On accurate imaging of steep salt flanks

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Summary

The accurate imaging of steep flanks of salt domes has long been a challenging problem for exploration geophysicists. The problem continues to be relevant today as more and more salt domes are being shot with *3D* seismic in order to exploit remaining hydrocarbon reserves. Unfortunately, the seismic images of steep salt flanks are often not satisfactory; they are either broken or appear as smeared events. Interpretation of the salt body in these cases is difficult and somewhat confusing (see figure la).

In this paper we present a method to solve the difficulties in accurately imaging and positioning steep salt flanks. The method is called *controlled stacking,* and is based on automatic selection of direct reflected wavefronts from migrated common shot gathers. The application of the method is done in three steps. We start by prestack depth migrating the input data. Next, we construct the direct illumination zone of each shot gather. Having the shot location, as well as a rough estimate of the salt model geometry, the critical angles in the up-dip as well as down-dip directions along the salt flank are calculated. Using those points, a 'pass' triangle is constructed for physical muting of the partial images given by each shot gather. Finally, the data are sorted and stacked to obtain the final seismic section. This depth section consists of primary reflections only, and thus represents the subsurface geometry very accurately.

Introduction

The development of oil and gas reserves around salt domes has historically proceeded with a combination of gravity data, *2D* seismic, and test drilling. Although this approach has resulted in the production of a large volume of hydrocarbons, the reservoir model developed for these structures often changes dramatically when a *3D survey* is obtained. Frequently, this results in the upgrading of reserve values and a new cycle of development drilling. This kind of success usually proceeds from a clearer definition of the salt/sediment interface. In some cases, one can confidently define reservoir up-dip of the highest well penetration, while maintaining a safe drilling distance from the salt.
The geological exploration objective in the case presented is to define the position of the sediment/salt interface to within 100 feet at depths of up to about 18,000 feet, even when this interface is extremely steep. The geophysical processing objective is thus, to produce a high resolution seismic image in the depth domain that will be used for interpretation. A depth seismic volume can be produced using depth migration, applied either in the poststack or prestack domains. Nevertheless, interference of reflected data with refracted data reduces the quality of the final image. Thus, a method to separate and select primary reflected data is needed in order to achieve accurate image and correct positioning of the salt body (figure lb).

The method of controlled stacking

In the classical approach to processing of seismic data collected over salt bodies, the two imaging techniques employed are *DMO* correction, followed by poststack depth migration (see Lamer et al., 1989, for further discussion on migration techniques). Inspection of the images resulting from the above processing flow often reveals questionable identification of the salt flank reflection (see figure la). The broken and indistinct nature of the salt face reflection is attributable to two main causes. First, each down-going wave reaches the critical angle at some depth along the dome, depending on the source offset and the specific salt geometry. Below this point a

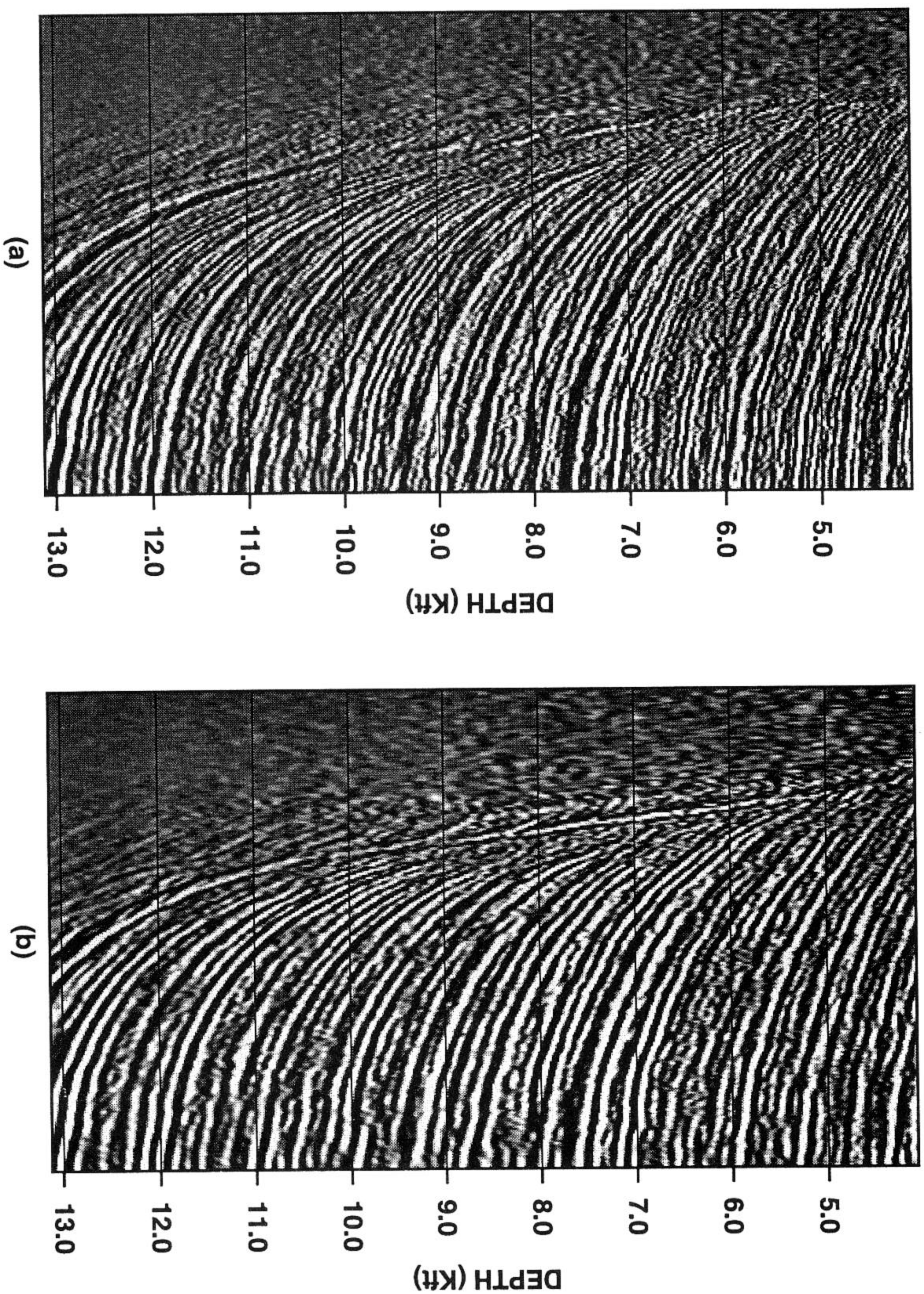

Figure 1: (a) Depth section obtained by conventional processing using 3D poststack depth migration. The salt flank (dips at 65 degrees) is broken and difficult to interpret. (b) Desired image quality of the salt flank on a depth section. The salt flank is continuous, clear and sharp.

refracted wave continues to propagate down the interface, generating secondary reflections from each sediment boundary it encounters. Thus, a seismic section recorded at the surface contains both primary reflections from the salt face, and secondary reflections sourced by the refracted waves. The interference of these two reflections during the migration process gives rise to the "broken" salt face on the seismic image. Second, the poststack depth migration typically employed assumes a zero-offset section as input, implying that down-going wave paths and up-going wave paths are identical. Migrating reflected-refracted waves in such a manner, does not obey the "exploding-reflector concept". As a result, the salt flank reflection is not fully migrated and appears smeared on the seismic image.

To overcome those two difficulties controlled stacking is used. We start by prestack depth migrating the input data. Using this method, different ray paths can be calculated for the down-going and up-going waves. In the migrated dataset, each shot record contains a portion of the final image, illuminated from a different angle. Thus, each record contains partial primary imaged reflections, as well as secondary imaged reflections. To select only the primary direct reflected waves, we construct a physical mute zone for each migrated shot gather. The mute area is designed by using the shot location and the two critical ray paths along the salt flank (in both up-dip and down-dip directions). Applying the constructed mute function during sorting and stacking of the migrated data, we obtain the controlled stacking result. The seismic energy contained in this section consists of primary reflection energy, which produces an image that is clear and positioned correctly.

Example

A *2D* dataset recorded in deep water in the Gulf of Mexico was used for demonstration of controlled stacking. The dataset consists of 526 shot records, each containing 120 channels. The trace length for processing is 5 seconds. The dataset was collected over a massive salt structure dipping at 70 degrees to the west. The velocity model was constructed using the *CVHS* technique (Kessler et al., 1995). Having a depth interval velocity model, two processing strategies where used. In the first, *DMO* correction was applied, followed by poststack depth migration. Downward extrapolation was done in the f-x domain (figure 2a). In the second, we applied prestack depth migration, followed by controlled stacking (figure 2b). The prestack migration algorithm used is based on the Kirchhoff summation method, with the Eikonal equation for computation of traveltime functions. Inspection of the salt flank images presented in figure 2 reinforces the theoretical assumptions used in the development of the controlled stacking method.

Conclusions

A method was presented for the automatic selection of reflected primary energy from migrated shot records. This is the basis of the controlled stacking method. Applying the method for data recorded over salt domes enables the construction of a clear salt flank as well as correct positioning of the salt/sediment terminations. The method is also appropriate for other types of geological models that include steep dips and wave mode conversions (De Bazelaie and Viallix, 1994), such as steep fault planes.

References

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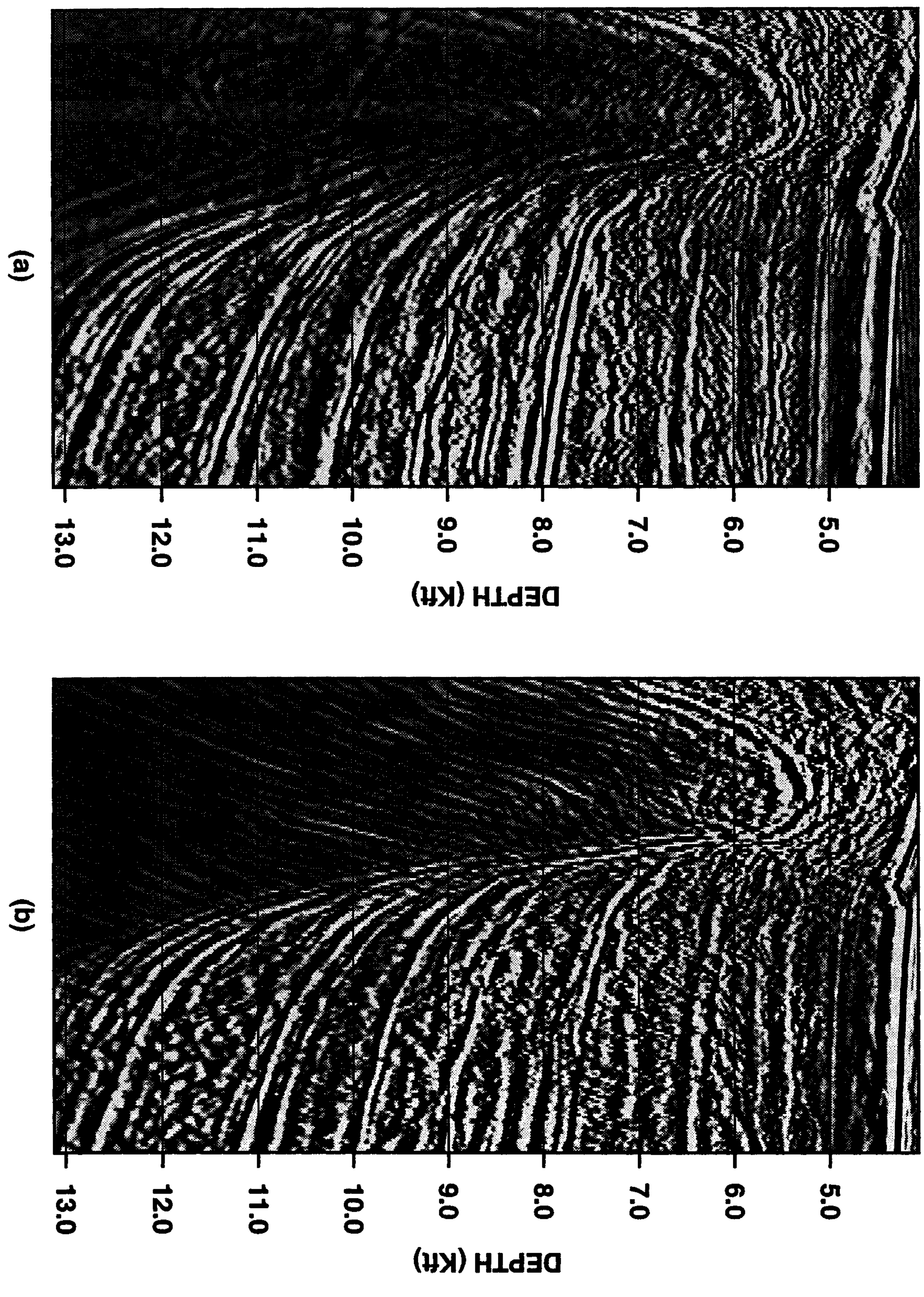

Figure 2: (a) Depth section obtained by conventional processing using DMO and 2D poststack depth migration. The velocity model was constructed by the CVHS technique. (b) Depth section obtained by prestack depth migration followed by controlled stacking, using the same velocity model as used in (a).