Seismic uncertainty estimation in reservoir structural modelling

Vinicius Ramos Pinto[1]*, Carlos Eduardo B. de S. Abreu[2], Rubens C. Monteiro[2], João Rosseto[2] and Garrett M. Leahy[1] introduce a methodology to allow reservoir modellers to rapidly assess uncertainty during the seismic interpretation phase.

Introduction

Seismic interpretation is an important step in the reservoir model building workflow, and involves mapping the main surfaces and faults to establish the structural framework of the studied reservoir. However, uncertainties are inherently related to the seismic data due to several factors, such as limited registered bandwidth, structural and stratigraphic complexities associated to the reservoir encasing rocks and overburden, to seismic acquisition and processing workflows, energy spreading, tuning effects and noise, among others.

Another important source of uncertainty – which is seldom treated – is conceptual uncertainty introduced by the interpreter. Bond et al. (2007), for example, present different interpretations obtained from the same seismic image. Despite the nature of the sources, these effects must be addressed in order to predict their impact on subsequent reservoir modelling steps and volume calculations.

MacDonald et al. (2009) provide a description of the uncertainties present in each step of the reservoir modelling process. Leahy and Skorstad (2013) present a new workflow to quantify the uncertainties in seismic interpretation and use this information in the further modelling steps. Leahy et al. (2014) use the horizon uncertainty information to enhance the quality of the surface mapping, and hence reduce ambiguity on the interpreted surface.

However, irrespective of the advantages in correctly identifying and quantifying the level of uncertainty on the interpretation of geological surfaces, it remains a highly labour intensive and time-consuming activity. Many interpreters do not have the available time or expertise to perform a detailed inspection of their data.

Furthermore, each interpreter may quantify uncertainty in subtly different ways, creating some difficulty when comparing reservoir interpretations. The result is that all too often uncertainty analysis is superficially performed or completely absent, impacting the economic evaluation of the prospects.

In order to provide valuable uncertainty analysis as fast and as accurately as possible, a new methodology to quickly assess the uncertainty information based on seismic data has been developed.

This methodology lets the interpreter construct an uncertainty map through a combination of seismic attributes and can be used as initial, or ‘a priori’, information to correctly discriminate the low and high-resolution regions that correspond to areas of major and minor uncertainties, respectively.

This approach of building the uncertainty map and the details of each step are described in the next section.

The proposed methodology

Firstly, for the purpose of this study, it is assumed that the external geometry and the internal architecture of the reservoir have been built. The uncertainty quantification involved in this process is of vital importance to measure its impact on further volume calculations.

However, it is sometimes difficult to investigate the amount of uncertainty present in the data. The seismic signal can be distorted by many sources and most of these sources lay together on the post-stack seismic data. As it is very difficult to decompose the contribution of each factor separately disturbing the data, the interpreter has to commonly deal with the sources of uncertainty when analysing the final data.

Some techniques have been introduced to coherently identify the uncertainties presented on the seismic image. Leahy and Skorstad (2013) and Leahy et al. (2014) use visual criterion to establish the size of ellipses that control the vertical and lateral uncertainties.

Although this methodology is very useful – depending on the quality of the seismic data – it is very difficult to determine the value of the uncertainty based on visual inspection. In areas where there is no signal to pursue or with random noise, the reflectors are completely untraceable or almost absent.

A quick and simple way to extract the uncertainty information from seismic data is proposed in this article. It configures seismic-based information so that it is considered when performing the uncertainty quantification.

According to Widess (1973) and Kalweit and Wood (1982), the wavelength map can bring out information about data resolution and represents the minimal uncertainty of the seismic data. Here, we assume that – if it was possible to have no distortion or noise affecting the seismic data – even then the resolution constraints would be present.

The wavelength map can be constructed from the velocity and frequency information, according to the Equation 1:

$$v = \lambda \bullet f \tag{1}$$

where the represents the wavelength, v is the interval velocity and f is the frequency information of a particular interpreted

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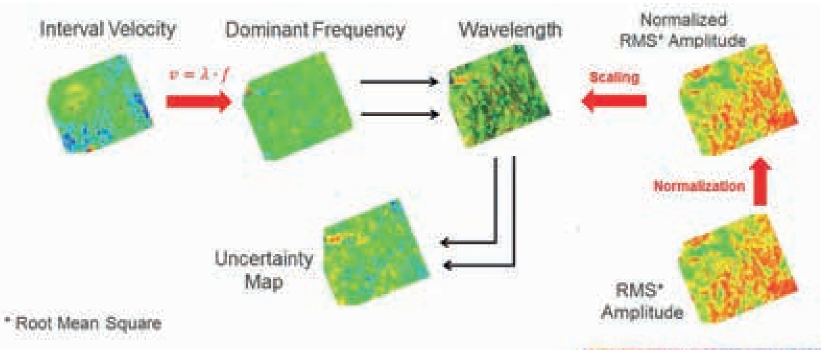

Figure 1 Diagram showing the methodology for achieving the uncertainty map from seismic attributes.

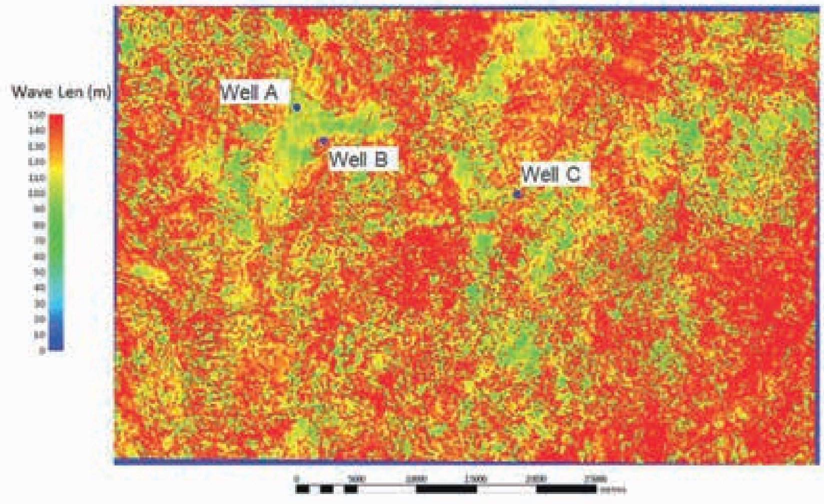

Figure 2 Resolution map (λ/4) showing the regions with low (red and yellow) and high (green and blue) data resolution.

surface. The wavelength map represents the uncertainty that can be attributed to the wavelet characteristics.

Additionally, the root mean square (RMS) amplitude can be very useful in measuring the level of incoherent noise present on seismic data. The RMS amplitude is directly proportional to the signal-to-noise ratio (SNR) and provides information about where seismic quality degrades.

Because of this, it is plausible to think that where the SNR is high, there must be enough quality to uniquely estimate seismic uncertainty through the wavelength map. Otherwise, where SNR is low, the uncertainty must be higher than predicted by the wavelength map.

In this scenario, the RMS amplitude map may be used as a weighting (scaling) factor map to rescale the wavelength map. However, the RMS amplitude map needs to be normalized to be able to act as a scaling factor. Equation 2 presents the normalization applied to the RMS.

$$A_{rms}^{n} = 1 + \left(1 - \frac{A_{rms}}{\max\left(A_{rms}\right)}\right) \cdot p \qquad (2)$$

where the terms A_{rms} and A_{rms}^{n} represent the Original and Normalized RMS Amplitude, respectively – and max (A_{rms}) is the maximum RMS amplitude along the interpreted surface.

Additionally, the term p denotes a subjective parameter that can be introduced by the interpreter in order to better characterize how the normalization is to be done.

The suitable values for p to be representative of the uncertainty present on the seismic data ranged from 0.1 to 0.4, which means an increase on the Normalized RMS amplitude on the low-quality regions of up to 10% to 40%. These values have been found due to the comparison of the mismatch in the wells present in the region.

However, this decision is up to the interpreter and higher values can be applied. This should be decided based on previous experience about the area or even on visual information. Due to this, the methodology can be configured as a semi-quantitative method to describe the seismic uncertainty. Moreover, the term can be thought of as a weighting penalty factor, increasing the values of the resolution map.

Note the assumption of the penalty factor leads this method to strongly mimic other frequency-based uncertainty estimates – for example the second moment calculation. In effect, p establishes a baseline SNR to identify a 'valid' seismic event. The methodology described above can be seen in Figure 1, which demonstrates all the involved steps from the seismic attributes to the final uncertainty map.

Discussion of results

Figure 2 presents some red and yellow regions where the wavelength values are higher and represent regions with high wavelength, and hence, low seismic resolution data. One can see a very noisy pattern related to those areas, which is due to the dominant frequency information that also has a noisy pattern.

On the other hand, the green (and blue) colours represent regions with lower wavelength or, in the same sense, high resolution data. Despite that, figure 2 has not been smoothed, although it might be advisable in order to be more representative and avoid some unrealistic values.

The values present in Figure 2 have been divided by four (λ/4), in order to represent the limit of resolution, according to Widess (1973). The difference between the concepts of detectability and resolution is interesting and valid, but the idea of this work is to establish a threshold for interpretability.

Figure 3 presents the RMS amplitude map. The data has been smoothed to better identify the regions with different behaviour regarding RMS Amplitude values. The northern and centre western part of Figure 2 and Figure 3 present the lower and higher values for the wavelength and RMS amplitude maps, respectively. These areas represent the regions with high seismic quality and one can see a clear match between them.

In general, the p factor is only to be applied on the low-resolution areas shown by Figures 2 and 3. The normalized RMS amplitude map ranges from 1 to $1+ p$, where values close to 1 represent unchanged areas and values close to $1 + p$ represent areas with increased values due to the penalty factor. Additionally, the normalization of the RMS amplitude data does not change the structure of the original map, but only rescales the range of the data.

The RMS amplitude map scaled the resolution map. The normalization was performed using a penalty factor of 0.4, i.e. the low-quality areas were increased by a factor of 40% while the high-quality ones remained unchanged. In fact, the choice of the penalty factor can have a considerable impact on the final uncertainty map, but it is important to consider that this impact is going to be verified only in the low-quality areas.

Figure 4 shows the uncertainty map obtained from the wavelength and RMS amplitude maps. This map represents the final seismic uncertainty map and shows how the quality of the seismic data is distributed along the interpreted surface. Through a detailed inspection of Figure 4 and comparing this one to Figure 2 and Figure 3, one can see the highlighting of some regions that would not have been possible when analysing the maps separately.

The uncertainty map (Figure 4) has been used to determine seismic uncertainty envelopes in the same sense as Leahy and Skorstad (2013). Figure 5 presents a seismic intersection view with the uncertainty envelopes calculated based on the uncertainty map from figure 4 (top of the figure). One can see the difference in thickness when going from regions close to well C to the eastern portion of the intersection line. In these areas, close to well C, the thickness of the envelope is about 150 m, which is aligned to the uncertainty map (note yellow arrow). On the other hand, in areas close to the eastern part of the intersection the line and the thickness of the envelope increase to approximately 200 m due to noise artifacts.

Thus, the seismic envelope can be thought of as a volume of uncertainty where the interpreters can only estimate the

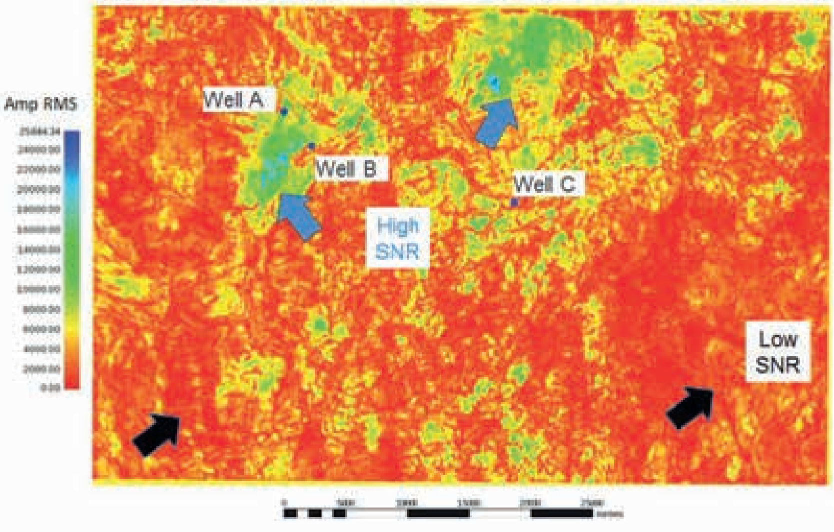

Figure 3 RMS amplitude map. The data has been smoothed in order to filter the noisy pattern out of the resolution map (Figure 2).

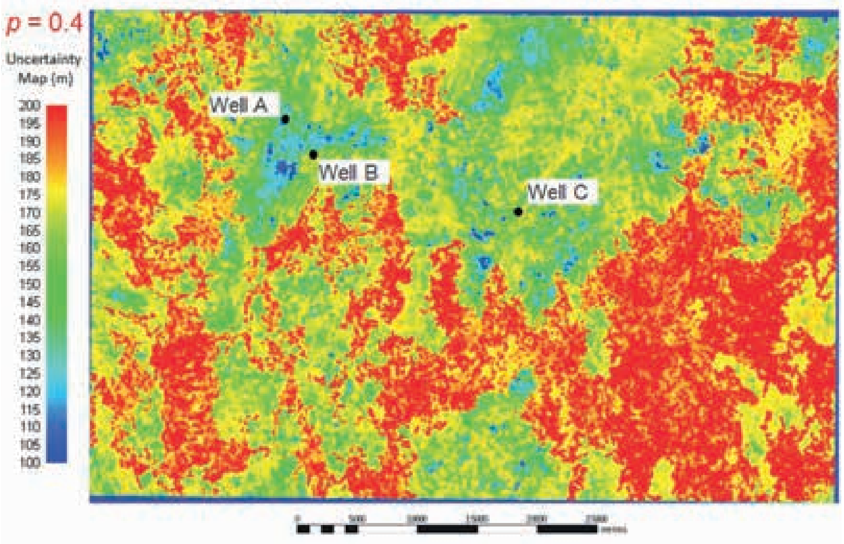

Figure 4 The final uncertainty map obtained from the wavelength and RMS amplitude maps. The red and yellow areas represent the high uncertainty regions and the green (and blue) represent the low uncertainty regions.

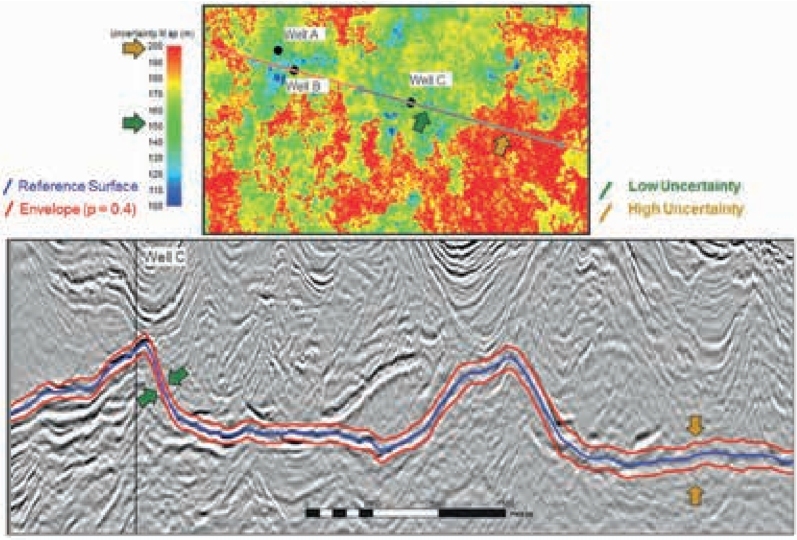

Figure 5 Seismic intersection view showing the uncertainty envelope calculated based on Figure 4 (top). One can see the thickening of the envelope from left (close to well C) to right in the seismic intersection view. The envelope thickness changed from 150 m to 200 m, approximately.

position of the reflector. Due to this, a stochastic approach instead of a deterministic one should be placed in order to honour the behaviour of the data and the constraints imposed by the nature of the seismic acquisition.

Conclusions

The methodology described in this paper accounts for the effects of seismic resolution and the amount of noise during interpretation. These effects – when combined – can turn the seismic interpretation into a very labour and time-consuming activity, which can delay the decision-making process.

The aim of this work is to compensate for these in order to coherently provide a threshold for the uncertainties present on seismic interpretation and further structural modelling steps. Thus, a concept of interpretability can be introduced by comparing the uncertainty values in different regions of the data.

Seismic attributes have been used to understand how these effects are distributed along the seismic data. The wavelength map has been generated from the interval velocity and dominant frequency to evaluate the seismic resolution at the reservoir level. Additionally, the RMS amplitude has been obtained to analyse the amount of noise (SNR). Both maps have been combined in a final uncertainty map that exhibits the low and high-quality regions of the seismic data.

The RMS amplitude map has been used to scale the wavelength (resolution) map based on a particular equation. This equation represents a normalization that transforms the distribution of the RMS values into a new scale where it is possible to use the map as a scaling factor. The severity of the normalization can be controlled by a penalty factor - a parameter that controls how the increasing on the uncertainty for the ‘low quality regions will be performed.

The normalization has been performed using $p = 0.4$ for the RMS amplitude map and the final uncertainty map has been built. This can be thought of as a measure of the confidence in the interpretation. It is reasonable to think that where the uncertainty is lower, the interpretation will probably be more accurate.

Owing to the amplitude scaling factor, the calculation can be incorrect in calculating the presence of AVO effects or transitions in fluid content. It would be possible to have the calculation for different offsets stacks to get different estimates.

This kind of calculation could possibly be successful when applied towards determining fault uncertainty, but this will require some modifications, as the concepts of wavelength and resolution do not always translate exactly from horizon surfaces. This workflow can also be successfully applied in different spectral bands.

These estimates can be integrated to provide increased stability and accuracy in the final estimate. For example, they can be combined in a Bayesian framework to obtain a posterior probability distribution. Other parameters that can be added to the uncertainty analysis include illumination (hit count or fold maps) information to adapt the weighting factor.

These calculations can be applied farther down the workflow to create estimates of subsurface risk related to volumes, or even as part of drilling operations when approaching over-pressured formations.

Acknowledgements

The authors would like to thank Petrobras for providing the data and permission to publish this work.

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