Carbonate Reservoirs study by seismic inversion using a physical modeling data

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Abstract. The storage spaces of Karsts carbonate reservoir are characterized as heterogeneity. Due to low signal to noise ratio, seismic inversion using partially stacked data is often used to characterize the carbonate reservoir. A physical model is used to analyze influence of seismic inversion on heterogeneity. On the one hand, the difference in lateral resolution is quantitatively studied. On the other hand, the influence of noise on the lateral resolution in seismic inversion is discussed by adding random noise of different degree. The results demonstrate that the signal to noise ratio can be improved by seismic inversion while the lateral resolution is reduced subsequently. Additionally, random noise influences the lateral resolution, that is, the inverted volume of heterogeneity become smaller as the noise increased.

1. Introduction
Carbonate reservoir is widely developed in China western area (Zhao, et al., 2009; Zhang, et al., 2011). Because seismic data is in low signal to noise ratio, pre-stack inversion using partially stacked data is performed to characterize the caves (Peng et al., 2008; Han, et al., 2006). As is known, the stacked gather is suitable for noise suppression, yet some effective information such as the variation of amplitude versus offset will inevitably be lost to some degree (Ji, et al., 2009). In fact, sample in partially stacked gather used for AVA inversion comes from a bin of certain size, not from a single point(Wang, et al., 2005). Thus the lateral resolution will be reduced. In this paper, both AVO and AVA inversion is performed on a caved physical model and the results are compared and analyzed to study the influence of stack on lateral resolution of heterogeneity, further providing significance to study on karsts carbonate reservoir heterogeneity.

2. Physical model parameters
A physical model contains five caves of different diameter, as is shown in figure 1, is used in this study. Each cave is filled by the same low velocity materials. Two dimensional seismic data was acquired in Cistern-Collecting-System in CNPC key lab. Seismic frequency in target layer is about 25Hz. The physical model consists of three horizontal layers, with five caves in the middle of the second layer. P-wave velocities of each part is shown in the figure, and S-wave velocities for the three layers are 1368m/s, 1528m/s and 1301 m/s, respectively. P-wave and S-wave velocities for the infilling materials are 1326m/s and 300m/s respectively.
Figure 1. Schematic view of seismic data collection and physical model parameters, the model consists of three horizontal layers, displayed in green, white and yellow respectively. (Simulation proportion: 1/10000)

3. **AVO/AVA inversion on reservoir heterogeneity study**
Two-dimensional Kirchhoff pre-stack time migration was used to produce offset gathers. Then, incident angle gathers were produced by ray tracing method. Inversion was done on the basis of Aki-Richards theory.

Figure 2. Display of eight offset gathers prepared for AVO inversion, number 1~5 denotes the five caves. Offset is marked on the top of each figure.

For AVO inversion, the actual velocity model is input to inversion software JGW. Due to restrictions of the inversion software and computation cost, only eight offset gathers shown in figure 2 are chosen, which are equally spaced from 240m to 1920m. For AVA inversion, limited by noise and other factors, incidence angle gathers were chosen in a range of 6-35°, equally divided into three parts, including 6-15°, 16-25° and 26-35° (shown in Figure 3).
Figure 3. Display of three partially stacked incidence angle gathers prepared for AVA inversion

Figure 4 shows the AVO/AVA inversion results. Take the cave 5 as an example, the difference of lateral resolution for heterogeneity on AVO/AVA inversion mainly lies in two aspects: 1. for the same hole, AVA inversion result shows bigger than AVO inversion and they also have obvious difference in both P-impedance and Vp/Vs ratio; 2. AVO inversion is more influenced by noise than AVA inversion.

Figure 4. Inverted results for cave 4 and cave 5. PI and SI represent impedance of P-wave and S-wave respectively.

For a further analysis, the following flows are done to verify the influence of stack to lateral resolution for heterogeneity: 1. two neighboring offset gathers are stacked to improve S/N ratio while not influencing on lateral resolution in AVO inversion too much; 2. the incident angle gathers were equally divided into five parts. In this way, we can get totally four sets of pre-stack seismic data: AVO single-trace, AVO stacked gathers, AVA stacked gathers of three parts, and AVA stacked gathers of five parts.

Figure 5 is the inversion P-impedance from the four dataset. For all the four cases, the P-impedance decreases gradually. The single trace AVO inversion reflection (the yellow line) has the highest resolution, where the inverted cave size is the most close to the actual size. An assumption was made that caves diameter on single trace AVO inversion results equals to actual diameter. On this basis, it was found that caves boundary of inversion results should be defined at \( \sqrt{\frac{1}{2}} \) of the maximum impedance gap between caves and surrounding rocks.
Figure 5. Inverted P-impedance under four different cases. The P-impedance is extracted for cave 5, through its centre.

3.1. Influence of random noise on the AVO/AVA inversion results

Random noise of different degree was added to gathers for AVO/AVA inversion. Original seismic data and other two sections of random noise added at different ratio used for AVO inversion are shown in Figure 6. The corresponding inversion result shows that random noise make P-impedance lower and S-impedance unstable in caves. The inverted volume of heterogeneity become smaller as the noise increased (Shown in Figure 7).

Figure 6. Display of three partially stacked gathers with random noises added of different ratio for AVO inversion.
Figure 7. The corresponding inverted results of three cases that mentioned in Figure 6
Distribution of Inversion results of P-impedance (shown in Figure 8) and S-impedance (shown in Figure 9). From which we can get the follow two aspects: 1. random noise makes caves smaller in inversion results, the more noise added, the smaller it becomes. It may reduce the enlargement of stacked gathers inversion and cause the resolution of "false improve" 2. S-impedance is more influenced by noise than P-impedance.

Figure 8. Inverted P-impedance under six different cases. The P-impedance is extracted for cave 5, through its centre.

Figure 9. Inverted S-impedance under six different cases. The S-impedance is extracted for cave 5, through its centre.
4. Conclusions
Influence of stack and random noise on the lateral resolution of AVO/AVA is studied in this paper, using a caved physical model. The results can be summarized as flows:

1. Compared to AVO inversion, AVA inversion improves signal to noise ratio while reducing the lateral resolution.
2. The random noise reduces the lateral resolution of AVO/AVA inversion on heterogeneity.

Acknowledgments
The research is financed by Doctoral Scientific Research Foundation of China Hebei GEO University.

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