Texture Characteristics of Tight Formations with Hydrocarbon Seal and Leakage Mechanisms

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Summary

In the Beaufort-Mackenzie Basin (BMB), six types of hydrocarbon seals have been identified. Three of these are formed at significant depth and three are shallow seals with relatively low hydraulic permeabilities (kH) that play a role in the trapping and formation of gas hydrates. The main concern for these six seals is the possibility of some having textural characteristics that allow significant leakage, regardless of their very low kH values.

Grain-size combinations are the key in determining these seal and leakage characteristics. Although well-compacted clay-rich formations are generally considered as good seals, certain combinations with larger grains, such as silt grains, can reduce the seal quality. Clay poor formations are generally considered to be poor seals, but recent studies have shown that certain combinations of large and smaller grains can contribute to improving their seal characteristics. Therefore, it is important to understand the effect of texture on seal quality and develop field methods to detect these characteristics. This understanding is also essential for predicting and detecting possible leakage mechanisms in rocks that are thought to be good seals. Bacterial activity and low temperature effects are also important factors in enhancing seal quality in shallow formations.

Introduction

In the Beaufort-Mackenzie Basin (BMB), six types of hydrocarbon seals are recognized. Three of these are formed at significant depth (>2.5 km) with very low kH values (0.2-10 nD); three are shallow (<1000 m) seals that also can have low kH values (20-200 nD) (1.0 nD = 10-21 m2). The three deep seals consist of (1) those with a high clay content, (2) those with a lower clay content but with a larger range of grain-size combinations, and (3) those with diagenetic cement (Katsube, et al., 2004). Although the shallow seals may have low integrity, they can significantly impede the flow of gas and, if within the gas hydrate stability zone, promote the formation of gas hydrates. The formation texture characteristics are the key to determining the formation seal quality. The main concern for these seals is the possibility of some having textural and grain-size combinations that allow significant leakage, regardless of their very low kH values. For this presentation, we primarily introduce studies that discuss the basic textural structure and characteristics of seals and their possible leakage mechanisms, followed by some examples of seals in the BMB. We then discuss some petrophysical considerations for the leakage mechanism in a tight seal.

Theory

Texture of Deep Seals: The texture of sedimentary formations consists of various grain-sizes, ranging from clay particles under 4 □m to sand grains of over 1000 □m in size. As sea floor sediments are compacted due to increased burial, the larger grains usually form a framework grain texture with the smaller grains, such as clay, filling their intergranular pore spaces. If the fine-grain content such as clays is high compared to the larger grains, then a matrix texture is formed. Formations with a matrix texture or high clay content are expected to have good seal qualities (e.g., Yang and Aplin, 2007). However, a recent study suggests that clay is not necessarily the only intergranular pore filling material needed to create a seal. Combinations of various silt grains can contribute to this process, including combinations of different sizes of the framework grains (Katsube and Connell-Madore, 2008). At depth, diagenetic cementation can also contribute to seal formation. Therefore, three types of hydrocarbon seals can be formed at depth (see Figure 1 of Katsube et al., 1999a).

Texture of Shallow Seals: Sea floor sediments can have relatively low kH values due to three different mechanisms (Katsube et al., 2004; 2005). These are sea floor sediment formations rich in clay (Katsube and Williamson, 1998), formations with thin sulphide and carbonate layers created by bacterial activity (Katsube et al., 1999b), and formations with increased bound water layer thickness on their grain surfaces due to low arctic temperatures (Katsube et al., 2005). These formations may not have good integrity, but could be sufficient to retard upward gas flow and promote gas hydrate formation (Katsube et al., 2004; 2005). Once a gas hydrate layer is formed, it can enhance the seal quality by preventing further upward gas flow. These gas hydrate seals may not last for long periods of time during burial, but they could last long enough to allow clay rich formations to form above them resulting in a good seals at a later time.

Leakage Mechanisms: A recent study suggests that even in good seals with kH values below 10 nD (<10-20 m2), there can be a few pores that allow leakage of water in the order of tens of millions of barrels over a few million years (Katsube et al., 2006). Although their pore diameter could be in the order of a few tens of nano-metres, their density could be so small that they would not be detected by normal petrophysical techniques. However, the amount of fluid movement through such small pores in thick seals could be very significant. More details of this study are expected to be reported in the near future.

Seal Examples in the BMB

Ex-1: Shales from depth of 2-4 km in compaction zones-2 , -3 and -4 of the BMB (Issler, 1992) have shown good seal qualities with in-situ kH values of 0.2 to 0.4 nD (Katsube et al., 1996), although the pore-size distribution data (Connell-Madore and Katsube, 2006) suggests that some may have silt mixed with the clay.

Ex-2: There is a sandstone formation at a depth of 920-930 m in Zone-4 which is cemented by dolomite with an effective porosity (□E) and pore-size mode (dm) of 2.2 % and 5 nm (Katsube, et al., 1999b), respectively. Cemented shales with such □E and dm values can have kH values of 2-35 nD (Katsube, et al., 1991, 1996; Bowers and Katsube, 2002).

Ex-3: There is a siltstone formation at 890-900 m depth in Zone-4 with a kH value of about 20 nD that was reduced to about 2 nD because of bacterial activity (Katsube et al., 1999b, 2004, 2005).

Ex-4: There is an abundance of gas hydrate seals up to a depth of just over 1000 m in the BMB.

Ex-5: The BMB does have unconsolidated sea floor sediments. Clay-rich sea floor sediments in eastern Canada have shown kH values of 30-100 nD (Katsube et al., 1996; Katsube and Williamson,1998). Such kH values, if existing in the BMB, should be sufficient to generate gas hydrate seals.

Conclusions

The nature of the six types of seals identified in the BMB is totally dependent upon their formations texture characteristics. Well compacted clay-rich formations are generally expected to be good seals with clay-poor formations being considered poor seals. However, this paper discusses cases where a certain content and combination of large and smaller grains can contribute to creating a relatively good seal. Therefore, it is essential that a good understanding of the texture effect on seal characteristics be developed, besides development of field methods to detect these characteristics. This understanding is also essential for predicting and detecting possible leakage mechanisms in tight low kH formations. The burial and exhumation history of these formations is also essential for this purpose. Although the several shallow seals included in the six types stated above are unlikely to have good integrity, they can be sufficient to assist development of good gas hydrate seals that are significant for a limited period of time.

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