Quick-look AVO crossplotting from post-stack seismic data

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Summary

Identification of anomalous amplitude variation with offset can contribute significantly to prospect definition, lithology and fluid prediction, and risk reduction. Crossplotting attributes such as AVO gradient and intercept, usually derived from common depth-point gathers, is a simple and effective analysis tool. However, pre-stack seismic data are not always part of the seismic interpreter's basic dataset and are often expensive to store and time-consuming to procure. More commonly available, and cheaper to store, are limited-offset partial stacks (for example, near- and far-offset data). This paper presents a method for quick AVO crossplotting from post-stack data, using standard interpretation software.

Introduction

Almost all seismic reflections display some kind of amplitude variation with offset. Anomalous amplitude versus offset (AVO) behaviour is widely recognized as an important aid to lithology and fluid prediction. It also significantly reduces risk in exploration prospects, and can be a powerful tool in the search for new prospects (Castagna 1993).

Amplitude versus offset analysis makes use of Shuey's linear approximation to the Zoeppritz equations (Equation 1), which relates P-wave reflection coefficient R_i at angle of incidence i to AVO intercept R_0 and AVO gradient G. Crossplotting seismic events in AVO gradient–intercept space usually requires the interpreter to load pre-stack common depth-point gathers, re-interpret events in the gathers, and finally extract and plot the AVO attributes.

$$R_i = R_0 + G \sin^2 i \qquad (1)$$

Unfortunately, from the interpreter's point of view, there are drawbacks to this workflow. Pre-stack data may not be available, may take some time to load, and are often expensive to store. Furthermore, appropriate software might not be available, or be unfamiliar to the interpreter. As a result of these constraints, the candidate anomaly, which might be of critical importance, could remain just an observation, with no real evidence to back it up. Worse still, if the anomaly is subtle, it may be missed completely.

However, as Lee et al. (1998) pointed out, if a seismic reflector's amplitude A is normalized to its normal incidence value A_0, then Equation 1 may be rewritten as Equation 2. This relationship is illustrated in Figure 1.

$$A_i = A_0 + G \sin^2 i \qquad (2)$$

Since the relationship is linear, and provided A_i and i are known for at least two i (i.e. two offset ranges), partial stacks contain all the information needed to construct the amplitude versus $\sin^2 i$ plot in Figure 1. It follows that partial stacks should allow us to find A_0 and G and thus construct AVO crossplots.

Based on this premise, and notwithstanding the warnings of Castagna (1993) and Allen et al. (1993) against AVO analysis without inspecting gathers, the aim of this paper is to demonstrate how, using only simple tools in SeisWorks™ (a seismic interpretation application) and RAVE™ (an attribute plotting utility), AVO gradient and intercept may be quickly calculated and crossplotted by the interpreter.

Method

The idealized AVO plot for the top of a Class 3 sandstone shown in Figure 1 illustrates the basis for the computation of gradient and intercept. Equations 3 and 4 show how AVO gradient G and intercept A_0 are calculated for near- and far-offset amplitudes A and angles of incidence i.

$$G = (A_f - A_n) / (\sin^2 i_f - \sin^2 i_n) \qquad (3)$$

$$A_0 = A_n - G \sin^2 i_n \qquad (4)$$

The interpreter's workflow is detailed in Table 1. If the seismic data represent angle stacks, simply find the average i for the two stacks, and calculate $\sin^2 i$ for each. The difference in $\sin^2 i$ for the near and far offset datasets can be calculated and used as the basis for finding G, and then A_0. Constant offset muted stacks require the equivalent angles to be calculated, as shown in Table 1.

hypothetical anomaly with a single seismic line is shown in Figure 2. A horizon is interpreted in two parts, one clearly within, the other clearly outwith the anomaly. It is important to capture a significant number of points both inside and outside the candidate anomaly. This horizon is interpreted in both the near- and far-offset datasets. The calculations in Table 1 are performed on these seismic horizons, and since most of the operations are done in SeisWorks™ the entire algorithm can be rapidly executed. It is helpful if these two sets of points are unambiguously distinguished by some other independent attribute, such as x- or y-position. This enables easy identification in the crossplot, as schematically represented in Figure 2. The two sets of points are clearly identifiable and indicate that the bright spot has a Class 3 AVO response.

References

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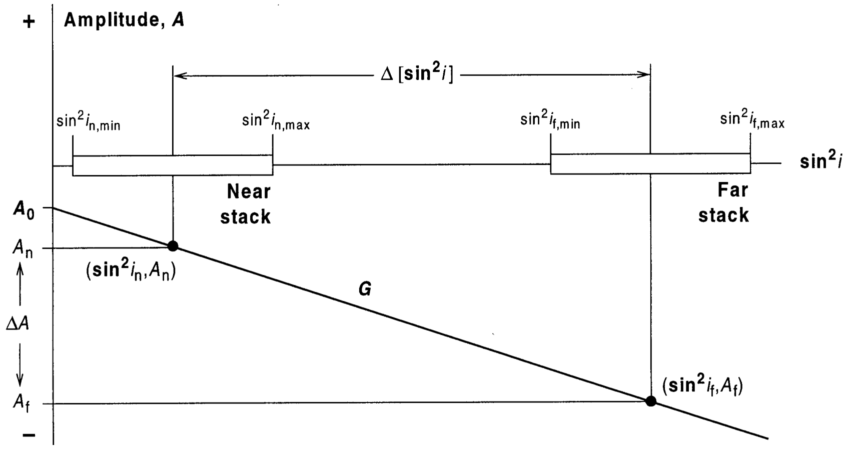

Figure 1 Amplitude versus $\sin^2 i$ crossplot for a hypothetical seismic reflector. Provided the offset ranges are known, the amplitudes in the near- and far-offset stacks allow computation of G and A_0.

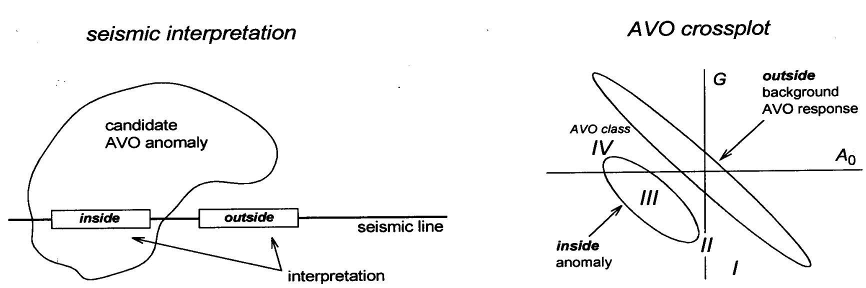

Figure 2 The candidate anomaly (left) is interpreted on a single line, inside and outside the apparent boundary, in both the near- and far-offset stacks. These horizons are used to calculate G and A_0 (see Table 1), which are then crossplotted (right). For helpful pointers in crossplot interpretation, see Castagna & Swan (1997) and Simm et al. (2000).

Background information

1) Find the inner and outer mutes for each of the offset stacks: are they angle stacks or constant offset stacks?
2) If angle stacks, find the average angle for each offset range, e.g. $i_n = (i_{n,max} - i_{n,min}) / 2$ for the near-offset data
3) If constant offset stacks
   a Calculate the average offset for each offset range, e.g. $O_n = (O_{n,max} - O_{n,min}) / 2$ for the near-offset data
   b Find the average velocity v for the area of interest
   c Calculate $i_n = \tan^{-1}(O_n/vt)$ and $i_f = \tan^{-1}(O_f/vt)$, where t = two-way travel time for the interval of interest
4) Calculate $\sin^2 i_n$ and $\sin^2 i_f$
5) Find the difference between the two, $\Delta[\sin^2 i] = \sin^2 i_f - \sin^2 i_n$

Interpretation and horizon calculations in SeisWorks™

6) Interpret a line in the near-offset data, making horizon N; interpret both inside and outside the candidate AVO anomaly, for comparison later
7) Interpret the same event, on the same line and in the same place, in the far-offset data, making horizon F
8) Extract amplitudes from the near-offset data on N, making horizon A_n
9) Extract amplitudes from the far-offset data on F, making horizon A_f
10) Subtract horizon A_n from horizon A_f: $A_f - A_n = \Delta A$
11) Calculate the AVO gradient horizon, $G = \Delta A / \Delta[\sin^2 i]$
12) Calculate a temporary horizon $H = G \times \sin^2 i_n$
13) Calculate the AVO intercept horizon $A_0 = A_n - H$

Crossplotting in RAVE™

Import horizons G and A_0, plus any others you wish to compare with, such as time, amplitude or other attributes
Open a 2D crossplot, putting G on the y-axis, A_0 on the x-axis, and your differentiating attribute (e.g. x-position) for the colourbar

Table 1 Recipe for calculating gradient from amplitude and sine squared of offset angle