Attribute Expression of Mass Transport Deposits in an Intraslope Basin- A Case Study.

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Summary

Mass transport deposits (MTDs) are common features that help us reconstruct the depositional environment in deepwater basins. Unlike turbidite sands that form in similar environments, MTDs only rarely form hydrocarbon reservoirs. Near the water bottom, recent MTDs can indicate the risk of future hazards to submarine platform legs, drill stems, pipelines, and communication cables. MTDs commonly exhibit an overall chaotic seismic pattern; several other associated features help to differentiate MTDs from other kinds of deposits in deep water depositional environments. MTDs have similar characteristics in intraslope basins (also called salt minibasins) but vary as a function of restricted transport direction for sediment input, limited accommodation space, and syndepositional salt movement. By coupling principles of geomorphology with seismic attributes and a depositional model, we analyze the characteristics of an MTD within an offshore Gulf of Mexico study area to determine how it differs from other deepwater architectural elements.

Introduction

Weimer and Slatt (2006) consider mass transport deposits (MTDs) as one of the four main architectural elements of deep water environments. Mass transport deposits generally form due to slope failure or slumping from the shelf-slope area when sea level falls rapidly, exposing the shelf-slope area and changing sediment pore pressure. For intraslope basins, MTDs often "develop from the failure of delta front or canyon walls, have extensive erosion at their base, and overlying sediment fill" (Weimer and Slatt, 2006)

Although mass transport deposits (also called mass transport complexes, or MTCs) are not prolific reservoirs, these deposits are still of great interest to industry, government safety departments, and academics. Shallow mass transport deposits are common drilling hazards due to their complex internal structure and the potential to contain local gas pockets. In some basins, including the Gulf of Mexico, individual depositional sequences may consist of more than 50% slides and/or deformed sediments (Weimer and Slatt., 2006). For this reason, MTDs are very important in setting up the sequence stratigraphic framework in a basin or minibasin. In most cases MTDs are deposited at the top of sequence boundary at early Low Stand System Tract (LST), sometimes eroding sediments at their base. In some instances, remobilized massive sands can form MTD reservoirs. Finally, the displaced water associated with the formation of MTDs is second only to undersea earthquakes in the initiation of destructive tsunamis.

Our study focuses on an MTD located within the tabular salt minibasin tectono-stratigraphic province- which covers a large area of the continental slope along the northern Gulf of Mexico margin. Salt constrains the minibasin on the eastern, western and southern sides; the main sediment fairway is from the northern side. There is a broad variability in terms of the final geometric configuration of the minibasin, depending upon the interaction of the continuously-deposited sediment load on top of the allochthonous salt, giving rise to temporally-varying lateral changes in subsea topography. Due to the constrained sediment fairway and limited accommodation space, the geomorphology of deep water deposits differ from those in open marine conditions.

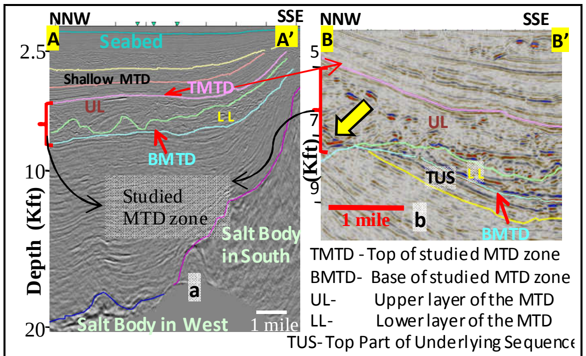

Figure 1: Seismic lines (a) AA' and (b) BB' showing a mass transport deposit (MTD) imaged by our 3D seismic survey. The MTD unit is comprised of two discrete flow events forming two layers having different attribute characteristics. Note how the upper flow of the MTD cuts down through and erodes the lower flow unit . In Figure 1a, Two salt bodies and another MTD situated in the shallower part are also indicated. In (b), the yellow arrow indicates the axis of the flow conduit of the upper flow. Data courtesy of Hess Inc.

Methodology

We focus on one prominent MTD within the 3D seismic volume (Figure 1- studied MTD zone). We used well logs and paleontological data to validate our time horizons and interpreted the bounding surfaces for the mass transport deposit. In addition to the migrated seismic amplitude we generate volumes of RMS amplitude, coherent energy (the square of the RMS amplitude of the coherent component of the data), eigenstructure coherence, generalized Sobel filter edge detectors, amplitude gradients, and both most-positive and most-negative curvature. Each attribute volume was then analyzed along stratal (proportional) slices between the two bounding horizons.

Each attribute was examined on each stratal slice. Although attributes such as RMS amplitude, coherence, and curvature are mathematically independent, they are often coupled through the underlying geology. For this reason, some the features can be identified on all the attributes while others were illuminated only by one or two attributes. Using this approach we set out to characterize our mass transport deposit. To put our MTD in the proper geological context, we also examined underlying and overlying sediments.

Results and Discussion

We begin our analysis at the base of the mass transport deposit. In general, MTDs are formed during the early Lowstand System Tract (LST) when sea level falls, rapidly exposing the shelf and slope region, resulting in the collapse of shelfal sediments, slope failure and slumps. In deeper water the LST is expected to overlie the maximum flooding surface of a previous Transgressive Systems Tract (TST) or shale deposited during the previous Highstand. In Figure 2 we display the Root Mean Square amplitude (RMS) computed in a 120 ft (40 m, or 5-sample) interval 400 ft below and at the base of the MTD. The low amplitude deposits in Figure 2a may have been deposited during the previous TST. Maximum erosion occurs near the main conduit such that the MTD often overlies channel-overbank or sheet sands deposited during the previous Low Stand.

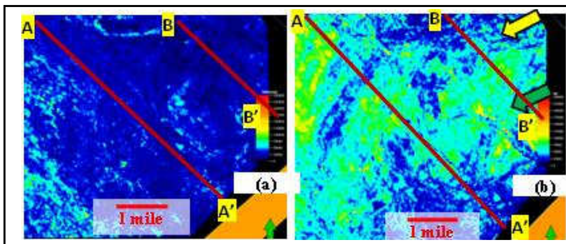

Figure 2: Stratal slice through the RMS amplitude volume (a) 400 ft below the base of the MTD and (b) at the base of the MTD. In (b), Green arrow indicate the lower flow while yellow arrow indicate the upper flow conduit of the MTD. AA' and BB' indicates the seismic lines shown in Figure 1.

Figures 1a and 1b indicate that the MTD is comprised of two different flows forming two distinct layers. The flow in the lower layer of the MTD is less erosive and relatively stratified, whereas the flow in the upper layer of MTD is highly erosive and more chaotic. Green arrows in Figure 3 indicate a broader conduit for the lower flow from the north

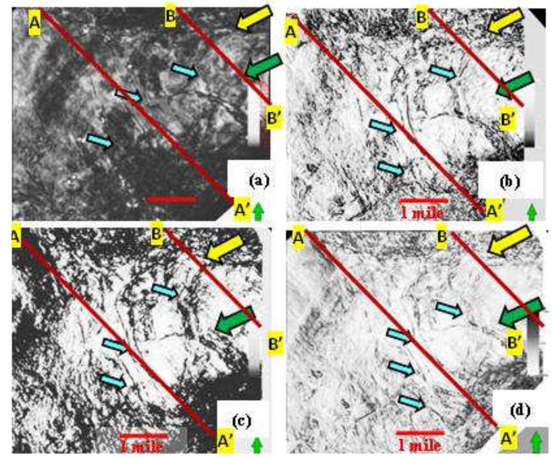

Figure 3: Stratal slices along the base of the MTD through the (a) coherent energy, (b) generalized Sobel filter, (c) eigenstructure coherence, and (d) variance volumes Green arrows indicate the lower flow while yellow arrows indicate the upper flow which cuts down through the lower flow. Cyan arrows indicate arcuate compressional faults formed in the MTD.

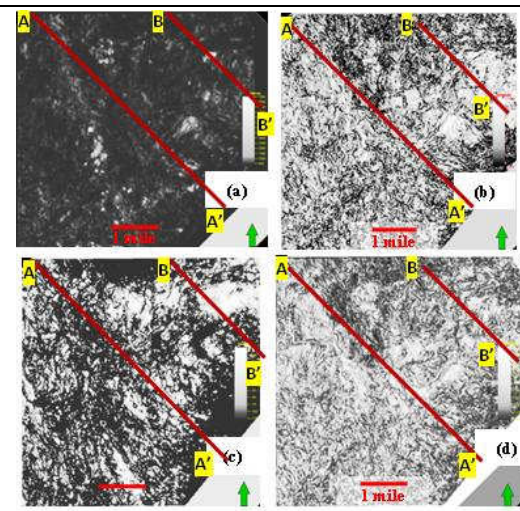

Figure 4: Stratal slices through (a) coherent energy, (b) generalized Sobel filter, (c) eigenstructure coherence, and (d) variance volumes through the upper flow of the MTD as it fills the minibasin. Note the more chaotic texture compared to slices through the base displayed in Figures 3 a-d.

eastern side. The axis of the upper flow forms a canyon-like conduit seen in Figure 1b from the same (north eastern) direction that erodes the lower flow (yellow arrows) as well as some part of the underlying sequence. We can see only part of the conduit in the available data set. The wings of the upper flow of the MTD are also erosive, but the flow energy is less. In Figure 3 we delineate the edges of these two layers of the MTD on stratal slices through the coherent energy, generalized Sobel filter, coherence, and variance volumes. In general, the lower layer is relatively smooth and continuous. In contrast, Figure 4 through the upper layer shows the more typical chaotic texture characteristic of MTDs. Indeed, the flow is so chaotic that the attributes cannot discriminate between internal discontinuities and the discontinuities associated with bounding faults. We interpret the difference seen in the two flows as the magnitude of the failure activity.

In Figure 5a, we note increased reflector continuity towards the top of the upper flow in the MTD. We interpret this continuity as either deposition of suspended sediments after failure or as better-sorted deposits trailing the slump front.
The RMS amplitude mostly shows a discontinuous nature especially in the upper flow of the MTD, but in some places some continuity in the amplitude pattern can be seen (Figure 5b). This pattern can be observed from the most positive curvature slice (Figure 5c) that indicates that in addition to the main flow from north west-south east, there are additional flow conduits from the northwest and north. This pattern continues above the mass transport deposit.

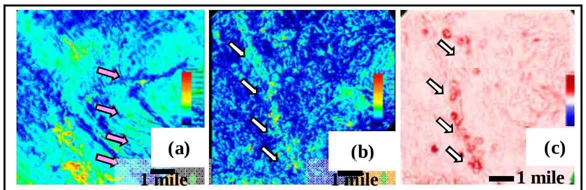

Figure 5: Stratal slices through RMS amplitude volumes (a) at the top and (b) within the MTD. (c) Stratal slice through most-positive curvature within the MTD. Lavender arrows in (a) indicate faults. White arrows in (b) and (c) indicate flow conduit from north or northwest.

Although not common, we identify a groove or striation at the base of the MTD in Figure 6. The surface is almost perpendicular to the faults and may have been created due to dragging of some coarser material.

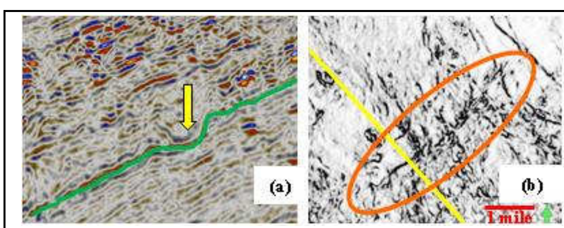

Figure 6: Striation or groove seen in (a) vertical seismic indicated by yellow arrow and (b) horizon slice through generalized Sobel filter volume, indicated by the red ellipse. Horizon slice corresponds to green pick in (a). Vertical slice corresponds to yellow line in (b).

One of the most interesting features of the mass transport deposit is the presence of several high amplitude blocks showing bright spots in the seismic (Figures 7a and b) that trend as a NNE- SSE arc (dashed cyan line in Figure 7e). These high amplitude bodies are seen near the top of the mass transport deposit or top of the upper flow. The apparent flow direction indicated from coherent energy and most positive curvature does not follow the main mass transport direction. These features might be sand blocks deposited within the MTD from a sandy debris flow which came from the NNE direction. The strengths and confined character of these bright spots suggest that they are hydrocarbon charged sand bodies. Such bright spots are often observed in MTDs. If these bodies are sufficiently large, they may be considered for commercial exploration, otherwise they should be considered to be a potential hazard.

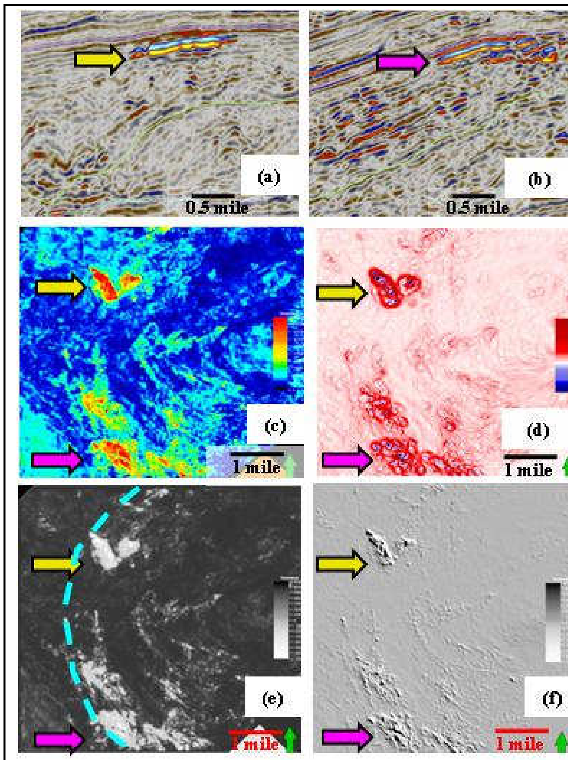

Figure 7: (a) and (b) Vertical slices through the seismic amplitude showing bright spots towards the top of the MTD. Horizon slices through (c) RMS amplitude (d) most-positive curvature, (e) coherent energy and (f) crossline amplitude gradient. Yellow and magenta arrows indicate the two bright spots shown in (a) and (b). Dashed cyan line in (e) indicates the trend of the high energy features.

A series of faults can be seen throughout the mass transport deposit. Horizon slices through eigenstructure coherence, variance and the generalized Sobel filter gives a very good picture of the faults (Figures 2b-d and 8). The faults are arcuate-shaped in profile and they are formed due to toe-thrusts perpendicular to the direction of flow (e.g. Posamentier and Walker, 2006). The fault blocks are rotated (Figure 8) with the base of the mass transport deposit acting as the decollement surface. Our area of interest is confined by salt in all directions including the south western direction, such that the flow was not able to move a long distance and a thrust situation developed after entering the minibasin. Most of the faults in the studied zone were probably generated by the processes within the MTD. These faults were reactivated during the salt activity and consequently most of the faults have been extended beyond the MTD.

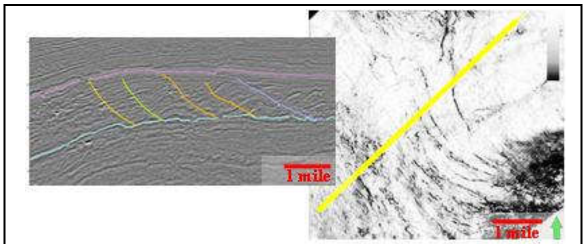

Figure 8: Stratal slice through generalized Sobel filter volume showing arcuate faults. Yellow line indicates the position of the seismic line where we have interpreted a suite of rotated faults that may be toe-thrusts.

In contrast to the MTD, the overlying deposits are characterized by continuous reflection events. RMS amplitude indicates a thick sheet deposit (Figure 9a). The feeder channels of the sheet can be observed at a shallower level (Figure 9b), and is characteristic of early LST after the deposition of a MTD. The fact that the feeders are above the sheet indicates they were open during sheet deposition and later backfilled during sea level rise. The internal texture contains a smaller network of channels of the sheet deposit and a sediment fairway from the NNE (indicated by pink arrows) can be observed from the inline amplitude gradient attribute (Figure 10a), eigenstructure coherence (Figure 10b) and generalized Sobel filter (Figure 10c).

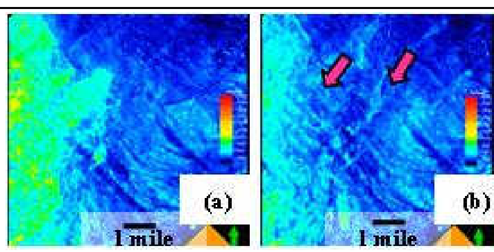

Figure 9: Stratal slices through RMS amplitude volume showing the sheet deposit overlying the MTD. Pink arrow indicate feeder channels from the north.

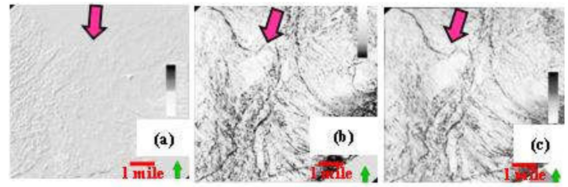

Figure 10: Attribute expression of the sheet sand deposit overlying the MTD: (a)inline amplitude gradient, (b) eigenstructure coherence an (c) generalized Sobel filter. Pink arrows indicate sediment fairway from the north.

Conclusions

By analyzing different seismic attributes in the MTD interval, we are able to identify characteristic features of mass transport deposits in intraslope basins. In addition to the well-known chaotic nature of mass transport deposits, we also identify more coherent stratification indicative of energy from different directions or completely decoupled flow events. We recognize fault patterns on coherence, variance and generalized Sobel filter slices that indicate upslope failure as well as terminal toe thrusts. These attributes with coherent energy helped us to identify the sediment fairway and channel conduits. A grooved or striated trail may be identified at the base of the MTD which also helps to determine the flow direction. The most interesting features we identified were the internal sand blocks probably charged with hydrocarbons. They might have resulted from a sandy debris flow and came from a different direction than the main flow of MTD. The attribute characteristics of these features are completely different from the features of the overlying and underlying sediments. The sets of seismic attributes lead us to systematically characterize the complex deep water deposits and, more importantly, help us to set up seismic sequence stratigraphic framework in the basin. We will continue this study with this dataset and also with more sets of attributes and datasets if available to find more characteristics improving the seismic geomorphological study.

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