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Original paper

Gas Hydrates in the southern Jalisco subduction zone as evidenced by bottom simulating reflectors in Multichannel Seismic Reflection Data of the 2002 BART/FAMEX campaign

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Resumen

Evidencia de la presencia de hidratos de gas en forma de un reflector que simula el fondo marino (BSR) es observado en un perfil sísmico multicanal en el talud continental del área sur de la zona de subducción en Jalisco, frente a Manzanillo, México. Los reflectores son encontrados a 0.4 segundos (en el tiempo de viaje doble) bajo el reflector del fondo marino y se extiende a lo largo de 7 km del perfil. Este resultado aunado a otros resultados previos en la parte norte de la zona de subducción de Jalisco sugiere que los hidratos de gas pudieran existir en la región del talud continental de toda la zona de subducción de Jalisco, sin embargo se necesitan más datos de reflexión sísmica para verificar esta aseveración.

Palabras clave: Hidratos de Metano, BSR, Zona de Subucción de Jalisco, reflexión Sísmica.

Abstract

Evidence, in the form of bottom simulating reflectors (BSRs), for gas hydrates is observed on a multichannel seismic reflection profile in the continental slope area of the southern Jalisco Subduction Zone, off Manzanillo, Mexico. The reflectors are found at 0.4 sec (two-way travel time) below the seafloor reflector and extend for about 7 km along the profile. This result along with previous results in the northern part of the Jalisco Subduction Zone suggests that gas hydrates may exist in the continental slope region of the entire Jalisco Subduction Zone, however, more seismic reflection data needs to be collected to verify this assertion.

Key words: gas hydrate, BSR, Jalisco subduction zone, seismic reflection.

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Introduction

Gas hydrates trapped within the sediments of continental slopes are thought to represent a significant worldwide, source of energy for the future (e.g. Max *et al*., 2006; Allison and Ray, 2007). Although gas hydrates have been recovered in sediment cores, their presence is normally inferred from observations of bottom simulating reflections (BSRs) on seismic reflection profiles (e.g. Stoll *et al*., 1971; Hyndman and Spence, 1992; Laberg *et al*., 1998; Posewang and Mienert, 1999). Presently, there is a scarcity of published seismic reflection data along the Pacific margin of Mexico from which one could adequately analyze the gas hydrate potential of this region. However, BSRs have been reported in several areas including off the Pacific margin of Baja California Sur (Cruz-Melo, 2008) and along the Middle America Trench off southern Mexico (Shipley *et al*., 1979). Gas hydrates were observed off Acapulco in cores from holes 490, 490 and 492 collected during Leg 66 of the Deep Sea Drilling Project (Shipley and Didyk, 1981). In the Jalisco Subduction Zone, at which the Rivera plate subducts beneath the North American plate (Figure 1), a few single channel seismic reflection profiles have been presented by Ross and Shor (1965), Bourgois *et al*. (1988), Bourgois and Michaud (1991), Bandy (1992), Khutorskoy *et al*. (1994), and Michaud *et al*. (1996). Khutorskoy *et al*. (1994) observed several BSRs in their data located within the continental slope area in the offshore extension of the Tecoman Graben within the southern Colima Rift. Multichannel data are particularly scarce in the Jalisco Subduction Zone where the only published multichannel data are those collected during the 1996 CORTES P96 campaign (Minshull *et al*., 2005; Bartolomé *et al*., 2011) and the 2002 BART/FAMEX campaign (Bandy *et al*., 2005). Minshull *et al*. (2005) and Bartolomé *et al*. (2011) report the presences of BSRs in the northern part of the Jalisco Subduction Zone off Puerto Vallarta between 20º and 20.5ºN. Thus, there is evidence to suggest that the Pacific margin of Mexico may contain significant gas reserves in the form of gas hydrates, However, much of the margin has yet to be explored so that a full evaluation of this potential cannot presently be determined.

In this paper we present some previously unreported evidence for gas hydrate accumulations in the southernmost part of the Jalisco subduction zone off Manzanillo found on a multichannel seismic reflection profile collected during the 2002 BART/FAMEX campaign of the N/O L'Atalante. On this profile, BSRs are clearly observed in the continental slope region. These data and observations should be of value to other investigators interested in evaluating the gas hydrate potential of the Jalisco Subduction Zone in particular and worldwide distribution of gas hydrates in general.

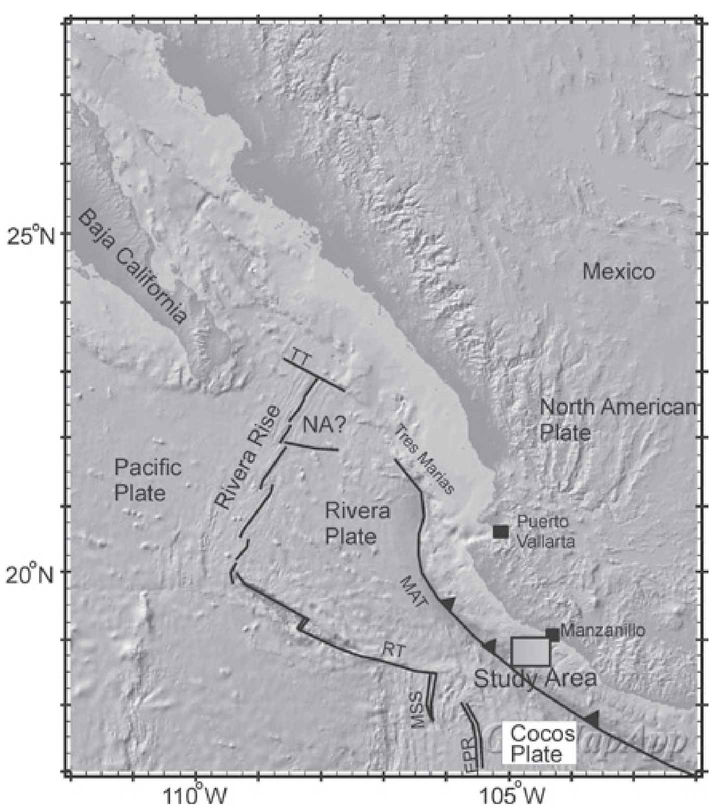

Figure 1. Study area location. Abbreviations are: MAT=Middle America Trench; NA= North American Plate; MSS=Moctezuma Spreading Segment; EPR=East Pacific Rise; TT=Tamayo Transform; RT=Rivera Transform. Background image from GeoMapApp.

Geologic setting

The Jalisco Subduction Zone comprises the northernmost part of the Middle America Trench (MAT), north of Manzanillo, Colima (Figure 1). This zone is an active continental margin at which the Rivera plate is subducting beneath the North American plate. The offshore part of this continental margin, from the coastline to the trench axis, is on average 80 km wide. Although no drilling has been done in the offshore are of this margin, seismic reflection data indicate that, offshore, the subsurface consists of a thick sequence of marine sediments along the entire margin (Ross and Shor, 1965; Bourgois *et al*., 1988; Bourgois and Michaud 1991; Bandy, 1992; Khutorskoy *et al*. 1994; Michaud *et al*., 1996; Minshull *et al*., 2005; Bandy *et al*., 2005; Bartolomé *et al*., 2011). In the southernmost part of the Jalisco Subduction Zone, within the Tecoman trough and over the Manzanillo Horst (Figure 2) these sediments are observed in submersible dives to unconformably overlie pre-Eocene plutonic rocks: granodiorites and gabbros (Mercier de Lépinay *et al*., 1997).

Bottom simulating reflectors and gas hydrates

The association between BSRs and gas hydrate accumulations is illustrated in Figure 3. Briefly, gas hydrates form within the uppermost part of the sedimentary column within the "gas hydrate stability zone", which is the zone within which the physical conditions within the sediments (i.e. pressure, temperature, interstitial water salinity, etc.) allow for the formation of gas hydrates. Below this zone the physical conditions do not permit hydrate formation, consequently, the gas is in a free state and collects within the pore spaces of the sediments. Since the gas hydrates form a seal, the upward migrating free gas is trapped at the base of the gas hydrate stability zone. This free gas lowers the acoustic impedance of the gas charged sediments below the base of the hydrates, which normally results in a negative acoustic impedance contrast as well as an increase in the absolute value of the acoustic impedance contrast. Thus, the seismic reflections (BSRs) from the base of the gas hydrate stability zone are expected to be of high amplitude and to have a polarity that is the reverse of the down-going seismic pulse.

As the name implies, a BSR in general mimics the shape of the seafloor reflector (Stoll *et al*., 1971). The depth of the base the gas-hydrate stability zone is controlled by temperature, pressure, gas chemistry and salinity of the interstitial fluids; therefore if these parameters do not vary drastically within a given area, then the depth of the base of the hydrate layer below the seafloor should remain fairly constant and hence the BSR should mimic the seafloor reflector (Zatsepena and Buffer, 1997; Max, *et al*., 2006).

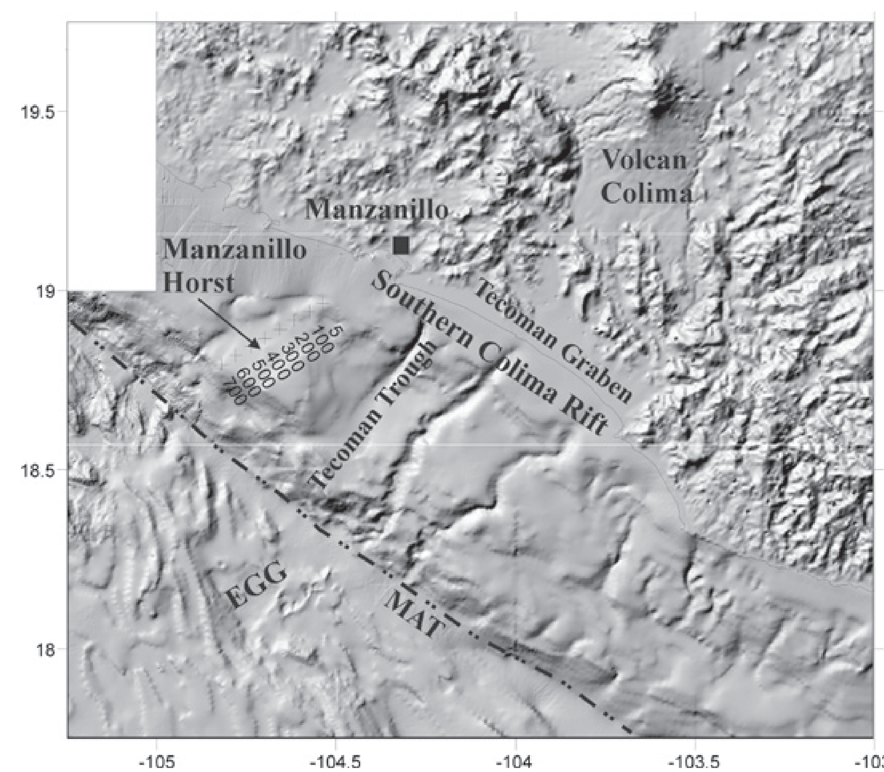

Figure 2. Relief map illustrating location of Seismic reflection profile shown in Figure 4. Numbers refer to CMP locations. Abbreviations are: EGG=El Gordo Graben; MAT=Middle America Trench. (Modified from Bandy *et al*., 2005).

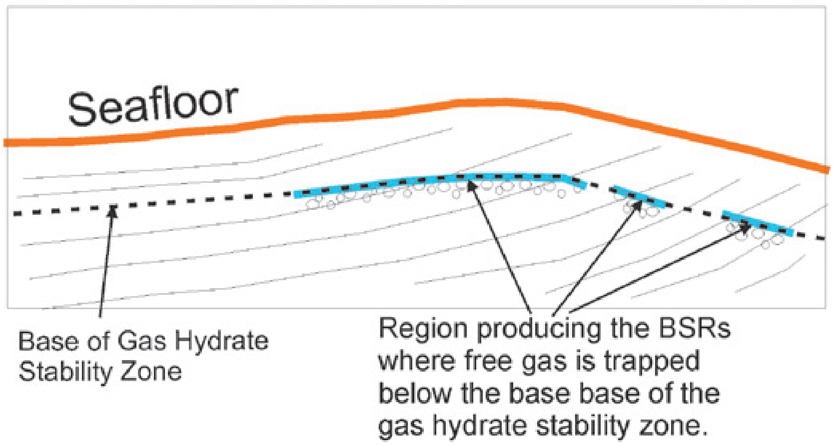

Figure 3. Drawing illustrating how the BSR is produced. Note how the BSR (Blue lines) can cut across the sediment layers (thin lines). Circles represent free gas within the sediments.

In summary, a BSR should exhibit the following characteristics:

(1) It should exhibit high amplitudes,

(2) It should have reverse polarity (i.e. the reflected pulse should be180 degrees out of phase with that of the down-going pulse).

(3) It should mimic the shape of the seafloor reflector.

Another distinguishing characteristic of the BSR is that in areas where the sediment layers are inclined relative to the seafloor, the BSR will cut across the reflections from the sediment layers. For more details about the underlying physics of gas hydrates and BSRs, the reader is referred to one of the many publications that deal in depth with this subject, such Max *et al*. (2006).

Data

The seismic reflection data used in this study were collected along a profile (see Figure 2 for profile location) during the BART/FAMEX campaigns conducted during April 2002 aboard the N/O L'Atalante. Three-fold data were acquired employing 300 in.^{3} Gas injection (GI) guns tuned in harmonic mode and a hydrophone streamer with 6 hydrophone groups (48 hydrophones per group) spaced 50 m apart. The spacing between stacked traces is 25 m. The data was sampled at 4 ms and recorded using SEG-Y format. During processing, the distance between Common Mid Point (CMP) locations was set at 50 m.

The data was processed using the following processing sequence:

1. Geometry assignment

2. Spherical divergence correction

3. 10-70 Hz band-pass filter with a high and low rolloff rate of 18 dB/octave

4. Normal Moveout (NMO) correction

5. Stack

6. Migrated using the Gazdag phase-shift method (Gazdag, 1978) employing a constant velocity of 1500 m/s.

Results and discussion

The upper continental slope along the profile (Figure 4) consists of a sequence of relatively undisturbed sediments that were deposited on a subsiding, seaward tilting seafloor (Bandy *et al*., 2005). This unit extends down to water depths of about 750 m. No BSRs are observed in this area. At the seaward end of this unit (at CMP 131), the water depth increases rapidly to about 1200 m and a mid-slope terrace is present between CMPs 195 to 720. Water depths gradually increase from 1200m to 1500m seaward across this terrace. The terrace is disrupted in its northeastern part (between CMPs 250 to 551) by a series of anticlines. No BSRs are clearly observed in this area; however, the complex deformation might be masking these reflectors if present.

Seaward of CMP 551 the terrace is underlain by relatively undisturbed sediments typical for a mid-slope terrace (Figures 5 and 6). A prominent BSR is present in the undisrupted SW part of the terrace between CMP 580 to CMP 720 at a depth of about 400ms TWTT (two-way travel time) below the seafloor reflection. This represents a distance of about 7 km. The BSR is of high amplitude, it cuts across the more steeply dipping reflectors from the sedimentary units, and the reflector mimics the seafloor (i.e. it consistently lies at about 400 ms TWTT below the seafloor). Thus, it clearly exhibits three of the requirements for being a BSR. Also, the polarity of the BSR (peak-

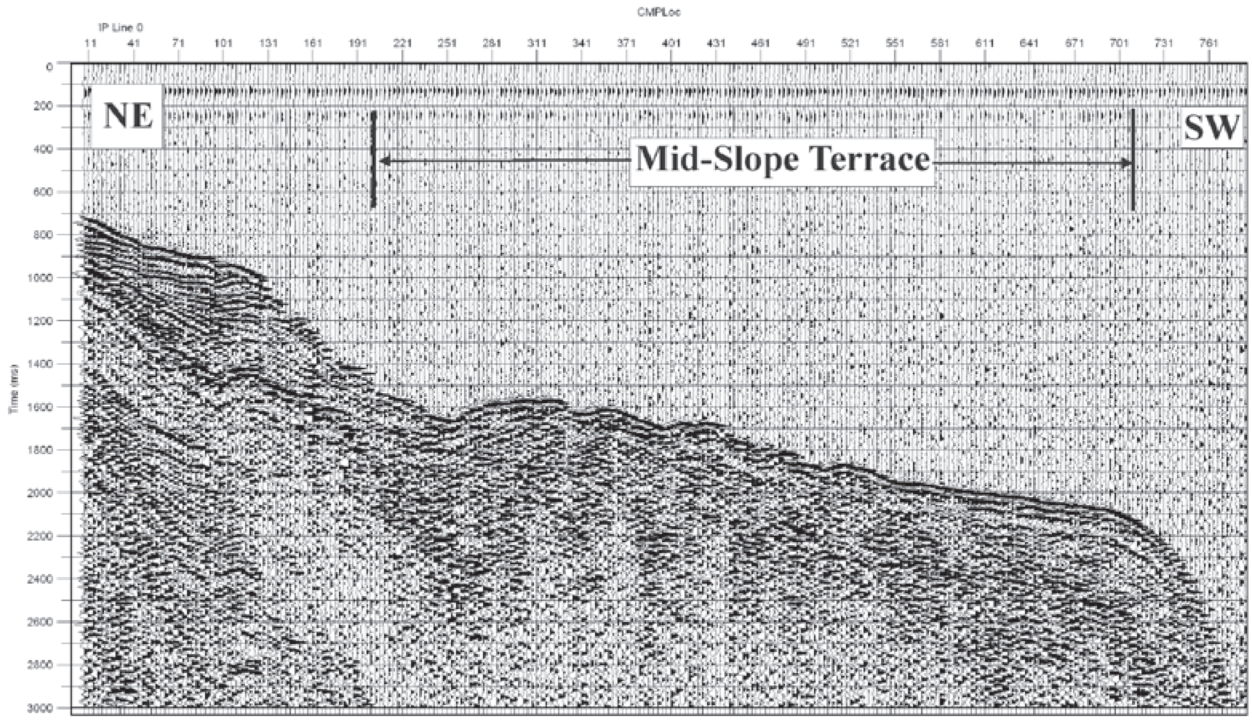

Figure 4. Seismic reflection profile illustrating the character of the mid-slope terrace off Manzanillo. Every 10th trace is plotted. The Middle America Trench is located to the SW. Time plotted is two-way travel time (modified from Bandy *et al*., 2005).

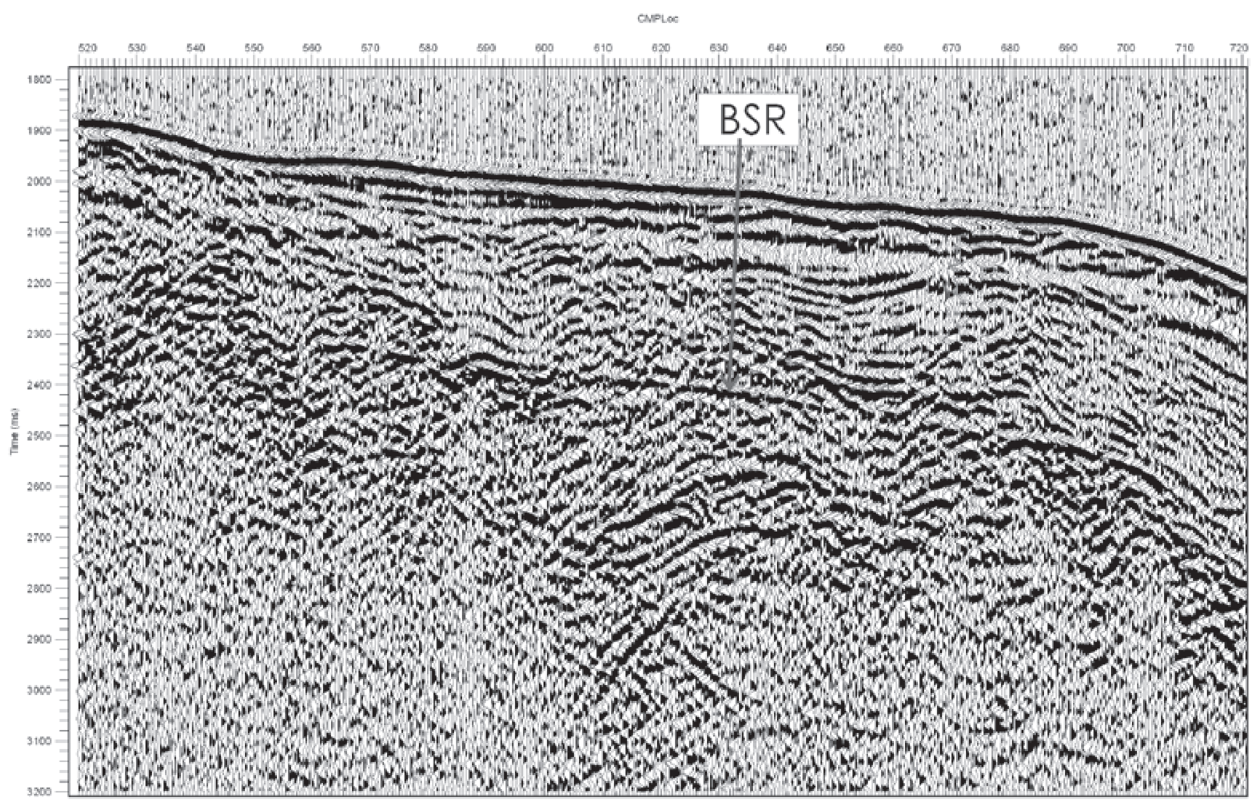

Figure 5. Uninterpreted blowup of the seaward part of the profile shown in Figure 4 illustrating the BSR.

trough-peak) appears to be 180 degrees out of phase with the seafloor reflector (trough-peak-trough), however this is not entirely clear.

Trying to quantify the amount of gas in the sediments is quite difficult. However, one can obtain a very rough estimate of the volume of gas present in the outer part of the mid slope terrace over the Manzanillo Horst as follows. The width of the Manzanillo Horst is about 20 km and the BSR covers the outer 7 km of the horst. Now, assuming that the p-wave velocity in the sediments is 2 km/sec, and assuming that the gas hydrates extend from the seafloor to the BSR, then the thickness of the gas hydrate layer can be estimated to be 400 meters. Thus, the volume of sediments containing the gas is 66 km^3. Assuming that the sediments have a porosity of 10% (a value which may be quite low given that these sediments are most likely unconsolidated) then the volume of gas is estimated to be 6.6 km^3. One needs to add to this value the volume of the free gas trapped beneath the base of the gas hydrates, unfortunately there is no way to estimate this from the seismic data as even a very small amount of gas in the pore space will produce a high amplitude reflection (e.g., Domenico, 1977).

Our results provide additional seismic evidence for significant accumulations of gas hydrates in the continental slope region on the southern part of the Jalisco Subduction Zone. This result in conjunction with the BSRs observed in the continental slope region of the northern part of the Jalisco Subduction Zone suggests that the continental slope area along the entire Jalisco Subduction Zone may contain significant accumulations of gas hydrates. Therefore, a more extensive seismic reflection survey of the rest of the Jalisco Subduction Zone may be warranted to fully evaluate the potential gas reserves in this area.

Conclusions

(1) In the continental slope area of the Jalisco Subduction Zone off Manzanillo, the multichannel data of the 2002 BART/FAMEX campaign reveal a high amplitude, possibly reversed polarity, reflector that mimics the seafloor reflector and cuts across the more steeply dipping sedimentary reflectors.

(2) The characteristics of this reflector are consistent with it being a BSR, and thus, strongly indicate the presence of gas hydrates.

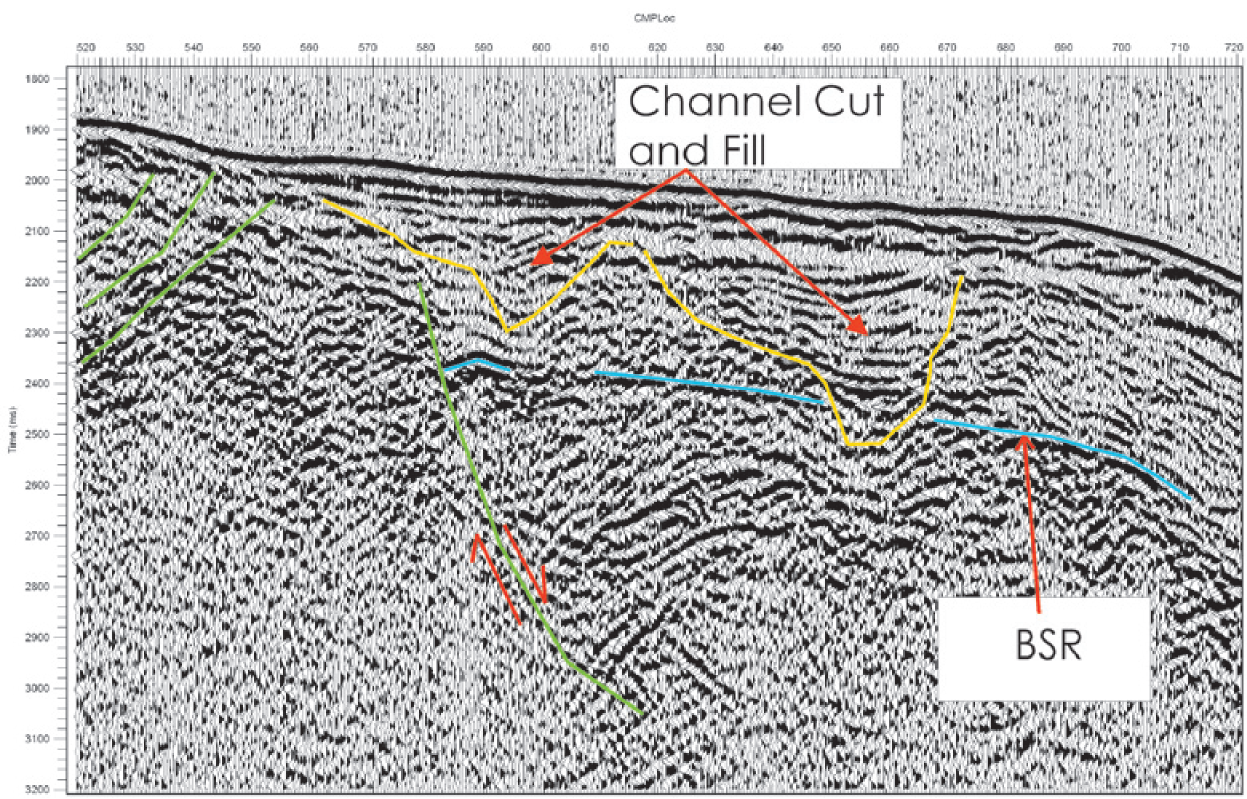

Figure 6. Interpretation of the profile shown in Figure 5. Green line marks faults, blue line is the BSR, and yellow lines mark unconformities interpreted to be the base of channel fill sequences.

(3) The BSR consistently lies at 400 ms (TWTT) below the seafloor reflector and extends for a distance of 7 km along the profile, which suggests that a substantial accumulation of gas hydrates (greater than 6.6 km^3) may be present in this area.

(4) Our results, in conjunction with the BSRs observed in the northern part of the Jalisco Subduction Zone during the CORTES-96 campaign, indicate that a more extensive seismic reflection survey is warranted and needed to fully evaluate the gas potential of the continental shelf area of the Jalisco Subduction Zone.

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Bibliography

Allision, E., and Ray, B., 2007, Methane Hydrate: Future Energy within our grasp, a review, 20 pp., US Department of Energy, Washington, D.C. 20585.

Bandy, W.L., 1992, Geological and Geophysical Investigation of the Rivera-Cocos plate boundary: implications for plate fragmentation. Ph.D. dissertation, Texas A&M University, College Station, 195 p.

Bandy, W.L., and 16 others, 2005, Subsidence and strike-slip tectonism of the upper continental slope off Manzanillo Mexico. *Tectonophysics, 398,* 115-140.

Bartolomé, R., Dañobeitia, J., Michaud, F., Córdoba, D., and Delgado-Argote, L.A., 2011, in Geodynamics of the Mexican Pacific Margin, Bandy, W.L., Taran, Y., Mortera Gutiérrez, C., and Kostoglodov, V. (eds.), Pageoph Topical Volumes, Birkhäuser, 123-139, ISBN 978-3-0348-0196-6.

Bourgois, J., and Michaud, F., 1991, Active fragmentation of the North American plate at the Mexican Triple Juntion Area off Manzanillo (Mexico). *Geomarine Letters, 11*, 59-65.

Bourgois, J. and 11 others, 1988, Fragmentation en cours du continent Nord Américain: les frontiers sous marines du bloc de Jalisco (Mexique). *C.R. Acad. Sc.Paris, 307 II*, 1121-1130.

Cruz Melo, C.E., 2008, Análisis de la presencia de hidratos de metano con los horizontes sismicos BSR al suroeste de la Península de Baja California, México. Tesis de Maesría, Instituto de Geofisica, UNAM, Mexico, D.F., 110pp.

Domenico, S.N., 1977, Elastic properties of unconsolidated porous sand reservoirs. *Geophysics, 42,* 1339-1368.

Gazdag, J., 1978, Wave-equation migration by phase-shift, *Geophysics, 43,* 1342-1351.

Hyndman, R.D., and Spence, G.D., 1992; A seismic study of methane hydrate marine bottom simulating reflectors. *J. Geophys. Res., 97,* 6683-6698.

Khutorskoy, M.D., Delgado-Argote, L.A., Fernández, R., Kononov, V.I. and Polyak, B.G., 1994, Tectonics of the offshore Manzanillo and Tecpan basins, Mexican Pacific, from heat flow, bathymetric and seismic data*. Geofisica Internacional, 33,* 161-185.

Laberg, J.S., Andreassen, K., and Knutsen, S.-M., 1998, Inferred gas hydrate on the Barents Sea Shelf – a model for its formation and volume estimate. *Geo-Marine Letters, 18,* 26-33.

Max, M.D., Johnson, A.H., and Dillon, W.P., 2006, Economic Geology of Natural Gas Hydrates, *Springer,* The Netherlands, 341pp.

Mercier de Lépinay, B., and 11 others, 1997, Large Neogene subsidence event along the Middle America Trench off Mexico (18º -19ºN): Evidence from submersible observations, *Geology,* 25, 387-390.

Michaud, F., Mercier de Lepinay, B., Bourgois, J., and Calmus, T., 1996, Evidence for active extensional tectonic features within the Acapulco trench fill at the Rivera-North America plate boundary. *C.R. Acad. Sc.Paris, t. 321 sèrie IIa*, 521-528.

Minshull, T.A., Bartolomé, R., Byrne, S., and Dañobeitia, J., 2005, Low heat flow from young oceanic lithosphere at the Middle America Trench off Mexico. *Earth and Planetary Science Letters, 239,* 33-41.

Posewang, J., and Mienert, J., 1999, High-resolution seismic studies of gas hydrates west of Svalbard. *Geo-Marine Letters, 19,* 150-166.

Ross, D.A., and Shor Jr., G.G., 1965, Reflection profiles across the Middle American Trench, *J. Geophys. Res. 70, 5551-5572.*

Shipley, T.H., and Didyk, B.M., 1981, Occurrence of methane hydrates offshore southern Mexico, in Watkins, J.S., Moore, J.C., *et al*., Init. Repts*. DSDP, 66:* Washington (U.S. Govt. Printing Office), 547-556.

Shipley, T.H. *et al*., 1979, Seismic reflection evidence for widespread occurrence of possible gas-hydrate horizons on continental slopes and rises. *Am. Assoc. Pet. Geol. Bull., 63*, 2204-2213.

Stoll, R.D., Ewing, J., and Bryan, G.M., 1971, Anomalous velocities in sediments containing gas hydrates. *J. Geophys. Res., 76,* 2090-2094.

Zatsepena, O.Y., and Buffer, B.A., 1997, Phase equilibrium: Implications for the formation of hydrate in the deep seafloor *Geophys. Res. Lett., 24*, 1567-1570.