ASSESSING THE *ALLOCHTHONOUS* AND *AUTOCHTHONOUS* SEDIMENT INPUTS IN CONJUNCTION WITH CATCHMENT AND *IN SITU* DEPOSITIONAL CONDITIONS IN SEVERAL SHALLOW LAKES OF THE DANUBE DELTA AND THE BLACK SEA LITTORAL AREA

Irina CATIANIS[1], Adriana Maria CONSTANTINESCU[1], Ana Bianca PAVEL[1], Iulian POJAR[1,2], Dumitru GROSU[1], Oana DOBRE[1]

[1]*National Institute of Marine Geology and Geo-Ecology (GeoEcoMar), 23-25 Dimitrie Onciul St., 024053 Bucharest, Romania*
[2]*Faculty of Geology and Geophysics, University of Bucharest, 1 Nicolae Bălcescu Blvd., 010041 Bucharest, Romania*
e-mail: irina.catianis@geoecomar.ro

Abstract: In order to assess the origin and contribution of the *autochthonous* and *allochthonous* material to the recent natural sedimentation, analyses of the main lithological components, *i.e.*, total organic matter (TOM%), total carbonates (CAR%) and minerogenic fraction (SIL%), were performed on several bottom sediment samples, gathered from five lakes. These lakes represent different environmental situations (*i.e.*, deltaic, lagoon and littoral/coastal environment), but they are all influenced by the river/rivulet input of water and sediments. Sampling techniques take into consideration an undisturbed substratum (0 – 30 cm) from surface and subsurface bottom sediment samples, that were collected, using Van Veen Grab Sampler, from 141 stations, along the selected longitudinal and latitudinal transects of the lakes. Loss On Drying and, respectively, Loss On Ignition Methods were used to estimate the percentage contents of TOM%, CAR% and SIL%. The main physical processes that influence the sediment deposition within these lakes are generally related to hydrodynamics and sediment transport, climatic conditions, and environmental variables within the depositional areas. The results reveal a similar alternating lithology between organic-rich sediments (low energy environmental conditions), mineral-rich sediments (higher energy environmental conditions) and "transitional"/mixed sediments (mixed sediment environments). In complex environments, like the study area, with both fluvial input and high *in situ* productivity, separating and quantifying the two constituents is not straight forward. Further investigations are required to corroborate the findings of this paper for recent sediment accumulations in environments with mixed sedimentary processes.

Key words: bottom sediment, physical-chemical characteristics, spatial variability, organic matter content, transitional environment

Abbreviations: CAR – Total Carbonates; Ch – Channel; Cnl – Canal; DDBR – Danube Delta Biosphere Reserve; DM – Dry Matter; EU-WFD – European Water Framework Directive; GPS – Global Positioning System; ha – hectares; L – Lake ; LOD – Loss On Drying; LOI – Loss On Ignition; r – coefficient of correlation; RV - Research Vessel; SIL – Siliciclastic Fraction; TOM – Total Organic Matter; WC – Water Content; *vs* – versus.

1. INTRODUCTION

Sediments in aquatic systems are of particular interest for environmental research, due to their interconnections with several processes, as, for example, eutrophication, transport and storage of pollutants, and silting (Forsberg, 1989). Catchment sinks (*i.e.,* lakes, ponds, wetlands, swamps, lagoons etc.) represent receiving bodies for several types of terrigenous materials carried by streams and rivers or by the aerial transport. In addition, a significant amount of organic and mineral matter is produced through in-lake biogeochemical processes and cycles. Gaining a better insight into the composition and sources of accumulated sediments in lake areas are very important for understanding of the processes of sediment transport, erosion and deposition.

The Water Framework Directive (EU-WFD, 2000) appeals at improving and protection of all water resources, namely, rivers, lakes, transitional and coastal waters, using a holistic approach, including sediment studies. The integrity of an aquatic ecosystem strongly depends on the proper functioning of its own fundamental constituent parts, such as, hydrologic regime, sediment flux, water and sediment quality, as well as biological communities. All these individual components are influenced by several natural and anthropogenic factors. Anthropogenic activities – urbanization, agriculture, mining activities, industry, land use (Foley *et al.*, 2005) have associated negative imprints upon the environment, impairing, for example, sediment fluxes which lead to the deterioration of terrestrial and aquatic environments (Syvitski *et al.*, 2005; Lotze *et al.*, 2006; Halpern *et al.*, 2008; Owens *et al.*, 2010). Aquatic sediments represent the last stage of both natural and artificial material accumulation yielded within the aquatic environment, and they are utilized as proxies for environmental assessment, climate archives and human-related activities (Hodell *et al.*, 1999; Zhang *et al.*, 2010). Unconsolidated sediments are in a continuous dynamic state, migrating through the ecosystem and accumulating in wetlands, floodplains, streams, lakes, and on the banks of the shoreline. Aquatic sediments, in particular, play an important role in controlling the system dynamics in the fluvial, lacustrine, estuarine, and marine environment (MacDonald *et al.*, 2000; Gholizadeh & Patimar, 2018), and in evaluating the contamination levels (Kulbat & Sokolowska, 2019; Duncan *et al.*, 2018), and ecological risk assessment (Duodu *et al.*, 2016). Sediment flux and dynamics pose significant impacts upon these vulnerable terrestrial and aquatic environments, under anthropic pressures, which become sensitive to siltation of navigation channels (Van Rijn, 2013) and ports, increased coastal flood risk (Pollard *et al.*, 2018), loss of biodiversity and water quality impairment (modified turbidity, resuspension and redistribution) (Cuthbertson *et al*. 2008). Depending on the environmental circumstances, sediments can load/unload a series of constituents, such as organic matter and nutrients, as well as contaminants and pollutants (*e.g.,* phosphorus, heavy metals etc.) (Lutz *et al.*, 2002; Sothwell *et al.*, 2011; Hou *et al.*, 2013).

Generally, aquatic basins store inorganic and organic materials of *allochthonous* input, derived from surrounding terrestrial watershed, weathering and erosion, as well as *autochthonous* input, derived from *in situ* basin processes and biological production (Hope *et al.*, 1994; Finlay & Kendall, 2007). Sediments are, generally, a combination of solid particles transported from the surrounding areas by surface runoff due to rainfall, alluvial and shoreline eroded materials (clay, mud, sand), as well as settling down suspended loads, *i.e.*, organic debris, chemical precipitates (provided by in-lake chemical processes), or a mixture of these constituents.

Likewise, sediments may be cohesive (mixture of clay, silt, sand and organic matter) and non-cohesive (sand, gravel etc). Freshwater and marine sediments (porous, soft or lithified) are made up of three major constituents (organic matter, carbonate and siliciclastic sediment) constituting their solid fraction (Ricken, 1993). The type and composition of the sediment substrate are considered critical elements in environmental assessment of natural aquatic ecosystems. Generally, the approximate levels of the different constituents' contribution (prevalence of organic/mineral fractions) within a sediment volume, can be attributed to some extent to *allochthonous* or *autochthonous* sources. All these external (high rates of fluvial sediment supply, discharges from upstream feeders, aeolian transport, climate conditions – drought, floods etc.) and internal (geological substrate of the depositional environment, *in situ* biological, chemical, physical and geological processes etc.) environmental factors, may induce changes in sediment yield and composition.

In this context, the study of aquatic sediments becomes important for the global assessment of the potential impact of anthropogenic activities and/or of natural factors in aquatic environments (water, sediments and biota). The purpose of this paper is to evaluate the impact of *autochthonous* and/or *allochthonous* contributions in the investigated lakes, that represent different environmental circumstances (deltaic, lagoon and coastal environment), as well as to investigate the spatial patterns of distribution of the main lithological components. The analytical results were converted using Golden Surfer Mapping Software, which is an useful tool to spot areas of prevalent organic/mineral content storage. Image interpolation was used spaciously by standard Kriging technique allowing the differentiation of the sampling stations in relation to their geographical coordinates and lithological content. Gaining a better insight into the distribution of the main lithological content (such as, organic matter, carbonates and siliciclastic fraction) in these depositional environments (namely, Fortuna, Razim, Golovița, Tașaul and Corbu lakes), will contribute to improve the existing data base that aim to assess these natural resources belonging to the DDBR – an ecosystem of significant conservation and protection value in the region.

2. STUDY AREA

The Danube River is the main supplier of water and sediment fluxes to the northwestern and western Black Sea area. The Danube Delta acts like a transfer zone between the river energy, as well as water and sediment inputs, and the sea. At the same time, marine environmental conditions, as sea level fluctuations and stronger winds, also impacts the delta area, implicitly the sedimentation of the terrigenous material supplied by the Danube River. The continuous interaction between the Danube River and the Black Sea is determining factor for the hydro-sedimentary dynamics of this macro-geo-system (Panin *et al.*, 1999), each of the compartments being characterized by specific morpho-dynamic processes.

For this study, we have considered five distinct lacustrine environments, namely, **Fortuna, Razim, Golovița, Tașaul** and

Corbu lakes, which are more or less influenced by the river/channel/canal input of water and sediments. The selected aquatic basins are located in the southeastern part of Romania (Fig. 1).

Like many other areas of the Danube Delta Biosphere Reserve (DDBR) including the coastal zone as well, these aquatic basins have been adversely affected during the last decades by a variety of natural and human-induced stressors. DDBR is positioned in Romania, in the central southeastern part of Europe, in the lower course of the Danube River (Gâştescu, 2007), owing a triple international status as *World Cultural and Natural Heritage Site*, a *Biosphere Nature Reserve* and *Wetland of International Importance* (Ramsar Convention, 1987). To assess the main lithological constituents of bottom sediment in different depositional zones, we have considered different perimeters of research: **Fortuna** Lake, as well as **Razim** and **Goloviţa** lakes, that are situated in a river-sea transition zone, *i.e.,* DDBR, in contrast to **Taşaul** and **Corbu** lakes, which are located in the Romanian Black Sea coastal zone (Fig. 1).

2.1. Fortuna Lake

Also found in the literature under the name of Furtuna (Gâştescu & Ştiucă, 2008), is part of the Sireasa-Şontea-Fortuna hydro-morphological unit, belonging to the fluvial delta plain, within the DDBR. The structure, the function and the evolution of the deltaic ecosystems are controlled by the fluvial inputs of the Danube River. Significant amounts of terrigenous materials brought by the Danube River from its upstream reaches to the Black Sea (Panin & Jipa, 2002) are partially dissipated throughout the hydrographic network, including, as well, fluvial-lacustrine reservoirs. The aquatic landscape of this shallow lake (977.5 ha) is characterised by a series of inlet and outlet channels/canals, such as Fortuna 1 Cnl./Şontea Ch. (East), Fortuna 2 Cnl. (North), Fortuna 3 Cnl. (North), Şontea (the northern limit of Fortuna Lake), Mitchina (West) and Crânjală Cnls. (South). Fortuna Lake has direct connections with both Sulina Branch *via* canal Crânjală and with Şontea stream, as well (Fig. 2-a). It is important to mention that in the southern part of the lake a micro-delta has evolved (Rădan *et al.*, 2013) being fed by the sediment input of the Crânjală Cnl. *via* direct connection with the Sulina Branch - one of the three main distributaries which form the Danube Delta. Crânjală Cnl. played a significant role throughout the time regarding the alluvial supply of the lake from the Danube River. After the end of the World War II, this canal was dug and the stone bridge that blocked the circulation of water *via* the Old Danube was removed (Motoc, 2016). Then, in the '80s, the specific hidrosedimentary intense activity of the Crânjală Cnl. contributed to the creation of a micro-delta in the canal mouth area, providing a progressive silting up of the lake. Later on, in the '90s, when the canal was closed, the organic content of the sediment prevailed as a result of the hidrosedimentary regime changes, and the lake is now being fed by a northern connection canal *via* Şontea Stream (Rădan *et al.*, 2013). The environmental imprints of natural factors as hydrological inputs, geological background, sediment characteristics and excessive vegetation development in its catchment area, can lead in time to siltation. Therefore, the role of sediment and sediment dynamics in this aquatic environment is important to be elucidated.

2.2. Razim Lake

It is in fact a large freshwater lagoon – part of the Razim-Sinoie lagoon complex, situated on the shores of the Black Sea, south of the Danube Delta and included in the DDBR area. The water circulation within the Razim-Sinoie Lagoon Complex is assured by a freshwater inflow from the northern part, through Sf. Gheorghe distributary *via* Dunavăţ, Dranov, Lipovenilor and Mustaca canals (Fig. 2-b). In the south, the complex is interconnected through Sinoie Lake with the

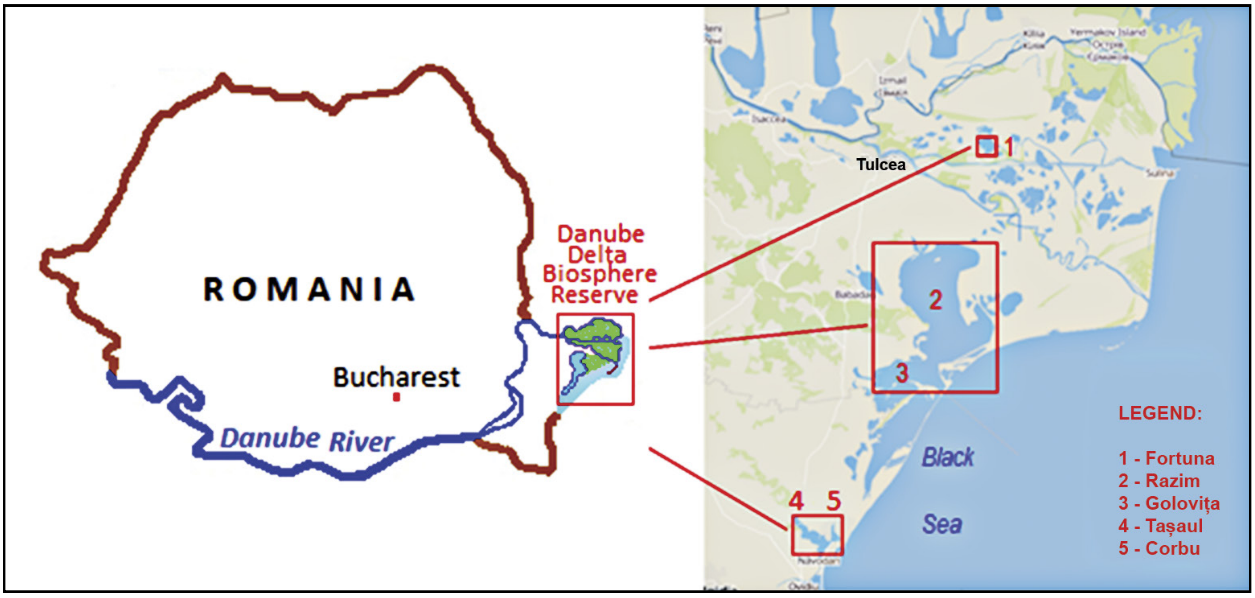

Fig. 1. Geographical location of the study area (Base map: https://www.google.com/search/romania)

Black Sea *via* Periboina and Edighiol outlets. Intermittently opened connections with the Black Sea strongly influence the water salinity, sedimentation, erosion and ecology within this lagoon complex (Stănică, 2012). Razim is the largest freshwater lagoon in Romania, with a surface of 54, 000 ha, and a maximum depth of 3.5 meters (Gâștescu, 1971, 1998).

2.3. Golovița Lake

With a surface of 11,870 ha (Gâștescu, 1971), it is connected to the largest Razim Lake on the northern part (Fig. 2-c). Until the 1970s, this lake communicated with the Black Sea through a natural restricted outlet, namely, Gura Portiței, that was artificially closed (Mihăilescu, 2006).

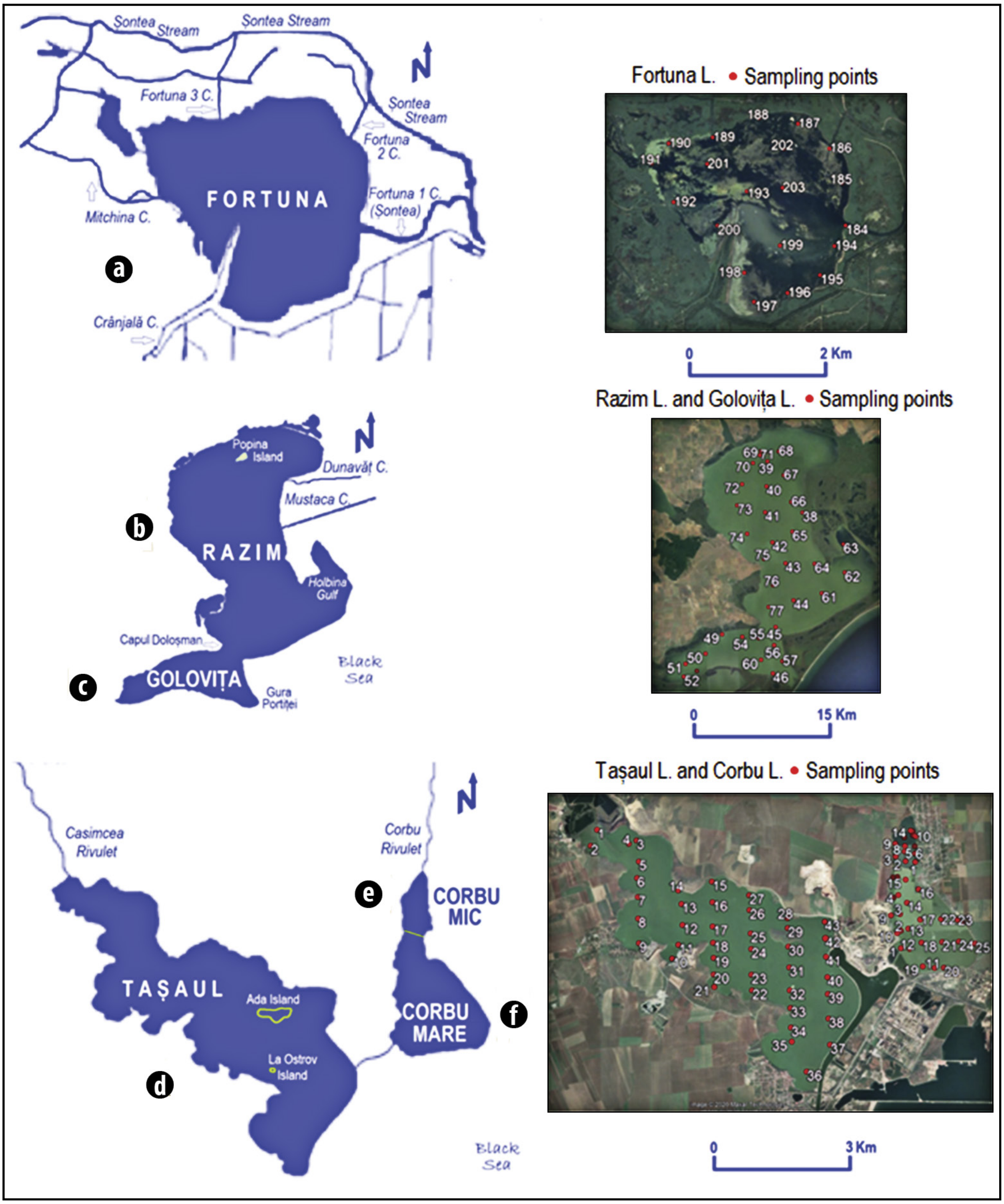

Fig. 2. Sitemap location of the lakes (Fortuna, Razim, Golovița, Tașaul and Corbu), including maps of the GPS coordinates for each sampling point (Base map: https://www.google.com/intl/ro/earth/)

2.4. Taşaul Lake

It is a fluvial-marine lagoon, south of the DDBRA, with a surface of 2335 ha and a maximum depth of 4 m (Alexandrov & Bloesch, 2009), which once used to flow into the Black Sea (Gâştescu *et al.*, 2016). There are two islands in Taşaul Lake: Ada Island, calcareous, with an area of about 30.3 ha, and a maximum altitude of 12.8 m and, respectively, "La Ostrov" Island, consisting of green schists, with a surface of about 3.0 ha and a maximum altitude of 4.6 m (Popescu & Caraivan, 2003). Currently, this lagoon has no direct connection with the Black Sea, but receives fresh water from the Casimcea River (Fig. 2-d). Also, through a pipeline, this lake is supplied by the southern part with fresh water from the Siutghiol Lake.

2.5. Corbu Lake

Corbu is a fluvial-marine lagoon, separated by a dam in two sub-basins, namely, Corbu Mic (40 ha) (Fig. 2-e), and Corbu Mare (430 ha) (Fig. 2-f). This lagoon is fed by the Corbu stream, and through a connection canal, it is linked to Taşaul Lake. The water exchange with the Black Sea also takes place through a connecting canal. Altogether, the Taşaul, Corbu Mic and Corbu Mare lakes form a lacustrine complex, that constitutes a protected area (ROSPA0060 - Special Bird Protection Area, NATURA 2000 Site) which provides beneficial habitats related to the development of the specific flora and fauna of these wetlands.

3. MATERIALS AND METHODS

3.1. Field activities

A total of 141 samples of bottom sediments were gathered from different areas of the lakes (Fig. 2), using a Van Veen Grab Sampler, aboard the RV "Istros" and from smaller boats, during three scientific surveys (Fortuna Lake – September 2019, Razim and Goloviţa lakes – May 2018, Taşaul and Corbu lakes – July 2019). The field sampling plan targeted the collection and analyses of samples distributed uniformly within the aquatic basins, in order to gain better insight into the spatial distribution patterns. The geographic coordinates (Fig. 2) were recorded with a handheld GPS receiver (Garmin Montana 680). For each station, an amount of approximately 100 grams of sedimentary material was collected from the upper layers of bottom sediments, labelled, described and stored for further analyses. *In situ* observations and sample descriptions considered a summary about the sampling location, the visual (macroscopic) description of the sediments (structure, texture, grain size, sorting, stratification), the main lithoclastic components (clay, mud, silt, sand, gravel), and bioclastics (shells and detritus, faunal and vegetal remains), as well as color, odor etc.

3.2. Laboratory procedures

All sediment samples were processed in the specific laboratory of Romanian National Institute for Research and Development GeoEcoMar, in Bucharest.

Physical properties and lithological analysis. The surficial sediment samples were analysed for their main physical parameters, based on water content - WC% and dry matter - DM% by Loss On Drying (LOD) and, respectively, their lithological components, as the total organic matter - TOM%, total carbonates - CAR% and siliciclastic fraction - SIL% by Loss On Ignition Method (LOI).

The preparation of the bottom sediment samples included subsampling, removal of vegetable/woody residues and large pieces of shells, drying, sequential weighing and calcination.

a) Loss On Drying (LOD) Method. The water and the dry matter content were gravimetrically estimated by the conventional LOD (Loss On Drying) method (Smith & Mullins, 2000; ASTM-D2216, 2010). The moisture content is a very important property of aquatic sediments as it oscillates between wide limits in the same set of sediment samples. Dry mass makes reference to the leftover mass of residue after drying. The dry residue content may be used as an indicator related to the degree of the material compaction. Within this study, the natural water content refers to the water content of a field-moist state and was assessed by using undisturbed sediment material. This method requires successive weights of sediment material before and after drying at 105ºC. Water content was acquired as the difference between wet and dry weights, and the data were expressed as the percentage of the total field-moist state mass (%).

b) Loss On Ignition (LOI) Method. Further on, the determination of the total organic matter (TOM%), total carbonates (CAR%) and siliciclastic fraction (SIL%) contents was done by calcination technique according to Dean (1974) and Santisteban *et al.*, 2004). Loss On Ignition (LOI) is a common, widely-used method of estimating the organic matter and carbonate contents of sediment samples (Heiri *et al.*, 2001), being rapid, inexpensive and easy to perform (Dearing, 1986). LOI involves weighing the samples before and after sequential heating, and measuring weight loss between heating stages, yielding estimation of organic and carbonate content with comparable precision and accuracy (Heiri *et al.*, 2001). Accordingly, a high-temperature electric furnace SNOL 8.2/1100 LHM01 was employed. The total organic matter content and the minerogenic matter/mineral residue (the inorganic non-carbonate fraction) were derived by calcination at 550ºC (Dean, 1974; Bengtsson & Enell, 1986), and, respectively, at 950-1000ºC (Digerfeldt *et al.*, 2000). The estimation of the carbonate content was done as stated in Loss On Ignition (LOI) Protocol (https://www.geog.cam.ac.uk/facilities/laboratories/techniques/loi.html). The results were expressed as percentage of total organic matter and total carbonates in each sample. The weight of the residue remaining after 950ºC (the inorganic non-carbonate fraction), as a percentage of the total original dry sample weight, is considered the silicate residue (minerogenic matter).

The final results of the main physical-lithological components (WC%, as well as TOM%, CAR% and SIL%) were plotted as maps to express the spatial (geographic) distribution of each component type. The areal distribution maps were designed using Surfer software - Golden Software, Inc., 2010, and the interpolation of data in the maps was performed by the Krigging method of gridding.

4. RESULTS AND DISCUSSIONS

4.1. Macroscopic characteristics of the bottom sediment samples

The characteristics of sediment samples, examined visually, showed significant differences related to environmental conditions and variations of the lithological components. The surface sediment samples collected during this study presented very different colours, odours and textures depending on the sampling points. Samples also showed wide variations in particle size, ranging from silt and clay to fine, medium or coarse sand. Fine sediments – clay and silt, were characteristic for low energy environments, while sand represents the bulk of the bottom sediments in high energy environments (*i.e.*, closer to inflow channels, or influenced by wind and waves). In terms of colour, darker sediments indicated generally high organic matter content, as opposed to sediments relatively lighter in colour showing low organic matter content or, probably a significant concentration of carbonates or soluble salts. Other colour varieties (such as, light brown, yellow, reddish, grey, greenish, rust-coloured etc.) are derived as a result of the dominant sediment chemical composition or abundant aquatic vegetation.

Macroscopic descriptions of the bottom sediment samples collected from **Fortuna L**. showed that the colour of the sediment material varied from dark green to dark grey and blackish grey. At the top of the organic-rich layer (top 1 cm) there was a yellowish-brown oxidation film (probably microbial or chemical oxidation). Structural and textural attributes were characterized by the presence of fine-medium and sporadically coarser triturated vegetal particles, incorporated, generally, into cohesive/non-cohesive muddy sediment (clay and silt). Within the interlayered mud-silts the predominant constituent showed an organic origin, as vegetal remains of reed, decomposed leaves, as well as friable and de-pigmented shell debris.

The macrobenthic fauna is abundant and representative for fresh waters ecosystems: *Viviparus viviparus, Dreissena polymorpha, Unio pictorum, Anodonta cygnea, Planorbis planorbis, Limnaea stagnalis, Valvata piscinalis*, *Radix ovata* along with *Chironomidae* sp.and *Oligochaeta* sp.

The samples gathered from the **Razim** and **Golovița** lakes generally had similar composition, with slight variations, depending on the sampling site location. The upper sediment layer (top1 cm) presented a yellowish brown oxidation film, and the colour of the sediment samples varied greatly from place to place, from dark grey to black and to light yellowish grey. Accumulations of fine clayey muds, up to sandy silts, or a mixture between fine mud and sandy silts are common. Generally, sand accumulations are prevalent in the eastern part of the Razim and Golovița lakes, as well as in the vicinity of the canal mouths, *i.e.,* Dunavăţ, Mustaca and Dranov.

These two lakes sustain a specific standing stock of brackish and freshwater macrobenthos: *Dreissena polymorpha, Cardium edule, Corbicula fluminea, Viviparus viviparus, Limnocardiidae* sp.*, Anodonta cygnea, Unio pictorum*, along with *Cumaceae* sp., *Chironomidae* sp.and *Oligochaeta* sp. Incidentally, shell hash layer (*e.g.*, lumachella) occur, with a preponderance of bivalves, gastropods and other shells, sometimes without muddy-clay matrix.

The structural and textural characteristics of the sediment samples obtained from **Corbu L**. did not vary significantly. The color variations of the samples ranged from yellow to grayish, with an oxidation film in the surface layer (top 1 cm). The majority of samples were fine sediments represented by unctuous muds, silts and clays. Only one sample was constituted of well sorted dark silty-sand. Rare decomposed plant fragments were identified. Most of the samples were characterized by a fetid odour (probably from the degradation of the organic material), and numerous bioturbation traces produced by the multitude of *Chironomidae* sp. The benthic macrofauna was poorly represented by *Anodonta cygnea* and some juveniles of *Dreissena polymorpha* encountered only in few samples.

Samples acquired from **Tașaul L**. represent a mixture of fine gray-brown mud or silt, with rare plant fragments, putrescent smell, a lot of *Chironomidae* sp. bioturbations and rare freshwater broken shells of *Anodonta cygnea*. A single sample was represented by fine-medium sand with rare gravel elements, and infrequent *Dreissena polymorpha* and *Cardiidae* sp. shells.

4.2. Evaluation and interpretation of the obtained data

A quantitative compositional analysis of sedimentary materials was performed and reported as percentages by weight for WC%, DM%, TOM%, CAR% and SIL% contents, estimated from the total weight of the dry residue sample.

A brief overview of these environmental indicators was performed in the following section.

- **Water content and dry residue**. The global composition of sediments incorporates two primary constituents, water moisture and dry residue content. Naturally, sediment samples of a field-moist state have very or extremely high values of water content. Water content is influenced by the structural and textural characteristics of sediments (degree of compaction and saturation, particle size, geochemical composition, mineralogy, organic content etc). The water content of surface sediments fluctuates in varying approximate proportions, from about 30–50% of minerogenic deposits to almost 95–99% in highly organic sediments (Håkanson & Jansson, 1983).

- **Total organic matter**. Organic matter embodies an inconsistent but important fraction of recent aquatic sediments, serving as a proxy indicator on the relative contributions of *allochthonous* input (*e.g.,* terrestrial materials) and *autochthonous* production (*e.g.,* algae, phytoplankton and macrophyte and also, animal organisms), in terms of their origin and sediment storage within the aquatic basins. Sedimentary depositional environments, such as deltas, or estuarine, lagoon and coastal areas are characterized by the affluence and diversity of the sources of organic matter either *autochthonous* or *allochthonous*. Several previous scientific studies provide evidence for two main sources of organic matter accumulated in sediments: *allochthonous* (high rates of fluvial sediment supply, discharges from upstream origins, aeolian transport, climate conditions etc.) and *autochthonous* (geological substrate of the depositional environment, *in situ* biological, chemical, physical and geological processes etc.) (Volkman & Tanoue, 2002; Mash *et al.*, 2004; Tesi *et al.*, 2007; Cresson *et al.,* 2012). The sources and dynamics of the organic matter in aquatic systems are a significant global issue related to several scientific and ecological aspects, *i.e.,* provides food source for a wide variety of organisms, may facilitate the potential ecological effects of contaminants, may be subject of the chemical transformations along the water column of the aquatic environments etc. (Canuel *et al.*, 1995; Canuel, 2001; Zimmerman & Canuel, 2001). The results obtained within this study linked to the distribution of sediment-organic contents were related to the descriptive classification of soil organic matter (Perrin, 1974; Tate, 1987; Van der Veer, 2006), since there is not a harmonized classification related to the organic matter content in aquatic sediments. Thereby, two simple categories were differentiated in regards to *mineral sediments* (≤15-30% organic matter), and *organic sediments* (≥15-30% organic matter).
- **Total carbonates**. The total carbonate content within aquatic sediments arises from organic (humus, plant remains, biogenic debris) and inorganic compounds (calcite, aragonite) (Kennedy & Woods, 2013). The original carbonate content of the sediment can be used as paleoenvironmental and depositional biogeochemical indicator (Clayton & Degens, 1959; Lapointe *et al.*, 1992; Zhao *et al.*, 2016). In this study, the acquired results were estimated in accordance with the weight percentage of the carbonate content. Empirically, our results were related to classification done by Emelyanov & Shimkus (1986), where the sediment samples were grouped as: *terrigenous non-carbonated sediments* ($CaCO_3 \leq 10\%$), *terrigenous low calcareous* ($10\% < CaCO_3 \leq 30\%$) and *terrigenous calcareous sediments* ($30\% < CaCO_3 \leq 50\%$).
- **Siliclastic fraction.** The siliciclastic content, specifically, the minerogenic matter/mineral residue/inorganic non-carbonate fraction is a paleolimnological indicator (Smol, 2010) related to *allochthonous* sedimentary particles' origin (supplied *via* fluvial or aeolian inputs, volcanic and hydrothermal activities etc.) or, to *autochthonous* provenience (geoechemical background, erosion, etc).

The interpretation of the obtained results within this study was performed separately, for each investigated lake. Then, the results were converted using Golden Surfer Mapping Software to spot areas of prevalent organic/mineral content storage. Image interpolation was used by the standard Kriging technique allowing the differentiation of the sampling stations in relation to their geographical coordinates and lithological content. The obtained results are represented graphically in the form of distribution maps. The achieved results related to the main lithological components are summed up in Table 1. In addition to that, the analytical results acquired within this study were evaluated from a statistical analysis point of view. In order to evaluate the possible associations between all investigated parameters through sediment physical-chemical characteristics, a simple linear correlation analysis was performed by calculating correlation coefficients (r). The bottom sediments showed both positive and negative relationships between investigated components (Table 2). The obtained results are represented graphically in the form of diagrams (*i.e.,* XY scatter plots) in order to illustrate the relationship between two investigated variables. To avoid redundancy only the most relevant correlations were shown as XY scatter plots.

4.3. Spatial distribution of the main lithological components in bottom sediments

Our results obtained from the LOD and LOI analysis yields some interesting variations concerning the investigated lacustrine environments.

4.3.1. Fortuna Lake

Bottom sediment analysis showed fluctuating values, and trends. Regarding the moisture of the sediment, it was noticed that the natural water content was considerably variable within each sample, and equally the magnitude and variation increased with the amount of dry residue content existing in the measured sample. In our case the moisture content may be associated with water level fluctuations (as a result of the local hydrographic network that supplies the lake) and climatic characteristics (*e.g.,* temperature, evaporation, precipitations etc). The obtained results were displayed as a contour map showing WC% variations (Fig. 3-a).

According to the distribution map, the largest sector characterized by a high WC% content (≈ 17-29%) was identified in the eastern area of the lake in the closeness of the Şontea Ch. mouth. Probably, this sector comprises more water saturated sediments due to the constant influx of water. The other sectors of the lake were characterized by lower WC% values and may be associated with structural and textural attributes of sediments.

Table 1. Concentration (%) of the main physical (WC, DM) and lithological parameters (TOM, CAR and SIL) in the bottom sediment samples of the six different sites

Lake		Physical parameters		Lithological parameters		
Fortuna (n =20)	Value	WC (%)	DM (%)	TOM (%)	CAR (%)	SIL (%)
	min	6.92	70.39	38.06	2.55	9.52
	max	29.61	93.08	81.52	20.33	52.89
	mean	13.21	86.79	67.33	10.98	21.69
Razim (n = 25)	Value	WC (%)	DM (%)	TOM (%)	CAR (%)	SIL (%)
	min	10.25	55.77	1.73	8.07	13.18
	max	44.23	89.75	78.76	67.30	62.89
	mean	25.66	74.34	49.00	19.08	31.92
Goloviţa (n =12)	Value	WC (%)	DM (%)	TOM (%)	CAR (%)	SIL (%)
	min	10.99	77.29	18.82	8.96	16.99
	max	22.71	89.01	74.05	28.40	64.93
	mean	16.37	83.63	56.28	12.32	31.40
Taşaul (n = 43)	Value	WC (%)	DM (%)	TOM (%)	CAR (%)	SIL (%)
	min	9.12	55.96	4.06	4.62	9.72
	max	44.04	90.88	74.86	86.22	83.65
	mean	20.52	79.48	55.81	10.61	33.58
CorbuMic (n = 14)	Value	WC (%)	DM (%)	TOM (%)	CAR (%)	SIL (%)
	min	17.46	64.50	27.40	9.20	30.11
	max	35.50	82.54	59.36	15.96	62.12
	mean	24.77	75.23	44.70	11.46	43.84
Corbu Mare (n = 26)	Value	WC (%)	DM (%)	TOM (%)	CAR (%)	SIL (%)
	min	8.08	66.78	3.79	7.47	27.27
	max	33.22	91.92	62.53	51.31	79.97
	mean	20.07	79.93	41.74	13.71	44.55

Table 2. Values of correlation coefficients (r) for relationships among the main lithological components (TOM, CAR, SIL, WC and DM) (%)

Correlated variables	Fortuna	Razim	Golovita	Taşaul	Corbu Mic	Corbu Mare	Reference coefficient interval and Reference correlation level (https://towardsdatascience.com/)
	Coefficient of correlation (r)						
TOM *vs.* CAR	-0.471	-0.755	-0.628	-0.524	-0.047	-0.549	***0.00 – 0.199 – Very low***
TOM *vs.* SIL	-0.908	-0.830	-0.954	-0.696	-0.982	-0.867	***0.20 – 0.399 – Low***
CAR *vs.* SIL	0.058	0.262	0.369	-0.245	-0.136	0.060	***0.40 – 0.599 – Moderate***
WC *vs.* TOM	-0.390	0.005	0.092	0.022	-0.447	0.331	***0.60 – 0.799 – Strong***
WC *vs.* CAR	0.431	0.066	0.230	-0.033	0.591	-0.247	***0.80 – 1.000 – Very strong***
WC *vs.* SIL	0.237	-0.064	-0.199	0.001	0.334	-0.248	
DM *vs.* TOM	0.390	-0.005	-0.092	-0.022	0.447	-0.331	
DM *vs.* CAR	-0.431	-0.066	-0.230	0.033	-0.591	0.247	
DM *vs.* SIL	-0.237	0.064	0.199	-0.001	-0.334	0.248	

TOM% variations are displayed as a contour map (Fig. 3-b). The TOM% distribution map showed that the most dominant class interval has values over 50% of the total weight of dry residue. TOM% was the dominant sediment fraction all over the lake, excepting the stations (≤50%) on the western shore of the lake (closest to Mitchina Cnl. mouth), as well as middle and southern inner lake stations (on the Crânjală Cnl. flow direction). Most of the high values obtained (≥60-80%) are probably the result of the in-lake productivity processes that significantly contribute to the accumulation of organic matter. The minimum of 38.06% (DD19-192) was identified in the western part of the lake.

The sample location was near the Mitchina Cnl., where the irregular character of inflows/outflows determines the rapid alluvial deposition and erosion and, probably, may obstruct the accumulation of organic matter. Instead, the maximum of 81.52% (DD19-190) was recorded in the northwestern part of the lake, a relatively sheltered sector characterized by excessive development of emergent and submerged vegetation and slightly disturbed by bottom water currents. These conditions can promote excessive *autochthonous* accumulation of organic material. Based on TOM% values (Table 1), obtained by the analysis, these sediments were categorized in total, as *organic sediments* (≥15-30% organic matter), subsequently followed by mineral sediments (≤15-30% organic matter).

The obtained results for CAR% variations are shown as a contour map (Fig. 3-c). The surficial sediment samples were characterized by higher CAR% content values (over 1% of the total weight of dry residue) encountered in all samples.

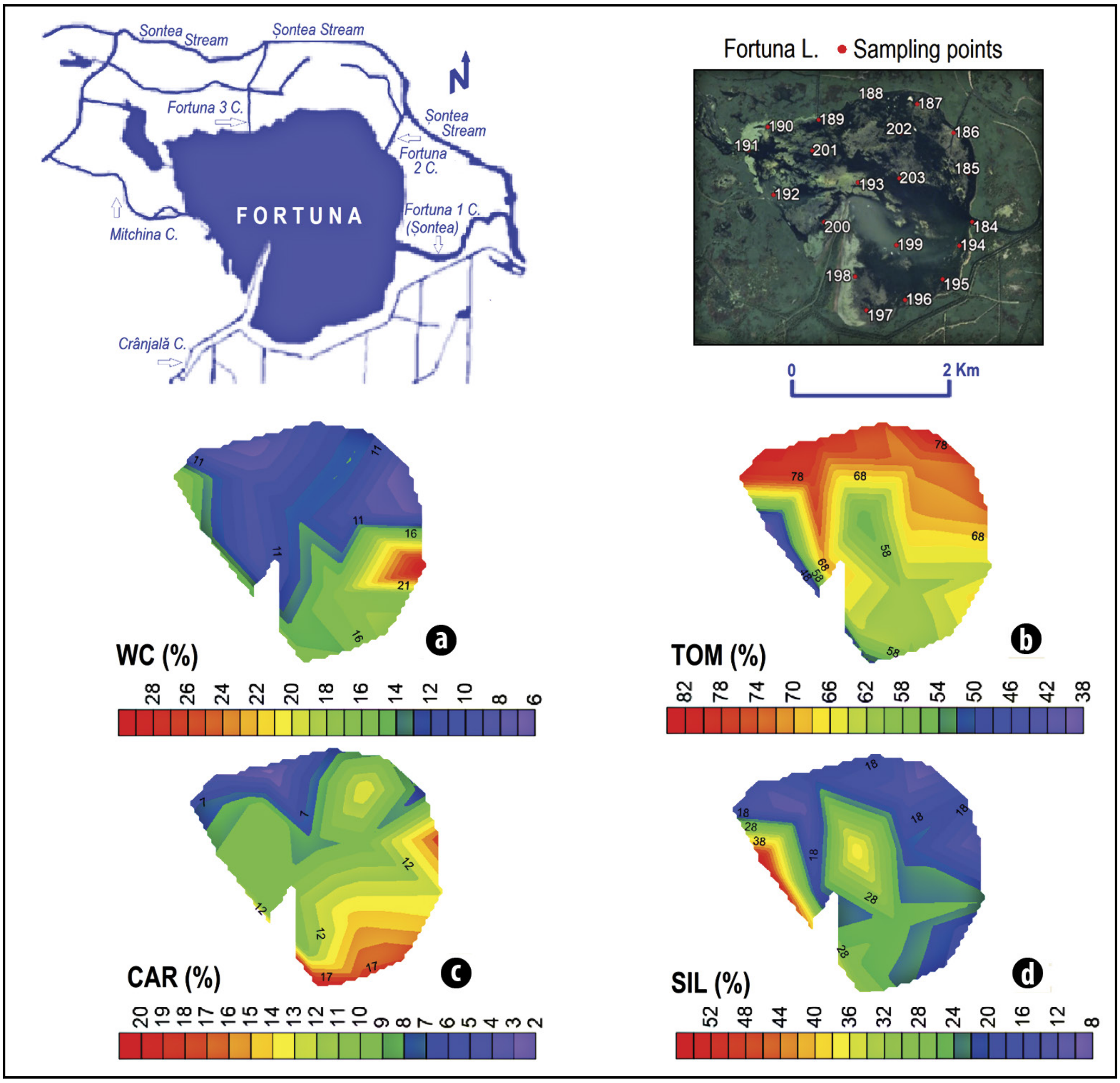

Fig. 3. Spatial variation of the water content and lithological components in bottom sediment samples from Fortuna Lake

The CAR% distribution map revealed a significant variation from a minimum value of 2.55% (DD19-189) encountered in the northern part of the lake (in the closeness of the Fortuna 3 Cnl. mouth) to a maximum value of 20.33% (DD19-197) occurred in the southern part. Sites with notably higher content of CAR (≥10%) were found predominantly in the southeastern half of the lake (Fig. 3-c). The carbonate-rich sediment samples may have probably an additional amount of shell debris, strongly incorporated into the sediment mass, which cannot be removed during sample preparation. Probably, this sector with higher values of CAR% promotes favourable conditions for the proper development of the benthic communities (so as, on long-term, these organisms can become a significant source of authigenic carbonates). Moreover, the authigenic origin of carbonates may be related to the chemical precipitation and recristalization or, due to the mechanical abrasion of *autochthonous* or *allochthonous* skeletal or non-skeletal carbonate elements present in the catchment area. Based on CAR% values (Table 1), obtained by the analysis, these sediments were categorized in total, as *non-carbonated sediments* ($CaCO_3$≤10%), as well as *low calcareous* (10%<$CaCO_3$≤30%).

The acquired results for SIL% fluctuations are shown as a contour map (Fig. 3-d). The range of variation is relatively narrow, fluctuating from 9.52% (DD19-187) to a maximum value of 52.89% (DD19-192). The maximal value occurred in the closeness of the Mitchina Cnl., where a lower content of TOM% had already been registered. The overall obtained results are also strengthened by ternary diagrams with the distribution of the investigated components (Fig. 4-a).

The investigated parameters (TOM%, CAR%, SIL%, WC% and DM%) were shown to be interrelated to varying degrees, being encountered both positive and negative correlations. Accordingly, **Fortuna L**. (Table 2) has faced a very strong negative correlation (TOM *vs.* SIL), a moderate negative correlation (TOM *vs.* CAR; DM *vs.* CAR) and a low negative correlation (DM *vs.*SIL; WC *vs.* TOM). It was also seen a moderate positive correlation (WC *vs.* CAR) (Fig. 5-a), a low positive correlation (WC *vs.* SIL; DM *vs.* TOM) and a very low positive correlation (CAR *vs.* SIL).

Generally, congruent with mixed energy conditions prevalent in the Fortuna L., the spatial distribution of the lithological components (TOM, CAR, SIL) (%) within the bottom sediments showed the existence of different types of accumulation related mainly to local hydrodynamic conditions. Results revealed a mixed lithology between *organic-rich, moderate carbonate* and *low siliciclastic sediments*. The organic-rich sediments were prevalent in areas dominated by quiet-water conditions and low energy setting, while the mineral-rich sediments were found in areas dominated by high hydrodynamic energy conditions (at the outermost station near the Mitchina Cnl., as well, in the mouth area of the Crânjală Cnl). Accumulation of fine sediments is impeded in areas with persistent bottom currents. Our results are consistent with previous research findings related to lithological data on recent lacustrine sediments from the Danube Delta (Rădan & Rădan, 2007; Rădan *et al.*, 2014, 2016), or adjacent to Fortuna L. (Rădan *et al.*, 2013; Catianis *et al.*, 2013, 2016).

4.3.2. Razim Lake

The bottom sediment analysis reveals a similar alternating lithology between *organic-rich*, *moderate carbonate* and *low siliciclastic* sediments, but with other prevalent percentages of the main lithological components (TOM, CAR, SIL) (%) identified in the investigated sediment samples.

With regard to WC%, the variations were displayed as a contour map (Fig. 6-a), indicating that water content varied greatly on the local scale. Large areas of the Razim L. (in the northern part, in the western part, as well as in Holbina Gulf – a shallow protected bay) had generally higher water contents (≥30-44) that can probably be attributed to a large extent, to sediment physical properties (sediment density, pattern of particle size variations, abundance of sediment macro-pores due to higher organic debris content in addition to sediment bioturbation). As well, other several higher values of WC% were associated with proximity to the principal lake inflow *via* Mustaca C. These WC% variations are probably common observed in lacustrine sediments belonging to mixed energy conditions that are prevalent in transitional (deltaic/marine) environment.

The TOM% content values, spotted in the bottom sediment samples varied, exhibiting a greater variability in organic matter content. The distribution map (Fig. 6-b) showed higher values (≥50-75%) that were identified in certain sectors, namely, in the northern half of the lake, in the southeastern part (Holbina Gulf) and in the southwestern part (Cape Doloșman). This was interpreted to indicate that the higher concentrations of organic matter encountered in the sediments of these shallow sectors could be associated with more quiet, low energy zones, favourable to the accumulation of organic material. On the other hand, Razim is a large shallow lake that is under the influence of winds which create high waves (up to 1 m and more in height), modify turbidity, increase resuspension and redistribution of sediment material in the water column thereby removing the organic matter.

These mixed energy conditions are prevalent in transitional (deltaic/marine) environment. Thus, recurrent perturbations are much intense in this large lake, with instantaneous, commonly irregular and significant variations in water level, flushing rates, seasonal turbidity, and mixing in the water column. This fact is also confirmed by the existence of other distinct areas dominated by high hydrodynamic energy conditions. These areas associated with lower values of organic matter (≥1-25%) are linked to the general direction of the water flow within the entire Razim-Sinoie Lagoon System (from north to south), that regulates the transport

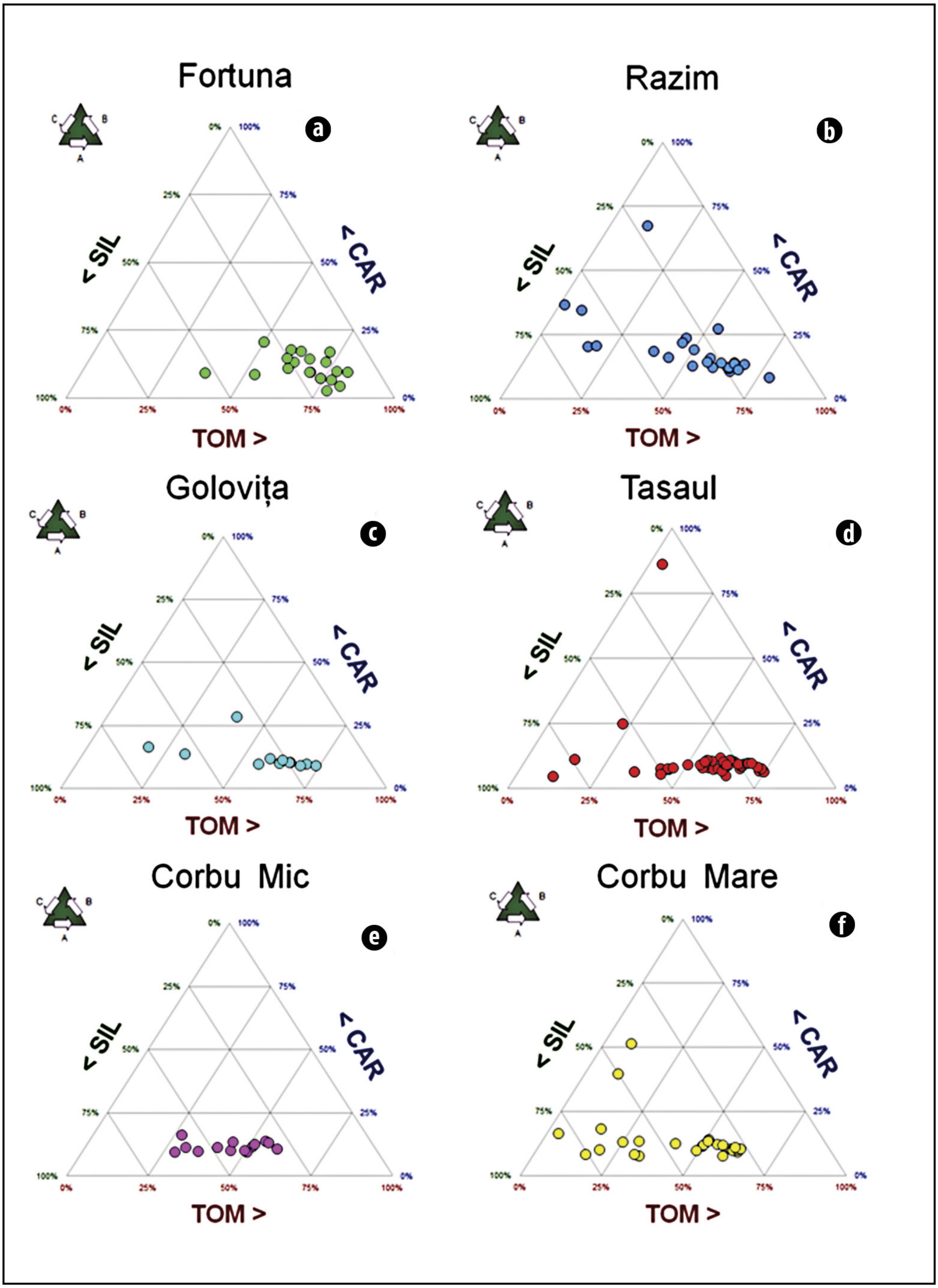

Fig. 4. Ternary diagrams showing the lithological component class distributions in tested bottom sediment samples from investigated lakes

of the main input of water and sediments distributed by the Danube River *via* Dunavăţ, Mustaca and Dranov Canals. Based on TOM% values (Table 1), these sediments were categorized in total as *organic sediments* (≥15-30% organic matter), subsequently followed by *mineral sediments* (≤15-30% organic matter).

In the analysed samples, total CAR% content varied, being distinguished by relatively high values (over 1% of the total weight of dry residue). The obtained results are shown as a contour map showing CAR% variations (Fig. 6-c). The highest value of 67.3% (DD18-75), occurred in the western part of the lake in an area of large bio-accumulation of shells, while the lowest value of 8.07% (DD18-40) was encountered in the northern part of the lake. The greater variations in carbonate content are not only related to bio-accumulation, but also to other sources, as authigenic carbonates, originating from the calcareous rocks within the catchment. The western banks of the Razim L. are at the Doloşman promontory (part of the Babadag Plateau), with an altitude of 57 m, consisting of Cretaceous limestones (a fossil sea cliff) (https://www.xn--delt-3sa.ro). Generally, based on CAR% values (Table 1), obtained by the analysis, these sediments were categorized in total, as *non-carbonated sediments* ($CaCO_3$≤10%), as well as *low calcareous* (10%<$CaCO_3$≤30%).

The SIL% content values showed a relative variation at the local scale. The results are shown as a contour map illustrating SIL% variations (Fig. 6-d). The range of variation is relatively large, varying from 13.18% (DD18-40), found out in the northern part of the lake, to a maximum value of 62.89% (DD18-38), encountered in the closeness of the Mustaca Cnl. The higher values of SIL% were found in the eastern part of the Razim L. where water and sediment input from the Danube is brought by the Dunavăţ and Mustaca canals. The concentration of the silica-rich sediments in this area also indicates the general direction of water and sediment flow of these two canals in the lake, from north to south. In addition, the intrusion of wind action may be responsible to some extent for the bottom mixed sedimentary processes in this lake.

The overall obtained results are also strengthened by ternary diagrams with the distribution of the investigated components (Fig. 4-b). The investigated parameters (TOM%, CAR%, SIL%, WC% and DM%) were shown to be interrelated to varying degrees, being encountered both positive and negative correlations.

Accordingly, **Razim L**. (Table 2) has faced a very strong negative correlation (TOM *vs.* SIL), a strong negative

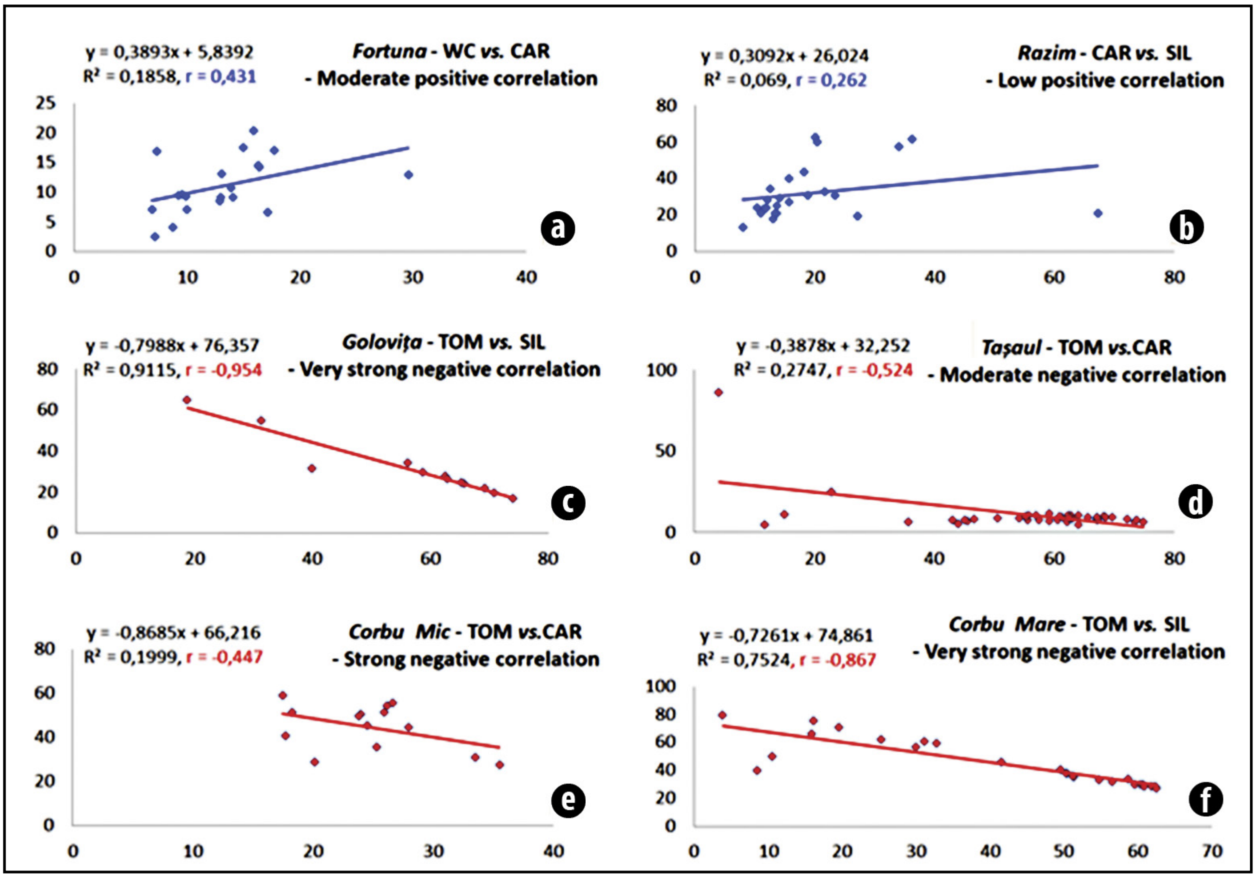

Fig. 5. XY scatter plots, and correlations between several selected parameters from investigated lakes (To avoid redundancy only the most relevant correlations were shown as XY scatter plots).

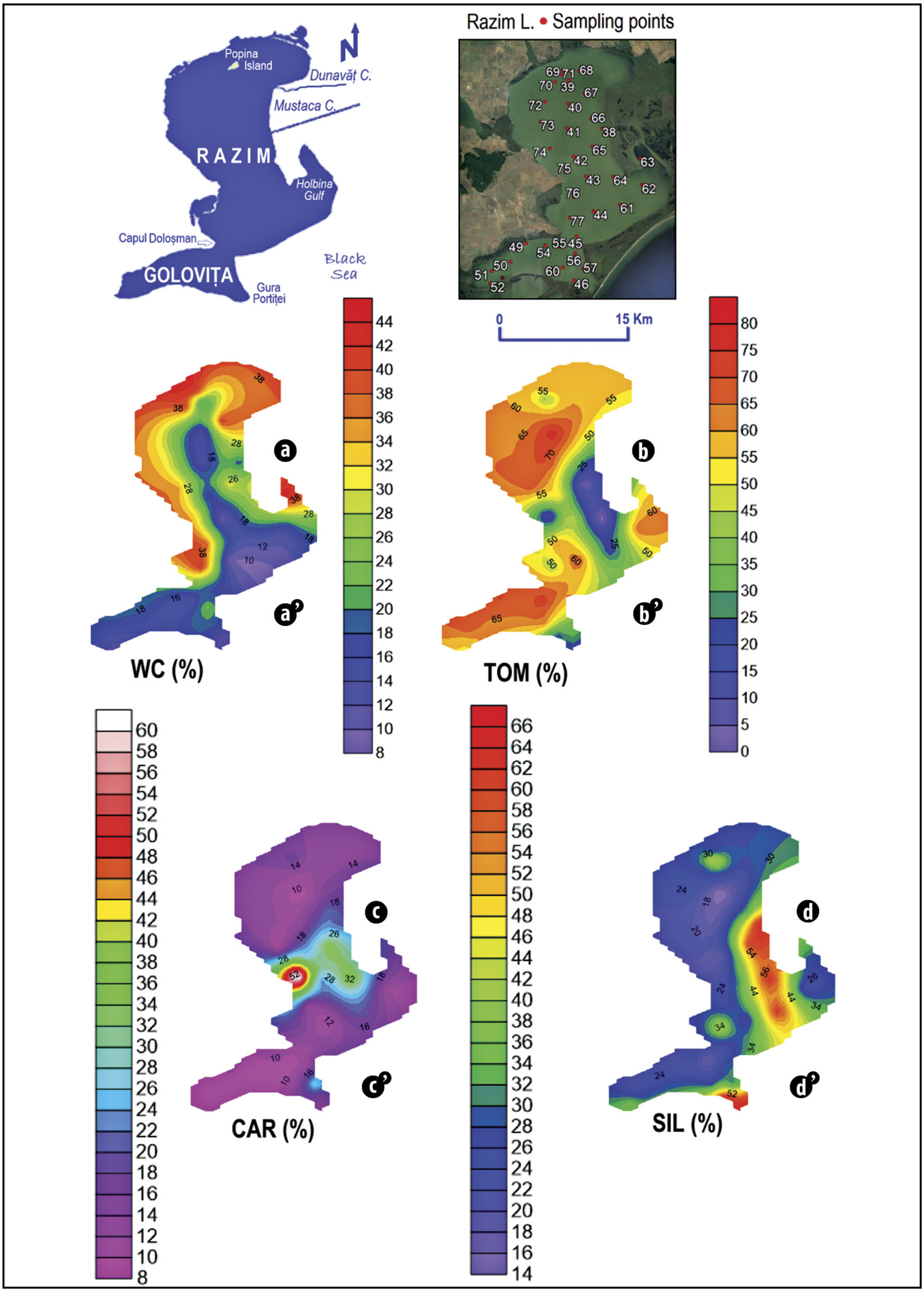

Fig. 6. Spatial variation of the lithological components in bottom sediment samples from Razim and Golovița lakes

correlation (TOM *vs.* CAR), and a very low negative correlation (WC *vs.* SIL; DM *vs.* TOM; DM *vs.* CAR). It was also seen a low positive correlation (CAR *vs.* SIL) (Fig. 5-b) and very low positive correlation (WC *vs.* TOM; WC *vs.* CAR; DM *vs.* SIL).

Preponderantly, in **Razim L**. it was identified a mixture of *organic-rich*, *moderate carbonate* and *low siliciclastic* sediments. The mixture between the organic matter and siliciclastic fractions indicates that recent sedimentation within this area strongly depends on the local environmental conditions. In Razim, while there is resuspension and mixing in the water column, the siliciclastic inputs from the Danube, the biogenic material resulting from either *in situ* organisms and the underlying geology play a very important part.

4.3.3. Golovița Lake

A series of similarities with Razim L.were also noticed for Golovița L.

For example, WC% content values revealed that the investigated surficial sediments relatively varied at the local scale (Fig. 6-a').

TOM% values are high overall, in this lake as well. They also show a broad variability, ranging from a minimum of 18.82% (DD18-46), in the southern part of the lake, to a maximum of 74.05% (DD18-55), in its northern part. In line with the distribution map (Fig. 6-b'), higher values of TOM% content were relatively uniformly distributed, being not significantly different, except a sector in the closeness of the Gura Portiței area (with lower values). Based on TOM% values (Table 1), obtained by the analysis, these sediments were categorized in total as *organic sediments* (≥15-30% organic matter), subsequently followed by *mineral sediments* (≤15-30% organic matter).

The collected samples from Golovița were also characterized by relatively high CAR% contents (over 1% of the total weight of dry residue) with values ranged from 8.96% (DD18-55) noticed in the northern part, to 28.40% (DD18-57), observed in its eastern part (Fig. 6-c'). The sediment sample with this higher carbonate content was characterized by an abundance of bivalve shells, freshwater mussel shells, as well as organic shell debris. Shells of freshwater and brackish macrofauna have a high carbonate content, which does not vary much, reaching 99% in certain cases (White *et al.*, 2007). Based on CAR% values (Table 1), obtained by the analysis, these sediments were categorized in total, as *non-carbonated sediments* ($CaCO_3$≤10%), as well as *low calcareous* (10%<$CaCO_3$≤30%).

The leftover material, specifically, the SIL% content, was also variable. According to data distribution map (Fig. 6-d'), higher values of SIL% were spotted in the closeness of the Gura Portiței area, which was to be expected, considering the proximity to the Black Sea, implicitly mixed sediment environments.

The overall obtained results are also strengthened by ternary diagrams with the distribution of the investigated components (Fig. 4-c).

The investigated parameters (TOM%, CAR%, SIL%, WC% and DM%) were shown to be interrelated to varying degrees, being encountered both positive and negative correlations. Accordingly, **Golovița** L. (Table 2) has faced a very strong negative correlation (TOM *vs.* SIL) (Fig. 5-c), a strong negative correlation (TOM *vs.* CAR), a low negative correlation (DM *vs.* CAR) and a very low negative correlation (WC *vs.* SIL; DM *vs.* TOM). It was also seen a low positive correlation (CAR *vs.* SIL; WC *vs.* CAR) and a very low positive correlation (WC *vs.* TOM; DM *vs.* SIL).

The obtained results were interpreted to indicate that the accumulation of the main lithological components is strongly linked to local natural changes that characterized the Golovița L. (water level variation, mixed sediment environments, erosion etc). Dominantly, in Golovița L. it was identified a mixture of *organic-rich*, *moderate carbonate* and *low siliciclastic sediments*.

The results within this study are comparable to previous findings for these aquatic systems or lakes with similar hydro sedimentary characteristics that belong to the DDBR area (Rădan & Rădan, 2009, 2010, 2011; Dimitriu *et al.*, 2008; Catianis *et al.,* 2016, 2018).

4.3.4. Tașaul Lake

The variability of the lithological components was also examined for Tașaul L.

Concerning the WC%, a great variability was noticed at the local scale (Fig. 7 a). The largest sector characterized by a high WC% (~ 45%) was noticed in the southern part of the lake. Most likely, these different WC% values may be influenced by the sediment physical properties.

Within the Tașaul L., the TOM% content did not vary significantly between sampling sites. The majority of the obtained values were high. The distribution map (Fig. 7-b) showed that the most dominant class interval has values over 50% of the total weight of dry residue. TOM% was the dominant sediment fraction all over the lake, excepting the inner stations (≤50%) situated in the central eastern part of the lake, in the area of Ada Island. The results indicate that the large fraction of organic matters appears to be of *authochtonous* origin. If we take into account the field observations regarding the sediment samples (meaning the predominance of organic muds, theirs putrescent smell, plenty bioturbation traces), we may strictly connect this to the inputs of primary organic matter from microphytoplankton, zooplankton, microzoobenthos, bacteria etc. Based on TOM% values (Table 1), obtained by the analysis, these sediments were categorized in total, as *organic* sediments (≥15-30% organic matter), subsequently followed by *mineral sediments* (≤15-30% organic matter).

The carbonate content values showed a large fluctuation from 4.62% (TS19-04) to 86.22% (TS19-30). One particular area with the highest intensity was located in the central part of the lake (Fig. 7-c). The higher CAR% content was related to a shell hash layer (*e.g.,* lumachella) formed mainly of bivalves and gastropods (TS19-30). On the other hand, the higher carbonate value that occurred in the central part of the lake, may be also related to the closeness of the Ada Island that it is known as a source of calcareous sediment, *i.e.,* Jurassic carbonate formation of Central Dobrogea - the Casimcea Formation (Drăgănescu, 1976). Generally, based on CAR% values (Table 1), these sediments were categorized in total, as *non-carbonated sediments* ($CaCO_3$≤10%), as well as *low calcareous* (10%<$CaCO_3$≤30%).

In the study area, relatively lower values of SIL% content were generally noticed (≤50% of the total weight of dry residue), varying from 9.72 (TS19-30) to 83.65% (TS19-04). For all that, two areas with the highest values (≥50%) were located in the northern part, in the closeness of the Casimcea Rivulet mouth, and respectively, in the central part, in the vicinity of the Ada Island (Fig. 7-d). In the first case, the results indicated that the higher values of the siliciclastic fraction may be as a result of the terrigenous material supplied by the Casimcea Rivulet. Then, in the second case, the siliciclastic fraction content may be due to the natural process of Ada Island bank erosion.

The overall obtained results are also strengthened by ternary diagrams with the distribution of the investigated components (Fig. 4-d).

The investigated parameters (TOM%, CAR%, SIL%, WC% and DM%) were shown to be interrelated to varying degrees, being encountered both positive and negative correlations. Accordingly, **Tașaul L**. has faced a strong negative correlation (TOM *vs.* SIL), a moderate negative correlation (TOM *vs.* CAR) (Fig. 5-d), a low negative correlation (CAR *vs.* SIL) and a very low negative correlation (WC *vs.* CAR; DM *vs.* TOM; DM *vs.* SIL). It was also seen a very low positive correlation (WC *vs.* TOM; WC *vs.* SIL; DM *vs.* CAR) (Table 2).

The fluctuations of all these values (TOM, CAR, SIL) (%) indicate that Tașaul L. acts as a semi-enclosed system with relative episodic changes in the water circulation, under the influence of the natural variations of the Casimcea River inputs, controlled by temperature and precipitation.

Prevalently, in Tașaul L. there is a mixture of *organic-rich*, *moderate carbonate* and *low siliciclastic sediments*. In all probability, the natural environmental factors determine the accumulation of different lithological components, especially, the amount of organic matter. Our results showed a series of values that were very similar to other precedent studies related to the principal lithological components of the Tașaul Lake sediments (Rădan *et al.*, 2008; Rădan & Rădan, 2010, 2011).

4.3.5. Corbu Lake

The surficial sediments were characterized by a relatively high WC%, with several sediment samples showing more than 25% water content. Sampling sites with notably higher sediment-water contents were located in both lakes (Fig. 7-a'). Two major areas with the highest intensity were located in the northern part of the **Corbu Mic L**., including, as well, the median part of the **Corbu Mare L.**

The TOM% content of surface sediments varied from relatively highly organic sediments with values of about 50–60%, occurred in the median part of both lakes, to approximately 15-40%, encountered in the marginal sectors (Fig. 7-b'). It is assumed that the in-lake productivity processes, supply a significant amount of organic matter in this lacustrine complex. Based on TOM% values (Table 1), these sediments were categorized in total, as *organic sediments* (≥15-30% organic matter), subsequently followed by *mineral sediments* (≤15-30% organic matter).

With regard to CAR% content, the sampling sites with remarkably higher sediment-carbonate content were identified in the southern part of the **Corbu Mare L**. (Fig. 7-c'). Otherwise, the spatial pattern distribution of CAR% content within the lacustrine complex is quite uniform, without significant variations (~10-15%). The presence of the carbonate in the bottom sediment samples could be directly linked to the presence of a limestone quarry on the southeastern bank of the lake. The limestone eroded particles from the open quarry are probably transported into the lake by means of surface runoff and eolian transport. Generally, based on CAR% values (Table 1), obtained by the analysis, these sediments were categorized in total, as *non-carbonated sediments* ($CaCO_3$≤10%), as well as *low calcareous* (10%<$CaCO_3$≤30%).

The SIL% content was variable in both lakes, with different prevalent percentages in function of the sampling site's geographical position. In concordance to the distribution map (Fig. 7-d') certain areas with the highest intensity (≥50%) were located in the western part of the **Corbu Mic L**., then in the eastern, and respectively in the southern part of the **Corbu Mare L.** The proximity of the Black Sea coast to this lake determines the local climate conditions, characterised by high winds which lead to shoreline erosion (from the surrounding areas, including the coastline) and may contribute to the transport and preservation of the siliciclastic content within the Corbu L.

The overall obtained results are also strengthened by ternary diagrams with the distribution of the investigated components (Fig. 4-e, f).

The investigated parameters (TOM%, CAR%, SIL%, WC% and DM%) were shown to be interrelated to varying degrees, being encountered both positive and negative correlations. Accordingly, **Corbu Mic L**. (Table 2) has faced a very strong negative correlation (TOM *vs.*SIL), a moderate

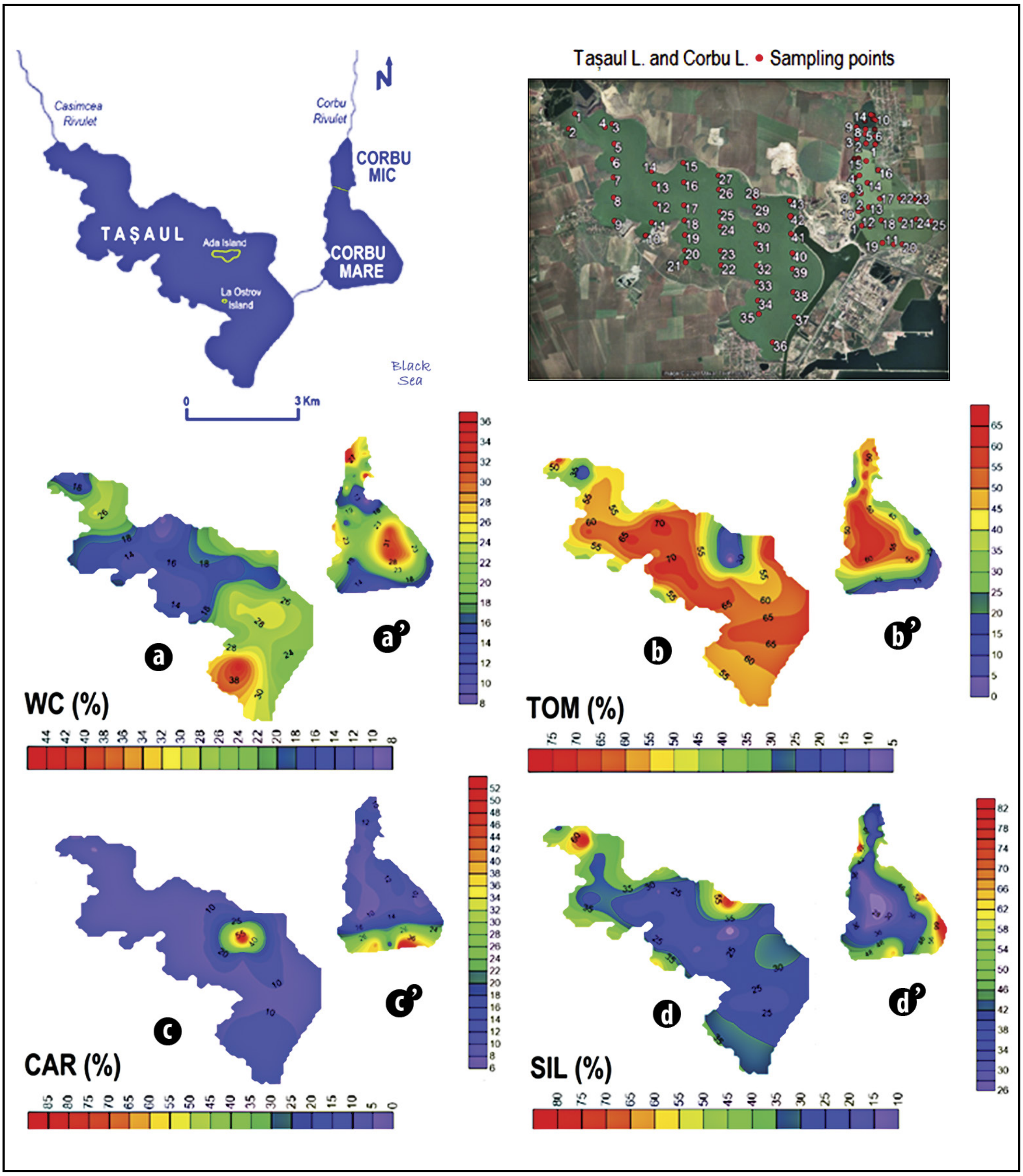

Fig. 7. Spatial variation of the lithological components in bottom sediment samples from Corbu and Tașaul lakes

negative correlation (WC *vs.* TOM; DM *vs.* CAR), a low negative correlation (DM *vs.* SIL) and a very low negative correlation (TOM *vs.* CAR; CAR *vs.* SIL) (Fig. 5-e). It was also seen a moderate positive correlation (WC *vs.* CAR; DM *vs.* TOM) and a low positive correlation (WC *vs.* SIL).

Then, **Corbu Mare L**. (Table 2) showed a very strong negative correlation (TOM *vs.* SIL) (Fig. 5-f), a moderate negative correlation (TOM *vs.* CAR) and a low negative correlation (WC *vs.* CAR; WC *vs.* SIL; DM *vs.* TOM). It was also seen a low positive correlation (WC *vs.* TOM; DM *vs.* CAR; DM *vs.* SIL) and a very low positive correlation (CAR *vs.* SIL).

Largely, Corbu L. is characterized by a mixture of *moderate organic-rich*, *moderate carbonate* and *moderate siliciclastic sediments*.

CONCLUSIONS

This study assesses the contribution of both *allochthonous* and *autochthonous* sediment inputs in five shallow lakes located in the DDBRA and the Black Sea coastal area, in relation to catchment and *in situ* depositional conditions, by means of lithological composition of the bottom sediments.

Within the five lakes of this study, sedimentary accumulation is conditioned by the local environmental conditions specific to the three depositional systems, *i.e.,* continental (fluviatile), transitional (deltaic/ lacustrine) and coastal environment.

The main physical processes that influence the sediment deposition within these lakes are mostly related to sediment transport, climatic conditions and hydrodynamic environmental variables within the depositional areas, as the influence of Danube River inputs on the trophic functioning of transitional ecosystems in the DDBR and North-Western Black Sea environment.

Based on the results obtained within this study, a spatial distribution of the principal lithological components and the main sources of recent natural sediment distribution pattern is obtained.

In this sense, the samples taken from all the aforementioned locations revealed sediments specific to the three mixed depositional systems:

- continental (fluviatile) – sediments with a high content of lithoclastic material - plus a subordinate content of organogenic material;
- transitional (deltaic/lacustrine) – muds rich in organic substances plus a subordinate content of lithoclastic material;
- coastal environment – mixed sediments.

Thereby the bottom sediment samples studied within this paper showed a similar alternating lithology between organic-rich sediments, mineral-rich sediments and ”transitional”/mixed sediments. In addition to the organic and inorganic content, there is also a relatively significant fraction of authigenic biogenic carbonates (shells, fragments of shells and shell debris), as well as parent material (geochemical background).

- **organic-rich sediments** (a large fraction of *autochthonous* organic matter) identified in most of the sampling sites, localized in regions under low energy conditions without high fluvial input, or hydrologically closed lakes (in sheltered near-shore lake sectors and/or at stagnant water);
- **mineral-rich sediments** (significant amounts of mineral matter) retrieved in disparate sampling points positioned in regions under higher energy conditions with significant fluvial input or hydrologically open systems defined by wind-induced and littoral currents (canal/stream mouth, coastal erosion, parent material/sediment texture);
- **”transitional”/mixed sediments** (relatively high concentration of organic /inorganic matter) encountered within mixed sediment environments.

Regarding the sources that supply these deposition areas, the *allochthonous* (eolian or fluvial transport from the catchment sources – soil or bedrock erosion) and *autochthonous* (in-lake productivity processes, emergent or submerged plants, planktonic biomass etc.) have different proportions. In complex environments, like the ones investigated, with both fluvial input and high *in situ* productivity, separating and quantifying the two constituents is not straightforward.

Further investigations are required to corroborate the findings of this paper for recent sediment accumulations in environments with mixed sedimentary processes.

ACKNOWLEDGEMENTS

The research leading to these results was supported by the Ministry of Research and Innovation – MCI –”Program Nucleu: **13N/16.03.2018-Proiect PN 18 16 01 02**, **13N/08.02.2019 - PN 19 20 02 03**, as well as **13N/08.02.2019 - PN 19 20 04 02.** Apart from that, we manifest our sincere thanks to reviewers for providing valuable suggestion and insightful commentaries that enhance manuscript quality. As well, we express our deep sense of thankfulness to Dr. Silviu Rădan for his valuable guidance, expert suggestions and constructive observations.

REFERENCES

Alexandrov M.L., Bloesch J. (2009). Eutrophication of Lake Tasaul, Romania – proposals for rehabilitation. *Environ SciPollut Res,* **16**(*1*), 42-45.

Bengtsson L., Enell M. (1986). Chemical analysis. *In*: B.E. Berglund (Ed): Handbook of Holocene Palaeoecology and Palaeohydrology, Wiley, Chichester, 423-445.

Canuel E.A. (2001). Relations between river flow, primary production and fatty acid composition of particulate organic matter in San Francisco and Chesapeake Bays: A multivariate approach. *Org. Geochem.,* **32**(*4*), 563-583.

Canuel E.A., Cloern J.E., Ringelberg D.B., Guckert J.B., Rau G.H. (1995). Molecular and isotopic tracers used to examine sources of organic matter and its incorporation into the food webs of San Francisco Bay. *Limnology and Oceanography*, **40**(*1*), 67-81.

Catianis I., Pojar I., Scrieciu A., Grosu D., Pavel A.B. (2016). A preliminary assessment of the physical-chemical features of water and sediments from different deltaic aquatic systems. Case study: Fortuna Lake, Matita Lake and Musura Bay - Danube Delta, Romania, INCD ECOIND – 19th International Symposium – SIMI 2016 "The environment and the industry", *Proceedings Book*, 342-350.

Catianis I., Pojar I., Scrieciu A., Grosu D., Pavel A.B. (2016). A preliminary assessment of the physical-chemical features of water and sediments from different deltaic aquatic systems. Case study: Fortuna Lake, Matita Lake and Musura Bay - Danube Delta, Romania, *Proceedings Book* of the 19th International Symposium – SIMI 2016 "The environment and the industry", 342-350.

Catianis I., Rădan S., Grosu D. (2013). Distribution of lithological components of recent sediments from some lakes in the Danube Delta; environmental significance. *Carpathian Journal of Earth and Environmental Sciences*, **8**(*2*), 55-68.

Catianis I., Secrieru D., Pojar I., Grosu D., Scrieciu A., Pavel A.B., Vasiliu D. (2018). Water Quality, Sediment Characteristics and Benthic Status of the Razim-Sinoie Lagoon System, Romania. *Open Geosciences*, **10**(*1*), 12-33.

Clayton R.N., Degens E.T. (1959). Use of carbon isotope analyses of carbonates for differentiating fresh-water and marine sediments. *Bull. Am. Assoc. Petrol. Geologists*, **43**, 890-897.

Cresson P., Ruitton S., Fontaine M.F., Harmelin-Vivien M.L. (2012). Spatio-temporal variation of suspended and sedimentary organic matter quality in the Bay of Marseilles (NW Mediterranean) assessed by biochemical and isotopic analyses. *Mar. Pollut. Bul.*, **64**, 1112-1121.

Cuthbertson A.J.S., Dong P., King S., Davies P.A. (2008). Hindered settling velocity of cohesive/non-cohesive sediment mixtures. *Coastal Eng,* **55**(*12*), 1197-1208.

Dean W.E. Jr. (1974). Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: Comparison with other methods, *J. Sediment. Petrol.,* **44**(*1*), 242-248.

Dearing J. (1986). Core correlation and total sediment influx. *In*: Berglund, B. (ed.) Handbook of Palaeoecology and Palaeohydrology, John Wiley and Sons, New York, 247-270.

Digerfeldt G., Olsson S., Sandgren P. (2000). Reconstruction of lake-level changes in lake Xinias, central Greece, during the last 40000 years, *Palaeogeography Palaeoclimatology Palaeoecology*, **158**(*1-2*), 65-82.

Dimitriu R.G., Oaie Gh., Gomoiu M.T., Begun T., Szobotka Ş., Rădan S.C., Fulga C. (2008). An Interdisciplinary Characterization of the Geo-ecological State of the Razelm - Sinoie Lagoon Complex at the beginning of the 21st Century, *Geo-Eco-Marina*, Supplement 1, [in Romanian], **14**, 69-74.

Drăgănescu A. (1976). Constructional to corpuscular spongalgal, algal and coralgalfacies in the Upper Jurassic carbonate formation of Central Dobrogea (The Casimcea Formation). *In*: Patrulius D., Drăgănescu A., Baltreş A., Popescu B., Rădan S., Carbonate rocks and evaporites. Guidebook., Guidebook series, Inst. Geol. Geofiz., Bucureşti, **15**, 13-41.

Duncan A.E., de Vries N., Nyarko K.B. (2018).Assessment of heavy metal pollution in the sediments of the River Pra and its tributaries, *Water Air Soil Pollut.,* **229**(*8*), 272-272.

Duodu G.O., Goonetilleke A., Ayoko G.A. (2016). Comparison of pollution indices for the assessment of heavy metal in Brisbane River sediment. *Environ Pollut*, **219**, 1077-1091.

Emelyanov E.M., Shimkus K.M. (1986). Geochemistry and Sedimentology of the Mediterranean Sea, D. Reidel Publishing Company, Dordrecht, Holland, 567 p.

Finlay J.C., Kendall C. (2007). Stable isotope tracing of temporal and spatial variability in organic matter sources to freshwater ecosystems, *In*: Stable isotopes in ecology and environmental science, 2nd Edn., edited by: Michener, R. H. and Lajtha, K., Blackwell Publishing, Malden, USA, 283-333.

Foley J.A., De Fries R., Asner G.P., Barford C., Bonan G., Carpenter S.R., Chapin F.S., Coe M.T., Daily G.C., Gibbs H.K., Helkowski J.H., Holloway T., Howard E.A., Kucharik C.J., Monfreda C., Patz J.A., Prentice I.C., Ramankutty N., Snyder P.K. (2005). Global consequences of land use, *Science*, **309**, 570-574.

Forsberg C. (1989). Importance of sediments in understanding nutrient cycling in lakes. *Hydrobiologia*, **176/177**(*1*), 263-277.

Găştescu P. (1971). Lacurile din România – limnologie regională, Edit. Academiei, Bucureşti, 372 p.

Găştescu P. (1998). Razim-Sinoie lake complex, Romania. *In*: Encyclopedia of Hydrology and Water Resources, edited by Reginald W. Herschy and Rhodes W. Fairbridge, Kluwer Academic Publishers, Dordrecht / Boston / London, 832 p., 549-551.

Găştescu P. (2007). The Danube Delta Biosphere Reserve. Geography, Biodiversity, Management. *The Annals of Valahia University of Târgovişte*, Geographical Series, **6-7**, 9-19.

Găştescu P., Ştiucă R. (2008). *Delta Dunării–rezervaţie a biosferei*. CD Press, Bucureşti [in Romanian, with Contents, Introduction and Summary in English], 400 p.

Găştescu P., Breţcan P., Teodorescu D.C. (2016). The lakes of the Romanian Black Sea coast. Man induced changes, water regime, present state. *Rev. Roum. Géogr./Rom. Journ. Geogr.*, **60**(*1*), 27-42.

Gholizadeh M., Patimar R. (2018). Ecological risk assessment of heavy metals in surface sediments from the Gorgan Bay, Caspian Sea. *Mar. Pollut. Bull.,* **137**, 662-667.

Håkanson L., Jansson M. (1983). Principles of Lake Sedimentology. Berlin-New York: Springer -Verlag 1983, ISBN 3-540 (Berlin) 0-387 (New York)-12645-7, 320 p.

Halpern B.S., Walbridge S., Selkoe K.A., Kappel C.V., Micheli F., D'Agrosa C., Bruno J.F., Casey K.S., Ebert C., Fox H.E., Fujita R., Heinemann D., Lenihan H.S., Madin E.M.P., Perry M.T., Selig E.R., Spalding M., Steneck R., Watson R. (2008). A global map of human impacts on marine ecosystems. *Science*, **319**, 948-952.

Heiri O., Lotter A.F., Lemcke G. (2001). Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results, *J. Paleolimnol.,* **25**, 101-110.

Hodell D.A., Brenner M., Kanfoush S.L., Curtis J.H., Stoner J.S., Song X.L., Wu Y., Whitmore T.J., 1999. Paleoclimate of southwestern China for the past 50, 000 yr. inferred from lake sediment records, *Quaternary Research,* **52**, 369-380.

Hope D., Billett M.F., Cresser M.S. (1994). A review of the export of carbon in river water: Fluxes and processes, *Environ. Pollut.,* **84**, 301-324.

Hou D., He J., Lu C., Sun Y., Zhang F., Otgonbayar K. (2013). Effects of environmental factors on nutrients release at sediment-water interface and assessment of trophic status for a typical shallow lake, Northwest China. *The Scientific World Journal*, 2013, Article ID 716342, 16 p.

Kennedy D.M., Woods J.L.D. (2013). Determining organic and carbonate content in sediments. In: A. D. Switzer and D. M. Kennedy, eds. Methods in Geomorphology. San Diego: Academic Press, 262-273.

Kulbat E., Sokolowska A. (2019). Methods of Assessment of Metal Contamination in Bottom Sediments (Case Study: Straszyn Lake, Poland), *Arch. Environ. Con. Tox.*, **77**(*4*), 605-618.

Lapointe B., Littler M.M., Littler D.S. (1992). Nutrient availability to marine macroalgae in siliciclastic versus carbonaterich coastal waters. *Estuaries,* **15**, 75-82.

Lotze Heike K., Lenihan Hunter S., Bourque Bruce J., Bradbury Roger H., Cooke Richard G., Kay Matthew C., Kidwell Susan M., Kirby Michael Xavier, Peterson Charles H., Jackson Jeremy B.C. (2006). Depletion, Degradation, and Recovery Potential of Estuaries and Coastal Seas, *Science*, 1806-1809.

Lutz M., Dunbar R., Caldeira K. (2002). Regional variability in the vertical flux of particulate organic carbon in the ocean interior, *Global Biogeochemical Cycles,* **16**(*3*), 1037-1055.

MacDonald D.D., Ingersoll G.G., Berger T.A. (2000). Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems, *Arch. Environ. Contam. Toxicol*., **39**, 20-31.

Mash H., Westerhoff P.K., Baker L.A., Nieman R.A., Nguyen M.L. (2004). Dissolved organic matter in Arizona reservoirs: assessment of carbonaceous sources. *Org. Geochem*., **35**(*7*), 831-843.

Mihăilescu, N. (2006). Danube delta geology, geomorphology and geochemistry. *In*: Tudorancea C. and Tudorancea M.M. (Eds.), Danube Delta, *Genesis and Biodiversity*, Backhuys Publishers, Leiden, The Netherlands, 444 p., 9-35.

Motoc C.S. (2016). Maliuc – Orașul Științei, Tipărit de ZOOM print & copy center, Iași, Romania, ISBN 978-973-0-21228-0, [in Romanian], 196 p.

Owens P.N., Petticrew E.L., Van der Perk M. (2010). Sediment response to catchment disturbances, *Journal of Soils and Sediments*, **10**, 591-596.

Panin N., Jipa D. (2002). Danube River sediment input and its interaction with the north-western Black Sea. *Estuarine, Coastal and Shelf Science*, Elsevier Sc. Ltd. UK, **54**(*2*), 551-562.

Panin N., Jipa D.C., Gomoiu M.T., Secrieru D. (1999). Importance of sedimentary processes in environmental changes: lower river Danube - Danube Delta-Western Black Sea System, Environmental Degradation of the Black Sea: Challenges and Remedies, *NATO Science Series*, **56**, 23-41.

Perrin J. (1974). Classification des sols organiques, *Bulletin de Liaison des Laboratoires des Ponts et Chaussées*, [in French], 36-47.

Pollard J.A., Spencer T., Brooks S.M. (2018). The Interactive Relationship Between Coastal Erosion and Flood Risk. *Progress in Physical Geography,* **20**(*2*), 1-12.

Popescu D., Caraivan G. (2003). Evoluția lacului Tașaul în Cuaternarul târziu (Lake Tașaul site evolution during the late Quaternary), *Pontica,* 2002-2003, **35-36** [in Romanian], 53-59.

Rădan S.-C., Rădan S. (2007). A magnetic susceptibility scale for lake sediments; Inferences from the Danube Delta and the Razelm-Sinoie lagoonal Complex (Romania), *Geo-Eco-Marina*, **13**, 61-74.

Rădan S.-C., Rădan S. (2009). Integrated magnetic susceptibility and lithological studies on lacustrine recent sediments from the Danube Delta, *Geo-Eco-Marina*, **15**, 139-159.

Rădan S.-C., Rădan S. (2010). Ecohydrological applications in southeastern Romania wetlands based on a magneto-lithological tool, *Geo-Eco-Marina*, **16**, 47-66.

Rădan S.-C., Rădan S. (2011). Recent sediments as enviromagnetic archives. A brief overview, *Geo-Eco-Marina*, **17**, 103-122.

Rădan S.-C., Rădan S. Cazacu C., Milu C. (2008). Magnetic susceptibility and lithological characterization of the lake sediments from the southeastern Romania wetlands; environmental significances, *Contributions to Geophysics and Geodesy*, Special Issue, *Geophys. Inst. Slovak Acad. Sci.*, Bratislava, Slovakia **38**, 107-110.

Rădan S.-C., Rădan S., Catianis I. (2013). The use of the magnetic susceptibility record as a proxy signature for the lithological composition of lake sediments: Evidences from Danube Delta short cores in the Meșteru – Fortuna Depression (Danube Delta), *Geo-Eco-Marina*, **19**, 77-105.

Rădan S.-C., Rădan S., Catianis I., Scrieciu A. (2014). Relationship between the magnetic susceptibility andlithological composition in sediment cores from lakes of Matița-Merhei Depression (Danube Delta, Romania): Towards a proxy method of minerogenic and environmental fingerprinting. *Geo-Eco-Marina*, **20**, 45-86.

Rădan S.-C., Rădan S., Catianis I., Grosu D., Pojar I., Scrieciu A. (2016). An environmental magneto-lithogenetic study in the lakes of the Gorgova-Uzlina Depression (Danube Delta, Romania). II. Insights from surficial sediments. *Geo-Eco-Marina*, **22**, 75-107.

Ricken W. (1993). Sedimentation as a Three-Component System. Organic Carbon, Carbonate, Noncarbonate. Lecture Notes in Earth Sciences Series, *Volume 51. XII*, *211* p., Berlin, Heidelberg, New York, London, Paris, Tokyo, Hong Kong: Springer-Verlag.

Santisteban J., Mediavilla R., Lopez-Pamo E., Dabrio C., Ruiz Zapata M., Garcia M. Gil Castano S., Martinez-Alfaro P. (2004). Loss on ignition: a qualitative or quantitative method for organic matter and carbonate mineral content in sediments? *Journal of Paleolimnology*, **32**, 287-299.

Smith K.A., Mullins C.E. (2000). Soil and Environmental Analysis: Physical Methods. Revised and Expanded. New York, NY, USA: Marcel Dekker, Inc. Soil Survey Division Staff (1993). Soil Survey

Manual. Washington, DC, USA: United States Department of Agriculture, 651 p.

Smol J.P. (2010). Paleolimnology, **56-65**, *In*: Gene E. Likens (ed.) Lake Ecosystem Ecology - A Global Perspective, 1st Edition**,** Academic Press, ISBN: 9780123820020, eBook ISBN: 9780123820037, 480 p.

Sothwell M.W., Mead R.N., Luquire C.M., Barbera A., Avery G.B., Kieber R.J., Skrabal S.A. (2011). Influence of organic matter source and diagenetic state on photochemical release of dissolved organic matter and nutrients from resuspendable estuarine sediments, *Mar. Chem.,* **126**, 114-119.

Stănică A. (2012). The Danube Delta. Back to nature through international cooperation. *In* "Climate of Coastal Cooperation", R. Misdorp Editor. Publishers: Coastal & Marine Union-EUCC (Leiden, the Netherlands), http://www.coastalcooperation.net/part-I/I-3-2.pdf, ISBN 978-90-75502-09-1

Syvitski J.P.M., Vörösmarty C.J., Kettner A.J., Green P. (2005). Impact of humans on the flux of terrestrial sediment to the global coastal ocean, *Science*, **308**, 376-380.

Tate R.L. (1987). Soil Organic Matter: Biological and Ecological Effects, John Wiley and Sons, Inc., N.Y., 291 p.

Tesi T., Miserocchi S., Goni M.A., Langone L., Boldrin A., Turchetto M. (2007). Organic matter origin and distribution in suspended particulate materials and surficial sediments from the Western Adriatic Sea (Italy). *Est Coast Shelf Sci.*, **73**, 431-446.

Van der Veer G. (2006). Geochemical soil survey of The Netherlands. Atlas of major and trace elements in topsoil and parent material; assessment of natural and anthropogenic enrichment factors, *Neth. Geogr. Stud*., **347**, 1-245.

Van Rijn Leo C. (2013). Basics of Channel Deposition/Siltation, *Aqua Publications*, The Netherlands, 1-24.

Volkman J.K., Tanoue E. (2002). Chemical and biological studies of particulate organic matter in the ocean, *J Oceanogr.,* **58**, 265-279.

White M.M., Chejlava M., Fried B., Sherma J. (2007). The concentration of calcium carbonate in shells of freshwater snails, *American Malacological Bulletin*, **22**(*1*), 139-142.

Zhang H.L., Li S.J., Feng Q.L., Zhang S.T. (2010). Environmental change and human activities during the 20th century reconstructed from the sediment of Xingyun Lake, Yunnan Province, China. *Quaternary International*, **212**, 14-20.

Zhao M.-Y., Zheng Y.-F., and Zhao Y.-Y. (2016). Seeking a geochemical identifier for authigenic carbonate, *Nat. Commun.,* **7**, 1-7.

Zimmerman A.R., Canuel E.A. (2001). Bulk organic matter and lipid biomarker composition of Chesapeake Bay surficial sediments as indicators of environmental processes. *Estuarine, Coastal and Shelf Science*, **53**(*3*), 319-341.

*******,** ASTM-D2216 , 2010. Standard test method for laboratory determination of water (moisture) content of soil and rock by mass, Standard D2216-10, ASTM International, West Conshohocken, PA.

*******,** European Union Council, EU-Water Framework Directive (WFD), 2000.

*******,** EU-Water Framework Directive (WFD), 2000.Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, 2000, *Official Journal of the European Communities*, **43**: L327, 1-73.

*******,** Golden Software, SURFER Version 10, 2010. Reference Manual, Golden Software, Inc., Golden, Colorado, U.S.A.

*******,** https://towardsdatascience.com/eveything-you-need-to-know-about-interpreting-correlations-2c485841c0b8

*******,** https://www.geog.cam.ac.uk/facilities/laboratories/techniques/loi.html

*******,** https://www.google.com/intl/ro/earth/

*******,** https://www.google.com/search/romania

*******,** https://www.xn--delt-3sa.ro/ro/locatii/lacul-razim

*******,** Ramsar Convention, 1987. Convention on Wetlands of International Importance especially as Waterfowl Habitat. Ramsar (Iran), 2 February 1971, UN Treaty Series No. 14583, As amended by the Paris Protocol, 3 December 1982, and Regina Amendments, 28 May 1987, Ramsar Convention on Wetlands, Gland, Switzerland.

*******,** ROSPA0060 - Special Bird Protection Area, NATURA 2000 Site