

PS Fluid Venting Structures of the Lower Congo Basin on 3-D Seismic: Gas Flux Variations Recorded by the Vertical Evolution of Pockmarks and Associated Amplitudes Anomalies*

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Abstract

In the Neogene of the oil and gas-bearing Lower Congo Basin, a number of venting structures such as acoustic pipes, pockmarks and amplitude anomalies are observed in 3-D high-resolution seismic data. Positive high amplitude anomalies (PHAs) associated with pockmarks or acoustic pipes have recently started to be studied by seismic interpreters. These PHAs in our study area often occur either at the top of acoustic 'pull-up' pipes or at pockmark bases or surrounded the lower part of pockmarks.

Their high positive amplitude indicates that they correspond to higher impedance material than the background sediments. In addition, seismic pull-up effects under the PHAs show that they correspond to high velocity material. Combined with the local character of the anomalies in the fine-grained clastic environment of the Neogene interval in this basin, PHAs are interpreted as seep carbonates, possibly associated with gas hydrates in some cases.

Methanogenic carbonates can form either at the seafloor or in the sulfate methane transition zone (SMTZ), a few tens of meters below at the maximum. Below the surface, they mostly result from anaerobic oxidation of methane (AOM), while at the seafloor they may result from AOM or from the development of chemosynthetic communities. Fluid leakage at the seabed can be indicated directly by pipes, pockmarks and PHAs. Among these indicators, only PHAs are diagnostic of methane gas.

The fact that PHAs form close to the seafloor (within the limits of SMTZ) means that their vertical successions reflect their temporal evolutions. The size, number and morphology of the PHAs are interpreted to reflect the relative quantities of escaped methane. In combination

with the presence of pockmarks and pipes associated with vertical successions of PHAAs on seismic, the dynamics of fluid expulsions and the flux rate variations over time can be determined.

The rules used in our interpretation were derived from the framework previously established by other authors. Linear PHAAs without pockmarks or depressions were observed above faults. This type of linear PHAAs characterizes relatively slow fluid seeps. Sub-circular PHAAs hosted within depressions. This succession in time indicates that relatively moderate flux rates at the venting site changed lately to faster rates until they reached the eruption threshold, making the final crater.

Thus, regional fluid flux stories can be reconstructed by studying these venting indicators.

Fluid venting structures of the Lower Congo Basin on 3-D seismic: gas flux variations recorded by the vertical evolution of pockmarks and associated amplitudes anomalies

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1. Abstract

The Neogene succession of the oil and gas-bearing Lower Congo Basin contains a number of venting structures such as acoustic pipes, pockmarks and amplitude anomalies which are observed in 3-D high resolution seismic data.

Positive high amplitude anomalies (PHAs) associated with pockmarks or acoustic pipes have recently become the focus of many studies. These PHAs in the study area presented here, occur either at the top of acoustic 'pull-up' pipes, or at the base of pockmarks.

Their high, positive amplitudes relative to laterally equivalent sediments indicates a localized increase in acoustic impedance. In addition, seismic pull-up effects below the PHAs show that they correspond to a material with higher internal velocity. Combined with the very local character of the anomalies in the fine-grained clastic environment of the Neogene interval in this basin, PHAs are interpreted as seep carbonates, possibly associated with gas hydrates.

Methanogenic carbonates can form either at the seafloor or in the sulfate methane transition zone (SMTZ), which occur a few tens of meters below the maximum. Below the seafloor, they mostly result from anaerobic oxidation of methane (AOM), while at the seafloor they may result from AOM or from the development of chemosynthetic communities. Fluid leakage at the seabed can be indicated directly by pipes, pockmarks and also PHAs. Among these indicators only PHAs are diagnostic of methane gas.

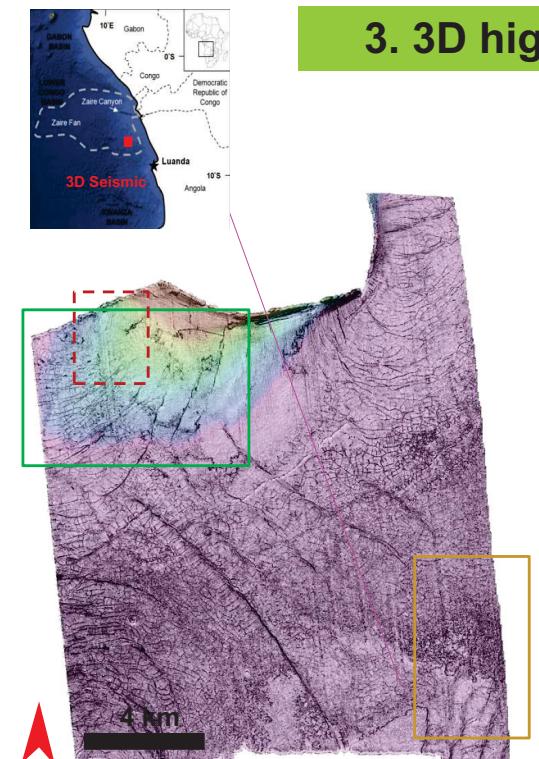
The fact that PHAs form close to the seafloor (within the limits of SMTZ) means that a vertical succession of PHAs could reflect a prolonged phase of venting. The size, number and morphology of the PHAs are interpreted to reflect relative quantities of methane escape. In combination with the presence of pockmarks and pipes associated with vertical successions of PHAs on seismic, the dynamics of fluid expulsion and the flux rate variations over time can be estimated.

The workflow used in the analysis presented here were derived from a framework previously established by several authors.

Linear PHAs without pockmarks or depressions were observed above faults. This type of linear PHAs characterizes relatively slow fluid seeps. Sub-circular PHAs are hosted within depressions. This succession records the following variations in flux rate. An initial moderate rate of flux which increased in more recent times until a eruption threshold was reached and a crater was created. Using these principles regional fluid flux rates can be reconstructed.

2. Research objective

- To establish if different types of venting structures are indicative of episodes of different, relative flux rates
- To develop a method to analyse the dynamics of palaeo-fluid venting from the spatial distribution of seismic anomalies
- To reconstruct the history of fluid flow from the evolution of venting structures
- To present and describe new types of fluid venting structures
- To understand the evolution of fluid venting structures into pockmarks, and how their infill geometries are influenced by the changes in venting rate over time
- In addition to these objectives the poster focuses on Positive High Amplitude Anomalies (PHAA) that occur at (palaeo) seep locations which are characterized by pockmarks, shallow depression and seismic chimneys

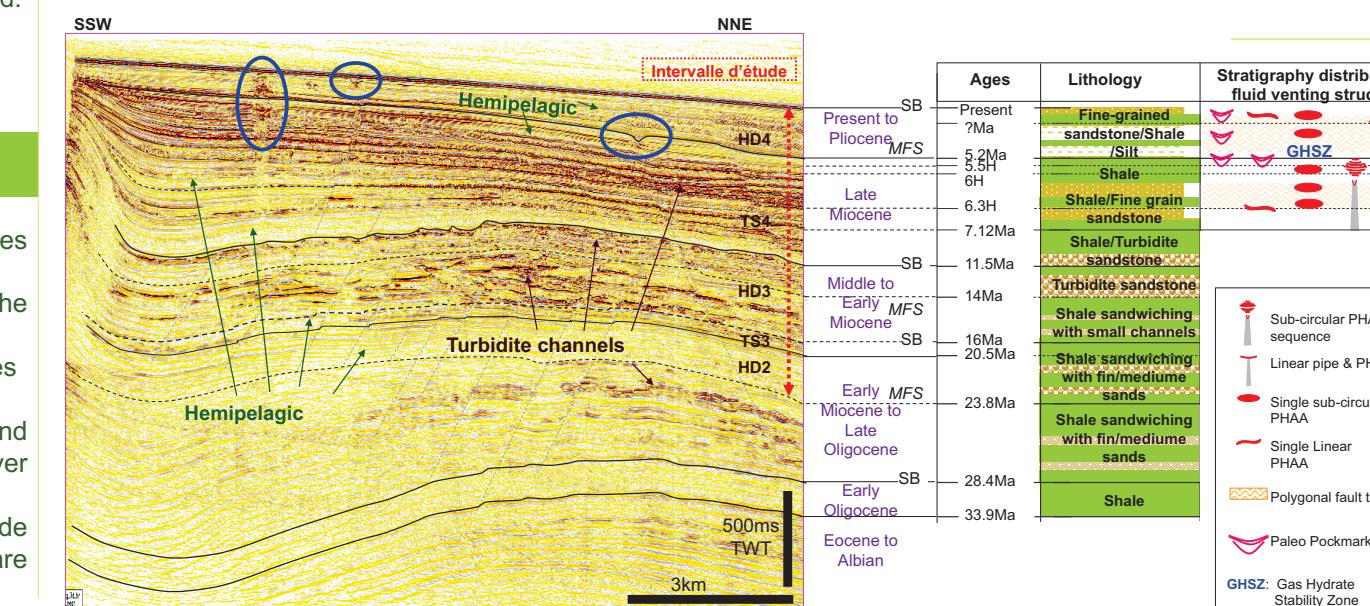


3. 3D high resolution seismic survey

The study area is located in the Lower Congo Basin. The basin formed in the Late Jurassic – Early Cretaceous rifting during the break up of Western Gondwana and opening of the South Atlantic. (Larson and Ladd 1973; Mascle, 1972). Following rifting, a thick sequence of evaporites were deposited in the Aptian. The Late Cretaceous and Cenozoic aged strata comprising mainly siliciclastic sediments (Serrane et al., 2005), have been heavily deformed as a result of gravity driven salt tectonics (Liro & Dawson, 2000; Lavier et al., 2001). This deformation is typical of that on passive margins in which gravity gliding drove halokinesis (Cramez & Jackson, 2000). The study area is located in the transitional zone containing typical salt structures such as vertical salt stocks and elongate salt walls (Lavier et al., 2001). The post-Eocene sediments are also deformed by a layer-bound array of polygonal faults (Gay et al., 2006).

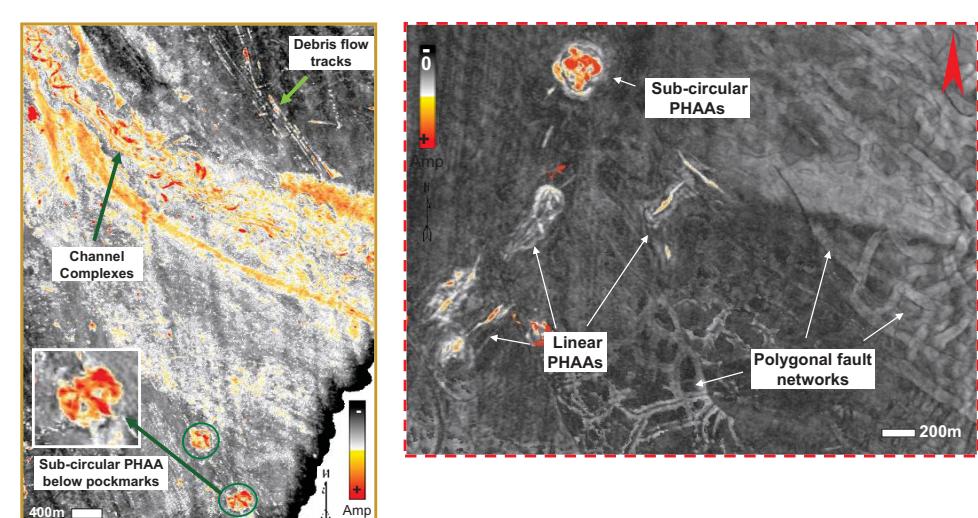
4. Stratigraphy

- The study area is located in water depths of 800-1200 m
- The interval of interest is the post Early Miocene sedimentary succession
- The succession comprises hemipelagic fine-grained clastic sediments (Vignau et al., 2000)
- Fine-grained turbidite channel complexes occur within well bedded hemipelagic units, The later are cemented by clay in parts (Vignau et al., 2000)
- The shallow stratigraphy is deformed by a layer-bound array of polygonal faults. (Gay et al., 2006)
- Salt-related faults intersect Miocene aged reservoirs consisting of turbidite channels and silty, clay-dominated seals
- Fluid venting structures occur mainly in the interval in the post Late Miocene stratigraphy

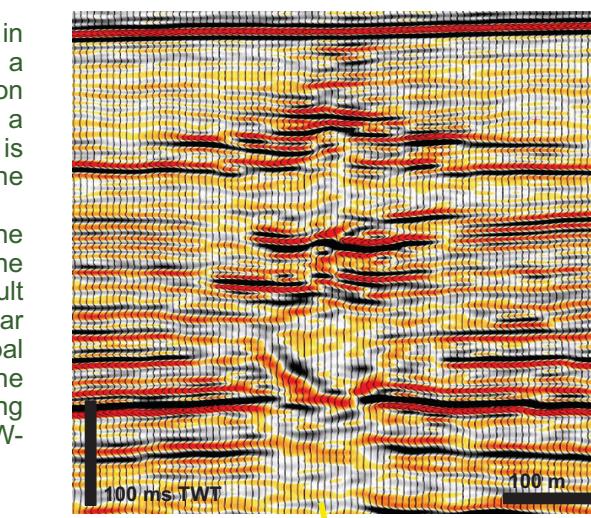


5. Positive High Amplitude Anomaly (PHAA) in seismic

- Linear PHAA**
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- Sub-circular PHAA**
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- Two types of PHAs: linear and circular
 - PHAs are expressed by peaks (red positive wavelet) above troughs (black negative wavelet), it suggests they correspond to geological interfaces that are seismically hard (Coffeen, 1978)
 - Pull-up effects are associated with PHAs, which indicate high velocity material (Hustoft et al., 2007)
 - Therefore PHAs indicate materials have relative higher velocity and density thus it has strong impedance
 - The plan form geometry of PHAs are comparable with that of associated depressions
 - The depth of depression range from 5 – 7 ms (= 3 – 5 m)
 - PHAs are very localised features and therefore unlikely related to turbidite sands
 - PHAs are organised into a stacked-up, vertical succession which are linked with regional faults

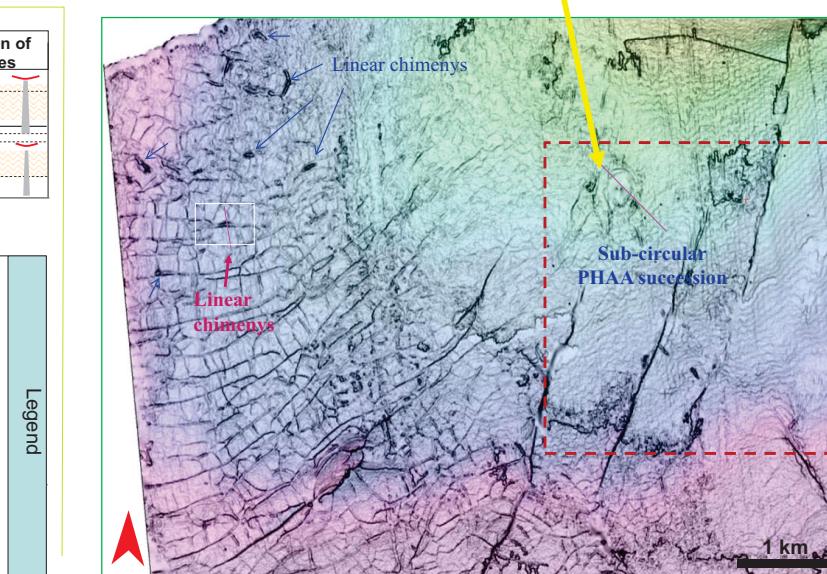


Upper left) 20 ms thick amplitude window of within the late Miocene sediment, shows positive high amplitude anomalies are distinguished from other high amplitude "sedimentary deposits".
Upper right) 20 ms thick amplitude window above the top boundary of polygonal fault tier shows linear PHAs follow the trend of polygonal faults.



Right) A seismic section in wiggle display showing a vertically stacked up succession of circular PHAs above a regional fault (location is shown by the pink line on the horizon dip map below).

Below) Dip horizon of the polygonal fault tier base. The venting structures occur at fault locations, in particular linear PHAs follow the principal polygonal fault network. The latter are orientated in following the main faults direction (NW-SE).



6. Interpretation of PHAs

Diagnostics features for regarding methane-related carbonates as the origin of PHAs

- Isolated shapes suggest local development
- Pull-up seismic effects suggest high velocity material
- Positive high amplitude anomalies suggest seismically harder material
- High velocity & seismically harder materials suggest are not typical of fine-grained clastic sediment
- Linear and circular, shallow depressions suggest slow and moderate fluid expulsion
- Preferred orientations parallel to dominant polygon could imply that faults provide fluid migration pathways
- "Softer" background sediments which are silt and shale in this area are thus not consistent with seismically harder material
- So: PHAs are interpreted as fluid related geological features, the methane-related carbonates or gas hydrates
- Methane-related carbonates and gas hydrates occur at present day seabed in Low-Congo basin (Charlou et al., 2004; Ondreas et al., 2005; Pierre & Fouquet, 2007)
- MDAC without seismic calibration were found in a drill location here, in clay rich facies (hemipelagic or muddy turbidite deposits; Vignau et al., 2000)

6.1. Methane-Derived Authigenic Carbonate (MDAC)

MDAC results from Anaerobic Methane Oxidation (AMO) + Calcite precipitation (Regnier et al., 2011):

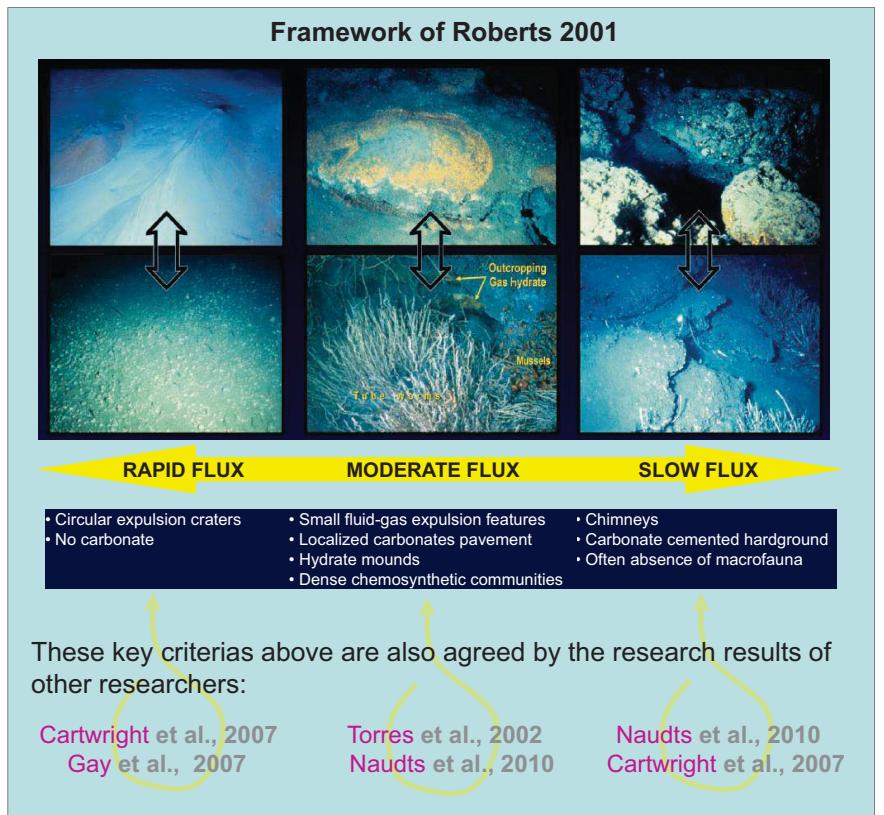


Reactions take place in the Sulphate–Methane Transition Zone (SMTZ): <1 cm to 10s m below the seafloor = Indicator of methane escaping at paleo seabed

PHAs = Methane-related carbonates and/or gas hydrates + Seismic pull up effects association
BSR
PHAs = Methane-related carbonate



6.2. Relationship between methanogenic carbonates and fluid fluxes



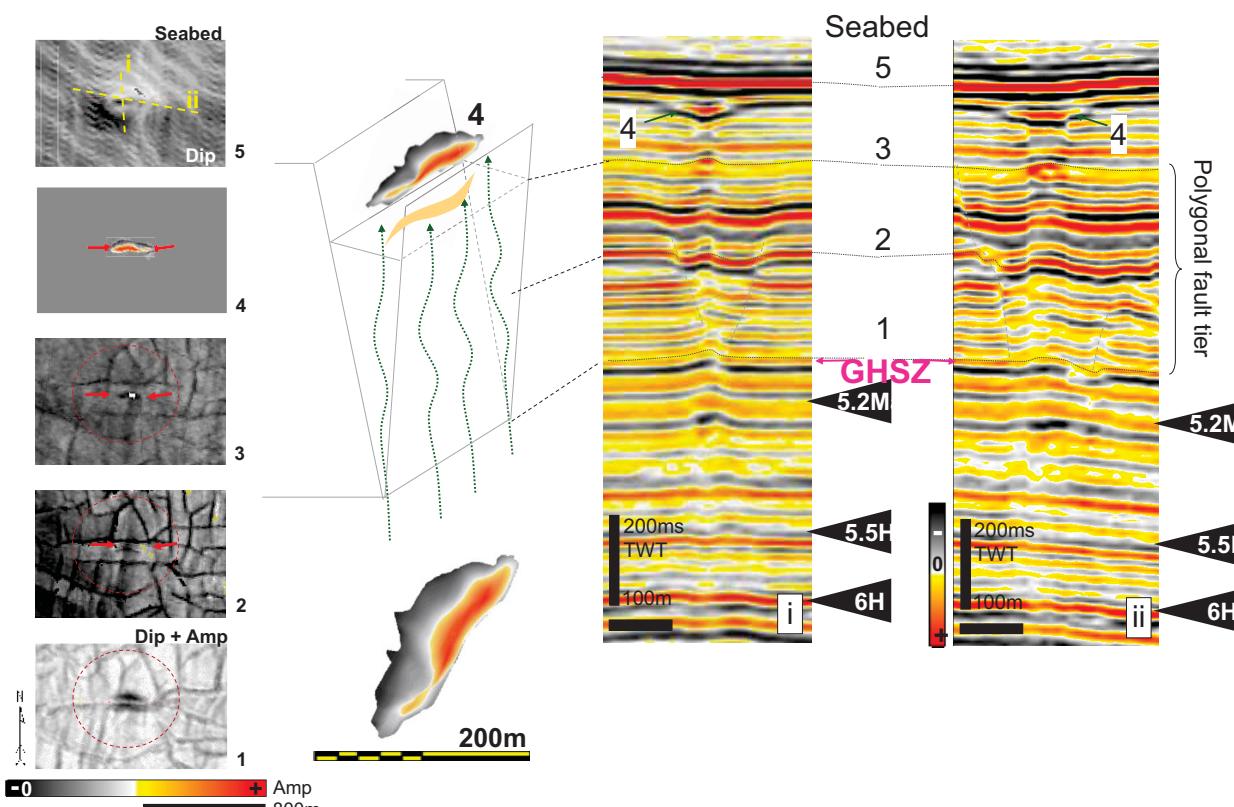
This framework is used in this study for the interpretation of fluid venting structures.

6.3. Slow vent

Linear PHAAs

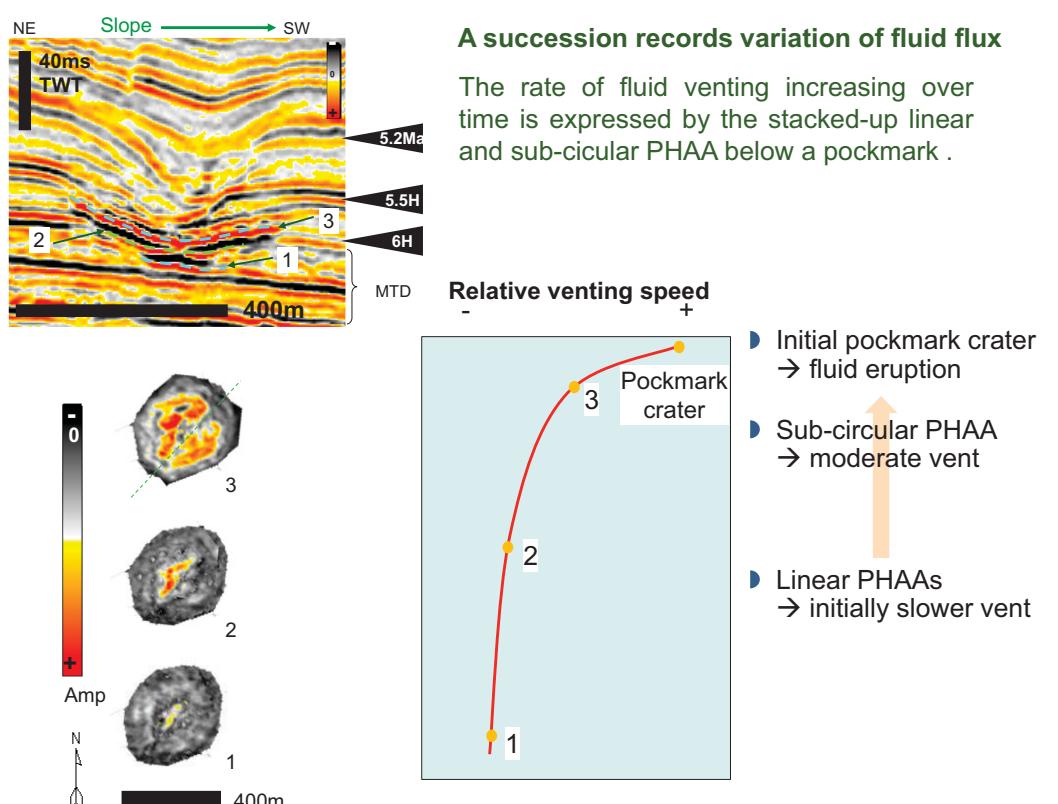
They occur mainly within well-bedded sediments that overlay the polygonal fault tier to within 40 ms of the seabed (reflection 3). They have the same orientation as the polygonal fault at the bottom of the fault tier and are often associated with elliptical depressions at the seabed. Their associated elliptical depressions have diameters ranging from 200 to 300 m.

The individual linear PHAAs: These are expressed by a single, high amplitude reflection with shallow negative reliefs on seismic sections (reflection 4). They have the same trend as principal polygonal faults below, and frequently have similar orientations to tectonic faults to which they are often linked with.



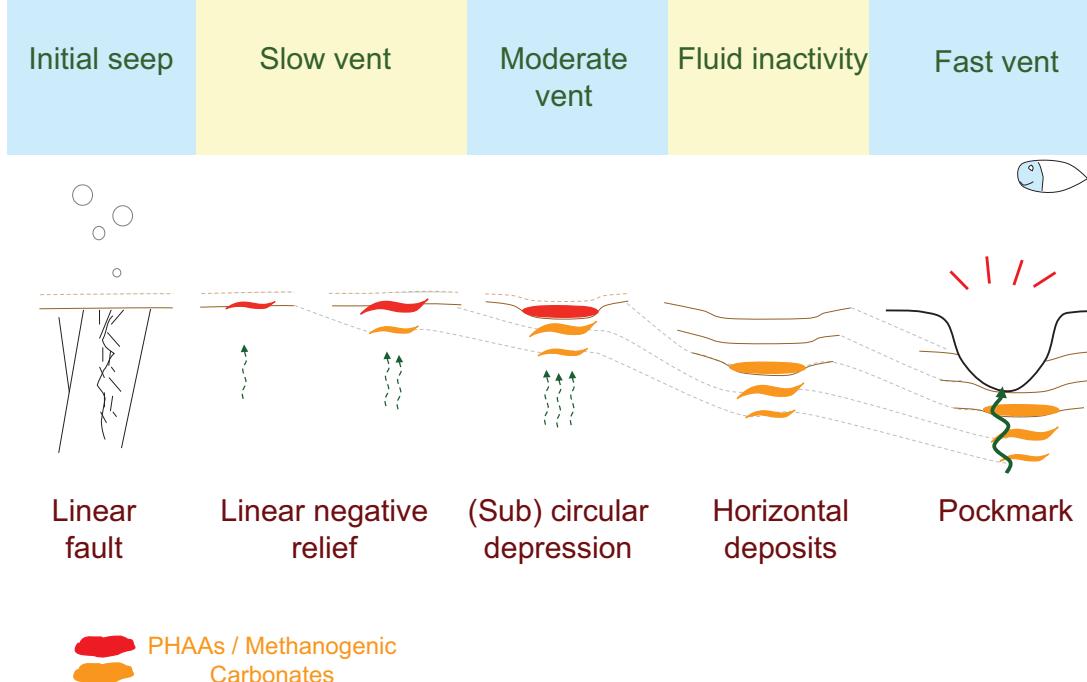
Upper) Seismic section shows an isolated linear PHAA at the top of a seismic chimney, which affected by pull-up effect and developed vertically through the middle of a graben of a polygonal fault tier.

6.5. Slow to Moderate to Fast vent



7. Conceptual model

The evolution of a compositional vertical succession of venting structures



Summary

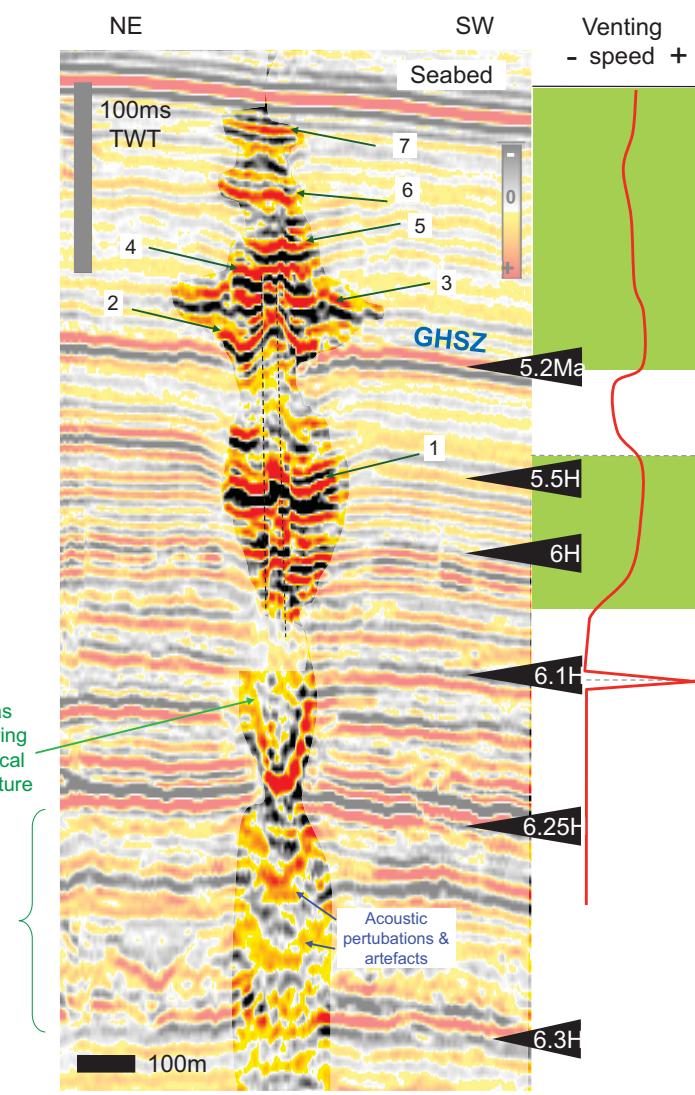
The genetic relationship between chimney structures, PHAAs, pockmarks is brought out, through studying their geometric and morphologic on seismic, and in integrating the interpretation of amplitude variations.

- PHAAs are interpreted as hard layers that we interpret as methanogenic carbonates, which may also contain gas hydrate in specific cases
- Thin layers of carbonate and the presence of gas hydrate in seep points are likely to give sufficient velocity anomalies to result in a pull-up effect. This is interpreted to include even thin accumulations of carbonate deposits below vertical seismic resolution
- Sub-circular PHAAs are associated with sub-circular depressions, while linear PHAAs associate with the linear conduits
- The reflections which contain PHAAs represent a datum close to the near water-sediment interface because methanogenic carbonates only occur in shallow sediments near water-sediment interface or at the seabed, according to the depth of SMTZ
- The depth of PHAAs, within or beyond the sulphate reduction zone is the key criteria used to differentiate between fossil and active episodes of seepage
- The dynamics of fluid expulsion is expressed by the venting structures and by the geometries of associated PHAAs and supports the model of Roberts et al. (2006)
- Linear conduits and PHAAs presenting with linear negative relief indicate slow rates of venting
- Sub-circular PHAAs within shallow depressions are interpreted as the expression of moderate rates of venting and potentially signify the stage before the development of pockmarks
- Linear conduits and PHAAs are observed at fault locations for all cases which leads us to hypothesise that fluid migrates through faults from the deeper sources thus implying a thermogenic origin for the methane
- PHAAs which terminate in pockmarks and craters suggest an increase of methane flux over time which changes from a moderate to a faster rate of venting

6.4. Moderate vent

Stacked up sub-circular PHAA succession

- The stacked up, circular PHAAs are associated with circular, shallow depressions indicate moderate seepage
- Venting dynamics are moderate and great enough to induce shallow depressions instead of creating a crater (Roberts, 2001)
- Their size variations are interpreted to represent qualitatively, the variations in the volume of methane evacuated to the palaeo seabed
- Fast fluid eruptions are expressed by pockmarks (6.1H)
- Venting restarted and ceased between the interval of after 6.1H and before 5.2Ma. It was indicated by a disappearance and a re-appearance of PHAAs after 6.1H, with the PHAAs sizes increasing then decreasing upward, until a second disappearance of PHAAs before 5.2Ma
- From 5.2Ma to present time fluid flux was became active and fluctuated till present day.
- This is demonstrated by the PHAAs that increase and decrease in size



Upper right) A seismic cross section shows a series of circular PHAAs stacked up above a pockmark crater and on trend with a deep seated fault. Upper left) 3D amplitude horizons of this vertical success show sub-circular PHAAs. Shallow depressions (depth ca. 2ms TWT) have been observed along the strike of these PHAAs.

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