Exploring the Alentejo continental shelf for minerals and Quaternary environmental changes: preliminary results of the MINEPLAT survey

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Abstract - **This study presents the preliminary results of MINEPLAT survey, organized by Universidade de Évora in partnership with Instituto Português do Mar e da Atmosfera (IPMA) based on an integrated analysis of geophysical data namely, ultra-high resolution seismic data (UHRS), multibeam data, backscatter data and magnetic data. The survey took place on north Alentejo continental shelf (30 to 200 meters depth) between Tróia and Sines. The interpretation and integration of the acquired data allows substantial improvement on the knowledge on the morphology and geology of the surface and subsurface of the Alentejo continental shelf towards the assessment of the mineral resources potential in the continental shelf off Alentejo and of the environmental conditions caused by the tectonic uplift in the Pliocene-Quaternary.**

Resumo – **Este trabalho apresenta os resultados preliminares da campanha MINEPLAT, organizada pela Universidade de Évora em parceria com o Instituto Português do Mar e da Atmosfera (IPMA), baseados na análise integrada de dados geofísicos, nomeadamente, sísmica de reflexão multicanal de muito alta resolução (UHRS), multifeixe, retro dispersão e magnética. A campanha decorreu na zona norte da plataforma continental do Alentejo (entre os 30 e os 200 metros de profundidade) entre Tróia e Sines. A interpretação e a integração dos dados adquiridos constituem uma melhoria substancial no conhecimento da morfologia e geologia do fundo marinho e da subsuperfície marinha da plataforma continental do Alentejo diretamente relacionados com a avaliação do potencial em recursos minerais na plataforma continental do Alentejo e as condicionantes naturais impostas pelo soerguimento da margem continental no Plio-Quaternário.**

Key words – Alentejo continental shelf, Geophysical survey, Mineral resources, Pliocene-Quaternary, Tectonics.

INTRODUCTION

Alentejo is a region where the extraction of mineral resources has a relevant contribution for economy since at least Roman times. Nowadays the raw materials sector has concentrated its activity in the exploration and exploitation of ornamental rocks and massive sulphides ore deposits. There are other types of ore deposits but their economic exploitation is not been feasible at the present market conditions (e.g. gold in the Montemor-o-Novo and uranium in the northeast Alentejo).

The first phases of onshore/offshore prospection include geophysical investigation, geological mapping, definition of targets, physical sampling and mineral and chemical analysis of the sampled materials. Despite the lack of existence of detailed geological studies of the Alentejo continental shelf, the present state of knowledge shows that the potential for existence of both metallic and non-metallic resources is real and promising. This respects mainly the assessment for placers of metallic ores associated with the breakdown of hydraulic transport capacity (some recent deposits have been recognized on the littoral of St. Torpes, Sines) and aggregates for beach artificial nourishment.

Placers deposits form when the hydraulic transport capacity breaks down, for example at the mouth of rivers or in marginal-littoral environments. These zones are fairly well known for the present-day conditions. However, due to the various glaciations that occurred in the last three million years, when the sea level was positioned ~150m below present day sea level, the geography of coast was very different, as the coastline was tens of kilometers offshore.

The Pliocene-Quaternary uplift that is widely accepted by the scientific community has not been quantified but it most probably contributed to erosion and deposition of the Alentejo most superficial metallic ores possibly forming placers in the continental shelf.

This argues in favor of the potential existence of placers in the continental shelf and the need for the detailed investigation that will allow determination of ideal location for placers deposition in the past Pliocene-Quaternary (5 My).

The main goal of MINEPLAT project is the assessment of the potential of mineral resources of the Alentejo continental shelf (metallic and non-metallic ores) formed during Pliocene-Quaternary times.

This will be achieved by producing a detailed mapping and characterization of the seafloor. Geophysical surveying, sampling and mineral and chemical characterization of the collected materials are the main methods to be used. This will allow the definition of mineral deposits or better located targets, creation of a database for future studies, as well as the formation of the human resources involved and technical capacity to develop work at sea, which constitutes an area for demand for specialized technicians worldwide.

STATE OF ART

The tectonic uplift of South Portugal in the last 5 Million years (My) was firstly identified based on morphologic criteria by Mariano Feio (1952, "The evolution of the relief of Baixo Alentejo and Algarve", transl.).

However, the assessment of continental vertical movements off Portugal and its relation with tectonics was only initiated in the 1990-ies. The swath bathymetry cartography of the southwest part of the Iberian Peninsula [1] resulted from the effort of European and national projects, of 19 oceanographic surveys, a total of 200 ship time days executed from 2000 to 2006, involving 14 research institutions from 7 European countries. This mapping that comprehends the area from the Gibraltar Straits to the parallel of Sines included the deep sea only, not the continental shelf.

The swath bathymetry was complemented with acquisition of thousands of kilometers of multichannel seismic reflection (MCS), side scan sonar (or backscatter of the multibeam echo-sounder), direct visual observation and sampling of seafloor allowed (among other results) the definition of the present day active tectonic structures, mapping the Africa-Eurasia plate boundary and mud volcanoes in SW Iberia, detection of hydrocarbon seepage and methane hydrates occurrences, characterization of Fe-Mn (polymetallic) nodules and crusts, etc., [2].

Seismic refraction and monitoring of the deep-sea seismicity [3] using OBSs allowed characterization of the seismicity and the deep constitution of the oceanic basement. The study of hydrocarbon seepage in the area [4] cast new ideas on the economic potential. Among various outputs from these works the following can be highlighted: i) new scientific knowledge of southwest Iberia that allowed various funding by the EU, USA and European countries; ii) implementation of early warning tsunami centres in the Mediterranean and Portugal; iii) assessment of the tsunami risk of the industrial Sines centre; iv) investigation of the oil industry in the Algarve and Alentejo; v) discovery of potential metallic ore deposits in the Portuguese Exclusive Economic Zone; vi) the relationship between the submarine morphology and the Pliocene-Quaternary tectonics in the deep sea.

This research on the deep ocean showed how the Alentejo continental slope and abyssal plain deformed and uplifted in the Pliocene-Quaternary [5]. Rodrigues [6] also showed that the Monchique alkaline complex was exhumed during this time interval based on mineral thermocronology. It is also accepted that continental uplift is responsible for the sand cover erosion and denudation of the Alentejo coast to the south of Sines. The eroded sand that is liable to be re-deposited on the upper shelf remains to be assessed in what respects locals and volumes, an important information to be used for future beach artificial re-nourishment.

Adding to this, the uplift of the margin increase erosion and transport of materials from the Monchique and Sines alkaline complexes and from the Iberian Pyrite Belt; it is possible that some of these materials formed economic valuable placers in the continental shelf.

The mapping of the mobile sedimentary cover (Instituto Hidrográfico, 2005) initiated in the 1960-ies and was established from approximately 10 cm deep sampling of the seafloor using a 1 nautical mile grid (~1825m). Albeit its important value, these maps can only constitute a departing point for further useful evaluation of mineral resources.

The stock of multichannel seismic reflection profiles (which allows measuring sedimentary thicknesses) offshore south Portugal is quite considerable. However, these data are of very low resolution (usually <10m) not allowing for the imaging of the shallowest deposits. This results from the fact that the goal of most of these surveys was either deep located hydrocarbon deposits/sources or neotectonic basement sources.

DATA AND METHODS: THE MINEPLAT SURVEY

The imaging of the recent mobile cover can only be ensured by using very high resolution methods, complemented by other acoustic methods such as side scan sonar, by seafloor sampling and sedimentological analysis and these data are still lacking on the Alentejo continental shelf.

Therefore, to obtain geophysical data to produce a detailed geological mapping and characterization of the seafloor of the Alentejo continental shelf and to model the Pliocene-Quaternary uplift, a multidisciplinary geophysical survey ((acoustic and magnetic data), organized by Universidade de Évora in partnership with Instituto Português do Mar e da Atmosfera (IPMA), took place on north area of Alentejo continental shelf between 4th and 15th of October 2016 (Figure 1).

The acquisition of geophysical data was done using the research vessel NI Noruega of the project partner IPMA. During the MINEPLAT survey 2090 km were navigated and the following data were acquired: 350 km of ultra-high resolution multi-channel seismic data (UHRS), 450 sq. km of multibeam echo-sounder data (MBES bathymetric), 450 sq. km of backscatter (MBES backscatter) data and 600 sq. km of magnetic data.

The UHRS data was acquired using a Geo Marine Survey Systems spread, towed from the vessel aft at starboard, consisted of one 200 tips sparker source, a power supply unit configured to output 400-600 J shooting every

0.5 s, a 24-channel hydrophone chain with 3.125 meters of group interval towed with a slanted geometry. The slanted geometry has several advantages namely: i) as the hydrophone groups are towed underwater they are more protected of the swell noise allowing acquisition data at maximum of two meters of swell, ii) the ghost reflection removal is easier to be done because the receiver notch differs as the cable depth diverges from the near to the far offset, and iii) it allows improving the recovery of high and low frequencies of the seismic spectrum during the full processing of the data.

The geometry of the acquisition lines was designed to characterize the main regional geological structures (Figure 1). The in lines were acquired perpendicular to the coastline spaced a nautical mile and the cross lines were acquired perpendicular to the in lines spaced four nautical miles.

The multibeam bathymetric data were collected with a Reson SeaBat T50-P echo-sounder mounted in a pole at middle ship portside. This system produces 512 beams arrayed over a 150º equidistant arc and operates by ensonifying a narrow strip of sea floor across- track, and detecting the bottom echo with narrow, across-track, listening beams. The swath of sea floor imaged on each survey line was about 5 times the water depth. Line spacing was designed to ensure a minimum 30% of overlap between surveyed lines.

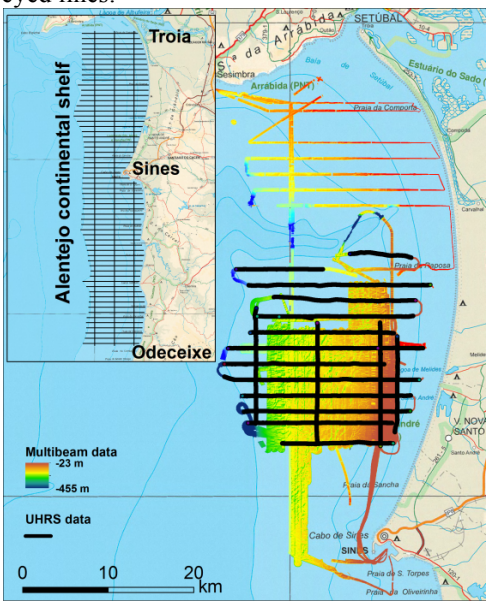

FIGURE 1
GEOPHYSICAL DATA COLLECTED IN THE MINEPLAT SURVEY.

In addition to the bathymetric data, backscatter data were simultaneously collected by the Reson T50-P echo-sounder. The seafloor backscatter is defined as the amount of acoustic energy received by the sonar after a complex interaction with the seafloor. This information can be used to determine bottom type, because a different bottom type distributes sound energy differently. For example, a softer bottom such as mud will return a weaker signal (-10 to -30 dB) than a harder bottom, like rock (-30 to -60 dB). UHRS profiles and swath bathymetry together with seafloor sampling will constrain the seafloor backscatter maps.

The main advantage of simultaneous acquisition of bathymetry and backscatter is that they are co-registered, meaning they are geographically referenced together, ensuring the backscatter snippet data will always be shown in the right place on the seafloor.

The magnetic data was acquired with a Geometrics G-882 magnetometer. This device was towed at aft center 200 meters behind the vessel to avoid his magnetic interference into the data. The magnetometer was towed 4 meters below the sea surface. The total magnetic field provides information of possible magnetic anomalies that can reveal metallic objects (e.g. shipwrecks on the seafloor or in sub-seafloor) or geologic structures such as intrusive bodies or metallic placers. The magnetic record was corrected using a static magnetic station in Alentejo at the S. Teotónio IPMA facilities.

PRELIMINARY RESULTS. DISCUSSION AND CONCLUSIONS

The presented results are based on the interpretation of the acquired data with basic data processing. The MBES bathymetric and backscatter data were only processed to clean the outliers and make the data readable. The URHS data was only brute stack processed to make the quality control of the data and to perceive the main seismic features/structures of the seafloor sub-surface.

From the preliminary analysis of UHRS data of the study area, some major morphologic and tectonic-sedimentary features can be highlighted. The UHRS profiles shows, at first sight, that the studied part of the Alentejo middle continental shelf is apparently sediment starved, as suggested by the thin shallowest seismic units that probably contain the sediments deposited during the last high stand stage.In the UHRS inline profiles there is a seismic unit that corresponds to a succession of progradational wedges towards W probably deposited during a low stand stage. These progradational wedges are truncated by the seafloor, or more accurately, by a thin top unit, suggesting that this area is currently under dominant erosive processes. In the shelf break the UHRS profiles show several shelf-margin sedimentary wedges possibly related with low stand stages. Landslides near the shelf are also imaged indicating present day local instability. Faulting and folding of recent deposits sometimes affecting the seafloor indicate recent tectonics in agreement with reported onshore neotectonics.

The preliminary analysis of the MBES bathymetric model of the study area, shown on Figure 1, revealed a continental shelf with a gentle slope, with a shelf break at 200 m below sea level.

One of the main highlights that can be shown without the full processing of the data is a 15-km long belt of sediment sorted sediments and shallow bed forms in the middle shelf, between 90m and 120 m of depth (Figure 1).

The belt where bed forms occur corresponds to gentle change of the seabed dip. The bed forms are crescent shaped and generally oriented parallel to the N-S direction in the northern part of the study area and NNE-SSW in the southern part of the area indicating a slight change of the seabed currents direction.

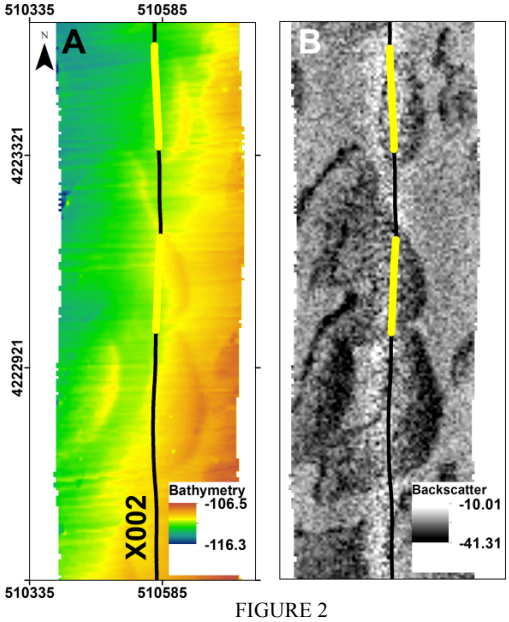

FIGURE 2
EXCERPT OF MULTIBEAM DATA (A) AND BACKSCATTER DATA (B).

In Figure 2A, the MBES bathymetric shows an example of the crescent shaped bed forms. These bed forms, located in the northern part of the study area, strike N-S with a gentle slope (1-1,5º) to the West and 1 meter of maximum height.

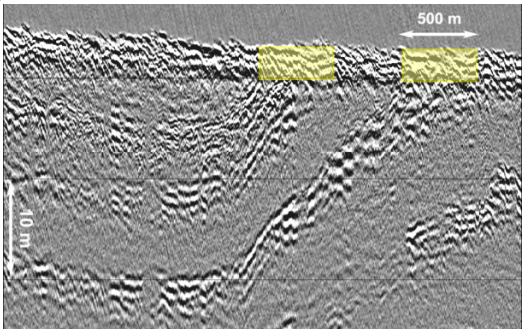

FIGURE 3
EXCERPT OF UHRS X002 SEISMIC PROFILE.

The analysis of MBES backscatter model of the study area, for the same area of the bedforms field, shows a sorted bedform pattern. The acoustic response of the bedforms is characterized by lower values of backscatter intensity. In contrast the acoustic response of the sea floor in the bedform depressions shows higher values of backscatter intensity. Figure 2B displays the backscatter data of the seabed correspondent to the morphology shown on Figure 2A. The visible sorted bed forms pattern, where the black colors indicate fine sediment whilst white colors indicate coarse sediment, show a match between the morphology of the seabed and the lithology. Cross check of the bathymetric and backscatter images with UHRS profile suggests there is a structural control of the bed forms by sub-surface structures (compare Figure 2 A and B with Figure 3). In Figure 2 (A and B) is highlighted the area where the seismic profile X002 crosses longitudinally two bed forms. In seismic profile (Figure 3) the bed forms position is highlighted and matches the area where the dipping hard strata provide sedimentation traps for mobile sediments. This suggests that the edification of the bedforms is structurally conditioned, probably.

This preliminary cross-analysis of the different types of data (MBES multibeam, MBES multibeam and UHRS) points to a belt of bed forms that corresponds to a sequence of small depressions characterized by coarse-grained sediments alternated with small elongated mounds of finer sand bodies. Ground-truthing (previewed for next year cruises) will allow checking for the nature of the trapped sediments.

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