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Integrating lithostatic compression into velocity models for anisotropic depth imaging of complex-structure land seismics

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Summary

In complex-structure land settings, like a continental rift in Central Africa or a thrust belt in the Andes, seismic data is often affected by low signal-to-noise ratios and subsurface complexity. Under these conditions, the seismic data is far too underconstrained for data-driven seismic methods, so we need as many geologic constraints as possible to constrain the seismic velocity model.

Subsurface rock velocity is a function of lithology, geologic age, and compression due to lithostatic load. Our goal is to isolate the compression effect so that we may focus on the interpretation of the geologic structures and the rock types within the fault blocks. Ideally, our velocity model would be parameterized such that the same lithology of the same age would have the same velocity regardless of the depth of burial, and then, prior to depth migration, we can include a compression factor into the velocity model to account for the lithostatic load that results from depth of burial.

We tested a few parameterization schemes, including weighted averages and multiplicative scalars, and we have examples from a variety of structural-geology settings where different methods apply with varying degrees of success. Generally, we find that parameterizing the compression function as a multiplicative scalar is the most effective method for incorporating compressive effects into a geologic velocity model. Data examples include the foothills of the Rockies, Andes, and Zagros mountains.

Introduction

Seismic imaging in thrust-belt environments benefits significantly from geologial input to velocities used for depth imaging. With low fold in the near surface, low signal-to-noise ratios, and complex horizon geometries, automated velocity-model-building tools fail to produce an optimum velocity model for TTI anisotropic depth imaging in these areas. In a setting with such under-constrained seismic velocities, geologic constraints are crucial in the interpretation of our velocity model.

The interpretive, geologically constrained approach to depth migration for these noisy data areas has developed over decades (e.g., Schmid et al., 1996; .Wu et al., 1996, Vestrum and Muenzer, 1997; Isaac and Lawton, 1999; Vestrum et al., 1999; Kirthland Grech et al., 2003; Newrick and Lawton, 2005; Vestrum, 2014). The principle is simple: any update to the velocity model must have a geological justification. For example, if the depth-imaging practicioner observes high velocity in a certain zone in the subsurface, then he or she would identify a geologic reason for increasing the velocity before updating the model. The explanation may be as simple as lithostatic compression causing the velocity of a rock unit to be higher at depth, or the depth imager may need to consult with the structural geologist to determine the likelihood of a structural change to the velocity model that wold add higher-velocity lithology above a major fault. The factor that we focus on for this study is the dependence of velocity on depth of burial or lithostatic load.

If we can separate out the effect of lithostatic load on the depth-imaging velocity model, we can simplify the model-building process in addition to creating models that are both more consistent and more accurate.

Theory and Method

Hooke's Law tells us that the force needed to compress a spring increases linearly with the amount of compression, so it logially holds that rocks under increased pressure would be less compressible. Since early studies in seismic velocity effects (e.g., Faust, 1950), geoscientists have observed that seismic velocity increases with an increase in confining pressure. Depth-imaging practitioners understand thid phoneomenon from both a theoretical perspective and from experience building velocity models for depth migration. It is second nature to incorporate a depth dependency of the seismic velocities.

The objective here is to separate out the compression effect and build velocity models that depend only on lithology and geologic age in the context of the structural model. If we can separate out the compression effect, we may simplfy the model-building process by using one velocity function for a given lithologic unit, regardless of the depth of burial. The models become simplified, and the models also become more consistent. If we expect minimal stratigraphic changes across an exploration block, then we can build models with consistent velocities in each rock unit across the modelling area, which has an application for building a consistent 3D model across a grid of 2D seismic data (Vestrum et al, 2015).

For the first attempt at separating out the compressional component used a weighted average of the lithologic model and the compressional model on a 3D survey the Zagros Foothills (Vestrum, 2014) and a 2D project in the Peruvian Andes (Vestrum et al, 2015). It worked well in those specific cases, but that approach breaks down when there is significant lateral velocity variation in the near surface, because the averaging would bias high velocities down or low velocities up. (It is a mystery to these authors how we didn't see that one coming.)

To extend the method to areas with dramatic lateral-velocity variation, we decided to parameterize the compression factor with a compression multiplier. Following a concave-down pattern from Faust (1951), shown in Figure 1, we chose a function that we could parameterize the scalar, *s*, in terms of a minimum scalar, *m*, and a depth factor, *d,* as follows*:*

$$s = \frac{2}{\pi}(1-m) * \arctan\left[\frac{x}{d}\right]. \qquad (1)$$

Figure 2 shows the velocity scaling function with values *m*=0.6 and *d*=1000. The depth factor gives the depth at which the scaling factor is halfway between the minimum scaling function, *m*, and 1, which is the asymptote for the scaling function.

Rocks become more resistant to compression as they are under greater pressure as pore spaces decrease in size and fractures close under increasing pressure. Observations of rock samples under pressure (e.g., He and Schmitt, 2006; Schijn et al., 2010) show that compressional velocities change rapidly at low pressures and stabilize at higher pressure.

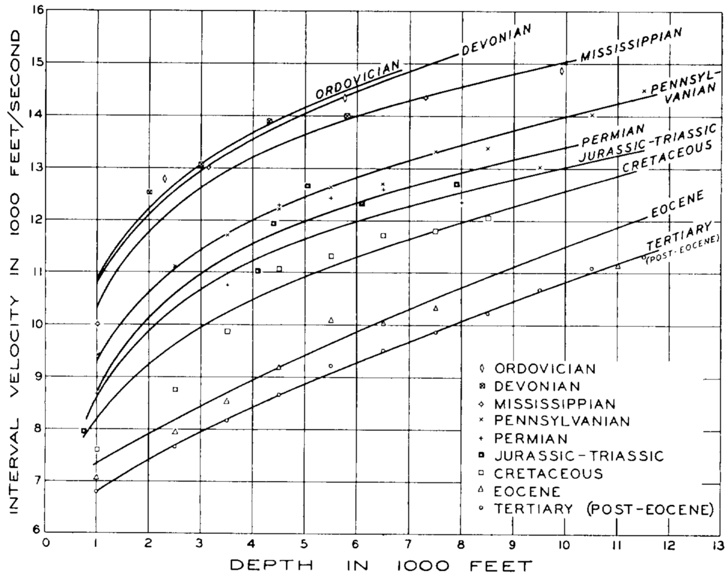

Figure 1: Seismic velocity as a function of depth and geologic age

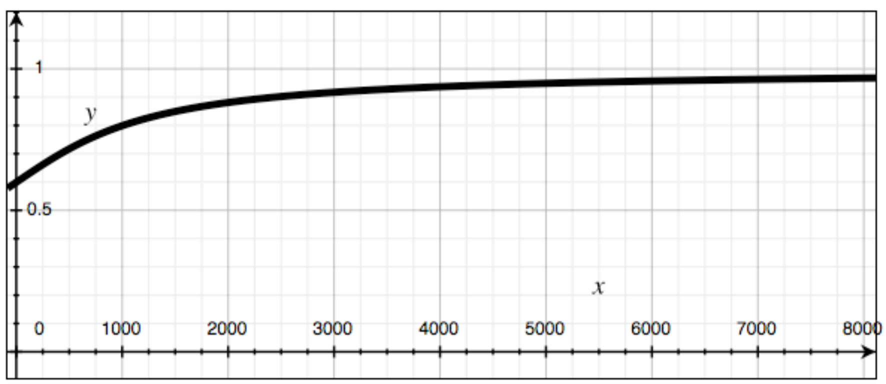

Figure 2: Compression scaling function using Equation 1 for m=0.6 and d=1000.

Example

Figure 3 shows the depth-imaging velocity model for the public-domain foothills dataset from Benjamin Creek. Figure 3a shows the lithologic velocity model that has constant velocities within each layer of the same lithologic type and age. Figure 3b shows the velocity model after application of a compressional scaler. The result of applying the scalar is that the same rock units exhibit slighly lower velocity near the surface than at depth for the same rock layer.

Conclusions

By separating out the effect of compression using a scaling function, we are able to create more lithologically consistent velocity models for depth migration. With a separate compression factor, the depth-imaging practitioner can focus on defining the lithologic velocities for the rock layers and the fold and fault structures. The benefits are consistency in the velocities and efficiency in the model-building process.

(a)

(b)

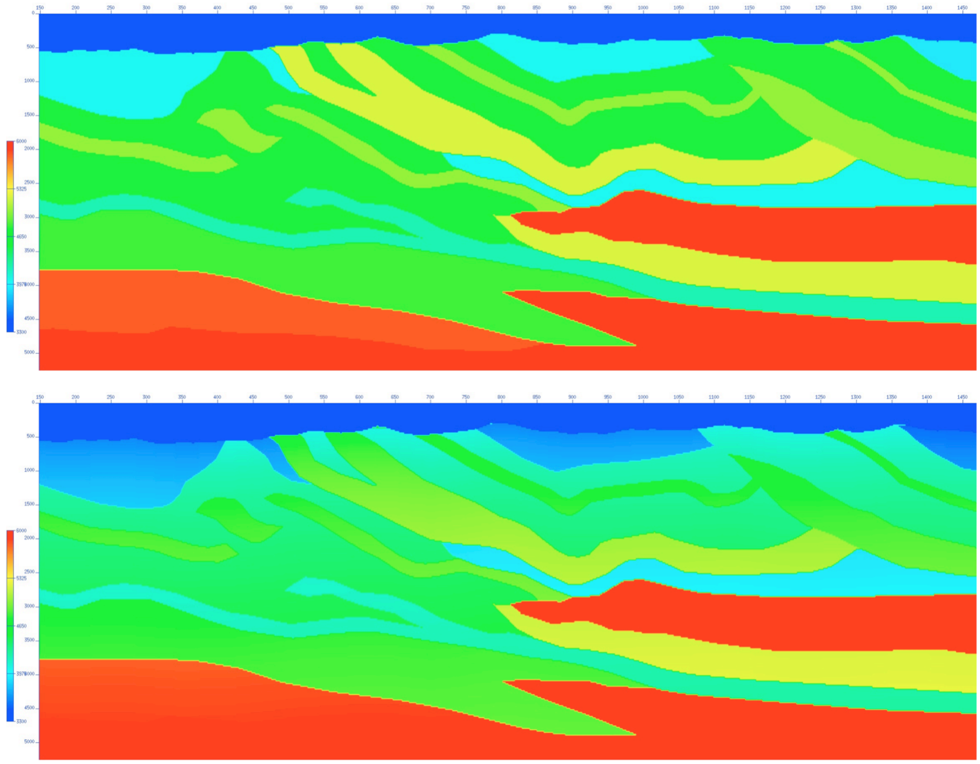

Figure 3: Velocity model for depth imaging (a) before and (b) after applying a compressional scalar.

References

Faust, L.Y. (1951). ”Seismic velocity as a function of depth and geologic time” GEOPHYSICS, **16** (2), 192-206.

He, Taiwei, and Schmitt, D.R. (2006) “Velocity measurements of conglomerates and pressure sensitivity analysis of AVA response”, 206 Natnl. Mtg., Soc. Expl. Geophys

Kirtland Grech, M. Graziella, Don C. Lawton, and Scott Cheadle (2003) ”Integrated prestack depth migration of vertical seismic profile and surface seismic data from the Rocky Mountain Foothills of southern Alberta, Canada.” GEOPHYSICS, **68**(6), 1782-1791.

Newrick, R.T. and Lawton, D.C. (2005) “Geologically Reasonable Vεδθ Models for Depth Imaging”, RECORDER **30**, no. 6,

Schijns, H., Schmitt, D.R., Jackson, I. (2010) “Velocity dispersion measurements on micro-cracked and fluid-saturated rock”, 2010 Natnl. Mtg., Soc. Expl. Geophys.

Schmid, Ron, Brian Link, and Patrick Butler (1996) “A comprehensive approach to depth imaging in thrust belt environments”. SEG Technical Program Expanded Abstracts 1996: pp. 366-368.

Vestrum, R.W. (2014) “Geologically constrained seismic imaging in the Kurdistan fold belt”, PETEX 2014, London.

Vestrum, R.W., Don C. Lawton, and Ron Schmid (1999) ”Imaging structures below dipping TI media” GEOPHYSICS, **64**(4), 1239-1246.

Vestrum, R.W. and Muenzer, K. (1997) “Imaging below dipping anisotropic shales:” 1997 Natnl. Mtg., Can. Soc. Expl. Geophys.

Vestrum, R.W., J. Vilca, M. Di Giulio Colimberti and D.K. Ellison (2015) “Creating a 3D Geologic Model for 2D Depth Migration in the Peruvian Andes”, 77th EAGE Conference and Exhibition 2015.

Wu, Wen-Jing, Larry Lines, Andrew Burton, Han-Xing Lu, William Jamison, Jinming Zhu, and R. Phillip Bording (1996) “Prestack depth migration of an Alberta Foothills data set — The Husky experience”. SEG Technical Program Expanded Abstracts 1996: pp. 559-561.