The potential of marine aggregate deposits off a highly eroded coastal area in Lesvos Isl. (Greece) - Implications for coastal management

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Abstract

This paper presents the results of a marine geophysical and sedimentological study carried out offshore of Eresos beach (Lesvos, NE Aegean) to investigate the potential of the area in exploitable Marine Aggregate (MA) deposits that could be used for the nourishment of the eroding beach. High-resolution data were acquired using an echo-sounder, a chirp subbottom profiler (SBP) and surface sediment samples. The SBP data analysis indicated the presence of a wedge-shaped deposit probably consisting of medium-coarse-grained sediments, being up to 8.0 m in thickness. Grain size analysis of the surficial sediments samples revealed a sandy deposit (90-100 % sand) down to water depths of 65 m, with the dominant fraction being fine sand. Mineralogical analysis revealed that these sediments are similar to the nearby beach sands, with albite being the dominant mineral and quartz the most significant secondary mineral particularly at shallower waters. A rough estimation on the basis of the geophysical evidence indicated a deposit volume of about $3x10^6$ m^3 at water depths between ~30 and 60 m. It appears that the area is a promising site for MAs suitable for beach nourishment, but more geological and environmental studies are needed in order to estimate the quality and volume of the reserve more accurately and determine the environmental impacts of the extraction.

Keywords: marine aggregates, geophysical prospecting, granulometry, mineralogy, NE Aegean Sea

1. Introduction

Marine aggregates (MA) are non-metallic deposits of sand, gravel and shell debris extracted from the seabed for use, mainly in construction and beach nourishment projects. MA are divided into modern deposits (the result of recent hydrodynamic and sedimentological status) and relict deposits, formed during the Pleistocene sea transgressions and regressions (Velegrakis *et al*, 2010). Comparing to land-based aggregates they have both advantages and disadvantages. MAs have (generally) smaller fractions of fine sediment (clay/silt) since much of the material present is rinsed off/removed during the dredging operation (Stamatakis *et al*, 2015); moreover, the silica rich MAs tend to be harder than those in land deposits, due to the removal of the more easily erodible constituents during their longer sedimentary history. MAs are also very suitable for beach nourishment schemes, due to their grain size and spherical shape (Bates *et al*, 1997) Their disadvantages are mainly associated with their high content in salts and biogenic material (e.g. broken shells), which for specific uses may be problematic. For example, there are specific limits for e.g. the quantity of chlorine allowed in construction and, thus, salts should be thoroughly rinsed off prior to their use (Stamatakis *et al*, 2013). The exhaustion of land-based deposits, an increasing need for adaptation to coastal erosion (which is predicted to be exacerbated by climatic changes), and certain operational advantages make them an increasingly important marine resource (Hasiotis *et al*., 2014). In Greece, where there will be a large need for beach nourishment material to battle the projected catastrophic beach erosion under the climatic changes (Monioudi *et al*., 2017), there is very little information on the distribution, type and volume available at the different areas of the Greek Seas; notable exceptions are the studies on the relict sand deposits of the North Aegean shelf (Perisssoratis *et al*, 1987) and recent studies at the bay of Afantou in Rhodes (Kapsimalis *et al*., 2013) and offshore of the south Euboea (Kapsimalis *et al*., 2015). In this contribution, we present the results of a MA prospecting study, which was carried out using high resolution geophysical information, offshore of a touristic, but heavily eroding, island beach (Eresos, Lesvos, NE Aegean Sea).

2. Study Area

Eresos (Figure 1) is located along the SW coast Lesvos, the largest island of the N. Aegean. It is a characteristic pocket beach with a length of about ~2.2 km. The upstream drainage basin covers an area of about 57 km^2 and it consists of volcanic formations with local outcrops of crystalline limestones with the lowland areas dominated by Quaternary alluvial deposits. The most important river of the basin and a main sediment supplier for Eresos beach is R. Halandras, the upstream section of which has been dammed since 1999. Presently, the touristic beach suffers from erosion that is mainly driven by (Velegrakis *et al*., 2008): (i) a potential change in the hydrodynamic (wave) regime), (ii) the construction of the dam that may have reduced beach sediment supply by > 50 % and (iii) the extensive development at the southeastern section of the beach very close to the shoreline (Figure 1). Eresos beach is a sand-barrier type beach that fronts an extensive lowland backshore plain. Its geological setting suggests that (a) the beach forms a transgressive sand barrier, moving landwards with the Holocene sea level rise; and (b) offshore sands are likely to consist also of the (mostly) volcanic material that forms the present beach. The above characteristics of Eresos provided reasonable indications that a (exploitable) marine aggregate deposit could be located offshore of the bay left behind during the transgression; such a deposit could provide also economic and operational advantages for the much needed beach nourishment at Eresos (e.g. Chatzipavlis *et al*., 2012).

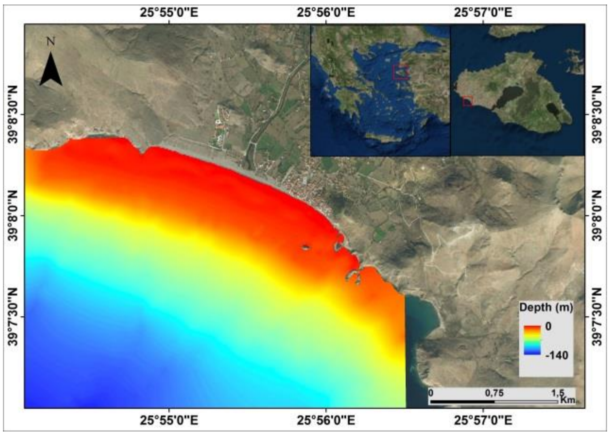

Figure 1. Bathymetry of Eresos inshore area. Inset maps show the location of the study area.

3. Methods

The geophysical survey was conducted with the *R/V Alkion* (Hellenic Centre for Marine Research) in July 2014, using a GeoAcoustics subbottom profiler (SBP) (chirp: 1.5-18kHz) in combination with the Triton Elics software. Bathymetric data were acquired with a Hi-Target hydrographic echo-sounder and surficial sediment samples were collected using a Smith-McIntyre grab. Navigation and positioning of the survey lines and sample stations were provided by a DGPS, while the vessel speed during the survey was maintained at about 4 knots. A sound velocity of 1500 m/s was used to calculate penetration of the SBP and thickness of subsurface horizons. The interpretation of the seismic data was performed through the SonarWiz 6 software. Grain size analysis was carried out by dry sieving (Folk, 1980) due to the coarse nature of the sediments (sands) and grain size parameters were extracted by Gradistat software. Mineralogy was examined with X-Ray Diffraction (XRD) analysis, carried out on a Siemens Model D5005 X-ray diffractometer in combination with the DIFFRACplus software package. Due to the absence of high-resolution multi-beam data, the bathymetric map (Figure 1) was created through interpolation. However, it is well-known that different interpolation techniques produce different values at the same grid points introducing a degree of uncertainty (Chiles & Delfiner, 1999). In this study, 3 interpolation methods were examined: Topo to raster; Natural Neighbor (NN); and Triangular Irregular Network (TIN). In order to quantify errors, we used the Mean Absolute Error (MAE) and the Root Mean Square Error (RMSE). For the validation procedure, a subgroup of 4237 points was pre-selected (25.15% of the total points) in order to compare the results with the initial, and estimate the MAE and RMSE according to:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|\hat{z}(x_i) - z(x_i)| \quad (1)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\hat{z}(x_i) - z(x_i))^2} \quad (2)$$

where n is the number of samples, $\hat{z}(x_i)$ is the predicted value and $z(x_i)$ the initial value. The comparison showed that Topo to raster was better than both NN and TIN, having the least MAE (0.10) and RMSE (0.71). For the interpolation, mapping and the estimation of the deposit volumes the ArcGIS 10.2 software was used.

4. Results

The shallow water bathymetry (< 10 m) has been previously studied by Andreadis *et al*. (2016), who have detected significant spatio-temporal variability in the two systems of longshore bars and troughs that are found inshore. The bathymetric information collected in the present study was merged to that of Andreadis *et al*. (2016) to produce a unified bathymetry (Figure 1). The results show relatively steep seabed slopes at water depths 15 – 40 m, at a distance 600 to about 900 m from the coastline, whereas towards deeper waters the slope gradients decrease. The seafloor in the eastern and central parts of the study area has greater slopes. The study of the SBP data has shown the presence of two main echo-types (ET) in the surveyed area (Figure 2). ET-1 is characterized by a prolonged bottom echo with no sub-bottom reflectors, which may be due to numerous bedded silt/sand layers in the topmost meters of the seafloor (Damuth, 1980) or related to the acoustic basement (consolidated sediments?) of the region (Figure 2a,b). It extends over an area of about 1.05 km^2, mainly down to water depths of ~35 m. ET-1 is also locally founded between the ~65 and 90 m, with slightly different acoustic characteristics (wavy relief and/or a few overlapping hyperbolic reflections tangential to the seafloor) indicating the potential rise/outcropping of the acoustic basement; this results in an uneven terrain, particularly in the central part of the study area that might have created a sediment trap during lower sea levels, which favored upslope sediment accumulation in depths less than ~60 m. ET-2 returns a strong surface reflection with intermittent parallel/subparallel, distinct or indistinct, locally intense, subsurface reflections; such patterns may indicate a surficial sedimentary cover containing coarse (sandy) beds (Damuth, 1980) (Figure 2c). ET-2 has the largest aerial extent, spreading over 3.7 km^2 and develops deeper than the 35 m isobath. A major finding is a mounded feature (Figure 2d) between 35 and 50 m that seems to rest over ET-2. This feature has a width of about 500 m and an average height of about 7 m relatively to the adjacent seabed. Its acoustic characteristics (very intense surficial reflection without or with one only sub-surface reflection) indicate recent sedimentary deposits consisting of coarse sediments. Regarding the seismostratigraphy, two discrete reflectors were recognized and digitized (mapped) in the area of the ET-2 each type. The lower reflector probably corresponds to the Holocene/Pleistocene boundary, whereas the upper reflector was traced within the surficial sedimentary sequence bounding the lower limit of an acoustically semi-transparent layer with few internal reflectors that may correspond to a coarse (sandy) surficial layer (Figure 3).

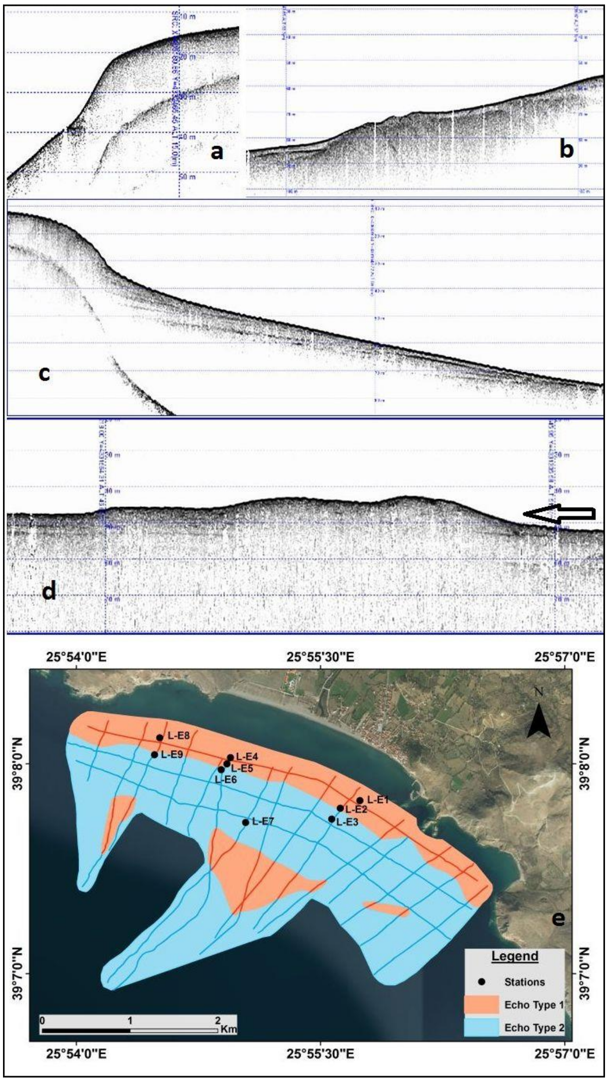

Figure 2. Seismic profiles showing the ET 1 (a,b) and ET 2 (c), which were distinguished in the SBP profiles. A large deposit has also been observed at the east part of the study zone (d). Aerial distribution of the two SBP echo-types in Eresos coastal area, also showing the survey grid and the sediment sampling stations (e).

Grain size analysis of the surficial samples (Figure 4) revealed that the dominant sediment class in the area is sand; 90 to 100 % of the volume of the surficial sediment at water depths 13 to 65 m were found to be sand-sized. The greatest mud fraction (~10 % of the total) was found at the deepest sampling station (L-E7, 65 m). The major sand sub-class is fine sand (250 – 125 μm), with concentrations varying from 7.4 % to 49.9 % and with an average of 37.3 %. The second most frequent sand sub-class is the medium-grained (500 – 250 μm) sand (3.7 - 47.1 % with a mean value of 26.7%). Yet, it should be mentioned that at the central part of the study zone at water depths between 18 and 30 m (L-E4 & L-E5), the surficial sediments were found to consist mainly of coarse sand (1 mm – 500 μm) (concentrations of up to 50 %). In general, all the sediments are classified as medium-sorted (0.11 - 0.36 mm). The mineralogical analysis showed that the primary mineral of the deposit is albite, with quartz being the second most significant phase especially at shallower waters. Other minerals such as calcite, potassium feldspars, biotite and edenite were also recognized in minor trace amounts. Halite was also determined in some unwashed samples.

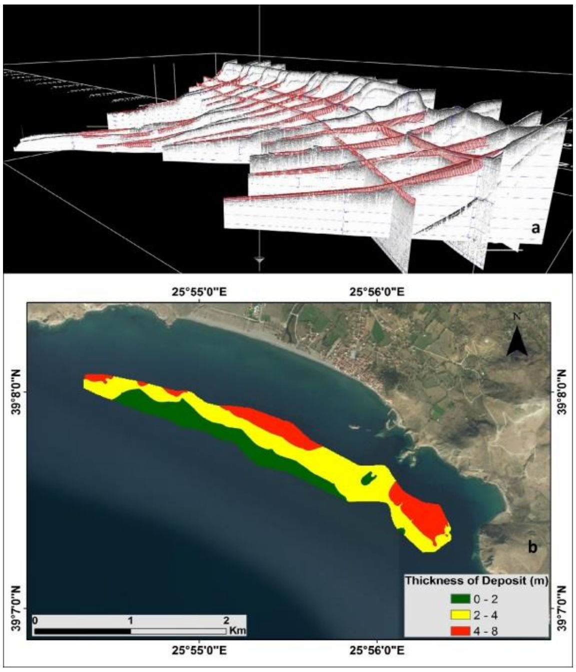

Figure 3. 3-D representation of the seismic profiles, showing the extent of the potential sandy deposit (red hatched area) in the subbottom profiles (a) and thickness map of the coarse deposit (b).

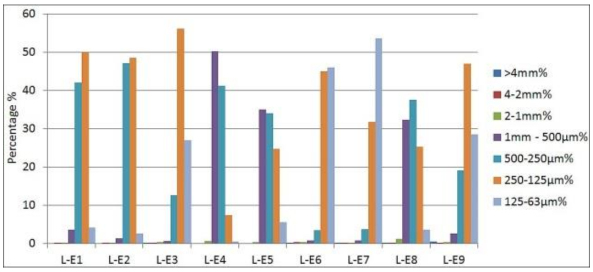

Figure 4. Percentage of sand sub-classes of the surficial sediments of Eresos wider inshore area.

Based on the geophysical information and assuming that the grain size distribution shown by the sea-bottom samples represent the whole surficial sedimentary layer (Figures 2 and 4), the extent and thickness of the surficial layer was mapped and its volume estimated (Figure 3b). The results show that the thickness of the surficial (coarse) layer ranges between 0.7 and 8 m, covering an area of about 1.x 10^6 m^2. The central and eastern parts of the study area seem to have the greatest thickness, although there are similar, but smaller in extent and localized, deposits at the western part.

Towards deeper waters the deposit decreases in thickness (< 2 m). The total volume of the inferred coarse surficial deposit was estimated at about 3 x 10^6 m^3.

5. Discussion – Conclusions

Marine aggregate prospecting in Eresos inshore area has shown promising results. The geophysical information shows that the surficial sedimentary cover (assuming a relatively homogeneous deposit) at areas deeper than 30 m has acoustic characteristics indicative of coarse-grained sediments in relatively high quantities. This layer has been probably deposited during the Late Quaternary. The structure and location of the deposit suggest that it could form a relict sand barrier left behind during the Holocene transgression. However, there might be also influences from the present hydrodynamic regime when considering MA abstraction operations; energetic events can result in offshore transportation of beach sediments beyond the closure depth (Chatzipavlis *et al*. 2012), particularly during the relaxation phase, i.e. during the (after-event) offshore flows induced to relax the extreme inshore sea levels due to storm surges and wave set ups (Andreadis *et al*., 2016). The MA deposits are found to water depths less than about 60 m, which are considered well within the operational ability of the modern dredging vessels (Bates *et al*, 1997). Even if operations were to be difficult/hindered in the area of the steep seabed slopes (water depths of 15 – 40), and the common environmental terms for the exploitation of such deposits were introduced (e.g. not to remove a surficial layer more than 2 m thick), there is still a sufficient MA deposit at suitable water depths, that can be abstracted to feed the nourishment schemes needed to battle the extensive erosion of Eresos beach, particularly as the sedimentological and mineralogical analysis have shown a close material resemblance between the borrow and fill sites. Furthermore, it must be noted that this potential homogeneous MA deposit has low silica content in order to be classified as siliceous raw material for the construction industry. Low SiO_2 values are related to the extremely low quartz content. Finally, other potential environmental impacts of the MA operations on the marine environment and the adjacent beaches should be also considered, particularly in relation to protected habitats (e.g. *Posidonia oceanica* meadows, priority habitat 1120 (European Directive 92/43/EOC)) that may be present in the area.

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