GAS HYDRATE ANOMALIES IN SEISMIC VELOCITIES, AMPLITUDES AND ATTENUATION: WHAT DO THEY IMPLY?

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ABSTRACT

Gas hydrates are found worldwide and many studies have been carried out to develop an efficient method to identify and quantify them using various geophysical as well as other anomalies. In this study, various seismic anomalies related to gas hydrates and the underlying gas are analysed, and correlated them to rock physics properties. Observations of velocities in sediments containing gas hydrates show that the rigidity, and hence the velocity of sediments increases with increase of hydrate saturation. The increase of velocity due to the presence of gas hydrate can be explained in terms of gradual cementation of the sediment matrix. In the case of seismic attenuation, gas hydrate bearing sediments are quite different from common sedimentary rock behaviour of low seismic attenuation with high rigidity. In contrary gas hydrate bearing sediments is observed to have increased seismic attenuation of higher frequencies with increase of hydrate saturation. This strange phenomenon can be explained in terms of differential fluid flow within sediment and hydrate matrix. Also it is observed that the presence of large amount of gas hydrate can result in an increase of seismic amplitudes, a signature similar to the presence of small amount of gas. Hence misinterpretation of these enhanced amplitudes could result in the under estimation of gas present not only as shallow drilling hazard but also on the resource potential of the region. The increase of seismic reflection amplitude results from the formation of gas hydrates in selective intervals causing strong positive and negative impedance contrasts across the formations with and without gas hydrates.

Keywords: gas hydrate, BSR, attenuation, velocity.

INTRODUCTION

Gas hydrates are mainly observed in seismic data as a bottom simulating reflector (BSR), which is a reflection parallel to the seafloor and opposite in polarity [1]. But recent studies in many areas shows that the BSR is not a necessary criterion for the existence of gas hydrates but they indicate the presence of free gas below the gas hydrate containing sediments (for example, [2]). Gas hydrates are mainly observed in sediments of continental margins and permafrost regions. Sediments containing gas hydrates also form an impermeable layer trapping gas beneath it. Higher velocities than that of water-filled, normally compacted marine sediments can be attributed often to the presence of gas hydrate [3]. However, it has been observed that the presence of gas hydrate can increase attenuation even though the stiffness of the composite matrix is increased [4]. Also seismic sections from high hydrate saturated formations are observed to show amplitude enhancement or bright spots. Here the reasons for these increases of velocity, attenuation and amplitude enhancement in the presence of hydrate are analysed. Datasets from different regions of the world along with theoretical modelling results are used to critically analyse these observations.

THEORY

Chand et al [5] relate the seismic properties of gas hydrate bearing sediments to porosity, mineralogy, micro-structure, fluid flow and hydrate saturation. The basic back bone of the model is an effective

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medium theory [6] based on a combination of a self-consistent approximation (SCA) [7], a differential effective medium theory (DEM) [8] and a method of smoothing for crystalline aggregates [9]. The SCA/DEM model structure consists of inclusions embedded in a homogenous matrix [10]. The SCA medium with hydrate as part of the matrix creates the biconnectivity between hydrate and other coponents. Hence, the overall strength of the medium increases significantly with increasing hydrate content. The connectivity of hydrate with the sediment matrix is assumed to vary with hydrate saturation. The porosity is adjusted using DEM to create unconnected space for the remaining (non-matrix) mineral grains. This model with a portion of hydrate saturation as load-bearing cement and the remaining as pore-filling inclusions could be more close to reality (Fig. 1).

The increase of velocity is relative to the nature of the host sediment. For consolidated sediments with low porosity, the increase of velocity is small with increase of hydrate saturation. While for high porosity host sediments, where hydrate plays a major role in binding the sediments together as well as filling the pore space, the increase in velocity is large (Fig. 2).

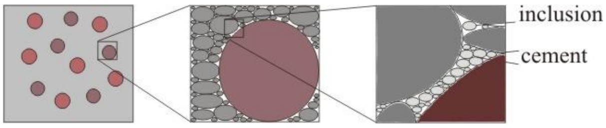

Fig. 1. The microstructure of hydrate formation in the pore space is shown here. Hydrate forms partially in the pore space and partially attached to the sediment matrix.

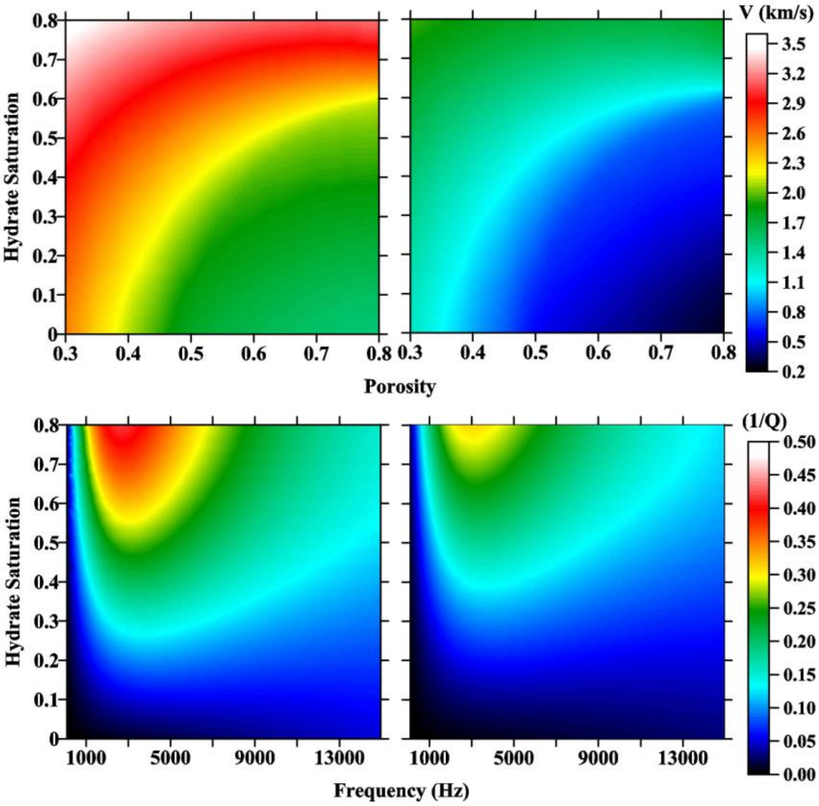

Fig.2. Top two plots show the increase of P (left) and S (right) wave velocities with hydrate saturation against porosity. The lower two plots shows the variation of P (left) and S (right) wave attenuation with hydrate saturation and frequency. The composition of the sediment used here contains 50% quartz and rest clay. Notice the net change in P and S wave velocity for the whole range of hydrate saturation used here (80%), which is about 1.0 to 1.5 km/s and 0.6 to 1.2 km/s respectively. The P and S wave attenuation peaks at 3 kHz and for the highest hydrate saturation.

Chand et al [5] uses a model in which seismic wave attenuation is addressed using theories describing the influence of fluids on the poro-elastic behaviour of materials [11]. A combined poro-elastic wave equation is used including both Biot macroscopic fluid flow [12, 13] and inter crack squirt flow [14] (BISQ) mechanisms (Fig. 2).

Impedance contrast across a boundary is a factor dependent upon the velocity and density variation across the boundary. Even though, density variation can result from change in porosity and/or sediment composition, the major factor for impedance contrast is from the stiffness variation of the medium. In the case of hydrate occupying the pore space, the change in density is limited since the hydrate has density comparable to formation water. Contrary, the change in velocity can be quite substantial (Fig.2), and if the presence of hydrate is limited to some particular formations, it can result in the amplification of reflection amplitudes from positive and negative impedance contrast boundaries. It is similar to high amplitude reflections produced by the presence of small amount of gas, where gas lowers the stiffness of the medium thus creating negative and positive impedance contrast boundaries. A combination of these parameters due to gas hydrate can be thus explained through a physical model in which gas hydrate is partially cementing the grains causing increase of velocity and also blocking the pore throats to affect the fluid flow causing higher attenuation (Fig. 1).

EXAMPLES

The theory described above can be validated from examples of gas hydrate anomalies worldwide. The best example to describe the model comes from the exploratory wells drilled as a part of Mallik gas hydrate research program in a permafrost region in the Mackenzie Delta area of Canada [3]. Archie's law interpretation of resistivity logs suggests that gas hydrate occupies an average of 47% of the void space increasing locally to 80% [15] (Fig. 3). Borehole seismic data are also consistent with up to 80% hydrate saturation [16]. It can be observed that the P (12 kHz) and S (2.5 kHz) wave velocities increase linearly by 1.2 km/s and 1 km/s respectively and their attenuations increase with hydrate saturation due to the presence of hydrate saturation increasing up to 80% (Fig. 3). In another gas hydrate province across Nankai Trough 25% hydrate saturation in pore space is reported and the observed velocities and attenuation also increases with hydrate saturation [17] (Fig. 4).

Acoustic amplitude anomaly related to gas hydrate is the most confusing anomaly among the three types of anomalies discussed here. It has been described until recently that the gas hydrate zone represents a blanking zone for the seismic signal where the seismic reflections are subdued due to the filling of gas hydrates in the pore space making everything uniform. But the observations from gas hydrate provinces with large amount of gas hydrates show a totally different signature.

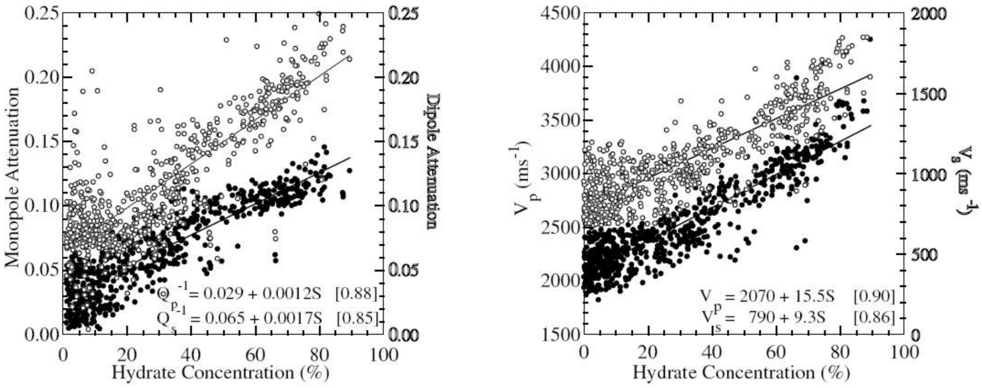

Fig. 3. Variation of attenuation and velocities at Mallik exploratory well vs hydrate saturation [3]. Notice the linear trend shown by the observations denoting a linear increase of hydrate cementation, which is comparable to those given in Fig. 2.

Gas hydrate zones are seen as high amplitude seismic reflection zones [18, 19, 20] similar to gas zones and often there is no clear demarcation of a BSR (Fig. 5). This confusing signature on seismic data could result in the under estimation of gas present while drilling through the gas hydrate stability zone and hence the associated hazard of gas blowouts while drilling so also the resource potential of the region for gas reservoirs. It once again suggests the importance of gas hydrate stability modelling and detailed velocity analysis of high amplitude anomalies before drilling in deep water regions lying in gas hydrate stability zone.

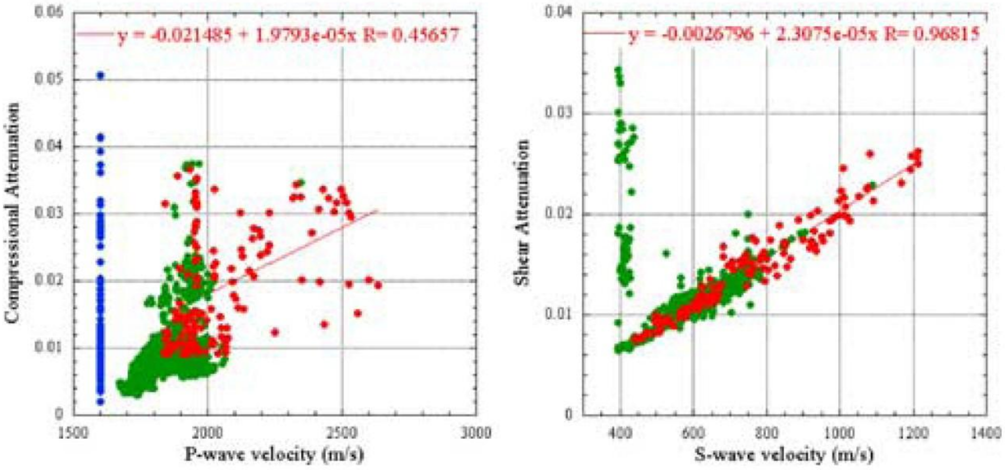

Fig. 4. P and S wave velocities versus attenuations from Nankai Trough [17]. Red, green and blue dots represent hydrate, no hydrate and gas zones respectively.

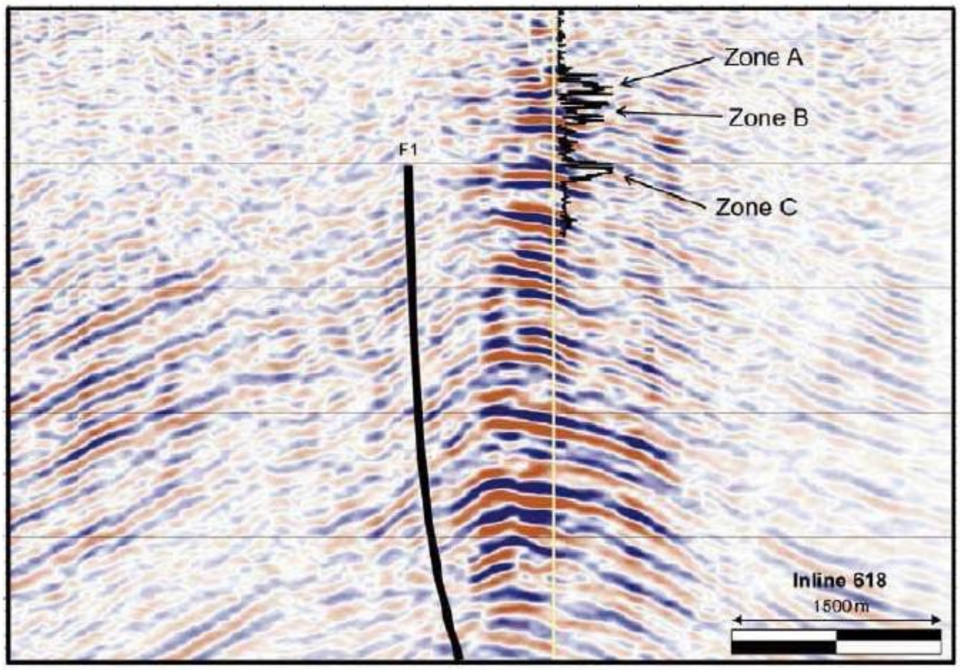

Fig. 5. Seismic section across gas hydrate zone near Mallik research wells [18]. Notice the high amplitudes both in the gas hydrate zones with high log velocities and the gas filled zones below. It is impossible to demarcate the gas hydrate zone from the gas zone directly from the seismic section. The supply of gas needed for the formation of hydrate is suggested to be controlled by open faults similar to the one shown.

CONCLUSIONS

1. Velocities increase considerably with the presence of a large amount of hydrates in unconsolidated sediments due to cementation by hydrates. The increase of velocity is less for low porosity compacted sediments since they are already partially cemented.
2. Attenuation of high seismic frequencies in gas hydrate bearing sediments increases with hydrate saturation but is highly variable with the type of host sediment.
3. Gas hydrates are usually confined to permeable sand layers causing large changes in velocity across sedimentary formations. The large impedance contrasts so produced will result in high amplitude anomalies similar to those formed due to the presence of gas in sediment pore space.

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