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Overpressure Condition Versus BSR

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SUMMARY

In order to improve the hydrate knowledge, it is very important to analyze the relationship between hydrate stability and overpressure condition. The overpressure condition in the free gas zone causes the disagreement between theoretical and seismic BSR depth. We model the effect of the overpressure condition versus sea water depth, geothermal gradient and hydrate stability. We introduce the following concepts: 1) hydrostatic BSR, which is the theoretical BSR evaluated supposing hydrostatic pressure in the pore space, and 2) the overpressure BSR, which is the BSR shifted with respect to hydrostatic condition because of the overpressure in the free gas zone. We draw the following considerations: i) the difference between the hydrostatic and the overpressure BSR depths is inversely proportional to water depth; ii) the geothermal gradient is inversely proportional to the difference between the hydrostatic BSR and the overpressure BSR depths. These results of this study are very useful in many fields. First of all, they should be considered in the environmental hazard. In fact, the hydrate present below the hydrostatic BSR is probably in meta-stable condition and more sensible to boundary conditions. Moreover, the effect of overpressure is important in shallow water, where human manufactures are located.

Introduction

Gas hydrate and free gas play an important role in marine geohazards (Kvenvolden 1998). They pose a possible hazard to offshore installations and, for this reason, mapping of sub-seabed layers becomes a crucial part in the planning in drilling operations. Moreover, the gas hydrate may be related to global climate change because they can be affected by temperature and pressure changes (Kvenvolden 1998).

In the last years, the hydrates and the free gas are studied from an exploitation point of view. Gas hydrate accumulations are geophysically inferred from the presence of a cross-cutting, polarity reversed, high-amplitude bottom simulating reflection (BSR) on seismic profile (Miemert et al. 2005). BSRs form at the transition between sediments containing gas hydrate, above, and sediments containing free gas, below. Hydrate-related BSRs consequently lie at depths that closely corresponds to the base of the hydrate stability zone (Hyndman et al. 1992), although several authors have pointed out that the theoretical BSR depth does not correspond to the seismic BSR depth (i.e., Bangs et al. 1993, Ruppel 1997). To justify this disagreement, they have suggested considering an increased pressure, instead of hydrostatic pressure; they considered a pressure ranging between hydrostatic and lithostatic pressure to evaluate the hydrate stability curve without a theoretical explanation (i.e., Ganguly et al. 2000, Bouriaik et al. 2000). This approach corresponds to suppose overpressure condition in the pore space. This condition is already recognized below the BSR where the free gas can be in overpressure condition (i.e., Tréhu et al. 2006), as already showed from a theoretical point of view (i.e., Tinivella 2002). On the basis of these considerations, it is important to study the relationship between BSR depth and pore pressure. We introduce the concept of hydrostatic BSR (HBSR), which is the theoretical BSR evaluated supposing hydrostatic pressure in the pore space. In this paper, we model the effect of the overpressure condition versus sea water depth, geothermal gradient and hydrate stability.

Modeling

The BSR is generally considered an interface between gas hydrates and free gas, which can be in overpressure condition (Tréhu et al. 2006), changing the elastic properties of the sediments. On the other hand, the gas hydrate stability is strongly related to the pore pressure and, theoretically, it could form in the free gas layer if overpressure was present. To verify this hypothesis, we consider the following boundary conditions: water depth equal to 300 and 600 m and two different geothermal gradients, equals to 30 and 40 °K/km. We analyze the effect of hydrate stability versus overpressure condition below the HBSR at a depth equal to 5% and 10% of the HBSR.

Initially, we calculate the effects of the overpressure conditions in shallow and deep sea water. The results show that the effect is not significant in deep water and, for this reason, we considered just the cases of sea water depth ranging between 300 and 600. These results are in agreement with other studies (Spence et al. 2007), suggesting that the overpressure condition is significant at shallow water/BSR depth.

Generally, in gas hydrate study advanced seismic analyses are performed in order to obtain the seismic BSR depth. The estimated seismic depth error is generally 5% (Tinivella et al. 2002). So, we consider the hydrate stability at minimum depth that can be detected by seismic analysis. On the other hand, we consider depth below 10% of the HBSR depth.

Finally, we consider geothermal gradient values typical of geological environmental hosting gas hydrate reservoir. Moreover, higher geothermal gradient are not interesting from our point of view, because in the temperature/pressure domain the slope decreases, i.e. at selected pressure, the difference between the hydrate stability and temperature curve increases.

The gas hydrate stability curve was calculated by using Dickens and Quinby-Hunt (Dickens and Quinby-Hunt 1994) equations, considering that the hydrate is formed by methane and sea water, characterized by salinity of 35 ‰. We adopt the errors equal to 0.2 °K for the temperature and 0.07 MPa for the pressure (Dickens and Quinby-Hunt 1994). The water density is considered equal to 1020 kg/m³. The HBSR depth is the crossing between the hydrate stability curve and the temperature/pressure curve in the sediments. Sloan equations (Sloan 1998) can be used alternatively

in order to model a mixture of gases. In our modeling, a pure methane hydrate is considered for three main reasons: 1) often, it is very difficult to have direct measurements about the composition of gas; 2) methane hydrate stability curve is restrictive case; and 3) the empirical equation of Dickens and Quinby-Hunt (Dickens and Quinby-Hunt 1994) is the most used in the literature.

For each case, we consider the following overpressure conditions: 25%, 50%, 75% and 100% of the ΔPP .

Fig. 1 shows the modeling supposing a geothermal gradient equal to 30 °K/km. The HBSR depth is 375 m and 987 m considering a water depth of 300 m and 600 m respectively. In the first case, we study the hydrate stability at a depth of 19 m (i.e., 5% of the HBSR depth) and 37 m (10%) below the HBSR depth. In the case of 600 m water depth, it is considered equal to 49 m (5%) and 99 m (10%) below the HBSR depth.

For the first case (dotted line in Fig. 1), theoretically, small overpressure condition (less than 25% of ΔPP) shifts in depth the base of the gas hydrate stability zone, hereafter defined overpressure BSR (OBSR). For example, the maximum depth at which the hydrate can be formed is about 37 m below the HBSR if we assume an overpressure equal to 25% of the ΔPP . In the second case (dashed-dotted-dotted line in Fig. 1), even if high overpressure is present, the gas hydrate stability is not verified below the HBSR. Fig. 2 shows the modeling considering the geothermal gradient equal to 40 °K/km. In the first case (300 m sea water depth), higher overpressure condition is required to form hydrate below the BSR (more than 50% of ΔPP). On the contrary, as expected, considering a water depth equal to 600 m, not hydrate stability below the BSR is reached.

Figure 1 Hydrate stability curve (solid black line) considering Dickens and Quinby-Hunt approach (Dickens and Quinby-Hunt 1994). The dashed lines are the error bars. The dotted and dashed-dotted-dotted lines are the temperature/pressure curve supposing a geothermal gradient equal to 30 °K/km and a sea water depth of 300 m and 600 m respectively. The solid circles represent the degree of overpressure 25% (green), 50% (blue), 75% (purple) and 100% (red) of the ΔPP . The insert is a zoom of the overpressure effect at 300 m sea water depth.

Figure 2 Hydrate stability curve (solid black line) considering Dickens and Quinby-Hunt approach (Dickens and Quinby-Hunt 1994). The dashed lines are the error bars. The dotted and dashed-dotted lines are the temperature/pressure curve supposing a geothermal gradient equal to 40 °K/km and a sea water depth of 300 m and 600 m respectively. The solid circles represent the degree of overpressure 25% (green), 50% (blue), 75% (purple) and 100% (red) of the ΔPP . The insert is a zoom of the overpressure effect at 300 m sea water depth.

Discussion and Conclusions

On the basis of our results, it is possible to give a new interpretation to the results obtained by previous works related to the disagreement between the seismic BSR and the HBSR depths and the presence of double BSR. For example, in the Nankai slope, Foucher et al. (2002) observed a so-called BSR2 that was interpreted as a residual BSR left in the sediments after migration upward of the stability field, related to sea bottom warping and tectonic uplift of the seafloor. During the upward migration of the hydrate stability, a large amount of free gas was released in the pore space by hydrate dissociation (Haacke et al. 2008), producing overpressure condition. Foucher et al. (2002) observed a disagreement between the HBSR and the seismic BSR depths in the shallower water, which could be interpreted as the OBSR. Moreover, we suggest that the BSR2 could be the base of the free gas layer, characterized by positive reflection coefficient. In our hypothesis, the BSR2 follows the seafloor and it is produced by the interface between free gas (generated by hydrate dissociation due to climate change, as suggested by the authors) and water bearing sediments.

In conclusions, we draw the following considerations by the analysis of our modelling:

1. the difference between the HBSR and the OBSR depths is inversely proportional to water depth;
2. the geothermal gradient is inversely proportional to the difference between the HBSR and the OBSR depths.

Note that if the hydrate is formed by mixture of gases, the effect of the overpressure versus hydrate stability could be stronger.

The results of this study are very useful in many applications. First of all, it should be considered in the environmental hazard. In fact, the hydrate present below the HBSR is probably in meta-stable condition and more sensible to boundary conditions. Moreover, we underline that the effect of overpressure is important in shallow water, where human manufactures, such as pipelines, are presents. Then, the difference between the HBSR and the seismic BSR depth (observed by several authors; i.e. Foucher et al. 2002, Bangs et al. 1993, Bouriaik et al. 2000) could be somewhere related to the overpressure condition in the free gas zone. This requires improving the knowledge of these gas

hydrate sites about overpressure conditions and their effects. To reach this goal, it could be very useful to acquire information about the shear wave velocity, which decreases in the free gas layer where overpressure conditions are present (Tivinnella 2002). Finally, for a gas hydrate and free gas exploitation, accurate analysis of the BSR nature and the pore pressure study are required to improve the reliability of the gas-phase estimation.

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