Elastic modeling initiative, part II: converted mode energy in subsalt exploration

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Summary

In seismic exploration through salt, elastic wave propagation effects can be quite significant. High amplitude reflections which underwent one or more mode conversions during propagation pose both challenges and opportunities for interpretation and imaging. Elastic wavefield modeling plays a critical role in identifying, understanding and utilizing these events. As an example, we present a study of field data from the Green Canyon area.

Introduction

This work is intended to provide support for extending the SEG/EAGE modeling project to 3-D elastic modeling. In exploration seismology, a number of research topics could benefit from a publicly available computational survey including three-dimensional and elastic propagation effects; e.g., reservoir characterization and seismic attribute analysis. Our concern here is to motivate the creation of such a survey for a salt dominated environment as a resource for studying seismic penetration and converted mode phenomena in this environment.

In a brief background of the SEG/EAGE modeling project, House et al. (1998) notes that the acoustic salt model data produced by that project are ideal for benchmarking the performance of 3-D seismic imaging software. This is true because acoustic wave propagation is usually assumed in processing and interpreting seismic exploration data. Commercial emphasis in subsalt imaging has focused on the use of prestack depth migration to account for distortions of the seismic wavefield. This is an acoustic imaging approach, and its underlying assumption is that all imaging objectives are represented by primary reflections or diffractions.

Actually, elastic wave propagation effects are highly significant in seismic exploration through salt bodies. At salt-sediment interfaces, the combination of a high velocity differential and complex geometry can generate pronounced mode conversions. In the Gulf of Mexico, the contrast in elastic parameters between salt and surrounding sediments is especially great. Shear wave generation at salt interfaces is common in these environments (Purnell, 1992; Ogilvie and Purnell, 1996). As a consequence of this energy partitioning, less primary mode energy is transmitted through the salt to illuminate the horizons beneath it.

Applications of converted modes

High amplitude converted mode energy is both a problem and an opportunity for subsalt imaging and interpretation. Converted mode events in the seismic image can interfere with primary reflections and obscure the structural picture. If they are not properly identified, these events present an interpretation pitfall. However, when they are recognized and mapped, they have diagnostic value for confirming the location of the base of salt (Ogilvie and Purnell, 1996). In addition to the structural information inherent in converted mode events, their occurrence and strength carries information about the variation in rock properties across the salt interface.

In our previous work, we have only considered converted mode events that convert back to compressional energy at either the base of salt or top of salt interface (Kessinger and Ramaswamy, 1996; Miley et al., 1997). There are numerous recent examples of multi-component seismic exploration in the North Sea where spectacular imaging results were achieved by imaging P-SV reflections collected at the seafloor (e.g., Sollid et al., 1996). The success of this work should motivate investigation into the use of multi-component acquisition for subsalt exploration.

Applications of elastic modeling

Elastic wave modeling methods are required to properly model the seismic response of salt bodies. With 3-D elastic modeling, we can obtain a more complete understanding of energy penetration into complicated salt structures, energy transmission through salt, mode conversions at salt interfaces and amplitude variations with offset in complicated geological settings.

Furthermore, seismic modeling can be used to simulate a field experiment over an idealized version of a geologic section. By comparing modeling results with field data, survey specific modeling can suggest efficient processing and interpretation methodologies tailored to the problems associated with each survey.

These arguments support the notion of modeling as a survey-specific tool to aid in processing and interpretation. However, economic considerations preclude the use of full-survey 3-D elastic modeling as a standard tool for integrated exploration studies. The availability of a realistic 3-D elastic computational dataset would be a resource the exploration community could use to study elastic effects commonly encountered in subsalt imaging and interpretation, and would serve as a valuable companion to the SEG/EAGE acoustic data.

Green Canyon example

The Green Canyon survey demonstrates the use of single-shot modeling to identify converted modes. The data are from deep water (greater than 1 km) Gulf of Mexico offshore Louisiana. A dip line was acquired in this area across the Sigsbee escarpment. Data were acquired using two ships to collect offsets up to 12 km. The salt body is a tabular structure extending from approximately 4 to 7 km in depth, with a rugose upper surface. There are numerous events below salt which may be primary reflectors, converted modes or multiples.

Using a velocity model derived from prestack depth migration of the field data, two computational shots were generated at the same location using 2-D acoustic and elastic modeling. Velocity boundaries within the sediments were smoothed so that reflecting interfaces were limited to the water bottom, the top of salt and the base of salt. Through comparisons of the acoustic and elastic shot results, we were able to identify converted modes in the elastic data.

Figure 1 shows the composite field shot which was modeled by the computational experiments. On the basis of the computational results, we were able to identify the events labeled, including the PSPP base of salt reflection. In the elastic modeling, a PSPP base of salt reflection was generated between 5.7 and 6.5 seconds for offsets between 3000 meters and 8000 meters. This energy traveled through the sediments as a P-wave, converted at top of salt to a shear wave, converted back to compressional energy upon reflection off the base of salt, and continued traveling as a compressional wave back to the receivers at the surface.

A second high amplitude converted mode event was identified in the computational data between 6.5 and 7.7 seconds. It corresponded to a PSSP base of salt reflection; i.e., conversion to the shear wave mode occurred at the top of salt as the energy propagated downward, and conversion back to the compressional mode occurred at the top of salt during propagation back to the surface. This event appeared over an offset range of 4000 meters to 7500 meters. We were unable to identify any reflection in the field data as a candidate for a PSSP base of salt event, as none of the subsalt events in Figure 1 appear to have a sufficiently steep move-out for this low velocity mode path. It is possible that the PSSP base of salt reflection is masked by primary or peg-leg multiple reflections.

By examining partial stacks of limited offset ranges, we can observe the spatial extent of the PSPP base of salt reflection throughout the field survey. Figures 2a and 2b show partial stacks for a 9 km long section of this line. Figure 2a is a partial stack of offsets from 2275 m to 2725 m. In this figure we observe a number of diffractions associated with the irregular top of salt, and a strong, continuous primary base of salt reflection. Underneath the base of salt reflection, we see a number of dipping reflectors between 5.7 and 6.7 seconds which may indicate subsalt sediment structures.

Figure 2b is a partial stack of offsets from 5425 m to 5875 m. Underneath the primary base of salt reflection, we observe a fairly strong expression of the PSPP base of salt reflection that we identified on Figure 1. This event becomes more continuous for offsets around 7000 m. We also note that between 6.7 and 7.5 seconds there are hints of subsalt dipping reflectors that may correspond to the dipping events in Figure 2a, particularly around CMP 2600.

As a final note, we would like to emphasize that the Green Canyon example shown here is of a relatively well-behaved salt sill. For more complicated salt bodies, the relative significance of various mode conversions may differ dramatically, and it may not be possible to segregate different seismic modes on the basis of source-receiver offset.

Conclusions

Seismic mode conversions present both challenges and opportunities for structural imaging and interpretation in salt dominated environments. By reiterating the significance of mode conversions in subsalt seismic exploration, we are seeking to support and motivate the extension of the SEG/EAGE modeling project to 3-D elastic modeling. The Green Canyon example presented here demonstrates the use of elastic modeling in the identification of mode conversions and documents the significance of these events in field data. By 3-D modeling of these effects, we can study them in more detail and evaluate various methods to exploit their use for structural imaging and interpretation.

Acknowledgments

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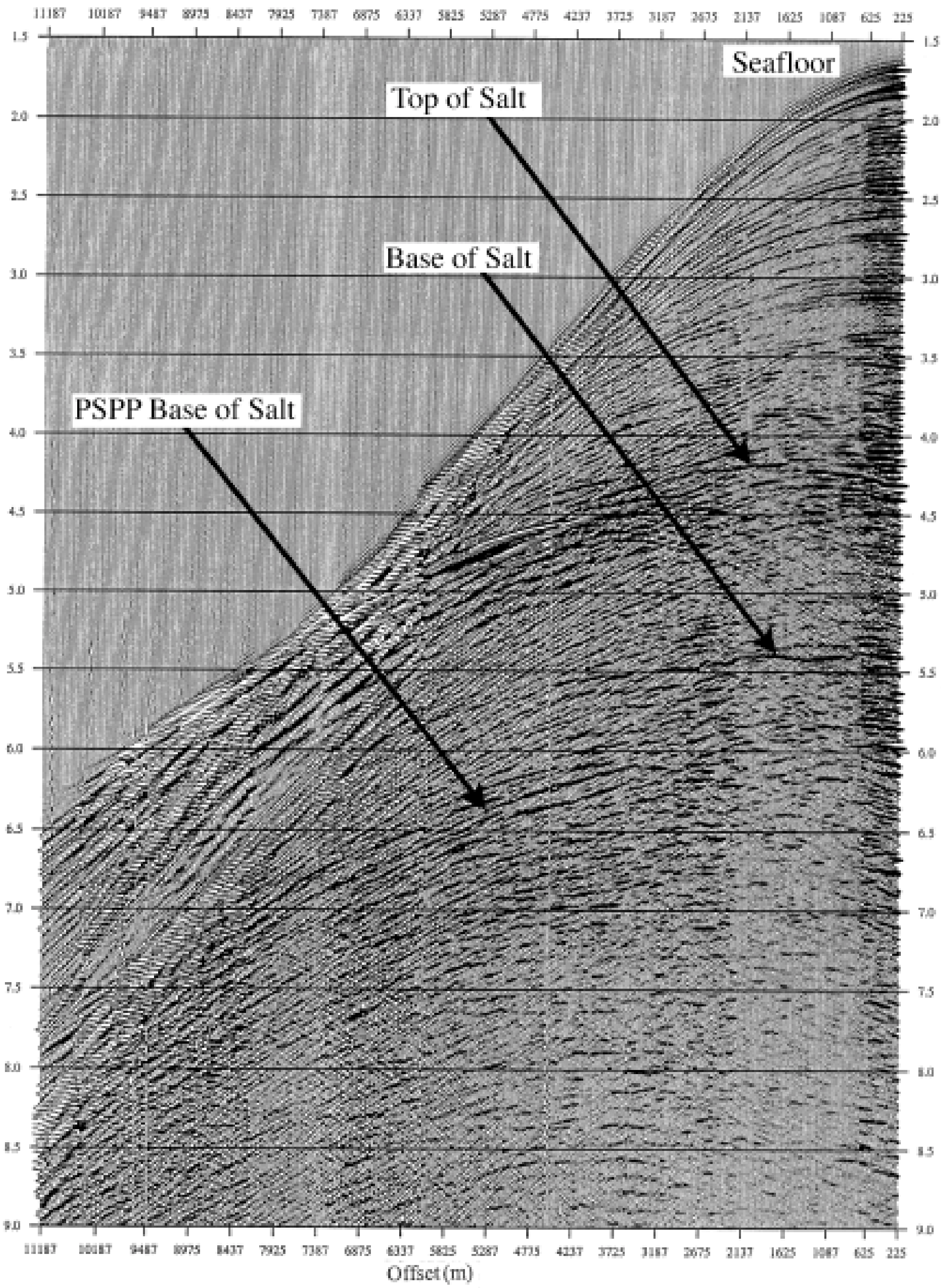

Figure 1: Composite shot gather from Green Canyon two-ship survey. Offsets range from 225 m to 11187 m.

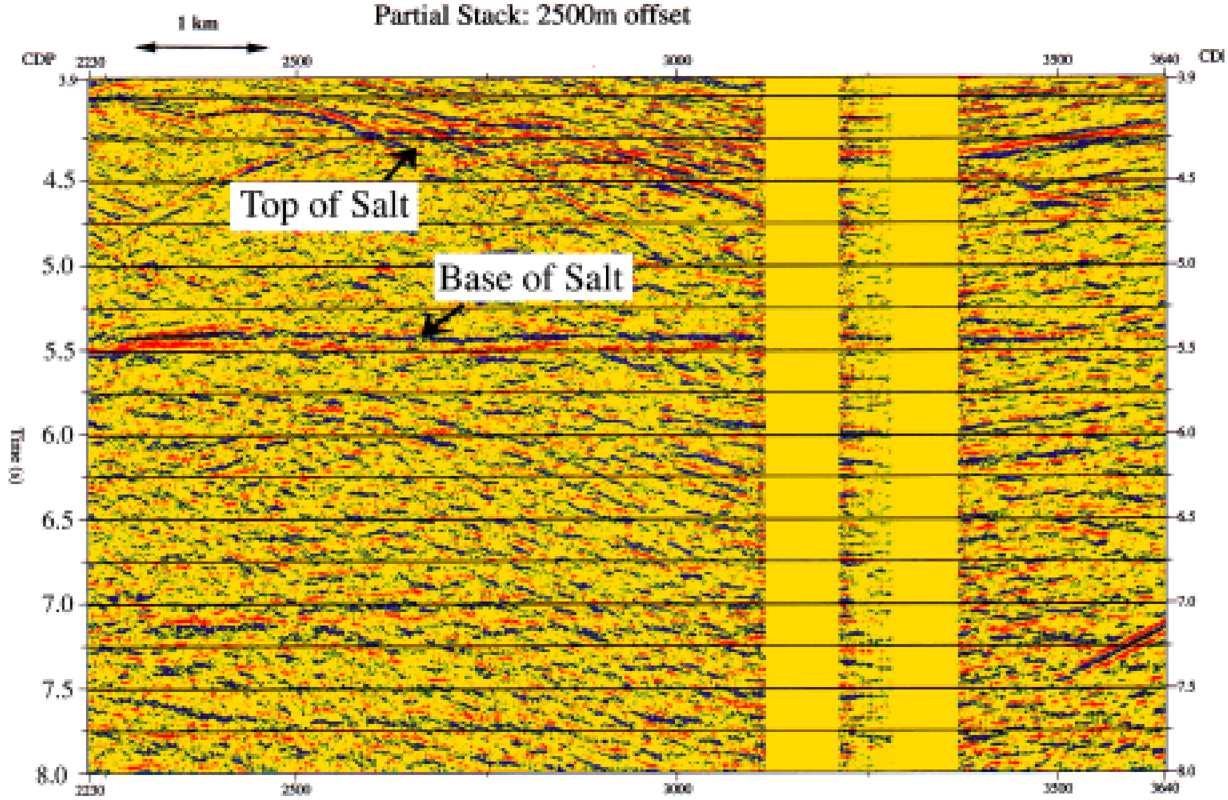

Figure 2a: Partial stack of offsets 2275 m to 2725 m for 9 km section of Green Canyon survey.

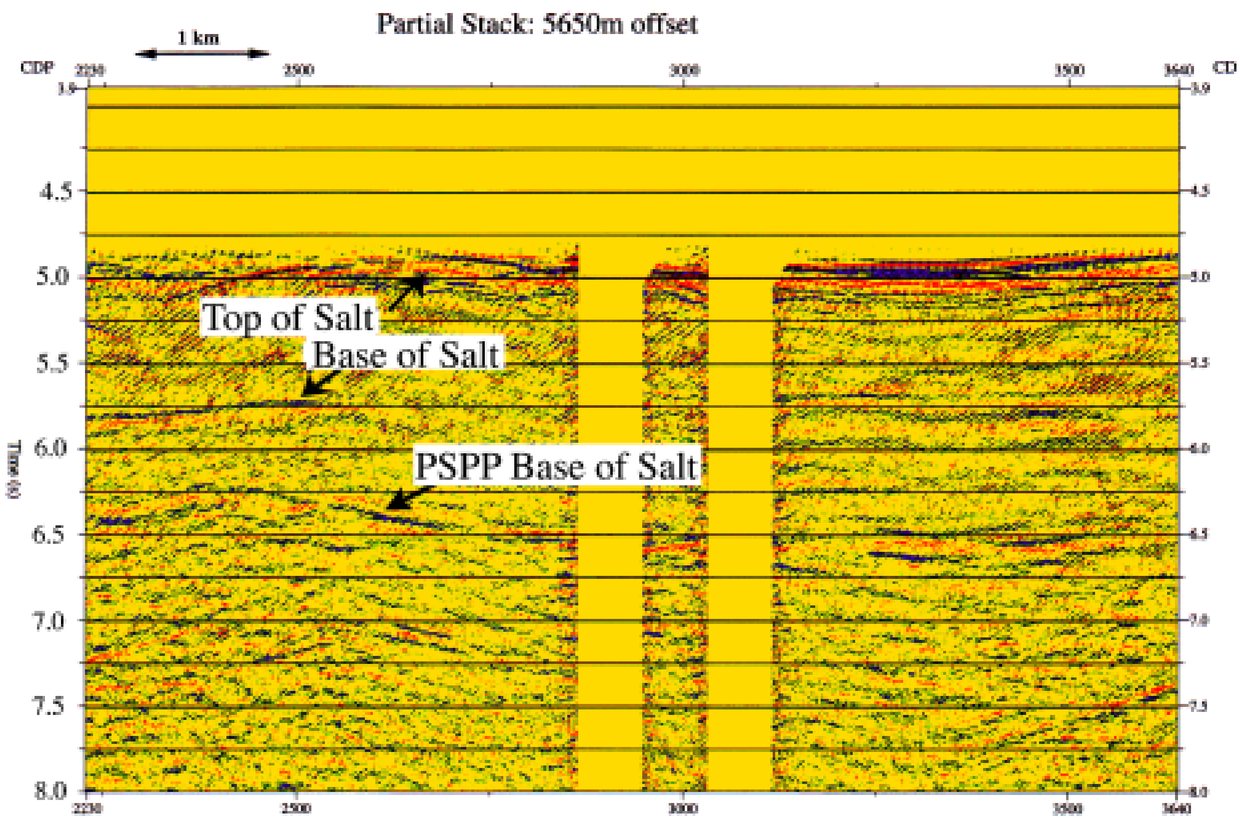

Figure 2b: Partial stack of offsets 5425 m to 5875 m for 9 km section of Green Canyon survey.