Introduction

Bright spot technology has been widely applied in hydrocarbon exploration and development since its presentation in 1960s. Over the past few decades, this method has facilitated the discovery of numerous oil and gas fields all around the world. However, the deficiencies of this method are also increasingly prominent along with the continuous improvement of geophysical exploration. A large number of studies have shown that, bright spot technology can indeed obtain favorable results of hydrocarbon detection in Neogene formation, with relatively shallow buried depth and simple geological conditions. For the Paleogene cases with deeper buried depth and complex geological conditions, however, discriminating bright spots related with hydrocarbons from those that are not could be challenging using amplitude information alone since it’s often affected by various factors such as lithology and tuning effect besides improper seismic processing. So we should watch out for traps in hydrocarbon detection of bright spots within Paleogene.

High amplitude seismic anomalies are found to be commonly distributed within Paleogene Dongying Formation in Liaodong Depression, Bohai Oilfield. Hydrocarbon detection on these bright spots is of great importance for further exploration within this area. In order to avoid the multi-solution and uncertainty of seismic amplitude, we start our research with rock physics analysis and forward modeling so as to reveal the mechanism of the bright spots. Then frequency characteristic analysis is performed and the spectrum of hydrocarbon-bearing sand is proved to be different from others. Finally, low-pass filtering based peak energy sum and frequency attenuation gradient (FAG) analysis are conducted together to characterize the hydrocarbon prospects as well as the distribution of these bright spots.

Formation mechanism of the high amplitude seismic anomalies

First of all, rock physics analysis and forward modeling are integrated to reveal the formation mechanism of the bright spots. Result shows that brine sand has similar P-wave velocity and density with shale, gas sand manifests as relatively lower P-wave velocity and density while gravel sand within the target formation is just the opposite. Forward modeling is then followed up with parameters based upon the above analysis (Figure 1) and a 35Hz-Ricker wavelet. Notice that except for oil sand and brine sand corresponding to weak seismic reflections, both gas sand and gravel sand result in high amplitude seismic anomalies and the later is more prominent, which means that hydrocarbon detection using seismic amplitude alone may well likely to bring about pitfalls.

![Figure 1](image.png)

*Figure 1 Original model (a) and forward modeling result.*

In order to further distinguish the hydrocarbon-associated seismic anomalies from those caused by other geologic factors, we turn to spectral analysis. Amplitude spectrums of the forward modeling results are computed as seen in Figure 2. It’s shown that gas sand has the lowest dominant (about 12Hz) and narrowest bandwidth, followed by oil sand and then brine sand, while gravel sand has the highest dominant frequency (about 35Hz) and widest bandwidth. What’s more, similar phenomenon is also observed on actual seismic data through spectral decomposition of the inline section passing through Well J1, which contains two thin gas layers with thickness being respectively 4.2m and 2.5m.
As shown in Figure 3, the two gas layers are both most prominent (red color) on the 10Hz single-frequency section and fade away gradually as the frequency increases.

![Figure 3 Spectral decomposition of the inline section passing through Well J1.](image)

**Figure 2** Amplitude spectrum of (a) gas sand, (b) oil sand, (c) brine sand and (d) gravel sand.

**Figure 3** Spectral decomposition of the inline section passing through Well J1.

**Frequency analysis based hydrocarbon detection**

Based on the above analysis, we can conclude that it’s feasible to conduct the identification and characterization of hydrocarbon-associated seismic anomalies through their frequency characteristics. Since the dominant frequency of oil and gas-bearing sand is much lower than brine sand and gravel sand, a straightforward method to highlight low frequency information is low-pass filtering. According to the result of spectral decomposition, the filtering is performed on a seismic section (the position is marked as the black line with arrow in Figure 5a) passing through some of the bright spots, with 10Hz as the high-pass frequency and 15Hz as the high-cut frequency. Comparison of seismic sections before and after low-pass filtering shows that the “true bright spots” we trust to be associated with hydrocarbon still present as strong amplitude reflections, but those “false bright spots” caused by other geologic factors are significantly weakened, as shown in Figure 4.

Then peak energy sum within the target layer is followed based on seismic data before and after low-pass filtering. As seen in Figure 5, the “false bright spots” with high frequency are effectively filtered and those “true bright spots” are well preserved at the same time, which are thought to be associated with the presence of hydrocarbon.
The above work conducts the discrimination of high amplitude seismic anomalies just by applying low frequency information, which may be not accurate enough and what’s more, the vertical resolution is decreased because high frequency components are filtered. Therefore, frequency attenuation gradient (FAG) analysis is applied since the dominant frequency of oil and gas-bearing sand decreases much faster than the others (Figure 2). In order to verify the effectiveness of this method, we calculate the frequency attenuation gradient of the seismic record resulted from the above forward modeling (Figure 1). As shown in Figure 6, the gas sand demonstrates as very strong frequency attenuation gradient, followed by oil sand while the other two are relatively weak, which can effectively help us to discriminate the hydrocarbon-associated seismic anomalies from others.

Then this method is further applied to the actual seismic data in Liaodong Depression, Bohai Oilfield. Figure 7 demonstrates a section (the location is marked as the black line with arrow in Figure 8a) of frequency attenuation gradient crossing Well J1 and the target blocks. It can be seen that the result perfectly matches the two thin gas layers within Well J1, which both present as relatively weak anomalies. As for the target blocks, much stronger anomalies (red color) of frequency attenuation gradient can be seen on the profile. We are therefore more confident that these anomalies to be associated with hydrocarbons.
Figure 7 The section of frequency attenuation gradient crossing Well J1 and the target blocks.

Based on the above analysis, the distribution of petroliferous area is further characterized through stratal slice of the frequency attenuation gradient (Figure 8a). Notice that the gas-bearing area (red color) of Well J1 doesn’t fill up the entire trap, which marked as the yellow area. We therefore zoom in the well block within the dashed box, it can be seen that the high point 1210ms locates at the south of the trap and gas accumulates only at the high parts (Figure 8b), which is consistent with geological rules and more accurate than Figure 5b. What’s more, the predicted hydrocarbon-bearing areas are all located at high parts of the traps, demonstrating great exploration potential.

Figure 8 (a) Superimposition of frequency attenuation gradient and structural map, (b) partial enlarged view of the dashed box in Figure (a). The black line with arrow indicates the position of seismic section in Figure 7.

Conclusions

A complete set of technical process is adopted to characterize the hydrocarbon prospects and spatial distribution of high amplitude seismic anomalies in Liaodong Depression, Bohai Oilfield. The integration of rock physics analysis and forward modeling shows that both gas sand and gravel sand would result in high amplitude reflections, the differences between which are then revealed through frequency analysis and spectral decomposition. Finally, low-pass filtering based peak energy sum and frequency attenuation gradient analysis are applied to discriminate the bright spots associated with hydrocarbons from those caused by other geologic factors. According to the research in this paper, those high amplitude seismic anomalies exhibiting low dominant frequency, narrow bandwidth, as well as high frequency attenuation gradient are believed to be prospective.

References