Sigsbee2 synthetic subsalt dataset: image quality as function of migration algorithm and velocity model error

Josef Paffenholz, BHP Petroleum

Summary

Consistent high quality subsalt imaging in the Gulf of Mexico is to this point still an eluding goal. The SMAART JV calculated an acoustic FD dataset modeled after the Sigsbee escarpment to increase the understanding of the imaging failure in this environment. I used this dataset to investigate a) the relationship between imaging algorithms and subsalt image quality and b) the sensitivity to errors in the velocity model. The results indicate that the way to significantly increased subsalt image quality is through increased accuracy in the determination of the salt shape combined with wavefield imaging. I propose a new technique to establish the salt shape using the velocity model independent multifocusing stack.

Introduction

Poor subsalt images are a major impediment to efficient exploration and development in the Gulf of Mexico deep water plays. The Subsalt Multiple Attenuation And Reduction Technology (SMAART) JV is an industry joint venture by bp, BHP, Chevron and Texaco charged with increasing our understanding of why subsalt images are often so poor and finding ways to improve yhese images.

The geologic environment near the Sigsbee escarpment challenges the seismic method due to the presence of highly irregular strong impedance contrasts in the form of allochthonous salt bodies. The presence of those salt bodies gives rise to strong surface multiples and may lead to a significant decrease in illumination of the subsalt targets. The combined effect may be a significantly reduced S/N ratio below the salt. Surface multiple attenuation has made much progress in recent years, however implementation in 3D is still a topic of active research. Efforts are underway to address the illumination issue by moving to true 3D acquisition geometries in a marine environment as opposed to the low azimuth standard streamer acquisition. However in this paper I address two other issues.

The first is the effect of the imaging algorithm on the final image. The current industry standard algorithm for prestack depth migration is Kirchhoff migration. The algorithms use ray tracing to calculate the travel times for the stacking operators. Varying degrees of velocity model smoothing have to be applied to avoid instabilities which can arise if the velocity model contains high impedance contrasts with complex shape. Implementations differ in the type (minimum time, minimum path, maximum amplitude) and number of arrivals considered in the computation of the operator.

During the last few years a another class of algorithm has become computationally tractable, wavefield migration. In wavefield migration both source and receiver wavefields are propagated downwards and the image is established by cross-correlation of the two wavefields. Implementations differ according to the manner of the wavefield propagation (e.g. finite difference, phase shift) .

The second topic of investigation is the sensitivity of the subsalt image to errors in the velocity model, especially deviations from the true salt geometry.

Sigsbee2 synthetic model

To investigate these issues the SMAART JV calculated a 2D acoustic FD dataset which models the geologic setting found in on the Sigsbee escarpment in the deep water Gulf of Mexico (Figure 1). The model has been designed to exhibit the illumination problems due to the complex salt shape with rugose salt top found in the area. The dataset was calculated with an absorbing free surface condition, i.e. the data do not contain free surface multiples. The model consists of a salt body with very complex geometrical characteristics in a relatively simple sedimentary velocity section (5100 ft/sec under the water to about 11500 ft/sec at depth of 30000 ft) (Figure 1). The color scale in Figure 1 is chosen merely to emphasize reflectors and faults and does not represent the real velocity contrasts. A number of normal and thrust faults separate the sedimentary blocks. The complex geometry of the salt leads to a situation in which the syncline segments of the salt top focus reflection energy from the salt bottom and the sub salt reflections and produce non-hyperbolic arrival travel time curves.
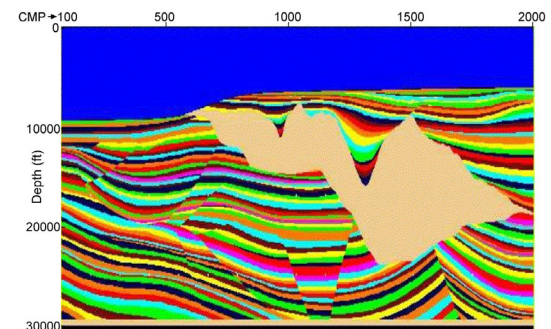

Fig.1 Sigsbee2 synthetic model

The correct velocity-depth model is shown in Figure 2.. The reflection interfaces are all the result of velocity contrasts, which are fluctuations about a mean velocity $V = V_0 + kZ$ where V_0 is the velocity directly beneath the water, k is the vertical velocity gradient and Z is the depth below the sea floor. The relative velocity fluctuation average dV/V is about 0.03, which is enough to produce reflections, but not sufficient to destroy the basic gradient macro model which is used in depth migration.
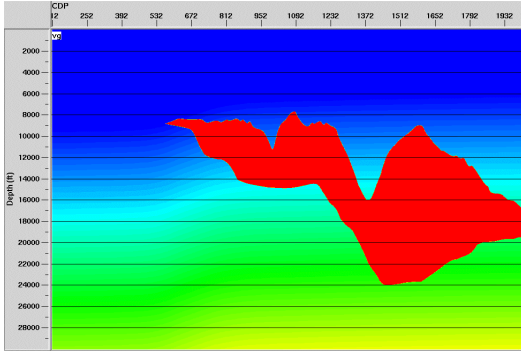

Fig. 2 Sigsbee2 migration velocity

Imaging with the correct velocity model

The image produced with a multi-arrival Kirchhoff migration using the correct velocity model is shown in Figure 3. The same velocity model has been used to produce the image in Figure 4, which shows the result of a FD shot migration. The qualitative differences in the subsalt images are not primarily caused by the specific implementations used, but are typical for all the tested Kirchhoff and wavefield migrations. I conclude that currently employed Kirchhoff migration technology is stretched to the limit and wavefield migration can provide the necessary step chance.

Sensitivity to errors in the velocity model

The SMAART JV asked two seismic contractors to derive a velocity model from the prestack data without any a priori knowledge of the model. The purpose was to establish the fidelity of the velocity model derived using standard industry practice and to determine the change in image quality as a result of errors in the derived velocity model. Figure 5 shows the velocity model derived by a contractor.The overall shape of the salt body is reproduced quite well. Most notable deviations from the correct shape are the slightly enlarged bulge at the salt bottom and a smoothing of the salt top rugosity.
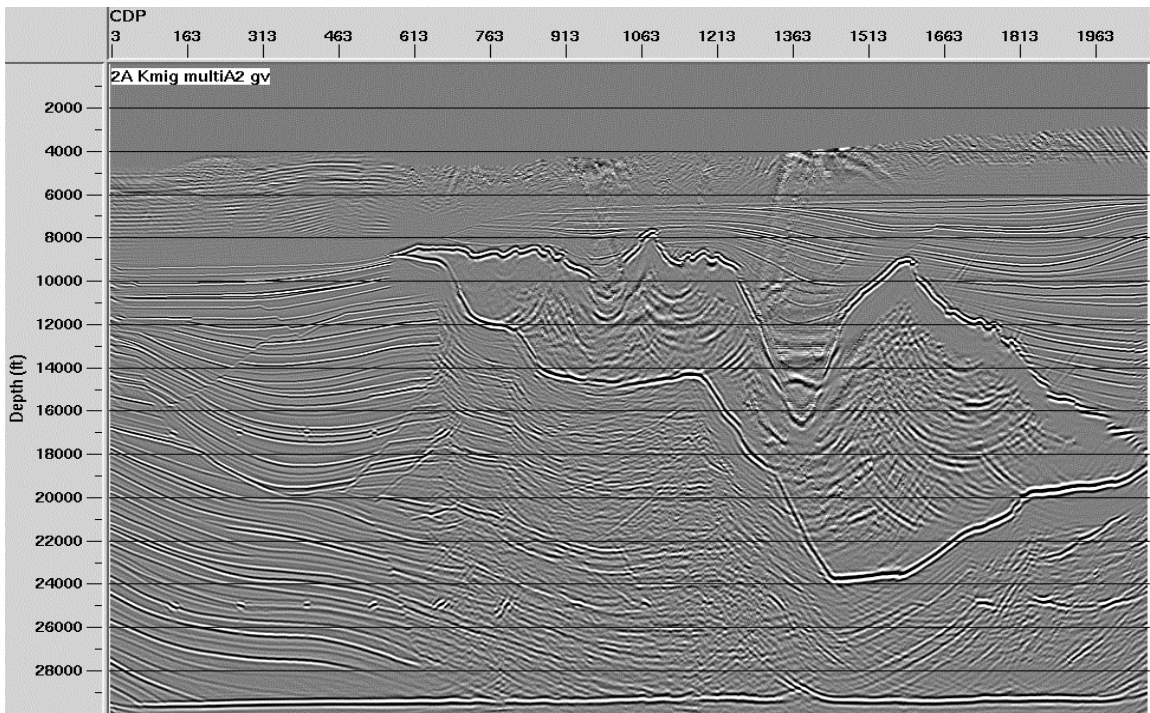

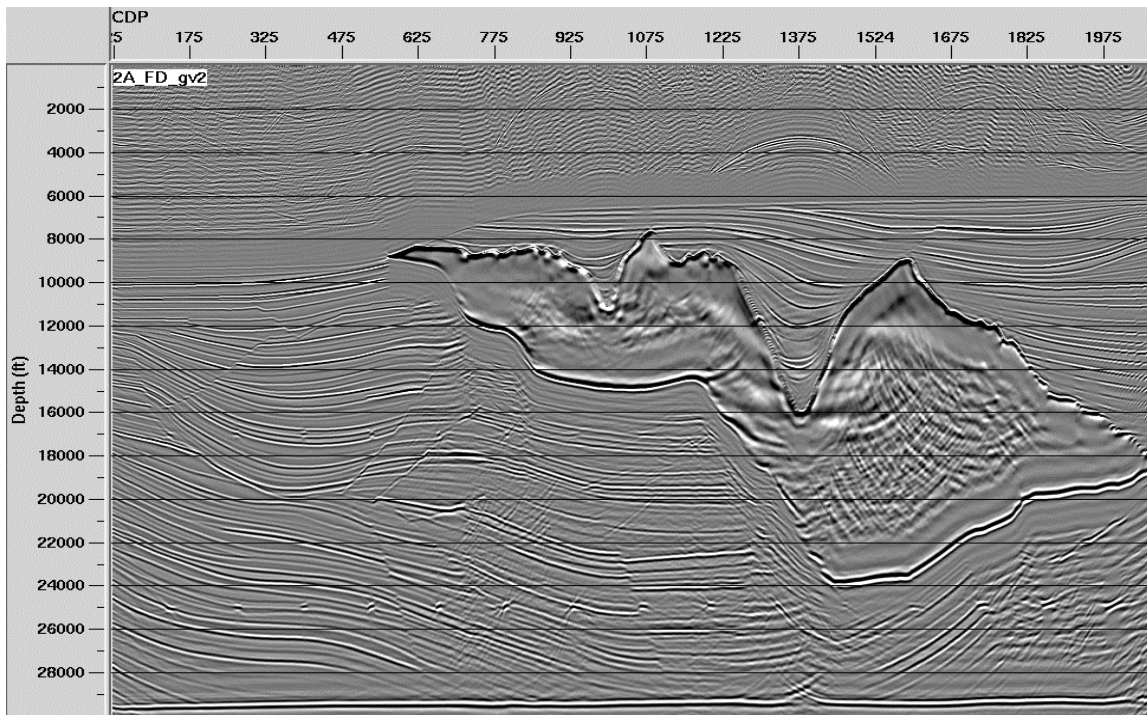Fig. 3 Image from FD shot migration using correct velocity model

2

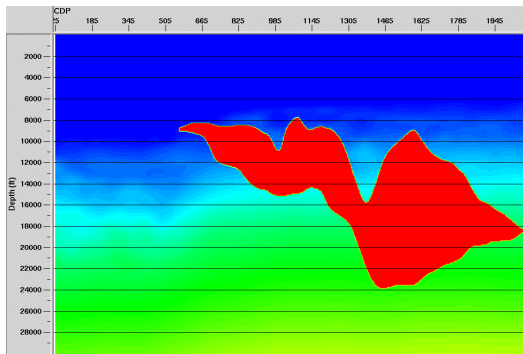Fig. 4 Image from FD shot migration using correct velocity model

Fig. 5 Velocity model derived by contractor

While those errors appear to be well within acceptable limits, inspection of Figure 6 reveals the extent of the damage to the subsalt image due to those small errors in the definition of the salt geometry.

Likewise, a lateral shift of the velocity model with respect to the data of only 450 ft causes almost complete destruction of the subsalt image.

If the velocity model contains errors with respect to the location of the high impedance contrasts the advantage in image quality of the wavefield migration over Kirchhoff migration vanishes rapidly. I suggest that the a main reason for the lack of real data observations indicating a superiority of wavefield migration is due to the insufficient accuracy in the definition of the salt shape in the velocity model. This

is because errors in the salt model prevent proper focusing of the subsalt events. On the other hand, errors in the salt velocity and subsalt sediment velocities have comparatively little influence on the focusing of subsalt events, but determine their exact position.

Defining the salt shape

To successfully image subsalt targets it is mandatory that the geometry of the high impedance contrast is captured in the velocity model to a high degree of fidelity in order to correctly focus the subsalt events. Current practice is often successful but sometimes lacks a full appreciation of the importance of the high frequency component in the velocity model. Here I propose a new technique to built a high fidelity salt model for incorporation into the final velocity field.

The technique uses a model-independent multi-focusing or common-reflection surface zero offset stack using the multifocusing or common reflection surface implementations (Gelchinsky et al., 1999; Mann et al., 2001). For a display of the MF stack see Glogovsky et al., 2001. The MF stack migrated with the correct velocity field shows the shape of the salt perfectly, while it is well established that conventional poststack migration breaks down if the velocity model is as complex as in this example.

This observation leads to the conclusion that MF/CRS stack enables building the salt geometry using
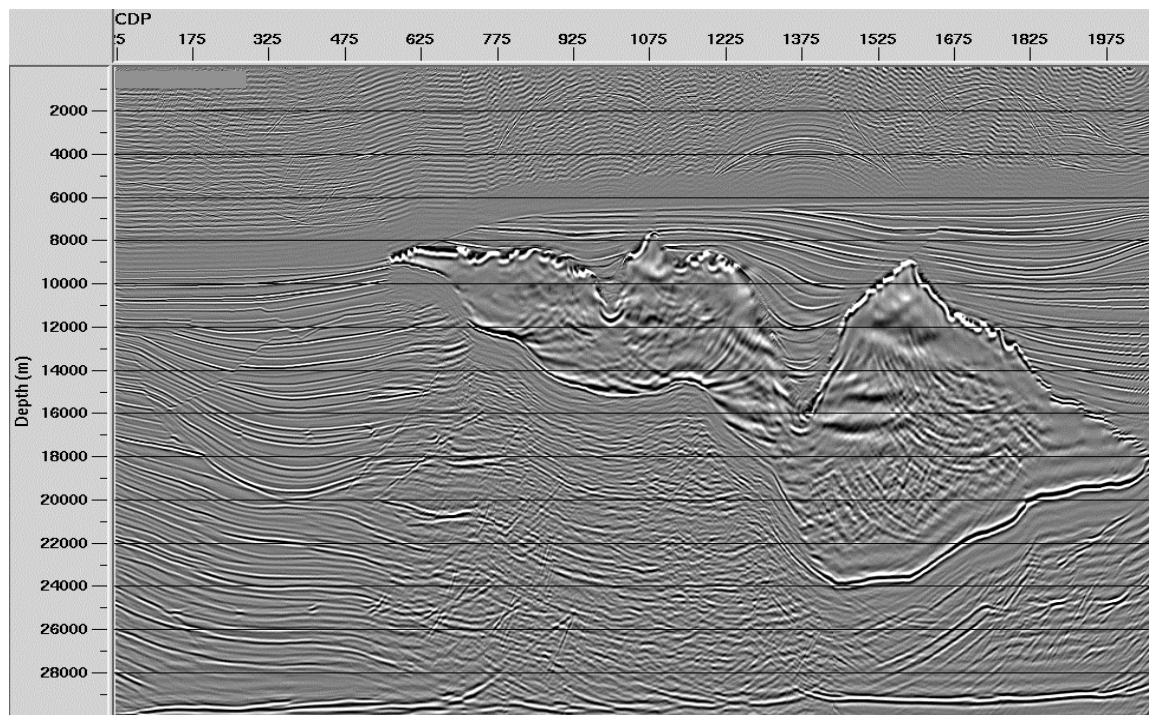
3

Fig. 6 Image from FD shot migration using derived velocity model

poststack migration, thus allowing many iterations to refine the model.

A preliminary test in which I presumed knowledge of the sedimentary velocity between the water bottom and the top of the salt showed convergence to the true top and base of salt after three iterations.

Conclusions

The tests using the Sigsbee2 dataset indicate that significantly improved subsalt images are achievable through better velocity model building combined with wavefield migration. The results show that the importance of the correct definition of the high impedance contrast cannot be overestimated. Use of the MF/CRS stack might be the way to help achieve the required level of accuracy in the definition of the salt shape.

How significant are these result from a 2D test for 3D data? I am not aware of any argument indicating that the conclusions drawn from this 2D test might not be valid for 3D data. On the contrary, 2D data tests allows denser sampling of the raytracing and therefore might favor Kirchhoff migration. Therefore the gap in potential image quality between wavefield and Kirchhoff migration might be even larger for 3D data if practical aspects are taken into account.

References

Gelchinsky, B., Berkovitch, A., and Keydar, S., 1999, Multifocusing Homeomorphic Imaging: Part I. Basic concepts and formulae: J. App. Geophysics, 42, 169-228.

Glogovsky, V., and Gogonenkov, G., 1988, Study of methods for determining velocity and depth parameters in layered realistic media, Geophysical Transactions, Vol. 33, No. 3-4, 157-173.

Glogovsky V., Landa E., Paffenholz, J., 2001, Integrated approach for subsalt depth imaging: a synthetic case study, workshop "Velocity Model Independent Imaging in Complex Media" at the 71st Ann. Internat. Mtg., Soc. Expl. Geophys.

Mann, J., Bergler, Steffen, and Hubral, P., 2001, Common-Reflection-Surface-Stack, workshop "Velocity Model Independent Imaging in Complex Media" at the 71st Ann. Internat. Mtg., Soc. Expl. Geophys.