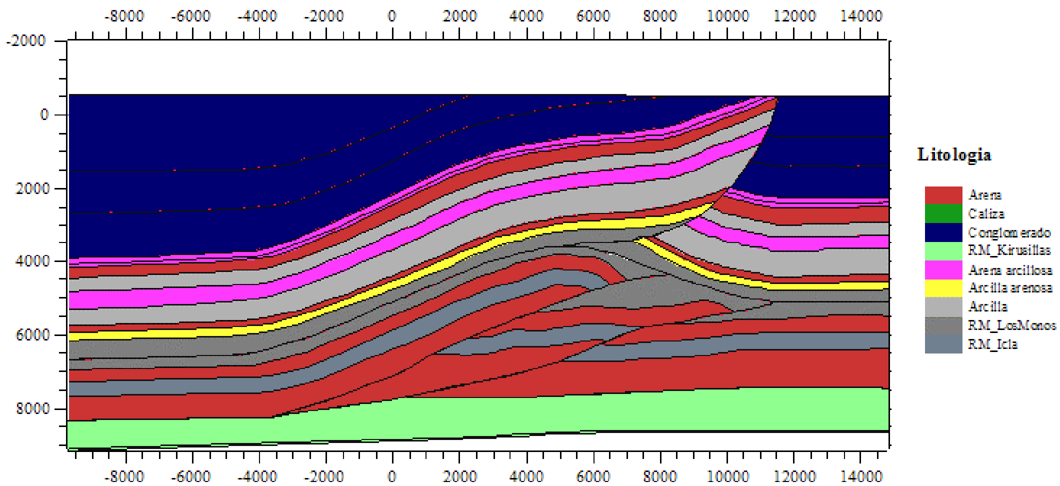

Figure 1: Lithology and structure at 0 MA.

The structural interpretation was validated through the restoration and balancing of the section. Therefore, a deformation sequence chronology was proposed.

The thrusting and folding of the Devonian and Carboniferous layers are not the result of one single structural event. The first event happened around 5 Ma ago and structured the Devonian layers with a detachment level located around the base of the Silurian rocks. This first event is followed by the activation of a second detachment level placed inside the shale of Los Monos Formation.

Reconstruction of the thermal regime

The thermal regime reconstruction consists in the calibration of the heat flow history. The calibration is done against temperature and maturity data measured in wells. A general evolution of the heat flux is determined with respect to the geodynamical evolution of the studied area.

A good calibration is reached with the following thermal history:

Cold regime during the Palaeozoic and the Mesozoic with a heat flux around 40 mW/m²;

A rifting event that took place in a region near the study area at the end of the Cretaceous with a heat flux around 75 mW/m²;

Since the end of the Tertiary to the present an average heat flux around 65 mW/m^2 has been calibrated in order to respect the present day thermal gradient around 28 °C/km;

The ice period at the end of the Palaeozoic (265 – 346 MA) has been accounted for by the reduction of the surface temperature.

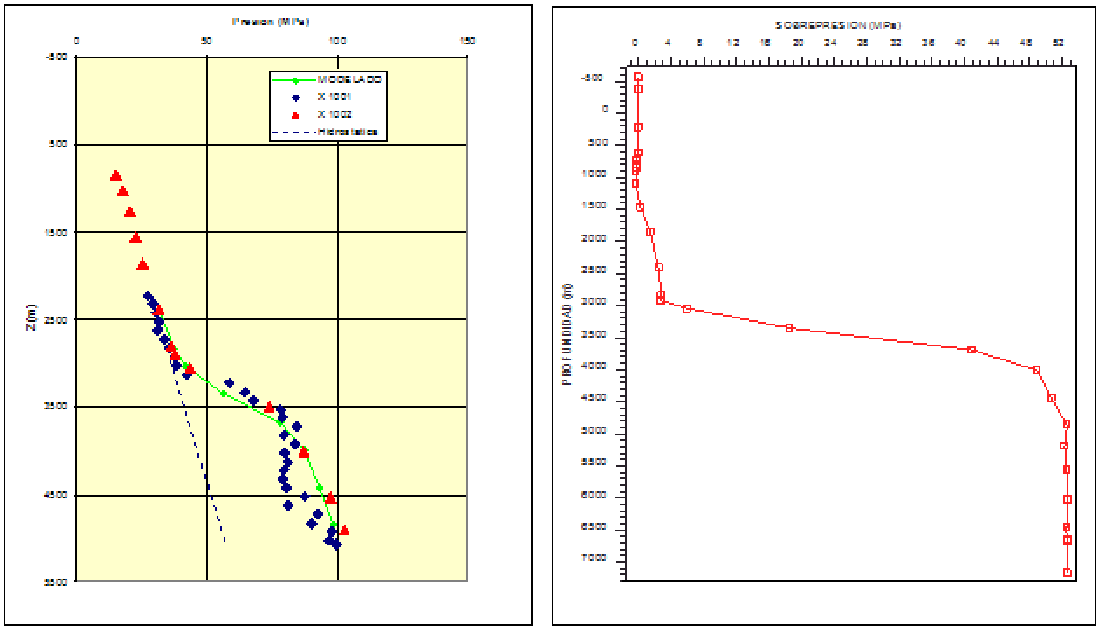

Figure 2: Pressure calibration and overpressure profile.

Reconstruction of the overpressure regime

The pressure regime is characterized by high overpressure in the Silurian and Devonian levels. The regional seal of Los Monos is the main permeability barrier. As a consequence, the fluids cannot escape from the Huamampampa reservoir level and the overpressure can reach values up to 50 MPa (Fig. 2).

The overpressure modelling shows that a smooth increase of the overpressure is observed during the sedimentation of Los Monos during the Palaeozoic. After that event, the system relaxed and went back to a hydrostatic normal pressure. The overpressure increased drastically during the Tertiary thrusting, as a result of the overburden caused by the very rapid sedimentation of the Tertiary molasse.

Hydrocarbon Generation and expulsion

The Kirusillas source rock is completely mature since 240 Ma, while Icla reached a TR of 100% at the beginning of the Tertiary (around 50 Ma). The Los Monos source rock has been mature since 20 Ma in this area (Fig 3). Since the structure is young (less than 5 Ma), it should be noticed that the source rocks have generated their potential before the deformation.

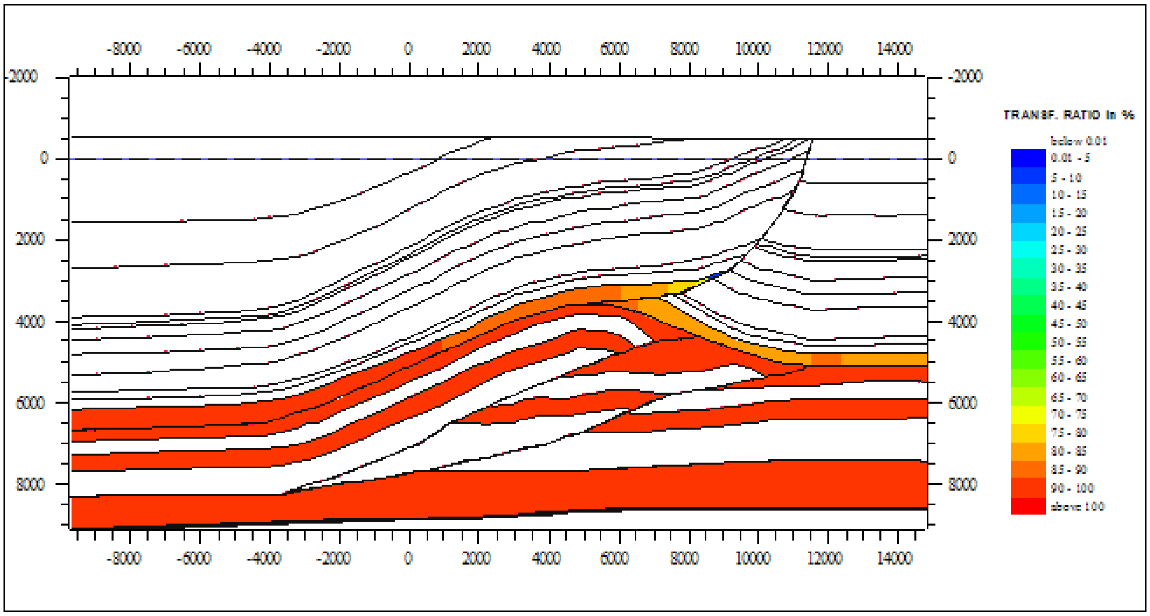

Figure 3: Transformation ratio in the present.

In this study the expulsion occurs when the hydrocarbon saturation reaches a given threshold. With a threshold set to 15%, the three source rocks began to expel hydrocarbons before the creation of the structure. Thus the presence of hydrocarbon in the structure could only be explained by remobilisation from previous trap or by late expulsion of the remaining hydrocarbons in the source rock. These two scenarios could not be tested within the frame of this study.

Conclusions

The use of a 2D basin model able to account for folding and thrusting allowed us to build a consistent scenario including the structural evolution, the thermal reconstruction, the overpressure generation and the hydrocarbon maturation, expulsion and migration.

The resulting model is well calibrated against the observed data. The temperature, maturity and pressure data are well reproduced in the area of the study.

Maturation of the source rock is older than the deformation time. The classical approach that considers a saturation threshold to simulate the expulsion of the hydrocarbon should be used with care in this area. Indeed, the hydrocarbons may have been trapped and then remobilised during the last 5 Ma or late expulsion of non-expelled hydrocarbons might have occurred during thrusting.