

## We N105 08

# Incorporating Seismic Velocity Data in AVO/AVA Low Frequency Models by Honoring Local Geology

B. Hak (CGG) & P. Mesdag\* (CGG)

## SUMMARY

---

Low frequency information is required for quantitative reservoir characterization. Because borehole measurements are laterally sparse and preferential towards reservoir locations, there is much uncertainty on the low frequency models away from well control. Methods to improve the reliability of the low frequency data include the use of low frequency update schemes or seismic attribute maps. The use of seismic velocity data for trend modeling is well recognized, but the methodology for incorporating the velocity is not always clearly described. Especially in case of an AVO/AVA study, where low frequency information for several elastic properties is required, a rigorous workflow is desired. Here, we propose a method to include seismic velocity data. The methodology uses local geological knowledge through rock physics relations. We validate the method by comparing results of a more common method with our proposed workflow at blind wells. This shows that a low frequency model that does not use the velocity data misses significant lateral variations that are representative of the local geology.

## Introduction

Low frequency elastic information is an important factor to properly convert reflections into impedance layers and do quantitative reservoir characterization work. Reflections are the quotient of elastic contrasts and the local, absolute elastic amplitude. The elastic contrast comes mainly from seismic data. The absolute elastic amplitude is not in the seismic bandwidth and primarily comes from constructed low frequency models. Typically, low frequency models are built by combining borehole log data with a structural model and a mathematical weighting scheme. The structural model is commonly formed by horizon & fault interpretations and rules that govern the “internal” stratigraphic layering. Borehole log data is vertically densely sampled, but laterally sparse and often preferential towards reservoir locations. Combined with simple mathematical interpolation schemes, conventional low frequency models can easily result in unrealistic low frequency models when there is structure in the subsurface. A method to include more unbiased information in the lateral (and vertical) variability is desired, especially in cases where geological variations can be expected (e.g., considerable depth variation in the reservoir layers, faulting, salt diapirs) or when very limited and local borehole data is available. Here we use the term *conventional low frequency models* for models that have inter-/extrapolated borehole log data along a structural model with a mathematical weighting scheme.

Several alternate low frequency modeling methods have been proposed to improve the model and include more information relating to the local geology. For instance, one method updates the low frequency model with results from a first pass inversion and knowledge of the local geological setting (Jarvis, 2006; Mesdag et al., 2010). Other authors propose ways to use seismic velocity attribute information (Van Boom and Betzler, 2005; Pedersen-Tatalovic et al., 2008) or use some combination of both (Zou et al., 2013). Clearly, this list is not exhaustive, but many authors rightfully use the seismic velocity to aid their low frequency modeling. Especially ultra-low frequency energy —up to only a few Hertz— is contained in seismic velocity data. Since velocity data is laterally dense w.r.t. borehole measurements, it can provide additional information about the lateral variation of the elastic properties. Methods regularly use only part of the seismic velocity cube as guiding attribute. In addition, the different elastic parameters of AVO/AVA studies require a different treatment of the observed velocity variations. For these AVO/AVA studies a more rigorous workflow is desired.

In this paper we describe a methodology how to do this. The method can be of particular interest at an exploration stage where borehole log data is very sparse, but a quantitative analysis is important. Another interesting scenario occurs when using broadband seismic, as fully data driven and quantitative reservoir property estimation then becomes possible.

## Methodology

Variations in the seismic velocity typically are related to the variations in other (elastic) properties, such as S-velocity or density. However, the specific relationship depends on the lithology and some rock physics model. Well-known empirical relations include Gardner’s rule, which is routinely modified to the specific geology of the region. Here, we proposed to utilize such rock physics relations in the following manner.

First, the measured borehole P-velocity and the seismic velocity are compared, which need to agree for confidence and validity of the approach. Second, rock physics relations are constructed that connect the velocity to the other elastic properties. The ultra-low frequency models that follow from applying these relations to the seismic velocity are calibrated to the borehole data. This calibration should be done at a similar level of detail and thus requires upscaling the borehole data to the detail of the seismic velocity. Finally, the results are merged in with conventional low frequency models, in order to fill the gap between the highest frequencies of the created ultra-low frequency model and the lowest seismic frequencies. In the next section, a case study demonstrates this methodology.

## Case study

The case study concerns the Amberjack field in the Gulf of Mexico, offshore, block MC109. The area is controlled by channel systems and predominantly consists of sands and shales. The geological setting is explained in more detail in Mayall et al. (1992).

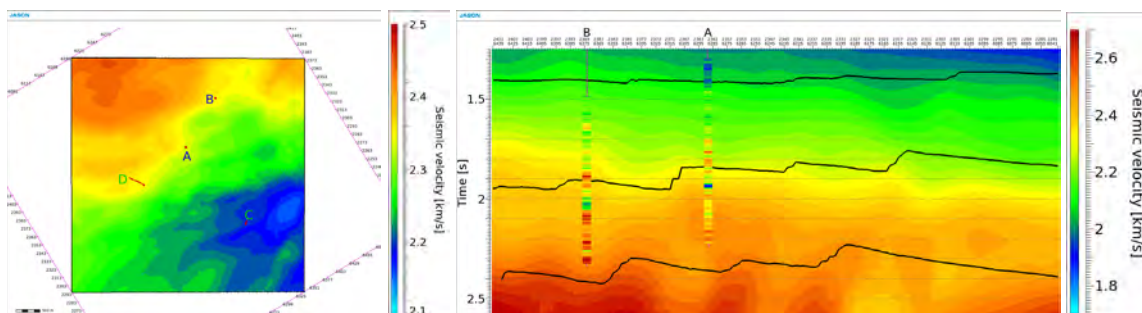
The dataset we use for this study includes two wells, three horizon interpretations, and a seismic velocity cube. Both wells are located in the (northern) center of the survey (wells A & B). The horizons include the top, middle, and base of the zone of interest, where the stratigraphy is generally conformal to top and base. A frequency of 3 Hz was identified as the upper limit of the seismic velocity frequency content. Two additional blind wells (wells C & D) are available for validation of the method and are not used elsewhere. Figure 1 shows a map of the study area and a north-south cross-section through both well locations. From the map it is seen that the region has some obvious large-scale velocity variation, which is related to faulting. Both project wells and blind well D lie in the northern fault block. Well C lies in the central fault block.

## Results

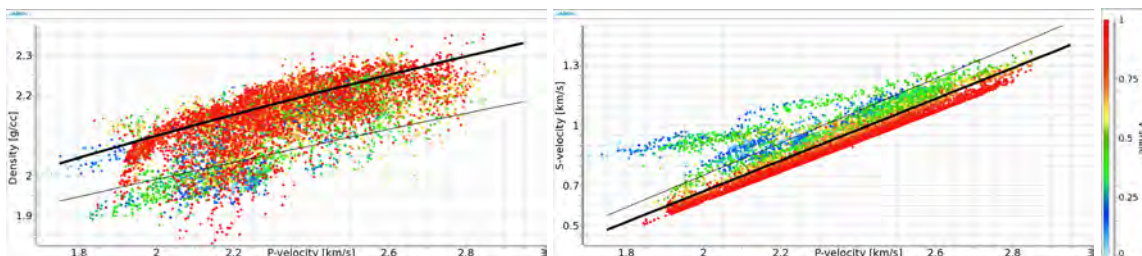
Figure 2 shows crossplots from which rock physics relations between P-velocity & density and P-velocity & S-velocity were established. The data trend matches reasonably well with standard empirical shale relations by Gardner and Castagna as found in Mavko et al. (1998). Hence, in this study we used the following equations.

$$\rho = -0.0261 V_p^2 + 0.373 V_p + 1.458 \quad \text{and} \quad V_s = 0.76969 V_p - 0.86735, \quad (1)$$

where  $\rho$  is the density (g/cc), and  $V_p$  &  $V_s$  are the P-velocity and S-velocity (km/s).



**Figure 1** The left panel shows the survey outlines of the study (black), including wells, where (used) project wells are shown in blue, blind wells are shown in green. In the map, the color represents the average (seismic) velocity in the area of interest. The right panel shows a cross-section through both project wells with the seismic velocity & horizons, where wells display the measured P-velocity.



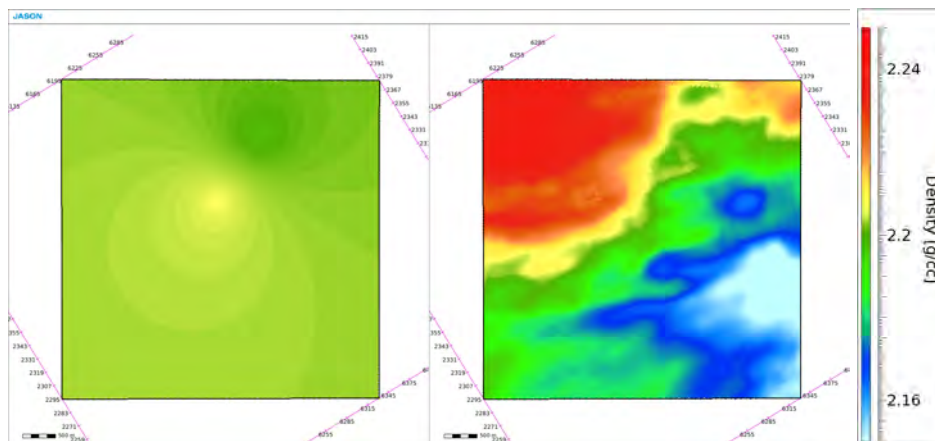
**Figure 2** Crossplot of P-velocity & density (left panel) and P-velocity & S-velocity (right panel). The left panel includes Gardner's shale polynomial (thick black line) and Gardner's sandstone polynomial (thin black line). The right panel shows Castagna's relation for shale and sandstone (thick and thin black line, respectively). The data is color-coded by  $V_{shale}$ , where warmer colors indicate more shale.

The equations (1) are used to transform the seismic velocity into the relevant elastic properties that can be used for inversion, i.e., P-impedance, S-impedance, and density. These properties are then calibrated to match the borehole log data filtered back to 3 Hz. Note that filtering to a (very) low frequency may require extending the borehole log data and possibly editing the logs so that local events are not included.

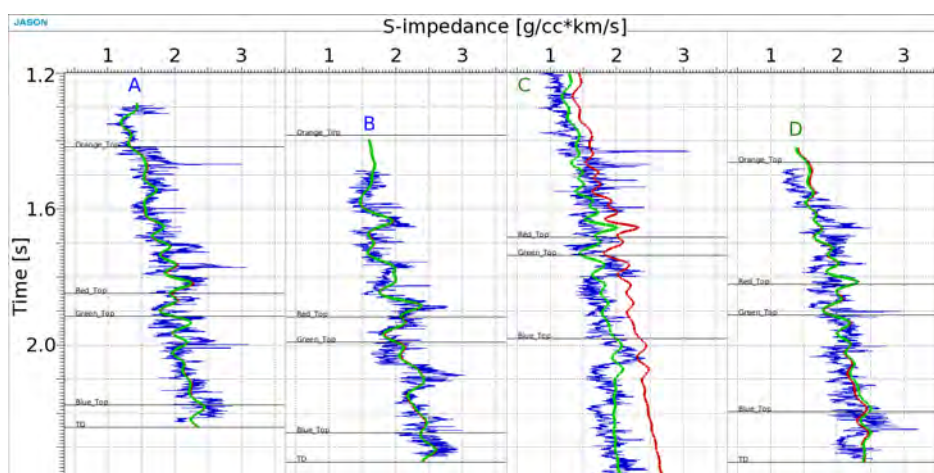
Finally, the results are merged with a conventional low frequency model, in this case a model that used inverse distance weighting for the borehole log data interpolation. Data were merged at 3 Hz (overlap 2 Hz). Figures 3–5 compare the results of the conventional method with the results of this workflow, directly and at the blind well locations. The results are summarized in the concluding section.

## Conclusions

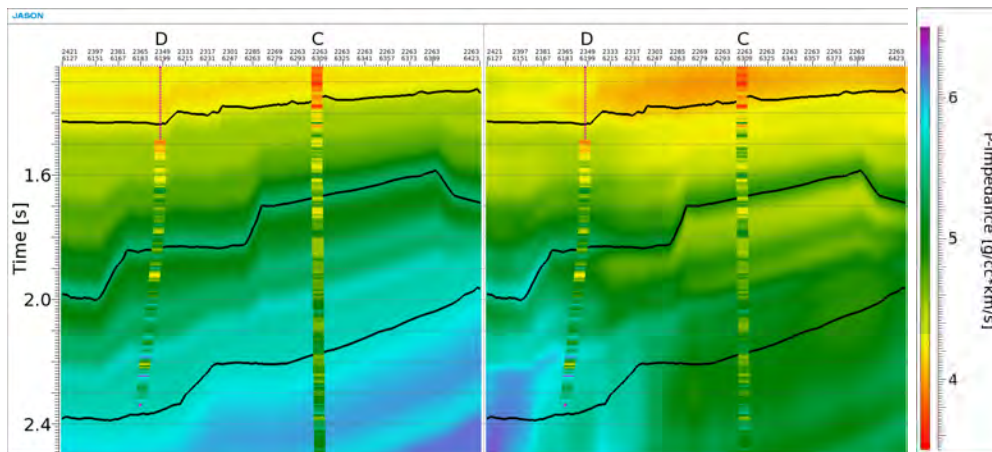
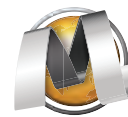
A methodology was described to rigorously incorporate seismic velocity data into the low frequency model building for AVO/AVA inversion work. The method uses the complete velocity cube, rather than attribute maps and is able to pick up and improve both lateral and vertical variations. In addition, the method is used to build models for simultaneous AVO/AVA inversion using consistent rock physics relations. The following observations hold for each modeled elastic property (P-impedance, S-impedance and density).



**Figure 3** Map showing the average density of the lower section of the modeling interval for a conventional low frequency density model (left panel) and for the density model that uses the seismic velocity trend (right panel).



**Figure 4** Borehole S-impedance data (blue) for all wells (ftr: A, B, C, D) together with pseudo-logs for the conventional model (red) and model that uses the seismic velocity (green). Wells C & D are blind.



**Figure 5** Validation of the modeling results by comparing P-impedance low frequency properties and borehole measurements at the blind wells. The left panel shows the results of a conventional low frequency model, the right panel shows the results when using the seismic velocity data as described here.

Figure 3 shows that the method integrates the lateral variation of the velocity into its model, rather than imposing a mathematical interpolation scheme. Figure 4 and Figure 5 show that by doing so, the lateral variation is much better described by the low frequency model, with a much better match at well C. In Figure 4, the difference can also be noticed at well D, but since that well is in the same fault block as wells A & B, the variation in the background trend is minor. In Figure 5, note that P-impedance values change across the fault from well D to well C. This variability is not at all described by the conventional model, whereas it is described by the model obtained from the workflow described in this paper. Further, the deep low-to-moderate impedance values at well C have not been captured at all by the conventional model. Having a good match at both blind wells gives confidence in the low frequency model result elsewhere and in further quantitative characterization work.

Part of the success of this methodology comes from using consistent rock physics relations rather than simple velocity scaling. For instance, when simple scaling relations between P-velocity & P-impedance and P-velocity & S-impedance are applied, unrealistic  $V_p/V_s$  ratio trends can potentially result.

### Acknowledgements

The author would like to thank Stone Energy for kindly providing the seismic data and his colleagues at CGG GeoSoftware for their advice and suggestions. Special thanks to Menne Schakel, who helped to evaluate the methodology and improve this abstract.

### References

- Jarvis, K. [2006] Integrating well and seismic data for reservoir characterization: Risks and rewards. *Australian Earth Sciences Convention 2006*, Extended Abstracts, MV6.
- Mavko, G., Mukerji, T. and Dvorkin, J. [1998] *The rock physics handbook: tools for seismic analysis in porous media*. Cambridge University Press, Cambridge, UK, 1 edn.
- Mayall, M.J., Yeilding, C.A., Oldroyd, J.D., Pulham, A.J. and Sakurai, S. [1992] Facies in a Shelf-Edge Delta – An Example from the Subsurface of the Gulf of Mexico, Middle Pliocene, Mississippi Canyon, Block 109. *AAPG Bulletin*, **76**(4), 435-448.
- Mesdag, P., Marquez, D., De Groot, L. and Aubin, V. [2010] Updating Low Frequency Model. *72<sup>nd</sup> EAGE Conference & Exhibition*, Expanded Abstracts, F027.
- Pedersen-Tatalovic, R., Uldall, A., Jacobsen, N.L., Hansen, T.M. and Mosegaard, K. [2008] Event-based lowfrequency impedance modelling using well logs and seismic attributes. *The Leading Edge*, **27**(5), 592-603.
- Van Boom, R. and Betzler, V. [2005] Improved low frequency model building for seismic inversion. *67<sup>th</sup> EAGE Conference & Exhibition*, Expanded Abstracts, F006.
- Zou, Z., Ling, Y., Wang, Y., Gao, J. and Xi, X. [2013] Low-frequency Impedance Modeling Based on Well Logs and Seismic Attributes. *75<sup>th</sup> EAGE Conference & Exhibition*, Expanded Abstracts, We P02 14.