Reservoir Characterization: Which Rock Physics Input Should You Put?

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Abstract

Seismic rock physics is a powerful tool for reservoir characterization.

Seismic data has a moderate resolution, but a terrific lateral and volumetric continuity, and may be the main driver for reservoir properties estimation. Reservoir seismic properties, e.g. impedances, velocities and even density, can be extracted from seismic volumes and these properties very often contains a lot of petrophysical and litological information. Nowadays there are some efforts trying to extract the petrophysical information directly from the seismic data volumes, without the intermediate step of seismic property estimation. Nevertheless, these data must be calibrated and validated with similar data obtained from more direct measurements, like sonic logs and laboratory experiments, in order to achieve a good quantitative match, no matter what inversion scheme is used.

Some strength, as well as some caveats, of rock physics data will be discussed on this paper. The aim of it is not to suggest any ground truth or rule of thumb, but ratter to provoke the discussion of this interesting subject.

Introduction

Seismic surveys are far the most used geophysical exploration tool, and plays a major role in reservoir characterization as well. The great lateral and volumetric continuity obtained on seismic data, as well as its fairly satisfactory vertical resolution turn it into an upmost geophysical tool. Advanced acquisition and processing tools, as multi-component seismic and seismic inversion schemes, increases even most the seismic application power.

However, in a skeptic point of view, the only direct measurements obtained from seismic data are the seismic amplitudes. Even the seismic velocities directly obtained from seismic data are not equivalent to the rock interval velocities, but are related to. In this sense, some more direct measurements may helps to extract layer petrophysical properties from seismic data.

Sonic logs, for instance, may "read" the real transit time of seismic waves on rock layers, and has the advantage of an increased resolution when compared to seismic methods. On the other hand, shear wave logging in unconsolidated formations is still a subject of warm discussions. Borehole conditions may also degrade the quality of sonic logs. In the case of anisotropic formations, further care must be taken to correct the sonic logs in order to estimate the effect of borehole deviation on the log measurements. Although they are natural candidates to translate seismic properties into reservoir petrophysical properties, with the aid of other logs, the sonic logs also suffer from a relatively small volumetric depth of investigation and poor areal sampling.

A still more precise and higher resolution seismic measurement is the laboratory investigation of seismic properties. It is possible to simulate in situ or, virtually, any desired underground condition during lab measurements. As perfection is a platonic quality, a lab measurement has an even poor volumetric representation and sampling. The integrity of rocks extracted from the borehole is also a subject of endless debates, as well as the issues associated with the use of different wave frequency in seismic, logging and laboratory.

Laboratory data can be representative of reservoir properties if an adequate sampling is made. Note that adequate sampling is not necessarily equivalent to an exhaustive sampling, if it is done in a "blind" fashion. Rather, the adequate sampling may be done with the aid of a geoscientist that is familiar with the particular reservoir under study, and may comprise a good sampling of the relevant reservoir and non-reservoir facies. Figure 1 illustrates the comparison of lab and rock properties for a good sampling case on which the relation between compressional and shear wave velocity from the two data types is almost identical.

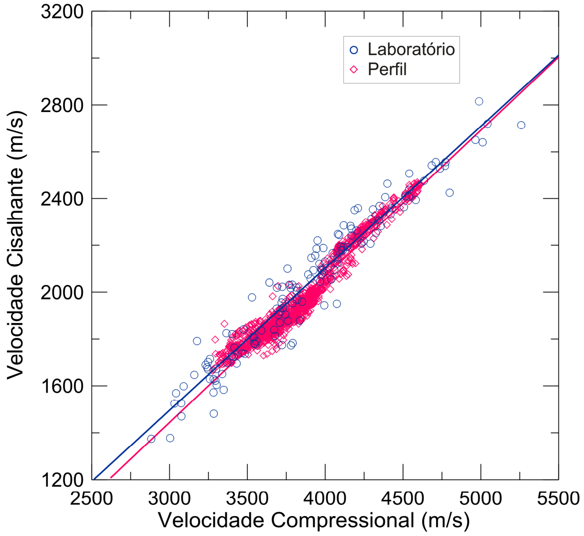

Figure 1 – Example of comparison of seismic properties obtained from log (red diamonds) and laboratory (blue circles) measurements.

Well Log, A Priori Model and Seismic Tie

For seismic inversion studies, a background model may be built in order to constrain the process. Well logs are the natural candidates to guide this model building. Nevertheless, although they represent measurements of density and seismic velocities, they may also be corrupted due to the borehole conditions.

Mud filtrate invasion, for instance, may contaminate the density and velocities measurement (Vasquez *et al*., 2004). This effect may be minimized by using special drilling fluids. It may be also of minor effect for logging tools that "reads" reasonably deep into the formation. The correction of this effect may be done by fluid substitution if the investigation depth fluid saturation is well known.

Another problem related to sonic logs, especially on old wells, deviated boreholes and in low shear-wave velocity formations, is the reliability of the shear-wave data. In old hydrocarbon fields there may be few or even none shear-wave logging and one must use empirical relations like those proposed by Castagna *et al*. (1985). Better shear-wave estimations can be achieved with local calibration of the empirical equations. In fact, Figure 1 represents the cross-validation of the relationship between shear and compressional wave velocities from the only one "digital sonic" obtained from a well of an offshore Brazilian field with laboratory data.

Under adverse conditions, like deviated boreholes, the shear-wave logs may be severely compromised due to tool eccentricity and Stoneley wave contamination (Beneduzi, 2005), so that laboratory results represent a safe way to check the quality and calibration of sonic logs.

Another serious problem on velocity logging on deviated wells relates to seismic anisotropy. As pointed out by Vernik *et al*. (2002) and Keir *et al*. (2011), the correction of anisotropy effects on the measured velocities is of paramount importance in well-to-seismic tie and seismic inversion.

Figure 2 illustrate the correction of acoustic impedance on deviated wells for an offshore area in Brazil. Note that the reservoir interval was not corrected, since it is relatively clean sand.

The correction of anisotropy may be done based on core measurements on lab, which requires the velocity measurement at least on three different directions in the simple case of a VTI Media. The representativeness of such measurements would be another important issue. In the case illustrated on Figure 2, a VTI anisotropy was assumed, but the Thomsen parameters, necessary to correct the velocities, was estimated directly from the well logs, with a inversion scheme similar to that proposed by Hornby *et al*. (2003).

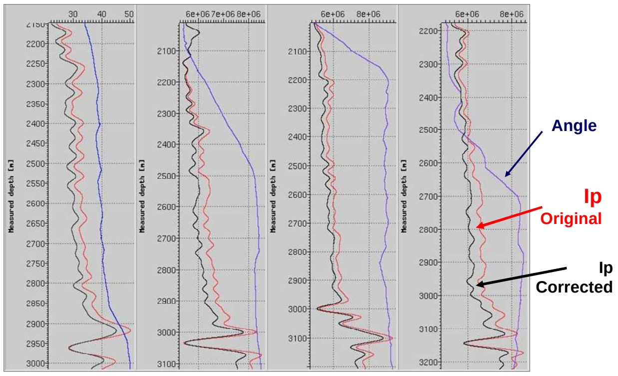

Figure 2 – Correction of acoustic impedance Ip from sonic logs based on VTI assumption.

4D Feasibility Studies

Technical feasibility analysis of seismic production monitoring is a common activity in Rock Physics. It is important to clarify that the technical feasibility studies does not involve any analysis related to logistics, economic viability nor to the information value that will add to the knowledge of the fields via a 4D seismic study.

Assuming no significant change in the reservoir rocks, which many times is a reasonable approximation the observed changes in seismic 4D imaging may be considered due to changes in fluid saturation or pore pressure. If geomechanical issues are strong enough to be disregarded, the above station may fail and the analysis is a little bit more complicated.

Figure 3 illustrates how the temperature variation can change the reservoir velocity without changes in saturation. In this figure are represented the data of compressional-wave velocities measured in a reservoir rock sample saturated with oil from a field subject to a steam injection enhanced oil recovery process, that eventually uses hot water instead of steam. There is a clear downward trend on the compressional-wave velocity with increasing temperature associated with increased oil compressibility. Interestingly, the behavior of the acoustic velocity in pure oil, also represented on the graph, exhibits almost the same gradient with temperature.

During the life time of a field, depending on the production strategy, beyond the saturation variations changes in effective stress will also occur, and it will affect the seismic properties of the reservoir.

The effects of changes in saturation can be relatively well modeled by applying Gassmann (1951). However, those effects due to the change of fluid pressure must be evaluated based on laboratory measurements for each reservoir. Each particular rock has a peculiar sensitivity to stress variation and the models designed to describe it are valid in a very small number of cases. There are few papers dealing with the estimation of stress effects directly from seismic logs.

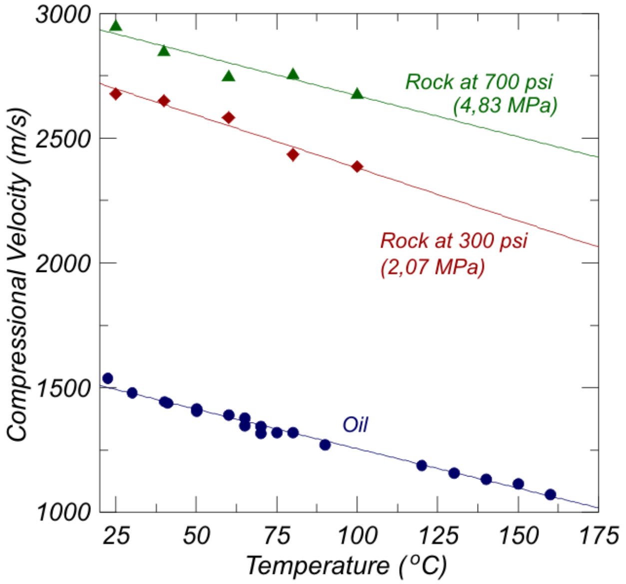

Figure 3 – Compressional-wave velocity behavior for a rock saturated with oil as a function of temperature (green triangles, to 4.83 MPa and brown diamonds, to 2.07 MPa) and the pure oil (blue discs). Modified from Vasquez et al., 1999.

Illustrated in Figure 4 is an example of behavior of the of compressional and shear-wave velocities in a reservoir with the change in pressure and saturation. Generally, the compressional velocity increases with decreasing fluid compressibility.

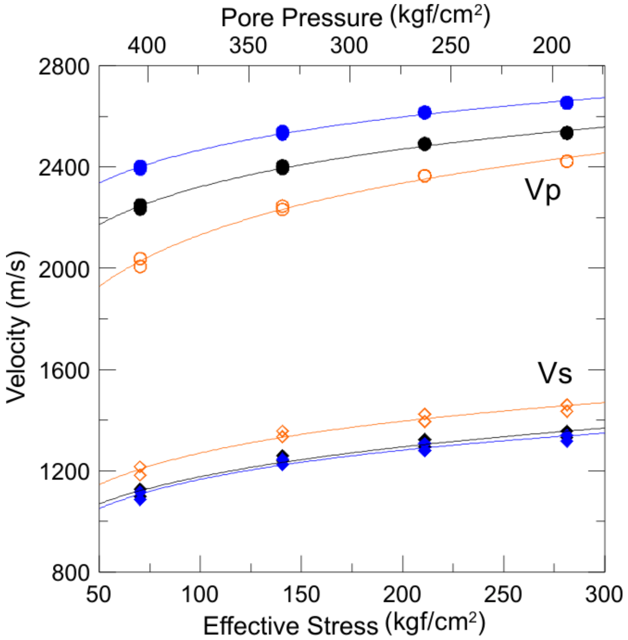

Figure 4 - Behavior of the velocities of a reservoir rock with stress for different saturations, water and residual oil (blue) original fluid (black) residual oil and gas (orange). Modified from Vasquez et al., 2005.

It is important to point out that 4D seismic feasibility studies are also indispensable during the interpretation of the time-lapse seismic results. A notable example of seismic monitoring in Brazilian reservoirs is the Marlin Field, its interpretation was strongly supported by rock physics modeling based on samples, well logs and also the reservoir simulation model results.

Discussion and Conclusions

Rock physics of Rocks is an important tool for seismic interpretation both in exploration and development of oil fields. It is now part of the seismic inversion process and has been also included in seismic imaging. Despite the progress of theoretical research and different field measurement methods, laboratory analyses are indispensable.

Well logs contain a dense and high resolution sampling of rock physics data. On the other hand, it may be contaminated by effects related to borehole conditions, for instance. A direct measurement of rock physical properties on laboratory presents still higher resolution, but it is difficult and expensive to achieve a dense sampling. In some circumstances, lab data may be also corrupted by undesired effects. It is and important and fundamental issue the right choice of rock physical inputs to seismic inversion and modeling.

Acknowledgments

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