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Research paper

Seismic characteristics and distribution of hydrothermal vent complexes in the Cretaceous offshore rift section of the Campos Basin, offshore Brazil

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ABSTRACT

Hydrothermal vents are structures that occur close to volcanically active areas. Their occurrence can have considerable impacts on the evaluation of the oil reserves of a basin. In the Campos Basin, eastern Brazilian continental margin, no hydrothermal vents have been previously recognized and related with magmatic events on seismic sections. This work aims to map the hydrothemal vents, ducts and associated intrusive bodies observed in the rifte section. With the use of 2D seismic data and a well with lithologic information, the occurrence of ten hydrothermal vents and seven ducts were mapped and the interval with volcanic intrusive rocks was characterized. The identification of intrusive rocks in seismic data is given by reflectors with high amplitude and disk or half-moon geometry with abrupt endings. The vent geometries shows dome and eye-shaped types and the ducts are fault-related, downward-tapering cone type. This study highlights new geological elements that can influence the petroleum systems of the Campos Basin, such as the identification of hydrothermal vents in seismic sections and the correlation with regional tectono-magmatic events.

1. Introduction

Hydrothermal vents are complex pipe-like structures, formed by fracturing, transport and eruption of hydrothermal fluids and/or volcaniclastic sediments (Planke et al., 2005). This kind of structure is recognized as a fissure in the earth's surface, bottom of a lake, sea or ocean, from which there is a geothermal heat anomaly produced by water seepage. The hydrothermal vents occur near the locations of volcanic activity, being associated mainly with sill complexes, (e.g. Planke et al. (2005), Hansen (2006), Hansen et al. (2008); Grove (2013)). Recent studies reveal that hydrothermal vents often correlate with fault systems that captured hydrothermal fluids, thus influencing their distribution (Jackson, 2012; Magee et al., 2013). Several studies in sedimentary basins around the world have emphasized the importance of hydrothermal vents as a diagnostic marker for magmatic intrusions, which generate heat in the surrounding rocks and thus change the timing and intensity of hydrocarbon maturation generator by localized heat anomalies (Hansen, 2006; Hansen et al., 2008; Planke et al., 2005; Magee et al., 2013; Alves et al., 2015).

Despite the importance of these features in the analysis of petroleum systems of sedimentary basins, there are few specific studies of hydrothermal vents in the Brazilian South Atlantic continental margin basins. Most of the previous studies have focused on the identification of magmatic events, highlighting the importance of magmatic intrusions and extrusions as possible factors to impact the generation and expulsion of hydrocarbons (Mizusaki et al., 1998; Oreiro, 2006; Thomaz-Filho et al., 2008). The aim of this work is to identify and map hydrothermal vents and ducts and to characterize the intrusive bodies associated with such structures in 2D seismic data, based on methodologies and models proposed by previous works in classic magmatic provinces, particularly in the North Atlantic margins (Planke et al., 2005; Hansen, 2006; Hansen et al., 2008).

These seismic anomalies were recognized during the systematic seismic stratigraphic mapping of depositional units and depositional systems (using seismic facies analysis) of the rift section of Campos Basin. The attribute analysis and correlation with specific

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lithologies in wells inside the study boundary indicated the interpretation as hidrotermal vents as discussed below.

2. Database and workflow

The database used to map the vents comprised 127 seismic lines (from the ANP library) totaling 5955 km regionally spaced, with intervals ranging from 4 to 10 km across an area of 11,900 km^2, located on the central platform of the Campos Basin (Fig. 1). The study here shows a selected number of those 2D lines. The lines proposed are time migrated (PSTM Kirchhoff), zero phase 2-D seismic reflection profiles. The data are represented with a direct polarity (that is downward increase in acoustic impedance corresponds to a positive blue reflection). The dominant frequency of the seismic data varies from 60 Hz (shallow seabed) to 10 Hz with mean values of 20–40 Hz in the target area, around the main vent, depending on the host sedimentary rocks and depth. Data from two wells has been used to constrain relative horizon ages down to the Ealry Cretaceous (Barremian to Neocomian) Lagoa Feia Gp. syn-rift deposits, to depth-convert relevant measurements and obtain the interval velocities for packages of sedimentary strata. The interval velocity of the pre-salt area obtained from the well ranges in values from 2.2 km/s to 4.9 km/s. This implies that locally the data has a limit of separability (controlled by the tuning thickness) varying between 122 and 10 m. The lowest resolution within the carbonate units shows a varying resolution, as intruding different units in the host sedimentary system. Recognition and mapping of the vents was based primarily on the analysis of the seismic stratigraphic relationship of the main units affected by the hydrothermal vent and then on the application of seismic attributes to identify the complex geomorphology by using image processing methods (Taner and Sheriff, 1977). Conventional mapping enabled a robust control on the intrusive bodies, creation of amplitude and attributes maps (Planke et al., 2005). However due to variability of density (rock density ranging from 2000 to 4000 kg/m^3) and velocities (2–4.1 km/s) of the host sedimentary rocks within the pre-salt units (varying from shales, sandstone to carbonate rocks) the contrast between the intrusive vents cannot always be easily recognized through simple amplitude analysis due to a reduced impedance contrast in respect to what is expected in more classical environments (Holford et al., 2012; Magee et al., 2013). The diffractive distortion and lack of continuity within the sedimentary host package surrounding the vent structures can be better highlighted through the combined used of both the amplitude and instantaneous phase attribute, which has been our approach. Recently, Purves (2014) demostrated that phase attributes appear to be sensitive to subtle discontinuities including fluid substitution and pinch-out that are not easily seen in input seismic amplitude data. Instantaneous phase often highlights small reflector breaks and discontinuity of events. So far these methods have been mainly used to map stratigraphical, faults and lithological contacts in 2D and 3D seismic data (*e.g.* Chopra and Marfurt, 2007) but showed effective results in our case. The cosine phase enabled discontinuities between the layers to be highlighted while the instantaneous phase allowed the observation of small-size faults associated with the vents and ducts (Fig. 2).

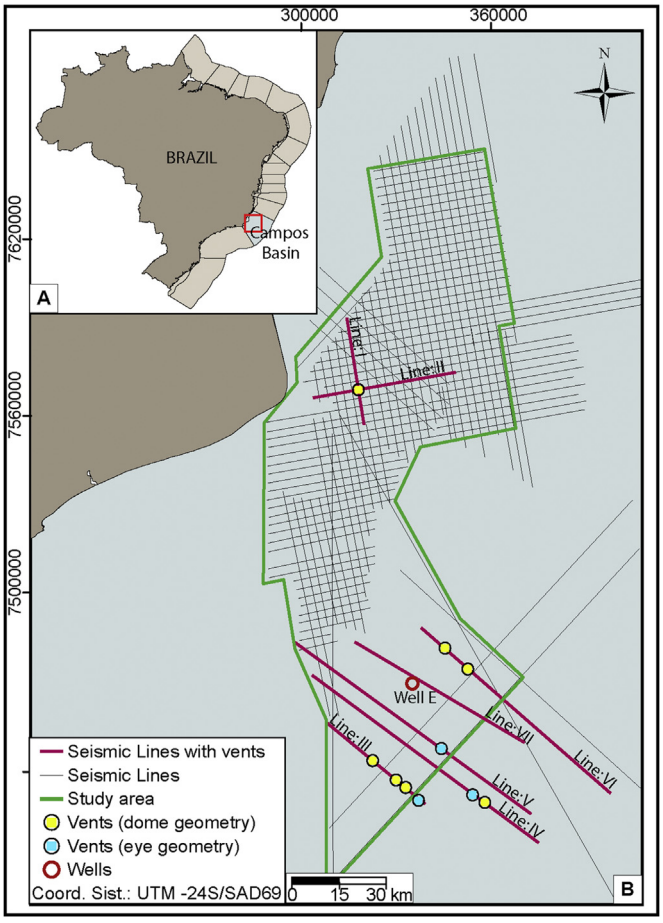

Fig. 1. Location map of the hydrothermal vents. A) Location of the Campos Basin in eastern Brazil. B) Seismic lines used for the identification of vents (yellow and cyan circles) and well E (red circle). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3. Geological setting

The Campos Basin is located in the eastern Brazilian continental margin, stretching from the Vitória High in southern Espírito Santo state to the Cabo Frio High in Rio de Janeiro state, covering an area of 115,800 Km^2 (Fig. 1), with a small portion on land (5800 km^2) and the rest offshore.

The origin of the Campos Basin is associated with the breakup of Gondwana and it presents two striking structural styles: a pattern of faulted blocks related to the initial rifting and listric faults due to salt tectonics in the upper portion (Guardado et al., 1990; Mohriak, 2003). In the early stages of opening of the Atlantic Ocean, an elongated SW-NE rift valley was formed, where grabens, half-grabens and horsts were developed. These structures produced highs and lakes in the depocenters, where the main hydrocarbon source rocks in the Campos Basin, comprising black shales within the Lagoa Feia Group, were deposited.

The beginning of the basin was associated with rifting and intense volcanic activity, which resulted in an extrusive volcanic substrate (the Cabiúnas Formation) with ages between 120 and 113 Ma (Misuzaki et al., 1988). The basin fill is divided into three stratigraphic megasequences (Fig. 3), associated with tectonic phases: rift, transitional and marine megasequences, the latter corresponding to a passive margin (Dias et al., 1990; Rangel et al., 1994). The rift package includes the oldest rocks of the basin (Upper Neocomian–Barremian) (Winter et al., 2007). They consist of interbedded volcaniclastic rocks of the Cabiúnas Formation and lacustrine deposits of the basal-intermediate Lagoa Feia Group (Fig. 3). The transitional sequence comprises the upper Lagoa Feia Group, composed primarily of a thick basal clastic package, interlayered with lacustrine carbonates in the middle-upper section (known as the pre-salt reservoirs) and succeeded by the Retiro Fm. evaporites at the top (Fig. 3). This sequence has an Aptian age and marks the transition from a continental to a marine environment