

## GEOMORPHOLOGICAL AND PALEOENVIRONMENTAL CHANGES OF ISMARIDA LAKE DURING HOLOCENE (N. GREECE)

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### Abstract

*In this research, the geomorphological and environmental changes of Lake Ismarida during Holocene are studied. Ismarida is located 20Km south of Komotini city and 5Km NNE of the archeological site of ancient Stryme at Rhodope Province, (N. Greece). The analysis of geomorphological, paleontological, sedimentological and magnetic susceptibility data as well as the evaluation of <sup>14</sup>C datings, showed that four environmental units are recognized in the lake sediments. The environment changed from shallow marine to open lagoonal of low energy (~5400-3400 years BP), to shallow marine to open lagoonal of high energy (~3400-3000 years BP), subsequently turned into brackish to lagoonal with fresh water inputs (~3000-2000 years BP), and finally formed to fluvial-terrestrial, until present time. The Lake Ismarida as it is known today was formed 2000 years BP on the isolated western part of the pre-Holocene valley between the deltaic deposits of the rivers Filiouris and Vosvozis.*

**Keywords:** lake geomorphology, paleogeography, paleoenvironment, magnetic susceptibility, Filiouris River.

### Περίληψη

*Στην παρούσα εργασία μελετώνται οι γεωμορφολογικές και περιβαλλοντικές μεταβολές της λίμνης Ισμαρίδας, κατά το Ολόκαινο. Η Ισμαρίδα βρίσκεται 20Km νότια της πόλης της Κομοτηνής και 5Km ΒΒΑ του αρχαιολογικού χώρου της αρχαίας Στρώμης στη Ροδόπη (Β. Ελλάδα). Η ανάλυση των γεωμορφολογικών, παλαιοντολογικών, ιζηματολογικών και μαγνητικής επιδεκτικότητας δεδομένων καθώς και η εκτίμηση των χρονολογήσεων <sup>14</sup>C, έδειξαν ότι προκύπτουν τέσσερις ενότητες στα λιμναία ιζήματα. Το περιβάλλον μεταβλήθηκε από ρηχό θαλάσσιο-λιμνοθαλάσσιο χαμηλής ενέργειας (~5400-3400 χρόνια BP) σε ρηχό θαλάσσιο-λιμνοθαλάσσιο υψηλής ενέργειας (~3400-3000 χρόνια BP), στη συνέχεια μετατράπηκε σε υφάλφυρο λιμνοθαλάσσιο με επιρροές γλυκών υδάτων (~3000-2000 χρόνια BP) και τέλος κατέστη χερσαίο-ποτάμιο και παραμένει το ίδιο έως σήμερα. Η λίμνη Ισμαρίδα όπως είναι γνωστή σήμερα, σχηματίστηκε 2000 χρόνια BP στο απομονωμένο δυτικό τμήμα της προ-ολοκαινικής κοιλάδας μεταξύ των δελταϊκών αποθέσεων των ποταμών Φιλιούρη και Βοσβόζη.*

*Λέξεις κλειδιά:* λιμναία γεωμορφολογία, παλαιογεωγραφία, παλαιοπεριβάλλον, μαγνητική επιδεκτικότητα, ποταμός Φιλιούρης.

## 1. Introduction

In the last decade, many studies have been performed in several Greek coastal, providing information about paleoenvironmental changes during Holocene (Syrides *et al.*, 2008, 2009a, 2009b; Vouvalidis *et al.*, 2010; Koukousioura *et al.*, 2012; Triantaphyllou *et al.*, 2010). Lake Ismarida is a Ramsar protected area situated at the deltaic plain of the Vosvozis River and the Filiouris River. Many researchers have studied the lake as well as the Vosvozis River during the last years, covering different scientific aspects. Pinaras *et al.* (2007), developed a groundwater flow model for water resources management in the Ismarida plain and Giannopoulos (2008), developed models for preventing and monitoring pollution at Vosvozis River. Moustaka *et al.* (2011), studied the phytoplankton and zooplankton of Ismarida and Katsavouni and Papadimos (2012a, 2012b), studied the physical and chemical parameters that affect ecology and biology of the lake. Additionally, Tsiaras and Nikisianis (2014), studied how tourism influences the protected sites.

The aim of this research is to study the geomorphological and paleoenvironmental changes of Ismarida Lake during Holocene, by taking into account the geomorphological, lithological, paleontological and magnetic susceptibility data.

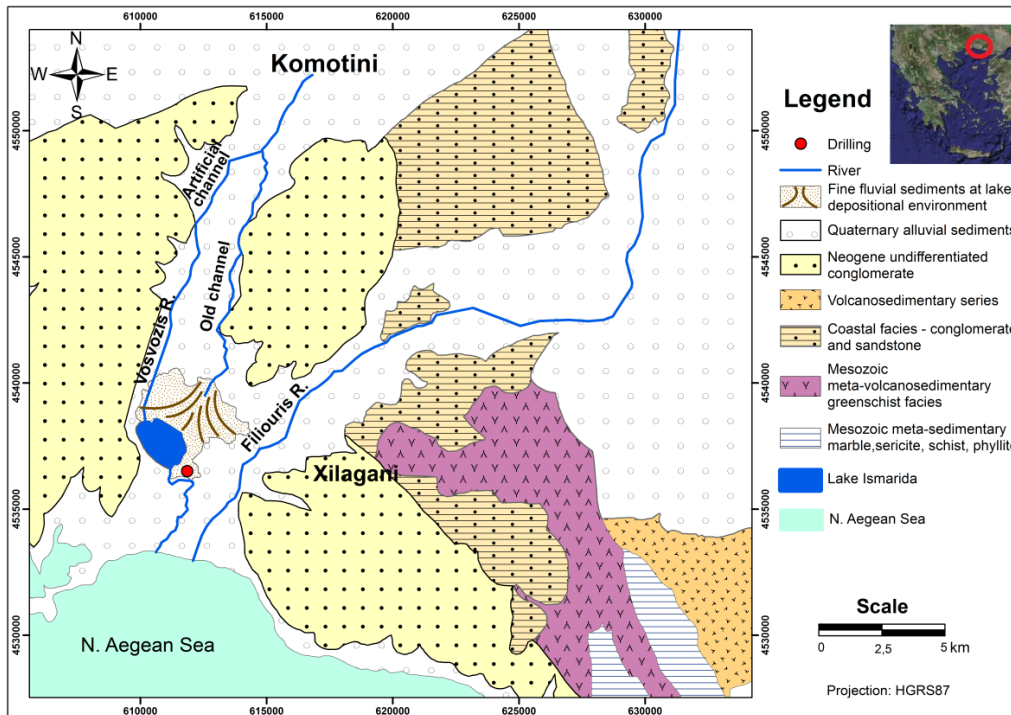
## 2. Geological-Geomorphological Setting

Lake Ismarida administratively belongs to Komotini Municipality of Eastern Macedonia and Thrace Province. It is located at the southern part of Rhodope Province, 20Km south of the city of Komotini. Pagouria village is located at the north side of the lake, Neo Sidirochori village at the north-east and Imeros village at the south-east. Ismarida Lake is located 5Km north-northeast of the archeological site of ancient Stryme and 7Km north-east of Molyvoti headland.

Ismarida Lake is the only natural shallow lake containing fresh water at the northern Greece. The maximum lake surface is about 3Km<sup>2</sup>, while the mean depth is about 1m. Vosvozis River supplies Ismarida Lake with fresh water, flowing into the lake at the northern part. Both the lake and the river are parts of the Komotini drainage system, included in the 12th water management district of Thrace. The total area of its drainage basin occupies 366Km<sup>2</sup>. In the eastern part of the lake, Filiouris River is located, flowing into the North Aegean Sea (Figure 1) and creating its deltaic plain between Ismarida Lake and the North Aegean coastline. During heavy rainfall periods the river's overbank flow floods the lower area of the lake surroundings.

Ismarida Lake is located at the wider area of the Rhodope geotectonic Massif. This wider area includes the Rhodope Mountains at Thrace, south Bulgaria and part of Eastern Macedonia reaching Strymon River as the western limit. Neogene sediments delimit the lake on the west, while on the northern and eastern part of the lake Quaternary alluvial sediments appear (Bousbouras *et al.*, 2010).

The lake sediments of the area dated to Holocene Era. The lake bottom is covered by silty sediments deposited during various phases of lacustrine sedimentation. At the peripheral area of the lake, sandstones and sediments of sandy marls and sandy clay are spotted. At certain parts, undifferentiated conglomerates are located (Bousbouras *et al.*, 2010).



**Figure 1 - Geological map of Ismarida Lake and the surrounding area, (modified from IGME, Dimadis and Zachos, 1986).**

### 3. Methodology

#### *Borehole data*

The main sampling process determining subsurface stratigraphy was vibracoring. The sediment cores were obtained by using an Atlas Copco vibracoring device (Cobra MK 1). The 1m in length corer used, was equipped with a 40mm in diameter core cutter and a basket type core catcher. The inner sampling was achieved by using plastic PVC tubes with a 40mm outer diameter. After sampling, all the tubes were sealed in order to avoid loss of humidity, marked and stored properly for further analysis. The maximum recovery depth was 5.80m below surface.

#### *Magnetic Susceptibility*

The magnetic susceptibility volume of core sediments was measured by using a Bartington MS2C Core Logging Ring Sensor. A total of 288 measurements were obtained using a 2cm step.

#### *Sampling - Laboratory analysis*

By dividing the core samples, stratigraphic description and photographic record were allowed. 191 selective samples using 2.5cm step, or denser when needed, were collected from the undisturbed parts of the vibracores. After oven dried up at 40°C, samples of ~10g were separated and weighted. All samples were treated with 30% H<sub>2</sub>O<sub>2</sub> and washed with normal water into a stainless steel sieve of 0.063mm wire mesh, for paleontological analysis. All the samples were inspected under a JENA stereoscope and all the fossils (gastropods, bivalves, etc.) were handpicked, sorted and stored into small glass and plastic vials. The finest parts of the samples (<0.063mm), were collected for further sedimentological study. The complete individuals of gastropods and the isolated valves of bivalves were taken under concern in terms of determining environmental facies. Total samples were studied

for paleontological purposes. All sorted shells were counted and afterwards total number and density/10g of dry sediment was calculated. Although the crushed shells and shell fragments were present in many samples, only complete individuals were considered for further paleontological analysis and interpretation.

#### *<sup>14</sup>C Dating*

Four radiocarbon age determinations of in situ marine shells and plants of ISMR-2 borehole were obtained by AMS technique (Table 1). All the samples were submitted to BETA ANALYTIC INC., Miami, Florida, USA. The conventional radiocarbon ages of the marine shells have been calibrated in calendar years after IntCal13 by using MARINE13 curve for marine data (Reimer *et al.*, 2013).

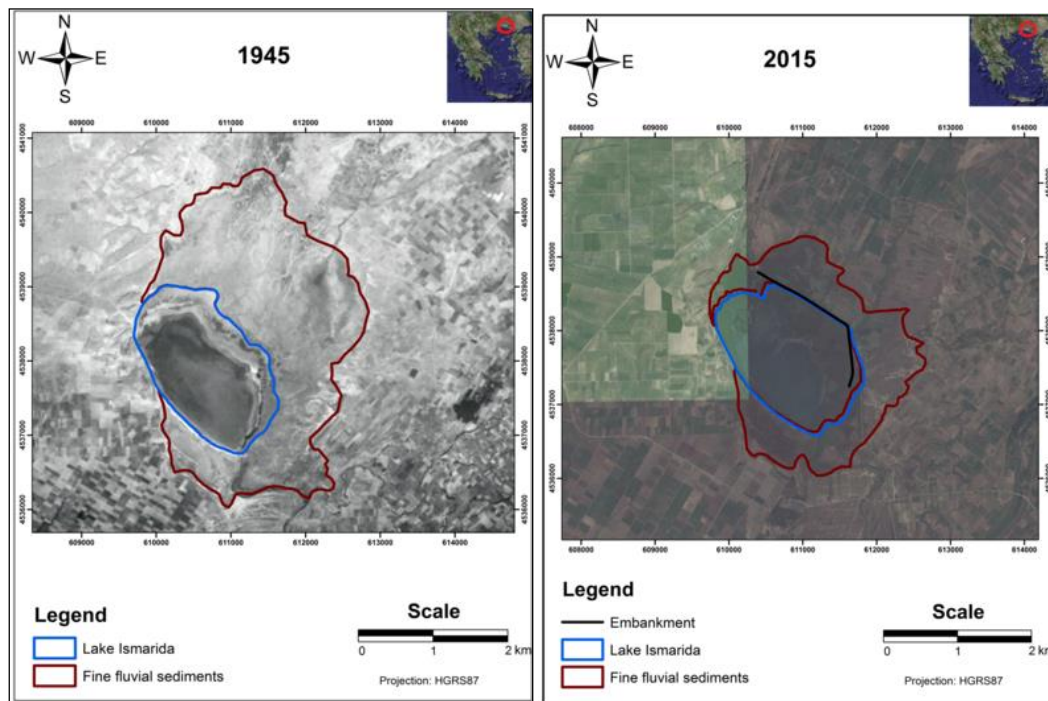
#### *Maps and Aerial photographs - Positioning and GIS*

The maps produced derived from processing aerial photographs from Hellenic Military Geographical Service (H.M.G.S.) using GIS software. All the coordinates are in Hellenic Geodetic Reference System 1987 (HGRS87). The borehole coordinates were obtained with a TRIMBLE R-6 receiver. In order to ortho-rectify the aerial photographs, GPS measurements were also obtained with a Garmin GPSmap 60CSx device. Various points of interest around the lake that identified on aerial photographs, like human constructions etc., were selected as control points.

## 4. Results

### 4.1. Geomorphological changes

Lake Ismarida and the surrounding lowland area has undergone a considerable evolution since 1945. The key factors for the lake and the plain evolution are respectively the construction of a side wall at the east shoreline of the lake in 1976 and the construction of the new artificial channel of Vosvozis River westwards of its old channel (Figure 1).



**Figure 2 - a) maximum surface of Ismarida Lake (blue line) and the lake delta (red line) in 1945, b) maximum surface of Ismarida Lake (blue line) and the lake delta (red line) in 2015.**

According to the aerial photograph of 1945 (Figure 2), the surface of the lake is 2.77Km<sup>2</sup> and the area of the lake delta with fine grained sediments is 6.67Km<sup>2</sup>. Until 1976, the Vosvozis River channel reaching the lake side from northeast creating a lake delta fan with a length of its longitudinal axis about 2Km.

Since 1976, because of the new artificial channel construction (Figure 1), the river channel enters the lake from the north side, deviating its initial course from the old lake delta. Since then the sediment deposition takes place in the lake reservoir. As a result of this artificial channel construction, the old floodplain of the lake delta is not supplied with fine river sediments anymore.

Today, the maximum lake surface is 2.65Km<sup>2</sup> whereas the minimum is 1.18Km<sup>2</sup> and the area of the old lake delta is only 3.30Km<sup>2</sup> (Figure 2). The volume of the lake reservoir is continuously being reduced due to the depositional process of the Vosvozis River. Additionally, there is a change of the physical and chemical parameters of the lake water causing changes in aquatic vegetation (reed expansion).

#### 4.2. Lithology and molluscan composition

A borehole (ISMR-2) was drilled at the south-east side of lake Ismarida (0.81m above m.s.l., 5.80m depth, x: 611885.718; y: 4536536.64) is depicted in Figure 1. Molluscs were found into 148 samples from the 191 of the borehole (1.49m - 5.73m depth). The fauna of gastropods comprises *Bittium* spp., *Cerithium* spp., *Rissoa* spp., *Cyclopes* sp., *Caecum* spp., *Hydrobia* sp., *Retusa* spp., *Planorbis* sp., *Potamides* sp. and *Gibula* sp., and the fauna of bivalves comprises *Loripes* sp., *Parvicardium* sp., *Venus* spp., *Tapes* sp., *Donax* sp., *Plagiocardium* sp., *Glycymeris* sp., *Cerastoderma* sp., *Abra* sp., *Macra* sp., *Dosinia* sp., *Clausinella* sp., *Corbula* sp., *Barbatia* sp., *Arca* sp., *Pecten* sp. and *Mytilus* sp. (Figure 4b). In some samples organic matter, plants, Echinoidea, Crustacea and scaphopoda such as *Dentalium* sp. were found.

Facies determination is based on macro-faunal analyses from the borehole studied samples. At vibracore profile ISMR-2, four distinguished units are distinct.

The upper part, 0.00m - 1.49m (Unit 1), consists of sandy mud to mud sediments (Figure 3, 4) and lacks invertebrate fauna.

The middle part, 1.49m - 3.68m (Unit 2), consists of sandy mud to silty sand sediments (Figure 3, 4). A molluscs fauna is present, containing abundant *Cerastoderma* sp., *Abra* sp., *Macra* sp. (max. 11/10g) and *Bittium* spp. (max. 29/10g), also accompanied by *Rissoa* spp., *Caecum* spp., *Loripes* sp., *Parvicardium* sp., *Echinoid* and Crustacean fragments.

The next part, 3.68m - 4.54m (Unit 3), consists of muddy sand sediments (Figure 3, 4). Molluscs are present, abundantly with *Bittium* spp. and *Parvicardium* sp. (max. 42/10g), *Loripes* sp., and *Dosinia* sp., and with lower values with *Cerithium* spp., *Rissoa* spp., *Caecum* spp., *Tapes* sp., *Donax* sp., Echinoids, Crustacean and a small concentration of Veneridae. At this part, *Cerastoderma* sp., *Abra* sp. and *Macra* sp. are totally absent.

The base part, 4.54m - 5.80m (Unit 4), consists of silty sand sediments (Figure 3, 4). Mollusc fauna mainly represented by *Bittium* spp. (max. 47/10g), Veneridae (max. 12/10g), *Cerastoderma* sp. and *Macra* sp. (max. 22/10g), followed by *Cerithium* spp., *Rissoa* spp., *Caecum* spp., *Hydrobia* sp., *Parvicardium* sp., *Donax* sp., *Plagiocardium* sp., *Dosinia* sp., *Clausinella* sp., *Arca* sp., *Mytilus* sp., Echinoids and Crustacean. At this part, the higher concentration of Veneridae was noticed in total borehole sequence.

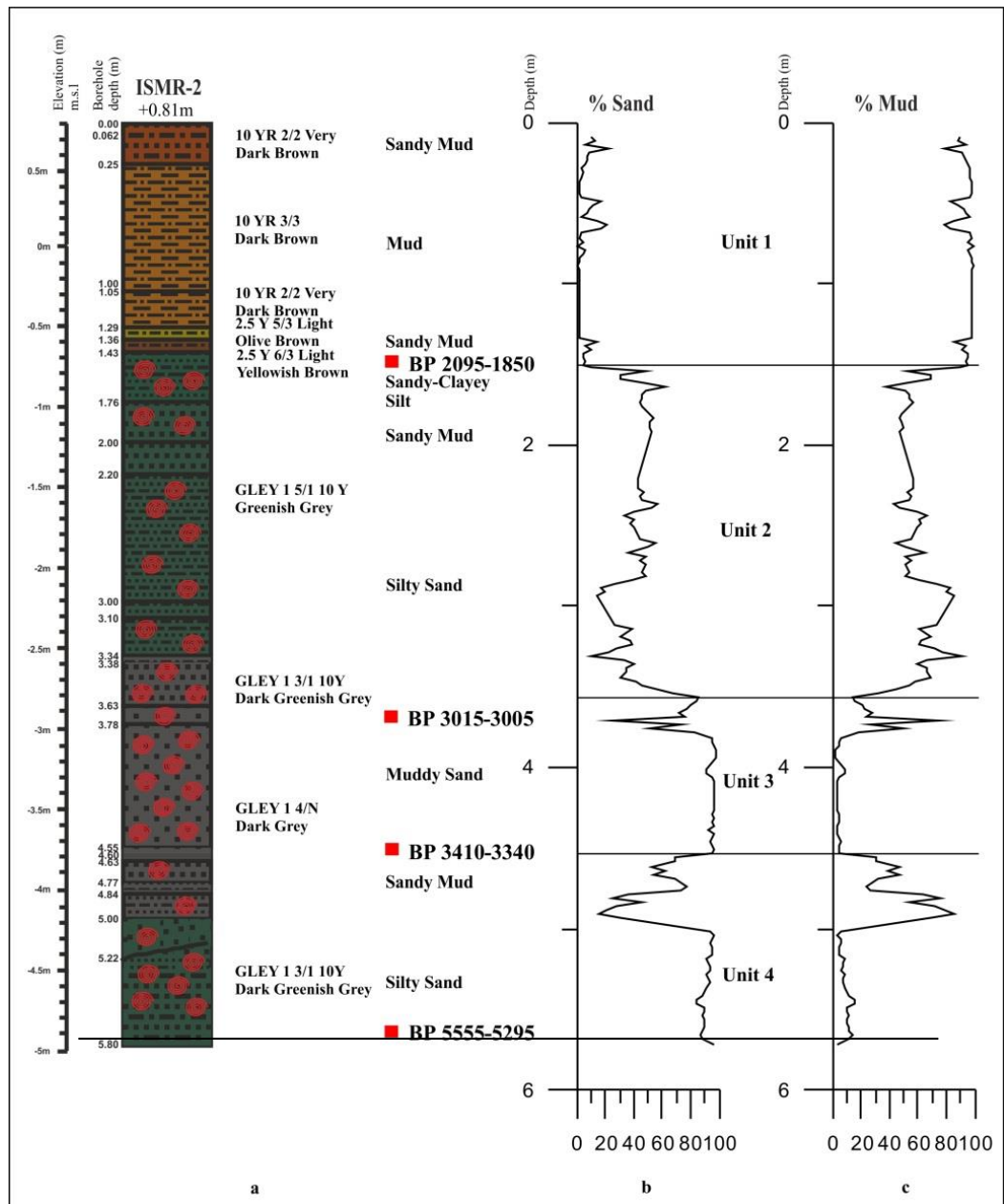
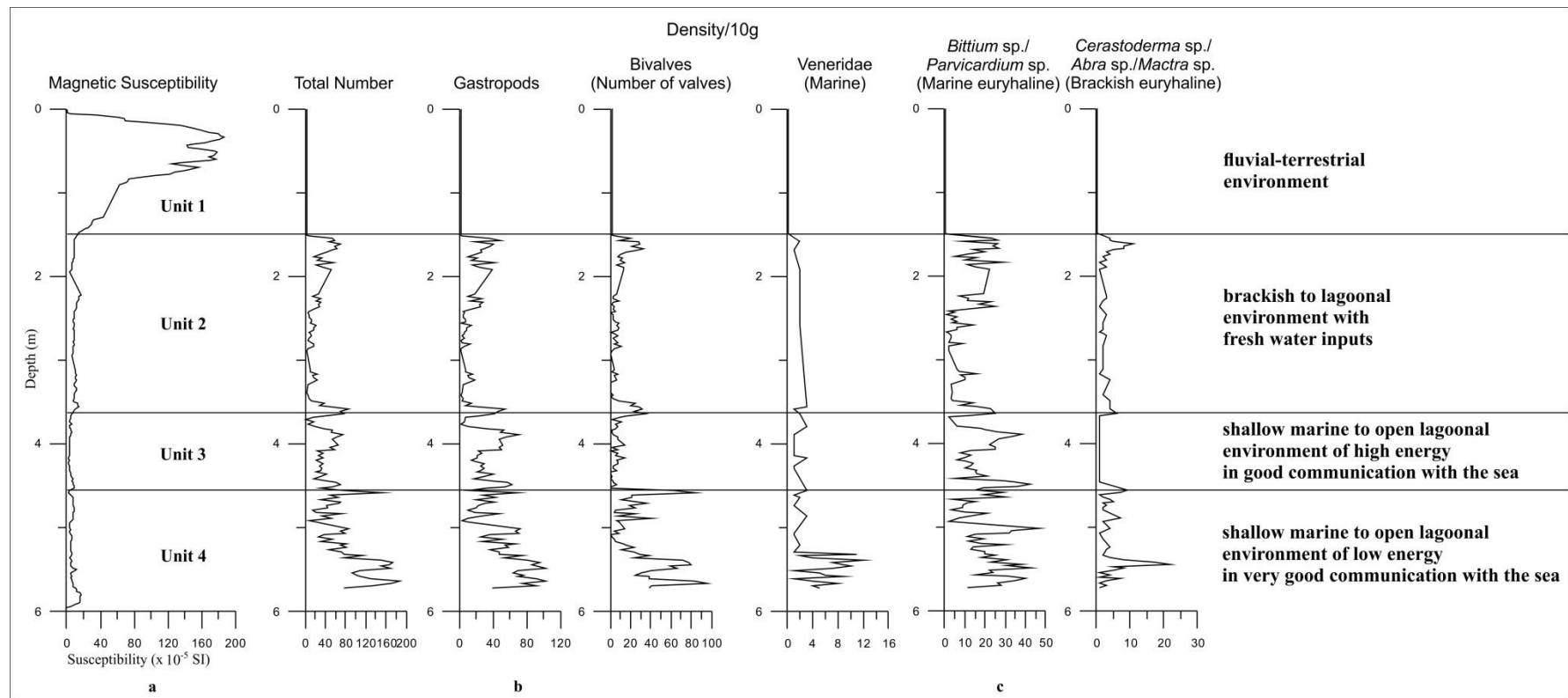


Figure 3 - a) Lithology of the ISMR-2 borehole, b) Relative frequencies of sand, c) Relative frequencies of mud.



**Figure 4 - a) Magnetic Susceptibility, b) Molluscan abundances/10g, c) Abundances/10g of the most common molluscan taxa.**

### 4.3. Magnetic Susceptibility

Figure 4a shows the variation of the magnetic susceptibility along the core. The higher values of the whole core are revealed in the upper part of the borehole at 0.00m - 1.49m depth (Unit 1), reaching  $186.2 \times 10^{-5}$  SI. At 1.49m - 5.80m depth (Unit 2, Unit 3, Unit 4), the values differentiate and range at lower rate between  $2.1 \times 10^{-5}$  SI and  $17.2 \times 10^{-5}$  SI with the maximum value at 2.22m depth.

### 4.4. $^{14}\text{C}$ Dating

Four samples of marine shells and plants, from the borehole ISMR-2 were dated with the  $^{14}\text{C}$  -AMS method. The type of dated materials, their depth below present mean sea level and their calibrated age, are presented in Table 1.

**Table 1 - Radiocarbon dating results for borehole samples of Ismarida Lake, calibrated after IntCal13 (Reimer *et al.*, 2013).**

Sample Code/ Lab. number	Depth (m) b.m.s.l.	Material	$^{13}\text{C}/^{12}\text{C}$ Ratio (‰)	Conventional R/C Age	2 $\sigma$ Calibrated age
12-ISMR2-155/ Beta - 397441	0.74	Shell	-1.4	2490 +/- 30 BP	Cal BC 145 - AD 100 (Cal BP 2095-1850)
13-ISMR2-373/ Beta - 397442	2.92	Plant	-14.4	2960 +/- 30 BP	Cal BC 1065-1055 (Cal BP 3015-3005)
14-ISMR2-459/ Beta - 397443	3.78	Plant	-13	3150 +/- 30 BP	Cal BC 1460-1390 (Cal BP 3410-3340)
15-ISMR2-564/ Beta - 397444	4.83	Shell	+1.4	5210 +/- 30 BP	Cal BC 3605-3345 (Cal BP 5555-5295)

## 5. Discussion and synthesis

### 5.1. Environmental identification

The obtained data of the present study indicate that the four units recognized from the lithological and molluscan analyses (described above) can be distinguished, from the oldest to youngest as follow (Figure 4):

**Unit 4** (4.54m - 5.80m depth): In this Unit, silty sand sediments with low values of magnetic susceptibility appear. These results, in combination with the abundance of brackish euryhaline molluscs *Cerastoderma* sp. and *Macra* sp., of marine euryhaline mollusc *Bittium* spp. and of marine molluscs Veneridae, indicate a shallow marine to open lagoonal environment of low energy in very good communication with the sea (Sakellariou, 1957; Syrides, 2008; Liu *et al.*, 2012).

**Unit 3** (3.68m - 4.54m depth): This Unit consists of muddy sand sediments. The abundance of marine euryhaline molluscs *Bittium* spp. and *Parvicardium* sp. brackish euryhaline mollusc *Macra* sp., in combination with low values of magnetic susceptibility at sediments, indicate a shallow marine to open lagoonal environment of high energy in good communication with the sea.

**Unit 2** (1.49m - 3.68m depth): In Unit 2, brackish euryhaline molluscs *Cerastoderma* sp., *Abra* sp., and *Macra* sp. and of marine euryhaline *Bittium* spp. and *Parvicardium* sp. are abundant. This fauna in combination with sandy mud to silty sand sediments with low values of magnetic susceptibility, indicate a brackish to lagoonal environment with fresh water inputs.

**Unit 1** (0.00m - 1.49m depth): the sandy mud to mud sediments with high values of magnetic susceptibility and lack of mollusc fauna indicate a fluvial - terrestrial environment.



## 5.2. Holocene paleoenvironmental changes: paleogeography

Evaluation of the aforementioned geomorphological, lithological, paleontological, chronological and magnetic susceptibility data allows determination of paleoenvironmental changes in Ismarida Lake and its surrounding lowland area. According to this scenario, before ~5400 to ~3400 years the area of interest was at good communication with the sea, and the environment was shallow marine to open lagoonal of low energy. Probably, the area was the inner part of a bay created by the sea transgression which covered the pre-Holocene paleosurface of the Vosvozis and Filiouris river valleys. The area at ~3400 years BP to ~3000 years BP, remained in good communication with the sea at a shallow marine to open lagoonal environment, but subsequently changed into high energy. This bay was open from south, allowing high energy waves with a south-north orientation to arrive at the beach creating a wave dominated coast. This is proved by the lack of mollusc *Cerastoderma* sp. and the rapid sedimentation. The shallow marine environment gradually turned into brackish to lagoonal with fresh water inputs, and remained like this for 1000 years. This occurred before ~3000 years due to the deltaic prolongation of the Filiouris River. The area of the lake was isolated and the open communication with the sea was interrupted. Finally, at ~2000 years BP a fresh water lake was formed. The Filiouris River delta plain was developed further southwards isolating the area from the sea. The area turned into a fluvial-terrestrial environment silted by fine grained sediments derived from Vosvozis River and overbank flow of Filiouris River.

## 6. Conclusions

The study area has gradually evolved from a shallow marine to a fluvial-terrestrial environment during upper Holocene. At ~ 3000 years BP the water communication between the lake and the sea interrupted due to fluvial process of the Filiouris River. The lake as it is known at present time was formed years later, when it was cut off by the deltaic plain of Filiouris River. The new deltaic plain of Filiouris is now located at the south of the lake. The lake was formed on the isolated western part of the pre-Holocene valley between the elevated deltaic deposits of Filiouris River and the alluvial fan of Vosvozis River further northwards. Nowadays, Lake Ismarida is supplied with fresh water only by Vosvozis River. The coarse sediments of the river are still deposited at the plain further northwards and only the fine sediments are transferred and deposited into the lake.

## 7. Acknowledgments

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