Geophysical Corner

Structural Geology is a Key to Seismic-Imaging Success

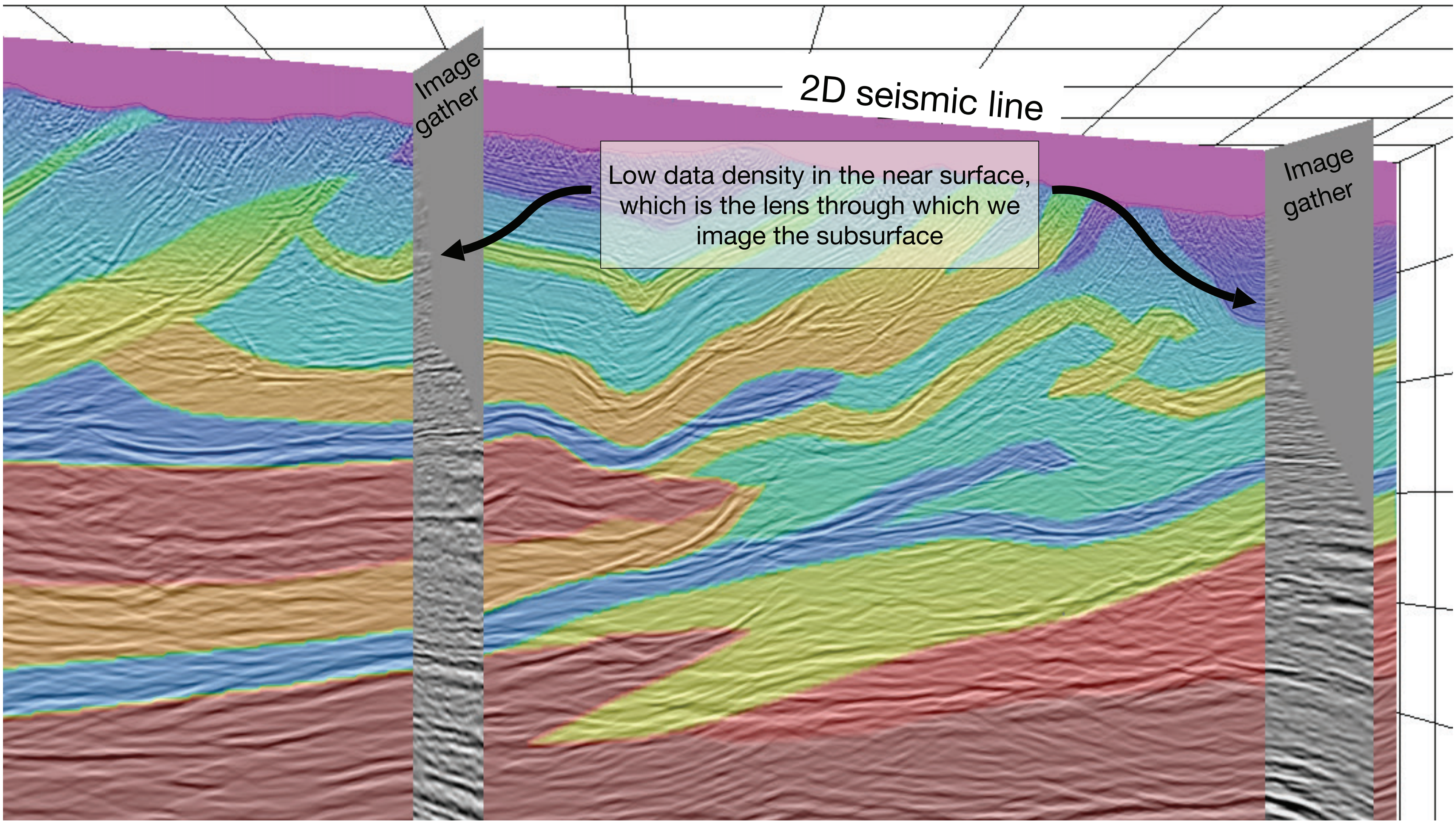

Figure 1: Interactive model building display showing a 2-D seismic line with its velocity model overlaid in color. Warmer colors indicate higher velocity. Each gray strip of traces displayed orthogonal to the 2-D line is the prestack image gather at that location on the line. Offset increases outward from the line.

Seismic data in fold and thrust belts across mountain ranges from the Andes to the Zagros have challenges that break traditional seismic-imaging methods designed for offshore or flat-land exploration. The under-constrained nature of these seismic data requires tight integration with the structural geologist to reduce exploration risk.

Seismic imaging is a vital tool for mapping complex geologic structures. The method of imaging the Earth's subsurface with seismic waves is powerful, but it has certain limitations – especially when deployed in complex-structure land areas like the foothills and high plains of mountain ranges.

Defining the Velocity Structure

Seismic data in thrust-belt environments are typically low in data density and have low signal-to-noise ratios, all while attempting to image complex geologic. The data are acquired over rough topography with laterally-varying velocities from the surface down. If the near surface is the lens through which we image the subsurface, our lens is bumpy and distorted.

Figure 1 shows a zoomed-in view of an interactive velocity-model-building display for prestack depth migration. The seismic section is displayed at an oblique angle with the velocity model overlaid in color. The warm colors indicate higher velocity and cool colors low velocity. The gray strips of seismic traces are the prestack image gathers from those locations along this 2-D line. The source-receiver offset increases outwardly away from the line. A key indicator of accurate velocities is when

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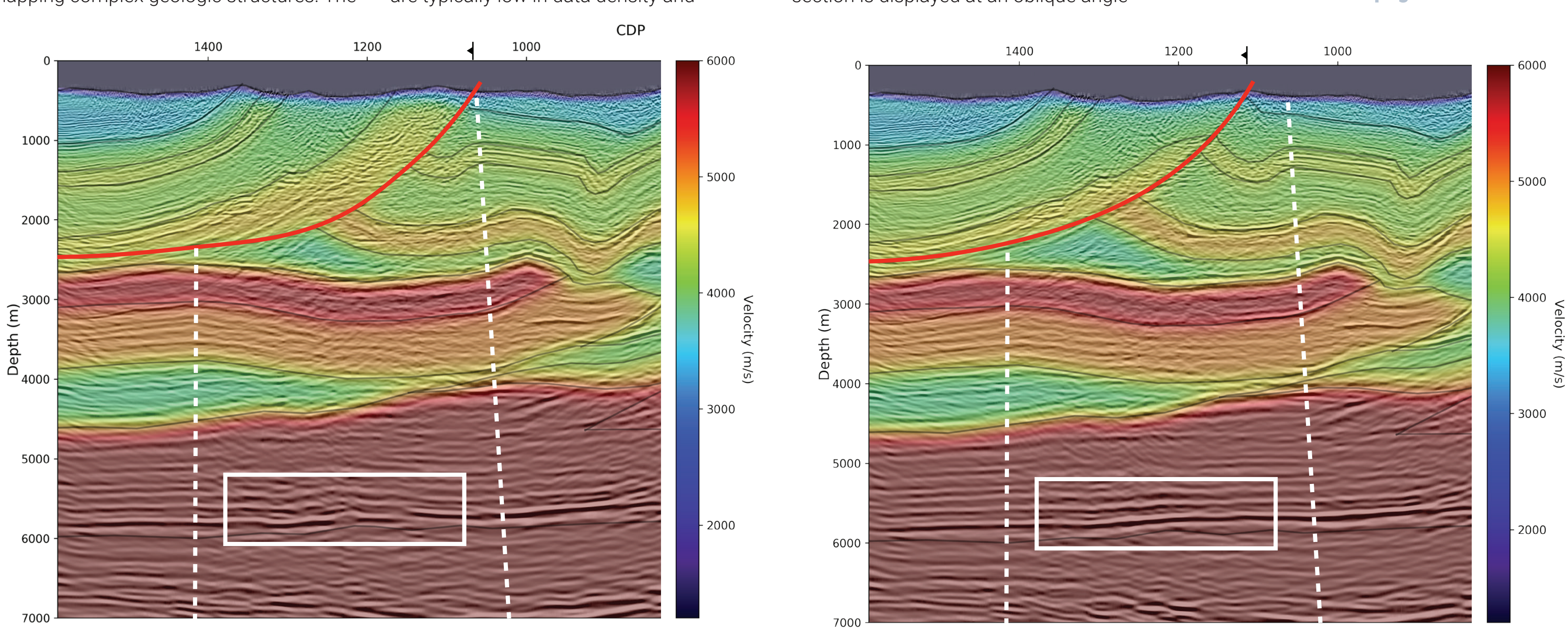

Figure 2: Two velocity-model scenarios that show the change in the seismic image resulting from a change in near-surface fault geometry (fault highlighted in red). In 2(a), the fault was interpreted along the truncations of footwall reflectors. In 2(b), the fault was interpreted at a shallower angle along a reflector above. White dashed lines indicate the zone of influence caused by this change in imaging velocity. The white box highlights the change in reflector coherency at the basement reflector that results from the change in near-surface velocity structure.

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the events on these gathers are flat. Each offset images the same reflector at the same depth, even though each offset has a different raypath length, so flatness of events on image gathers is a key indicator of the accuracy of the velocity model. Near the bottom of the figure, there are strong events on the gathers that span the entire offset range. However, in the near-surface, the events are weak and only a few of the near-offset traces show reflectivity. This narrow-offset range results in low data density in an area close to our acquisition surface. The near surface is the lens through which we image the subsurface, and it is an area with minimal seismic velocity information.

There is not enough information in the seismic reflectivity to accurately define the velocity structure of the near-surface lens.

The Impact of Fault Geometry

The following example shows the sensitivity of seismic imaging to changes in the near-surface structural interpretation of the velocity-model boundaries. Figure 2a shows a PSDM seismic section with the velocity model overlaid. The thrust fault highlighted in red was interpreted based on the truncations of the footwall reflectors. After a few model iterations and signal processing to enhance the imaging, we observed that there is a reflector above our model fault that could be the fault-plane reflector. We discussed the fault geometry with a structural geologist who had worked this area, and the outcrop of the fault was observed to the west of our modeled location. We then created a model with the fault shifted to the left, following the reflector on the migrated stack, and intersecting the surface at the approximate location of the observed fault trace at surface.

Figure 2b shows the imaging improvements that result from the change in fault geometry in the model. Note that the velocity profile, as indicated in the color overlay, has not changed. The only change is the geometry of the fault highlighted in red. The approximate zone of influence of this geometric change to the velocity structure is indicated by the white dashed lines. Within this zone, several of the reflectors are more continuous after (figure 2b) the change in fault geometry as compared to those same reflectors on the seismic image before (figure 2a) this model update.

Of particular interest is the change in the basement reflector within the white square near the bottom of each seismic image (figure 2). With a subtle change in reflector geometry in the near surface, the deepest reflector on the section shows strong improvements in imaging. The delicate nature of depth imaging as compared to the more robust time imaging gives us an opportunity to use depth migration as an interpretation quality control if we have a few model scenarios that we are considering. Perhaps if we wonder how much high-velocity carbonate is carried in the hanging wall of a thrust, then we can test these velocity-model scenarios to see how the seismic image responds to the different carbonate thicknesses. In the case shown in figure 2, the seismic reflectivity has confirmed that the gentler dip on the fault plane is a more accurate representation of the fault geometry.

Conclusion

Understanding structural styles and other geologic constraints are key levers to overcome the limitations of seismic data in the difficult imaging areas of complex geologic structures. In turn, the seismic response can offer guidance to the structural interpretation through the testing of different structural scenarios. The synergy between the concerned structural geologist and seismic imager can improve seismic imaging and reduce exploration risk. ▣

(Editors Note: The Geophysical Corner is a regular column in the EXPLORER, edited by Satinder Chopra, founder and president of SamiGeo, Calgary, Canada, and a past AAPG-SEG Joint Distinguished Lecturer.)

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Tim MacArthur earned a bachelor's in geophysics from the University of Calgary and has worked with Thrust Belt Imaging for nine years. MacArthur has been responsible for many 2-D land projects, processing complex data in time and depth in various areas worldwide, from Albania and Pakistan to Colombia. He is currently studying for a master's in information systems focusing on data analytics. This research includes data science applications to geophysics and wave equation finite-difference modeling.