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The control of palaeo-topography in the preservation of shallow gas accumulation: Examples from Brazil, Argentina and South Africa

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ABSTRACT

Acoustic anomalies in seismic records have revealed that gas-charged sediments are very common features in the coastal environments around the world. The ubiquitous gassy sediments challenge the effective acoustic mapping of shallow stratigraphy by seismic means, as well as having an important influence on environmental issues related to the coastal zone occupation and management. This paper documents examples of gassy sediments from coastal lagoons, estuaries, rivers, bays and the inner shelf and nearshore environments of Brazil, Argentina and South Africa. Seismic echograms from selected areas show several gas-related anomalies, which present distinctive morphologies for sediment-trapped gas, leaking or free gas discharge into the water column. In several places the gas-charged sediments occur in areas of palaeo-topographic lows related to fluvial channels and valleys that developed in the coastal zone due to sea level oscillations during the Quaternary period. This forcing by palaeo-topographic features results in the occurrence of shallow gas being controlled in most coastal sites by the previous environmental scenario, the stratigraphic arrangement of the transgressive infilling elements, and the local hydrodynamic conditions.

1. Introduction

Gas accumulations in shallow shelf and coastal sediments are a common phenomenon worldwide (Park et al., 1991; Karisiddaiah et al., 1992; Papatheodorou et al., 1993; Garcia-Garcia et al., 1999, 2007; Okyar and Ediger, 1999; Fleischer et al., 2001; Missiaen et al., 2002; Garcia-Gill, 2003), the origins of which may be either biogenic (Kaplan, 1974) or thermogenic (Lee et al., 2005) in nature. The various gas sources and modes of accumulation are closely related to the sedimentary and evolutionary processes occurring in the coastal depositional environment (Garcia-Gil et al., 2002). Transgressive and regressive sea level fluctuations can produce dramatic changes in depositional environments and coastal physiography, sedimentation rates and sediment type. As a consequence, the distribution of organic matter and its quantity can vary considerably based on the coastal response to sea level fluctuations. Sandy packages may form gas reservoirs, while the finer, mainly muddy sediments may form sealing layers. Gas features can be

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formed in various types of environments, like shallow or enclosed seas and continental shelves (Emeis et al., 2004), lakes (Lafferty et al., 2006), bays (Jensen and Bennike, 2009) and rías (Garcia-Gil et al., 2002; Diez et al., 2007; Duarte et al., 2007; Iglesias and Garcia-Gil, 2007), since these sites provide favorable conditions for gas formation due the local high biological productivity of such environments. Ultimately the various gas reservoir and trapping sites, together with their associated types of gas accumulation, may provide windows into the evolution of the coastal and shallow marine environment (Garcia-Gil et al., 2002).

The presence of gas in sediments is especially well detected by high-resolution seismic surveying due to the change of speed of the acoustic wave between media with and without gas. The higher the speed gradient between the media, the stronger the echo response that will be generated by the variation of acoustic impedance between them. The intensity of the reflected acoustic signal recorded in the seismic profiles can be related to the concentration of gas bubbles occurring in the sedimentary package (Judd and Hovland, 1992; Aliotta et al., 2009). In echograms the gas structures may display various features comprising blankets/blanking, curtains, columns, acoustic turbidity zones, pinnacles, intra-sedimentary plumes and others, according to their seismic signature (Garcia-Gil et al., 2002; Frazão and Vital, 2007). Leak features are similarly common and occur as plumes and pockmarks, amongst other features (Garcia-Gil et al., 2002).

Gas is generated in the sediments and normally slowly released to the atmosphere and such total contribution to the global budget is poorly constrained (Judd, 2004). Further, gassy sediments may represent risks to engineering works and terrain stability (Premchitt et al., 1992). This paper thus aims to describe and discuss the various gas features found in shallow marine and coastal environments from a number of sites in the Southern Hemisphere. Diverse settings in Brazil, Argentina and South Africa are reported on, and several examples of gas-induced acoustic anomalies in echograms are shown. By comparing and contrasting the styles of gas accumulation and leakage in such diverse systems and settings, we hope to add to what is known concerning the controls on the accumulation and distribution of gas in coastal marine sediments.

2. Shallow gas accumulation signatures

Anomalous acoustic reflection responses observed in gas accumulations are related to the amount of gas concentration in the sediments. The acoustic turbidity is a phenomenon caused by diffusion of acoustic energy due to gas bubbles trapped in the sediments (Hart and Hamilton, 1993). Most of the common acoustic signatures of gas-charged sediments have been recognized in coastal sediments.

The gas occurrences can be described and classified from the echo-character signatures observed in sub-bottom profiles (SBP) and sidescan sonar (SSS) records. Various terms have been used to describe and classify the shallow gas occurrences. There is some overlap of names referring to the classification of different features, with different names for similar accumulations. The following list of gas features is not exhaustive, but summarizes those we have observed in the echograms from the focus regions in this study and the terminology used in this paper.

2.1. Acoustic blanking

In this acoustic phenomenon the seismic reflector below the gas horizon is very weak or absent due the attenuation of the sound wave traveling through the charged sedimentary package (Judd and Hovland, 1992; Orange et al., 2005). The top of the gas occurrence is very reflective, which masks any underlying seismic reflector, thus preventing connection of the trapped gas to the source or the mapping of seismo-depositional architectural elements. This acoustic phenomenon has been also referred to as blankets or acoustic masking (Garcia-Gil et al., 2002; Frazão and Vital, 2007; Mazumdar et al., 2009).

2.2. Gas curtain or pocket gas

A gas accumulation which usually shows a well-defined morphology, in the form of boxes of anomalous seismic reflection with an upper surface well marked by strong, relatively continuous, horizontal or gently dipping top reflectors. The acoustic response below the top reflectors is usually chaotic, masking the underlying sedimentary structures (Weschenfelder et al., 2006, 2014).

2.3. Acoustic turbid zone

A type of gas accumulation in which the acoustic anomaly is characterized by a more irregular and less pronounced top reflector than in zones with gas curtains. The seismic reflectors underlying the top of the gas accumulation are not entirely hidden, allowing the identification and mapping of the sedimentary structures beneath (Judd and Hovland, 1992).

2.4. Gas brightening

This is the phenomenon of brightening sectors of the echogram caused by the increasing contrast of the acoustic speed between zones with minor quantities of gas and gas free strata (Judd and Hovland, 1992; Hart and Hamilton, 1993).

2.5. Acoustic windows

These refer to echogram sectors with strong gas-induced anomalies interspersed with sectors free of such anomalies. These windows occur due to an abrupt lateral change from gas-charged to gas-free sediments (Figueiredo et al., 1996; Costa and Figueiredo, 1998).

2.6. Black shadow

Is marked by several multiples of the surface of the gas, which makes it impossible to identify any structure below it (Baltzer et al., 2005). The multiples are the expression of the reverberation of the seismic energy from the gas-induced extra reflectivity of the upper interface.

2.7. Turbidity pinnacles

A variation of acoustic blanking, which manifests in a downward concave U-shape and obscures any feature below it (Iglesias and Garcia-Gil, 2007; Souza et al., 2011).

Gas leaks or gas seeps have been classified into several types according to their specific echo-character signatures. These are:

2.8. Acoustic plumes

These appear as discrete hyperbolic curves in the water column which are related to free gas bubbles in the water. They are usually associated with zones of acoustic blanking, and represent the exhaust of gas into the water column (Taylor, 1992; Lee et al., 2005; Garcia-Gil et al., 2002; Frazão and Vital, 2007; Diez et al., 2007; Duarte et al., 2007).