PAPER T

DIFFRACTION TOMOGRAPHIC INVERSION: FIELD DATA STUDY

Guan Y. Wang

ABSTRACT

The field data from McElroy and King Mountain test sites are studied using diffraction tomographic inversion techniques. The diffraction tomography methods with uniform and stratified background media are applied to single frequency wave fields. In the reconstructed scattering potential and velocity images, the fine scale structures and subtle dips are apparent but absent in the traveltime tomogram. The results show that diffraction and scattering inversion techniques have enormous potential in subsurface characterization and delineation with comparison to the transmission tomography.

INTRODUCTION

Small changes of velocities superimposed on large stratified variations is of interest to reservoir imaging. The general theory of diffraction indicates that diffraction tomography has the potential to achieve maximum spatial resolution and minimum image distortion for crosswell seismic data. In this paper we study the field data from McElroy and King Mountain test sites in West Texas using diffraction tomographic inversion techniques. Although powerful, the applications of the diffraction inversion methods are successful only if the heterogeneity represents small deviations from background, and if the correlation lengths of these deviations are large compared to a wavelength. With these limitations in mind, we use diffraction tomography in conjunction with traveltime tomography. Traveltime tomography does not explicitly depend upon any assumption about the scale, the strength of the variations in the inhomogeneity, and yields velocities from virtually any starting model. The resulting images then can be adequately used as reference velocities or the background model for diffraction tomography. We also account for variable background velocity using the distorted Born approximation to make the reconstruction more accurate.

The paper is divided into two sections. In the first section, the methodology used for the inversion is described briefly. The reconstructed images of McElroy and King Mountain are presented in section two with the detail discussions and comparison. The results illustrate the enormous potential of scattering and diffraction inversion techniques to usefully address reservoir delineation and characterization problems.

METHODOLOGY DESCRIPTIONS

Since diffraction tomography is used to deal with scattered effects, a background or host medium model is needed to calculate the illuminating field. This is difficult for a real experiment since the host medium is not known. Our intention is that traveltime and diffraction tomography should be used in conjunction with each other to provide high resolution images. Ray tomography does not explicitly depend upon any assumption about the scale, the strength of the variations in the inhomogeneity, and yields velocities from virtually any starting model. The resulting images then can be adequately used as reference velocities or the background model for diffraction tomography. It can be shown that ray tomography is a special case of diffraction tomography. Therefore, this complementary nature of two processes is justified. We apply the method of diffraction tomography for a stratified background medium (Harris and Wang, 1993) to field data from the McElroy field in West Texas.

In real data, the source functions and coupling factors are unknown. Instead of directly estimating them, the source function and coupling factors are eliminated by normalizing the amplitude of the wave field at the nearest offset receiver position according to the corresponding geometrical spreading. The amplitudes of the wave field at the rest of receiver positions are normalized relative to the one at the nearest offset. The rationale is that the diffraction tomography does not necessarily require good amplitude information to be effective, even though its performance would be enhanced by good amplitude information. The phase of Fourier transforms carries essential information about the object. A shift of an object in the space leads to a shift of the phase in Fourier wavenumber domain.

We are aware that multiple frequency reconstruction could enhance the quality of the image. It would be ideal to stack coherently to enhance desired features, and incoherently to get rid of unwanted distortions. But a coherent multi-frequency stacking may involve data stretching and interpolation in the wave number domain and it is difficult to apply when the background medium is inhomogeneous. In other words, a simply addition of the images obtained with different frequencies will not necessary improve the reconstruction. In fact, the strength of the image will change dramatically with change of the frequency. Therefore, simple addition of the images would degrade the quality of the image. In this study we consider single frequency inversion.

In an ideal situation in which the source and receiver lines are extended to infinity, the maximum vertical wave number is $2\pi/\Delta$ and the maximum horizontal wave number is one wavelength that is approximately 10 ft. If the spatial sampling interval Δ is 2.5 ft (one quarter of the wavelength), then the best resolution of the image would be 2.5 in the vertical direction and 10 ft in horizontal direction. Due to the limited aperture and relatively low frequency, the wave numbers in both vertical and horizontal directions can not reach these maximum values and the reconstructed image is blurred. The resolution of the reconstructed images is reduced. Taking into consideration both of resolution limits and the distortion effect of limited aperture, the resolution of the image can be estimated as approximately half the wavelength or 5 ft in vertical direction and one and one half wavelength, or 15 ft in horizontal direction respectively.

McELROY FIELD DATA INVERSION

We apply the algorithm for a layered background medium to the field data from McElroy test site at West Texas. The measurement geometry is shown in figure 1. For the 185 ft well separation, both the source and receiver spacing were 2.5 ft apart. For the 600 ft well separation, the sources and receivers' intervals are 5 ft. According to prior known geological information, the reservoir is located at the depth between 2850 ~ 2950.

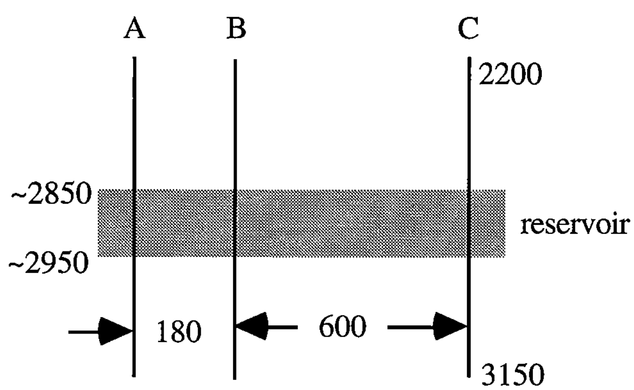
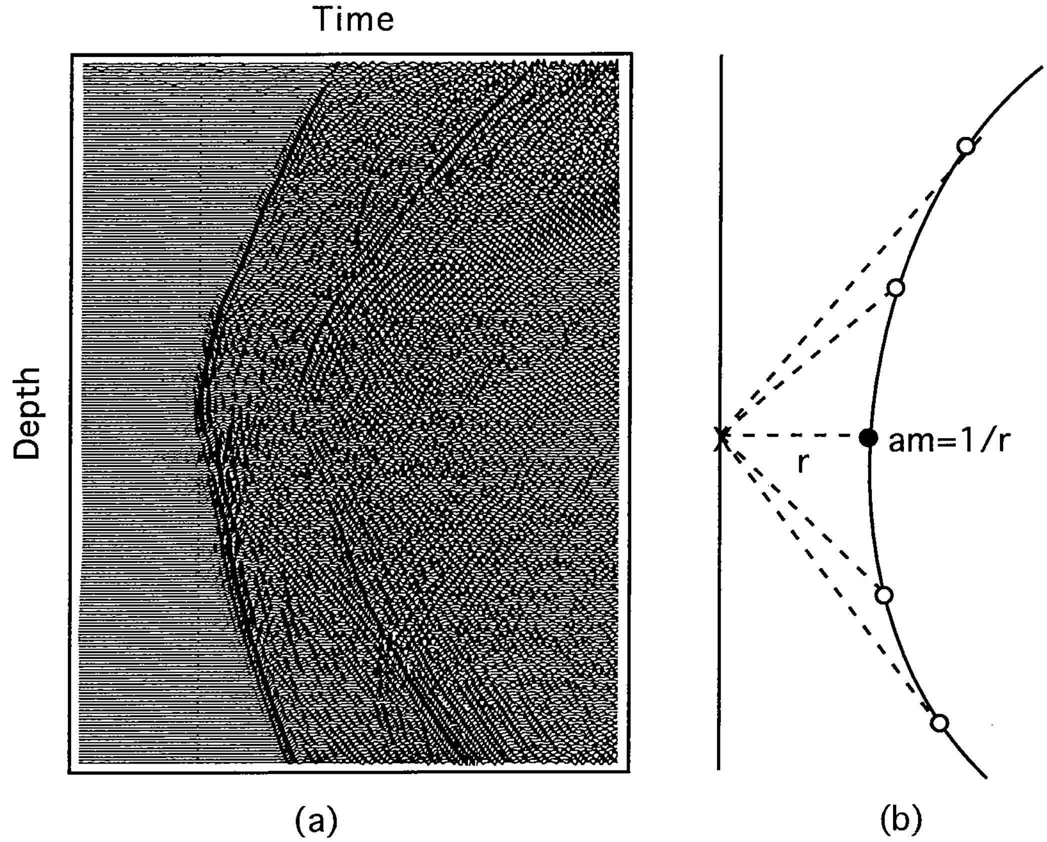


Fig. 1. The well locations of the McElroy field survey



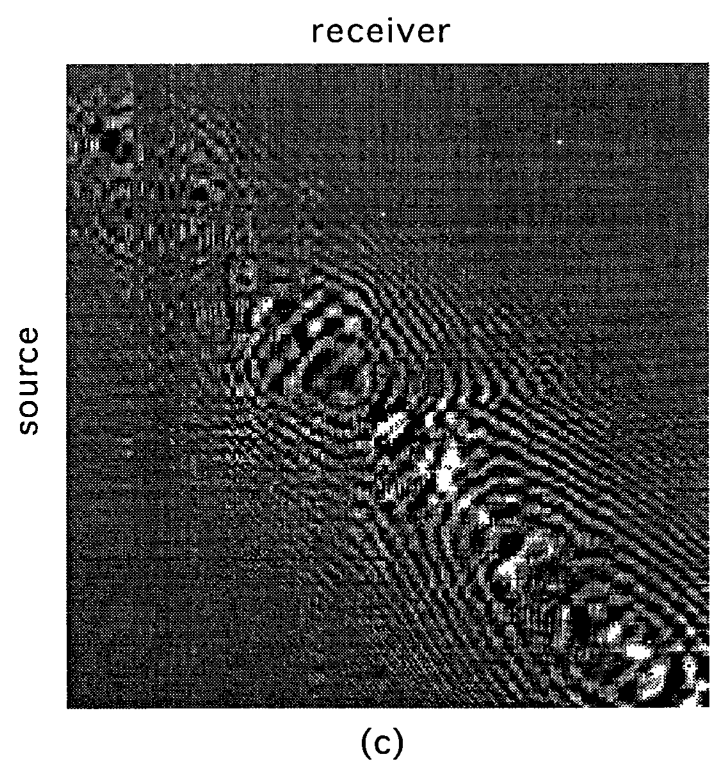


Fig. 2. (a) A typical common receiver gather from McEroly near offset survey.
(b) The amplitude of the wave field at the nearest offset is normalized to a geometrical factor 1/r.
(c) the real part of normalized wave field at frequency=1250 Hz

A typical common receiver gather is plotted in figure 2 (a). A traveltime tomogram (figure 3) of the field data is used to create a 1-D background model for the inversion. In the field experiment, the data is recorded at 202 receiver and 202 source positions. For convenience, the source line and receiver line is padded with zeros to form a 256 by 256 matrix and then Fourier transformed to the wave number domain (figure 2c).

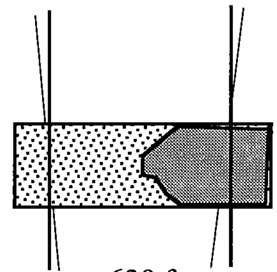
The images are reconstructed with the data at frequency 1400 Hz and the results are shown in figure 4. From the scattering potential image and velocity image one can identify the internal structure of the reservoir. Notice that although the reservoir zone can be seen, its internal structure is not resolved by traveltime tomogram. This is not surprising, because in essence, with the traveltime tomography one reconstructs the low frequency components of the inhomogeneity. With the diffraction tomography one recovers the higher frequency components. Most of the structures in the reconstructed images here are comparable to those with crosswell reflection imaging and migration techniques (Larazators, et al., Mo, et al., 1992).

The inversion results of the McElroy far offset data are shown in figure 5. From the scattering potential image and velocity image, we can see the improvement of the resolution compared to the traveltime tomogram, especially around the reservoir area. Notice that although the resolution is lower, the far offset images can still be tied to the near offset images, see figure 6.

KING MOUNTAIN FIELD DATA INVERSION

A well was drilled with the target being a prolific "carbonate mound". A second well offset 630 ft from the first missed the target. It is desirable to know the lateral and vertical extents of this carbonate mount so that a horizontal step-out well could be drilled (Langan, 1994). The survey geometry is shown in figure 7. Notice that both the receiver well (M13) and the source well (M35) are deviated wells that may greatly influence the inversion results. In this study, we account for well deviation in traveltime inversion but not in diffraction inversion.

Fig. 6. The well locations of the King Montain field survey. Both the receiver and source well are deviated.



Unlike the situation at McElroy test site, the sonic log and transmission tomography study indicate that the low frequency component of the velocity field at King Mountain test site has two dimensional characteristics. A stratified background medium is no longer applicable. Because of non-uniform background, it is impossible to choose a single velocity to calculate the background field. On the other hand, if we can treat the diffraction theory of a constant velocity as an approximation to a general theory, including variable background velocity in the algorithm is important. In other words, we use the algorithm of the diffraction for constant background velocity, but replace the velocity with a variable one. Actually, this procedure is a good approximation to a rigorous diffraction algorithm for a variable background (Wang, 1994).

The inversion results are show in figure 8. The vertical and lateral extents of the reef are apparent in the traveltime tomogram. The scattering potential image and the velocity image not only match the sonic log better but also revel some structure features which are absent in the traveltime tomogram. However, we believe these results are still primary due to the nature of an incomplete inversion theory and without accounting for well deviation.

CONCLUSIONS

We have shown how crosswell direct wave traveltime and scattering are combined to image the internal structure of a West Texas carbonate reservoir. The high resolution images result from the complement nature of the direct wave field and scattered fields. We believe our results illustrate the enormous potential of scattering and diffraction tomographic inversions to usefully address reservoir delineation and characterization problems.

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