Introduction

The Pañacocha oil field is located in the Oriente Basin of Ecuador (Figure 1), approximately 350Km^2 with 26 wells drilled in three platforms. The field consists of several main stacked reservoirs belongs to Cretaceous: M1 sand, M2 sand, A sand, U and T sand. A steep north-south trending reverse fault developed in central of field and controlling main structure characteristic. This paper concentrates on the M2 reservoir prediction; it is a typical sand-shale interbed unit. The sand thickness of entire unit range is from 6.06ft to 42.17ft (most of wells are thinner than 18ft), the single sand body thickness is varied from 1.5ft to 16.3ft (Figure 2).

Figure 1 *Location of study area*

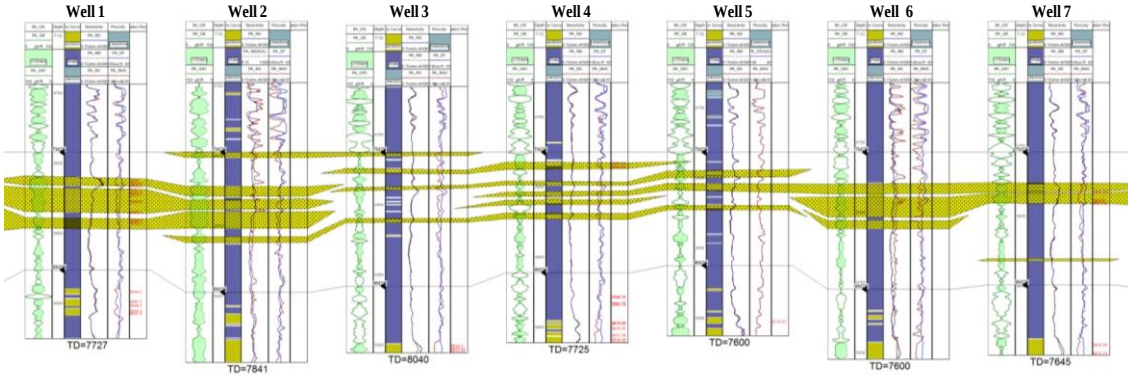

Figure 2 *sand body correlation profile from south to north (Flatted by M2 sand top, SSTVD)*

Basic theory and method

Pre-stack inversion is better for accurate reservoir prediction because it is able to get P-wave impedance and S-wave impedance simultaneously, which reduces ambiguity. Derived from Shuey's classic linearization of Zeoppritz equations for non-normal PP reflectivity, elastic impedance (EI) provides a tool to calibrate and invert on-zero offset seismic data such as angle stacks (Connolly, 1999). Connolly defines that the P is the P-wave impedance (EI) with incident angle.

$$EI = V_P^{(1+\tan^2\theta)} V_S^{(-8K\sin^2\theta)} \rho^{(1-4K\sin^2\theta)}$$

There are three unknown values (Vp, Vs, ρ) in the equation. Using different incident angle seismic data to do the inversion and get elastic impedance volumes, the equation set can be established and then calculate other elastic parameters (three equations required at least), which can be used to predict the lithology possibility. This paper attempts to present an integrate and effective approach to do pre-stack inversion for thin layer reservoir characterization (Figure 3).

The key steps of ensuring prediction accuracy and resolution are:

1. Initial geological model construction;

2. Wavelet extraction;

3. Inversion parameter optimization.

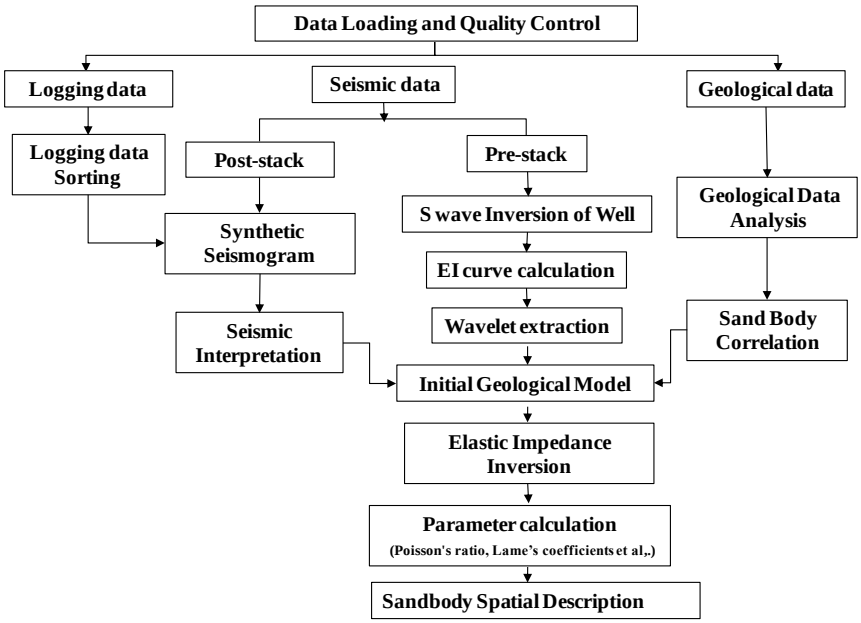

Figure 3 *Reservoir prediction workflow*

Key steps of inversion

1. Precise initial geological model

Grounded in petrophysics theory, the initial model construction technique integrates all available knowledge of research area (lithology, well correlation, depositional framework, structure background etc.) to build 3D geological models for key wells in reservoir. An appropriate geological model is a basement to get accurate seismic inversion result. Base on geological background and well logging analysis, geologist built sand correlation profile first (Figure 4).

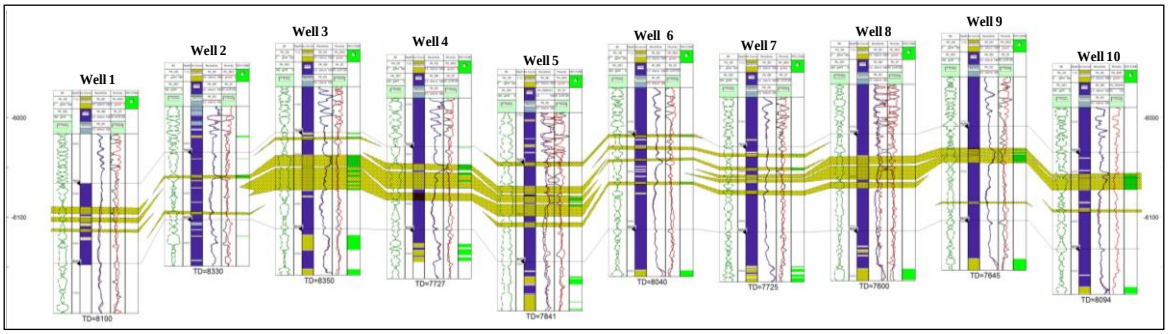

Figure 4 *Sandbodies correlation profile (SSTVD)*

After fine horizon interpretation and well seismic calibration, the initial model was constructed, taking sand correlation profile as reference. The depositional framework is based on the geological model, and the formation contact relationship also should be considered. It is an indicator of relationship between EI parameter (Poisson's ratio) and lithological information too.

So there are several main purposes for this step:

- Combine all well information (geological and petrophysical)
- Check time-depth relationship of all used wells (take sandbodies correlation as a reference)
- Check logging curves quality (EI curves)

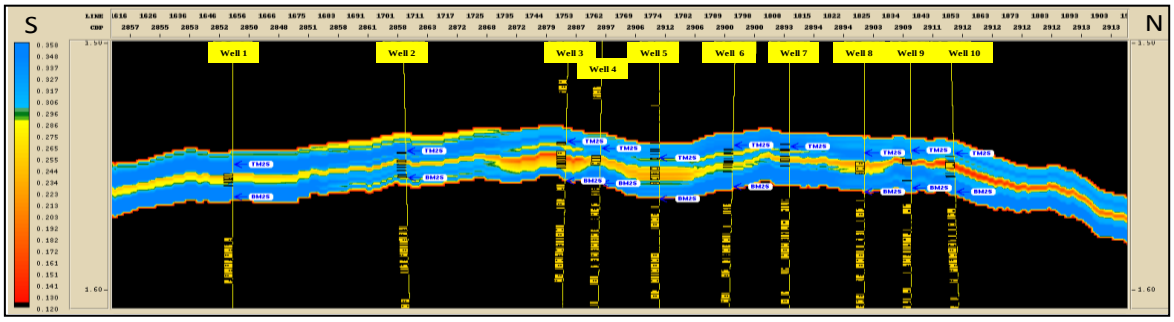

Figure 5 *Initial model section (Poisson's ratio) of well tie from south to north*
Based on sensitivity analysis, Poisson's ratio is the best EI parameter to distinguish sand from shale in this area. Warm color presents sand in section and it is matched well with well drilled result (yellow square lab along well path.) Meanwhile, sand connection is consistence with sand correlation profile (figure 4)

2. Stable wavelet extraction

Wavelet is one of key factors to get accurate inversion result, it can be extracted from uphole seismic trace for difference incident angle volumes. That is associated with appropriate frequency, equal phase, right length and not alternated by layer filter effect. During doing wavelet extraction, there are two main principles:

- To get good synthetic seismogram result of all wells
- To make sure all wavelets are stable and similar in whole study area

Good synthetic seismogram result is precondition to get accurate inversion around wells; stable wavelet can ensure the inversion result in non-well area is reasonable. As there are three incident angle seismic volumes involved during inversion process, three wavelets has to be estimated for each well (Figure 6). The length of all wavelets are around 90ms~100ms, the frequency range is from 0Hz to 90Hz, the energy is concentrate around 30~40Hz.

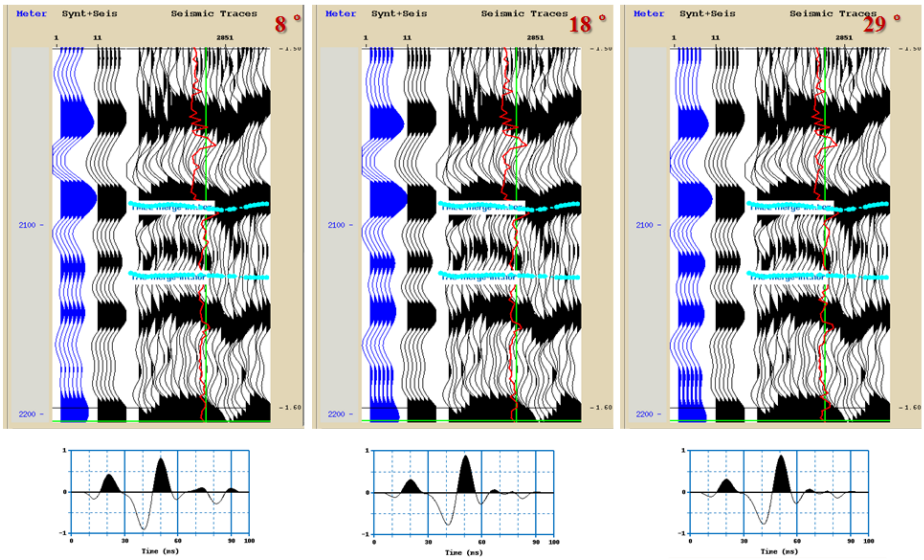

Figure 6 *M2S layer wavelet extraction results for incidence 8˚, 18˚, 29˚*
(Blue trace is synthetic result; black is original uphole seismic trace. Seismic horizon are in blue colour, dash line.)

3. Suitable inversion parameter

During doing inversion parameter test and optimization, how to balance the calculation weight of initial model and incident angle seismic volumes is an essential issue. Normally, the error of Elastic

impedance between well-based calculation result and inversion result should be less than 5% at well location, which requires less modification of initial model. But the seismic volume information is very important to get reliable sand distribution between wells and in non-well area, so the incident angle seismic volumes should be used properly.

Based on GMAX software, there are several inversion parameters can be defined for each incident angle seismic volumes separately, according to quality and character of each incident angle volume. They are Iteration Number (the maximum number of iterations), Search Range (control the modification range of model), Trace mix and Crossover frequency. After hundreds times of test, the best parameters for each EI inversion result of different incident angle can be obtained, which can ensure the accuracy of well location and reliable beyond. These results can form as equations set and get Elastic parameters finally, such as Poisson's ratio (Figure 7).

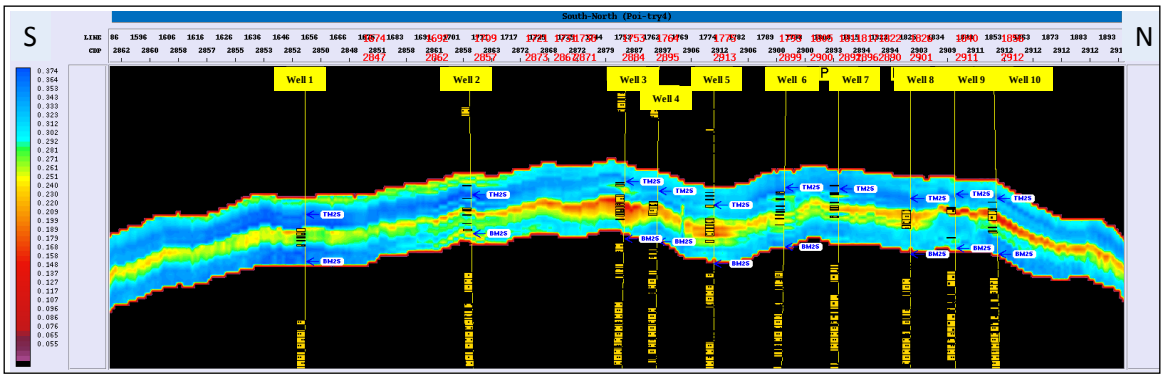

Figure 7 *Inversion result (Poisson's ratio) of M2 result*
Warm color presents sand in section. The sand distribution is not only matched with well drilled result (yellow square lab along well path.) but also reliable between wells and in non-well area, which has been proved by new drill result.

Conclusions

There is no doubt that pre-stack elastic parameter inversion can be used to detect and map reservoir distribution of Napo formation in Oriente basin. Furthermore, cautious geological analysis, exact time-depth relation, precise initial geological model, stable wavelet and suitable inversion parameters can help to get more detailed information of thin sand layer with high resolution inversion result, which definitely reduces drilling risks. Successful application of M2 reservoir prediction has proved that though optimizing calculation parameters and effective workflow can help this method to develop to a new useful stage.

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