Summary

Bright spot (including stacked seismic bright-spot and traditional AVO anomaly) does not mean high gas saturation hydrocarbon (maybe non-reservoir, or brine, or low gas saturation hydrocarbon), and high gas saturation hydrocarbon maybe not exhibit bright-spot (maybe non-bright-spot) behavior especially in deep water area or deep gas situation. But high gas saturation hydrocarbon must exhibit low elastic properties (Poisson’s ratio, or density, etc.) behavior in the northern South China Sea and Gulf of Mexico. Quantitative elastic prediction is the effective solution of non-gas bright-spot and non-bright-spot gas identification problem in those areas.

Introduction

In past decades, bright-spot of stacked seismic amplitude has been used to predict gas (high gas saturation hydrocarbon) in the northern South China Sea and Gulf of Mexico. It is commonly accepted that the identification of commercial gas based on bright-spot technique will take great risk due to the presence of non-gas bright-spot caused by low gas saturation hydrocarbon since 1980s.

In recent years, multiple exploratory wells failed in exploiting gas based on bright-spot technique in deep water area in the northern South China Sea, since those bright-spots were caused by non-reservoir, or brine, or low gas saturation hydrocarbon. Few exploratory wells also encountered gas zone which didn’t exhibit bright-spot behavior in the northern South China Sea.

Allen and Peddy (1993) noted that many seismic amplitude anomalies are not caused by economic hydrocarbon (gas) accumulation and discovered close relationship between Poisson’s ratio and Sw (water saturation). It is commonly accepted that density may reveal crucial information about fluid saturation. Roderick W. Van Koughnet et al. (2001, 2003) discovered that low density is the main behavior of gas-sand with high gas saturation in deep water Gulf of Mexico.

In this paper, we present multiple examples of non-gas bright-spot and non-bright-spot gas in the northern South China Sea, and then analyze the elastic property of non-gas bright-spot and non-bright-spot gas and give the solution of identification and prediction. Finally, one case study will be given to prove that elastic prediction is the effective solution of non-gas bright-spot identification problem in the northern South China Sea.

Non-gas bright-spot and non-bright-spot gas

Non-gas bright-spot means that those bright-spots are caused by non-reservoir or brine or low gas saturation hydrocarbon rather than commercial (high gas saturation) gas. Non-bright-spot gas means high gas saturation hydrocarbon which does not exhibit bright-spot behavior.

In this paper, bright-spot means high amplitude reflections on stacked seismic, P-wave reflectivity (or P-wave impedance reflectivity) and traditional AVO anomaly (including Class I, II, III and IV AVO anomaly).

It is not true to be high gas saturation hydrocarbon for bright-spot

Bright-spot can be caused by non-reservoir

Example 1: In the northern South China Sea, there are two high amplitude reflections (bright-spot) at target zone in S Formation in Block C in deep water area, which were considered as commercial gas before drilling. But those bright-spots were proven to be seismic response of two shale zones with low density and low velocity in thick shale (non-reservoir). Figure 1 shows CRP gather and Class IV AVO, stacked seismic, synthetic seismic and geologic column of well C1.

In deep water B Sag in the northern South China Sea, It is the main reason not to encounter good sand for multiple exploratory wells failing in exploiting gas (Xiong Pang, 2014).

Statistics show that 37% of total unsuccessful DHI (bright spot technique) is from non-reservoir (Paul Weimer and Roger M. Slatt, 2007).

Bright-spot can be caused by brine

Example 2: Bright-spot can be caused by brine in deep water area in the northern South China Sea. There are two high amplitude reflections (bright-spot) with Class IV AVO anomaly at target zone in Y Formation in deep water A Sag, which were considered as commercial gas before drilling. But those two bright-spots were proven to be seismic response of two brine zones. Figure 2 shows stacked seismic, synthetic seismic and geologic column of well C2.
The solution of non-gas bright-spot and non-bright-spot gas identification: Elastic prediction

In Block P in the northern South China Sea, two fifths of total exploratory wells (Five wells) encountered brine zones with bright-spot behavior, which exhibits both high stacked seismic amplitude and Class III AVO anomaly (Weiwei Zhang, 2012).

In the deep water Gulf of Mexico, up to 62% of brine sand is corresponding to Class III AVO response, and Class IV AVO response of brine sand is much more than that of gas sand (Roderick W. Van Koughnet, 2001).

Statistics show that 35% of total unsuccessful DHI (bright spot technique) is from brine sand (Paul Weimer and Roger M. Slatt, 2007).

**Bright-spot can be caused by low gas saturation hydrocarbon**

Example 3: Bright-spot can be caused by low gas saturation hydrocarbon in deep water area in the northern South China Sea. There are two high amplitude bright-spots at target zones in L Formation in A Sag, which were considered as commercial gas before drilling. But those two bright-spots were proven to be seismic response of two low gas saturation gas-sand zones. Figure 3 shows stacked seismic, synthetic seismic and geologic column of well C1.

Statistics show that 22% of total unsuccessful DHI (bright-spot technique) is from low gas saturation hydrocarbon (Paul Weimer and Roger M. Slatt, 2007).

**It is not true that high gas saturation hydrocarbon must exhibit bright spot behavior**

High gas saturation hydrocarbon may not exhibit bright-spot behavior. In deep water B Sag in the northern South China Sea, there are a couple of low amplitude reflections (non-bright-spot) at target zone in Z Formation (Neogene), which were considered as non-commercial gas before drilling. Since people used to think that high gas saturation hydrocarbon must exhibit bright-spot behavior. Actually those non-bright-spots were proven to be commercial gas after drilling (Weiwei Zhang, 2015).

In offshore Mexico and the North Sea, multiple non-bright-spot gas zones had been discovered (Alistair R. Brown and William L. Abriel, 2014).

**It is really true to exhibit low elastic properties (Poisson’s ratio, or density, etc.) behavior for high gas saturation hydrocarbon**

Brine/gas sand exhibits high/low elastic properties behavior

In Example 2, bright-spot is caused by brine sand. First, it is important fundamental work to conduct elastic property analysis of different fluids (brine, low gas saturation hydrocarbon).

Figure 1: Bright-spot is caused by non-reservoir. Bright-spot on both stacked seismic (left) and synthetic seismic (middle) is caused by two low density and low velocity shale zones in thick shale. Density of shale (including shaly sand) is more than 2.300g/cc. AI does not work to differentiate sand from shale.

Figure 2: Bright-spot is caused by brine sand. Two bright-spots (with Class IV AVO) on both stacked seismic and synthetic seismic are corresponding to brine zones. Poisson’s ratio is more than 0.34.

Figure 3: Bright-spot is caused by low gas saturation hydrocarbon. Two bright-spots on both stacked seismic and synthetic seismic are corresponding to low gas saturation hydrocarbon. Compared to other elastic properties, Poisson’s ratio is more sensitive to fluids. Poisson’s ratio is more than 0.35.
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for brine sand (Figure 2) and less than 0.28 for low gas saturation gas-sand (noted not gas-sand) (Figure 3). Obviously, brine sand exhibits high elastic properties (Poisson’s ratio) behavior in A Sag in the northern South China Sea.

In deep water B sag in the northern South China Sea, rock physics analysis based on 14 exploratory wells shows that low density and low Poisson’s ratio are the main elastic behavior for high gas saturation hydrocarbon (Chengzhi Yang, 2010).

In deep water Gulf of Mexico, Statistics (19 wells) show that low density is the main elastic behavior for high gas saturation hydrocarbon (Roderick W. Van Koughnet, 2001).

The higher gas saturation is, the lower elastic property is.

In Example 3, there are two brine sand zones. Water saturation is 75% for the upper sand zone with Poisson’s ratio of 0.24 and 81% for the lower sand zone with Poisson’s ratio of 0.28 (Figure 3). The higher gas saturation is, the lower Poisson’s ratio is. Poisson’s ratio of gas-sand should be lower than that of low gas saturation hydrocarbon.

Figure 4 show the close relationship between water saturation and Poisson’s ratio based on one exploratory well in deep water area in the northern South China Sea; note that the porosity of all samples in left figure is the same (about 20%). Poisson’s ratio of gas-sand is less than that of low gas saturation hydrocarbon, whose Poisson’s ratio is less than that of brine. Obviously, the higher gas saturation is, the lower elastic property (Poisson’s ratio) is.

Density from AVO fluid substitution increases linearly with gas saturation increasing in the northern South China Sea (Figure 5).

Actually, as early as in 1993, Allen and Peddy discovered an important close relationship between Poisson’s ratio and gas saturation. Poisson’s ratio decreases substantially when gas saturation reaches only a few percent, then decreases linearly with gas saturation increasing (1993, Allen and Peddy).

The solution of non-gas bright-spot and non-bright-spot gas identification: Elastic prediction

How to identify non-gas bright-spot and non-bright-spot gas? Bright-spot technique using stacked seismic or traditional AVO analysis does not work. The effective solution is elastic prediction. Elastic Prediction is the key to open the door of non-gas bright-spot and non-bright-spot gas identification problem.

Figure 4: In the northern South China Sea, there is close relationship between Poisson’s ratio and water saturation. High gas saturation hydrocarbon exhibits low Poisson’s ratio behavior, and low gas saturation exhibits high Posson’s ratio behavior (left). All samples in left figure are from those fluids with the same porosity (three red circles)(right). Noted that AI does not work to discriminate sand/gas from shale/low gas saturation hydrocarbon.

Figure 5: Density from well C1 increases linearly with gas saturation increasing in the northern South China Sea.

Elastic prediction means the prediction of reservoir and hydrocarbon using elastic properties based on pre-stack seismic inversion without well, which is quantitative prediction method of reservoir and hydrocarbon. In this paper, pre-stack seismic inversion technique used is full gather based elastic direct inversion without well.

The strategy of high gas saturation hydrocarbon prediction is: reservoir prediction first, high gas saturation hydrocarbon prediction next.

In Example 1, bright-spot is caused by non-reservoir (shale). Density is the most sensitive to lithology. Density is more than 2.39g/cc for shale and less than 2.25g/cc for sand (Figure 6). Therefore quantitative pre-stack density inversion for reservoir prediction is the solution of non-gas bright-spot (caused by non-reservoir) identification problem.

In Example 2 and Example 3, bright-spot is caused by brine or low gas saturation hydrocarbon. Based on rock physics analysis of well C1 and well C2, Poisson’s ratio is more than 0.35 for brine and less than 0.28 for low gas saturation hydrocarbon (between 0.22 and 0.28).
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Furthermore, the higher gas saturation is, the Poisson’s ratio is. Poisson’s ratio of gas-sand should be lower than about 0.2. Therefore, quantitative pre-stack Poisson’s ratio inversion for high gas saturation hydrocarbon prediction is the solution of non-gas bright-spot (caused by brine or low gas saturation hydrocarbon) identification problem.

Figure 6: In A Sag in the northern South China Sea, density is more sensitive to lithology than other elastic properties. Density is more than 2.39g/cc for shale and less than 2.25g/cc for sand. Quantitative pre-stack density inversion for reservoir prediction is the solution of non-gas bright-spot (caused by non-reservoir) identification problem.

Case study

In Block E in the northern South China Sea, there are three high amplitude bright-spots at target zone (Figure 5a), which were considered as commercial gas before drilling. Figure 5b shows quantitative Poisson’s ratio inversion section, in which bright-spot A and C are corresponding to high Poisson’s ratio (between 0.22 and 0.26) zones, which indicate non-gas sand based on rock physics analysis (Figure 4). Bright-spot B is corresponding to low Poisson’s ratio (<0.21) zone, which indicates gas-sand with high gas saturation. Well E2 encountered brine sand at bright-spot A and gas-sand at bright-spot B. Bright-spot C is below gas-water contact.

Conclusions

It is not true to be high gas saturation hydrocarbon for bright-spot; It is not true that high gas saturation hydrocarbon must exhibit bright-spot behavior; It is really true to exhibit distinct low elastic properties (Poisson’s ratio, or density, etc.) behavior for high gas saturation hydrocarbon. Bright-spot technique based on qualitative stacked seismic amplitude and traditional AVO analysis is ambiguous, complicated and dangerous for hydrocarbon detection. Quantitative elastic prediction based on pre-stack seismic inversion is definite (less uncertainty), and it is the effective solution of non-gas bright-spot and non-bright-spot gas identification problem in the northern South China Sea and Gulf of Mexico.

It is also feasible to predict high gas saturation hydrocarbon using quantitative elastic prediction method in other area. But the elastic behavior (how low) of high gas saturation hydrocarbon needs to be re-confirmed in a new area.

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REFERENCES


