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Seismic characterization of fluid migration and Pockmarks formation in the Estremadura Spur, Western Iberian Margin

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Abstract: A field with more than 30 pockmarks was recently discovered in the Estremadura Spur outer shelf (Lourinhã Monocline). The processing of high-resolution seismic lines permitted the characterization of this pockmark field and of the seismic sequence of the Plio-Quaternary basin where they occur. Results show that this region has been affected by several episodes of fluid migration and fluid escape during the Plio-Quaternary, expressed by the presence of the pockmarks that at the present-time seem to be mainly inactive.

Keywords: *pockmarks, seepage, Estremadura Spur, Western Iberian Margin, high-resolution seismic*

1. INTRODUCTION

A field with more than 30 pockmarks was recently discovered in the Estremadura Spur (ES), during the PACEMAKER cruise seismic survey (Kim & the shipboard scientific party, 2011). These pockmarks are the first fluid seepage related structures identified in the Western Iberian margin. The nearest occurrences of gas seepage of this margin are found only in estuarine environments in the Ria de Vigo (García-Gil *et al*. 2002), the Aveiro Estuary (Duarte *et al*. 2007), and in the Gulf of Cadiz (Pinheiro *et al*., 2003; Magalhães *et al*., 2012).

1.1 The Study Area

The study area is located in the NW region of the Estremadura Spur outer shelf (Lourinhã Monocline; Fig 1). The ES is a trapezoidal promontory elongated in an east-west direction with an area of about 3583 km^2, located between the Cabo Carvoeiro and the Cabo da Roca, extending offshore until the Tore seamounts. It separates the Iberian Abyssal Plain (at north) from the Tagus Abyssal Plain (at south).

1.2 Fluid escape structures and pockmarks

Pockmarks are negative topographic features found on the seabed of round to oval shape, with steep flanks and a relatively flat bottom, and are seabed culminations of fluids migration through the sedimentary column (Judd & Hovland, 2007). In the ES more than 45 individual pockmarks are identified in the available PACEMAKER multibeam dataset. They occur between 220 and 350 m water depth with diameters that vary between few meters to over 400 m and they vary in depth between < 1 m up to 20 m.

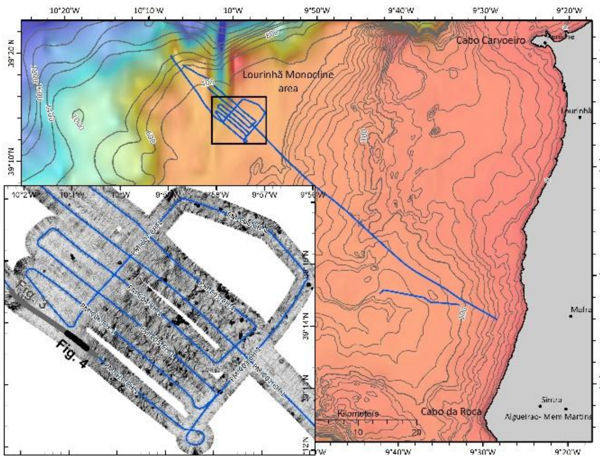

Fig. 1. Location of the study area in the Estremadura Spur, showing the PACEMAKER seismic dataset used in this work and the bathymetry slope map showing some of the pockmarks.

1.3 Geological Setting

The Western Iberian Margin (WIM), were the ES is located, began to develop during the opening of the North Atlantic Ocean, from the Late Triassic through the Early Cretaceous (Rasmussen *et al*., 1998; Pinheiro *et al*., 1996). The rocks that form the basement of the WIM are part of the Hesperian Massif. Since the beginning of the Cenozoic the evolution of WIM was characterized by periods of compression and tectonic inversion related to the Alpine orogeny (Pyrenean and Betic phases), resulting in the uplift of some regions of the margin, such as the ES. The peak of deformation, with maximum compression of NW-SE direction, occurred in the Late-Miocene, possibly during Tortonian (Rasmussen *et al*., 1998; Pinheiro *et al*., 1996). Badagola *et al*. (2006) sustains that in the Lourinhã Monocline region, where the ES pockmarks occur, sedimentary basins are established and filled with up to 40 meters of Pliocene and Quaternary sediments. These basins are representative of the Late-Miocene extensional tectonics (NE-SW).

2. DATABASE AND METHODS

2.1 Dataset

This work data set was collected during the scientific cruise 64PE332 onboard the RV Pelagia (Kim & the shipboard scientific party, 2011), within the PACEMAKER project. The dataset consists of 30 km of high resolution sparker single channel seismic data (Geo-Marine Survey System), corresponding to 14 seismic lines.

2.2 Methodology

2.2.a Seismic data processing

The processing of PACEMAKER seismic lines was carried out at the University of Aveiro, with the SPW software package (Seismic Processing Workshop, from Parallel Geoscience Corporation). The seismic raw data in SEG-Y format was first imported into SPW. This was followed by the picking of the seafloor reflection, data sorting, spectral analysis and Butterworth band-pass filtering. The data was also corrected for swell and tide statics. Then, the data was processed with source signature deconvolution, in order to increase the vertical resolution of the seismic section and attenuate the multiples. Finally, the seismic section was migrated to correctly position the seismic events at their correct subsurface location. Migration was performed the 2D Stolt algorithm, with a constant velocity of 1500 m/s (sound velocity in sea water). The data trace spacing was 2.2 m. An early mute was applied in order to eliminate the relative contributions of the direct arrivals and the noise present in the water column. Before inserting the data into an interpretation package, the navigation was corrected for offset and layback. The geographic coordinates were converted to Universal Transverse Mercator (UTM) and the trace headers of the seismic data were exported as ASCII files.

2.2.b Seismic Interpretation

Seismic interpretation was performed using Halliburton's SeisWorks from Landmark software. It was developed a seismic-stratigraphic model, based on the analysis of seismic facies that were identified in the seismic profiles. Seismic horizons, which separate different facies, were picked by delineating clearly traceable high-amplitude and continuous reflectors or by following discontinuities in the seismic records. Fluid flow can often be recognized on seismic data, because it causes an acoustic, diagenetic or mechanical change in the geological sequences. Direct indications for fluid and seepage are expressed in characteristic seepage features both at seabed and in the subsurface. Evidence of the presence of gas and fluid flow in seismic data is inferred by the observation of geophysical indicators, such as acoustic turbidity, enhanced reflections, intrasedimentary doming, pulldown, gas chimneys and bright spots (Judd & Hovland, 2007; Duarte *et al*., 2007).

3. RESULTS

3.1 Seismic data

3.1.a Data processing

In general, the results obtained with the application of the processing flow provided satisfactory results. For the seismic lines PM-C01, PM-C02, PM-C02pt1, PM-Cc01, PM-Cc02 and PM-Cc02pt1 the results obtained did not show great improvements, because in these lines the signal to noise ratio was very low.

3.1.b Interpretation

The seismic profile PM-C10, oriented along NW-SE direction, image the Lourinhã Monocline and the major basin in the external ES shelf where the pockmarks occur (Fig. 2). In this high-resolution seismic profile is possible to observe six seismic units (U1 to U6), delimited by horizons (M to H4) that mark major discontinuities or variations in the seismic facies.

The basal unit (U1) is characterized by coherent high amplitude, continuous and parallels reflections, with a thickness of >15 ms (twt) that is top-bounded by a major discontinuity (M), a erosive surface that separates this severely folded unit from the overlying sequence U2.

U2 does not present the same degree of deformation and the unit bellow, and is bounded by the horizons M, at the bottom and H1 (a reflector that marks the variations of seismic facies), at the top. U2 is a chaotic body, but in some zones are observed reflectors parallels and with some lateral continuity (transparent reflections). It have a lenticular shape and 11 ms (twt) of maximum thickness. This unit was only punctually

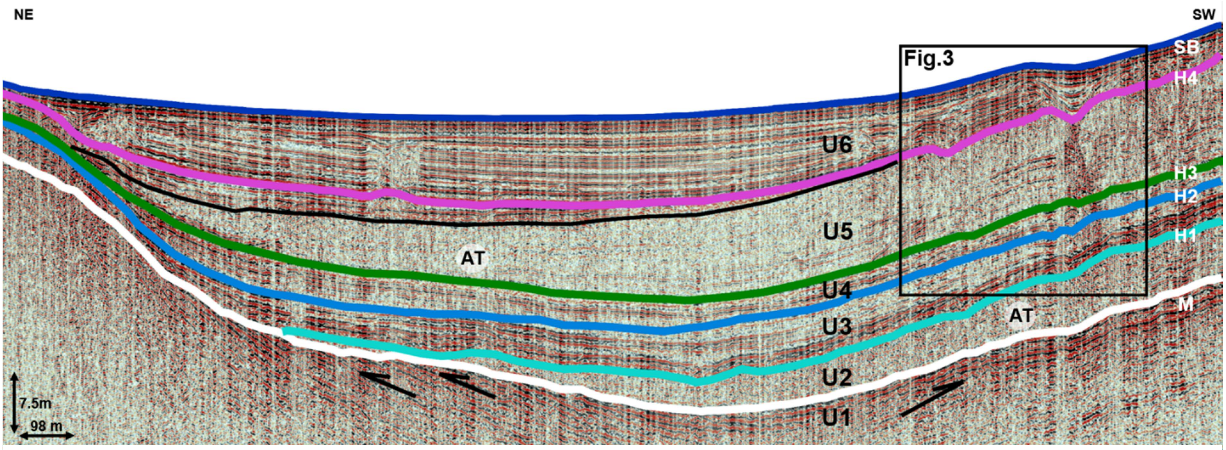

Fig. 2. Seismic line PM-C10 (location in Fig.1) showing the Plio-Quaternary seismic units defined.

observed, being restricted to zones where the discontinuity M occurs deeper.

The third unit (U3) is laterally continuous, with high amplitude and parallel reflections along the seismic profile, with a thickness of about ±5 ms. Occasionally this unit seems to lose it lateral continuity. It is limited by the horizons M or H1 in the bottom and by horizon H2 (that marks the variation of seismic facies) in the top.

Unit 4 (U4) is a unit similar to U3, with continuous and parallel reflections but of less amplitude and with less lateral continuity. U4 have maximum thickness of 10 ms. In shallow areas U4 has a chaotic character. U4 is limited at the bottom by H2 and at the top by H3, which marks another facies variation.

Unit 5 (U5) is characterized by chaotic to transparent reflections, locally with some lateral continuity. Its maximum thickness of ±15 ms is observed in the basin maximum depocenter region. It is limited by H3, in the bottom and by H4 (reflector with high amplitude that marks a discontinuity) in the top.

The top unit (U6) is characterized by high amplitude, continuous and parallel reflections that are locally disturbed. This unit is restricted to the basin area, with a maximum thickness of ±15 ms and lenticular shape. It is possible to subdivide U6, since in this interior are observed reflectors with toplap and onlap terminations, marking local discontinuities. Its bottom is defined by H4 and top-bounded by the seabed (SB).In the seismic profiles it was also possible to identify craters, with depth ranging from less than 1 ms to 7 ms, localized in the seabed, and many reflections that seemed disrupted, as stated above (many units with continuous reflections have parts with chaotic facies).

4. DISCUSSION

4.1 Seismic stratigraphy

The seismostratigraphy of this dataset allowed the identification of five seismic units (U2 to U6) bounded by major discontinuities (M to H4) within the Pliocene and Quaternary sedimentary infill of the Lourinhã Monocline basin (38 m thick). The basement of this basin corresponds to the seismic unit (U1) that consists of Upper Miocene to Lower Pliocene age sediments. The chronostratigraphic constrain for this seismic unit relay on the intense ductile deformation, associated with the peak of alpine compression (during the Late Miocene), that affect the basal unit (U1) but is not observed in the overlying units (U2 to U6). This suggests that the seismic horizon M marks the Miocene discontinuity.

4.2 Seismic evidences of fluid flow

The acoustic evidences of gas accumulation and seepage in this seismic dataset are expressed by seabottom pockmarks, buried pockmarks, intrasedimentary doming (ID) and acoustic turbidity (AT) (Fig. 2 and 3). The depressions observed in seismic profiles were interpreted as pockmarks with depth ranging from 1 to 15 meters. It was also possible to observe pockmarks filled with sediments, at various depths in the seismic sequence. The occurrence of disturbed reflections, widespread in units U2 and U5 and less frequent in U6 was interpreted has evidence of the presence of fluids in the subsurface. In Fig. 3 it is possible to observe a pockmark with expression in the seabed. Beneath this feature the reflections seems to be disturbed by ID. It is visible, along the seismic sequence, some near vertical disturbed zones that were assumed as migration pathways for fluid flow. U2 and U5 seem to be widely affected by AT, since occasionally it is possible to follow continuous reflections, although their transparency. It is also possible to identify in U6 locally perturbed reflectors that are interpreted as being associated with the culminations of migration pathways (gas chimneys). It is possible that these perturbed reflectors are caused by fluid accumulations.

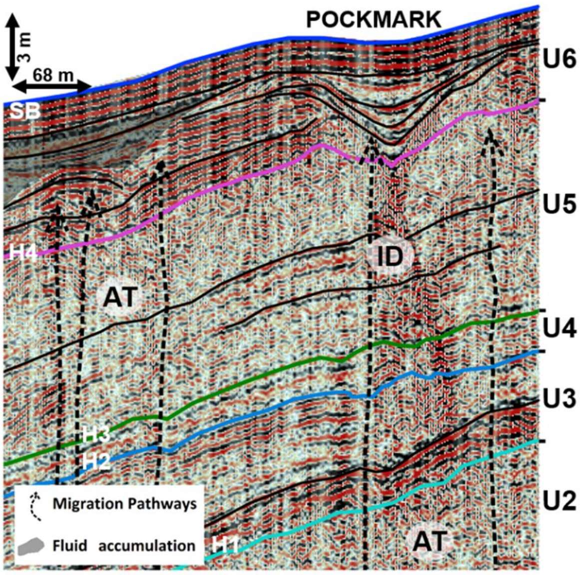

Fig. 3. Detail of PM-C10 (location in Fig.1): buried pockmark with ID.

4.3 Past seepage manifestations

The pockmarks field of the ES can be subdivided in two regions: in the region of the basin depocenter the pockmarks are in general buried, whereas in the region where the Plio-Quaternary sedimentary package is thinner, the pockmarks occur at the seafloor and with a seabed expression. This is interpreted as indicating that here the fluids expulsion is occurring at present-day or has occurred recently. In the region where the Plio-Quaternary sedimentary basin is thicker, the seabed pockmarks are recovered by sediments, indicating that they are inactive. The occurrence of these features along the seismic sequence (at various depths) also indicate that the migration of gas is intermittent and repeated periodically, possibly caused by the cyclical sea-level changes or by seismologically driven periodical overpressure variations.

5. CONCLUSIONS

The NW region of the Estremadura Spur outer shelf has been affected by several episodes of fluid migration and fluid escape during the Plio-Quaternary that are expressed by a vast number of seabed and buried pockmarks. Our analysis of the PACEMAKER high-resolution seismic dataset allowed the identification of a sequence of six seismic units, disturbed by the migration and accumulation of fluids. It was concluded that the migration of fluids to the seabed isn't only recent but occurred over the Plio-Quaternary, as indicated by the buried pockmarks at different depths. At present-time the pockmarks are mainly inactive, as the seabed pockmarks are recovered by recent sediments.

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