Interpretation of Gas Seepage on Seismic Data: Example from Malaysian offshore

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Abstract: Gas seepage is one of the geological hazard in the subsurface exploration. Migration of gas usually originated from the deeper reservoir due to poor sealing properties of the cap-rock as well as existence of faults or fractures within the reservoir. In order for us to get familiar with the existence of gas seepage on seismic data, we need to know their characteristics and how do they look like. This paper present several features of gas seepages as viewed on seismic data and how to straight away recognize them at the first time viewing the data. Detailed observation of the seismic data affected by gas leakage shows that the top of the gas leakage always exhibit bright amplitude with notable wipe-out zone within the gas chamber. The seismic reflections within the gas seepage also gives chaotic reflection and give difficulties in interpreting the structure within the gas seepage. Use of seismic attributes in characterizing the gas seepage is also presented in this paper as an aid to improve the interpretation in the area/zone affected by the seepage.

Keywords: Gas seepage, seismic interpretation, seismic attributes, seismic anomalies, wipe-out zone

1. Introduction

Hydrocarbon leakage particularly gas seepage from the deeper reservoir is a common occurrence in most of the hydrocarbon producing basins all over the world such as in the North Sea Basins [1], Timor Sea Basin [2], Malay Basin [3] and Australian Basin [4]. The existence of hydrocarbon leakage in the rock formations had become an indication that there is a larger hydrocarbon reservoir sitting quietly underneath all the formations, waiting to be explored. However, before we can reach the bigger reservoir underneath this seepage, we have to be extra careful in managing the field with the hydrocarbon seepage. This is because, the seepage is also considered as a geological hazard especially while drilling the wells and placement of the rig, Apart from that, this hydrocarbon seepage is also an obstacle for the geophysicists to correctly process and interpret the seismic data due to the acoustic blanking appearance created by the seepage. Hydrocarbon seepage may be studied for several different reasons. In this paper, the authors present the characteristics and representation of hydrocarbon leakage, with emphasis on the gas seepage as observed on the seismic data. The example of seismic data used in this paper is from a producing hydrocarbon field from clastic reservoir in the Malay Basin, offshore Malaysia.

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2. Representation of Gas Seepages on Seismic Data

Gas seepage on seismic data is categorized as a seismic anomaly, which means it brings interruption to the data as shown in Figure 1. According to [5], poor illumination of seismic data with gas seepages is a result of scattering, attenuation and decrease in velocity of compressional waves (P-waves) passing through the gas-effected zone. Løseth, et al. [6] had introduced a simple three steps workflow to interpret any hydrocarbon leakage on the seismic data, which are observed, described and finally mapped the leakages. Observation and description of the gas seepage on the seismic data required the interpreters to know the characteristics of these seepages. The gas anomalies on seismic data are variable in sizes and shapes but usually show the same seismic characteristics such as chaotic reflection, poor amplitude within the gas seepages and low velocity zone.

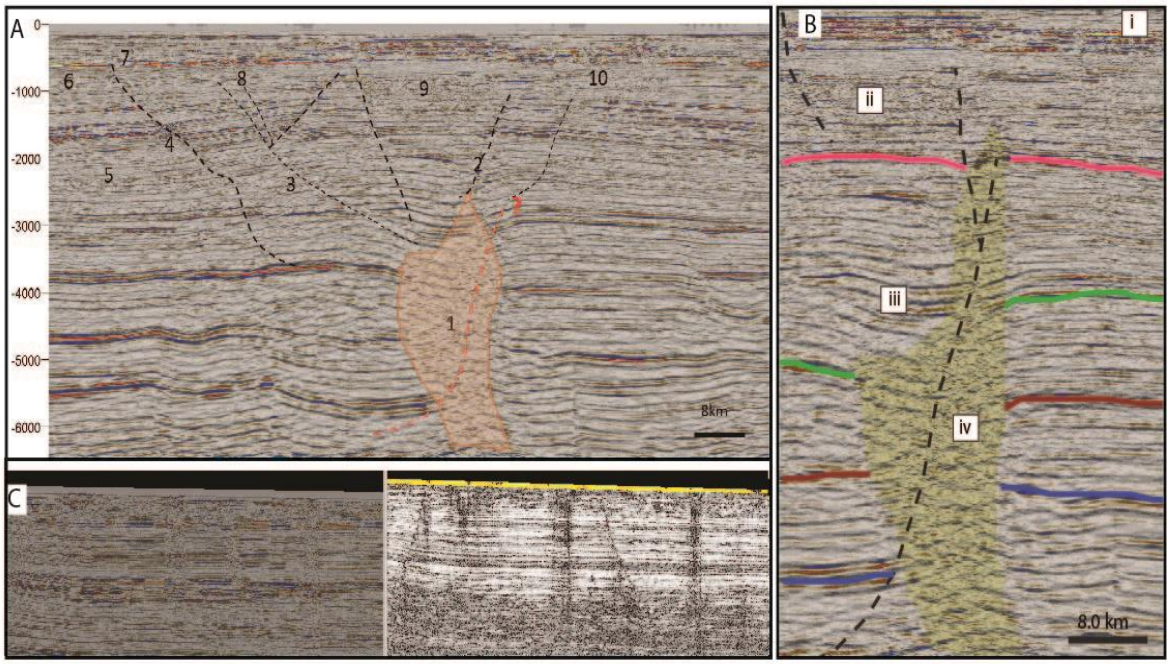

Figure 1: A) Labelling of Gas seepages (1-10) observed on the seismic data used in this study with Seepage-1 being the largest seepage and blanking the area of about 10-15km wide and 8.0km deep. A major fault is interpreted to be responsible for the migration of the gas from deeper reservoir based on the notable displacements of the horizons. Seepage 2-10 are randomly distribute all over the seismic section particularly on the shallow part of the data with some interactions with faults. B) Zoomed Section from Figure 1A (rectangle) summarized the characteristics of gas seepage on seismic data. i: High Amplitude (Direct Hydrocarbon Indicator (DHI)) at top of the seepage; ii: Chaotic, blurry with sand papery look that dimmed the reflection; iii: Time-sag (push down effect); iv: Acoustic Blanking (vertical wipe-out zone). C) Shallow section of the data, viewed on original amplitude and variance attributes. Variance attribute can clearly locate the location of the faults and gas seepages associated with it.

In this work, we had interpreted ten individual gas seepages (Figure 1) that are variable in shapes and sizes but show typical seismic features such as *wipe-out zone (acoustic blanking)* for larger gas seepage, *vertical dimmed zone, high amplitude (bright spot/flat spot) at the top* of the seepages, *low continuity reflector* within the effected zone, *chaotic reflection pattern with sand-paper look* and *local depression or time-sag (push down effect).* The gas seepage can be divided into two groups, either they are migrated seepage through structural deformation in the rock formation or localized gas seepage. The summary of our interpretation is presented in Table 1.

Gas that seeps out from the reservoir can create physical deformation in the sedimentary layering. This usually takes place in soft-sediments and mostly associated with formation of fractures. The physical deformation can be characterized as either *pockmarks or craters* (Figure 2). Pockmarks are depression observed on the shallow sea-bed with few metres to tens of metres deep, within soft, fine-grained sea-bed sediments, produced by the outbreak of fluid or gas into the water column [7]. Craters, on the other hand are larger circular sea-bed depressions that may take up to few hundreds of metres in radius and several metres deep, and usually occurs in relation to the formation of faults and fractures**.** Pockmarks and craters are two common examples of gas seepage representation on the seismic data used in this research as presented on Figure 2.

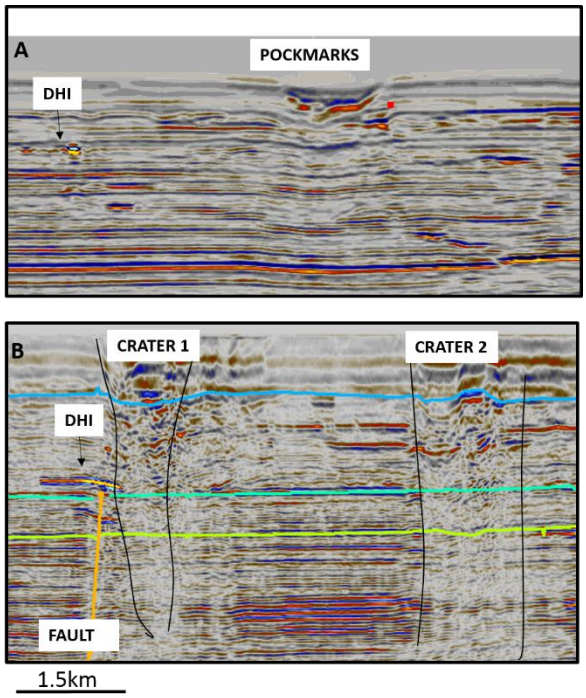

Figure 2: A) Example of sea-bed depression or pockmark. This depression is about 1.25km wide and 17m deep with circular, bowl shape structure on cross-section. B) Example of craters associated with fault at shallow section of the data. Crater 1: 1.484km deep, 700m wide. Crater 2: 1.5km deep, 1.2km wide. Depth is measured from the interpreted surface that originated the gas to the top (high amplitude) of the gas seepage.

Another characteristic of a gas seepage zone is the amplitude anomalies. First amplitude anomaly is the bright amplitude as *Direct Hydrocarbon Indicator (DHI)* in the cap rock of the gas seepage zone (Figure 1 and 2). The bright amplitude usually captures the attention of the interpreters if it is properly sealed. However, in the case of hydrocarbon seepage zone, this type of high amplitude anomaly is located above pressured hydrocarbon (in our case-gas) accumulations, without any structural deformation within the sealing rock. Bright Spot or DHI associated with gas seepage might be due to the continuous gas saturations below a porosity and/or permeability boundary in the rock formations as explained by Løseth, et al. [6]. Second amplitude anomaly for gas seepage zone is *acoustic blanking* in sediments affected by the gas effected area. Acoustic blanking can be said as an area where the seismic data is loss (wipe-out) due to very poor reflection and scattering of the seismic wave.

A large gas cloud originated from the deeper part of the reservoir can be clearly observed and interpreted in this study. This gas seepage is hereby labelled as Seepage-1 (Figure 1 and Table 1). It gives an acoustic blanking and had camouflaged all the seismic reflection within the gas seepage, thus resulting in difficulties in interpreting the continuity of the stratigraphic layering in this section, as well as projecting is there any structural deformation within the affected zone. Many researchers [8, 9] had proven that, to improve the interpretation in a gas seepages area, application of seismic attributes such as coherency and relative acoustic impedance are extremely useful. In this study, we had compared the original amplitude data with Variance-Coherence, Chaos and Structural Dip Attributes to delineate more information about the seepages. Each attribute's algorithm is computed differently to serve for different interpretation and imaging targets.

3. Seismic Attributes on Gas Seepage

Due to poor amplitude within the gas seepage zone, we had first viewed our seismic data using Variance-Coherence attribute that works based on the continuity of the seismic wavelet. A highly coherence reflector reflects the wavelet continuity, thus low coherency zone on the data indicate poor continuity in the wavelet. Variance-Coherence attribute had clearly imaged the location of gas craters on our seismic data as seen on Figure 1C and Figure 3. Utilization of this attribute had make it easier for us to see the origin of the gas from the deeper part. Based on Figure 3, Variance and Chaos attributes had allowed us to see the continuity of the sediment layering in the gas seepage zone.

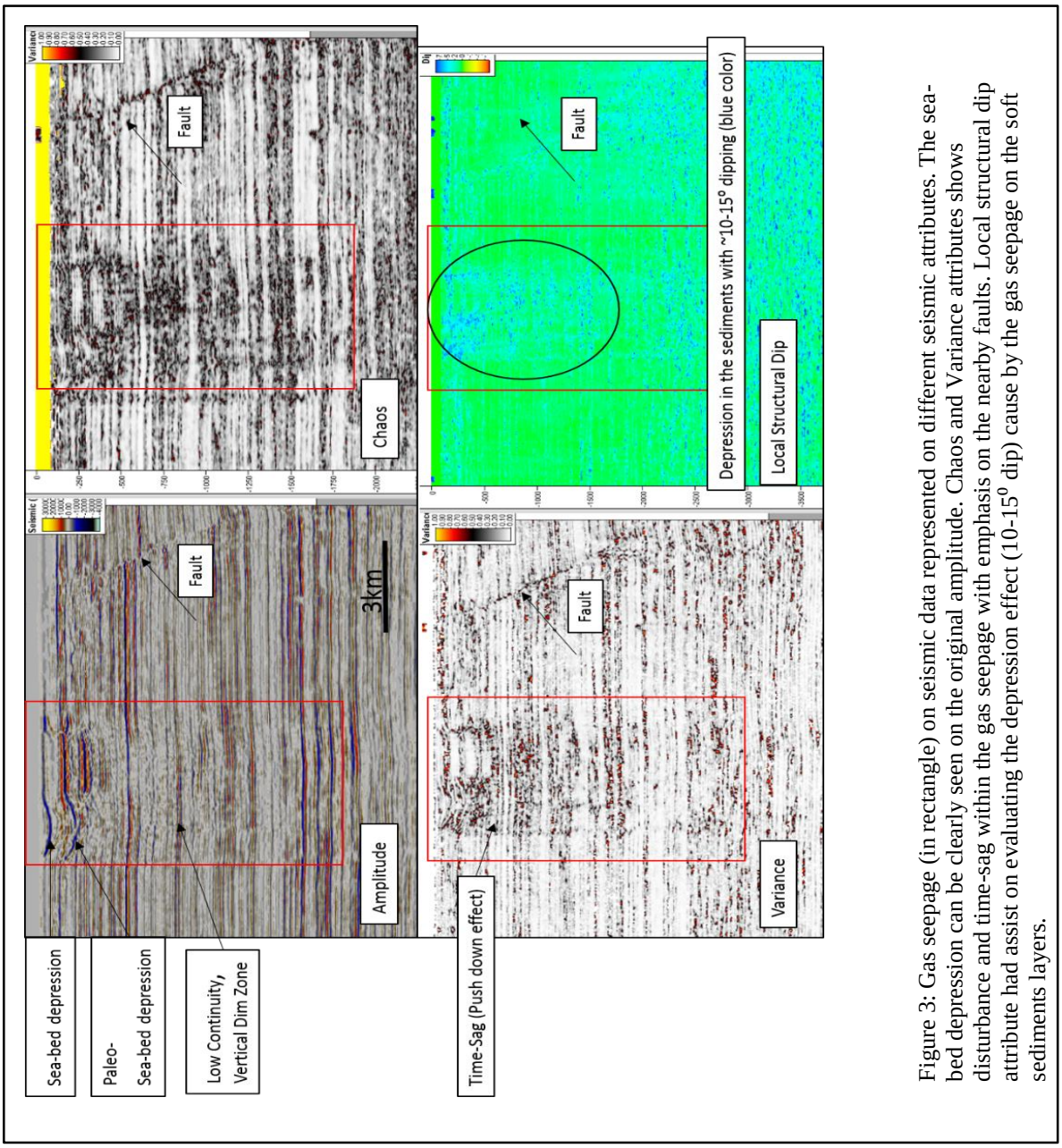

Figure 3: Gas seepage (in rectangle) on seismic data represented on different seismic attributes. The sea-bed depression can be clearly seen on the original amplitude. Chaos and Variance attributes shows disturbance and time-sag within the gas seepage with emphasis on the nearby faults. Local structural dip attribute had assist on evaluating the depression effect (10-15^0 dip) cause by the gas seepage on the soft sediments layers.

Another effective attribute used for analysis in this study is Local Structural Dip attribute. Local Structural Dip is a powerful in capturing properties of the seismic data on the basis for compensating

the value for the dipping events. Since, most of our interpreted gas seepages are related to faulting and fractures, Local Structural Dip had greatly assist us to estimate the degree of permanent depression within the sediments that is effected by the seepage which is more or less 10-15° dipping from the original horizontal bedding.

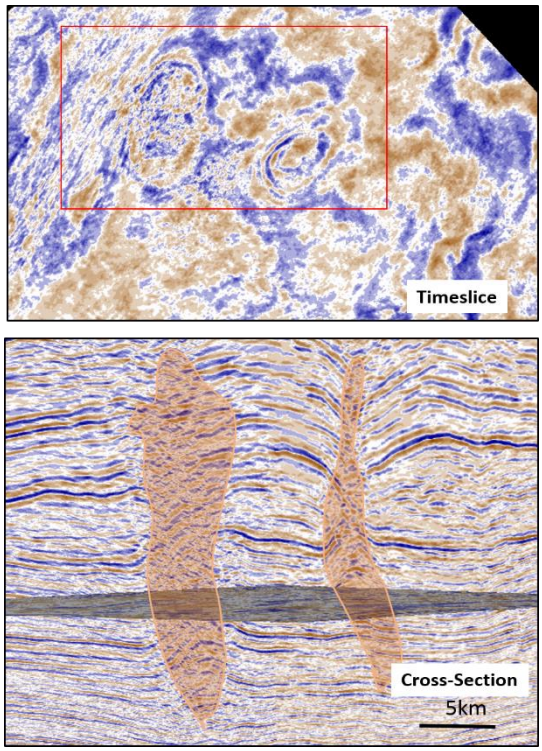

Figure 3: Seismic expression of vertical-wipe out zone caused by gas-pipe as seen on the cross section in the deeper part of the seismic. These gas-pipes look like circular depression on the time slice, which had gave a permanent disturbance in the rock formations.

In the deeper section of the seismic data, gas seepage are more prominent and easily noticeable without application of any seismic attribute, due to its larger size and loss of the amplitude. As shown in Figure 4, the gas seepages in the deeper section of our data are represented by large vertical pipes that wipe out most of the reflections behind them. This is an example of seepages form due to migrated gas from the reservoir sitting underneath. Migration of the gas from the reservoir is common due to tectonic activity in the area that created a path for the hydrocarbon to escape (usually via faults and fractures), together with poor sealing properties in the cap-rock and surrounding rock formations. If we view these vertical gas pipes on the time-slice, it will look as a circular depression which may indicate a prolong impact of gas migrating from the deeper source and voyaging within the sediments.

4. Conclusion and Future Works

Based on this study, detection of gas seepage on seismic data can be characterized based on several features. The observations include amplitude anomalies, which are poor amplitude continuity that leads to vertical wipe out zone/dimmed zone and acoustic blanking in the area covered by the gas and high amplitude anomaly at the top of the leakage zone (known as Direct Hydrocarbon Indicator- DHI). Time-sag or push down effect is another observation that can be seen in the gas seepage area that leads to an image seem like a bowl shape structure. Application of seismic attributes such as Chaos, Variance-Coherence and Local Structural Dip Attribute are helpful in detecting unique responses caused by the gas presence, as well as improved the interpretation in the affected area. We present a summary for all 10 individual seepages interpreted in this work in Table 1 below. Results of this work can be very useful in early stages of seismic interpretation, be it for academic purposes or for field monitoring/development in the industry. In the near future, on surface analogue (outcrop) studies will be conducted to further understand the occurrence of gas seepage within the reservoir and we believed that a gas-seepage model for the clastic reservoir can be developed. This has been proven informative in the study of gas seepage as presented by [10].

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Table 1: Summary of interpreted gas seepages on the seismic data used in this study

Label	Approximate Size	Seismic Characteristics	Fault-Related ?	Remarks
Seepage-1	Wide: 0.5-10.0km Tall: up to 8.0km	Vertical Wipe-out Zone with Acoustic Blanking and Discontinuity Zone; Push-up effects at the edge & Push-down effects within the zone.	Possible fault/fractures related	Largest and most obvious gas seepage in the data. (more likely a cloud of gas) . Migrated Gas from deeper.
Seepage-2	Wide: 2.5-3.0km Tall: ~0.5-1.0km	Dim-Spot, Sand-Paper effects (chaotic), push-down effect	Yes	Related to Seepage-1 through Fault. Migrated Gas.
Seepage-3	Wide: 0.5-2.5km Tall: 0.5-1.0km	Vertical-Dim Zone, chaotic and sand-paper effects	Yes	Migrated from deeper gas seepage through fault
Seepage-4	Wide: 0.5-1.5km Tall: 2.0-3.0km	Bright Spot at the top of the leakage, Low-Continuity	Yes	Migrated from deeper gas seepage through fault
Seepage-5	Smaller seepages distributed laterally	Bright Spot at the top of the leakage, Sand-paper effects	No	Localized seepage within the sediments
Seepage-6	Wide:~2.0km Tall: 1.0km	Vertical dim zone, Low continuity, bright-spot at the top of the leakage, time-sag.	No	A crater with paleo-seabed depression
Seepage-7	Wide: ~1.3km Tall:2.0km	Vertical dim zone, Low continuity, bright-spot at the top of the leakage, time-sag.	Yes	A crater with paleo-seabed depression
Seepage-8	Wide:~1.5km Tall:~3.0km	Bright Spot at the top of the leakage, Sand-paper effects.	Yes	Migrated from deeper gas seepage through fault
Seepage-9	Smaller seepages distributed laterally	Laterally low-continuity zone, Lateral-dimmed zone with acoustic blanking and bright spot at the top of the leakage	No	Localized Gas seepage
Seepage-10	Smaller seepages distributed laterally	Lateral-dimmed zone with bright spot at the top of the leakage	No	Localized Gas seepage

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