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A CONTRIBUTION TO ENVIRONMENTAL RESEARCH OF THE KORISSIA COASTAL WETLAND (CORFU ISL., GREECE), WITH THE APPLICATION OF COMBINED GEOLOGICAL AND GEOPHYSICAL METHODS SUPPORTED BY GEOGRAPHIC INFORMATION SYSTEMS

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Abstract

In the current paper are presented the results of a multidisciplinary study (stratigraphical, sedimentological, geophysical and geochemical) combined with modern techniques (G.I.S. and remote sensing). This study aims at integrating the natural and anthropogenic factors affecting the Korissia lagoon. It is a shallow coastal lagoon, communicating with the sea via an artificial channel. The area around the lagoon consists of alluvial sediments hosting, in places, newly formed and/or "old" (pre – Holocene) sand-dunes. The broader area constitutes a post-alpine sedimentary basin characterised by smooth morphological relief. The lower stratigraphic unit of the post-alpine sequence is a Pleistocene marly formation, which was detected as the basement (5-15 Ohm.m) by the geophysical survey. The resistivity-based basement map implies the existence of a "palaeo-gulf" trending E-W. These marls constitute the impermeable basement of a shallow aquifer hosted in the area. The salinity of the lagoon is very high during summer (>40psu) but it does not affect significantly the wells around it. The lagoon is well oxygenated, while the wells have lower D.O. values. Ammonia and nitrates are the main inorganic Nitrogen forms, in the lagoon and the wells, respectively. Phosphorus is the limiting factor for phytoplankton growth. Human activities affect the area that is in need of an environmental management plan in order to prevent ecological degradation.

Key words: Lagoon, Geomorphology, Geophysics, Stratigraphy, Geochemistry, G.I.S.

Περίληψη

Στην παρούσα εργασία παρουσιάζονται τα αποτελέσματα μίας πολυπαραμετρικής έρευνας (στρωματογραφικής, ιζηματολογικής, γεωφυσικής και γεωχημικής), σε

συνδυασμό με τη εφαρμογή σύγχρονων τεχνολογιών (Σ.Γ.Π. και τηλεπισκόπηση). Στόχος της έρευνας είναι η αποτίμηση των φυσικών και ανθρωπογενών παραμέτρων, που διαμορφώνουν το γεωπεριβαλλοντικό καθεστώς της Λιμνοθάλασσας Κορισσίων. Πρόκειται για μία ρηχή παράκτια λιμνοθάλασσα, που επικοινωνεί με τη θάλασσα μέσω ενός τεχνητού διαύλου. Η περιοχή καλύπτεται κυρίως από αλλούβιες αποθέσεις, ενώ κατά τόπους απαντούν πρόσφατες ή/και «παλαιές» (προ-ολοκαινικές) θίνες. Η ευρύτερη περιοχή αποτελεί μία μεταλλική λεκάνη ιζηματογένεσης, ήπιου γενικά μορφολογικού αναγλύφου. Την κατώτερη στρωματογραφική ενότητα της λεκάνης αποτελεί μία ακολουθία μαργών, η οποία από τη γεωφυσική έρευνα που πραγματοποιήθηκε, αποτελεί το γεωηλεκτρικό υπόβαθρο (5-15 Ohm.m). Η μορφολογία της επιφάνειας του γεωηλεκτρικού υποβάθρου υποδεικνύει την ύπαρξη ενός «παλαιοκόλπου» στη σημερινή θέση της λιμνοθάλασσας. Οι μάργες αποτελούν το αδιαπέρατο υπόβαθρο του φρεατίου υδροφόρου ορίζοντα, που αναπτύσσεται στα υπερκείμενα ιζήματα. Η αλατότητα της λιμνοθάλασσας, που εμφανίζεται ιδιαίτερα αυξημένη το καλοκαίρι (>50 psu), δεν επηρεάζει την ποιότητα του υδροφόρου ορίζοντα. Η λιμνοθάλασσα παρουσιάζει καλή οξυγόνωση, ενώ οι τιμές διαλυμένου οξυγόνου στα πηγάδια είναι χαμηλότερες. Η αμμωνία και τα νιτρώδη είναι οι κύριες μορφές ανόργανου αζώτου, που απαντούν στη λιμνοθάλασσα και στα πηγάδια, αντίστοιχα. Ο φώσφορος αποτελεί περιοριστικό παράγοντα για την ανάπτυξη του φυτοπλαγκτόν. Οι ανθρωπογενείς δραστηριότητες επηρεάζουν την περιοχή, για την οποία πρέπει να εφαρμοστεί ένα περιβαλλοντικό σχέδιο διαχείρισης, προκειμένου να αποφευχθεί η υποβάθμισή της.

Λέξεις κλειδιά: Λιμνοθάλασσα, Γεωμορφολογία, Γεωφυσική, Στρωματογραφία, Γεωχημεία, Σ.Γ.Π.

1. Introduction

Coastal wetlands, apart from their ecological value, are ecosystems of socio-economic significance. Such geoenvironments are the products of interaction between land (geology, hydrology), marine (waves, currents) and atmospheric (precipitation, temperature) processes.

The wetland under investigation is a shallow (<1.5 m) lagoon, lying at the southwest of Corfu island. Korissia lagoon covers an area of approximately 5 km² and it is connected to the Ionian Sea via a narrow artificial channel, which allows the exchange of water between the basin of the lagoon and the open sea (Fig. 1).

During the last decades, in Greece, many coastal and/or inland wetlands have been studied in terms of their geology, sedimentology, hydrology and ecology. Such an example is the Gialova lagoon (Petihakis et al., 1999). The present study, based upon a multidisciplinary survey, aims to inter-relate all the physical and human factors that are involved in the formation and the evolution of the Korissia lagoon.

2. Methodology

In this paper are presented the preliminary results of a multidisciplinary approach. Within the framework of a multiparametric data acquisition project, comprising of field surveys and laboratorial work, the initial data available in the existing literature (Maragoudakis, 1967, Leontaris, 1976, Tomara, 2005) were verified and enriched, while emphasis was given to specific targets, considered to represent key issues affecting the evolution and geoenvironment of the Korissia lagoon. Furthermore the implementation of a Geographic Information System (G.I.S.) was of crucial importance, providing valuable assistance for dataset management.

Fieldwork operations were carried out during two periods, in September 2005 and March 2006. This was deemed necessary in order to study and describe the current geo-environmental situation

and the seasonal variability of the prevailing physical and chemical conditions and, moreover, to estimate the physical or anthropogenic factors affecting the ecosystem. The main tasks of the field survey, during the aforementioned periods were the study of the area's tectonic, stratigraphic and geomorphologic features, the implementation of in situ measurements of abiotic parameters (water temperature, pH, dissolved oxygen, salinity), water and sediment sampling and an extensive geophysical survey. A detailed description of data acquisition operations follows below:

Geomorphological-Sedimentological Features

Three (3) topographic high resolution profiles (at 20m intervals) were carried out across the strip of land that separates the lagoon from the Ionian Sea, with the use of handheld GPS and topographic rods. Along these profiles surficial sediment samples have been collected and analysed, together with samples recovered from the bottom of the lagoon with the use of a Van Veen grab, according to Folk's (1974) procedure.

Geophysical Investigation

Fifty (50) Vertical Electrical Soundings (VES) were carried out in the area around the lagoon, in order to investigate the stratigraphic structure of the subsurface geological formations, underlying the study area. In order to overcome the limitations imposed by the absence of borehole data, a number of five (5) in situ measurements (VES No 23, 30, 41, 49 and 50) were carried out at outcrops of the main geological formations. Thus, representative resistivity values were obtained to be used for the interpretation of geoelectrical soundings. All soundings were performed by applying the Schlumberger array configuration. Maximum current electrode spacing (AB) reached up to 430 meters. Current electrode spreading operation met difficulties due to the occasionally steep relief, the dense vegetation and district construction (streets, residences, fences, etc). A Terrameter SAS300B with Booster (ABEM) was used for these measurements.

The geophysical data processing and interpretation was realised by applying the automatic method of Zohdy and Bisdorf (Zohdy, 1989), implemented by the software DCINV proposed by Markku Pirttijarvi (2004) and the commercial package WinSev6.1 of W-GeoSoft, with very good results.

Geochemistry

Surface water samples were collected from the lagoon, the communication channel and the open sea near the exit. Subsurface water samples were collected from wells around the lagoon. A small quantity of chloroform was added to each sample for nutrient preservation. The samples were filtered by Millipore nitrocellulose filters (8 μ m and 0.45 μ m) and stored in a refrigerator. Temperature, salinity, conductivity and dissolved oxygen were measured in situ by YSI63 and YSI 550A portable instruments. Ammonia, nitrites, nitrates and phosphates were measured spectrophotometrically (Grasshoff et al., 1999).

Several sediment samples were collected on September 2005 with the use of a Van Veen grab. Most of the lagoon's bottom was covered by grass and the samples contained large numbers of shellfish. The sediment samples were freeze-dried, dry sieved and analysed for Total N and Total P (Ladakis et al., 2003).

GIS Implementation

The multidisciplinary character of this study, made the use of geographic information systems necessary. A geodatabase covering the needs of archiving and visualizing the data, obtained from different sources, such as geological - geomorphological fieldwork, geophysical measurements and chemical analysis was therefore designed and implemented. The system was based on a digital elevation model (DEM) of 5 meters vertical resolution and a series of remotely sensed images of different spatial resolution and acquisition dates. The images (IKONOS, Quickbird, Landsat 5TM, air-photos) were spectrally analyzed and combined for producing digital pseudo chromatic and

multi temporal images, used in order to detect the progressive changes in the lagoon and the surrounding area.

3. Results and discussion

3.1. Geomorphology

The Korissia lagoon (Fig. 1) is elongated in shape (5300 m long and 1500 m wide) located parallel to the shoreline having a NW-SE orientation. It is shallow, with water depths below 1.5 m and connected to the sea via a narrow (8 m) and shallow (<1 m) artificial channel. Moreover, the coastal exit of the channel is protected from the waves by artificially placed breakwaters.

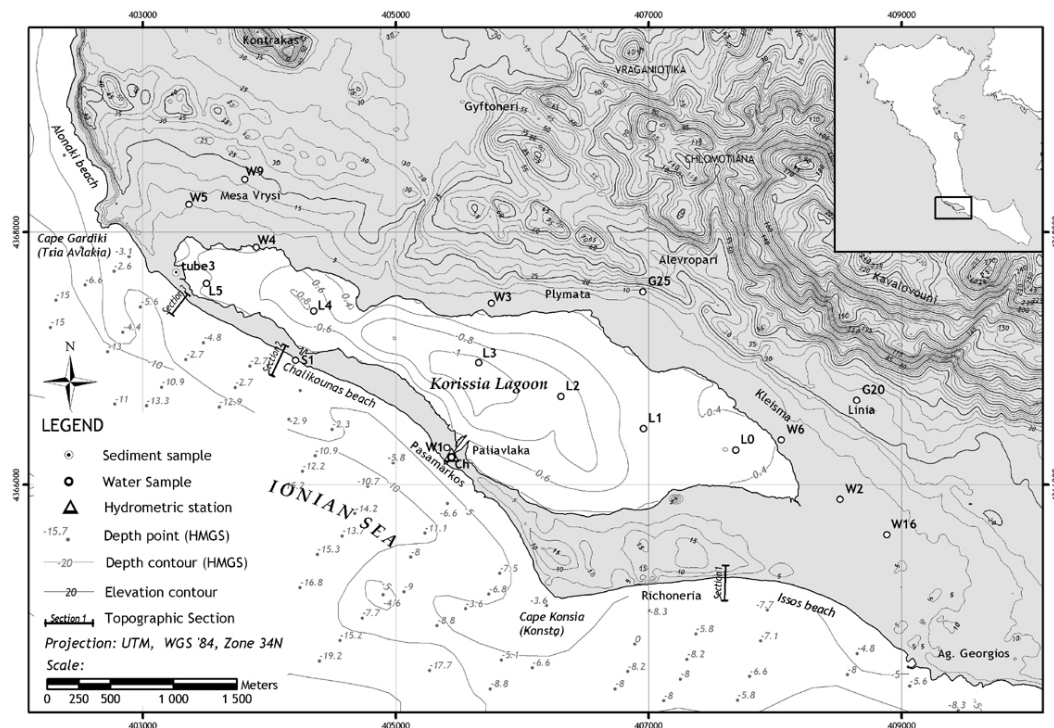


Figure 1 – Location and geomorphologic features of the study area. Location of water & sediment sampling sites.

It is separated from the open Ionian Sea by a strip of land, up to 200 m wide, which can be distinguished into two parts: a part southwards the channel which consists of uplifted Plio-Pleistocene formations, including “old” sandy dunes with maximum elevations up to 15 m and an elongated deposit northwards the channel, that is essentially a beach barrier hosting lower recent sand dunes, reaching up to 2 meters height (Fig. 2). In addition, at the foot of the “old” (pre-Holocene) high dunes, modern dunes have been developed, whilst the presence of beach-rock formations along parts of the beach face indicates mixing of fresh and sea water.

The nearshore bathymetry is smooth with the sandy bed dipping gradually with slopes up to 12 degrees. Sub-bottom morphology, especially at the southern end of the lagoon shows a northward along shore sediment transport.

Towards the hinterland, the lagoon is surrounded by a hilly relief with elevations up to 60 m. These hills represent “old” dunes of pre Holocene age, indicating the position of a palaeoshore zone. Furthermore, their sedimentological and stratigraphic characteristics are similar to the aforementioned “old” dunes, located at the SW part of the lagoon.

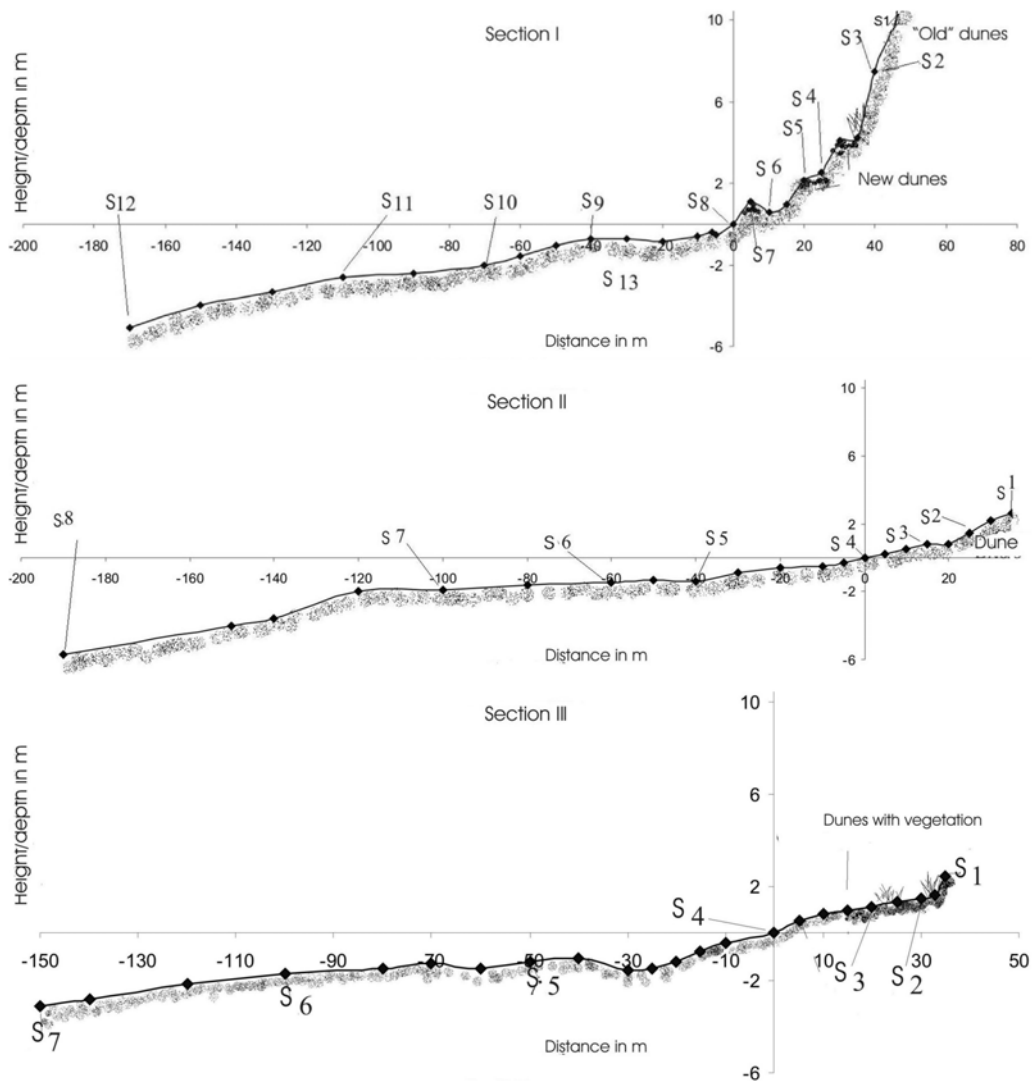


Figure 2 - Topographic profiles along the sections I, II and III, whose locations shown on figure 1. S denotes the locations of the surface sediment samples.

3.2. Geology – Stratigraphy

The alpine basement consists of sediments belonging to the Ionian tectono-stratigraphic unit (Aubouin, 1959, Jacobshagen, 1986) of the external micro-plate of the Hellenides (Papanikolaou, 1997). At the broader area of the Korissia lagoon, only part of the Ionian stratigraphic column is exposed (Fig. 3). At the northeastern part (Gyftoneri, Kavalovouni), where the relief is relatively higher, there are highly brecciated limestones and gypsum representing part of the Triassic evaporites. There is also a smaller outcrop of thick bedded limestones of Jurassic age at the northwestern part of the area, forming the Kontrakas hill. The major part of the alpine basement is covered by younger sediments which create a relatively impermeable layer beneath the formed lake.

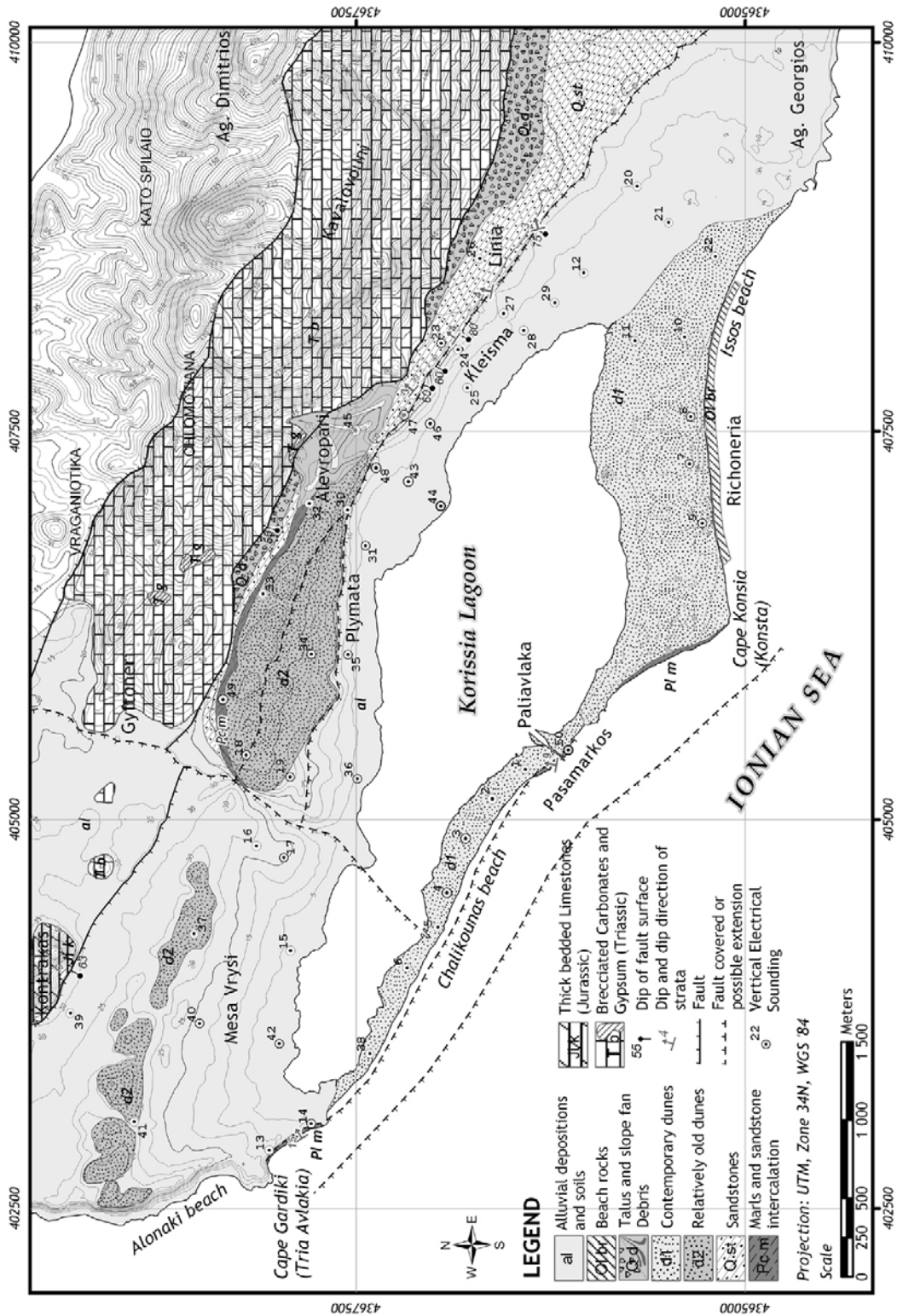


Figure 3 - Geotectonic map of the study area.

According to previously published studies, the oldest post alpine sediments exposed around the lagoon area are of Pleistocene age (Rögl et al, 1997). The lower stratigraphic unit is a marine to brackish, predominantly grey, marly to clayey sedimentary sequence, lying unconformably over the alpine basement. The sequence is continuing with a 10 m thick sandstone layer deposited over the 12 meters thick marls, ending with a thin sapropel layer of Late Pleistocene age. The sequence is slightly folded by open folds with E-W axis direction. Above these beds lies a formation dominated by siliciclastic sandstones, sands, and gravels, followed by a zone with fossiliferous cavernous, calcareous sandstones (corallineacean - packstone) of Late Pleistocene age.

The aforementioned post alpine successions are covered by cross bedded sand dunes. The older dunes are found at higher altitudes parallel and adjacent to the tectonic contact between the alpine basement and the recent deposits. The most recent dunes are located along the southern coastline, a forming a beach barrier that separates the lagoon from the Ionian sea. The unconformity is clear at the beach of Richoneria where beach rocks are currently formed along the coastline.

3.3. Geoelectrical Investigation

In almost all soundings, a formation with resistivity values between 5.0-15.0 Ohm.m was detected. In situ measurements in marl outcrops (VES 49 and 50), yielded resistivity values between 5.5 and 13.0 Ohm.m. An example of the interpretation results of VES 16 and 23 are presented in figure 4. The formation of 7.0-9.0 Ohm.m is considered to represent the basement, corresponding to the lower stratigraphic unit of the post-alpine basin in the investigated area.

According to the interpretation results of the geophysical investigation, a resistivity basement map was created (Fig. 5). This map shows that the absolute heights (elevation) of the basement, in the broader area, range from 40 to -30 meters. A 3D representation was drawn in order to visualize the relief of the surface of the geophysical basement (Fig. 6).

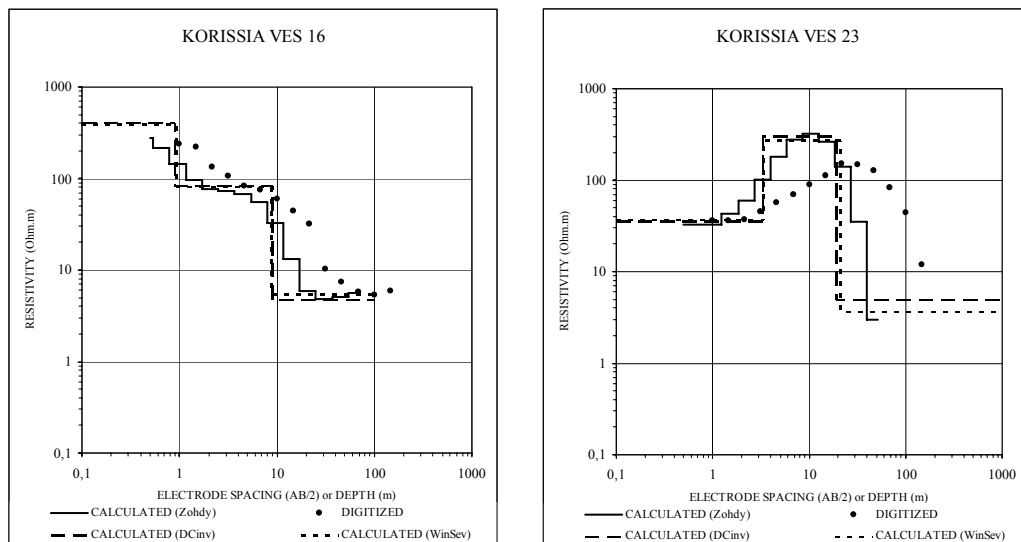


Figure 4 -Interpretation results of VES 16 and 23.

In the area of the lagoon the minimum absolute heights, approximately -20 meters, are observed in the western margin (VES 38). As indicated on the map of figure 5, the basement forms an asymmetrical sub-basin with its long axis trending E-W, delineated by the -10 meters contour line. The basement at the SE part of the investigated area submerges deeper (over -30 meters), probably indicating the existence of a different depositional environment.

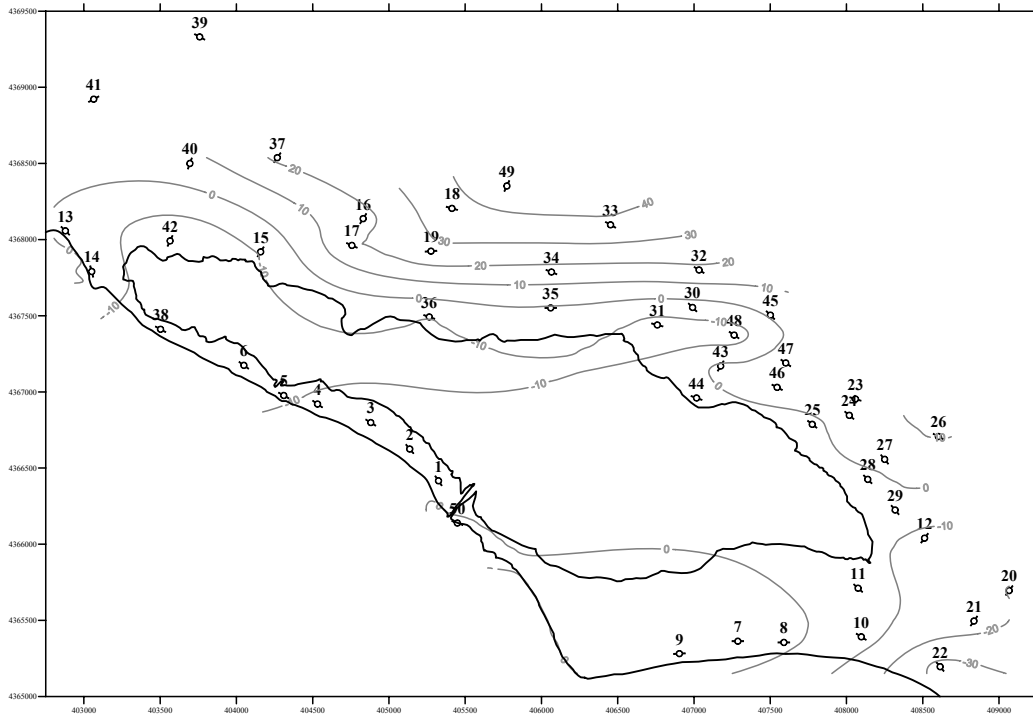


Figure 5 - Resistivity basement map, based on the VES interpretation.

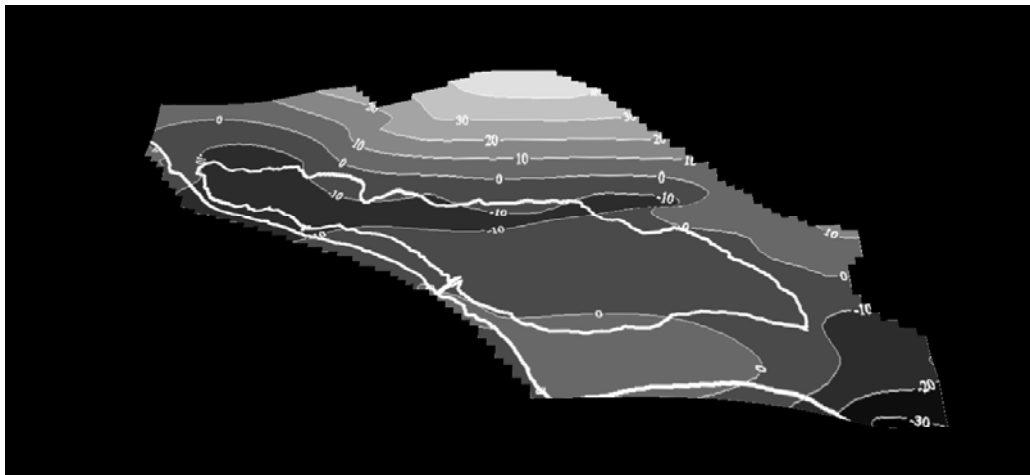


Figure 6 - 3D representation of the geoelectrical basement.

3.4. Sedimentology

The sediments of the beach zone consist mainly of sands (Table 1) with some gravels (<10%), which have been found on the foot of the beach face and/or along the berm-crest. In general, the subaqueous part of the beach zone is also sandy, while grain size becomes finer seawards. The granulometric characteristics of the sediment samples along the three sections (Fig. 1 and 2) are presented on Table 1.

Table 1 - Sediment characteristics of the surface samples taken along the topographic sections (I, II & III) from the beach zone and the old dunes (for locations see Fig. 1).

Sample No.	Gravel %	Sand %	Mud %	Mz (Φ)	σi (Φ)	Ski	Folk (1974) characterization
Topographic profile I							
1	4.4	95.8	0.1	1.60	0.88	-0.35	(g)S
2	0.7	99.3	0	1.65	0.50	-0.08	(g)S
3	0	100	0	1.73	0.35	0.15	S
4	0	100	0	1.68	0.34	0.26	S
5	0	100	0	1.57	0.44	0.02	S
6	0.9	99.1	0	1.09	0.46	-0.31	(g)S
7	0	99.9	0.1	1.58	0.38	0.17	S
8	0	100	0	1.86	0.42	0.01	S
9	0	99.9	0.1	1.57	0.49	0.41	S
10	0	100	0	1.89	0.58	0.16	S
11	0	99.9	0.1	2.42	0.63	-0.11	S
12	0	100.0	0	1.64	0.36	0.23	S
Topographic profile II							
13	0	100	0	2.173	0.47	0.31	S
14	0	100	0	2.062	0.38	0.24	S
15	0	100	0	2.140	0.41	0.35	S
16	0	99.9	0.1	2.187	0.53	0.26	S
17	0	99.9	0.1	2.457	0.59	-0.12	S
18	0	99.8	0.2	2.285	0.66	0.06	S
19	0	99.6	0.4	2.567	0.58	-0.11	S
20	0	99.2	0.8	2.548	0.66	-0.04	S
Topographic profile III							
21	0	99.8	0.2	2.367	0.51	0.25	S
22	12	87.7	0.3	1.963	1.39	-0.44	gS
23	0	100	0	2.334	0.50	0.30	S
24	0	100	0	2.193	0.51	0.27	S
25	0	100	0	2.463	0.55	-0.06	S
26	0	99.9	0.1	2.491	0.58	-0.10	S
27	0	99.8	0.2	2.569	0.56	-0.16	S
“Old” sand dunes							
28	0	99.9	0.1	1.190	0.56	0.07	S
29	0	99.9	0.1	1.821	0.34	-0.01	S

The fact that the samples collected from the “old” (pre-Holocene) dunes are relatively coarser compared to those taken from the modern beach zone, indicates that the latter have been formed, most likely, from the material of the aforementioned “old” dunes.

3.5. Hydrology - Geochemistry

The lagoon waters present exceptionally high values of salinity (>45 psu) during the summer, indicating the influx of sea water and the excess of evaporation over precipitation (Table 2). On the contrary, salinity values are ~20 psu during winter (wet season) due to increased precipitation and groundwater contributions. The fact that lagoonal waters never become fresh, shows that there is always mixing with marine waters, either through the communication channel and/or underground sea water intrusion.

Table 2 - Physical characteristics (temperature (T), pH, salinity (S), dissolved oxygen (DO)) of the waters from the lagoon, artificial channel, wells and the sea.

Region	September 2005				March 2006			
	Temp. (0 C)	pH	S (psu)	DO (mg/l)	Temp. (0 C)	pH	S (psu)	D.O. (mg/l)
Sea	25.4	7.9	37.1	9.1	14.7	8.1	35.7	9.8
Channel	26.2	8.0	48.5	8.9	15.9	8.0	19.3	10.1
Lagoon	23.6-26.2	8.0-8.4	>50	4.6-7.7	13.5-16.2	8.0-8.6	15.6-19.6	8.2-11.2
Wells	18.4-23.3	6.7-7.4	0.2-0.6	3.5-6.5	12.2-16.6	6.8-7.9	0.2-0.9	3.1-10.3

Most of the subsurface water of the area is used, through wells, for irrigation. Agricultural activities of the area mainly include vegetable and flower cultivations. Fishing is also practised, as the lagoon bottom is covered by sea grass, which constitutes perfect food for fish and contains large amounts of shell fish and crabs.

The saline water of the lagoon does not affect the wells, with the exception of wells W1 (2.3 psu), W4 (18 psu) and W6 (2 psu). This is most probably due to their proximity to the lagoon. The lagoon water was well oxygenated during both sampling periods. The D.O. values were higher on March 2006, due to decreased salinity and temperature at that time. The wells, in general, have lower dissolved oxygen values than the lagoon both in late summer and in late winter.

The following diagrams (Fig. 7) show the seasonal fluctuations of the various forms of nitrogen and phosphorous in lagoon and wells' water.

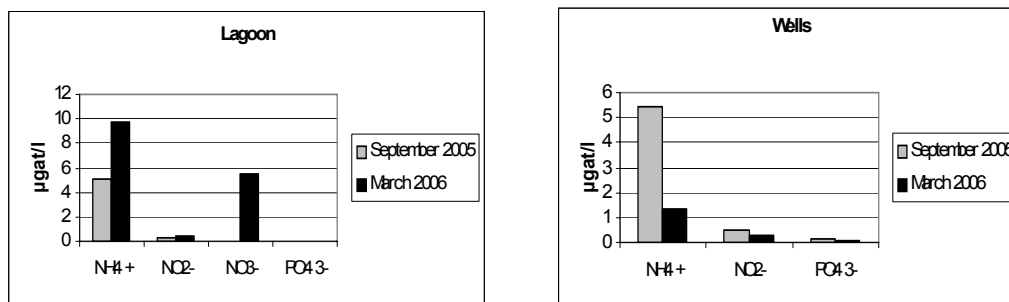


Figure 7 - Concentrations of nitrogen forms and phosphorous in the Lagoon and the well water samples (for sampling sites see Fig. 1).

Ammonia is the main inorganic N form in the Korissia lagoon (>75%) whereas nitrates are the predominating N form in the wells around the lagoon, with values higher than 400 µgat/l.

All inorganic N forms in the lagoon exhibit higher values in winter than in summer. The opposite trend is observed for inorganic N and P in subsurface water. The increased ammonia value in winter is attributed to the amount produced by the degradation of sedimental organic N (Diamantopoulou et al., 2006).

The high values of nitrates in well water samples are an indication of fertilizers contamination of the wells. Freshwater input to the lagoon in winter, containing such amounts of nitrates is probably the reason for the increased nitrates value in the lagoon water at that period. On the other hand, no nitrates were detected in the lagoon on September and this can be attributed to the low freshwater input and the simultaneous seawater (no nitrates detection) intrusion to the lagoon during summer. Nitrites values in the lagoon were higher than nitrites values of sea water especially on March 2006.

Phosphates values in the lagoon were very low (below 0.08 $\mu\text{g}/\text{l}$), whereas in the wells phosphates did not exceed 0.72 $\mu\text{g}/\text{l}$ with some exceptions that varied between 1.6-10 $\mu\text{g}/\text{l}$ indicating the existence of fertilizers contamination. Phosphorus is the limiting factor for phytoplankton growth in the Korissia lagoon (Tomara, 2006, Diamantopoulou et al., 2006) and as a result phosphates produced by sedimental organic P degradation, are consumed by aquatic flora very quickly. This results in the low phosphates values in the lagoon water at all sampling periods (Ladakakis, 2006).

According to eutrophication criteria (Karidis et al., 1988), Korissia lagoon can be characterized as eutrophic, referring to all nitrogen forms, especially on March 2006 and oligotrophic referring to phosphorous at both sampling periods.

4. Conclusions

Based on the results of the present research, the lagoon and the surrounding area constitute a recently developed geological structure, which is still evolving. The “old” dunes located in the northern margin of the lagoon delineate a “palaeoshore”. Moreover, the morphology of the surface of the resistivity basement (impermeable marly sequence), also supports the existence of a former narrow gulf, trending E-W. The SW part of the contemporary land strip, separating the sea from the lagoon, is associated with the earlier existence of a beach barrier.

Today, the lagoonal waters are strongly affected by freshwater inputs, especially during winter time, whilst during the summer period the influx of sea water and the excess of evaporation over precipitation make salinity values higher (>45 psu) than those of the Ionian Sea. Moreover, human activities and mainly agriculture influence the lagoon’s chemistry. The latter is also related to the aquatic flora. Accordingly, nutrient values in the lagoonal waters increase from autumn to late winter (wet period), while the opposite trend is observed in groundwater during the same period.

The Korissia lagoon is an interesting and fragile coastal wetland and needs further study and continuous monitoring in order to avoid possible environmental degradation and to ensure its sustainable exploitation; whilst the latter can only be achieved through the implementation of an environmental management plan based upon the obtained scientific knowledge.

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