GeoConvention 2015
GEOSCIENCE
new horizons
Telus Convention Centre • 4-8 May 2015 • Calgary, AB Canada

From Andes to Zagros: variations in structural styles and seismic data from a processors' perspective

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Thrust Belt Imaging

Summary

An overview of data examples from a variety of settings illustrates the similarities and differences in structural style, velocity structure, and acquisition conditions. We have observed that younger rocks typically show lower velocities and the lower compressibility of these strata results in velocities more sensitive to depth of burial. Velocity gradients need more testing in younger basins with lower velocity rocks. Another observation is that more topsoil with wetter surface conditions appear to offer better coupling for seismic sources and receivers, which could explain why we see better signal-to-noise ratios on seismic data from rainforest versus desert environments. Desert outcrops may read like a geology textbook, but visual clarity at the surface comes at a cost of clarity in the subsurface.

Introduction

The interpretability of seismic data in structured land environments vary significantly from basin to basin and from field to field within a basin. Surface conditions, including topography and outcropping lithology, have a strong effect on imaging subsurface structures. Complexity in the subsurface typically have a secondary effect on the imaging pitfalls, but structural complexity in the subsurface often results in structural complexity in the shallow section as faults come to surface and erosion reveals the soft centre of a crunchy carbonate fold.

The seismic data in the foothills if the Peruvian Andes produce some of the clearest images that these authors have seen in any complex-structure land setting. Moving north to Colombia, the more complicated tectonic history, with multiple phases of deformation, results in more challenging seismic data. Jumping over to the Kurdistan region in the Erbil province of Iraq, we see how surface conditions affect the seismic imaging of structures below. Once again moving to a more tectonically complex area, the Kohat Plateau of northwest Pakistan is in the tortured zone of the collision of three major tectonic plates, resulting in dramatic transpressional structures and very challenging seismic data.

Working datasets from the Canadian Foothills with so much variability in data quality proved to be an excellent training ground for the variety of problems we find in thrust belts around the world.

Method

As we apply methodologies we have learned from working the foothills of the Canadian Rockies to other basins, we found that the same principles applied to optimizing the seismic image (e.g.: Vestrum et al, 1999; Vestrum, 2005; Vestrum and Gittins, 2009; Vestrum et al, 2009; Vestrum et al, 2011). Fortunately for us, there is so much variability in surface conditions and subsurface complexity in the Canadian

Foothills that Canadian projects forced us to treat each project as its own problem-solving exercise in statics and velocities.

The processing examples are of the basic Kirchhoff prestack time and depth images. The simplifying assumptions in prestack time migration (PSTM) makes it the most robust algorithm in the seismic-imaging toolkit. The major advantage of PSTM in a structurally complex setting is that the velocity analyst can focus attention on the optimum RMS velocity for each individual reflector, ignoring the effects of heterogeneity and anisotropy above that reflector by averaging through all of that velocity complexity. The pitfall here is that ignoring complex ray paths above the target may result in imaging and position problems at the target level, but the simplifications give is the best chance of creating an optimized image.

For prestack depth migration (PSDM), we corrected for TTI anisotropy in the dipping clastic layers of the subsurface velocity model. We build a geologically constrained velocity model that corrects for both seismic anisotropy and velocity heterogeneity. The resulting image is typically more accurate than the PSTM, but the image is only as accurate as the velocity model. Even small inaccuracies in the velocity model result in a degraded PSDM image, which is what makes PSDM a more delicate process than PSTM.

Each dataset had its own treatment for statics to optimize the final image. Theoretically, first-arrival tomography has the greatest ability to handle the high near-surface velocity variation in complex-structure environments, but variability in quality of first breaks and near-surface data density sometimes requires a simpler, potentially more robust, statics algorithm like a generalized linear inversion or time-term solution. We test a minimum of two statics solutions on each dataset to see how the seismic reflectors respond to each algorithm, and we compare these results back to just elevation statics with no weathering correction. There are those rare occasions where the information in the first breaks does more harm than good, and we must proceed to the reflection-statics algorithm with only elevation statics on the data.

Examples

We start in Peru, where the soft ground and gentle topography results in near-ideal surface conditions for surface seismic data. One example of the data quality is in Figure 1, which shows a major thrust carrying older rocks to surface, creating a mountain.

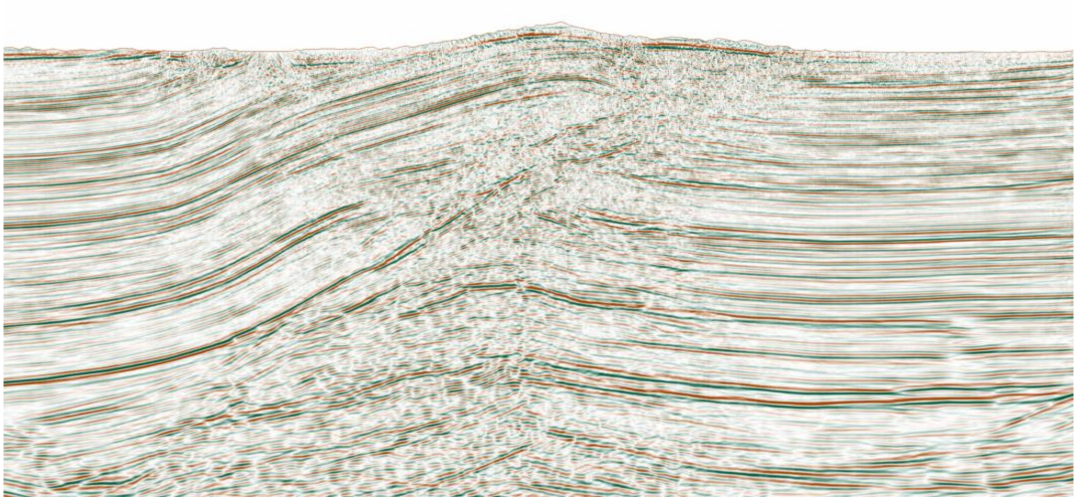

Figure 1: Depth image from an Andean subthrust in Peru (Stratton et al, 2014).

Compare that to a subthrust image in the foothills of the Zagros mountains (Figure 2), where one may see with a simple visual inspection that the resolution of the seismic data is lower. The image shows fewer reflectors than we see in the Peruvian Andes (Figure 1). On the example from the Andes, the lower central area of the image shows more noise with the foothill reflectors, but in the Zagros image, the lower central region of the image shows minimal reflectivity.

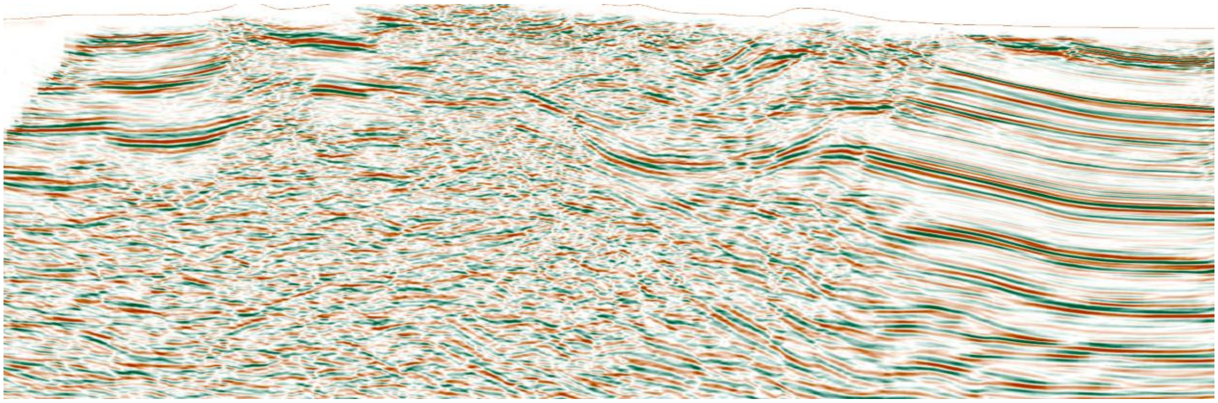

Figure 2: Depth image from a subthrust from the Zagros foothills

Surface conditions may play a large role in the data quality between these two datasets. In Figure 3, the satellite images overlaid on the terrain illustrate the differences in vegetation cover and general moisture level at the surface. Through a variety of geologic settings in tropical and desert environments, we have observed the trend that dryer climates result in lower signal amplitude and higher noise levels. Most of the problem, we suspect, is due do coupling of sources and receivers at the acquisition surface. The softer, wetter soils can transmit the seismic energy—both for sources and receivers—more effectively than loose sands or gravels. We have observed 3D surveys shot over the same terrain in wet and dry seasons show lower signal-to-noise when shot in the dry season.

Another factor may be the hard ground at the free surface. Softer ground with vegetation cover above would have a lower reflection coefficient at the free surface than a rock-hard surface, so surface-related noise an multiples should be smaller below softer ground. Desert outcrops may read like a geology textbook, but visual clarity at the surface may come at a cost of clarity in the subsurface.

Figure 3: (left) Foothills of the Peruvian Andes, which is covered in lush vegetation. (right) Foothills of the Zagros mountains shows bare rock and dry gravels. One may have the advantage of seeing the surface geology on satellite imagery in a desert environment, but coupling of surface seismic is weaker (Map data: DigitalGlobe).

Another trend we observed in seismic data processing across a variety of geologic settings is that, in general, younger rocks show lower velocities and these lower-velocity rocks have velocities more sensitive to depth of burial. Typically in our experience, older, harder, higher velocity rocks have less variability in seismic velocity with depth. This is because the higher velocity rocks are less compressible, therefore less affected by confining pressure. When model building in areas with rock velocities in the range of 2000 to 3000 m/s, we observed that stronger velocity gradients are needed to optimize the depth image than in areas with rock velocities in the 4000 to 6000 m/s. In the early days of depth imaging in the Canadian foothills, where even the “low” velocity clastic rocks have velocities near 4000 m/s, many depth imagers could get away with ignoring gradient effects. In fact, early iterations of depth-migration model-building software at service companies and in-house research at resource companies rarely had the ability to handle vertical gradients. We observe these same trends today, where we need to take more care defining gradients in younger basins with lower velocity rocks.

Summary and Conclusions

An overview of data examples from a variety of settings illustrates the similarities and differences in structural style, velocity structure, and acquisition conditions.

In general, younger rocks show lower velocities and these lower-velocity rocks have velocities more sensitive to depth of burial than older, harder, higher velocity rocks that are less compressible, therefore less affected by confining pressure. We need to take more care defining gradients in younger basins with lower velocity rocks.

More topsoil with wetter surface conditions appear to offer better coupling for seismic sources and receivers, which could explain why we see better signal-to-noise ratios on seismic data from rainforest versus desert environments. It is difficult to make this conclusion from these data examples, because the geologic setting in the desert environments was also more complex, with carbonate strata outcropping at surface. Desert outcrops may read like a geology textbook, but visual clarity at the surface comes at a cost of clarity in the subsurface.

Acknowledgements

The authors wish to thank the structural geologists and seismic interpreters that have taught us much about regional geology and variation in tectonic structures across a variety of geologic settings.

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