



Constraining Anisotropy – Lessons from 2D Modeling

Rob Holt*

WesternGeco, Calgary, Alberta, Canada
rholt@calgary.westerngeco.slb.com

Abstract

This paper examines the amount of quantitative information it is possible to derive about the Thomsen weak anisotropy parameters epsilon and delta from 2D anisotropic modeling. Modeling of observed residual curvature after isotropic depth migration shows that it is possible to constrain the ranges of these anisotropy parameters. With this information it would be possible, for example, to estimate the lateral positional uncertainty of a depth migration.

Introduction – Questions about Anisotropy

As prestack anisotropic depth migration becomes more and more widely accepted as the gold standard of seismic image processing, oil company interpreters are asking challenging questions about the simple anisotropic assumptions commonly used by seismic processing contractors in the Western Canadian Sedimentary Basin: Why use Thomsen anisotropic parameters epsilon = 12% and delta = 3% throughout the whole clastic sequence when numerous physical measurements have shown that anisotropy varies with lithology and depth? Isn't the anisotropy just limited to the more shaly formations in the section? How sensitive are the Thomsen anisotropy parameters? Et cetera, et cetera.

These questions are not easy to answer. Anisotropy parameters are difficult to determine with precision. Velocity moveout and anisotropic moveout look identical on migrated gathers when reflection angles are less than 30 degrees. Anisotropically migrated stacks have very subtle differences when the anisotropy parameters are changed by 3% or less. So why do we even bother with anisotropy? Critically, lateral image position (and therefore the accuracy of well drilling locations) is sensitive to magnitude of the anisotropy and orientation of the anisotropic dip. An overburden dip of just 15 degrees can lead to wells being mispositioned by more than 100m in the Foothills after interpretation is done on an isotropically migrated stack.

So, whilst accurate imaging and well positioning is sensitive to the correct determination of anisotropy, the accurate determination of the anisotropic parameters is very difficult to achieve. A number of options are available. The simplest is just to use the well-publicized 'standard' anisotropy parameters which work surprisingly well *in some cases*. Another, more time-consuming technique, is the 'trial and error' method where different anisotropic scenarios are run and the resulting images are compared, both to each other and all available well control. A third method is to model the anisotropy by accurate ray tracing through a simplified geological model, followed by the determination of the range of anisotropic parameters that match the observed seismic data. This paper shows examples of the sort of quantitative information that can be derived from 2D anisotropic modeling.



Anisotropic Modeling Method

A multi-layer 2D anisotropic ray tracer was written using Microsoft Excel. Two-way travel times are determined along the ray paths. Anisotropic moveout is determined by subtracting hyperbolic moveout from the predicted two-way travel times and the difference is then stretched to depth. Both vertical and lateral mispositioning errors are inferred. Extensive testing was performed to verify the ray tracer, from basic tests such as whether or not the code honors Snell's law for isotropic refractions, to checking the predictions against real data.

Modeling results are presented for the following questions:

- How exactly does anisotropy affect the ray path?
- Is it possible to differentiate between stronger anisotropy limited to a short depth interval and weaker anisotropy over a much larger depth interval?
- How sensitive is the image depth mispositioning to anisotropy parameters epsilon and delta?
- Can we quantify the effects of the different factors that affect sideslip (lateral mispositioning)?

Result 1 – How does anisotropy affect the ray path?

The relationship between anisotropy and ray bending is complex. In certain cases, notably the VTI case with the same amount of anisotropy on either side of the refractor, the relationship between anisotropic incidence and refraction angles is almost the same as the equivalent isotropic relationship (Snell's Law). As the anisotropic dip and anisotropy field becomes more complex, the relationship between angle of incidence and angle of refraction also becomes more complex (Figure 1). The only way to accurately determine the ray path is through ray tracing.

Result 2 – Is it possible to differentiate between stronger anisotropy limited to a short depth interval and weaker anisotropy over a much larger depth interval?

This is a question that comes up frequently in client meetings. Physical measurements consistently show that Shale has a higher degree of anisotropy than Sandstone (Thomsen, 1986; Wang, 2002). For this reason clients wonder if we are applying too much anisotropy when constant anisotropy estimates such as epsilon = 12% and delta = 3% are applied to the whole section. Modeling can answer this question (Figure 2).

Result 3 – How sensitive is the image depth mispositioning to epsilon and delta?

Certain authors have described delta as the 'depthing' parameter (eg. Audebert *et al.*, 2001). This is only true when velocities are picked over a very limited range of offsets. As further and further offsets are included in the velocity analysis, epsilon has a greater and greater role in the depth error. Over typical offset ranges used in velocity analysis (maximum offset equals depth), epsilon and delta can have a similar influence on the depth error (Figure 3).

Result 4 - Can we quantify the contribution of the different factors that affect sideslip?

By defining sideslip as the distance between the midpoint and the reflection point, it is easy to quantify how sideslip is dependent upon key factors such as TTI dip, epsilon and delta using 2D modeling (Figure 4). Please note that this should not be considered a general result as it was derived for a near offset trace using a very simple velocity model. Sideslip varies significantly with offset as described by Vestrum & Fowler (2005).



Conclusions

Applied correctly and with reference to migrated seismic gathers and well information, 2D anisotropic modeling can be a valuable tool for both constraining the depth migration Thomsen weak anisotropic parameters epsilon and delta, and for understanding the residual positional uncertainty after depth migration.

References

Audebert, F., Granger, P.Y., Gerea, C., & Herrenschildt, A., 2001. Can joint PP and PS velocity analysis manage to corner delta, the anisotropic depthing parameter. SEG International Exposition and 71st Annual Meeting, Ani 2.6.

Thomsen, L., 1986. Weak Elastic Anisotropy. *Geophysics*, v.51, p.1954-1966.

Vestrum, R.W., & Fowler, P.J., 2005, Quantifying imaging and position problems beneath TTI media: 67th Meeting EAGE, E026.

Wang, Z., 2002. Seismic anisotropy in sedimentary rocks, part 2: Laboratory data. *Geophysics*, v.67, p.1423-1440.

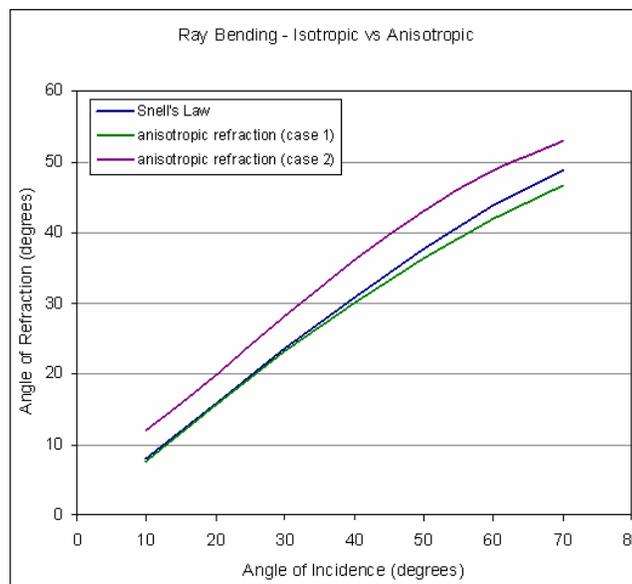


Figure 1. Diagram showing the complex relationship between the angle of incidence and refraction when dipping anisotropy is present.

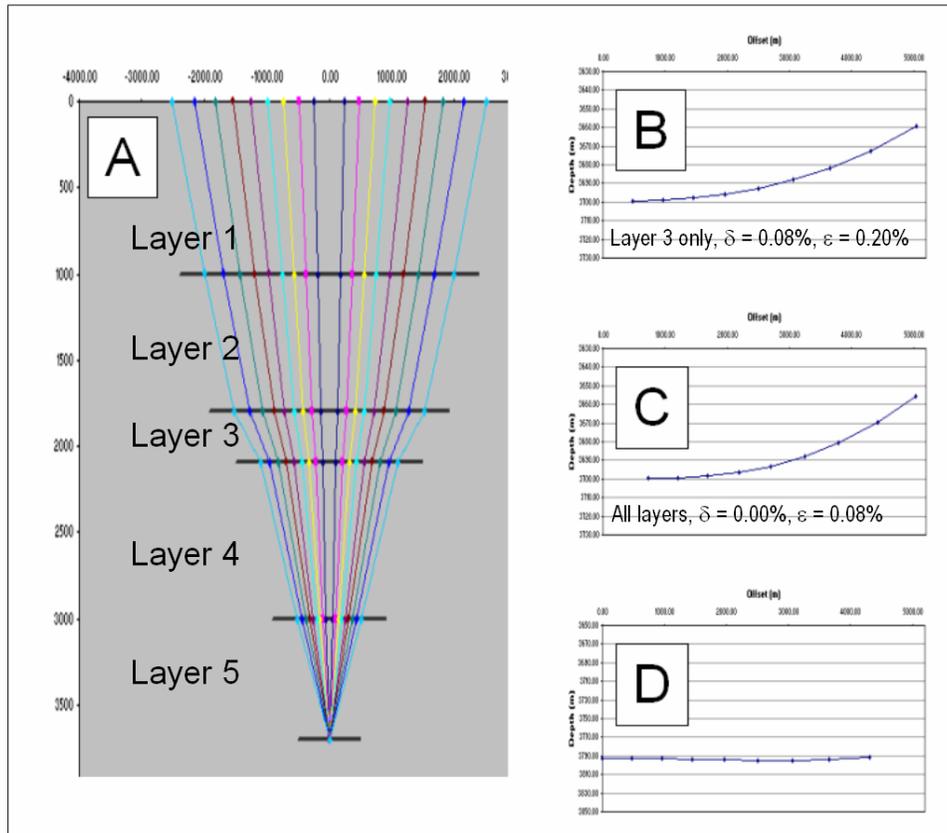


Figure 2. Modeling shows that strong anisotropy over a small depth range creates a relatively small amount of pull up on the depth migrated gather (B). The isotropic depth migration velocity that flattens out this moveout would result in depths that are ~2.5% too deep (D). An equivalent amount of pull up on the gathers could only have been produced by very weak anisotropy over the whole section (C).

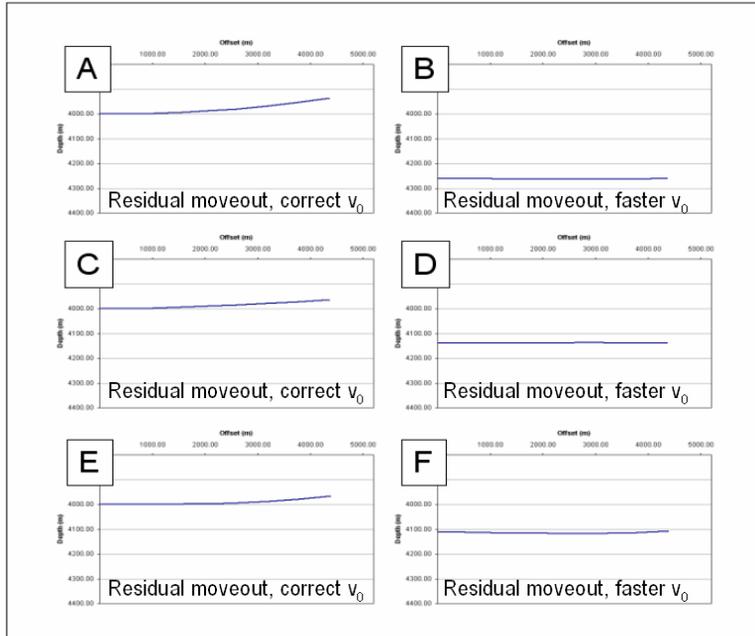


Figure 3. Analysis of causes of isotropic depth error shows that in this case, delta and epsilon each cause the depths to be inaccurate by ~3%. A: Isotropic residual moveout, delta = 4%, epsilon = 12%. B: Isotropic residual moveout, case A, after velocities increased by 6.5%. C: Isotropic residual moveout, delta = 4%, epsilon = 0%. D: Isotropic residual moveout, case C, after velocities increased by 3.5%. E: Isotropic residual moveout, delta = 0%, epsilon = 12%. F: Isotropic residual moveout, case E, after velocities increased by 2.8%.

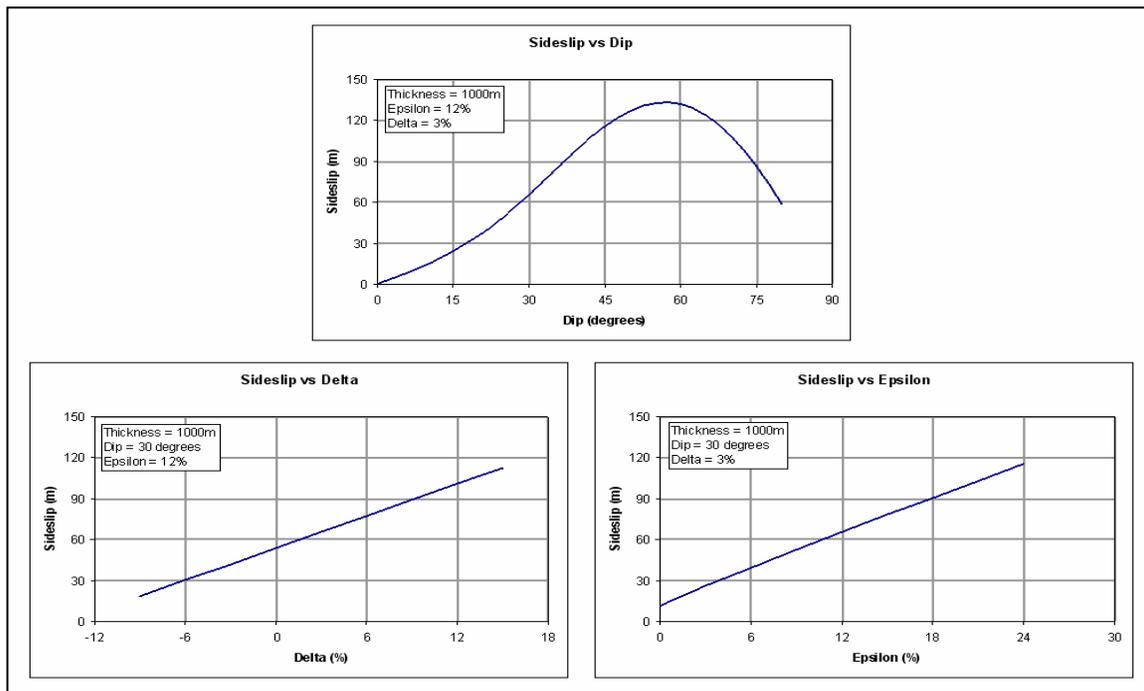


Figure 4. Modeling shows how sideslip distance is dependent on the dip of the anisotropic layers, and the magnitudes of delta and epsilon.