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SEDIMENTOLOGICAL AND PALAEOENVIRONMENTAL CHARACTER OF LAKE KORONIA SEDIMENTS

Doani S.[1], Albanakis K.[1], Koukousioura O.[2] and Koliadimou K.K.[1]

[1]Aristotle University of Thessaloniki, School of Geology, Department of Physical and Environmental Geography, 54124, Thessaloniki, Greece, sofiadoani@gmail.com, albanaki@geo.auth.gr, koliadim@geo.auth.gr

[2]Aristotle University of Thessaloniki, School of Geology, Department of Geology 54124, Thessaloniki, Greece, okoukous@geo.auth.gr

Abstract

The aim of the present study is to investigate the sedimentological characteristics of Lake Koronia down to a depth of 3.5m below lake bottom. Sampling operations took advandage of a season that the lake bottom was exposed to subaerial conditions. The sedimentological analysis proved that sediments consist of mud to sandy mud, with 2 phases of very fine sand fractions. The proportion of dry organic matter contained into sediment, appears to be generally small while the rates of moisture and volatiles are relatively high. Furthermore, this study examines the distribution of ostracod populations in the sediments of the lake in relation to depth, grain size and other environmental conditions of this water body. Four ostracod species were identified: Candona neglecta, Darwinula stevensoni, Heterocypris spp. and Limnocythere inopinata. The study of freshwater ostracods provides information for the palaeoecological/palaeoenvironmental conditions during the sedimentation.
Keywords: *Freshwater environment, grain size analysis, Ostracods.*

Περίληψη

Σκοπός της παρούσας μελέτης είναι η διερεύνηση των ιζηματολογικών χαρακτηριστικών της λίμνης Κορώνειας από τον πυθμένα έως το βάθος των 3,5 m. Η δειγματοληψία των ιζημάτων πραγματοποιήθηκε σε μια περίοδο που ο πυθμένας της λίμνης ήταν εκτεθειμένος σε χερσαίο περιβάλλον για μεγάλο χρονικό διάστημα. Η ιζηματολογική μελέτη έδειξε ότι τα ιζήματα αποτελούνται από ιλύ έως αμμούχο ιλύ. Η αναλογία της οργανικής ύλης επί ξηρού που περιέχεται στα ιζήματα, φαίνεται να είναι γενικά μικρή, ενώ τα ποσοστά υγρασίας και τα πτητικά είναι σε υψηλά επίπεδα. Επιπλέον, μελετήθηκαν τα οστρακώδη που περιέχονταν στα δείγματα ως προς την κατανομή των πληθυσμών τους σε σχέση με το βάθος, το μέγεθος των κόκκων και άλλες περιβαλλοντικές συνθήκες. Προσδιορίστηκαν τέσσερα είδη: Candona neglecta, Darwinula stevensoni, Heterocypris spp. και Limnocythere inopinata. Η μελέτη των οστρακωδών παρείχε πληροφορίες για τις παλαιοοικολογικές / παλαιοπεριβαλλοντικές συνθήκες που επικρατούσαν κατά την απόθεση των ιζημάτων.
Λέξεις κλειδιά: *Περιβάλλον γλυκού νερού, κοκκομετρική ανάλυση, Οστρακώδη.*

1. Introduction

Lake Koronia occupies the western lowland area of Mygdonia Basin where a complex system of wetlands exists, protected under RAMSAR convention and included in Natura 2000 network. (Mitraki *et al*., 2004). However, the lake is now considered as one of the most downgraded wetlands in Greece. During the recent years, the lake faced intense environmental problems and was heading to total drying out. Before the starting period of the large water loss (~1985), the surface of the lake was about 45-49km^2 and ranked (in terms of range) as the 4th largest lake in Greece (Mylopoulos *et al*., 2007). The downgrade, except of quantitative is also qualitative, as the wastewater from industrial activities and sewage from Lagadas town drained straight into the lake. By the late 1980s, Lake Koronia had an active commercial fishery, but this became no longer sustainable because of the progressive decline of the water level (Economidis *et al*., 1988; Fotis *et al*., 1992). Towards the end of 2014 and during 2015, heavy rains increased the lake water level. As a result, water reached up to 2m. According to measurements of the "Management Entity of Lakes Koronia-Volvi", (responsible for observation, protection and management of the National Park of Koronia-Volvi and Macedonian Tempe), the water covered areas where in previous years there was no water existence (http://www.foreaskv.gr/). The aim of the present study is to investigate the sedimentological characteristics of Lake Koronia until a depth of 3.5m below lake bottom. Sampling operations were performed at a time that lake bottom exposed to subaerial conditions for enough time that fieldwork was possible in an area where old maps indicate a depth of 5.5m. The knowledge of the sedimentological characteristics is essential for the dealing of the environmental problems this region suffers from. Furthermore, this study examines the distribution of ostracod populations in the sediments of the lake in relation to depth, grain size and other environmental conditions of this water body. Studies about freshwater ostracods are crucial in order to provide information for palaeoecological/ palaeoenvironmental analysis due to the establishment of ostracod habit patterns.

2. Study Area

Koronia Lake (latitude 40°41', longitude 23°08') is located a few kilometres northeast of the city of Thessaloniki. The lake has an oval shape and shallow water depth. It is considered, along with Lake Volvi, as the two remnants of an old Tertiary lake (Lake Mygdonia) of tectonic origin (Psilovikos, 1977). Tectonic origin lakes often have an elongated shape, steep cliffs and are quite deep. Since they are formed by earth's surface deformation, they are related to existence of normal faults, like in the study in question (Vouvalidis, 2011). Mygdonia Lake drained through Rechios gorge and gradually, deepening the gorge, drained completely to Srymonikos bay, leaving the two deepest regions occupied by the recent Koronia and Volvi lakes (Psilovikos, 1977). Koronia, until 1970 had a maximum water depth of 8m, an altitude of its surface at 75m and it was approximately 38m higher than Volvi Lake (Psilovikos, 1977). In terms of geomorphological and anthropogenic influence the region can be distinguished into a natural and an anthropogenic state. During the natural state, there was no surficial communication between Koronia and Volvi. The situation changed during 1930-1940, by the opening of the artificial drainage trench (trench Derveni) in order for new cultivation lands to be created (Zalidis *et al*., 2004). The main streams that discharge into Lake Koronia are: Bogdanas stream (that drains the area south of Lahanas and flows west of the lake), Kolchiko stream (that drains the Ossi-Krioneri-Kolchiko areas and flows north of the lake) and Agia Paraskevi-Platanaras stream (draining the Adramerio-Vasiloudi-Gerakarou-NE Hortiatis areas and flows southeast of the lake). The streams erode fluvial and old lake sediments, and transported large quantities loads into the lake, resulting in gradual silting of the lake, (Psilovikos, 1977). After 1990 due to malpractice in water usage Koronia Lake drops dramatically its surface altitude with depths fluctuating from 0.8m up to 2.5-3m, depending on the hydrological year (Zalidis *et al*., 2004). The dramatic recent reduction in the 'sediment accommodation space' might intensify sedimentation process that already had been observed by Psilovikos (1977).

3. Methods

3.1. Borehole data and sampling

The coordinates of the drilling were 40°41'45.4" N, 23°11'08.8"E and the reception was conducted by portable satellite GPS (Figure 1, Figure 2). The elevation above MSL (Mean Sea Level) was 71m according to personal discussions with scientists from “Management Entity of Lakes Koronia-Volvi”).

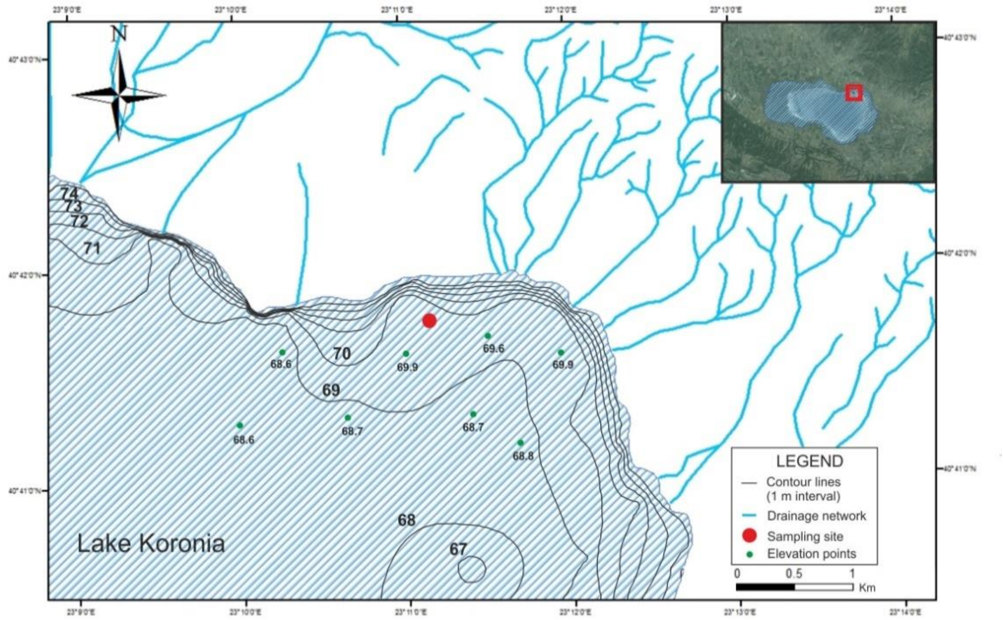

Figure 1 - Elevation map of Koronia, based on the map of GMS (Geographical Military Service) 1:50.000 (sheet of Thermi, March 1982), Coordinate System: WGS 1984 UTM, Zone: 34N, Projection: Transverse Mercator.

The sampling operation took advantage of a period that most of the Lake Koronia bottom was exposed and under subaerial conditions during all summer and early autumn of 2014. Mud-cracks were formed on the lake bottom, dry enough for a person to step on them without sinking into the underlying mud. A limitation was the weight of the sampling equipment, (because it had to be curried manually) since the mud-cracks had a mean diameter of 50-70cm, with gaps between them of 15cm, reaching a depth of 40-70cm. A test with a hand-held penetrometer showed that a sampling depth of 3.5m was achievable by pushing manually the sampler in the bottom. Special drilling equipment like vibracoring device was excluded, not only because of the transportation problems but also because the vibrations might cause liquidification of the soft and watery underling sediments, risking personnel and equipment to sink into the mud. Therefore a special sampling method was designed by the authors. An apparatus was constructed at the Department of Physical and Environmental Geography, Aristotle University of Thessaloniki, in order to ensure the sediment entering into the sampling cores at the right depths. After some field tests, it was realized that only 0.5m of watery sediment could be penetrate into a plastic tube sampler without distortion. Hence core samplers of 3.5 cm diameter PVC tubes were constructed, with a rubber valve fitted on the upper part of the tube, in order the air to come out as the sediment was pushed in. The valve had to close at retrieval, to prevent sediment come out by suction power. Each sampler attached to 1m steel rods extendable by securing one to the end of the other. A maximum of 3 steel rods were used, making a maximum of 3m length. In order to drive the sampler to appropriate depth, several tube-guides of 0.5m difference were constructed by 5cm diameter PVC tubes. Each of those tubes had a special head that was closing the deepest end and an apparatus to open it, when the appropriate depth was reached. The sampling procedure was to push 6 tube-guides (0.5m, 1.0m, 1.5m, 2.0m, 2,5m and 3.0m) into the sediments, of a 0.5m distance with each other. Then 6 sampling tubes were used, one for each depth, to achieve sampler cores from 0.5m-1.0m, 1.0m-1.5m etc. up to 3.0m-3.5m. Upon retrieval, each core sampler was sealed with plastic membrane and transferred to the laboratory. Sediment extracted from the samplers in the laboratory, photographed, described, on the basis of texture and the sediment color was identified by Munsell Soil Color Chart. Afterwards, smaller sub-samples were collected at intervals, for further sedimentological and micropalaeontological analysis. In the majority of the samples, sediment retrieval was about 70%. The 30% loss was due to the conditions of the sediment. The presence of mud cracks, on the top sediment layer, along with the collapsed surface material into the cracks, made a mixed top layer. Therefore, was decided that sampling 0m-0.40m would be no profitable, especially for micropalaeontological analysis. The method, despite the problem of 70% sediment retrieval in each 0,5m long sampler, ensures that each sample represents depths below the guide-tubes. Therefore the uncertainty of vertical position is 0,15m.

Figure 2 - Sampling site 40º41’45.4” N, 23º11’08.8”E Lake Koronia. (Modified photo by A. Avramidis, K. Koukoumakas, 30/07/2014, http://www.vice.com/gr/read/limni-korwneia).

3.2. Laboratory analysis

Detailed analysis performed in the laboratory of sedimentology of the Department of Physical and Environmental Geography, Aristotle University of Thessaloniki, where organic matter content, mo isture and volatile matter rates were calculated. For the determination procedure of the moisture rat es and the volatile matter, the calculation had to be done immediately after sampling in order to av oid losing moisture and volatiles through evaporation. This was an important factor for reducing th e error rate. Each sample was weighed on a precision balance. Then, all samples were dried in an o ven (90ºC) and weighed (once again) for the purpose of calculating the weight of the moisture and volatiles which original samples contained and were lost (due to oven heat evaporation). For the de termination of the organic matter, the hydrogen peroxide method was applied. According to this m ethod, the organic matter of soils is converted to carbon dioxide by means of moist and dry combus tion (Robinson, 1927). As soon as the soil with hydrogen peroxide H_2O_2 (Perhydrol) 30% was dige sted, a certain loss of weight was observed. This loss represents the organic matter percentage that has been removed through the reaction. Once the chemical reaction diminished enough, (boiling he lped to achieve that), the procedure was completed (for the calculation dry weight was used, before and after the chemical reaction) (Psilovikos and Psilovikos, 2010). Furthermore, it is known that o rganic matter’s specific weight is less than 1.5 and that of aluminosilicate minerals is 2.6-2.7 (Mac

Farlane, 1969). Consequently, it was necessary to calculate the specific weight of the sediments in order to verify that all organic matter had been successfully removed.

3.2.1 Grain size analysis

In this study, 7 samples from different horizons were analysed and determined according to the quantity of the fractions: sand, silt and clay. Therefore, a 0.063mm (4.0 φ) sieve was used to separate the sand particles by wet sieving. Finer particles (silts and clays) were analysed by the use of the pipette method, measuring weight percent of each sample (Folk, 1974). Sampling procedure evolved according to the following table (Table 1):

Table 1 - Details about pipette method sampling.

Diameter of Particle (mm)	< 0.063	< 0.004
Depth of Withdrawal (cm)	10	5
Time of Withdrawal	seconds	min'/sec"
Temperature (Celsius) ~23º	27	57'05"

Grain size statistical analysis was processed using the graphical technique according to Shepard (1954), Folk (1956) and Folk *et al.* (1970). Basic sand, silt and clay percentages were plotted on equilateral triangular diagrams that according to USGS, allow simple presentation, classification and comparisons between the samples (http://pubs.usgs.gov/of/2000/of00-358/text/chapter1.htm).

3.2.2 Faunal analysis

A total of 37 samples were collected from the entire length of the core, of which 12 were selected for subsequent detailed Micropaleodological analysis. These samples selected from the core at a sequence of 4-5cm or thicker (7g dry weight), treated with H_2O_2 (Perhydrol) 30%, washed into a 0.125mm (3.0 φ) sieve and dried in a 60ºC oven. Ostracod shells were collected from the >0.125mm size fraction. Each sample was splited into smaller representative fractions, required to contain at least 300 ostracod shells. If the collection of the required number of shells was not feasible, the analysis to the total sample was applied. Microfauna have been identified under a stereoscope (JENA). A scanning electron microscope analysis (SEM Jeol JSM- 840A, AUTH - Faculty of Sciences) has been used for taxonomical and other purposes. The identification of ostracods was based on Holmes *et al*. (2002), Horne *et al*. (2012), Xiangzhong *et al*. (2010), Mischke *et al*. (2012) and Van Baak *et al*. (2012). Total ostracod fauna in each sample was collected and measured. Afterwards, the ostracod assemblages have been calculated as relative abundance. Density/gr was calculated as the total number of ostracod assemblages contained in 1gr of dry sediment. Furthermore, other indices as Taxa (S) and Dominance (D) were calculated using Past.exe 1.23 software package (Hammer *et al*., 2001).

4. Results- Discussion

Results of grain size analysis showed that samples consist mainly of silt, clay and small rates of very fine sand (mud to sandy mud) (Figure 3, 4). From the stereoscopic examination of the finer fractions of sand, a significant number of ostracod shells was revealed (especially in sample 4 (1.98m-1.62m)). Apparently the sand fraction consist of two phases one allochthonus, consisting of very fine quartz and mica grains of fluvial origin with sizes from 3.5φ to 4.0φ and one autochthonous, consisting of biogenic origin ostracod cells with sizes 3.0φ to 3.5φ. The allochthonus phase of the sand fraction of sample 2 (2.78m- 2.66m) consists of very fine grains of mica and quartz, while sample 5 (1.48m- 1.20m) consists only of very fine grains quartz. The liquid phase and any organic volatile matter in the sediments, appear to be large, ranging from 37.2% to 53.63% of the total weight (Figure 4). If the weight proportion is converted to volume proportion then the dry sediment (density 2.67) represents roughly 35% to 24% of the total volume of the wet sediments. The proportion of dry organic matter contained into sediment, appears to be generally small (<2%) with an exception of the intermediate layer (sample 4, 1.98m-1.62m), as it contains 4% organic matter.

Pertaining to faunal analysis, from the quantitative study, a total of 4 species were identified in Koronia borehole, represented by *Candona neglecta*, *Darwinula stevensoni*, *Heterocypris* spp. and *Limnocythere inopinata* in good state of preservation. In some cases *L. inopinata* is the dominant species constituting 100% of the fauna. In further analysis, at 3.67m-2.12m depth, ostracod fauna mainly consists of *C. neglecta* and *Heterocypris* spp (max ~56% and ~55% respectively), accompanied by *D. stevensoni* and *L. inopitata* with lower values*. C. neglecta* is an oligothermophilic, freshwater to a-mesohaline species that lives in very shallow to deep waters with low oxygen (Horne *et al*., 2012), while *Heterocypris* spp. lives in shallow water bodies with clayey substrates lacking any macrophytes (Meisch, 2000). Density/gr and Dominance D are relatively low while Taxa S acquires the highest values. At 2.12m-0.83m, ostracod fauna is represented exclusively by *L. inopinata* (relative abundances of 100% in all studied samples). This species prefers waters rich in macrophyte debris on the lake bottom and calm water conditions as soon as it is unable to swim (Meisch, 2000). According to Geiger (1994) and Meisch (2000), *L. inopinata* can live in a wide range of environmental conditions, from freshwater to highly alkaline lakes, with ranging depth. Dominance D acquires the highest values while Taxa S the lowest. Density/gr is becoming relatively high (1325 speciments/gr). At 0.83m-0.45m borehole depth faunal composition changes again consisting of 3 species. *D. stevensoni* is presented with higher values (~43%), while *C. neglecta and L. inopinata* follow with lower values (both with ~28%)*. D. stevensoni*, demonstrates high hypoxia tolerance (Rossi *et al*., 2002) and is a thermoeuryplastic, freshwater to a-mesohaline species that lives in shallow waters with low oxygen (Horne *et al*., 2012). Density/gr and Dominance D are decreasing while Taxa S shows an increasing. Within each environment type, species existence is regulated by a wide range of factors, such as habitat type, stability, water depth, energy level, water temperature, salinity, presence of aquatic macrophytes and species competition (Holmes *et al*., 2002).

The obtained of the study could be distinguished into 4 units:

Unit 1 (3.67m-2.12m): Contains sandy mud sediments, low rates of organic matter (0.3%-1.2%) and approximately 38% moisture and volatiles. The ostracod fauna indicates a freshwater environment, shallow water depth, with the possibility of low oxygenation and a clayey substrate lacking or presenting minimal vegetation cover.

Unit 2 (2.12m-0.83m): This Unit contains two distinguished lithological subunits (Subunit 2a and 2b), although faunal composition does not present any differentiation. Subunit 2a (2.12m-1.48m), contains mud sediments, relatively high rates of organic matter (4%) and approximately 53% moisture and volatiles. Subunit 2b (1.48m-0.83m), contains sand to sandy mud sediments, low rates of organic matter (0.8%-1.2%) and approximately 45% moisture and volatiles. The ostracod fauna which only consists of *Limnocythere inopinata*, indicates calm water conditions, rich in macrophytes and extremely shallow water depth.

Unit 3 (0.83m-0.45m): Contains sandy mud sediments, low rates of organic matter (1.5%) and approximately 38% moisture and volatiles. The ostracod fauna indicates shallow calm water conditions, possibly with low oxygen and a substrate with vegetation cover.

Unit 4 (0.45m-0m): Contains the mud crack sediments affected by mixing circumstances, while they are relatively oxidized.

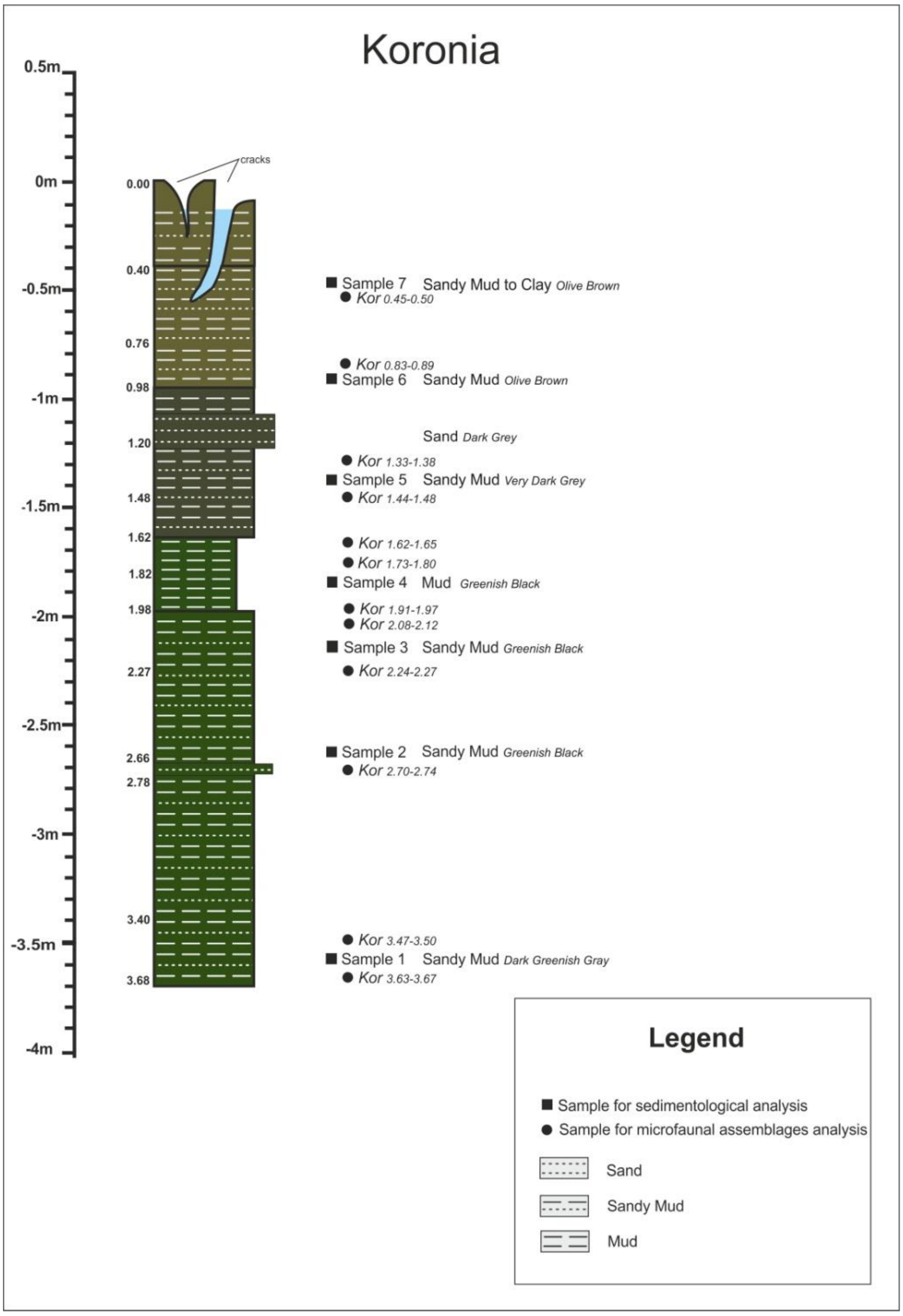

Figure 3 - Lithology of the borehole of Koronia Lake (see the online coloured version).

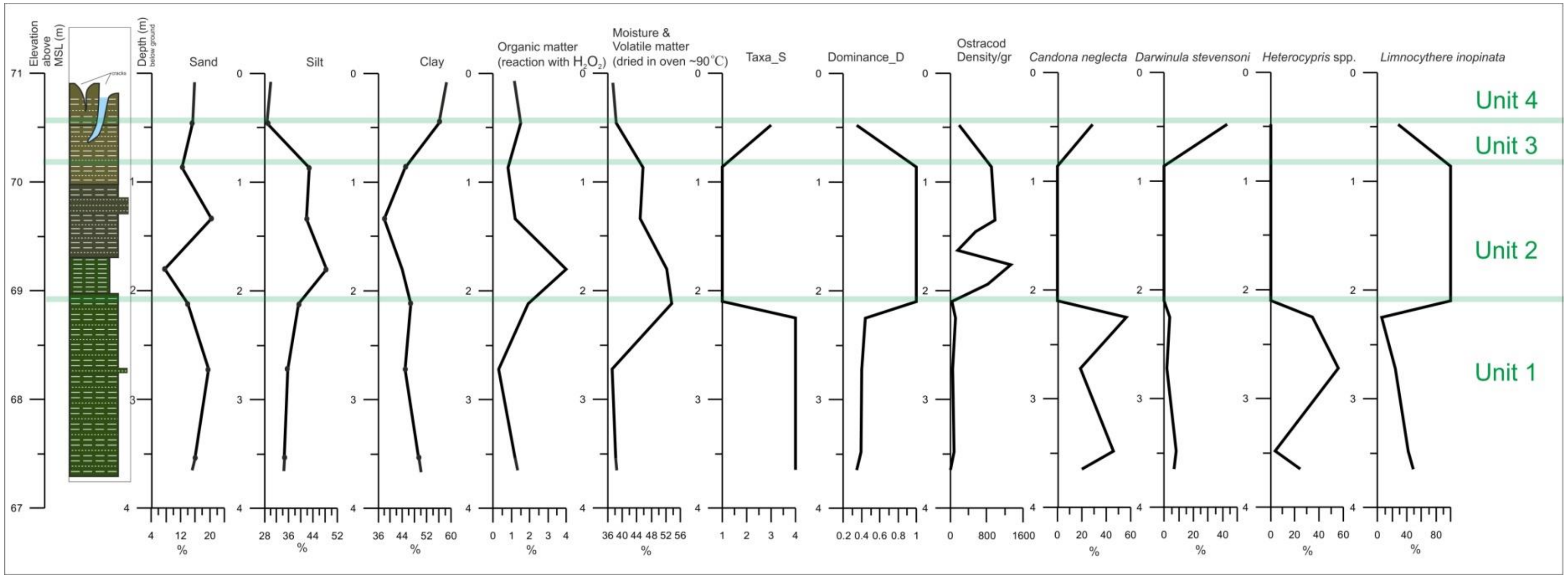

Figure 4 - Comparison between the relative frequencies of sand, silt, clay, dry organic matter, moisture-volatiles, as well as contents of total Ostracod relative abundance (%) of all presented taxa, Taxa S, Dominance D and Ostracod Density/gr, in Koronia borehole.

Lake Koronia presents a muddy to clayey sedimentation, showing a considerable alternation in faunal composition and paleoenvironmental evolution. Shallow water conditions prevail in the major part of the sediments, with some considerable differentiation in Unit 2 where extremely shallow conditions present, possibly due to near lakeshore environment. The fauna of this Unit consists only by *Limnocythere inopinata*, which favours macrophyte substrates, while species richness is obviously very poor. As it has been reported species richness is relatively low near the lakeshore, at which macrophytes are abundant (Xiangzhong *et al*., 2010). Although *L. inopinata* presents in all sedimentary sequence, the domination in this Unit leads to a dramatic transition in vegetation cover. Specifically for Koronia Lake, the macrophyte changes in distribution of *Myriophyllum spicatum* and *Phragmites* are well recorded during the last 45 years, depending on water level changes among other factors (Papastergiadou, 1995; Crisman *et al*., 2014; Zalidis *et al*., 2004), which confirms the vegetation transition that was observed in Koronia sediments. In the following Units faunal composition becomes more diversified until the upper part of the borehole sediments.

5. Conclusions

- Sediments of Koronia Lake, consist of silt, clay and small rates of very fine sand (mud to sandy mud).
- There are 2 phases of sand fractions. The allochthonus sand of fluvial origin, is very fine (3.5-4 φ), while the autochthonous biogenic fractions are sized 3-3.5 φ.
- The lake sediments are very watery, consisting of a liquid and a solid phase. The liquid phase appears to be large, ranging from 37.20% to 53.63% of their total weight. If the weight proportion is converted to volume proportion then the dry sediment represents roughly 35% to 24% of the total volume of the wet sediments.
- Ostracod fauna consists of four species: *Candona neglecta*, *Darwinula stevensoni*, *Heterocypris* spp. and *Limnocythere inopinata.*
- An alternation in species composition was observed, with all the species present at the lower part of the borehole sediments, while *L. inopinata* is the only species found at the middle part. At the upper part of the sediments faunal composition is diversified once again.
- Ostracod fauna composition alternations certify a dramatic transition in vegetation cover.

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