Impact of shallow volcanics on seismic data quality in Chicontepec Basin, Mexico

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Chicontepec Basin is one of the most productive in Mexico. Unlike the world-famous Cantarell and Poza Rica carbonate fields, characterized by high-producing wells tapping large continuous reservoirs, the Chicontepec play is characterized by thin, sometimes multistoried turbidite and fan reservoirs encased in shales and cut by mud slumps and mass transport complexes. The sand reservoirs are relatively small and have very low permeability. Most new wells need to be hydraulically fractured, with anomalously higher production being hypothesized as due to fractures draining nearby, otherwise disconnected, sand bodies.

Mapping laterally discontinuous thin sand fans and turbidites is difficult even with the best seismic data. These problems are exacerbated in the Amatitlán seismic survey, acquired in the northern end of the Chicontepec Basin, where rough topography, dense forest, human habitation, and archaeological sites add lateral amplitude and signal-to-noise heterogeneity that is due to acquisition obstacles, rather than to geology. Further complicating the effort at maintaining data fidelity are shallow volcanic sills (and perhaps shallow volcanic extrusives).

We show in this paper how careful, processor-intensive attention to fundamental issues significantly improves the image presented to the interpreter. We evaluate the improvement in quality of these images though attribute-horizon and time slices. As an ancillary product, we present the morphology and seismic expression of volcanic sills on 3D seismic data and attributes.

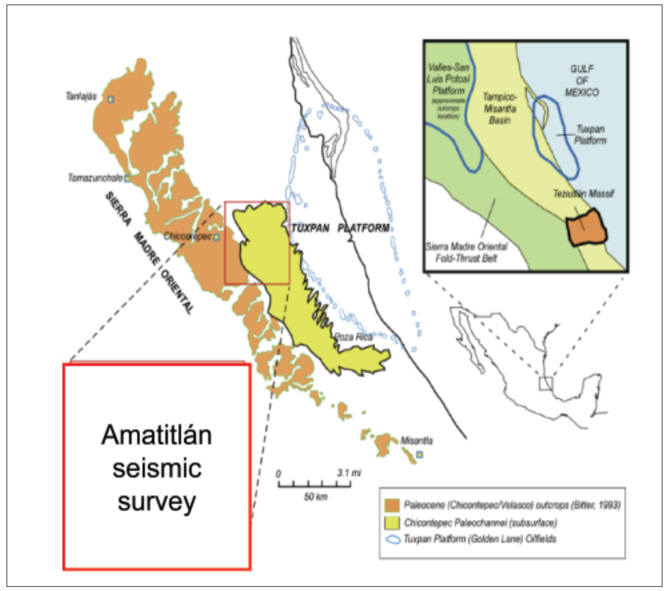

Figure 1. *Location of Chicontepec Basin and the Amatitlán seismic survey (after Abbaszadeh et al., 2003).*

Geologic overview

The Paleogene Chicontepec Formation, deposited between the Sierra Madre Oriental and the Golden Lane Platform, extends NW-SE along the Gulf Coast in Mexico (Figure 1). This formation is made of submarine fan turbidity sediments derived from the Sierra Madre Oriental to the west of the basin and is composed mainly of alternating shales and thin-bedded sandstones. The formation has a thickness of ~2000 m covering most of the 3731 km^2 in Tampico-Misantla Basin (Bermúdez et al., 2006). Although the Chicontepec play was discovered in 1925, production did not begin until 1952. Previous sedimentological studies demonstrate that multiple sediment supply systems formed submarine fans along the western margin of the Chicontepec Formation. Sediments derived from the uplifted Mesozoic carbonate units were deposited along a deep marine foreland basin east of the deformation front of the Sierra Madre Oriental fold-thrust belt.

The normal stratigraphic succession places the Chicontepec Formation disconformably on top of the Upper Cretaceous marls of the Méndez Formation. However, the most accepted interpretation (a deeply-eroding submarine canyon north of the modern city of Poza Rica) suggests that Chicontepec Formation rests unconformably on older rocks ranging from Lower Eocene to Upper Jurassic.

The Amatitlán seismic survey is in the northern part of the basin to the west of Tuxpan, Veracruz, and includes at least three distinct producing oil fields. The reservoir facies are highly compartmentalized and in general have very low permeability. The most commonly accepted description of the reservoirs is submarine turbidites and fans deposited from the west (and possibly from the east) sides of the basin margin. Although channel-like features have been mapped by 2D lines to the south of the play, these features have low permeability and it is unclear whether they are turbidites or mass-transport complexes. The 3D Amatitlán survey was acquired in 2003 to better understand/delineate the compartmentalized reservoir. While the deeper carbonate Mesozoic section is extremely well imaged, it is not clear whether the shallower Paleocene objective is incoherent because of an inherently chaotic depositional nature, because of the shallow obstacles to acquisition, or because of shallow volcanics in the section creating both "penetration" problems and lateral velocity heterogeneities.

Seismic data quality

The data were originally acquired and processed in 2003 us-

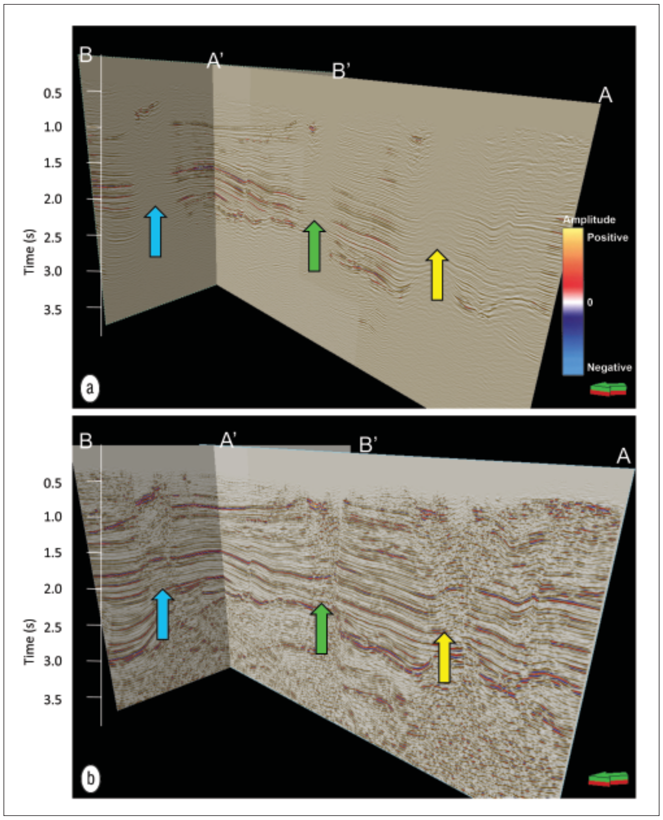

Figure 2. *Vertical slices along lines AA' and BB' through the seismic amplitude volume generated using the (a) original and (b) improved processing flow. Arrows indicate low-amplitude chaotic zones that we interpret are due to shallow overlying volcanics. Location of lines are shown in Figure 5.*

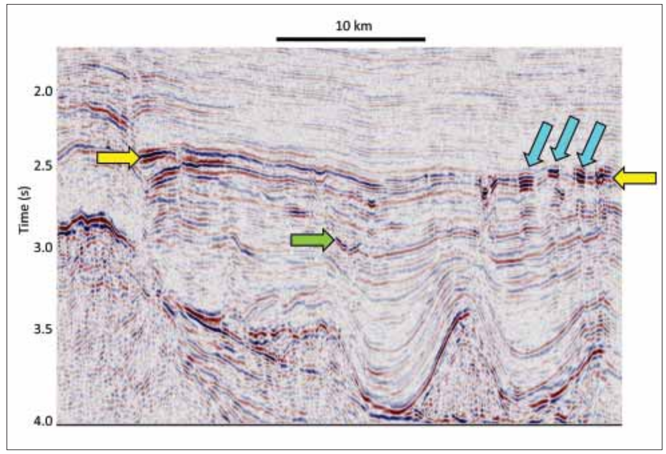

Figure 3. *The seismic expression of volcanics in the Santos Basin, offshore Brazil. Yellow arrows indicate a shallow lava flow that has since been buried. Cyan arrows are volcanic vents identified as circular features on the horizon slice. Green arrow indicates an intrusive sill (after Klarner et al., 2006).*

ing a well-established acquisition and processing workflow that had proven effective in other areas of Veracruz. However, the Amatitlán survey was both more expensive and more difficult to acquire than most other surveys. In addition to rugged topography, dense forest, human settlements, and sensitive archaeological sites, there appeared to be strong impedance anomalies in the shallow section that generated amplitude shadows deeper in the section (Figure 2a). For this reason, the survey was reprocessed in 2007 to obtain better shallow imaging. The new processing flow did not introduce new processing technology, but focused much more detailed and processor-intensive attention to trace editing, amplitude balancing, statics, regularization, and a careful, very detailed velocity analysis. After this basic reprocessing, the data were prestack Kirchhoff time-migrated; the migrated gathers were subjected to residual NMO corrections, random noise attenuation, and multiple suppression.

Seismic expression of shallow volcanics

Although volcanics commonly occur from Alaska to Patagonia, their expression on 3D seismic is somewhat underreported in the geological and geophysical literature. Davies et al. (2004) included three excellent case studies illustrating the seismic expression of volcanics in the North Sea in their volume on 3D illumination of sedimentary basins. Garten et al. (2008) identified a volcanic vent on seismic acquired in the Norwegian Sea. In Latin America, Klarner et al. (2006) showed how 3D seismic can image shallow volcanics and submarine vents, and deeper sills (Figure 3). Volcanics are routinely encountered in Argentina in both the Neuquen and San Jorge basins (Juan Soldo and Daniel Delpino, personal communication). These images are commonly shown at oral presentations, but published documentation is harder to find. Although the volcanics cause the same data quality problems as those we find in Amatitlán, Argentine volcanics can also serve alternatively as an updip seal, as the reservoir rock (if fractured), or as a cause of fracturing above intrusive dikes due to either the force of mechanical injection or due to subsequent differential compaction about these relatively rigid features. The volcanics in Argentina also have a profound effect on permeability. In some lithologies, volcanics reduce permeability through the formation of clays; in others, volcanics improve permeability through some kind of leaching process.

Given the relative paucity of published 3D seismic images of volcanics, a primary objective of this work is to map them and quantify the negative impact they may have on seismic data quality. A future question to be addressed is whether there is any correlation between the volcanics in Amatitlán and the overall poor permeability.

Correlation of extrusive and intrusive volcanics to magnetic data

Most volcanics have a strong, distinct pattern. However, since volcanics cool slowly through the Curie point, they also acquire a strong remanent magnetization. The magnetic response is the vector sum of the induced magnetization, which is a function on the inclination of Earth's magnetic field at the present time, and the remanent magnetization, which is a function of the inclination of Earth's magnetic field at the time of magmatic cooling. Figure 4a is a shaded relief map of the Amatitlán survey area. The topography ranges from near sea level in the east to 600 m within the

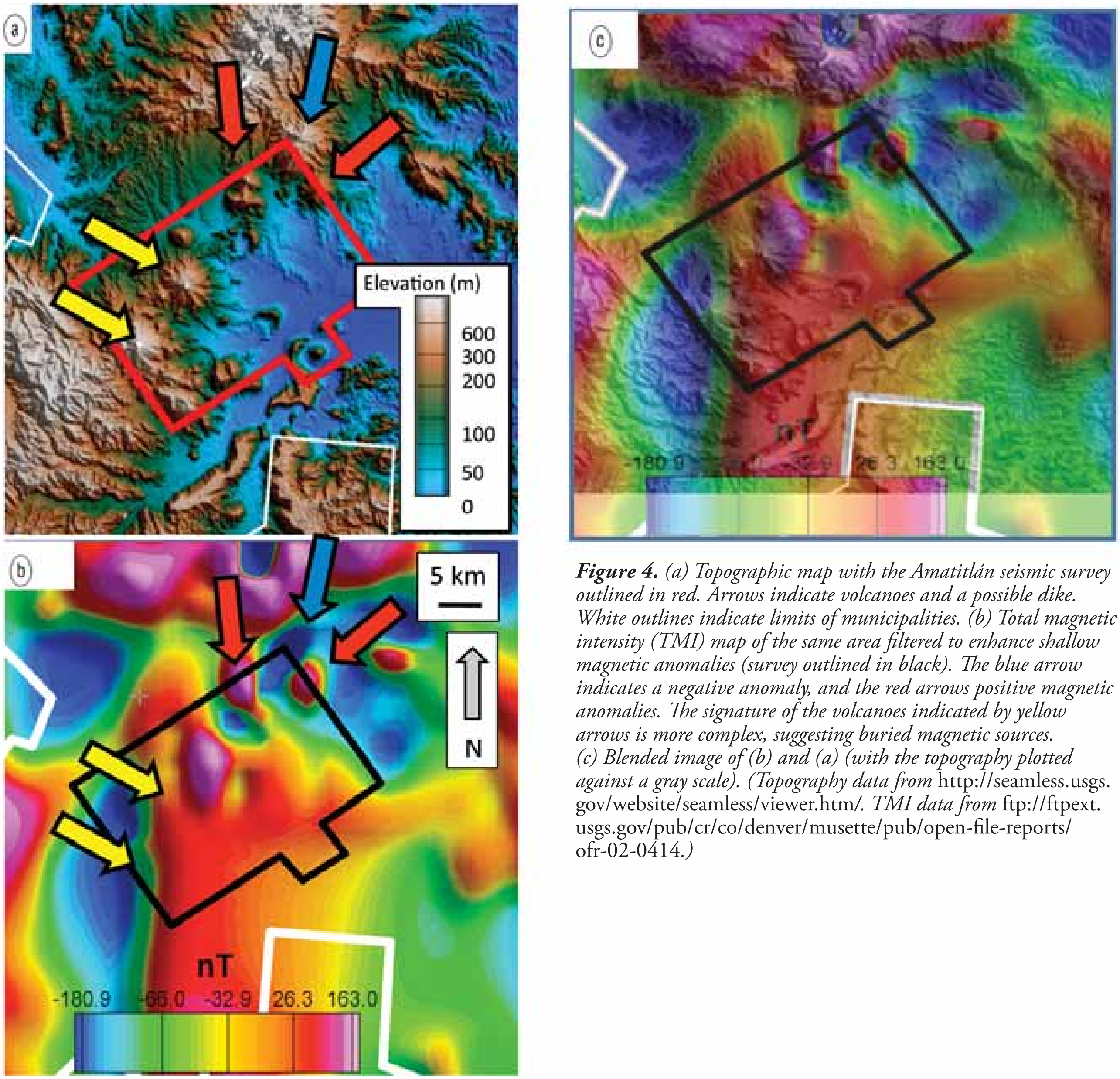

Figure 4. (a) Topographic map with the Amatitlán seismic survey outlined in red. Arrows indicate volcanoes and a possible dike. White outlines indicate limits of municipalities. (b) Total magnetic intensity (TMI) map of the same area filtered to enhance shallow magnetic anomalies (survey outlined in black). The blue arrow indicates a negative anomaly, and the red arrows positive magnetic anomalies. The signature of the volcanoes indicated by yellow arrows is more complex, suggesting buried magnetic sources. (c) Blended image of (b) and (a) (with the topography plotted against a gray scale). (Topography data from http://seamless.usgs.gov/website/seamless/viewer.htm/. *TMI data from* ftp://ftpext.usgs.gov/pub/cr/co/denver/musette/pub/open-file-reports/ofr-02-0414.*)*

survey. Arrows indicate volcanic cones and what appears to be an elongate ridge which falls within the survey. Figure 4b is a total magnetic intensity map that has been reduced to the pole to correct for the weak inclination at this latitude. As a processing step, the data have been upward continued to produce a long-wavelength approximation of the data, and then subtracted from the original data. This "shallow response" image suffers less from Gibbs' artifacts than if the data were high-pass filtered. We note that two of the volcanic structures (a ridge which may be a dike, as well as a cone) have a positive magnetic response. The volcanic cone indicated by the blue arrow has a negative magnetic response, suggesting remanent magnetization aligned with a magnetic pole reversal similar to that found in Picuri, New Mexico, USA, by Grauch and Keller (2004). The large cones indicated by the yellow arrows do not correspond to a simple magnetic anomaly, suggesting that there are deeper sills contributing to the total response. In order to better correlate the surface topography to the total magnetic intensity, we blended the two images (first converting the topography image to a gray scale) in Figure 4c.

The overall fold is good (between 30 and 40), although we note an anomalous ring-shaped low-fold area that is associated with lower elevation areas (Figure 5). In general, low fold results in lower signal-to-noise ratios, which in turn gives rise to the lower seismic coherence anomalies in Figure 6. By blending the shaded relief topography map shown in Figure 6a with the coherence image, we interpret other low-coherence areas as being due to shallow volcanics (the yellow, green, and cyan arrows corresponding to those on the vertical slices in Figure 2). The orange arrow indicates a low-coherence area corresponding to two overlying volcanic sills, which

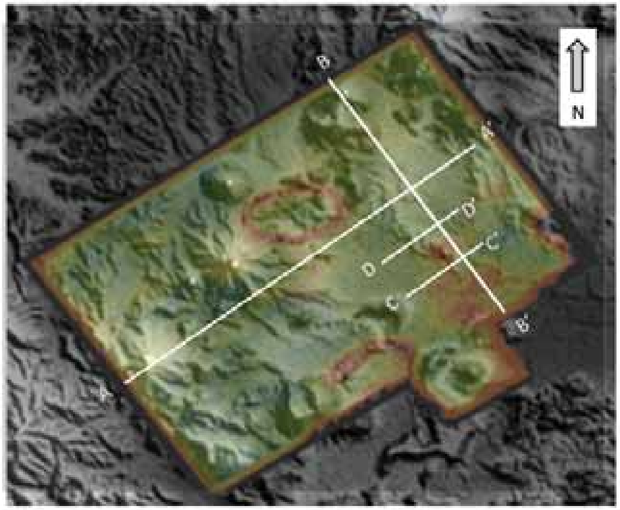

Figure 5. Fold map blended with the topography. Low-fold areas are not associated with the prominent volcanoes, but rather with lower elevation, swampy areas.

are displayed on vertical seismic in Figure 7.

Figure 8 shows a suite of shallow sills in the shallow section of the seismic data. We note in Figure 8b that the sill indicated by the yellow arrow starts at depth, jumps to a higher level, perhaps through a dike, and continues horizontally across, repeating this pattern at least three times. This nearly horizontal intrusion pattern does not seem to adversely affect the deeper seismic data quality.

In Figure 9, we display a time-structure map of the larger volcanic sills seen in the survey. By blending this map with the coherence image at t=1.335 s, we see a direct correlation between the location of some volcanic sills and the seismic data quality (incoherent zones) deeper in the section.

Conclusions

Seismic surveying in Amatitlán is handicapped by shallow volcanics that disrupt the deeper signal. Through careful statics, trace balancing, and velocity analysis, many of these disruptions can be attenuated, particularly those that generate "shadows" beneath the high-impedance volcanics. Sills that are intruded parallel to stratigraphic horizons cause fewer problems in deeper seismic data. However, sills that cut upward from horizon-to-horizon as well as stacked sills correlate with low seismic coherence seen at greater depths. Several sills give rise to strong interbed multiples which cut across deeper reflections of interest.

Chincontepec Formation is low-permeability turbidites and sheet sands encased in a shale matrix and cut by incoherent mass transport complexes. Geomorphological recognition of turbidites and mass transport complexes is made by their relatively chaotic texture as seen on seismic attributes. This pattern is overprinted by the chaotic nature of the seismic data associated with the overlying volcanics. At present, our objective is to map these poor data quality zones and thereby risk-weight our texture-based interpretation of the Chicontepec Formation. If yet more reprocessing is considered some time in the future, these shallow high-velocity zones can help

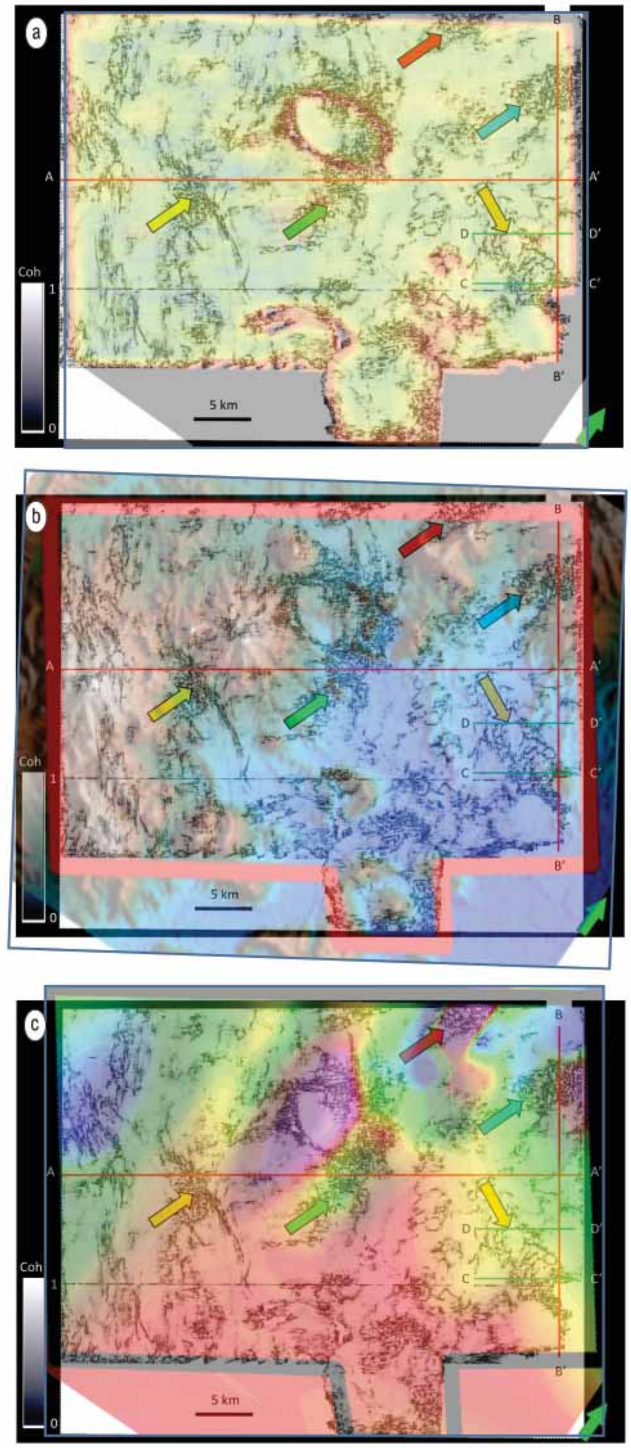

Figure 6. Coherence image (a) blended with the fold map, (b) blended with the shaded relief topography map, and (c) blended with the RTP total magnetic intensity map. We interpret the low-coherence areas indicated by the yellow, green, and cyan arrows to be due to shallow lava flows associated with the volcanic cones seen in Figure 4. The same arrows are shown on the vertical slices through the seismic amplitude shown in Figure 2. The low-coherence areas indicated by the red and green arrows (as well as the circular low-fold area) correlate to high total magnetic intensity. The ring-shaped low fold area in the north central part of the survey gives rise to a ring-shaped low-coherence image. Orange arrows indicating poor data quality beneath a volcanic sill shown on lines CC' and DD' are displayed in Figure 7.

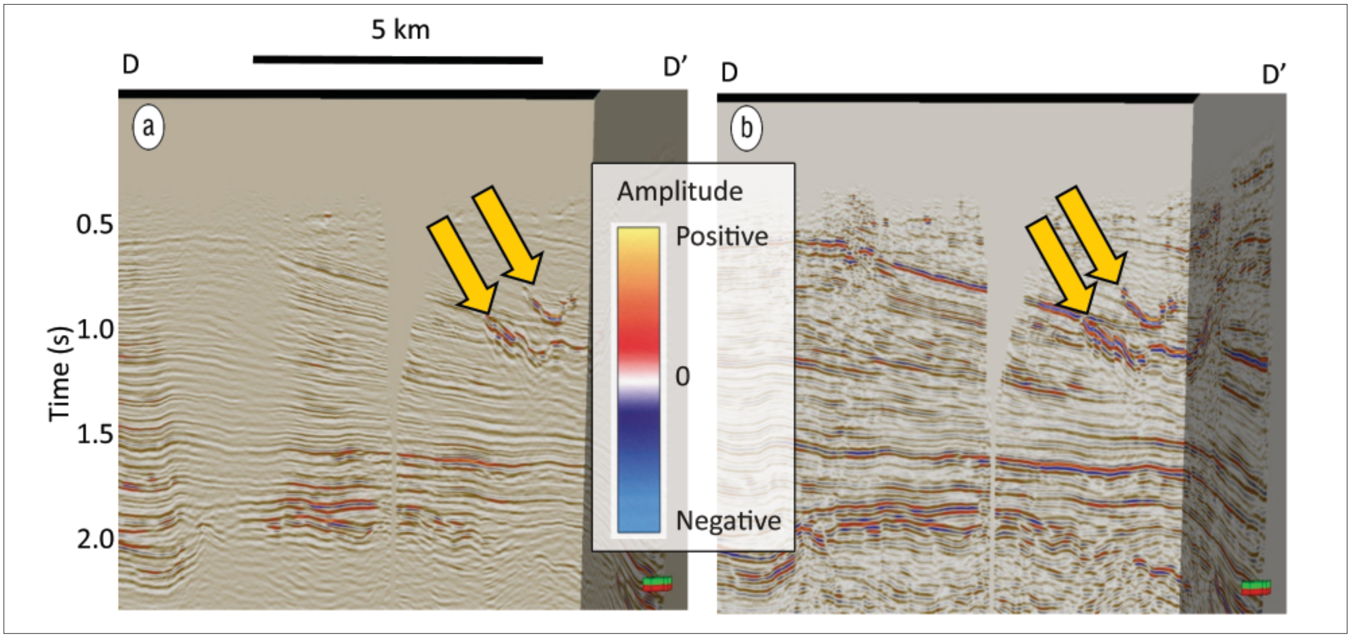

Figure 7. Seismic expression of two stacked igneous intrusive sills for the (a) original and (b) reprocessed data. Notice the lower amplitude below the volcanic sills indicated by the orange arrows has been better balanced while interbed multiples have been better attenuated. Location of lines are shown in Figure 6.

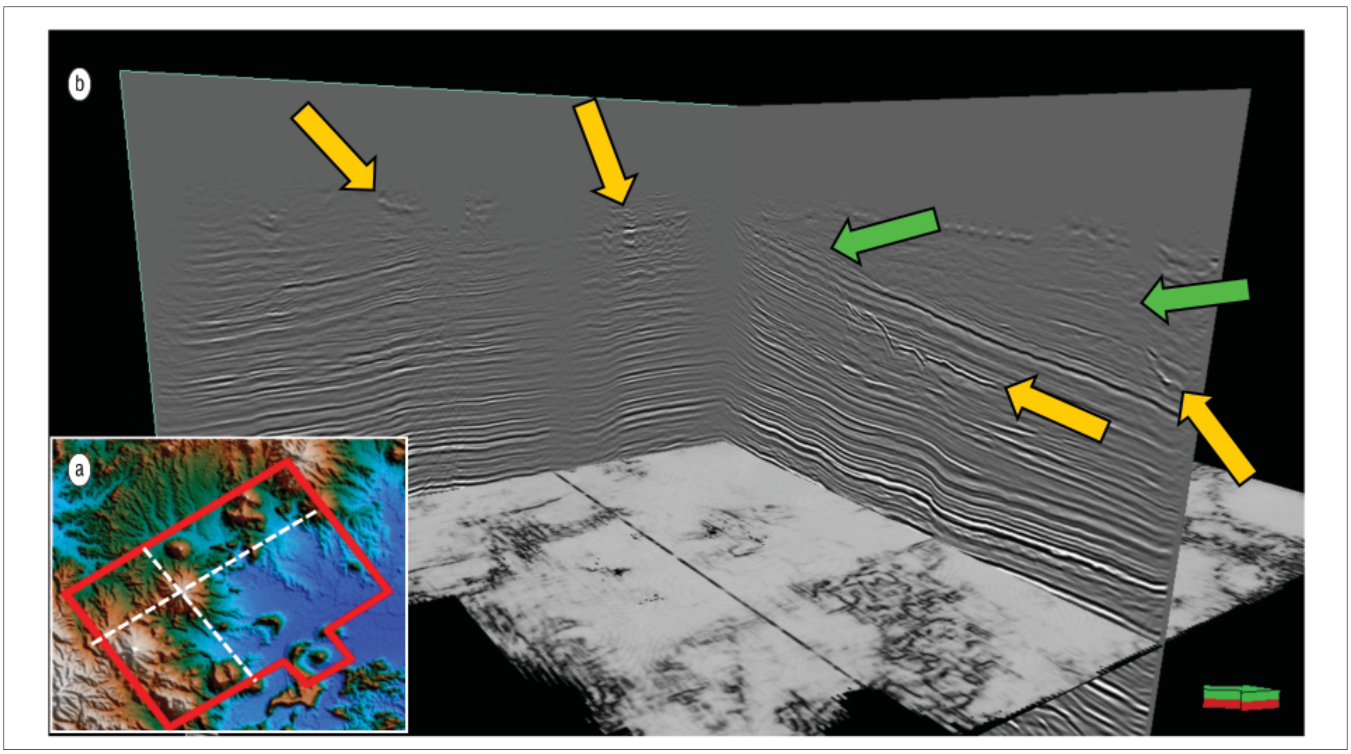

Figure 8. (a) Location of two vertical seismic lines crossing beneath the largest volcanic cone. (b) The two seismic lines are shown in (a), along with the coherence time slice at t=1.335 s. Orange arrows indicate volcanic sills. Green arrows indicate mounds that we interpret to be volcanoclastic buildups.

constrain our velocity analysis. Our next step is to evaluate the potential correlation of permeability measured in wells to proximity to volcanics.

Suggested reading. "Integrated geostatistical reservoir characterization of turbidite sandstone deposits in Chicontepec Basin, Gulf of Mexico" by Abbaszadeh et al. (SPE paper 84052, 2003). "Diagenetic history of the turbiditic litharenites of Chicontepec Formation, Northern Veracruz: Controls on the secondary porosity for hydrocarbon emplacement" by Bermúdez et al. (*Gulf Coast Association of Geological Societies Transaction*s, 2006). "Enhanced imaging workflow of seismic data from Chiconte-

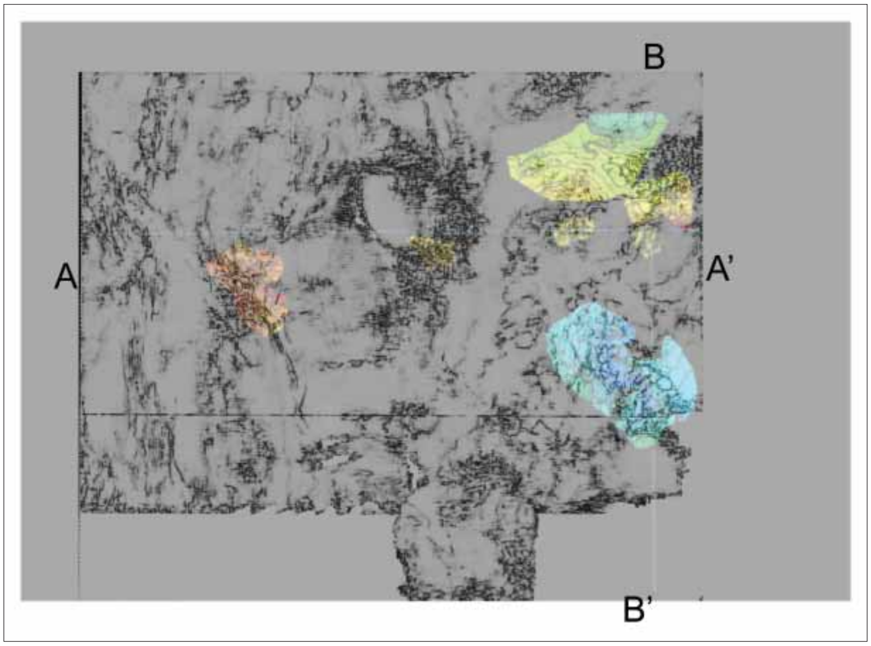

Figure 9. *Blended image of the time structure map with the coherence image at t=1.335 s. Note the correlation between the location of some of the volcanic sills and the data quality (incoherent zones) deeper in the section.*

pec Basin, Mexico" by Chávez-Pérez and Vargas-Meleza (*TLE*, 2008). *Seismic Attributes for Prospect Identification and Reservoir Characterization* by Chopra and Marfurt (SEG, 2007). "3D seismic technology: Application to the exploration of sedimentary basins" by Davies et al. (in *Geological Society of London Memoir* 29, 2004). "Seismic signature of Upper Cretaceous volcanics: Santos Basin, Brazil" by Klarner et al. (EAGE 2006 *Extended Abstracts*). "Vent complex at Heidrun" by Garten et al. (SEG 2008 *Expanded Abstracts*). "Gravity and aeromagnetic expression of tectonic and volcanic elements of the southern San Luis Basin, New Mexico and Colorado" by Grauch and Keller (in New Mexico Geological Society's 55th *Annual Field Conference Guidebook*, 2004). TLE

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