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AVO Analysis with the Elastic Impedance Concept

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ABSTRACT

Since the mid 80's, Amplitude Versus Offset (AVO) attributes have been widely applied as direct hydrocarbon indicators. The evolution of the technique is leading to two new trends: (1) introduction of AVO algorithms into routine seismic processing and interpretation; (2) application of AVO attributes in reservoir characterization studies. Both trends are favored by the use of elastic impedance data, which provides the means to interpret seismic amplitudes as a function of the elastic properties of the medium, instead of a function of the contrasts between the elastic properties of neighboring rocks. With elastic impedance data, it is theoretically possible to discriminate lithology and fluid where the conventional technique fails. Best results are obtained with large bandwidth data.

INTRODUCTION

Amplitude Versus Offset (AVO) is already an established technique. Its origin may be probably due to Koefoed, whose pioneer paper, published in 1955, proposed the possibility of extracting lithologic information from reflection coefficient measures at non normal incidence angles. Koefoed's hypothesis was expanded in the mid 80's, through the contribution of Ostrander (1984), who described the influence of gas on the variation of amplitude with offset. Since then, much of the research effort has been oriented to the use of AVO attributes as Direct Hydrocarbon Indicators (DHI's).

In the recent years, two new trends have been noticed. The first trend is the introduction of AVO algorithms into routine seismic processing, which means the possibility of interpreting, simultaneously, AVO attributes and conventional data. The second trend, related to another expansion in the limits of the technique, is the application of AVO attributes in reservoir characterization studies. Two examples of both trends were given by Barros and others (1999) and Moraes and others (1999).

The extraction of reservoir attributes from AVO data may be improved if seismic amplitudes are changed to elastic perturbations of the medium. In other words, AVO data may be even more useful if represented as a function of the properties of the rocks, instead of functions of the contrast between properties of neighboring rocks. This line of research has led to the concept of elastic impedance, defined as a combination of velocity, density and Poisson's ratio, ultimately responsible for the amplitudes measured at non normal incidence.

In the definition proposed by Mukerji et al. (1998), elastic impedance depends also on the incidence angle and is built from a far offset angle trace (see also Dillon and Dvorkin, 1999). That is not the case of this paper, for which elastic impedance is independent of the measurement direction. Furthermore, the definition followed here allows the application of conventional AVO techniques with small changes, both in terms of processing routines and interpretation.

THE ELASTIC IMPEDANCE CONCEPT

Conventional AVO analysis is based on the well known approximation

$$r(\theta) \cong A + B\,\mathrm{sen}^2\,\theta \qquad (1)$$

where r is reflection coefficient, θ is incidence angle, A is the intercept and B is the gradient. Both A and B are functions of variations in the elastic properties across the interface where the reflection was generated.

Consider now a trace angle, that is, a trace in which the incidence angle is constant. If such a trace is numerically integrated along time, the result is:

$$\sum_{k=1}^{t-1} r_k(\theta) \cong A_I + B_I\,\mathrm{sen}^2\,\theta \qquad (2)$$

where t is the time index at the point the numerical integral is evaluated, whereas A_I and B_I are new versions of the intercept and gradient. In the form obtained by Rosa and Ulrych (1991), an expression for A_I is:

$$A_I = \sum_{i=1}^{t-1} r_{0,i} \cong \frac{1}{2}\left(\frac{I_t}{I_1} - 1\right) \tag{3}$$

where I is acoustic impedance. A simple approximation for B_I, based on the expression obtained by Hilterman (Verm and Hilterman, 1995), is:

$$B_I \cong -A_I + \sum_{i=1}^{t-1} \frac{\Delta\sigma_{i+1}}{(1-\sigma_i)^2}$$

where σ is Pisson's ratio. This expression may be further simplified if the following approximation is used:

$$\frac{\Delta\sigma_{i+1}}{(1-\sigma_i)^2} \cong \frac{\sigma_{i+1}}{(1-\sigma_{i+1})} - \frac{\sigma_i}{(1-\sigma_i)}$$

The result is:

$$B_I \cong -A_I + \frac{\sigma_t}{1-\sigma_t} - \frac{\sigma_1}{1-\sigma_1} \tag{4}$$

The expressions 3 and, specially, 4 are applicable in the presence of slow variation in the elastic properties. Even with such limitation, they may be useful to characterize A_I and B_I as an acoustic impedance and an elastic impedance, respectively. Furthermore, a comparison between equations 1 and 2 leads to the following conclusion: in equation 1, A and B are proportional to the variation in the elastic parameters across an interface, whereas, in equation 2, A_I and B_I depend on the elastic parameters themselves.

APPLICATION

An example of application of the technique was selected from a basically clastic Campos Basin well. In the first step, the corresponding logs, including shear velocity, were used to compute full bandwidth trace angles (reflection coefficients), without integration. The results were displayed in the form of a crossplot of intercept versus gradient, as seen in Figure 1. Two aspects in the figure are noticeable: (1) there is not a clearly defined trend associated to the background (for a discussion on this topic, see Castagna and others, 1998) and; (2) at first glance, it is not possible to isolate the outlined points, which correspond to events at the top of an oil-bearing sandstone reservoir.

The same trace angles used in Figure 1 were numerically integrated along time so that elastic and acoustic impedances could be computed in the form of new intercept and gradient data. The corresponding crossplot may be seen in Figure 2. It is noticeable, in Figure 2, the presence of somewhat isolated trends associated to different elastic behaviors. Another important point to notice is that the outlined points, which correspond to the same oil-bearing reservoir mentioned above, is now easily discriminated.

DISCUSSION

It should be emphasized that the application of expression 2 to real data leads to *relative* impedances. The word *relative* is due to three reasons: (1) expression 2 is an approximation; (2) even in an angle trace, the incidence angle may vary along time and; (3) the seismic trace does not include useful information in the frequency components close to zero Hertz. These limitations indicate that the impedances obtained with expressions 3 and 4 should be seen as band limited perturbations of the medium properties.

Crossplots of acoustic versus elastic impedances proved to be a powerful tool when the data have a large bandwidth. In this case, there are numerous applications still to be tested. Limitations in the low frequency content of the data reduce the resolution power of the technique and suggest the need for application of spectrum extrapolation techniques. Another issue, related to seismic processing, is the phase treatment, essential for the generation of elastic impedance data but less necessary for conventional AVO.

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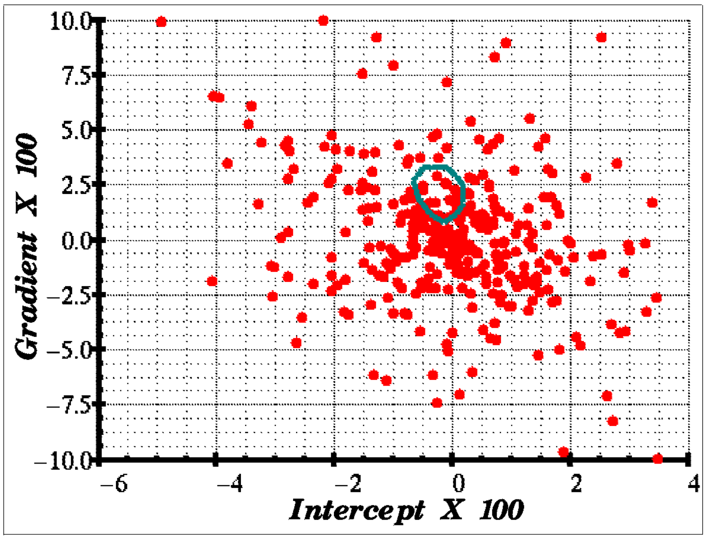

Fig. 1 – Crossplot of intercept versus gradient of reflection coefficient data. The outlined area corresponds to events at the top of the reservoir.

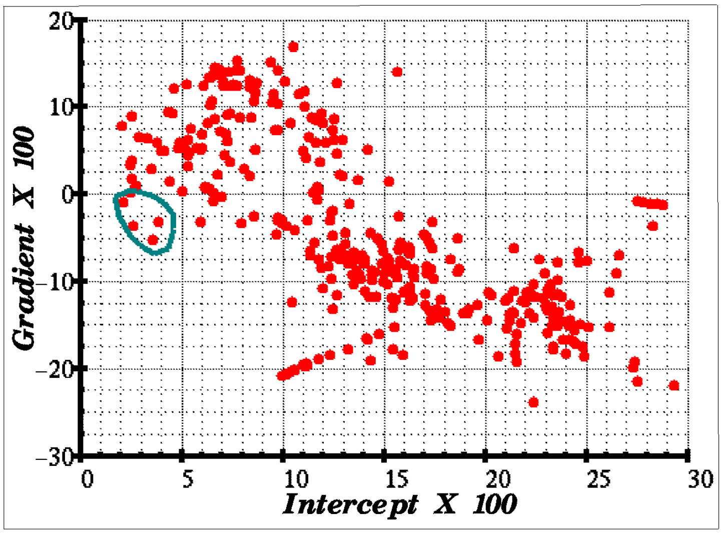

Fig. 2 – Crossplot of intercept versus gradient of time-integrated reflection coefficient data. The outlined area corresponds to events at the top of the reservoir and the straight line in the bottom center of the figure is due to a localized modification in the shear velocity log.