SAND DEPOSITS ON THE ROMANIAN CONTINENTAL PLATFORM

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Abstract. The beach nourishment is an already employed option on the littoral area of Romania, Black Sea. Quite large quantities of marine sand are necessary for implementing the program of artificial placement of sand on the eroded shore areas and for the maintenance of these works. In order to minimize the financial effort to find accumulations of marine sand on the Romanian continental shelf, in the 20-50m water depth domain, the seismo-acoustic methods (multibeam echosounding, sub-bottom profiling and side scan sonar) can be successfully employed. The concurrent use of these methods can allow the mapping the most favorable areas for sand accumulations areas.

Key words: beach nourishment, marine sand, multibeam echosounding, sub-bottom profiling, side scan sonar, favorable areas

1. INTRODUCTION

In the last few decades many studies and reports showed most of the Romanian coast is endangered by the erosional processes. The reason for this threat is both anthropic and natural (dams along the Danube River, civil works impeding the distribution along the shoreface by coastal currents of the sandy material, relative sea level rise and more frequent and stronger storms). The sand on the beaches is a mixture of terrigenous and shell particles (https://databases.eucc-d.de/files/000151_EUROSION_Mamaia.pdf), the proportion between the two origins being variable and depending spatially on the relative position to the Danube mouths and former rivers in the coastal zone.

The mitigation of the endangered beaches on the Romanian sector of the Black Sea is to nourish artificially the endangered littoral areas with sea-born sand, a periodic process that requires proper sand resources.

In the context presented above to know where the sand preferentially accumulated could help a better planning and more efficient exploitation of such marine resource.

2. GEOENVIRONMENTAL SETTING

Due to environmental and economic constraints the envisaged study area is in general between the isobaths of 20 and 50m. The areas with waters shallower than 20m are strictly environmentally protected and going deeper than 50m could be quite far from the sea coast and the exploitation of sea sand could not be economical.

The envisaged area is in the Romanian part of the NW continental platform of the Black Sea. Prior of all it is worth to mention that due to the fact Black Sea is small and an almost enclosed basin, it is a tideless marine environment.

Throughout the Quaternary times most of the sediments transported by the Danube River have been deposited in the deep-sea fan and in some intermediary depo-centers on the continental platform as the result of the glacial/interglacial melting phases (Panin, 2009)

During Quaternary the Black Sea has been subject of many sea level fluctuation, several authors studied this issue and there are many graphs available regarding the sea level changes (Esin, 2014). These graphs indicate several important sea level variations that took place after the Last Glacial Maximum Low Stand (LGMLS), when the level of the Black Sea was about 150m lower than today. According with the sea level change curve inferred by Chepalyga in 1984, represented in figure 1, close to the interval of water depths we focused on (20-50m) there are 9 peaks (noted 1÷9), 5 relative lows and 4 relative highs. These peaks amplitude ranges from about 33m to 8m and together with LGMLS they are the main driving factors regarding the development of the sand accumulation on the NW continental platform of the Black Sea. The corresponding repetitive regressions/transgressions controlled the sedimentary input of terrestrial origin, the former hydrographic network on the actual shelf area, the building or destruction of sandy sedimentary bodies associated to the coastal zone. The back-and-forth migration of the shoreline produced a palimpsestic seabed morphology and of the internal structure of the shallow sediments in the NW part of the Black Sea.

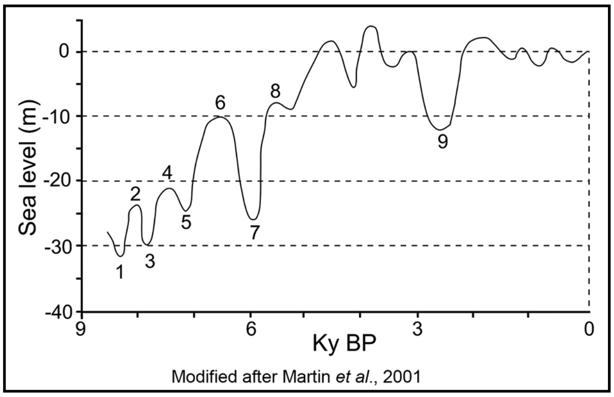

Fig. 1. Sea level variations curve.

Corresponding to the peaks 1÷6 there were 3 regression and 3 transgression periods and if we group the peaks there is a trend of continuous transgression from -33m to -10m. Between about 8500 years before present (BP) and 6400 years BP, the sea bottom has been swept by six successive transgressions/regressions that lasted around 2000 years. For this period, we can infer an intricate dynamics of deposition/removal of the terrigenous and sea born sediments, including the sandy ones. The most constant periods (the widest peaks) are about between 7800÷7400 years BP (peak 4 - a relative high stand RHS period that lasted around 400 years); this is corresponding to the nowadays water depth of 23m, a period named RHS-23m. Between 6900÷6500 years BP there is the peak 6 - a relative high stand period that lasted around 400 years, corresponding to the present day 10m water depth. For these periods of time, we can expect the development of specific sand bodies, which usually form close to a stable shoreline. Further advancing to the present times a regression followed down to 26m nowadays water depth, peak 7. The regression/transgression phases corresponding to the peak could reshape/partly destroy the sandy bodies formed during peaks 4 and 6. The next peak in the sea level variations is around 2600 years BP (peak 9), when the sea level was around 13m lower than today. After the peak 9, the level of the sea varied very little and was close to the present situation. It is worth mentioning that there are three peaks that indicate a higher level of the sea in comparison with the nowadays situation, the most prominent displays about 4m above the present sea level.

In the Black Sea area, the tectonic vertical movements could override the eustatic ones and consequently the sea level curves for this basin are mostly valid only locally (Brückner *et al.*, 2010).

The northern part of the area of interest is under the influence of the Danube River, the second biggest river in Europe, which brings an important quantity of sediments and discharges them into this part of the Black Sea. The sedimentary load of the Danube diminished considerably after 1970, when on the Danube the Iron Gates dams were been built (Panin, 1996). The Sulina jetty considerably impedes the southward dispersion of the sediments brought by the Chilia arm (Dan *et al.*, 2007) and directs offshore the load discharged by the Sulina distributary of the Danube.

In figure 2, between the isobaths 20m and 50m, in red, the area of interest in searching for sand bodies on the continental platform is delimited.

3. MATERIAL AND METHODS

Considering the large area of interest (more than 6300 km^2), we employed exclusively indirect methods, as multibeam bathymetry - MBES, sub-bottom profiling - SBP and side scan sonar - SSS, to search for most favorable areas where sand bodies could form on the continental platform.

We considered two main criteria in searching for sand accumulations, it is about the morphological and the structural criteria (Fig. 3). In an environment such as the Black Sea the evolution of the bedforms is mainly controlled by the direction of the sea level variation (upwards or downwards) and the availability of sediment (Carter, 1988).

The NW continental platform of the Black Sea is the widest in the basin and has been the subject of many sea level variation during Quaternary. For instance, several thousands of years, between the LGMLS and the melt of the polar ice sheet at the end of the last glacial era, all the shelf area was subaerial; therefore, the sandy sediments were subject of deflation and the young sediments become tougher. In front of the Danube Delta the sedimentary bodies are specific for the submerged deltas, in a tideless basin. All these dynamic phenomena modelled the aspect of the sea bottom, its detailed morphology, and the formation of specific bedforms.

The multibeam echosounding technology thanks to its high horizontal and vertical resolution can produce detailed Digital Terrain Models - DTMs of the sea floor.

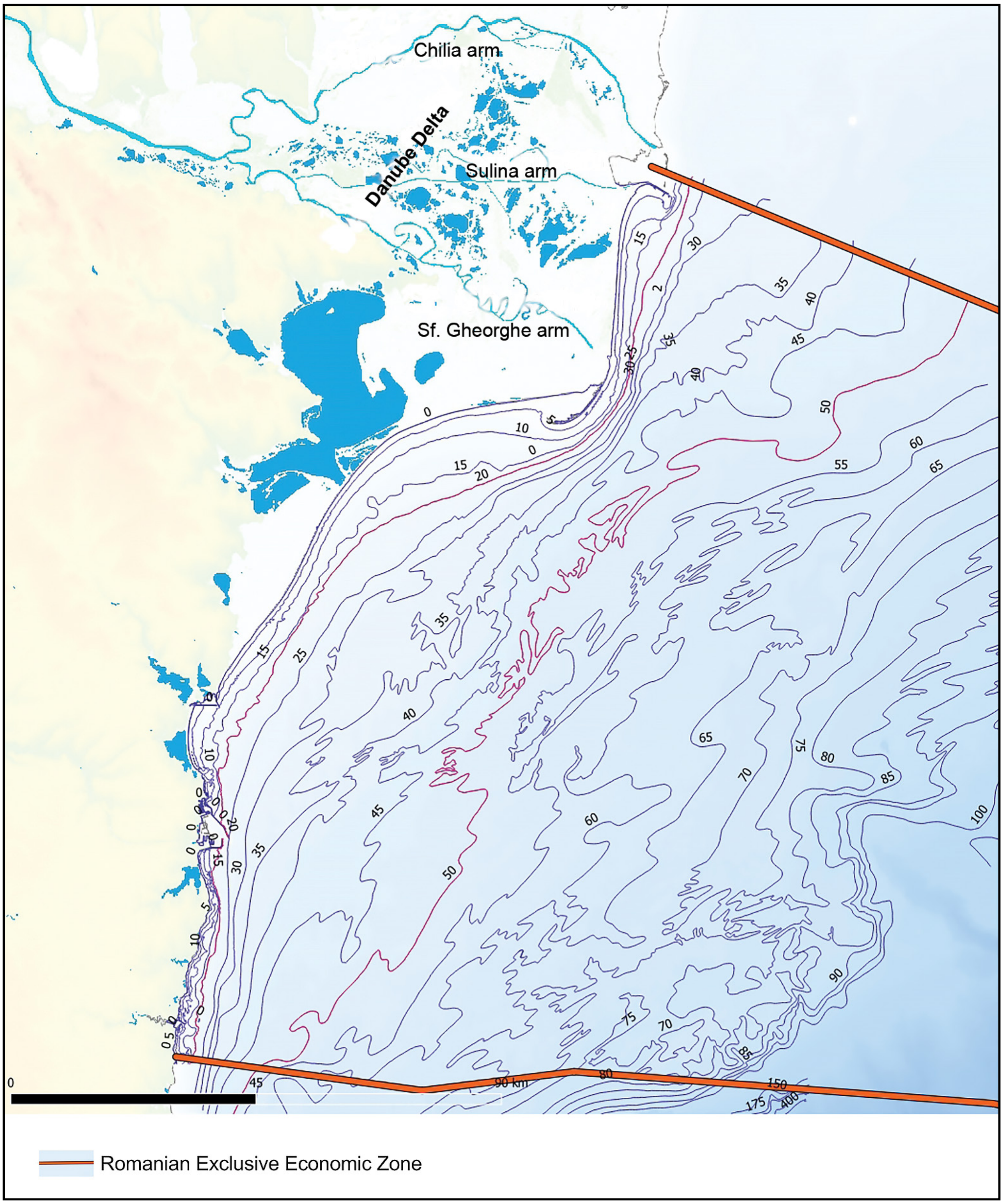

Fig. 2. Area of interest.

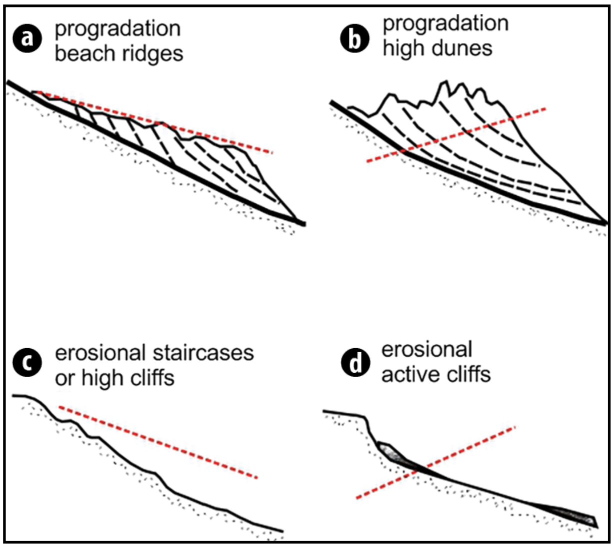

Fig. 3. Coastal development function of the relative sea level variation and availability of sediment **a**. falling sea level, high availability of sediment **b**. rising sea level, high availability of sediment **c**. falling sea level, scarce availability of sediment **d**. rising sea level, scarce availability of sediment (modified after Hansom, 2001).

The detailed DTMs allow us to map the specific sandy bodies on the seafloor, such as beach ridges, progradation dunes, sand waves, barchan dunes, *etc.* The main disadvantage of the method in shallow waters, as it is the case on the shelf area, i to be able to produce 100% coverage DTMs it needs a very dense network of profiles. The sub-bottom profiling method – SBP allow us to decipher the internal structure of the sedimentary bodies formed on the sea bottom and helps to produce an integrated interpretation of the data. The interpretation of the sea floor morphology in terms of sandy bodies normally needs large areas of DTMs, in this way being possible to have the context of the large developed linear features, fossil shorelines, shoals and any other feature associated with a submerged coastal area. In case of missing large areas covered by DTMs the SBP brings valuable information regarding the internal structures of the sub-bottom and thus is still possible to interpret data in searching for sand bodies, or even for accumulations of sand in areas with flat morphologies, as could be the eroded sea floors.

In figure 4 the available data are represented (Multibeam Echosounding - MBES, Sub-bottom Profiling - SBP and side scan sonar - SSS), as profiles and panels of DTMs. As it can be seen on this figure, the DTMs coverage is scarce at the level of the entire area of interest.

The area between Chilia arm and Cape Midia is under the influence of the Danube River, and the most of northern part of it represents the present prodelta, that covers the older Holocene and Pleistocene sediments. South of Cape Midia the sediment supply of danubian origin is much less significant and there is a sediment starving environment.

In figure 5 the interpretation of a DTM and a SBP profile is represented. By means of the SBP information it is possible to infer the internal structure of the elongated positive bodies and to assign a probability index that such feature to represent an accumulation of sand.

Because the area of interest is too large to be 100% covered in single project by MBES surveying, we performed a quite dense network of W-E MBES profiles and SBP. This approach allows the positive morphologies to be seen on the local DTMs of the sea bottom; the existence of such morphologies on adjacent lines, allow us to extrapolate and to interpret them as continuous bodies, function of their direction and horizontal extension.

The information presented in figure 6 (the DTMs) has been used to produce geomorphological profiles, to map the area susceptible to represent sand accumulations (see Fig. 7).

East of Constanta city, marine sand has been exploited with a Trailing Suction Hopper Dredger (TSHD) for the beach nourishment of an area situated to the north of the town. We considered this place the best option to calibrate our procedure for mapping the sandy bodies existing on the sea floor; for this we accomplished a detailed surveying by means of MBES and SBP.

In figure 8 the superimposed the images of DTM and SBP are represented. In this way it was possible to know the typical seismo-acoustic facies of the sand bodies.

For a better illustration of seismo-acoustic facies representative for sand accumulations zone, the SBP section from figure 8 is enlarged in figure 9.

To map the areas with different probabilities to host sand accumulations, to restraint the checking zones by vibro-coring, we established a series of representative seismo-acoustic facies and morphology (Table 1).

Table 1. Series of representative seismo-acoustic facies and morphology.

ID	Description	Examples
A	high probability of sand accumulation	• no layering, internal structure, little SBP penetration • systems of dunes and/or sand waves • barrier beaches like structures
B	average probability of sand accumulation	• some subtle layering and/or average SBP penetration in case of missing surficial gases
C	low probability of sand accumulation	• layered sub-bottom structure with/without shallow gases
D	not suitable for offshore sand exploitation	• rocky areas • fossil marshes and swamps

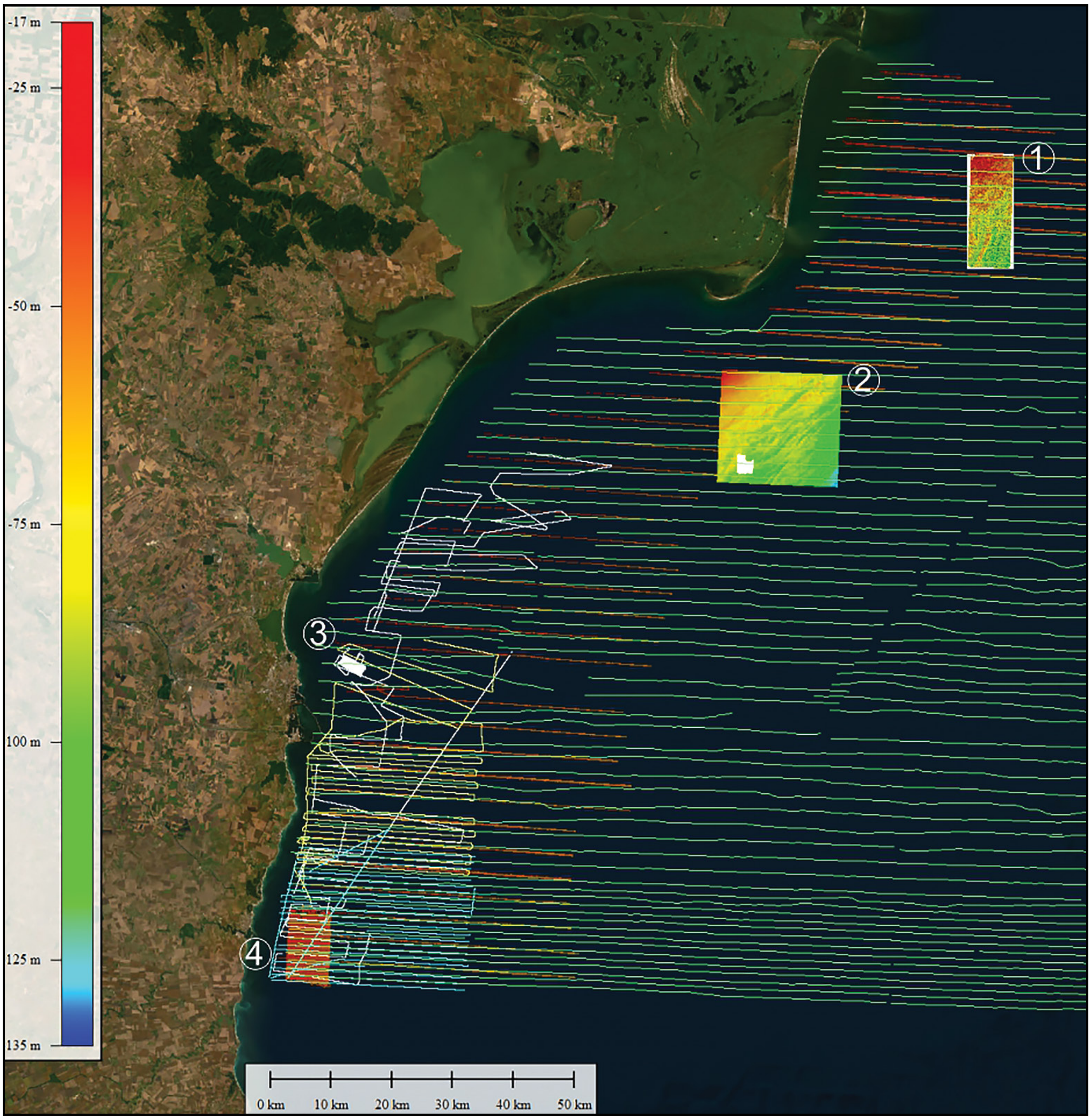

Fig. 4. Existing data in the area of interest (1, 2, 4 panels of DTM, 3 panel of DTM, SSS, and SBP): green lines – SBP 3.5 kHz; orange lines – MBES; yellow – MBES+SBP (chirp 2-12 kHz); cyan – MBMES + SBP (chirp 2-12 kHz); white – MBES+SBP (chirp 2-12 kHz).

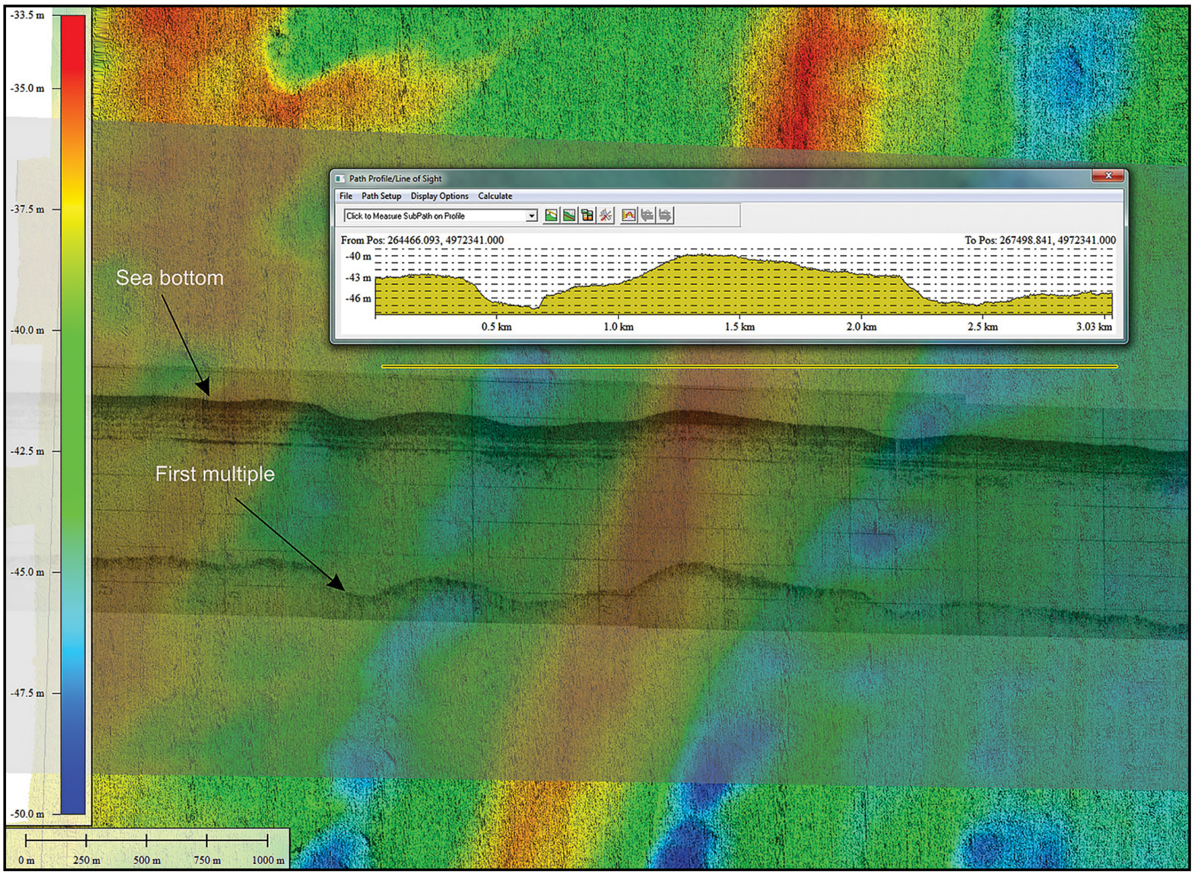

Fig. 5. Interpretation of MBES DTM and SBP data.

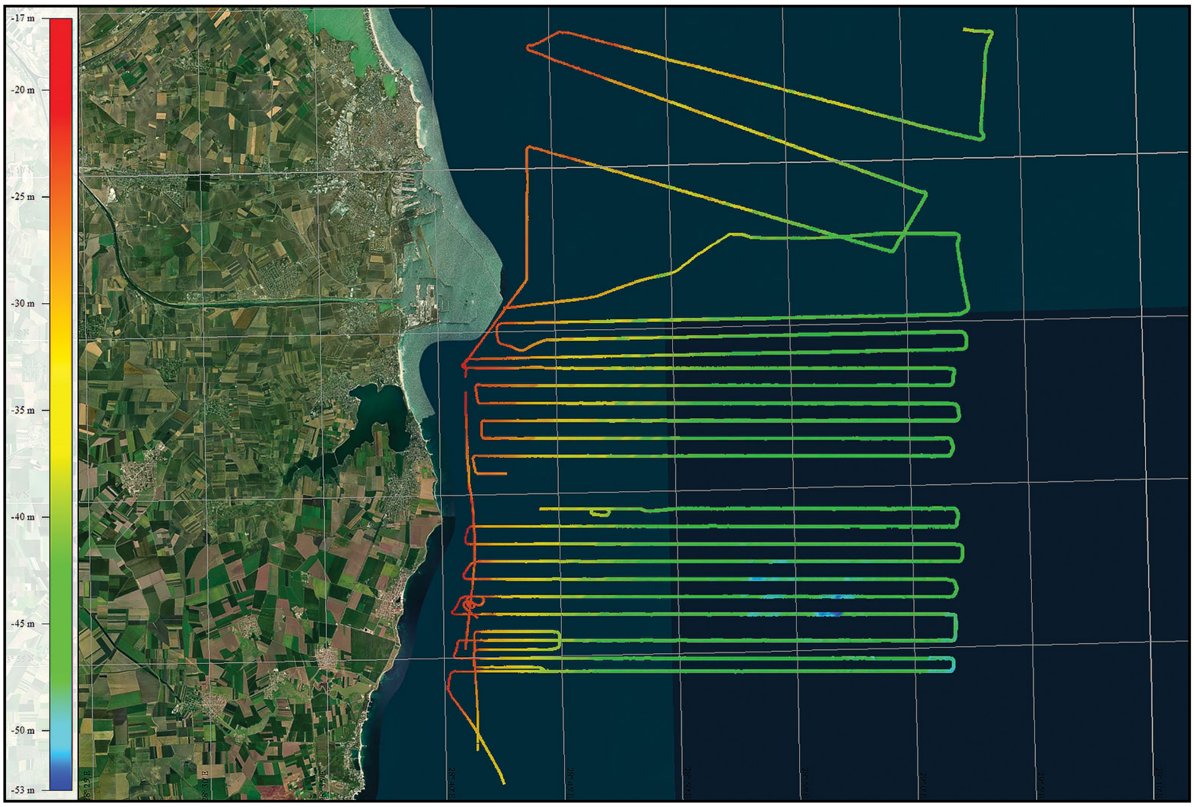

Fig. 6. Longitudinal along profile MBES DTMs, south of Constanta harbor (after Ion *et al.*, 2020).

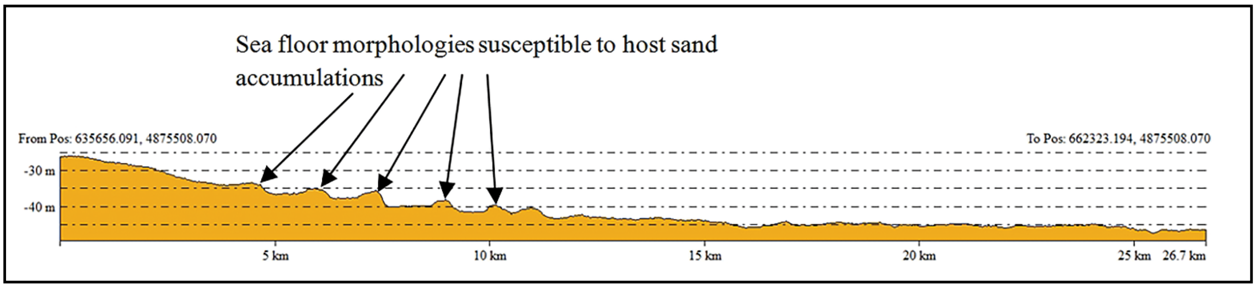

Fig. 7. DTM derived morphological profiles (after Ion *et al.*, 2020).

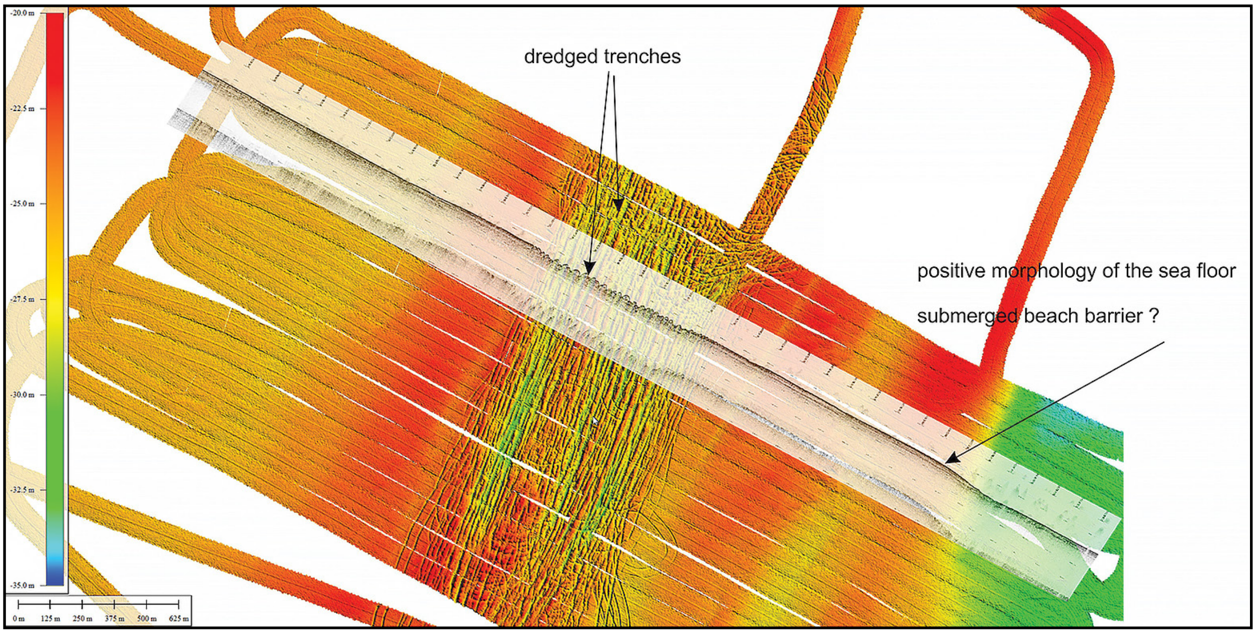

Fig. 8. Calibration of the seismo-acoustic facies on superimposed the images of DTM and SBP.

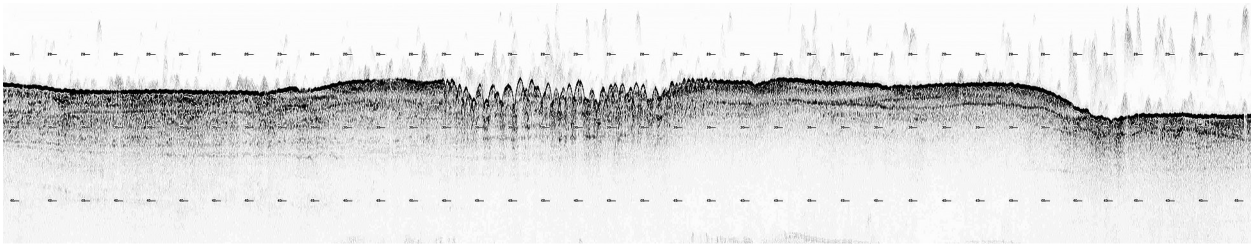

Fig. 9. Typical SBP seismo-acoustic facies for sand accumulations.

In the figures below (Figs. 10, 11, 12, 13) on the SBP cross-sections we have representative seismo-acoustic facies corresponding to the categories A, B, C and D.

4. INTERPRETATION OF DATA AND MAPPING

The data from the large protected areas (in front of the Danube Delta and Razelm-Sione lagoons) have been excluded from further processing and interpretation.

To map the favorable areas for sand accumulations, all the data has been processed and entered in a GIS database. MBES DTMs along lines (see Fig. 6) allowed us to produce morphological profiles and together with the SBP cross-sections, by means of visual interpretation and following the criteria mentioned above, we implemented probability attributes on segments corresponding to the lines of profiles and then transformed to GIS polygon features. All the process has been made using the GIS technology. Taking into account the high variability of the seismo-acoustic facies, in the table of attributes we have considered single or combined types (Table 2).

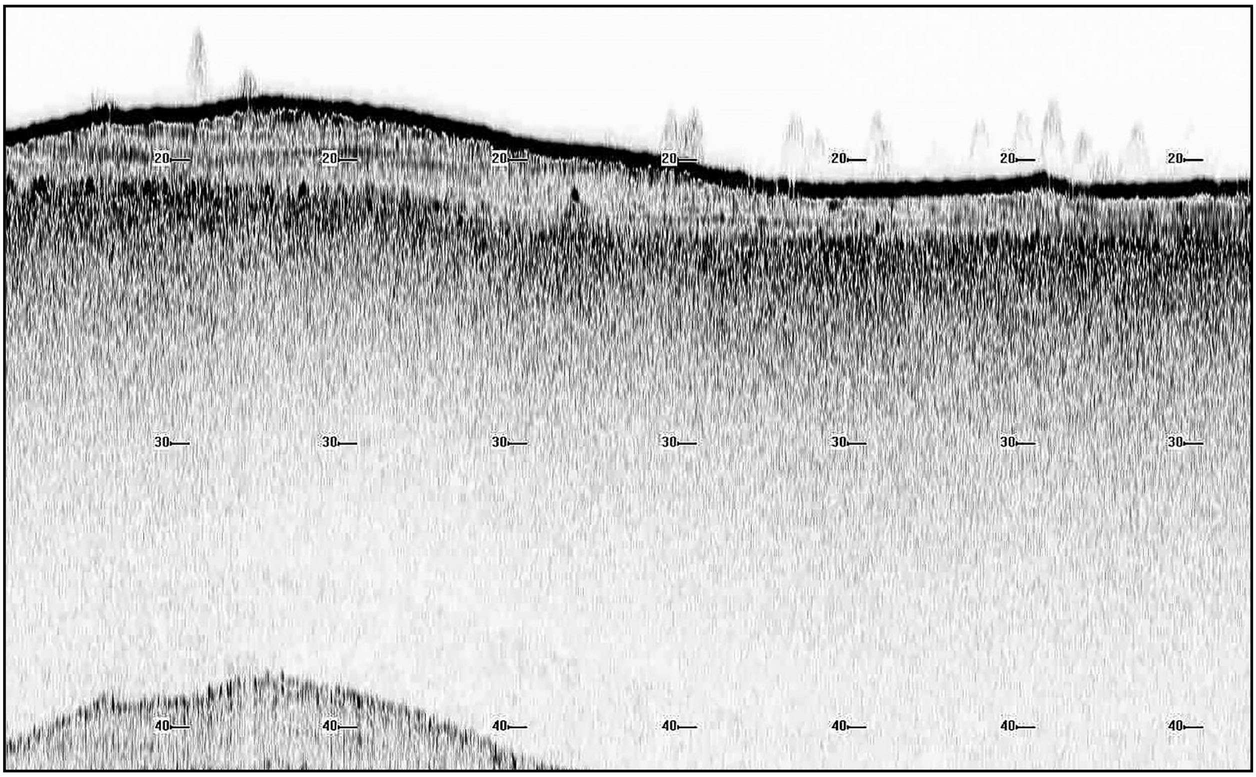

Fig. 10. Type A of seismo-acoustic facies.

Fig. 11. Type B of seismo-acoustic facies.

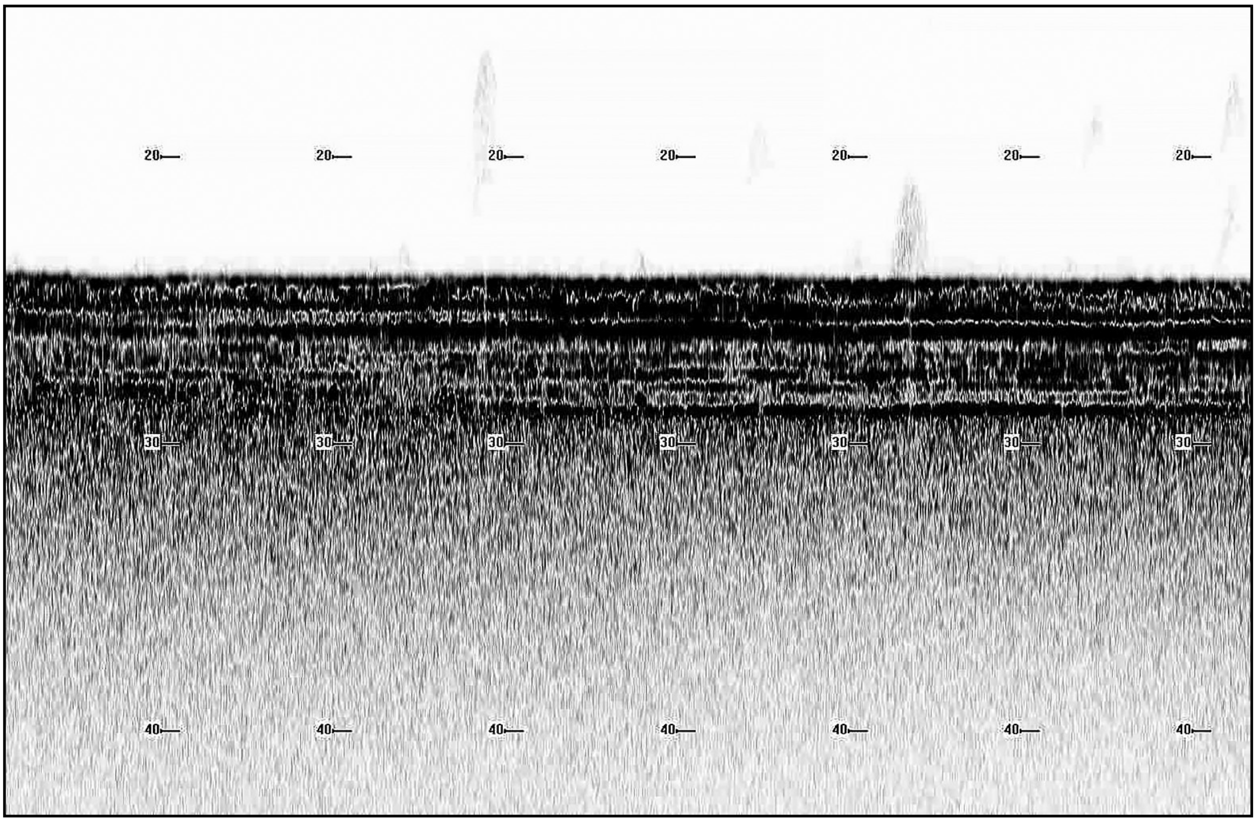

Fig. 12. Type C of seismo-acoustic facies.

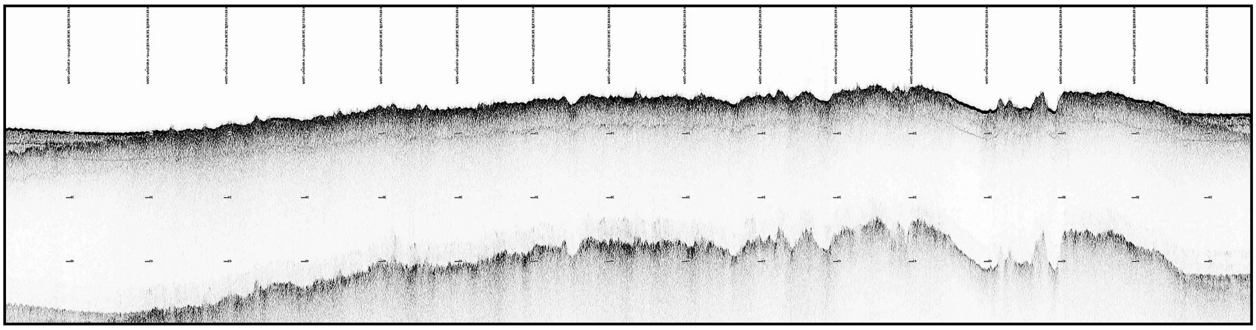

Fig. 13. Type D of seismo-acoustic facies (rocky).

Table 2. Single and combined types of seismo-acoustic facies.

A-B	high and average probability of sand accumulation
B	average probability of sand accumulation
B-C	average to low probability of sand accumulation
C	low probability of sand accumulation
D	not suitable for offshore sand exploitation

As it can be seen in the map presented in the figure 14, the combined high and average probability of sand accumulation is prevailing.

5. CONCLUSIONS

On large areas, in order to minimize the costs for searching sand accumulations for beach nourishment, the use of existing seismo-acoustic data (Multibeam Echosounding - MBES, Sub-Bottom Profiling - SBP and Side Scan Sonar - SSS) is a good option to map zones prone to host sandy bodies. We considered five classes of probability that the subsea structures host accumulations of sand: rocky bottom, low, low-medium, medium, medium-high probability.

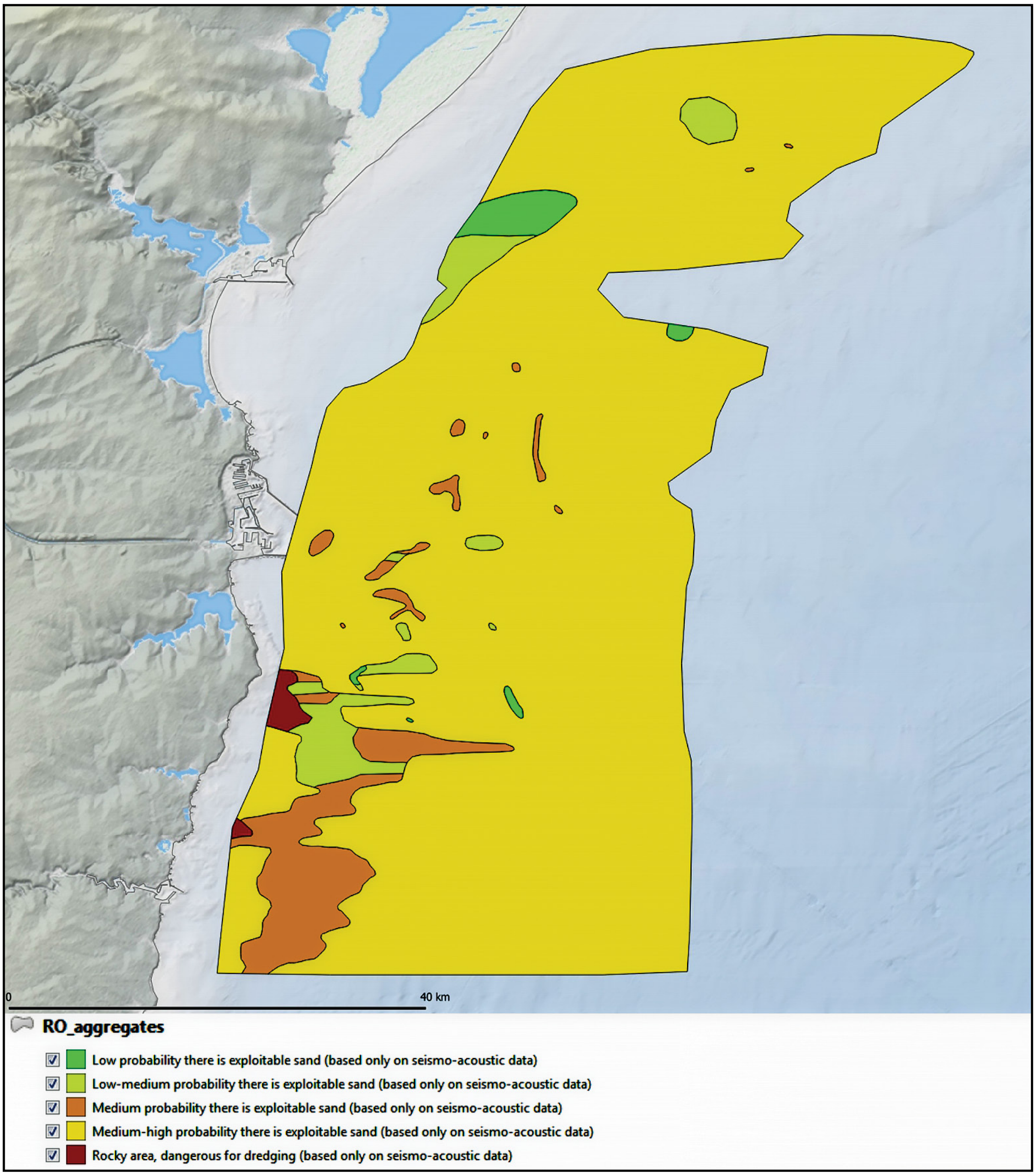

Fig. 14. Map of probability of offshore sand accumulations.

The direct sampling via vibro-coring should be performed in the favorable areas, in this way being possible to characterize the proper quality of the sand (grain size, mineralogy, origin, etc.) and to estimate the necessary dredging works for the sand exploitations. A 100% coverage with sesimo-acoustic methods is desirable for the blocks chosen for explorations via vibro-coring; in this way is possible to have a complete view of seafloor habitats and to know the proper environmental baseline conditions prior of the exploitation. At the end of the exploitation period, after some time, it is desirable to perform another seismo-acoustic survey, in order to estimate how the seafloor habitats recovered.

ACKNOWLEDGEMENTS

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