THE USE OF THE MAGNETIC SUSCEPTIBILITY RECORD AS A PROXY SIGNATURE FOR THE LITHOLOGICAL COMPOSITION OF LAKE SEDIMENTS: EVIDENCES FROM SHORT CORES IN THE MEŞTERU - FORTUNA DEPRESSION (DANUBE DELTA)

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Abstract. The paper analyses the enviromagnetic results obtained on short cores collected from *Danube Delta* lakes and channels. A Hydro-Bios type core sampler was used to investigate sediments up to ca. 60 - 80 cm depth from various sedimentary environments located both in the *Fluvial Delta Plain* (*e.g.*, *Lungu L.*, *Cuteţchi L.*, *Fortuna L.*, *Crânjală Canal*, *Băclăneşti L.*, *Matiţa L.*, *Babina L.*, *Bogdaproste L.*, *Gorgova L.*, *Uzlina L.*, *Isacova L.*) and the *Fluvio-Marine Delta Plain* (*e.g.*, *Puiu L.* and *Roşu L.*). In this article, the results achieved for the sediment cores taken in the *Meşteru - Fortuna Depression*, during the 2010 - 2013 interval, are presented. The data make possible to compare, in some cases, the magnetic susceptibility (**k**; **MS**) characterisation of the bottom sediments (sampled with the grab sampler) with the **MS** data associated with the first 10-30 cm of sediments collected from the upper half of the cores, taken out from the same places within a lake. More interesting are the variations in the magnetic susceptibility regime along the cores. In many cases, the enviromagnetic parameter "intensity" increased from the upper part towards the core base, but also some well-defined maximum and minimum **k** anomalies were detected. A clearly higher **MS** regime was identified along the whole short cores collected from the *Crânjală mid-channel*. The data demonstrate the capability of the **MS** parameter as a sedimentogenetic indicator, being possible to correlate the higher **k** values with the interception of a silted up zone or of two different sediment sequences within a core as a result of the hydrological regime changes occurred during the time. As regards the lower **k** values measured at the upper part of the cores, they are usually related to the muds rich in fine vegetal (organic) detritus and/or rich in shell fragments. Based on the values of the enviromagnetic parameter (**k**) and of the contents of the lithological components along the cores, several correlation coefficients (**r**) were calculated, taking into consideration all the possible pairs of magnetic and/or lithological parameters. The vertical distribution of the magnetic susceptibility associated with the cores clearly illustrates the particular characteristics of the "confined sedimentary environments" *versus* the "dynamic sedimentary environments".

Key words: environmental magnetism, deltaic lakes, sedimentary environment, short sediment core, bottom sediment, lithological components, enviromagnetic parameter.

1. INTRODUCTION

A number of papers which were published during the last years (see Rădan & Rădan, 2011, for a brief overview and references) dealt mainly with the bottom sediments collected with the "van Veen-type" grab-samplers. So, the first approximately 30 cm beneath the water/sediment interface were the subject of the respective multidisciplinary studies. The magnetic susceptibility vertical variation for six short cores was presented in two of the cited articles (in Rădan & Rădan, 2011). Four cores were taken (in 2006) from the lakes *Lungu* (*Meşteru - Fortuna Depression*), *Isacova* (*Gorgova - Uzlina Depression*), and *Roşu* (*Lumina - Roşu Depressio*n). Another two short cores (collected in 2010 and 2011) had been originated from the *Matiţa - Merhei Depression*, particularly from the *Babina L.* and *Matiţa L*, respectively.

The present article focuses on the magnetic susceptibility and the lithological composition of 7 short cores collected during the 2010 - 2013 period from 4 lakes and a canal situated within the *Meşteru - Fortuna Depression* (*Fluvial Delta Plain*, northern wing) (see Fig. 1).

The magneto-lithological data associated with short cores were firstly presented at several symposia, *e.g.* the "*DELTANET International Conference – Deltas and Wetlands*" (Tulcea, Romania, 14-16 September, 2011), *"13th Castle Meeting. Paleo, Rock and Environmental Magnetism"* (Zvolen, Slovak Republic, 17-23 June, 2012), and *IGCP 580* - "*Magnetic Susceptibility and Gamma-Ray Spectrometry through time*" (Graz, Austria, 24-30 June 2012) (*e.g.*, Rădan *et al*., 2012). Also, a series of results regarding the lithological components only, analysed for 14 short cores taken from 7 deltaic lakes, have been recently published (Catianis *et al*., 2013).

The present approach is directed towards the study of the existent connections between the magneto-susceptibilimetric regime, identified along the short cores, and the main lithological components of the sediments. In some cases, the **MS** and the lithological data determined for the surficial sediments, extending, in general, approximately 30 cm beneath the water/sediment interface, are integrated within the study, and the results are compared with the corresponding data provided by the samples sliced from the upper part of the cores. The final goal is to demonstrate the capability of the magnetic susceptibility record to be used as a proxy signature for the lithological composition characterisation of the lake sediments.

2. LOGISTICS, GEOMATERIALS AND METHODS

During the expeditions carried out by GeoEcoMar in the *Danube Delta* lakes over last four years (2010 - 2013), the field works were focused on the direct observations of the water and sediments, carried out aboard the fluvial vessel "*Istros*" (Rădan & Rădan, 2011), but also on sampling them (biological samples were added), for different laboratory analyses. A motor-boat "*Măriuca*" was used in the lakes where the depth was lower than 1.50 m. Besides the physico-chemical and chemical parameters investigated for the surface waters, and the study of the greenhouse gas emissions in different deltaic

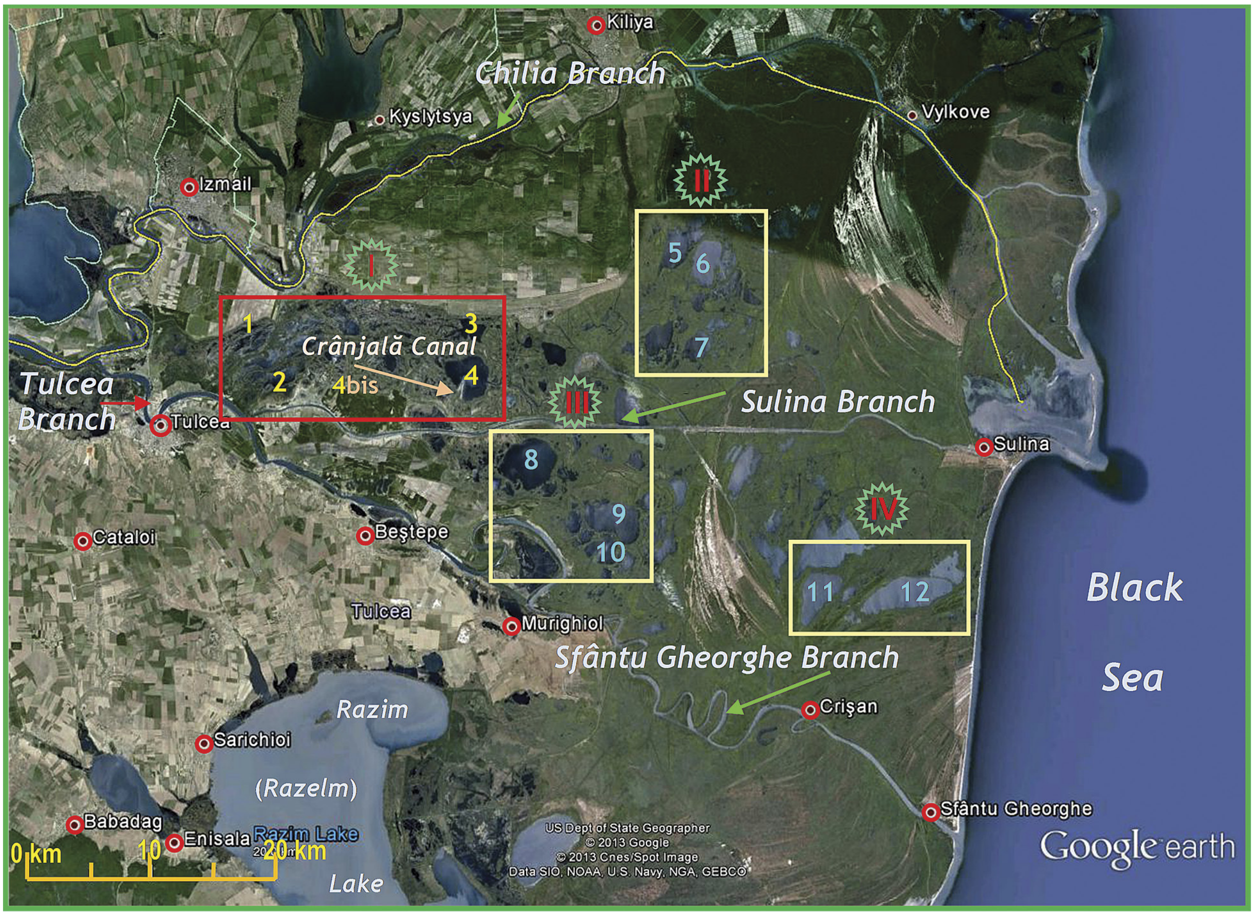


Fig. 1. Location of the lakes from where short cores were collected over the 2010 - 2013 period. **I.** *Meşteru - Fortuna Depression*: **1** - Cuteţchi Lake; **2** - Tătaru Lake; **3** - Băclăneşti Lake; **4** - Fortuna Lake; **4bis** - Crânjală Canal. **II.** *Matiţa - Merhei Depression*: **5** - Babina Lake; **6** - Matiţa Lake; **7** - Bogdaproste Lake. **III.** *Gorgova - Uzlina Depression*: **8** - Gorgova Lake; **9** - Isacova Lake; **10** - Uzlina Lake. **IV.** *Lumina - Roşu Depression*: **11** - Puiu Lake; **12** - Roşu Lake. *Note*: I - The area under attention.

ecosystems, the lithological and the magnetic susceptibility characterisation of the lacustrine sediments represents an important objective of the respective multidisciplinary campaigns performed in the *Danube Delta*, at least twice every year.

The present paper is dealing with various aspects of the integrated magnetic and lithological research of the sediments only. As regards the lake sediments, which are further under our consideration, 7 short cores were collected from 4 lakes and a canal located in the *Fluvial Delta Plain*, particularly, in the *Meşteru - Fortuna Depression* (*i.e.*, *Cuteţchi*, *Tătaru*, *Băclăneşti*, *Fortuna lakes*, and the *Crânjală Canal*; 1, 2, 3, 4/4bis, respectively, in Fig. 1).

Special attention was paid to chosing the lakes from the deltaic depressions, and then the locations of the cores within the respective lakes, aiming to investigate various ecosystems, and different sedimentary environments.

The sediment cores were collected with a Hydro-Bios corer, with a transparent tube (Fig. 2). The length of the core is up to 60 cm, when the standard corer was used, and up to 80 cm, for a modified version of the corer.

The sediment cores were sliced at 1-3 cm (Fig. 3a), using an extruder, aboard the R/V "Istros"; several sediment samples (Fig. 3b) were obtained from each core, and, subsequently, they were directed to different laboratories for specific analyses (Fig. 3c).

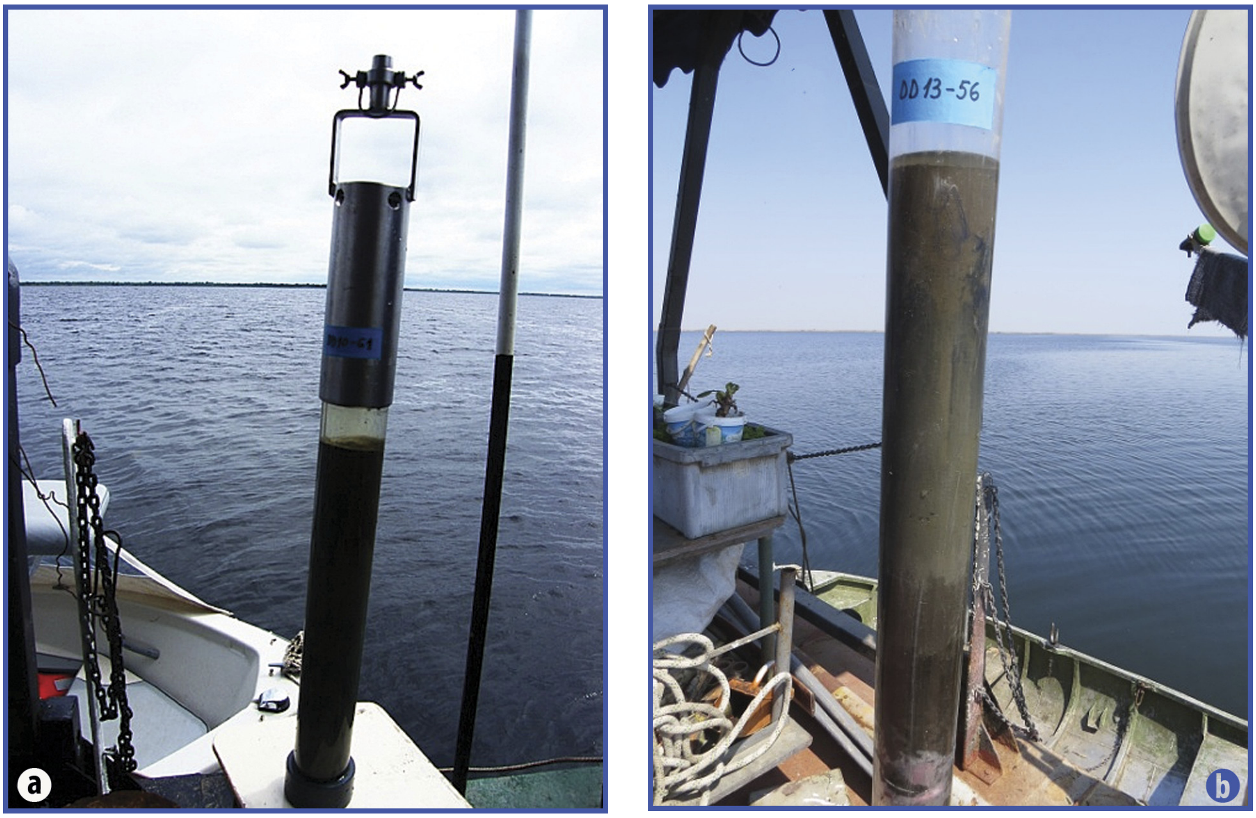


Fig. 2. Hydro-Bios corer (**a**), used for taking the short cores, and a transparent plastic tube with sediment inside (**b**).

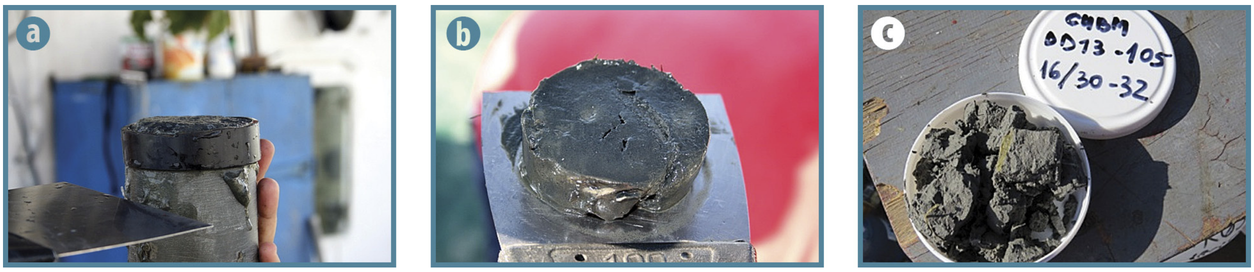


Fig. 3. Slicing the sediment core at adequate levels (**a**), the resulted sediment slice (sample) (**b**), and a sample within a box (station code, slice number and depth interval are written on its cover), prepared to be send to a lab for analyses (**c**).

The lithological composition of the sediment samples was determined by sequential heating (up to 950⁰) into a SNOL laboratory furnace by the *Loss on Ignition Method* (Dean, 1974, in Catianis *et al*., 2013). The lab procedure, which is shortly described in the cited paper, allows the assessment of the contents of the three lithological components, following the order **TOM** (**T**otal **O**rganic **M**atter), **CAR** (**CAR**bonates), and **SIL** (**SIL**iciclastic/mineral fraction).

The analysis and the interpretation of the integrated magneto-lithological data resulted from the investigation of the 7 cores collected from the above-specified lakes and a canal (Fig. 1) is supported by a number of correlation coefficients (**r**) which were calculated for **SIL** *vs*. **MS, TOM** *vs*. **MS**, **CAR** *vs*. **MS**, or (**TOM**+**CAR**) *vs*. **MS**. Beside these, the correlation between the other two pairs of lithological components (*i.e*., **SIL** *vs*. **TOM**, and **TOM** *vs*. **CAR**) has also been tested. A scale with 6 "correlation ranges" [inside the interval defined by the **r** values spanning from (-1) to (+1)], which was presented in some of the previously published papers and it is redrawn in Fig. 4a, is used to evaluate the size of the correlation.

An important parameter, which has been investigated for the *Danube Delta* lake sediments since 1977, is the magnetic susceptibility, measured also for the samples sliced from the different levels along the cores. The **MS** measurements were carried out with a KLY-2 Kappabridge (*Instruction Manual for magnetic susceptibility bridge - KLY-2, Geofyzika n.p. Brno, Czechoslovakia, 1981*), in the laboratory of environmental magnetism of the Geological Institute of Romania (GIR). Details concerning the methodology for measuring the magnetic susceptibility on lake sediments with this instrument were given in numerous unpublished research reports and in several previously published papers (cited in Rădan & Rădan, 2011). Based on a "*Magnetic susceptibility* (**k**) *scale*" (a version is redrawn in Fig. 4b), the vertical distribution of this magneto-environmental parameter represented by means of 3-D bar charts is complementary illustrated by the colours associated with the five **k** classes, assigned to each bar, according to the **MS** value to which the sediment sliced from the respective core depth interval is defined.

Correlation coefficients (r) **a**

0.65 ÷ 1.00	Strong positive correlation
0.32 ÷ 0.64	Moderate positive correlation
0.00 ÷ 0.31	No correlation – Weak positive correlation
0.00 ÷ (- 0.31)	No correlation – Weak negative correlation
(- 0.32) ÷ (- 0.64)	Moderate negative correlation
(- 0.65) ÷ (- 1.00)	Strong negative correlation

Magnetic susceptibility (MS; k) scale **b**

Vd	> 1000	Coarse silts and sands
Vc	675 ÷ 1000	
Vb	575 ÷ 675	
Va	275 ÷ 575	
IV	175 ÷ 275	
III	75 ÷ 175	Clayey up to fine siltic sediments
II	10 ÷ 75	Fine sediments, usually rich in organic matter and / or carbonates
I	< 10	

Fig. 4. Logistics, (geo)materials and methods. **a)** Scale used to evaluate the size of the correlation (**r**) between the enviromagnetic parameter (**k**) and the lithological components (**LC**), and between **LC** themselves (**SIL**, **TOM**, **CAR**); **b)** Magnetic susceptibility (**k**) scale (Rădan & Rădan, 2007). The **k** values defining the **MS** classes must be multiplied by (10 E-06) SI.

Finally, the magneto-lithological models associated with each sediment core are presented, discussed and interpreted. 3-D bar and 2-D line with marker charts showing the vertical distribution of the magnetic susceptibility, and 3-D bar and 2-D 100% stacked area charts, illustrating the contents of the lithological components along the cores, were drawn up. 2-D pie-charts, with the structure of the **MS** classes, and the distribution of the lithological components' mean contents, respectively, characterising the sediment cores, were carried out, as well. Diagrams with the graphic correlation between the magnetic parameter and the lithological components, but, also, between pairs of lithological components, are used for data interpretation. Maps with the areal distribution of the magnetic susceptibility, based on sediment samples taken over time, relating to several lakes where from cores were collected, are also integrated in the paper.

3. RESULTS AND DISCUSSION

The magnetic susceptibility and lithological data resulted from the study of the sediment cores are further presented, following the order suggested in Fig. 1. Firstly, the cores collected from the *western Meşteru - Fortuna Depression* (*i.e., DD 10-177 - Cuteţchi Lake* and *DD 12-03 - Tătaru Lake*; Fig. 1 and Fig. 5) are taken into consideration, followed by the cores taken from the eastern part of this deltaic area (*i.e., DD 13-61 - Băclăneşti Lake*, *DD 11-210*, *DD 13-56 - Fortuna Lake*, and *DD 13-54*, *DD 13-55 - Crânjală Canal*; Fig. 1 and Fig. 5).

3.1. Sediment cores from the western Meşteru - Fortuna Depression

The *core DD 10-177* was collected from the *Cuteţchi Lake* during the expedition carried out by GeoEcoMar in the Danube Delta, in October 2010, while the *core DD 12-03* was taken from the *Tătaru Lake*, during the campaign performed in April - May 2012 (location, in Figs. 5 and 6). In 2006, dur-

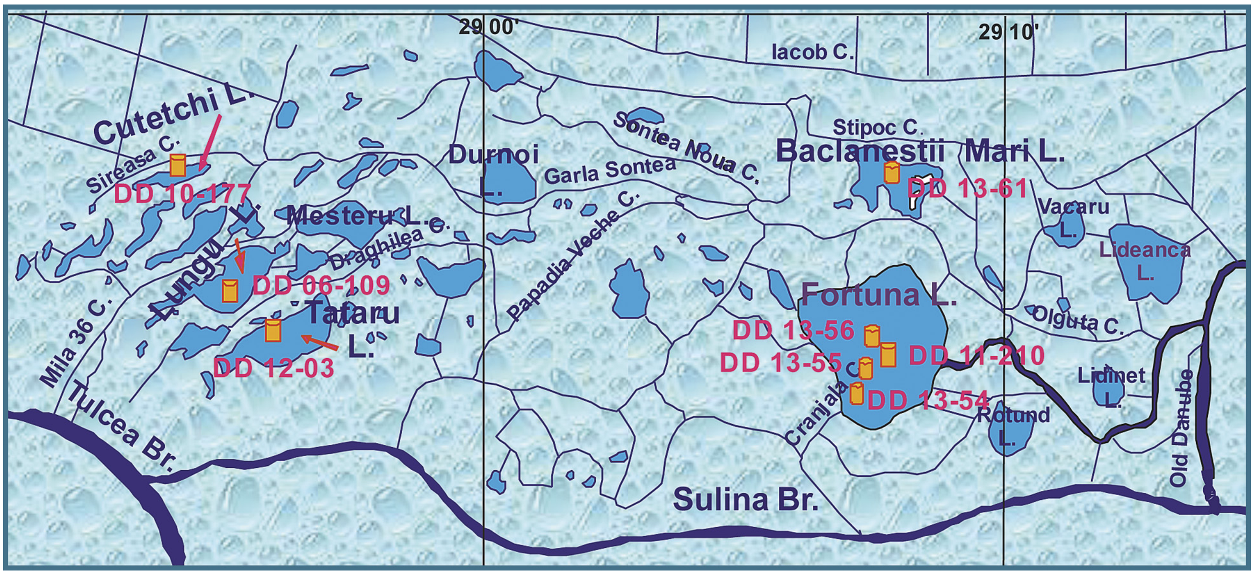


Fig. 5. Danube Delta, Meşteru - Fortuna Depression (M-F.D.; Fluvial Delta Plain). Location of 8 sediment cores collected from 5 lakes and a canal, in 2006 and in the 2010 - 2013 period.

ing the July expedition, it had been taken the *core DD 06-109* from the southern zone of the *Lungu Lake* (location, in Figs. 5 and 6); the results of the study of vertical variation of the magnetic susceptibility along this short sediment core (39 cm long) were already published (Rădan & Rădan, 2010).

a. Cutețchi Lake - *Core DD 10-177*

The *core DD 10-177*, collected in autumn of 2010 from the central zone of the *Cutețchi Lake* (Figs. 5 and 6), located in the northwestern zone of the *western Meşteru - Fortuna Depression* (see Fig. 1), is 57 cm long, and is characterised by a varied lithology: an organic, non-cohesive and loose mud on top, passing towards the bottom to a more compact sediment, darker in colour, rich in vegetal fragments, and with 2 - 3 coarser sequences.

The vertical distribution of the magnetic susceptibility values (**k**) reflects, accurately, the lithological variations, even where the changes are macroscopically less visible. The bar chart from Fig. 7a shows the **MS** signature of the *DD 10-177* core, with each bar coloured according to the **k** *class* (Fig. 4b) to which the sediment sub-sample was calibrated.

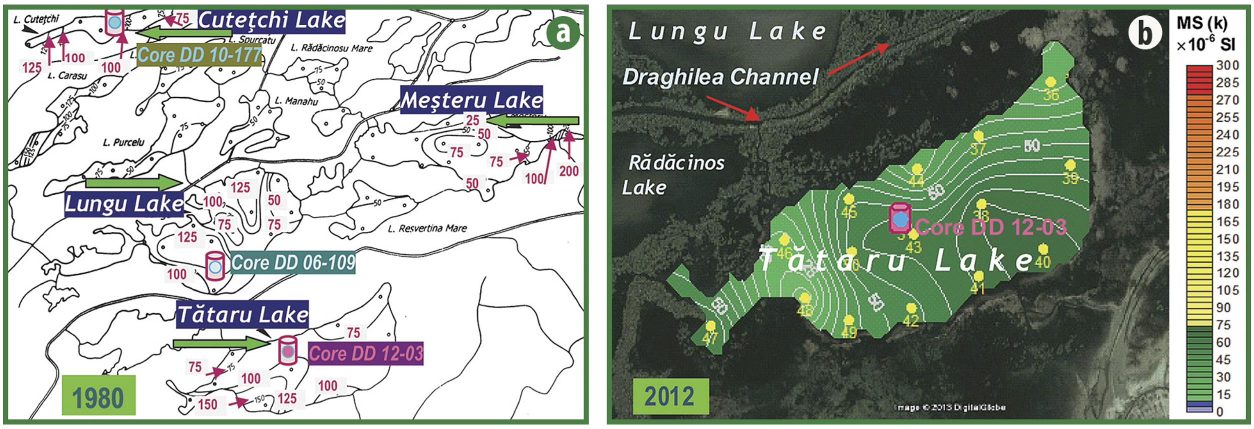


Fig. 6. Danube Delta. Western Meşteru - Fortuna Depression (M-F.D.; Fluvial Delta Plain). Location of the cores taken from the lakes *Cutețchi* (*DD 10-177*), *Lungu* (*DD 06-109*), and *Tătaru* (*DD 12-03*). **a)** Location on the magnetic susceptibility (**MS**) map performed for the western M-F.D on the basis of the bottom sediments sampled in 1980 (Rădan *et al*., 1999); **b)** Location of the *core DD 12-03* on the *Tătaru Lake* **MS** map, carried out on the basis of the sediments sampled during the Spring 2012 campaign. *Notes*: The scale used for drawing the 2012 **MS** map is according to the **k** scale used to calibrate the lake sediments. The values of **MS** (**k**) contours must be multiplied by 10^{-6} (SI). The figure (b) support is a *Google Earth* image.

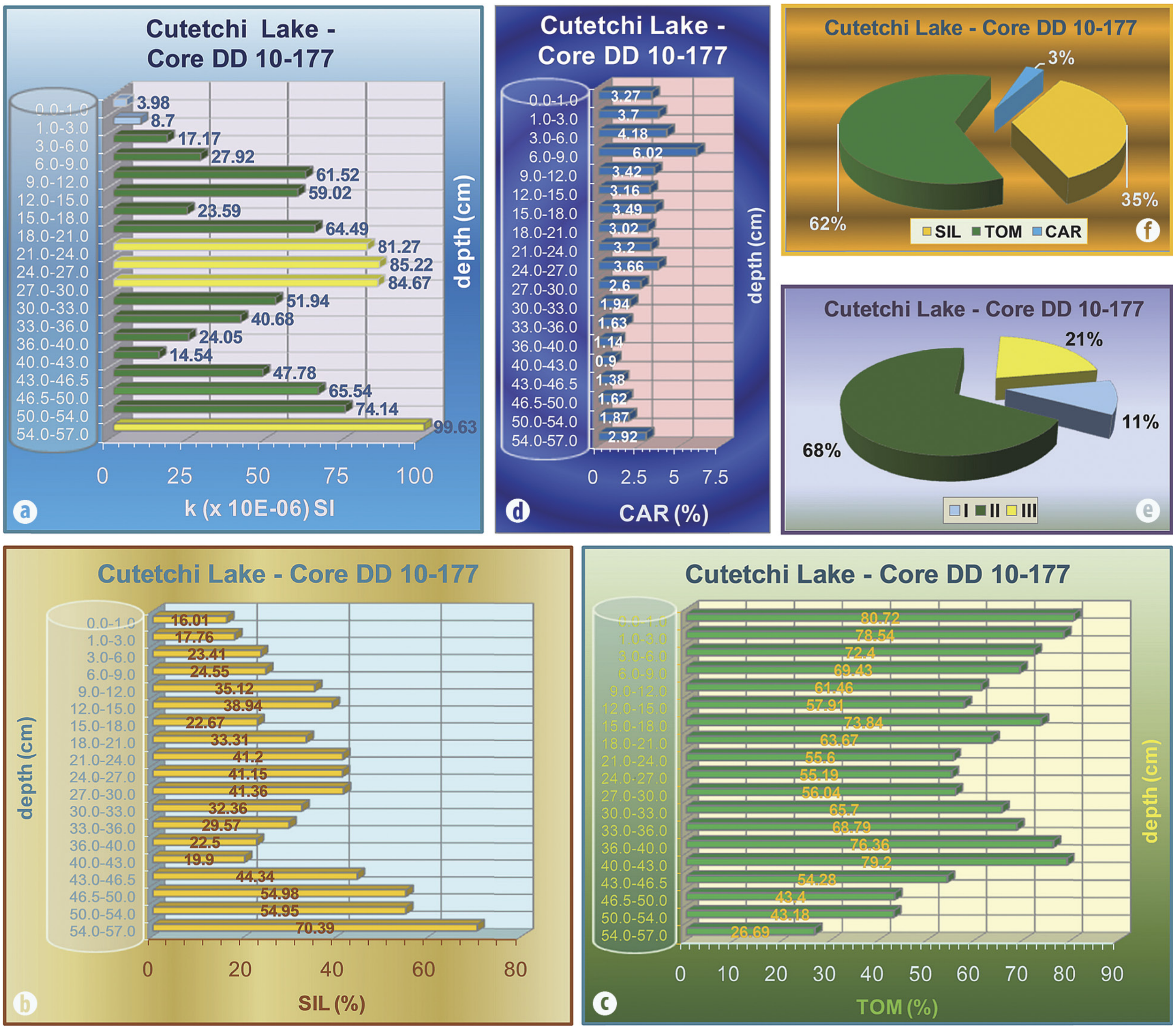


Fig. 7. Vertical distribution of the enviromagnetic and lithological parameters related to the *core DD 10-177* (*Cuteţchi Lake*). **a)** Magnetic susceptibility (**MS**; **k**); the **MS** bars are coloured according to the **k** scale classes (see Fig. 4b); **b)** Siliciclastic/detritial fraction content (**SIL**); **c)** Total organic material content (**TOM**); **d)** Carbonate content (**CAR**); **e) MS** calibration of the core sediments according to the **k** scale classes; **f)** Lithological composition of the core sediments, based on the **SIL**, **TOM** and **CAR** average contents.

The **MS** range is 3.98×10^{-6} - 99.63×10^{-6} SI. Most sub-samples (*i.e.*, 68%; Fig. 7e), sliced from the *DD 10-177* sediment core, are included within the **k** class **II**, followed by the class **III** (21%) and the class **I** (11%). The core magnetic susceptibility signature defines, in detail, the lithological modifications, which could be explained by the influence of the hydromorphological conditions within the surrounding area, during the last decades. The two main sequences, which are clearly marked out by the maximum **MS** anomaly in the core central zone (**k** class **III**), and by an increasing trend of the **MS** values towards the bottom of the core, are represented by coarser sediments, and by siltic muds, respectively (in agreement with the **k** classes and the corresponding lithological categories relieved by the **MS** scale from Fig. 4b).

The vertical variation of the contents determined for the siliciclastic/detrital fraction (**SIL**; Fig. 7b) follows, correspondingly, the **MS** signature recorded along the core *DD 10-177*, the lowest values (*i.e.*, 16.1%; 22.67%; 19.9%) coinciding with the lowest **k** values (*i.e.*, 3.98×10^{-6}; 23.59×10^{-6}; 14.54×10^{-6} SI) measured on the muds intercepted at the depth levels 0 - 1, 15 - 18 and 40 - 43 cm, respectively (Fig. 7a). The highest **k** value (99.63×10^{-6} SI; Fig. 7a), corresponding to the highest **SIL** content (70.39%; Fig. 7b), was measured on the compact silty sediment from the core base (depth 54 - 57 cm). Actually, the correlation coefficient **r** calculated for **SIL** *versus* **k** is 0.87 (see Fig. 8c), showing the **strong** *positive correlation* existing between this lithological component and the enviromagnetic parameter. The reverse situation is that of the vertical variation of the total organic matter content (**TOM**; Fig. 7c), the correlation between this lithological component and the **MS** being *negative*, also a **strong** one (**r** = - 0.88; Fig. 8e). Consequently, the highest **TOM** content (80.72%; Fig. 7c) was determined for the fine, black mud sampled at the core top (depth 0 - 1 cm), while the lowest **TOM** content (26.69%; Fig.

7c) was identified for the silty sediment slice ending the core *DD 10-177* (depth 54 - 57 cm). As regards the *carbonates*, although the correlation coefficients (**r**) calculated for the **CAR** *vs* **k** (Fig. 8d), **SIL** *vs* **CAR** (Fig. 8g), and **TOM** *vs* **CAR** (Fig. 8h) are very low (-0.08, -0.21, and 0.12, respectively), the vertical variation of the **CAR** component (Fig. 7d) shows a signature which is slightly similar to that of the enviromagnetic parameter (**k**; Fig. 7a), suggesting - though less evidently - the presence of 2 - 3 episodes within the core sediment sequence (particularly, an extended minimum area within the lower half of the **CAR** content vertical distribution diagram; Fig. 7d).

The pie-charts drawn for the lithological components and for the **k** classes to which the core sediment was calibrated show also a very good correlation between the two different characteristics under investigation in our study. Thus, the lithological composition of the core *DD 10-177* reveals the highest content of the *organic matter* and *carbonates* (62% + 3 %; Fig. 7f), and, on the other side, the lowest **k** classes **I** and **II** represent also the most part (*i.e.*, 11% + 68 %; Fig. 7e) within the pie-chart defining the magnetic susceptibility characterisation of the respective sediment core.

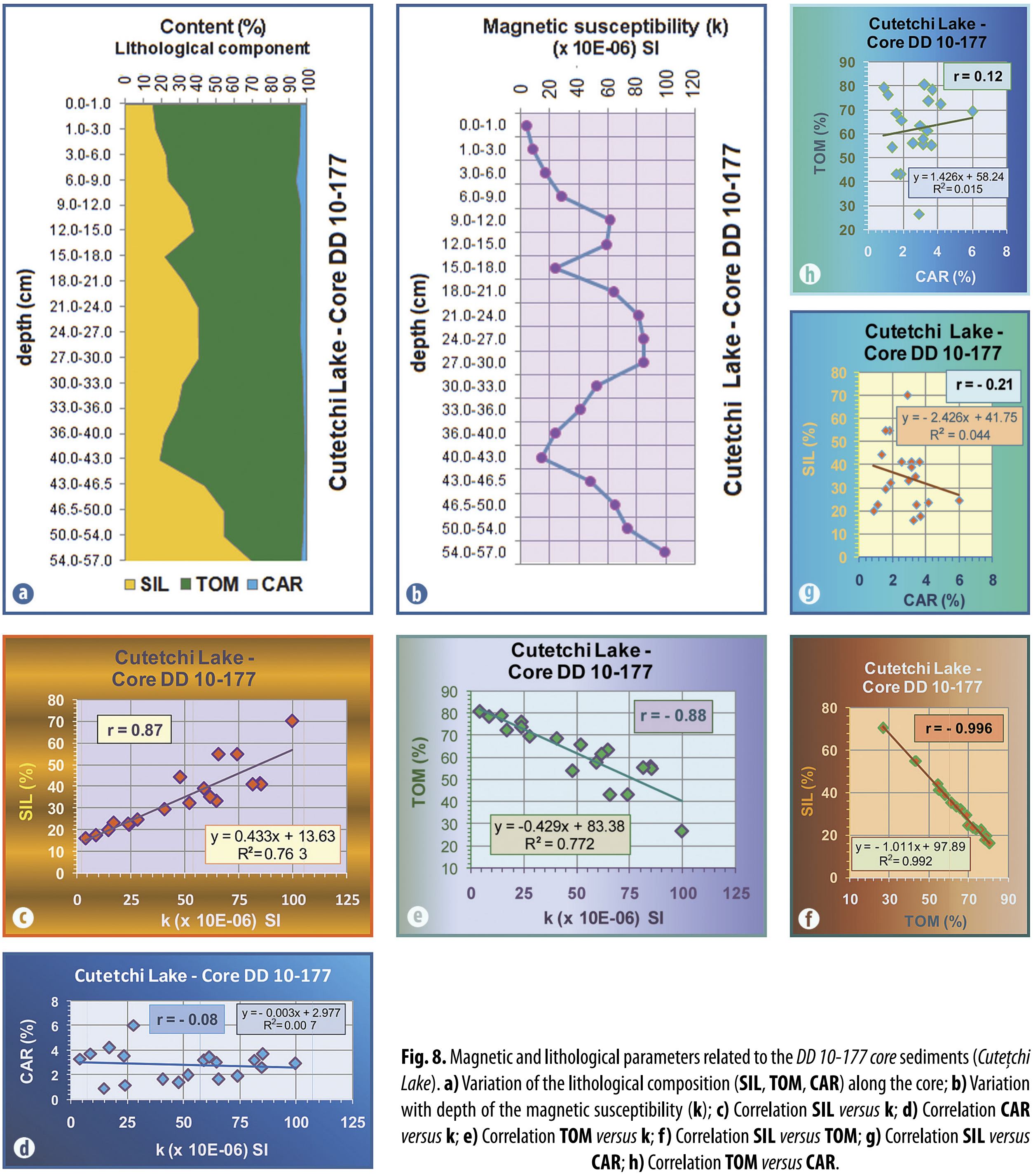


Fig. 8. Magnetic and lithological parameters related to the *DD 10-177 core* sediments (*Cutețchi Lake*). **a)** Variation of the lithological composition (**SIL**, **TOM**, **CAR**) along the core; **b)** Variation with depth of the magnetic susceptibility (**k**); **c)** Correlation **SIL** *versus* **k**; **d)** Correlation **CAR** *versus* **k**; **e)** Correlation **TOM** *versus* **k**; **f)** Correlation **SIL** *versus* **TOM**; **g)** Correlation **SIL** *versus* **CAR**; **h)** Correlation **TOM** *versus* **CAR**.

The parallel presentation of the images drawn for the *lithological* and the *magneto-susceptibilimetric signatures* given in Fig. 8a,b stands as a conclusion of the integrated magneto-lithological analysis of the core *DD 10-177*, taken from the central zone of the *Cuteţchi Lake*. The quality of *proxy parameter* of the *magnetic susceptibility* with regard to the *lithological composition* of the lake sediments is clearly demonstrated.

The following core - taking into consideration the spatial location, from north southwards - is *DD 06-109*, which was taken from the southern zone of the *Lungu Lake* (Figs. 5 and 6), during the cruise carried out in the *Danube Delta*, in July - August 2006. A 3D-bar chart with the vertical distribution of the magnetic susceptibility recorded along this core was presented in a previously published paper (Rădan & Rădan, 2010).

Consequently, the next newly analysed sediment core is *DD 12-03*, which was collected from the *Tătaru Lake* (Fig. 1, Figs. 5 and 6), situated in the same area, *i.e.*, the *western Meşteru - Fortuna Depression*.

b. Tătaru Lake - *Core DD 12-03*

This sediment core (61 cm long; Fig. 9a) was taken from the central-northern part of the *Tătaru Lake* (Figs. 5 and 6; see also Fig. 1), during the April - May 2012 campaign in the *Danube Delta*.

At the core bottom, an organic sediment level of brown colour is observed, which is similar to very fine peat; the horizon thickness is ca. 7 cm, and it is characterised by very low magnetic susceptibility values (14.04×10^{-6} - 36.99×10^{-6}) SI, belonging to **k** class **II** (Fig. 9a; see also Fig. 4b, for the **MS** scale). The Total Organic Matter (**TOM**) content determined for sediment samples taken from this depth interval records values up to 60.72 % (Fig. 10b), while, for the siliciclastic/mineral fraction (**SIL**), there were determined lower contents (with a minimum value of 36.12 %; Fig. 10a). Above this level, compact, clayey, cohesive muds are present (showing high **MS** values and **SIL** contents), which are gradually passing, on the upper part, to more fluffy and richer in organic substance muds, getting to dominantly organic sediments. This transition is very well illustrated by the **MS** values decreasing upwards; in the upper part of the core, the magnetic susceptibility records values assigned to **k** class **II**, which are typical for organic sediments (see Fig. 4b). These remarks are supported by the lithological components of the core sediments: the **TOM** content is increasing, in the upper part of the core being determined values up to 68.25 %, while the **SIL** contents are decreasing up to 25.68 % (Fig. 10a,b).

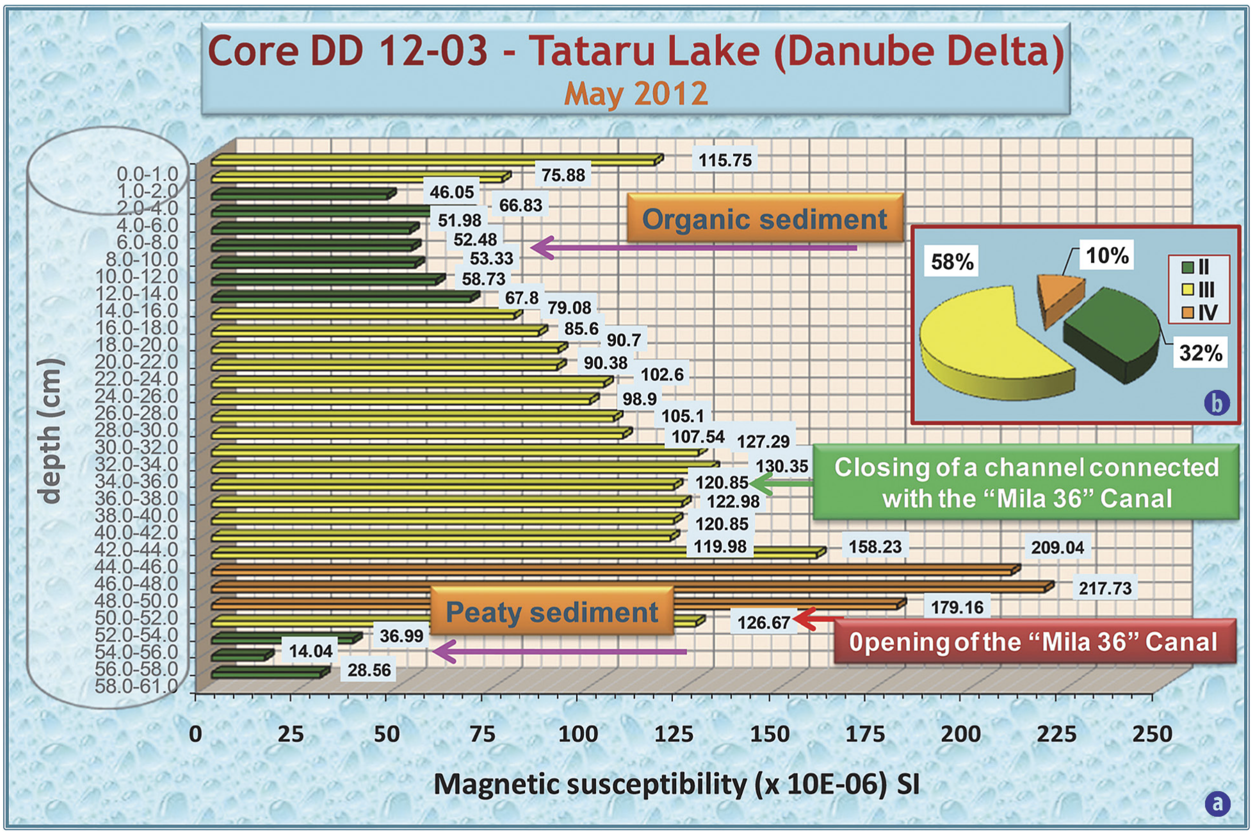


Fig. 9. Magneto-susceptibilimetric model for the *sediment core DD 12-03* (*Tătaru Lake*). **a)** Vertical distribution of the magnetic susceptibility along the core; **b) MS** calibration of the core sediments according to the **k** scale classes.

The two higher **MS** values (up to 115.75×10^{-6}; **k** class **III**), measured at the upper extremity of the core, are not concludent, as the measurements were performed on very small quantities of geomaterial relating to the standard samples [two thin sediment slices (1 cm thick each) were available for **MS** measurements]. Instead, the highest magnetic susceptibility (up to 217.73×10^{-6} SI, calibrated to **k** class **IV**), which was detected in the lower part of the core (Fig. 9a), immediately above the peaty horizon, is clearly explained by the impact on the sedimentation regime after the "*Mila 36*" *Canal* opening (see Fig. 5).

The lithological components **SIL** and **TOM** determined for the samples sliced from this core depth interval (*i.e.*, 48 - 54 cm), associated with the time since the above-mentioned canal was opened (1982 - 1983), record the highest (71.24 - 78.01 %), and the lowest (14.45 - 15.24 %) values, respectively (Fig. 10a,b), and clearly support the maximum recorded within the magnetic susceptibility vertical variation along the *DD 12-03 core* (Fig. 9a).

The calibration of the core sediments to the **k** scale is illustrated in Fig. 9b: most samples (58%) are assigned to **k** class **III**, followed by class **II** (32%) and **k** class **IV** (10%). This

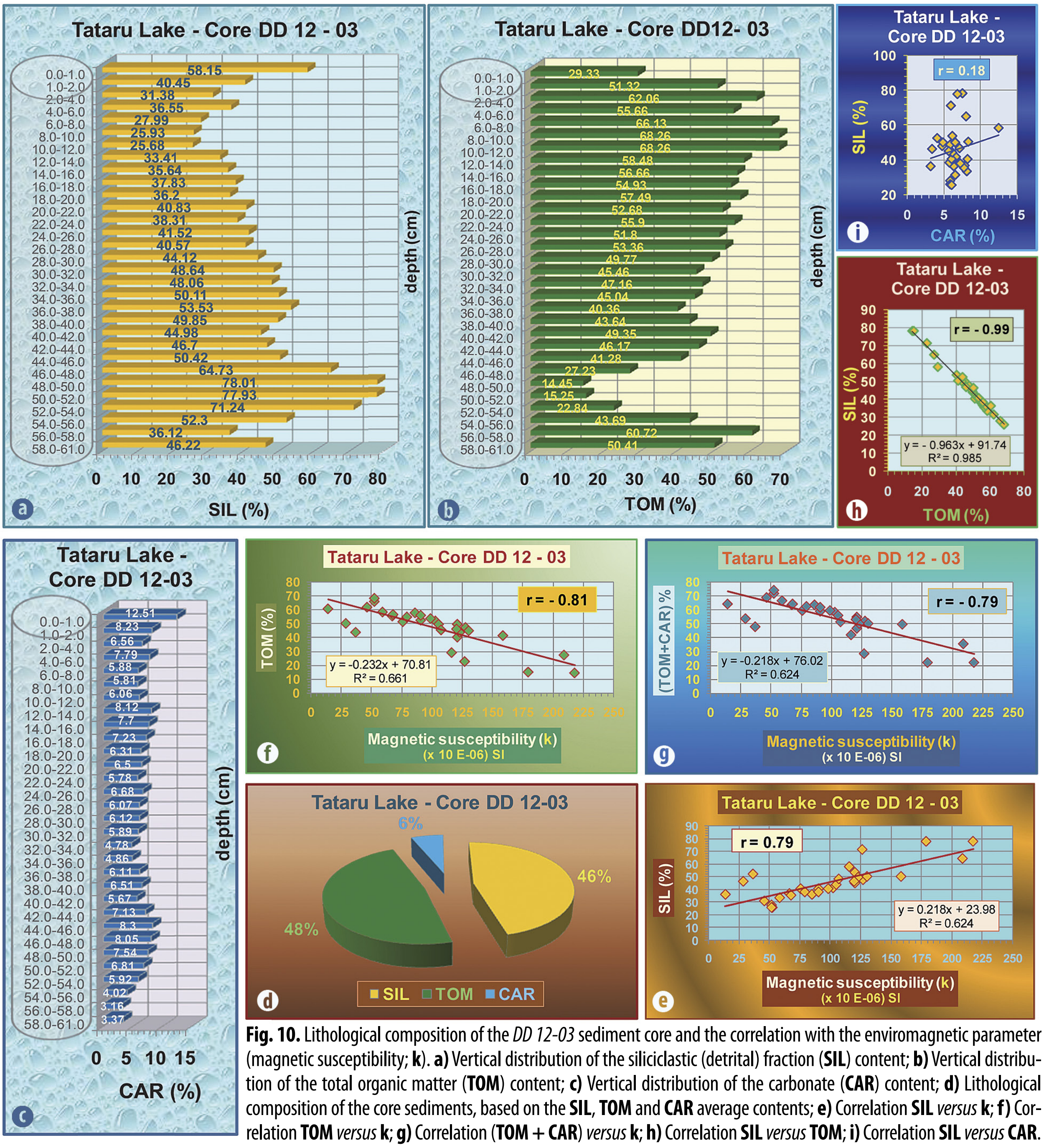


Fig. 10. Lithological composition of the *DD 12-03* sediment core and the correlation with the enviromagnetic parameter (magnetic susceptibility; **k**). **a)** Vertical distribution of the siliciclastic (detrital) fraction (**SIL**) content; **b)** Vertical distribution of the total organic matter (**TOM**) content; **c)** Vertical distribution of the carbonate (**CAR**) content; **d)** Lithological composition of the core sediments, based on the **SIL**, **TOM** and **CAR** average contents; **e)** Correlation **SIL** *versus* **k**; **f)** Correlation **TOM** *versus* **k**; **g)** Correlation (**TOM + CAR**) *versus* **k**; **h)** Correlation **SIL** *versus* **TOM**; **i)** Correlation **SIL** *versus* **CAR**.

"magneto-susceptibilmetric structure" of the *core DD 12-03* sediments is supported by their lithological composition (see the average contents of the **SIL**, **TOM** and **CAR** components in Fig. 10d).

The magneto-lithological interpretation of the three 3D-charts with the vertical distribution of the **MS**, **SIL** and **TOM** (Figs. 9a and 10a,b, respectively) is very well argued by the strong correlation coefficients (**r**) calculated for **SIL** *versus* **MS**, and **TOM** *versus* **MS** (Fig. 10e,f). The correlations (**TOM** + **CAR**) *versus* **MS, SIL** *vs*. **TOM**, and **SIL** *vs*. **CAR** are shown, as well (Fig. 10g,h,i). A low but positive **r** coefficient, determined for the correlation of the *siliciclastic fraction* with the *carbonates*, can be seen; it suggests, anyway, a possible detrital origin of the carbonatic material. The **CAR** record along the sediment *core DD 12-03* is illustrated in Fig. 10c.

The general similarity between the lithological and enviromagnetic signatures recovered from the *DD 12-03 core* sediments is clearly illustrated in Fig. 11a,b, particularly by the vertical distribution of the *siliciclastic detrital* component (**SIL**) and of the magnetic susceptibility parameter (**MS**; **k**).

The vertical distribution of the magnetic susceptibility (Fig. 9a and Fig. 11b) recorded for the *DD 12-03 core* reflects a series of very important events occurring in the evolution of this deltaic zone. The peaty sediment identified on core bottom (marked in Fig. 9a through a purple arrow) represents the sedimentation period before the digging of the "*Mila 36*" *Canal*, when the *Lungu*, *Meşteru* and *Tătaru Lakes* were isolated from the *Danubian* direct inputs, being dominated by an organic-type sedimentation. The *"Mila 36" Canal* opening (in the year 1983) has created a direct connection of these lakes - through the *Periteaşca Canal* - with the *Danubian* inputs, rich in detrital siliciclastic material, which has radically changed the lithology of the sediments that were deposited in this area. This process led to silting up of the northern sectors of the *Lungu* and *Meşteru Lakes*, and any less, of the *Tătaru Lake*, placed in a more protected position. The islet from the *Lungu Lake* northern zone was totally incorporated within the lake bank.

The modifications of the magnetic susceptibility fingerprints detected within the bottom sediments sampled from these three lakes during two distinct periods, related to the "opening moment" (1983) of the "*Mila 36*" *Canal*, particularly in 1980, and at different times during the period when this canal has exhibited a strong activity (1987, 1993, and 1995 - 1997), were presented in a previously published paper (Rădan & Rădan, 2007). The analysed data confirmed the above presented sedimentogenetic considerations.

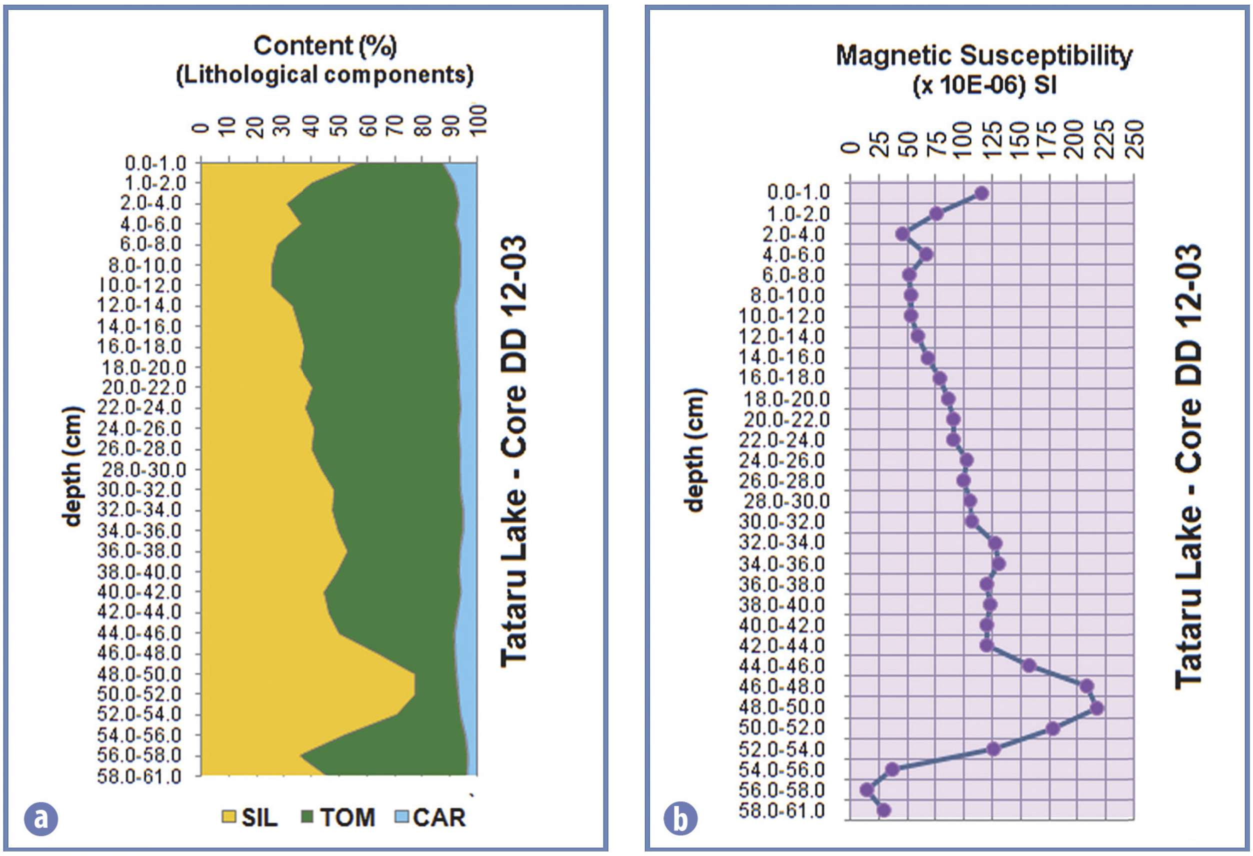


Fig. 11. Magneto-lithological characterisation of the sediments recovered from the *core DD 12-03* (*Tătaru Lake*). **a)** Lithological composition (**SIL**, **TOM**, **CAR**) along the core; **b)** Variation with depth of the magnetic susceptibility (**MS**; **k**).

Afterwards, the connection channels of the lakes have silted up, and the *Periteaşca Canal* was dammed upstream, so that, gradually, the lakes have reached again an almost protected regime. The increasing trend concerning the total organic matter (**TOM**) contents, and the decreasing trend related to the siliciclastic fraction (**SIL**) contents are suggested by the corresponding maps drawn up for the surficial sediments sampled from the *lakes Lungu* (Fig. 12a,b) and *Meşteru* (Fig. 12d,e), during the April - May 2012 campaign. The magnetic susceptibility signatures recovered from the bottom sediments of the two lakes (Fig. 12c, and Fig. 12f, respectively) show, correspondingly, lower intensities than those detected within the sediments sampled, *e.g.*, in 1987: up to 654×10^{-6} SI for the *Lungu L.*, and up to 334×10^{-6} SI for the *Meşteru L.* (Rădan & Rădan, 2010).

As regards the *Tătaru Lake*, with a spatial position that allows a double protection against the direct *Danubian* supplies, this has not undergone important changes after the severe modifications of the ecohydrological conditions in the area. The two **MS** maps drawn up for the *Tătaru Lake*, based on sediments sampled in 1980 (Fig. 6a), and 2012 (Fig. 6b), confirm its particular situation. Anyway, taking into consideration that the calibration of the bottom sediments sampled from this lake in 1980, 1993 - 1997, and 2006 revealed their assignement to **k** classes **II** and **III** only (Rădan & Rădan, 2010), an increasing trend regarding the **TOM** content is visible even in this lake, as long as the **MS** values which were measured on all the samples are placed within the **k** class **II** (see Fig. 6b) [excepting the station *DD 12-48*, where, moreover, **k** is a bit lower, *i.e.*, 9.78×10^{-6} SI (class **I**, a value placed in

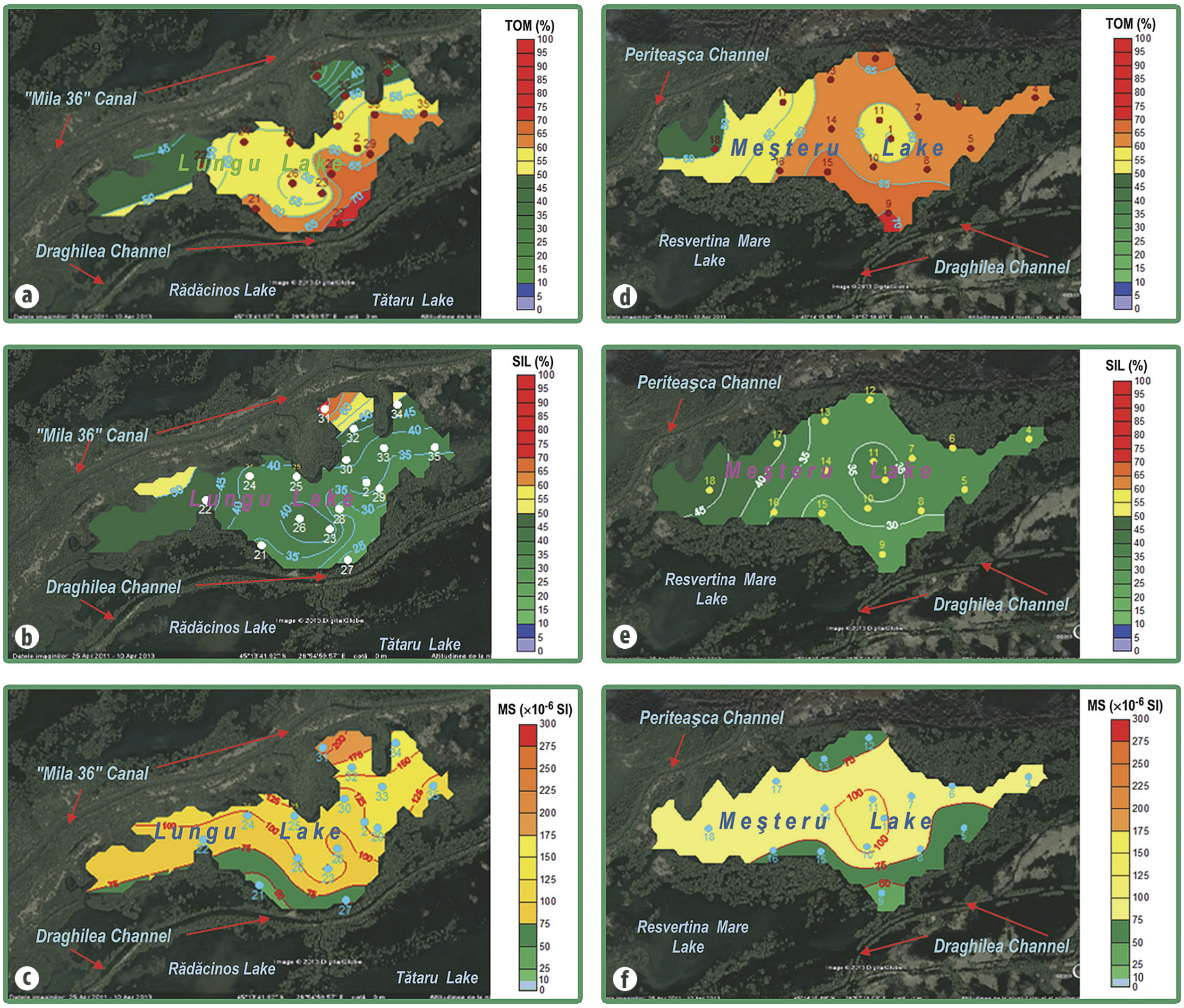


Fig. 12. Lithological and magneto-susceptibilimetric maps of the bottom sediments from the *Lungu* and *Meşteru Lakes* (April - May 2012 campaign). ▪ *Lungu Lake* sediments: **a)** Total organic matter (**TOM**) content map; **b)** Siliciclastic/mineral (**SIL**) content map; **c)** Magnetic susceptibility (**MS**; **k**) map. ▪ *Meşteru Lake* sediments: **d) TOM** content map; **e) SIL** content map; **f) MS** (**k**) map. *Legend*: **a)** to **f)** ●**29** Bottom sediment sampling station; **60** **TOM** content (%) contour (**a**,**d**). Similar legend for the **SIL** content map (**b**,**e**); **100** **MS** (**k**) contour (**c**,**f**). *Note*: The values of **MS** contours must be multiplied by 10^{-6} (SI). The figures (**a** to **f**) support - *Google Earth* images.

fact at the boundary with **k** class **II**)]. The **TOM** and **SIL** maps (Fig. 13) carried out for the *Tătaru Lake* bottom sediments sampled during the April - May 2012 campaign confirm this observation; they clearly show the higher contents of the organic matter (Fig. 13a) related to those determined for the siliciclastic/mineral fraction (Fig. 13b).

Taking into consideration that, at present, the connection canals with the *Periteaşca Cn*. are reopening, a new modification of the sedimentation regime in the future is presumably.

The magnetic susceptibility model from Fig. 9a is significant, as the sudden change of the **MS** values at 54 cm beneath the water/sediment interface, simultaneously with the disappearance of the peaty sediment, marks the opening of the *"Mila 36" Canal*. Relating the thickness of the detrital sequence to the time interval which has passed, *i.e.* 29 years, a sedimentation rate for the central zone of the *Tătaru Lake* of 1.9 cm/year is obtained; it is a big value, which suggests even higher sedimentation/silting up rates in the *Lungu* and *Meşteru Lakes*.

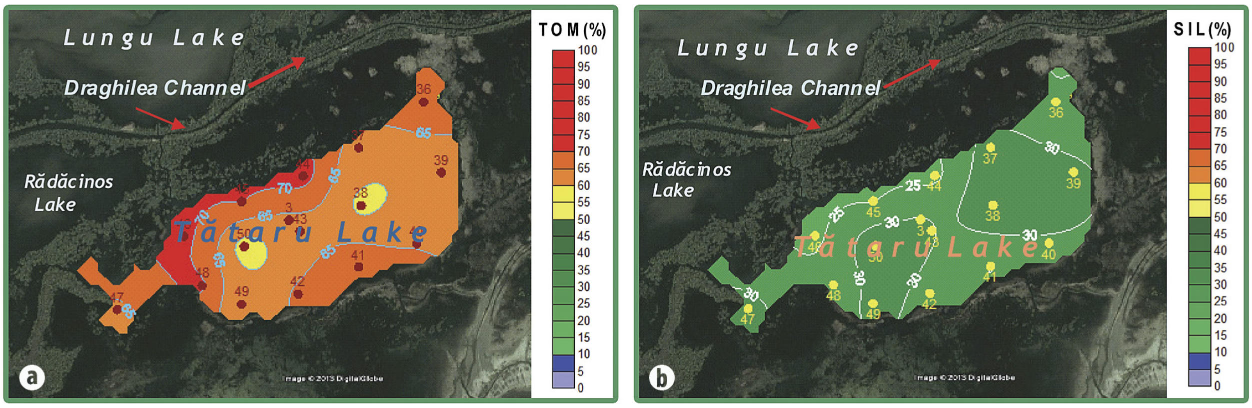


Fig. 13. Lithological maps of the bottom sediments from the *Tătaru Lake* (April - May 2012 campaign). **a)** Total organic matter (**TOM**) content map; **b)** Siliciclastic/mineral (**SIL**) content map. The figure (**a,b**) support - *Google Earth* images.

3.2 Sediment cores from the eastern Meşteru - Fortuna Depression

As regards the eastern part of the *Meşteru - Fortuna Depression*, we focus our attention to the *Băclăneşti Lake* (*DD 13-61* sediment core), as well as to the *Fortuna Lake* (*DD 11-210* and *DD 13-56* cores). Another two cores (*DD 13-54* and *DD 13-55*) were collected from the *Crânjală Canal microdelta*, in the southern part of the *Fortuna L*. (Figs. 1, 5 and 14).

a. Băclăneşti Lake - *Core DD 13-61*

The sediments of the *Băclăneşti Lake*, located north of the *Fortuna Lake*, are dominantly organic (in the first 25 - 30 cm at least), and are not affected by the proximity of the *Şontea Canal* (Fig. 14a,b). The magnetic susceptibility data, achieved for the sediments taken with a Van-Veen grab sampler, at a time interval of 33 years, that is, in 1980 (Fig. 14b,c; **k** classes **I** and **II**) and 2013 [**MS** values placed within the range $(-2.64)\times10^{-6}$ - 28.2×10^{-6} SI;.**k** classes **I** and **II**; Fig. 14d] proved that the *Băclăneşti Lake* surficial sediments are not influenced by a coarser detrital fraction supply *via Şontea Canal*. The main water and sediment supplies come from northwest through small canals connected with the *Stipoc* and *Băclăneşti Canals*.

In this context, the magneto-lithological data obtained for the core *DD 13-61*, collected from the lake central zone (Fig. 14a,b), show, also, that in the first 27 cm the **MS** values are very low (0.19×10^{-6} - 12.69×10^{-6}) SI (Fig. 15a); the siliciclastic/detrital fraction (**SIL**) records, also, low contents (7.67 % - 17.01 %; Fig. 15b), while the total organic matter component (**TOM**) reveals high contents along the first half of the core (74.03 % - 91.50 %; Fig. 15c). The carbonates (**CAR**) show a lower content, too (0.8 % - 2.8 %; Fig. 15d) in the first 27 cm beneath the water/sediment interface. The images carried out for the lithological composition and the magnetic susceptibility vertical variation along the core (Fig. 16a,b) clearly confirm these characteristics of the first part of the recovered signatures.

Actually, even the *core DD 10-61* is a short one, the extracted sediment column (52 cm thick) shows a rather complex situation. The magneto-lithological charts, presented in Fig. 15a,b,c,d and Fig. 16a,b, emphasise the existence of two distinct sequences: a) the upper one (ca. 27 - 28 cm thick) is constituted of organic muds, with a net subordinate participation of the detrital mineral material and a very reduced presence of the carbonates; b) the lower one, which is visible along ca. 24 cm, is characterised by a relatively balanced participation of the siliciclastic (45.91 - 56.73 %; Fig. 15b) and organic (38.46 % - 50.28 %; Fig. 15c) components, to which the carbonates are added, with relatively higher contents (3.81 % - 4.93 %; Fig. 15d) comparing with those from the upper sequence (but very reduced, anyway).

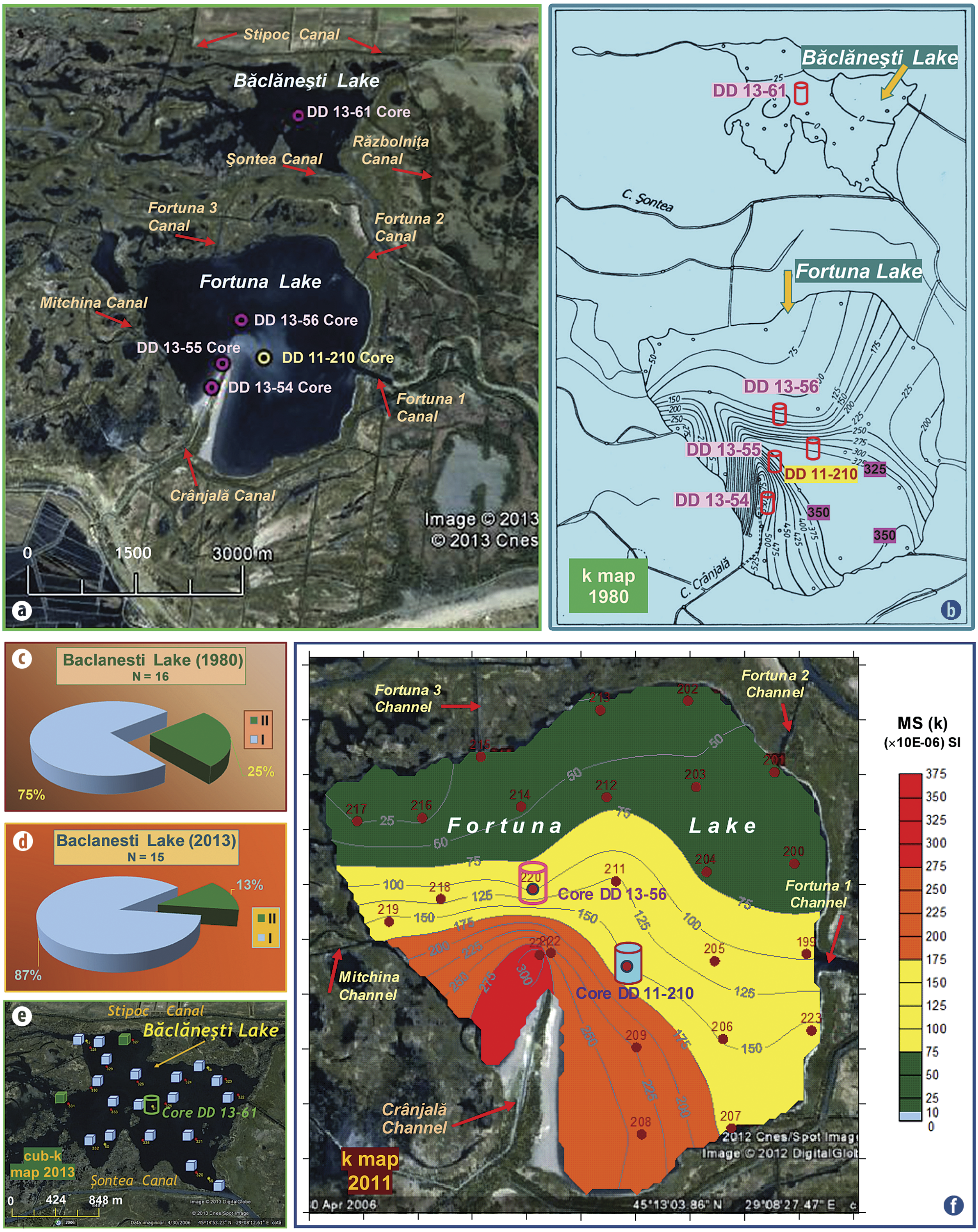


Fig. 14. Location of the sediment cores - in magneto-susceptibilimetric context - collected from the *Băclăneşti Lake*, *Fortuna Lake* and *Crânjală Canal* (eastern *Meşteru - Fortuna Depression*). **a)** Location of all the cores on a Google Earth image-support; **b)** Location of the cores on the magnetic susceptibility maps of the bottom sediments sampled from the *Băclăneşti* and *Fortuna lakes* in 1980 (Rădan *et al*., 1999). *Note*: The **k** values shown on the **MS** contours must be multiplied by 10^{-6} SI; **c), d) MS** calibration (according to **k** scale classes) of the surficial sediments from the *Băclăneşti Lake*, sampled in 1980 and 2013, respectively; **e)** Location of the core in the *Băclăneşti Lake*, on the **MS** map of bottom sediments sampled in 2013, drawn up by using coloured cubs, according to **k** scale from Fig. 4b; **f)** Location of the cores in the *Fortuna Lake*, on the magnetic susceptibility map of the bottom sediments sampled in 2011. *Note*: The colour scale used for the **MS** map is in agreement with the **k** scale.

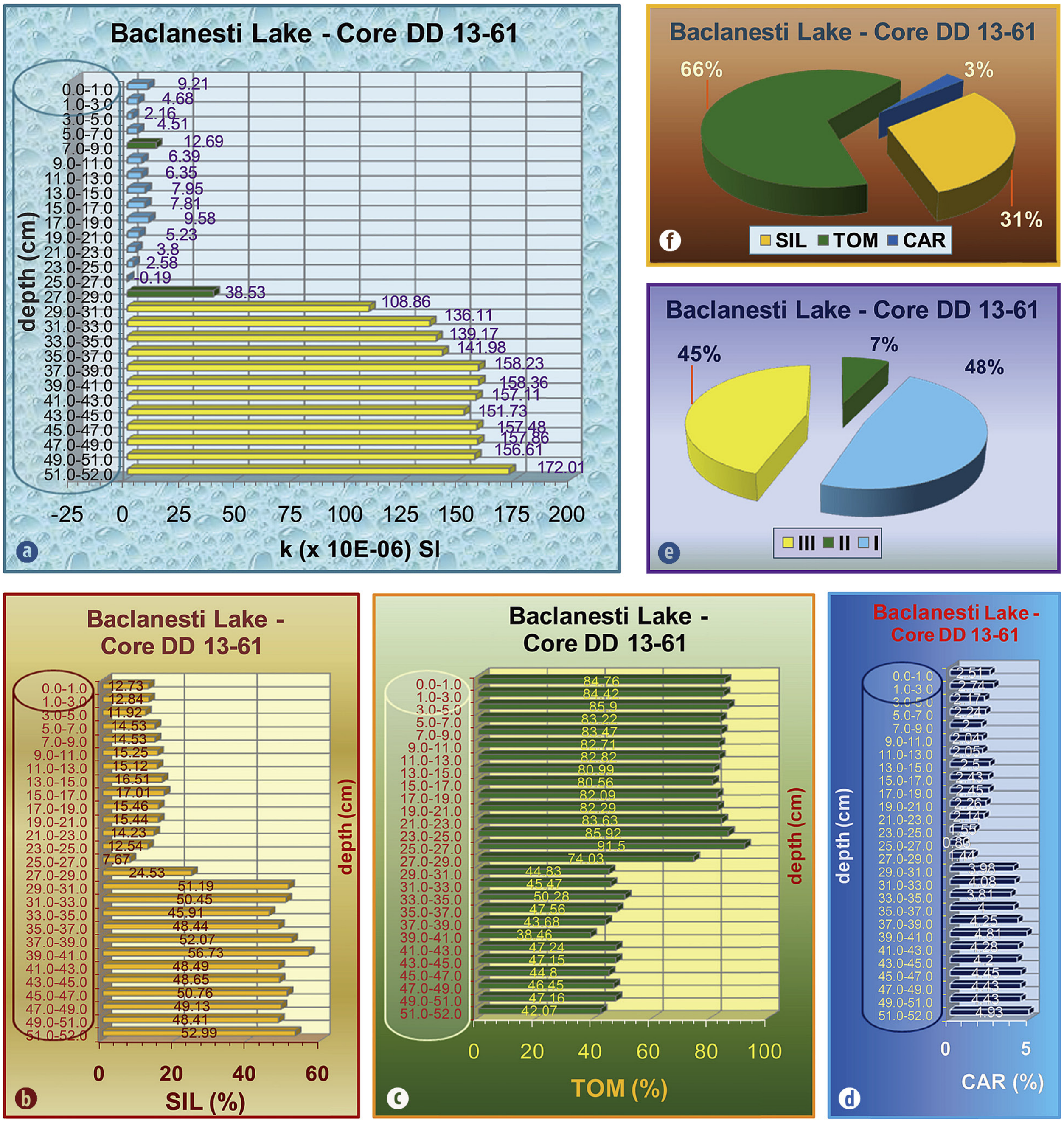
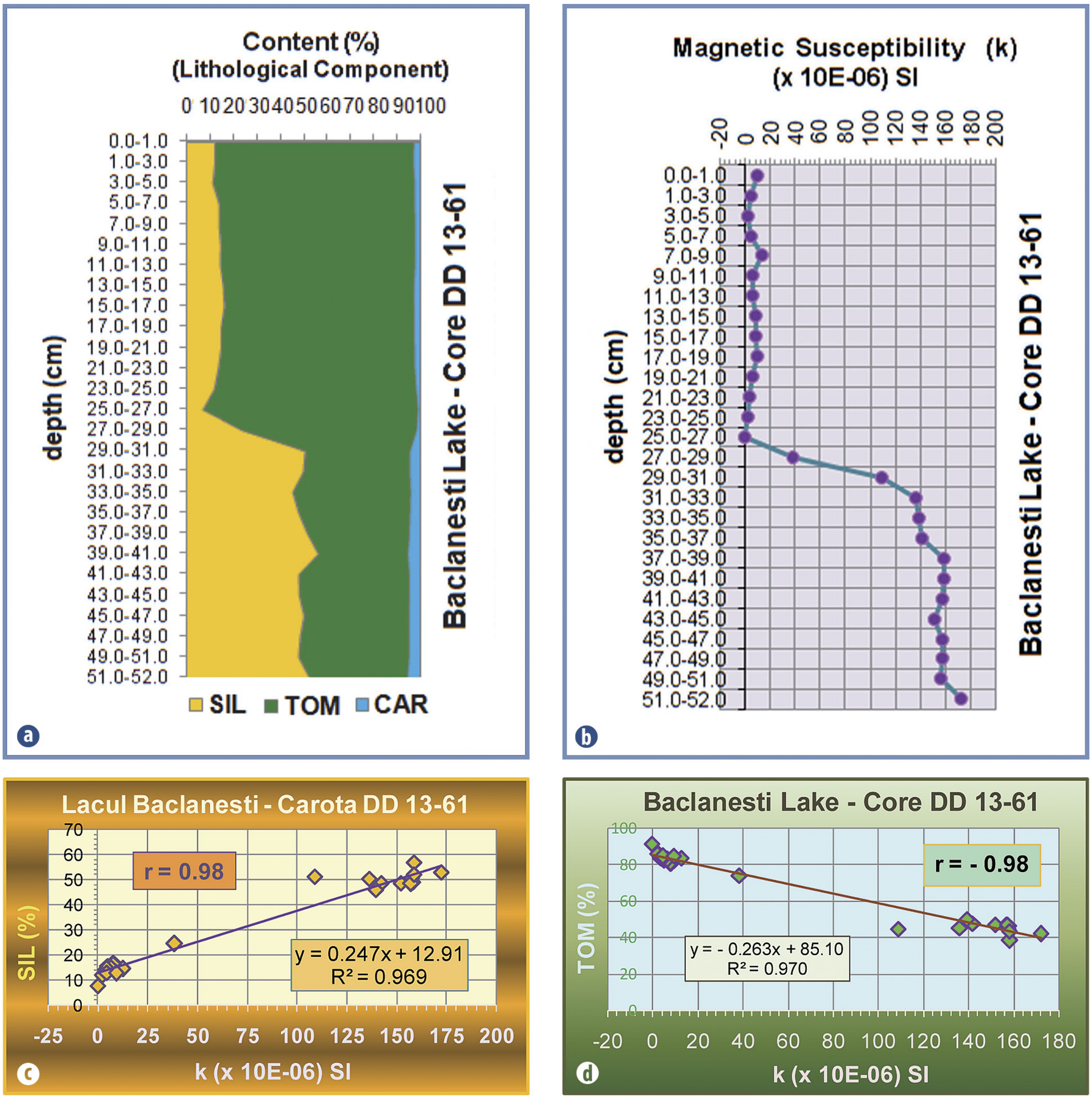


Fig. 15. Vertical distribution of the enviromagnetic parameter and the lithological components along the *Core DD 13-61* (*Băclăneşti Lake*). **a)** Variation with depth of the magnetic susceptibility (**MS**; **k**); the **MS** bars are coloured according to the **k** scale classes (see Fig. 4b); **b)** Variation with depth of the siliciclastic/detritial fraction content (**SIL**); **c)** Variation with depth of the total organic material content (**TOM**); **d)** Variation with depth of the carbonate content (**CAR**); **e) MS** calibration of the core sediments according to **k** scale classes; **f)** Lithological composition of the core sediments, based on the **SIL**, **TOM** and **CAR** average contents.

These characteristics prove a lithological composition corresponding to the (slightly dominant) mineral-organic and organic-mineral muds. The upper mud is grey-yellowish-brown, sometimes, slightly greenish, non-cohesive, fluffy, rich in fine organic material; the lower mud is grey, cohesive, and contains vegetal material, too. In the depth interval 27 - 31 cm, the mud shows transition characteristics between the above-described sequences (Figs. 15 and 16). The similarity between the vertical distribution of the siliciclastic detrital component and of the magnetic susceptibility parameter related to the *DD 13-61 core* sediments is evidently illustrated in Fig. 16a,b.



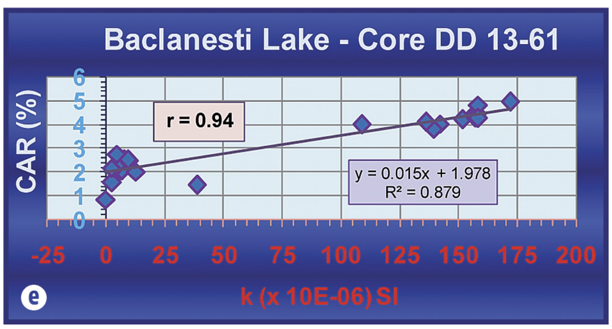


Fig. 16. Magneto-lithological parameters of the *DD 13-61 core* sediments (*Băclăneşti Lake*). **a)** Lithological composition (**SIL**, **TOM**, **CAR**) along the core; **b)** Variation with depth of the magnetic susceptibility (**MS**; **k**); **c)** Correlation **SIL** *versus* **k**; **d)** Correlation **TOM** *versus* **k**; **e)** Correlation **CAR** *versus* **k**.

The correlation diagrams (Fig. 16c,d,e) clearly reflect the existence of two different sets, corresponding to the two sequences. If the correlations are analysed in detail, separately for each sediment sequence (Fig. 17), it can be observed that, in the both groups, the *carbonates* (**CAR**) are positively correlated with the *siliciclastic fraction* (**SIL**), namely **r** = 0.69, related to the upper sequence (Fig. 17c), and **r** = 0.77, regarding the lower one (Fig. 17d), suggesting the detrital origin of the carbonatic material.

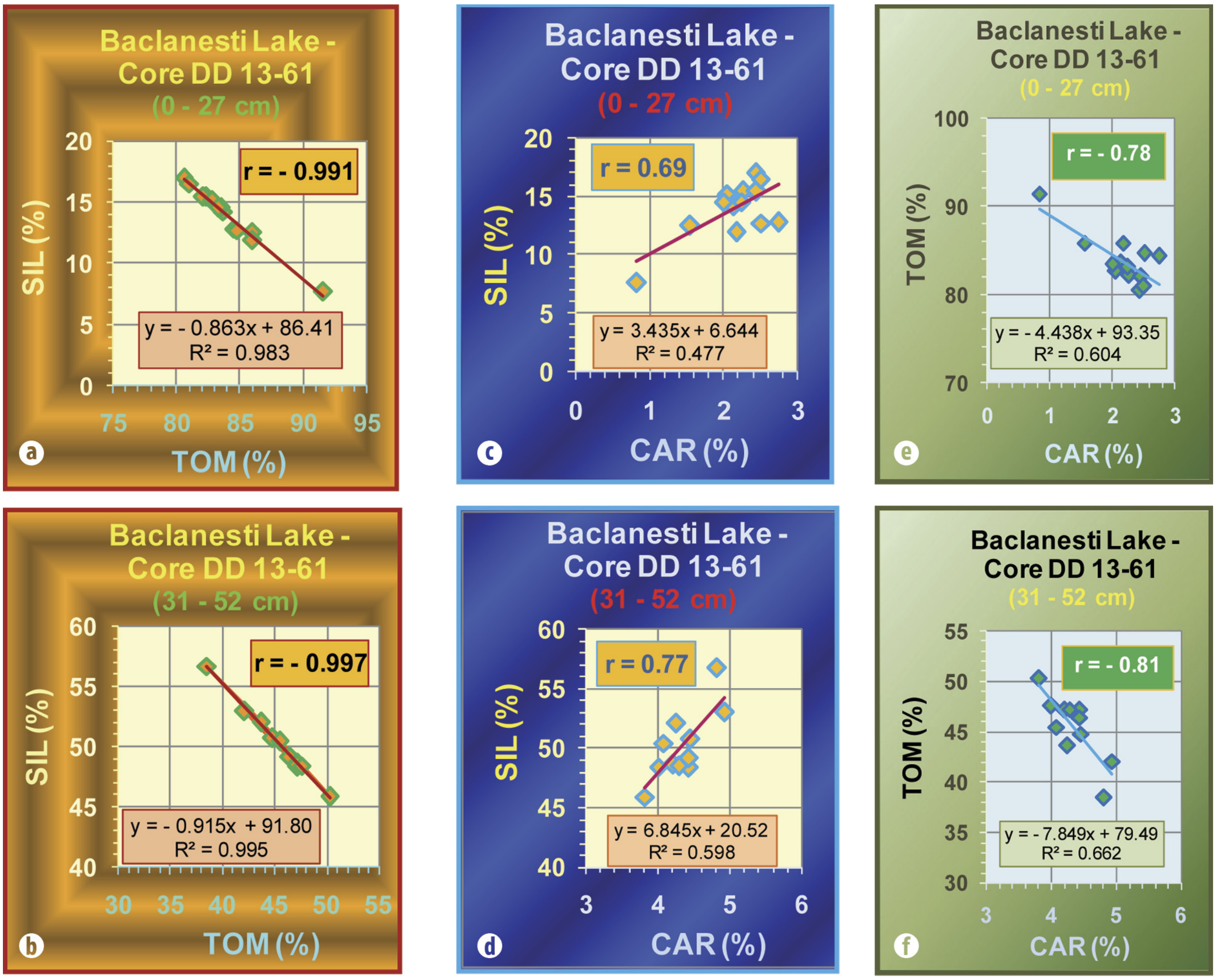


Fig. 17. Correlation diagrams concerning the lithological composition of two sediment sequences identified within the *sediment core DD 13-61* (*Bădăneşti Lake*). **a)** Correlation **SIL** *versus* **TOM** (depth interval 0 - 27 cm); **b)** Correlation **SIL** *versus* **TOM** (depth interval 31 - 52 cm); **c)** Correlation **SIL** *versus* **CAR** (depth interval 0 - 27 cm); **d)** Correlation **SIL** *versus* **CAR** (depth interval 31 - 52 cm); **e)** Correlation **TOM** *versus* **CAR** (depth interval 0 - 27 cm); **f)** Correlation **TOM** *versus* **CAR** (depth interval 31 - 52 cm). *Note*: The values corresponding to the transition level (cm 27 - 31) were not taken into consideration.

The separation of the two distinct "sediment packets" in the *Băclăneşti Lake* points out a significant change in the hydrological regime of the area, possibly connected to the diminution of northwestern supplies after the building of Pardina polder (1983).

b. Fortuna Lake - *Cores DD 11-210* and *DD 13-56*

❒ *Core DD 11-210*

The *DD 11-210 core* was collected from the southern zone of the *Fortuna Lake* (*eastern Meşteru - Fortuna Depression*, *Danube Delta*; Figs. 5 and 14).

The vertical distribution of the magnetic susceptibility offers interesting information on the sedimentation process in the southern half of the *Fortuna Lake*. In Fig. 14a, the core location is represented within the **MS** map constructed on the basis of the bottom sediment samples collected during the 1980 campaign (Rădan *et al*., 1999), that is when the *Crânjală Cn.* - a short artificial canal, which connects the *Sulina Branch* and the *Fortuna L.* - was very active. The **MS** anomaly (**k** values up to 581×10^{-6} SI), revealed by the contour map from Fig. 14a, shows the morphology of the underwater fan zone of the solid discharge provided by the *Danube River*. In the 3D-chart from Fig. 18a, two maxima are visible, one (with the highest **k** value of 145×10^{-6} SI) at ca. 30 cm under the water (w) / sediment (s) interface, the second one (with the highest **k** value of 452×10^{-6} SI) at ca. 12 cm beneath the w/s interface. The same pattern can be recognised in the similar diagrams for the lithological components (Fig. 18c,d,e). Actually, the **MS** calibration of the core sediments reveals that 44% of the sliced samples belong to **k** class **Va** (Fig. 18b), which mostly defines the upper maximum (Fig. 18a), 44% to class **III** (Fig. 18b), which mostly describes the lower maximum (Fig. 18a), and finally, 6% each to class **IV** and class **II**, respectively

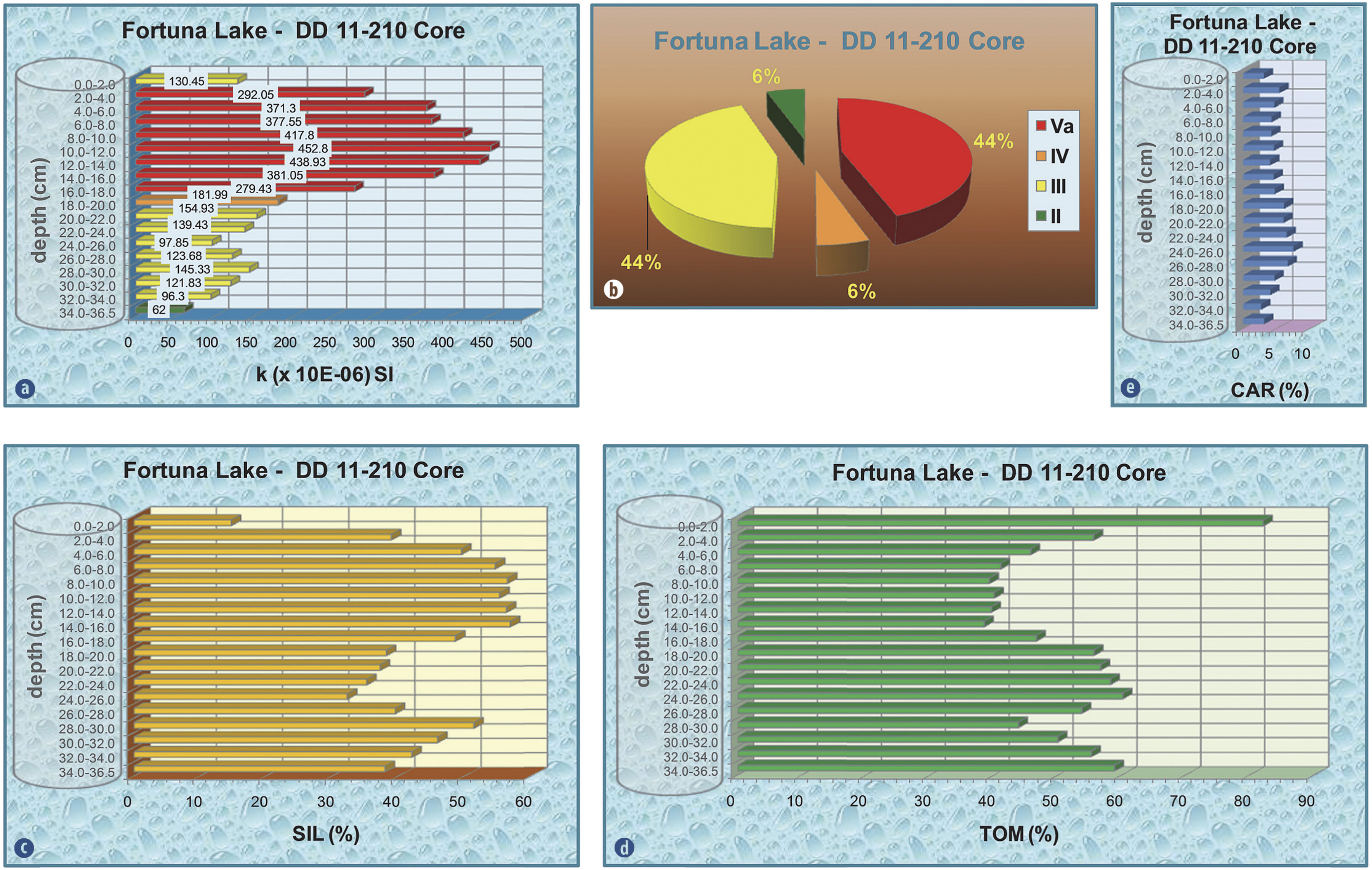
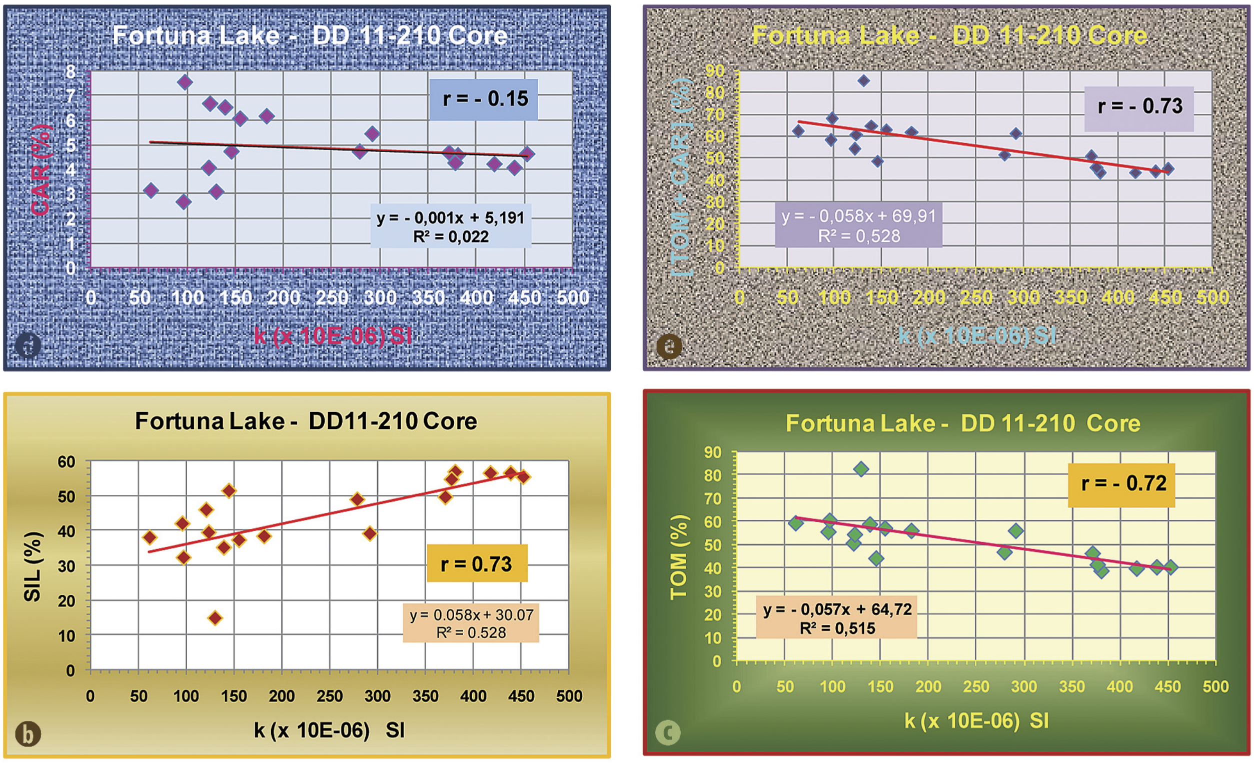


Fig. 18. Vertical distribution of the enviromagnetic parameter and the lithological components along the *DD 11-210 core*. **a)** Vertical distribution of the magnetic susceptibility; the bars are coloured according to the **k** scale; **b) MS** calibration of the core sediments according to the **k** scale classes; **c)** Vertical distribution of the siliciclastic/detrital fraction (**SIL**); **d)** Vertical distribution of the total organic matter content (**TOM**); **e)** Vertical distribution of the carbonate content (**CAR**).

(Fig. 18b), which belong to the decreasing arms of the upper and lower maximum, respectively (Fig. 18a). The two maxima represent two evolution phases of the detrital inputs, which could be found within the history of the canal activity. The **MS** maximum located in the upper part of the *DD 11-210 core* could be correlated with the high solid discharge characterising the *Crânjală Canal* activity in the '80s (the **k** map from Fig. 14a, as we mentioned above, is based on bottom sediments sampled in 1980). More information data are needed with regard to the time interval when the canal has acted at a maximum discharge to allow calculation of the sedimentation rate for the southern zone of the *Fortuna Lake*.

The sedimentogenetic significance of the magnetic parameter **MS** is supported by the high correlation coefficients (**r**) which were determined for **MS** (**k** values in Fig. 18a) *versus* the lithological components **SIL** (*siliciclastic/detrital fraction*; the vertical distribution along the *DD 11-210 core*, in Fig. 18c, and the average content, in Fig. 19a), **TOM** (*Total Organic Matter* content; Fig. 18d; Fig. 19a), and (**TOM**+**CAR**) (**CAR** - *Carbonates*, Fig. 18e, Fig. 19a). So, **r** = 0.73 (*i.e.*, a strong direct/positive correlation, according to the scale given in Fig. 4a), in the case of **SIL** *vs*. **MS** (Fig. 19b), and **r** = - 0.72 (*i.e.*, a strong indirect/reversed correlation), when referring to **TOM** *vs*. **MS** (Fig. 19c). The correlation between the **MS** and **CAR** is insignificant (**r** = - 0.15; Fig. 19d), due to their reduced weight (Fig. 18e; Fig. 19a) to the sediment constitution. When the contents of carbonates and organic matter are taken together, **r** = - 0.73, *i.e.* a strong negative/reversed correlation for (**TOM**+**CAR**) *versus* **MS** (Fig. 19e).

The magneto-lithological study of the *core DD 11-210* shows a diminution of the coarse *siliciclastic component* towards the base (**SIL**; Figs. 18c and 20a), which is even better illustrated by the *magnetic susceptibility* record (Figs. 18a and 20b), suggesting that the upper unit is the result of the lake silting up due to the influence of the *Crânjală Canal* sedimentary supplies**.**



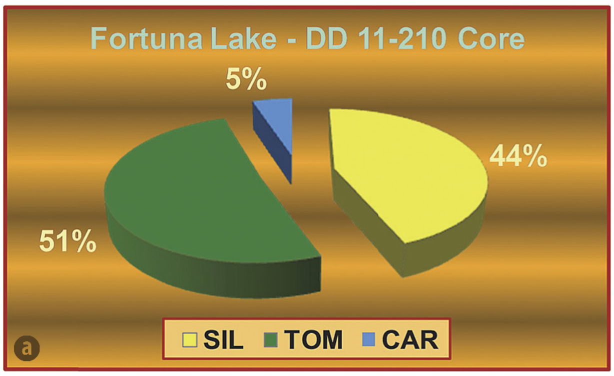


Fig. 19. Correlation diagrams of the lithological components (**SIL, TOM, CAR**) and the magnetic susceptibility enviromagnetic parameter (**MS**; **k**), related to the *DD 11-210 sediment core*. **a**) Lithological composition of the core sediments, based on the **SIL**, **TOM** and **CAR** average contents; **b)** Correlation **SIL** *versus* **MS**; **c)** Correlation **TOM** *versus* **MS**; **d)** Correlation **CAR** *versus* **MS**; **e)** Correlation (**TOM**+**CAR**) *versus* **MS**.

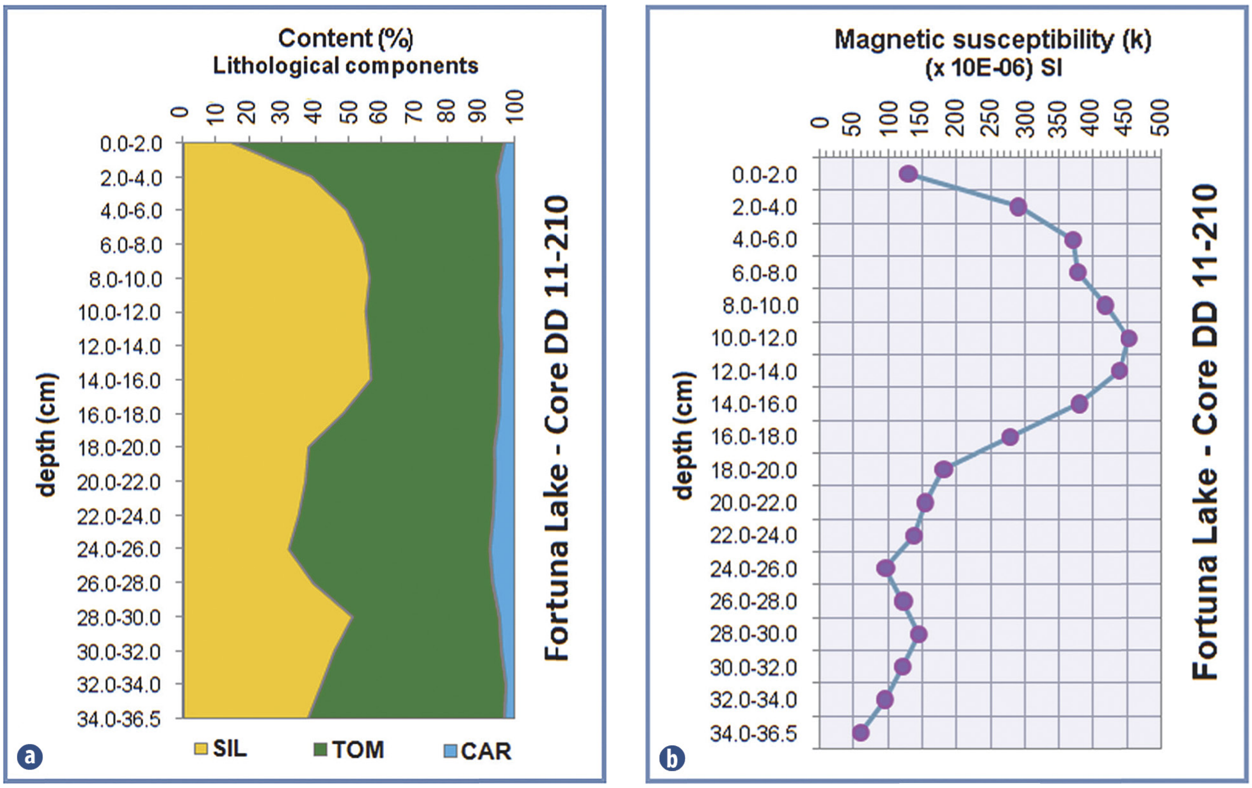


Fig. 20. Magneto-lithological characterisation of the sediments recovered from the *core DD 11-210*. **a)** Lithological composition (**SIL**, **TOM**, **CAR**) along the core; **b)** Variation with depth of the magnetic susceptibility (**MS**; **k**).

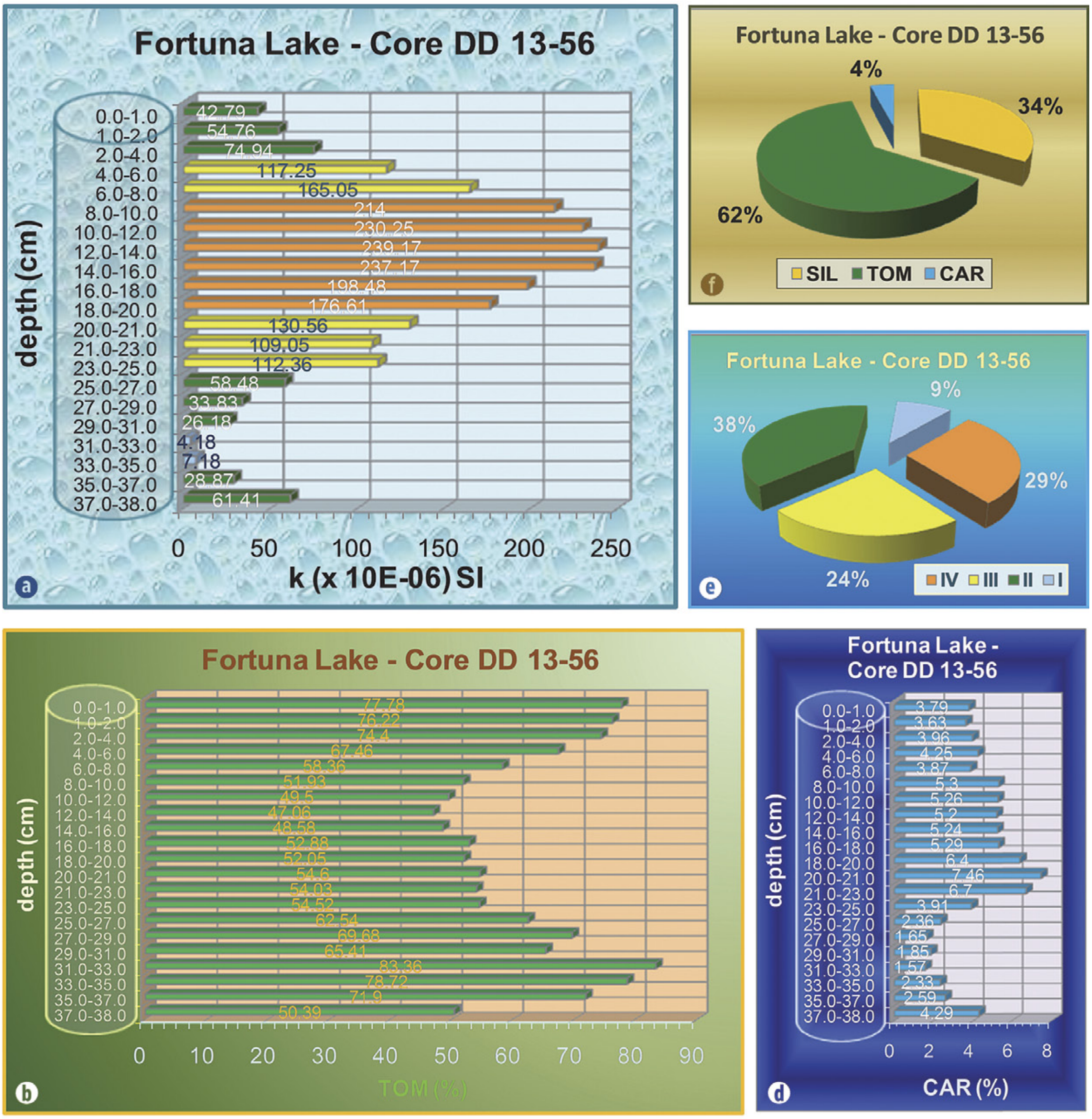
❒ *Core DD 13-56*

This core was collected from the *Fortuna Lake* central zone, northwest of the previously presented core (*DD 11-210*), not far from this, but outside of the former *Crânjală Canal* (Fig. 14a,b). Consequently, the magnetic fingerprints recovered from the sediments of the two cores are similar in morphology, but different in intensity (see Figs. 18a, 20b and Figs. 21a, 22b). The upper maximum zone recorded in the *Core DD 11-210* registers the highest **MS** value of 452×10^{-6} SI (**k** class **Va**) at ca. 12 cm beneath the water/sediment interface (Fig. 18a), while the maximum **k** value related to the upper maximum zone characterising the **MS** fingerprint extracted from the *DD 13-56 core* sediments is 239.17×10^{-6} SI (**k** class **IV**; Fig. 21a), and it was measured on cohesive muds from about the same depth.

The pie-charts in Figs. 18b and 21e point out the different intensities of the two **MS** fingerprints recovered from the *DD 11-210* and *DD 13-56* cores, respectively: a range extended from **k** class **II** (6%) up to class **Va** (44%), with an average **k** value of 236.93×10^{-6} SI in the first case, and a range covering an interval from **k** class **I** (9%) up to class **IV** (29%), in the second one, with an average **k** value of 110.60×10^{-6} SI. The magnetic susceptibility calibration of the *DD 13-56* core sediments shows - beside the mentioned **k** classes **I** and **IV** - the **MS** classes **II** (38%) and **IV** (24%) (Fig. 21e).

The lithological composition of the *DD 13-56* core supports the magnetic susceptibility signature characterising the sediments: a maximum zone in the upper-central part of the **SIL** record (Fig. 21c), followed by a narrower minimum zone towards the base, and *vice versa* relating to the **TOM** component (Fig. 21b), *i.e.*, a large minimum zone in the upper-central part of the core, and a narrower maximum zone towards the core base. Still, the contents determined for the carbonates existing within the core sediments show a slightly similar vertical distribution (Fig. 21d), with an increasing trend in the upper-central part, followed by a minimum zone in the basal part. The correlation coefficients **r** calculated for **SIL** *versus* **k**, **TOM** *vs*. **k**, **CAR** *vs*. **k**, as well as **SIL** *vs*. **TOM** (Fig. 22c,d,e,f) assert that the magnetic susceptibility is strongly positively correlated (according to the scale from Fig. 4a) with the lithological components **SIL** and **CAR** (Fig. 22c,e), and strongly negatively correlated with the **TOM** component (Fig. 22d). Strong negative correlations (*i.e.*, **r** = - 0.99, and **r** = - 0.71) are also shown by **SIL** *vs*. **TOM**, and **TOM** *vs*. **CAR**, respectively (Fig. 22f,h).

The **SIL** and **CAR** lithological components are moderately positively correlated (**r** = 0.62; Fig. 22g), suggesting a detrital origin of the carbonates found within the core sediments; a similar situation was found for the *core DD 13-61* collected from the *Băclăneşti Lake* (see Fig. 17c,d). This assertion is confirmed by the correlation **CAR** *vs*. **k**, which points out a strong positive correlation (**r** = 0.72; Fig. 22e).



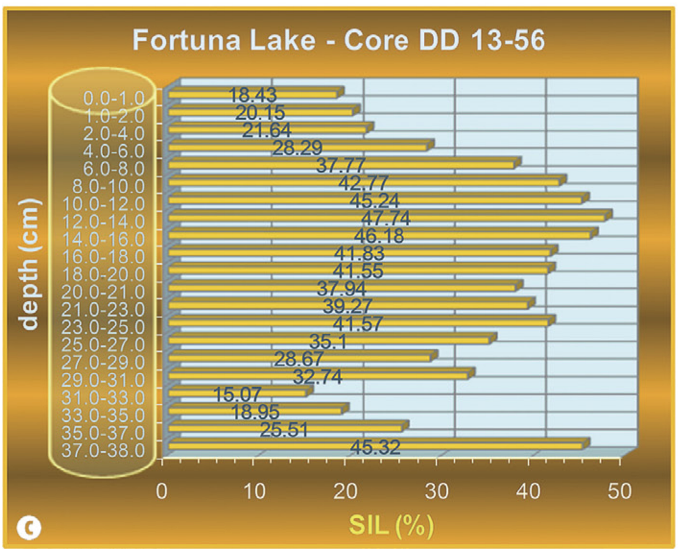
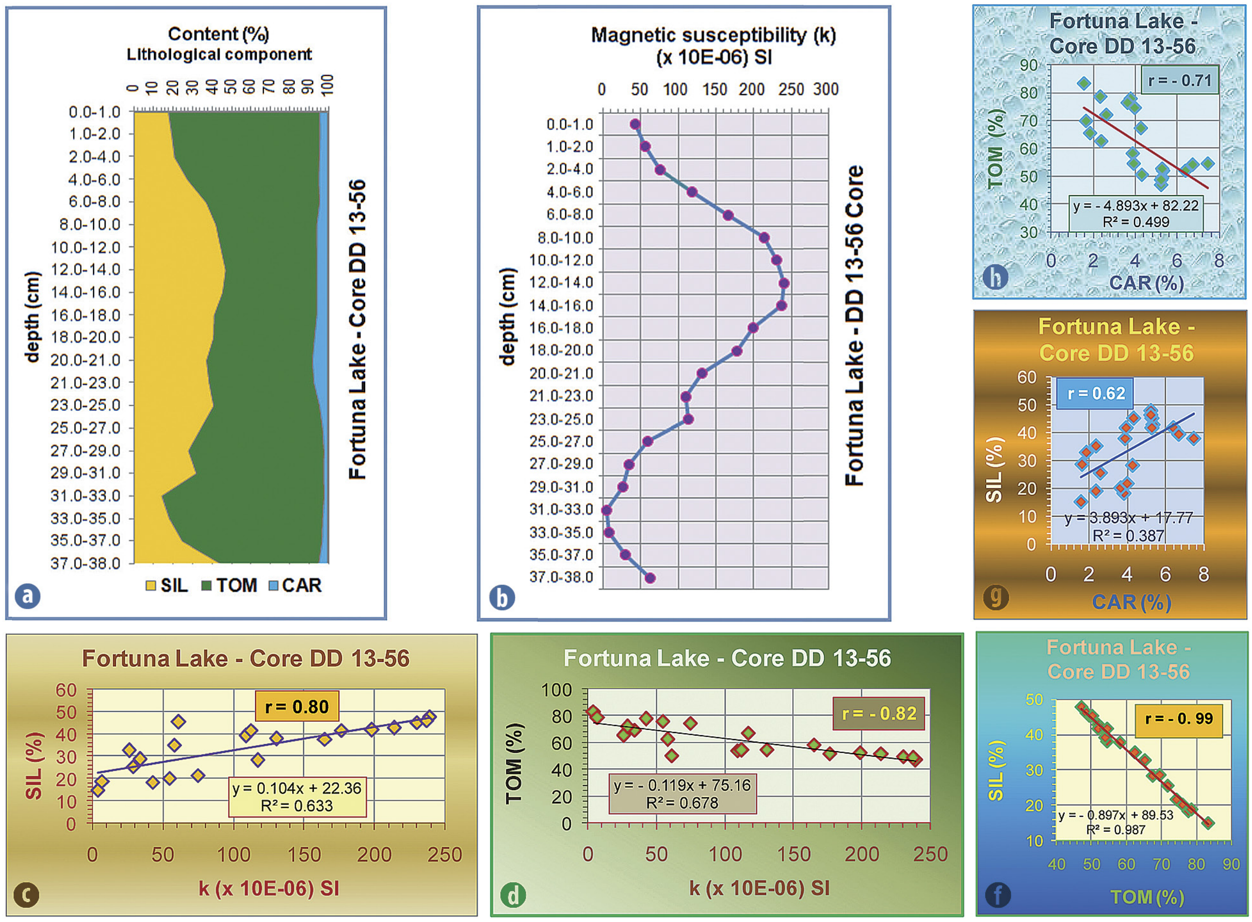


Fig. 21. Vertical distribution of the enviromagnetic parameter and of the lithological components along the *core DD 13-56* (*Fortuna Lake*). **a)** Variation with depth of the magnetic susceptibility (**MS**; **k**); the **MS** bars are coloured according to the **k** scale classes; **b)** Variation with depth of the total organic material content (**TOM**); **c)** Variation with depth of siliciclastic/detritial fraction content (**SIL**); **d)** Variation with depth of the carbonate content (**CAR**); **e) MS** calibration of the core sediments according to **k** scale classes; **f)** Lithological composition of the core sediments, based on the **SIL**, **TOM** and **CAR** average contents.



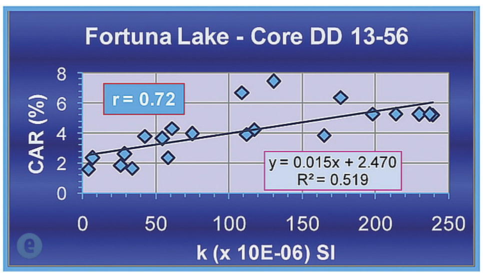


Fig. 22. Magneto-lithological characterisation of the *DD 13-56 core* sediments (*Fortuna Lake*). **a)** Lithological composition (**SIL**, **TOM**, **CAR**) along the core; **b)** Variation with depth of the magnetic susceptibility (**k**); **c)** Correlation **SIL** *versus* **k**; **d)** Correlation **TOM** *versus* **k**; **e)** Correlation **CAR** *versus* **k**; **f)** Correlation **SIL** *versus* **TOM**; **g)** Correlation **SIL** *versus* **CAR**; **h)** Correlation **TOM** *versus* **CAR**.

Finally, concerning the *core DD 13-56*, the parallel diagrams for the lithological composition (**SIL**, **TOM**, **CAR**) and the enviromagnetic signature (**MS**; **k**), respectively (Fig. 22a,b), are noteworthy. Their morphology analysis is supported by the above-presented correlation coefficients, determined for the two categories of characteristics defining the recovered 38 cm thick column of sediments, extracted from the central area of the *Fortuna Lake*.

c) Crânjală mid-channel/Fortuna Lake - *Cores DD 13-55* and *DD 13-54*

During the April 2013 campaign, two cores from the *Crânjală mid-channel* were taken, namely the *DD 13-54* and *DD 13-55* (location, in Fig. 14).

In the '80s, the influence of the *Crânjală Canal* on the *Fortuna Lake* sediments was very important, the direct solid discharges from the *Danube* contributing to the formation of a "*microdelta*" in the canal mouth area, providing a progressive silting of the lake. The magnetic susceptibility map performed on the basis of the sediments sampled in the year 1980 (Fig. 14b) clearly reflects the morphology of the underwater fan zone generated by the *Crânjală Canal* intense activity. The sediments were of fluvio-lacustrine type. Afterwards, in the '90s, when the canal closed, the sedimentation became predominantly organic, simultaneously with the change of the lake hydrological regime, nowadays filled up with watter from north, through a connection canal with *Şontea Cn.* (Fig. 14a). The magnetic susceptibility map carried out on the basis of the surficial sediments sampled in 2011 (Fig. 14e) emphasises these changes, the measured maximum **k** value being 329.68×10^{-6} SI (a maximum **k** contour of 300×10^{-6} SI); 30 years ago, the maximum **k** value recorded on a sediment sampled, roughly, in the same area (Fig. 14b), has reached 581×10^{-6} SI (a maximum **k** contour of 575×10^{-6} SI was drawn; Rădan *et al*., 1999).

Taking into account these short comparative considerations, based on **MS** data obtained at the ends of a 31 year interval, the information given by the two cores collected in 2011 from the *Crânjală mid-channel* (Fig. 14a,b) is relevant. The sequences, though not too thick (*i.e.*, 32 cm in the *core DD 13-55*, and 27 cm in the *core DD 13-54*), penetrated by the two cores, reflect the sedimentation conditions existing, anyway, during an earlier period.

❒ *Core DD 13-55*

The sediments penetrated by the *core DD 13-55*, collected from the *Crânjală mid-channel* (Fig. 14), show, as expected, a lithological composition dominated by the siliciclastic detrital material/**SIL** (ranging between 51.69 - 68.23%; average content: 61%; Fig. 23b,f), to which are added, subordinately, the organic material/**TOM** (26.71 - 44.54%; 35%; Fig. 23d,f), and a small amount of carbonates (3.67 - 5.06%; 4%; Fig. 23c,f). The sediments belong to the category of the mineral-organic muds, and are represented by coarse siltic muds, sometimes with sand traces, grey and grey-yellowish in the upper half core, and blacky towards the base. The vertical variations have not a big amplitude, being probably connected with the seasonal changes of the *Danubian* supplies since the *Crânjală Canal* had been active.

The magnetic susceptibility variations along the core (Fig. 23a, Fig. 24b), which perfectly correlate with the main lithological components determined for the analysed sediments (Fig. 23b,c,d; Fig. 24a), pointing out even in more detail the detrital sequences, assert its quality of proxy parameter for the lithological composition. Particularly, referring to the siliciclastic fraction (**SIL**) and the organic matter (**TOM**), the correlation coefficients are **r** = 0.91 for **SIL** *versus* **k** (Fig. 24c), and **r** = - 0.90 for **TOM** *versus* **k** (Fig. 24d). The dominance of the mineral fraction (Fig. 23f), and the fact that the sediments are mainly constituted of coarse siltic muds (with sand traces) are reflected by the calibration of the most samples (88%) to the **k** class **Va** (Fig. 23e), the rest of 12% being assigned to the class **IV** (**k** scale, in Fig. 4b). The high intensity of the magnetic fingerprints recovered from all the core sediment slices is defined by the range 263.61×10^{-6} - 376.11×10^{-6} SI (Fig. 23a) within which all the **MS** values are concentrated.

It is worth a remark concerning the strong correlations between the lithological components. So, for **SIL** *versus* **TOM**, **r** = - 0.999 (Fig. 24f), but very interesting are the correlations **SIL** *vs*. **CAR** (**r** = 0.79; Fig. 24h) and **TOM** *vs*. **CAR** (**r** = - 0.82; Fig. 24g); the strong positive and negative correlations, respectively, point out the connection of the carbonate fraction with the siliciclastic mineral material, suggesting a detrital origin of the carbonates, and not a biochemical one, as it has been recognised within some very organic muds. The enviromagnetic parameter **MS** confirms this inference, the correlation coefficient for **CAR** *versus* **k** being also positive (**r** = 0.61; Fig. 24e).

❒ *Core DD 13-54*

This second core taken from the *Crânjală mid-channel*, which is 5 cm shorter than the previously presented one, is located closer to the channel entry into the *Fortuna Lake* (Fig. 14). The magneto-lithological models achieved for the two cores (Figs. 23 and 24, and Figs. 25 and 26, respectively) are, generally, similar. Yet, the maximum zone identified in the upper half of the core *DD 13-54* is thinner, but more intense than that recorded for the *core DD 13-55*, while the minimum zone, observed in the lower half of the two cores, is larger, but less intense for the first mentioned core as compared to the second one. The measured magnetic susceptibility values on the 15 sediment samples sliced from the core *DD 13-54* are defined within a slightly more extended range than that concerning the core *DD 13-55*, namely 213.0×10^{-6} - 423.75×10^{-6} SI (Fig. 25a). Additionally, the average **k** values which characterise the intensity of the recovered **MS** fingerprints are very close (almost the same), *i.e.* 327.40×10^{-6} SI for the *core DD 13-54*, and 328.88×10^{-6} SI for the *core DD 13-55*. This fact could indicate the quite similar magneto-mineralogical and geochemical constitution of the two core sediments. The pie-chart from Fig. 25e illustrates the calibration of the sediments penetrated by the core *DD 13-54* to the same two **k** classes of the **MS** scale (Fig. 4b), with slightly different weights, *i.e.*, **k** class **Va** (73%), and class **IV** (27%) (see, for comparison, Fig. 23e).

The position of the *core DD 13-54* towards the upper part of the sediment fan developed into the lake at the channel mouth - as compared to the location of the *core DD 13-55* - results in a slightly more intense *magneto-lithological signature* assigned to the sequence from the upper half of the core. This small difference recorded within the vertical variation of the magnetic parameter could give a complementary information to the macroscopical description of the cores made aboard the vessel.

The lithological composition of the *core DD 13-54* is dominated, as for the previously analysed one, by the siliciclastic mineral material/**SIL** (66%), followed by the organic matter (29%), and carbonates (5%) (Figs. 25f and 26a). The sediments are placed into the category of the mineral-organic muds, and are represented by coarse siltic muds, dark grey in the core upper half, and light grey in the lower one, quite rich in vegetal material. This macroscopical description of the sediments is confirmed by the **MS** (**k**), **SIL** and **TOM** charts from Fig. 25a,b,d. Consequently, a maximum zone in the upper half is well-defined for the **MS** and **SIL** parameters, and a minimum one for the **TOM** lithological component; in the lower half, a minimum zone is outlined within the **MS** and **SIL** records, and a maximum zone within the **TOM** content vertical variation chart. These relations between the enviromagnetic parameter **MS** and the lithological components determined for the *core DD 13-54* sediments are quantified by the

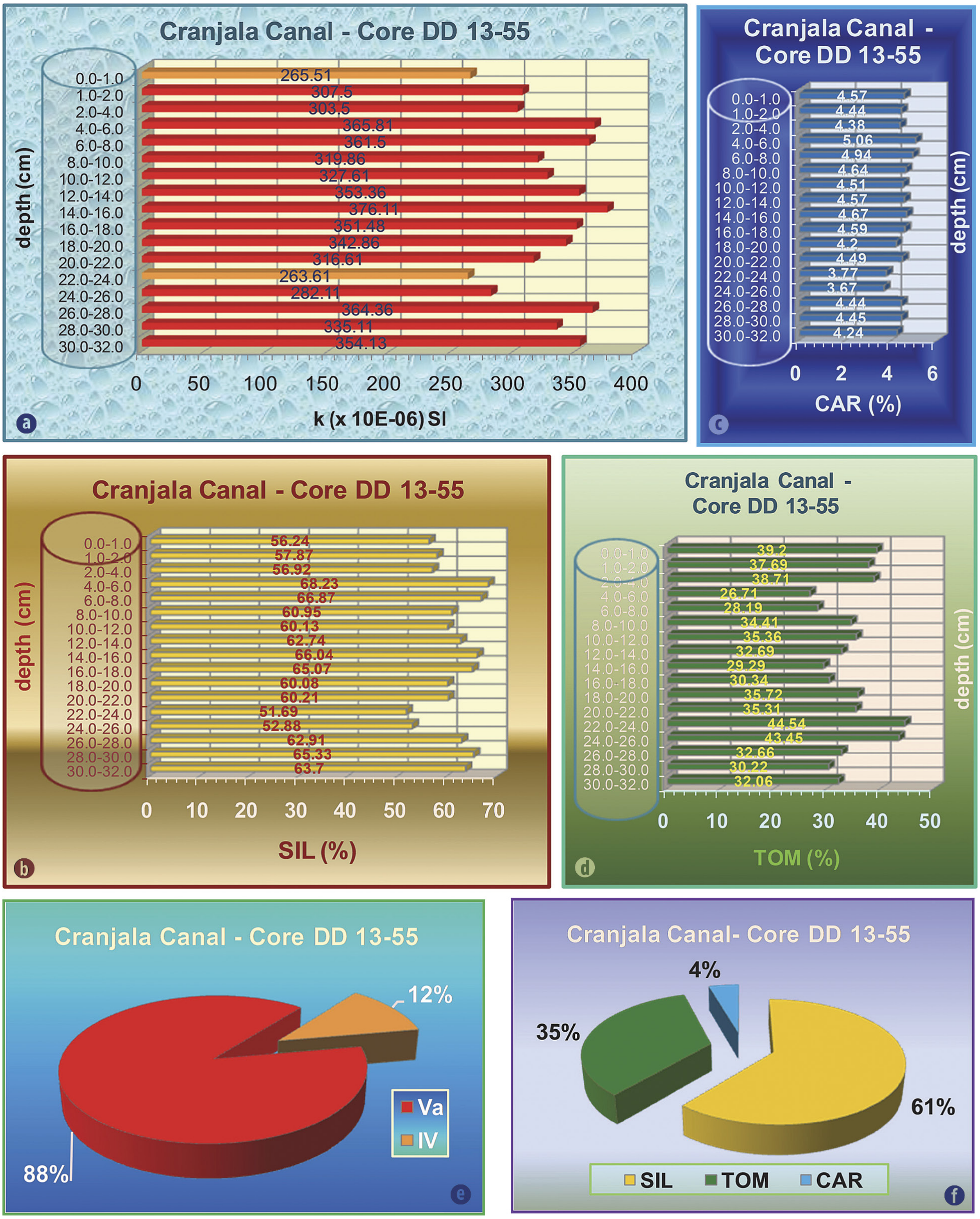
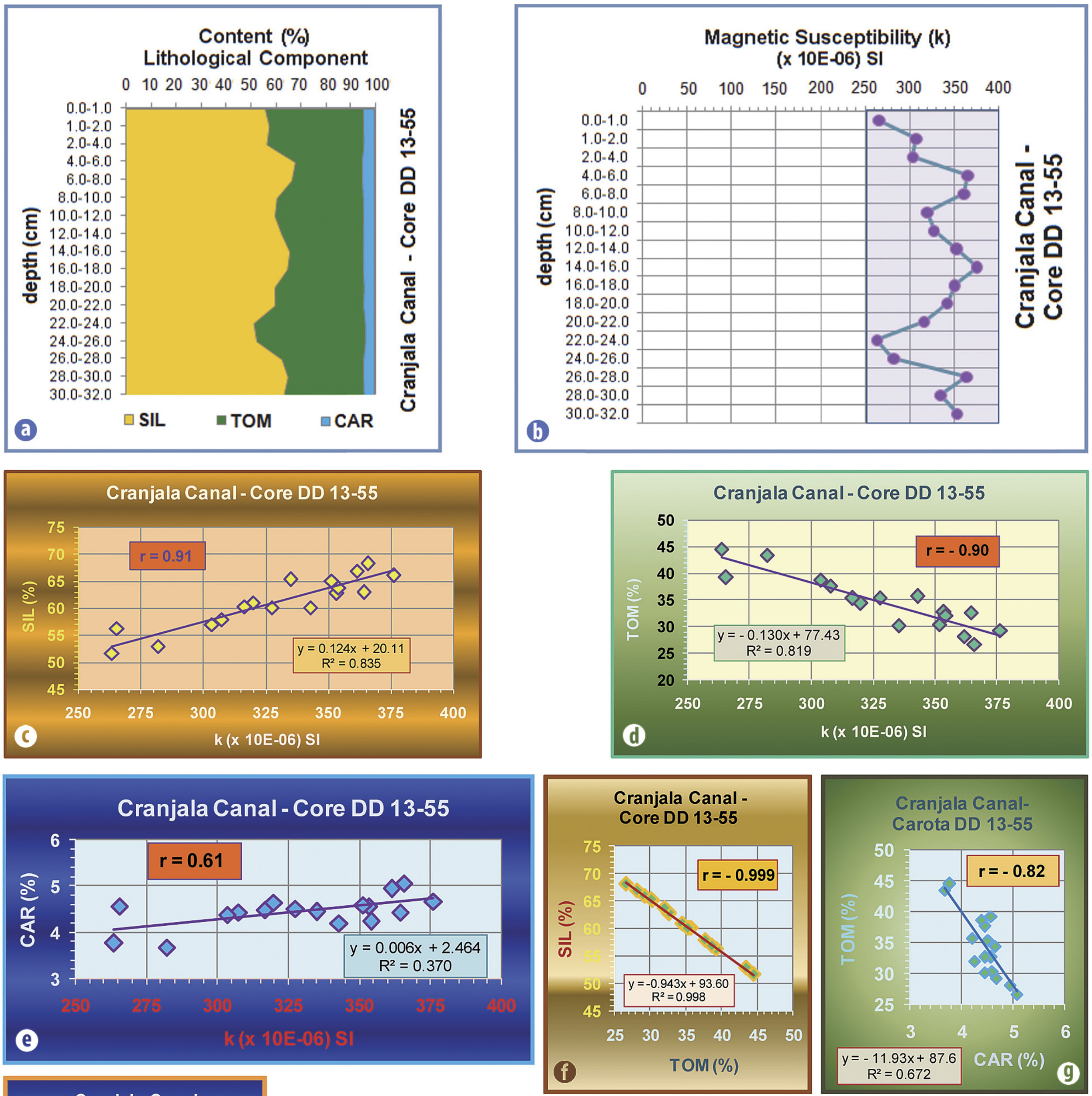


Fig. 23. Vertical distribution of the enviromagnetic parameter and the lithological components (*core DD 13-55*). **a)** Variation with depth of the magnetic susceptibility (**MS**; **k**); the **MS** bars are coloured according to the **k** scale classes; **b)** Variation with depth of the siliciclastic/detritial fraction content (**SIL**); **c)** Variation with depth of the carbonate content (**CAR**); **d)** Variation with depth of the total organic material content (**TOM**); **e) MS** calibration of the core sediments according to the **k** scale classes; **f)** Lithological composition of the core sediments, based on the **SIL**, **TOM** and **CAR** average contents.



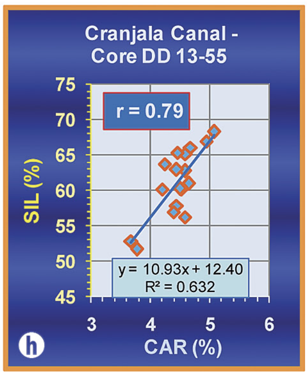


Fig. 24. Magneto-lithological characteristics of the *DD 13-55 core* sediments (*Crânjală Canal*). **a)** Lithological composition (**SIL**, **TOM**, **CAR**) along the core; **b)** Variation with depth of the magnetic susceptibility (**k**); **c)** Correlation **SIL** *versus* **k**; **d)** Correlation **TOM** *versus* **k**; **e)** Correlation **CAR** *versus* **k**; **f)** Correlation **SIL** *versus* **TOM**; **g)** Correlation **TOM** *versus* **CAR**; **h)** Correlation **SIL** *versus* **CAR**.

correlation coefficients (**r**) calculated between pairs of these magnetic and lithological characteristics. Thus, regarding **SIL** *versus* **k**, **r** = 0.65 (Fig. 26c), and for **TOM** *versus* **k**, **r** = - 0.64 (Fig. 26d), which confirm a positive/direct correlation between the siliciclastic detrital fraction and the magnetic susceptibility, and a negative/reversed correlation between the organic matter and the enviromagnetic parameter, respectively. Regarding the carbonates, present in small amounts in sediments (3.88 - 5.71 %; Fig. 25c,f), the correlation with the magnetic parameter is positive, but weak (**r** = 0.30; Fig. 26e), actually, close to the boundary which separates the weak and moderate correlation ranges (see Fig. 4a).

A suggestive illustration of the lithological characterisation and of the magnetic susceptibility signature related to the *core DD 13-54* sediments is given by the 2D-area chart from Fig. 26a, and the 2D line-chart from Fig. 26b, respectively. The parallel analysis confirms the above comments and adds even more details relating to the vertical distribution of the four parameters along the short core (only 27 cm long). It is also demonstrated the quality of magnetic susceptibility as a proxy parameter for the lithological composition of the lake sediments, even we are in a rarer case, referring to our investigated cores, when some **r** coefficients showed correlations placed - according to the scale from Fig. 4a - at the moderate/strong boundary (for **SIL** *vs.* **k** and **TOM** *vs.* **k**), or even at

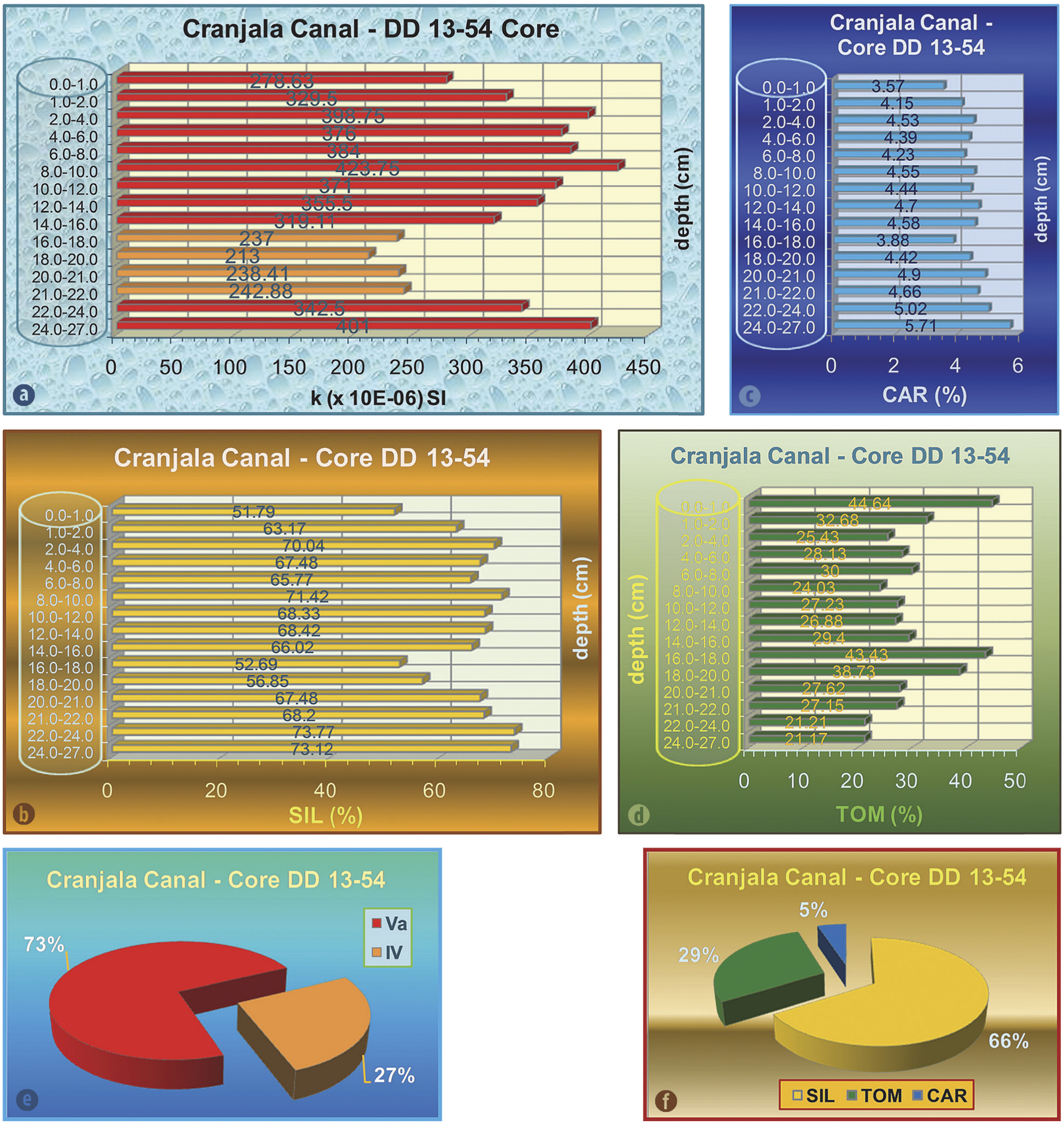


Fig. 25. Vertical distribution of the enviromagnetic parameter and the lithological components (*Core DD 13-54*, *Crânjală Canal*). **a)** Variation with depth of the magnetic susceptibility (**MS**; **k**); the **MS** bars are coloured according to the **k** scale classes (see Fig. 4b); **b)** Variation with depth of the siliciclastic/detritial fraction content (**SIL**); **c)** Variation with depth of the carbonate content (**CAR**); **d)** Variation with depth of the total organic material content (**TOM**); **e) MS** calibration of the core sediments according to the **k** scale classes; **f)** Lithological composition of the core sediments, based on the **SIL**, **TOM** and **CAR** average contents.

the weak/moderate one (for **CAR** *vs.* **k**). Anyway, these two images (Fig. 26a,b), compared to the corresponding ones for the *core DD 13-55* (Fig. 24a,b), collected also from the *Crânjală mid-channel*, provide an useful tool to observe the similarities and the slight differences between the two cores from a canal with an intense activity in the '80s, and closed afterwards, in the '90s. If the cores have the availability to point out the intense activity from the first mentioned period and before, the magnetic susceptibility maps from Fig. 14b,f, based on the surficial sediments sampled in the years 1980 and 2011, respectively, clearly illustrate the difference between the sedimentation process characteristics, as a result of the hydrological regime change, related to the two periods, before and after closing the *Crânjală Canal*.

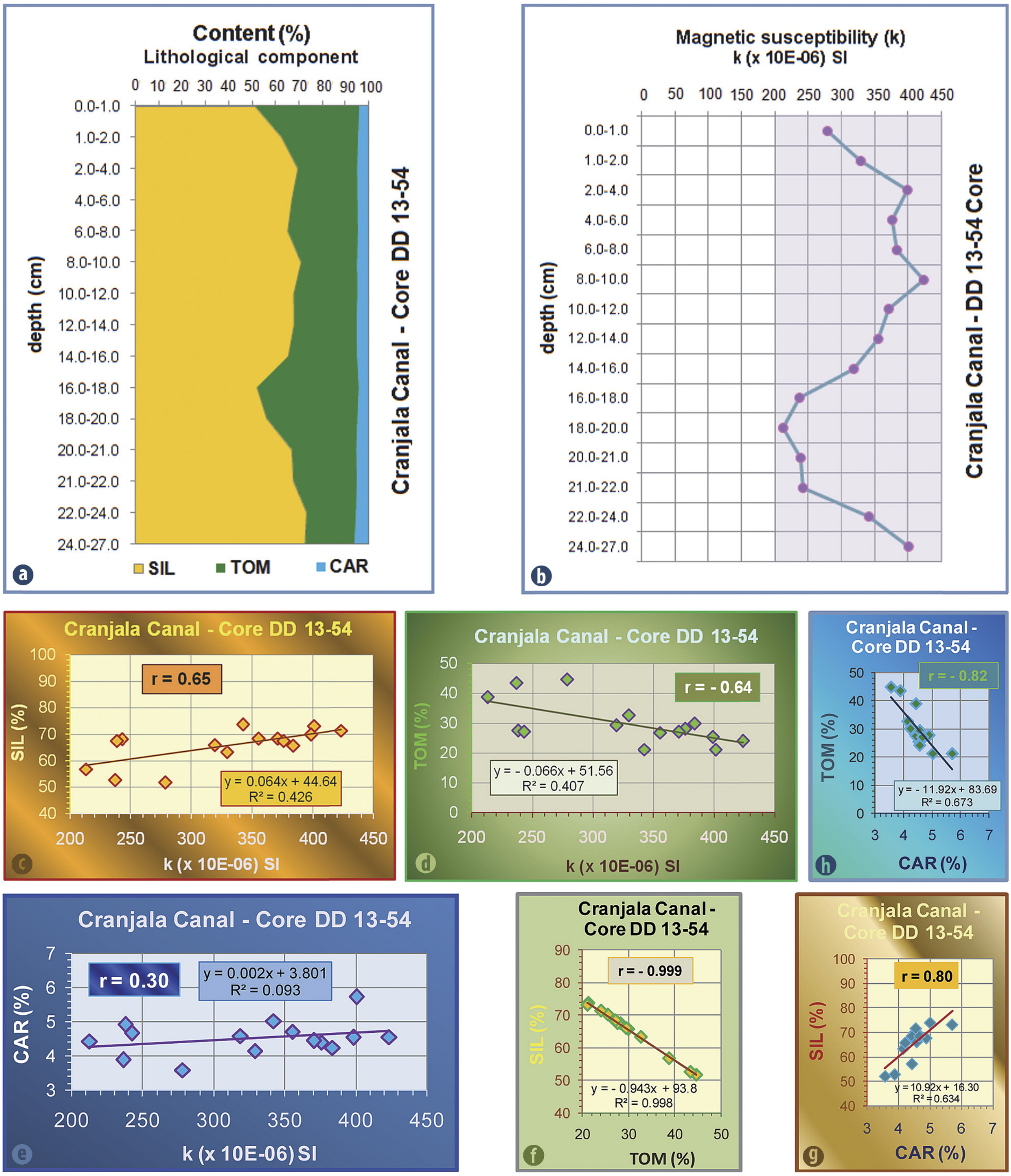


Fig. 26. Magneto-lithological characteristics of the *DD 13-54 core* sediments (*Crânjală Canal*). **a)** Lithological composition (**SIL**, **TOM**, **CAR**) along the core; **b)** Variation with depth of the magnetic susceptibility (**MS**; **k**); **c)** Correlation **SIL** *versus* **k**; **d)** Correlation **TOM** *versus* **k**; **e)** Correlation **CAR** *versus* **k**; **f)** Correlation **SIL** *versus* **TOM**; **g)** Correlation **SIL** *versus* **CAR**; **h)** Correlation **TOM** *versus* **CAR.**

4. CONCLUSIONS, INFERENCES, AND FUTURE WORK

The variety of the aquatic ecosystems and the diversity of the sedimentation environments in the *Danube Delta* are well characterised by specific magnetic susceptibility fingerprints, recovered from the sediments of the investigated lakes. The vertical distribution of the magnetic susceptibility values, recorded for numerous short sediment cores, collected during the 2010 - 2013 period from 12 lakes and a mid-channel, reflects, accurately, the lithological variations, which sometimes are macroscopically less visible. The integrated magneto-lithological study of the sediment cores concerns the main interdistributary depressions, situated in both the *Fluvial Delta Plain* and the *Fluvio-Marine Delta Plain*.

In this paper, the magnetic susceptibility (**MS**) characterisation and the lithological composition of 7 short cores from 4 lakes and a mid-channel from the *Meşteru - Fortuna Depression* (*Fluvial Delta Plain*) were presented. In the western area of this depression, a sediment core (57 cm long) from the *Cuteţchi Lake* (*DD 10-177*), and another one (61 cm long) from the *Tătaru Lake* (*DD 12-03*), collected in 2010 and 2012, respectively, were taken. As regards the eastern part of the aquatic depression, a core (with a length of 52 cm) from the *Băclăneşti Lake* (*DD 13-61*), two cores (36.5 cm, and 38 cm, respectively) from the *Fortuna Lake* (*DD 11-210* and *DD 13-56*, respectively), and other two short sediment cores (32 cm, and 27 cm, respectively), from the *Crânjală mid-channel* (*DD 13-55*, and *DD 13-54*, respectively), were collected. Apart from the core *DD 11-210*, taken in the year 2011, the other 4 cores from the eastern *Meşteru - Fortuna Depression* have recently been collected, during the campaign carried out by GeoEcoMar in the *Danube Delta* in April 2013.

Even this synopsis refers to the sediment cores taken from a single deltaic depression, the magneto-lithological results point out the various ecosystems and sedimentary environments which arise in the approached area.

From the very beginning, a noteworthy conclusion is the generally strong correlation existing between the magnetic susceptibility and the contents of the main lithological components, *i.e.* the siliciclastic/mineral/detrital fraction (**SIL**) and the total organic matter (**TOM**); these usually cover (together) more than 95 - 97% of the total content, while the rest is occupied by the carbonates (**CAR**). To evaluate the correlation between the two categories of characteristics investigated for the core sediments, a scale with 6 steps [3 in the positive part, *i.e.* 0 - 1, and 3 in the negative part, *i.e.* 0 - (-1)] was used. In all the cases, the **SIL** lithological component is strongly *positively* correlated with the enviromagnetic parameter **MS**, the correlation coefficient (**r**) recording values within the interval 0.73 - 0.98 (a lower value for *DD 13-54* core, where **r** = 0.65), while the **TOM** component is strongly *negatively* correlated, with **r** ranging from (- 0.72) to (- 0.98), excepting the same core, where **r** = - 0.64. As regards the minor lithological component, the *carbonates* (**CAR**), the correlation with the magnetic parameter was either positive or negative, covering all the 3 main classes: *weak*, *moderate* and *strong*. Yet, it is worth pointing out the direct correlations for **CAR** *versus* **k** (0.30 - 0.94), and for **SIL** *versus* **CAR** (0.62 - 0.80), which were determined for the cores taken from the *eastern Meşteru - Fortuna Depression*, namely from the lakes *Băclăneşti* and *Fortuna*, as well as from the *Crânjală mid-channel*. These results argue the dominant detrital origin of the carbonate material which is present within the sediments penetrated by the four investigated cores.

Another remark regards the proxy characteristics of the enviromagnetic signature in connection with the lithological composition, with a special view to some methodological aspects. Thus, performing the correlation charts relating to **SIL** *versus* **k**, and **TOM** *versus* **k**, in some cases, samples placed farther from the trendline were identified. They were analysed again for their lithological composition, by chosing new samples from the original sediment slices. The results are very stimulating, the correlation coefficients becoming much higher; *e.g.*, for **SIL** *vs*. **k**, an increase from **r** = 0.59 (first analyses) to **r** = 0.80 (after 8 samples were analysed again) has resulted, for **TOM** *vs*. **k**, from **r** = - 0.59 to **r** = - 0.72, and for **CAR** *vs*. **k**, from **r** = 0.24 to **r** = 0.72. The effect was visible for the correlation of lithological component pairs, as well; *e.g.*, for **SIL** *vs*. **CAR**, a change from a weak *negative* correlation (**r** = - 0.13) to a nearby strong *positive* (!) one (**r** = 0.62) was recorded, for **TOM** *vs*. **CAR**, from **r** = - 0.15 to **r** = - 0.71, and for **SIL** *vs*. **TOM**, from **r** = - 0.96 to **r** = - 0.99. Other tests have also confirmed this very important inference concerning the use of the magnetic susceptibility as a proxy parameter to improve the quality of the lithological analyses, particularly with regard to optimize sampling the most adequate material from the sediment core slices. This methodology is feasible, of course, to be applied to sub-sampling the surficial sediments collected with a grab sampler. In this respect, a first test has already been successfully done, too.

As regards a general view on the magnetic susceptibility calibration of the sediments investigated in the *Meşteru - Fortuna Depression*, this time by extracting short cores from the lakes, the use of the **MS** *scale* applied till now in the various ecosystems and sedimentary environments of the *Danube Delta* and the *Razim (Razelm) - Sinoie Lagoonal Complex* (Rădan & Rădan, 2007) led to new and practical results. These data confirmed the good functionality of the scale and its usefulness to characterise the lake sediments in a vertical direction, in the analysed cases up to 61 cm depth beneath the water/sediment interface. As result of the calibration process application, all the 5 main **k** classes (from **I** to **Va**) were identified. Higher weights of the classes **I** and **II** (together) were determined for the cores collected from the lakes *Cuteţchi* (*DD 10-177*; 79%) and *Băclăneşti* (*DD 13-61*; 55%), followed by *Tătaru* (*DD 12-03*; 32%), while greater percentages for the highest main classes (**IV** and **Va**) were identified for the sediment slices of the two cores taken from the *Crânjală mid-channel* (*DD 13-54* and *DD 13-55*; 100% in both cases). These were followed by the *core DD 11-210* sampled from the silted zone relating to the *Crânjală Canal* (within the *Fortuna Lake*), the total percentage for the classes (**IV**+**Va**) reaching 50%, a big weight (44%) showing also the class **III**. These results suggest that the vertical distribution of the magnetic susceptibility of the core sediments, nevertheless, integrates the particular characteristics of the sedimentary environments from lakes, to a certain extent, protected by the direct *Danubian* influence *versus* the lakes which are/or were directly influenced by the riverine supplies (see, *e.g*., Rădan & Rădan, 2011).

Although the cores were very short (less than 61 cm), they brought an interesting information on the respective sediment sequences, providing, anyway, more information than the bottom sediments taken with the grab sampler. A good example is the *Fortuna Lake*, in which case the two short cores (*DD 11-210* and *DD 13-56*) collected from the "*yellow zone*" of the **MS** map, that is the "band" in which the surficial sediments are calibrated to the **k** class **III** (**k** values range: 75×10^{-6} - 175×10^{-6} SI), show in their upper half (first ca. 18 cm) **MS** values assigned to **k** class **Va** (higher than 275×10^{-6} SI), and **IV** (range 175×10^{-6} - 275×10^{-6} SI). The respective maxima represent an evolution phase relating to the detrital inputs, which could be found within the history of the *Crânjală Canal* activity, possibly around the years '80, when it has acted at a higher discharge. Actually, the other two cores (*DD 13-54* and *DD 13-55*), taken in 2013 from this canal, which had made - along a short distance - the connection between the *Sulina Branch* and the *Fortuna Lake*, point out this assertion, the 27 - 32 cm thick sediments being entirely calibrated to the high **k** classes **IV** and **Va**. The lithological components, particularly the siliciclastic/detrital, and the organic matter fractions - directly (maximum zones/high **SIL** contents), and indirectly (minimum zones/low **TOM** contents), respectively -, support this inference. If more information data are brought with regard to the time interval when the canal has acted at a maximum discharge, a *sedimentation rate* calculation - based on the magneto-susceptibilimetric model - relating to the *Fortuna Lake* southern area could be possible. When such conditions were fulfilled, as in the case of the western *Meşteru - Fortuna Depression*, particularly concerning the *Tătaru Lake*, the sedimentation rate was determined (*i.e*., 1.9 cm/year).

The magneto-lithological data provided by the short cores collected from different sedimentary environments and ecosystems of the *Meşteru - Fortuna Depression* are very important in the context of deciphering the spatial and temporal evolution of the deltaic geosystem. Several examples have been already presented, and they support a series of conclusions and are resulting in interesting inferences, which have partially been pointed out above. Another one regards the case of the *Băclăneşti Lake*, where the taken core (*i.e*., *DD 13-61*) has clearly illustrated - by means of the vertical distribution of the *proxy enviromagnetic parameter* (**MS**) and of the main *lithological components* (**SIL** and **TOM**) - the existence of two different sediment sequences (at least, in the first 52 cm beneath the water/sediment interface). Consequently, the problem of the influences supported by this lake over the time must be taken into consideration. It seems a sudden change of the sedimentation regime has taken place. It could be said the lower sequence corresponds to a period characterised by a more agitated hydrological regime, with stronger fluvial influences. This action has almost suddenly closed down, when a barrier occurred, which has isolated the lake area from the supplies, the lake passing to a regime similar to that from nowadays.

As regards the spatial evolution of the deltaic geosystem, such an approach will be initiated by a parallel analysis of the magneto-lithological models achieved for the short cores collected in the *Meşteru - Fortuna Depression* (commented in the present paper); to this, a number of cores taken from other three important *Danube Delta* sub-units, *i.e*. the *Matiţa - Merhei*, *Gorgova - Uzlina* and *Lumina - Roşu Depressions*, will be added. The results of the study of the 17 short cores, which have already been investigated in the specific laboratories for the magnetic susceptibility and the lithological composition of their sediments, are to be the subject of the following parts of the composite paper. It seems the last one will be adequate for including a synopsis within the attempt to contribute towards deciphering the spatial and temporal evolution of the deltaic geosystem.

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