

Distribution and origin of natural gas leakage features on Block 2 of the Orange Basin as interpreted from 2D seismic reflection data off-shore the South African Margin.

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ABSTRACT

We have interpreted more than 300 2D seismic-reflection profiles located across the Orange Basin, offshore the western South Africa margin. The dataset covers an area of approx. 18750 km² which comprises the exploration Block 2. The main goal of this work was to analyse the occurrence of natural gases within the sedimentary column and the distribution of gas leakage features in relation to tectonic and sedimentary structures, in order to assess quantitatively the hydrocarbon generation, migration and seepage dynamics through geologic time in the basin. A long term aim is to integrate the results into climate change models as thermogenic methane is a strong greenhouse gas and such natural emissions may play a role in controlling climate evolution.

Keywords: volcanic continental margin, South Atlantic, Orange Basin, natural gas leakage, gas chimneys, South Africa

INTRODUCTION

The Orange Basin records the development of the passive continental margin formed by the break-up of Gondwana and the opening of the South Atlantic Ocean during the Late Jurassic to Early Cretaceous (Gerrard and Smith 1982, Brown et al 1995). The break-up began between 136 and 126 Ma. The synrift sediments of the basin (Nurnberg and Muller 1991) consist of grabens and half grabens with deposits of siliciclastic, laustrine sediment infill and volcanic intrusions. A transitional Early Cretaceous sequence was then deposited, showing a deepening up sequence from fluvial red beds to sand-prone deltaic deposits (Gerrard and Smith 1982).

Full marine conditions occurred during the Barremian-Aptian in response to the initiation of the main drift phase of the South Atlantic opening. This period of the Barremian-Aptian history is dominated by the regions highest quality of source rock, the 12 Ma Barremian-Aptian shale (Herbin et al 1987). Following this period, the late Cretaceous post-rift sediments (103 Ma) of clay or claystone lithology were deposited basinward of the Cretaceous sediments with a thickness of 1500m in the outer margin (Paton et al 2008).

Previous studies on the basin have documented the existence of an active petroleum system (i.e. Jungslager,

1999, van der Spuy, 2003, Paton et al 2007, Kuhlmann et al 2008). Paton et al. (2008) carried out a 2D petroleum system model within the southern part of the basin. More recently, Kuhlmann et al (2008) interpreted the seismic units deposited to the south of Block 2 (exploratory blocks 3 and 4) and constructed a basin model for the study area. Her results indicate that the Aptian source rock is currently generating gas in the outer part of the basin. In the northern part of the Orange Basin, a series of mud volcanoes have been identified in the outer margin in the area of Block 2 and have been linked to the existence of neotectonic faults in the submerged continental shelf (Ben Avraham et al 2002).

METHOD AND RESULTS

We have interpreted more than 300 2D seismic-reflection profiles located across the margin provided by PetroSA. Stratigraphic control was achieved by tying the seismic to 10 oil wells (stratigraphic picks and logs) located both in the shelf and slope of the basin (Figure 1).

The analysis of the seismic data reveals the existence of seven major seismic units separated by conspicuous stratigraphic unconformities (Table 1). This interpretation is consistent with the interpretation

carried in the southern area by previous authors (i.e. Paton et al 2007, 2008 and Kuhlmann et al 2008).

The Cretaceous mega-sequence is composed of five major seismic units: C1- Barremian to Aptian, C2-Early Aptian to Cenomanian, C3-Turonian to Coniacian, C4-Santonian, C5-Campanian to Maastrichtian and the Tertiary is subdivided into two sequences: T1- Lower Tertiary, and Unit T2-Upper Tertiary.

The main tectonic structures observed across the margin can be either extensional or contractional depending on their location. There is an extensional domain located in the present-day shelf-break/upper slope, which is characterised by basinward dipping listric faults rooted in a 112 Ma Barremian-Aptian shale layer that acts as a decollement level. In contrast, a contractional domain on the lower slope shows landward dipping asymmetrical thrusts which accommodate the up-dip extension. (Figure 2).

Various features probably associated with past or active natural hydrocarbon leakage have been identified both on the seafloor (pockmarks, mounds) and within the stratigraphic column (gas chimneys), as well as several seismic anomalies characteristic of gas presence (i.e. bright and flat spots). The gas chimneys either leak up to the seafloor (“active leakage”) or are sealed within the Miocene (14 Ma). Depending on their origin, we have classified them as structurally and stratigraphically related.

The structurally controlled chimneys are mainly found in the outer margin the basin, between 500 to 1500 ms (Figure 3). Whereas, the stratigraphically-controlled chimneys are mostly located on shelf and seem to be linked to an onlap/pinch out of the Aptian shales

The structurally controlled chimneys are located on top of flower structures, mounds and extensional-fault clusters (Figure 4a). The stratigraphically controlled chimneys end-up in seafloor pockmarks or in seismic bright spots close to the sea floor (Figure 4b)

Earlier studies in Blocks 3 and 4 of the Orange Basin have revealed the presence of stratigraphically-controlled gas chimneys on the shelf and upper slope (water depths up to 500m.). Nevertheless, to the best of our knowledge, the existence of structurally-controlled gas leakage features on the deep basin, where present-day active hydrocarbon generation may be present has not been reported before.

Interesting enough is also the presence of few so-far unclassified oversized (“giant”) chimneys which can have up to 7 km radius, are sealed by the Miocene section, and present indications of large vertical collapse. Although some bright spots indicative of gas presence have been identified close to these large features, there is no evidence of seismic pull-down

within the “chimney”, suggesting no present-day active gas leakage. It is still unclear whether they are stratigraphically-controlled or generated by basement faulting as the seismic record is not deep enough to identify the feeding source.

CONCLUSIONS

Our observations not only significantly expand what it has been known from previous work on the southern part of the basin (Ben Avraham et al 2002, Gesa et al 2008, Paton et al 2007 and 2008, Viola 2005), but also help to constraint future modelling of gas generation, migration and preferred leakage paths.

The major findings of our work can be summarized as follows:

1.- An extensional domain is observed at 200km west of the margin and it is characterised by basinward dipping listric faults rooted at an Aptian decollement level. A compressional domain, which accommodates the up-dip extension, is observed on the lower slope and is characterised by landward dipping faults and thrusting.

2.- Depending on their origin, the gas chimneys have been classified into two main categories: stratigraphically controlled and structurally controlled. The structural chimneys are mainly located on the extensional domain and originate upwards the normal faults, whereas the stratigraphically-controlled ones are linked to the presence of onlaps and pinch-out within the Aptian sequence. No gas chimneys were observed on the compressive domain.

4.- Several “giant” chimneys have been identified with sizes of more than 7 km in diameter. Further work will be done on characterising them and understanding their feeding mechanism.

Future numerical modelling along 2 major transects of the basin should provide insights on the timing of gas generation, migration and sequestration dynamics.

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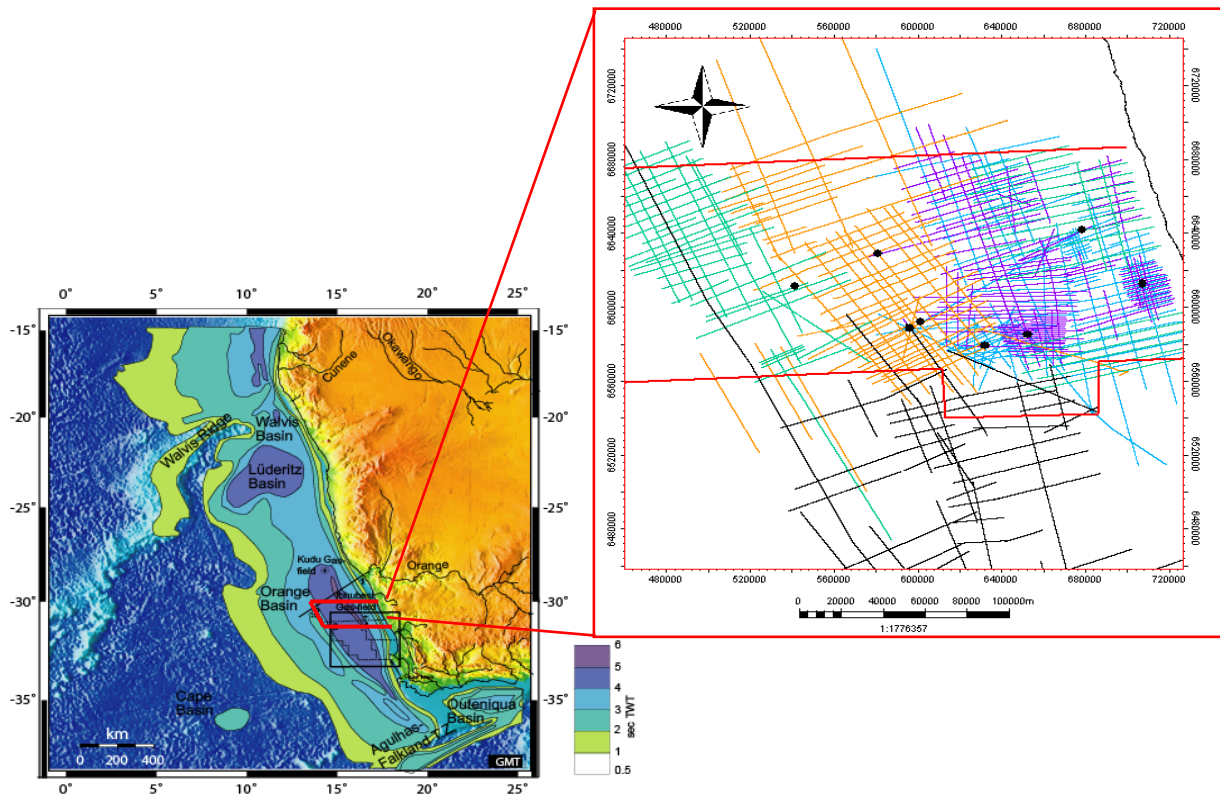


Figure 1. Isopach map modified from Seranne and Anka (2005) and location of the study area showing the seismic lines analysed during this work (The red block is Block 2 and the black dots are locations of oil-wells).

Chronostratigraphy	Epoch	Kuhlmaan 2008 & this study	Brown et al 1995	Serrane & Anka 2005	Paton et al 2007	de Vera 2008			
Tertiary	Pilo Pleisto	T2	Inner-Tertiary	Post Rift	D	Post-rift Sequence V			
	Mio	T1							
	Oligo								
	Eo								
Upper Cretaceous	Pal	22At	18At		C Upper Most	Sequence IV			
	MA						C5	17At	
	CA	C4		16Dt	Upper	Sequence III			
	SA						C3		
	CO						C2	16At	Lower
	TU	15At							
Lower Cretaceous	CE	14At	13At	Syn-Rift	B	Sequence I			
	AL						9At		
	AP	C1					6At	A	Syn-rift
	BA								
	HA								

Table 1. Post-Rift Chronostratigraphy of the Orange Basin according to different authors in this work

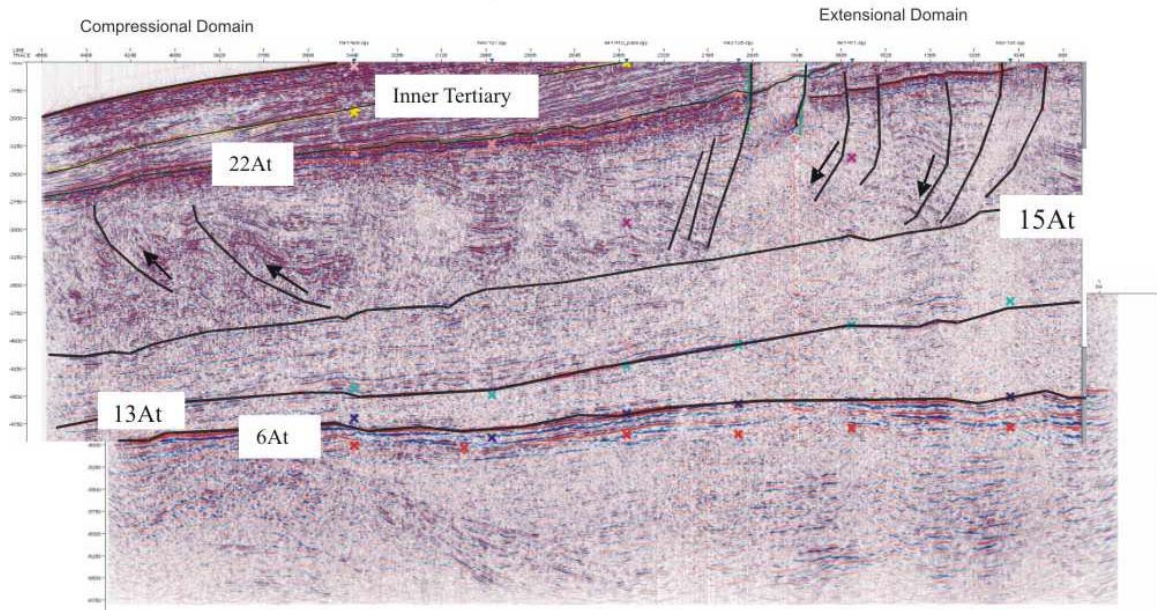


Figure 2. 2D seismic-reflection profile showing the structures of the extensional and contractional domains.

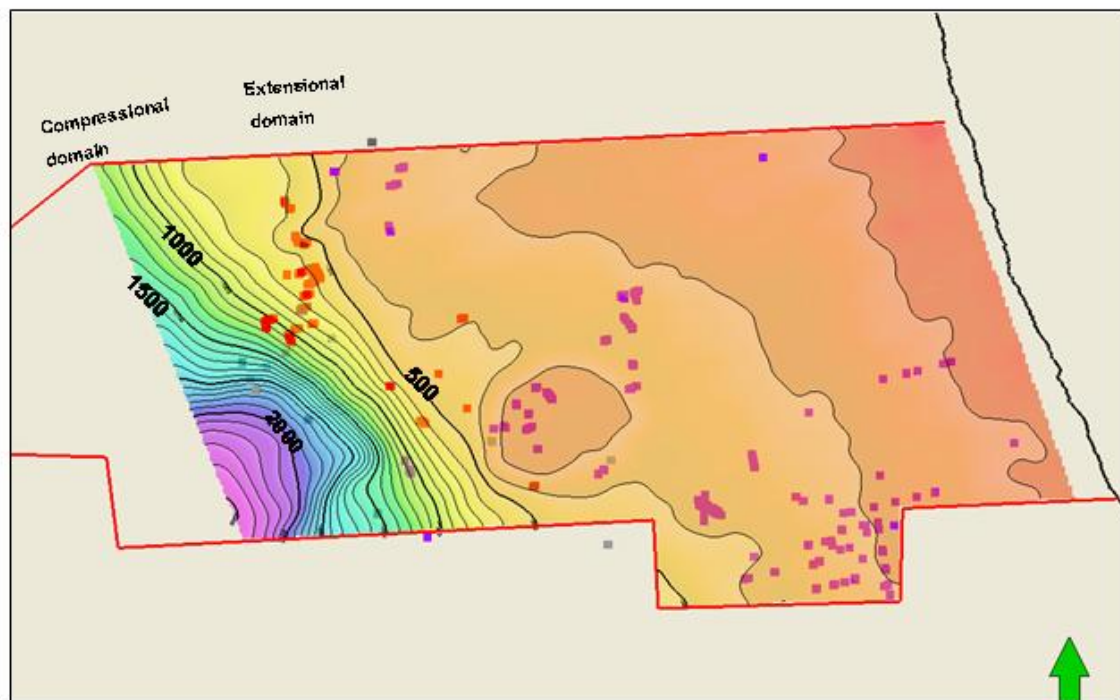


Figure 3. Distribution of the identified gas chimneys in the study area (bathymetry in milli-seconds TWT). The red dots are the structurally-controlled chimneys (bathymetry larger than 500 ms), the purple ones are the stratigraphically controlled (between 200-300 ms). The grey dots are the paleo-chimneys and the blue blocks represent the giant chimneys.

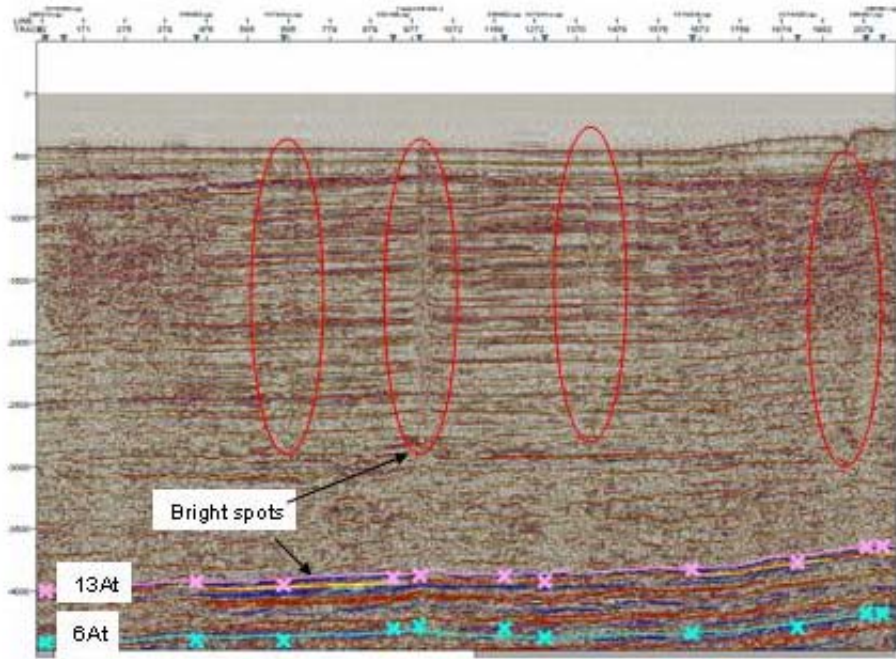


Figure 4a. Active Stratigraphically-controlled chimneys in the middle margin. Notice how the free gases migrate through the sedimentary column from the Aptian layer (13At) without any evidence of faulting.

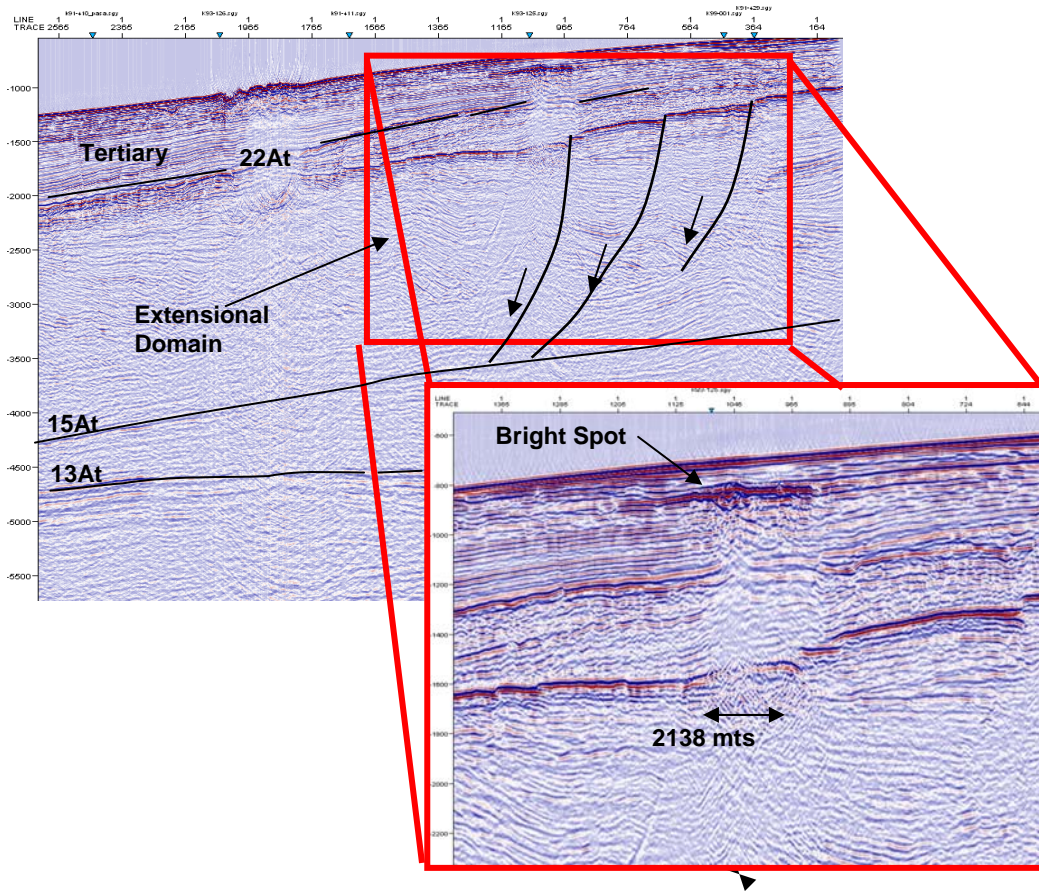


Figure 4b. Active structurally-controlled chimney in the outer margin of the Orange Basin. The chimney is sealed at about 0.1 sec (TWT) below the sea surface and end up below a flat seismic anomaly.