ENVIRONMENTAL MAGNETIC SIGNATURES RECOVERED FROM LAKE SEDIMENTS IN THE DANUBE DELTA (ROMANIA)

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Abstract. Numerous multidisciplinary cruises carried out in the Danube Delta during a period of time spanning more than two decades (i.e., 1977 – 1999), allowed the acquiring of a large magnetic susceptibility (**MS**) data base. Environmental *magnetic signatures* printed in bottom sediments, sampled from lakes located within two depressions of the northern fluvial belt of the delta plain, are deciphered and commented in the paper. Two distinct cases are under attention: *confined deltaic environments*, represented by lacustrine areas situated far from the main distributaries of the Danube Delta (i.e., Depression Matita – Merhei), and *dynamic deltaic environments*, directly and strongly influenced by the River, consisting of lakes connected by short channels to the main distributaries (i.e., Depression Mesteru – Fortuna). In the former case, the *magnetic signature* is expressed by low **MS** values/**k** (usually below $10x10^{-6}$ Slu., and negative **k** values), suggesting an "*area under no natural or anthropogenic stress*". In the latter, the *magnetic signature* is defined by high and very high **k** values (e.g., between $369x10^{-6}$ - $581x10^{-6}$ Slu.), evidencing an "*area under natural and/or anthropogenic stress*". A peculiar situation is presented, in order to demonstrate the ability of the **MS** as a magnetic indicator of the (negative) *anthropogenic impact* on deltaic ecosystems. It refers to the water system of the Depression Mesteru – Fortuna, where, after cutting of the "Mila 36" Channel in 1984, several lakes, and particularly L. Mesteru and L. Lungu, became strongly influenced by the Danube supplies, undergoing an intensive process of filling up with sediments. Finally, the good resolution of the applied rock magnetic technique, based only on magnetic susceptibility measurements – *rapid*, *simple*, *non-destructive* and *inexpensive* – performed on bottom sediments, is pointed out.

Key words: magnetic susceptibility, bottom sediment, deltaic ecosystem, sedimentary environment, anthropogenic impact, environmental magnetism, Danube Delta.

1. INTRODUCTION

In 1977–1978, in addition to the geological, geochemical and biological investigation tools used in the *Danube Delta* (*DD*) and the *Razim – Sinoie lagoonal complex* (*RSLC*), the application of the rock magnetism and of magnetic survey has been attempted. The main objective of the multidisciplinary research, started in 1971, was the complex study of the bottom sediments and the evaluation of the economic potential of the *DD* and *RSLC*, hence other aim than a geo-ecological one (Mihăilescu *et al.*, 1972–1991; unpublished scientific reports, *Archive of the Geol. Inst. of Romania*). Of course, this approach has not excluded the implicit record of the environmental context in the above-mentioned area. In this respect, it is worthy to remember here the case of the ***environmental magnetism***. It is generally accepted that "*the first explicit description of environmental magnetism as a distinct field did not appear until 1980*", when Thompson and his co-workers showed in an article published in *Science* how mineral magnetic parameters can be used in a wide range of environmental studies (Verosub & Roberts, 1995; see also Dekkers, 1997). However, "*many types of studies* – as Verosub & Roberts (1995) think about – *that are now classified as environmental magnetism have been in existence for some time*". It is equally the case of the magnetic susceptibility data achieved – in the fore-specified frame – on bottom sediments from the Danube Delta and the Razim–Sinoie lagoonal complex. The present paper supports this assertion. For another example of categorizing as *environmental magnetism* such results, obtained around two decades ago, the reader is referred to Rădan *et al.* (1995).

Since 1992, geo-ecological aspects, related to the *DD* and the *RSLC*, have directly been approached in the framework of the monitoring program dedicated to the examination and supervising activity focussed on the various environments within the Danube – Danube Delta – northwestern Black Sea macrosystem (Panin *et al.*, 1992).

Some comparative data, resulting from the numerous cruises carried out during a long period of time (1977–1999), are briefly discussed further. The ***environmental magnetic signatures*** printed in bottom sediments, which are deciphered and commented in the present paper, concern the lakes from the northern part of the fluvial delta plain.

The impact of the human activities (e.g., engineering works, such as the cutting of new channels) on the deltaic ecosystems led to certain environmental changes. The ability of the ***magnetic susceptibility*** as *environmental proxy parameter* is argued by the results presented below.

2. METHODS

Bottom sediments have been collected, using grab samplers (Van Veen type), in numerous stations, located within the main lakes and channels of the various interdistributary depressions of *DD*, and also within the *RSLC*. The samples were divided for different analyses, on the board of the boat. The sub-samples for *magnetic*

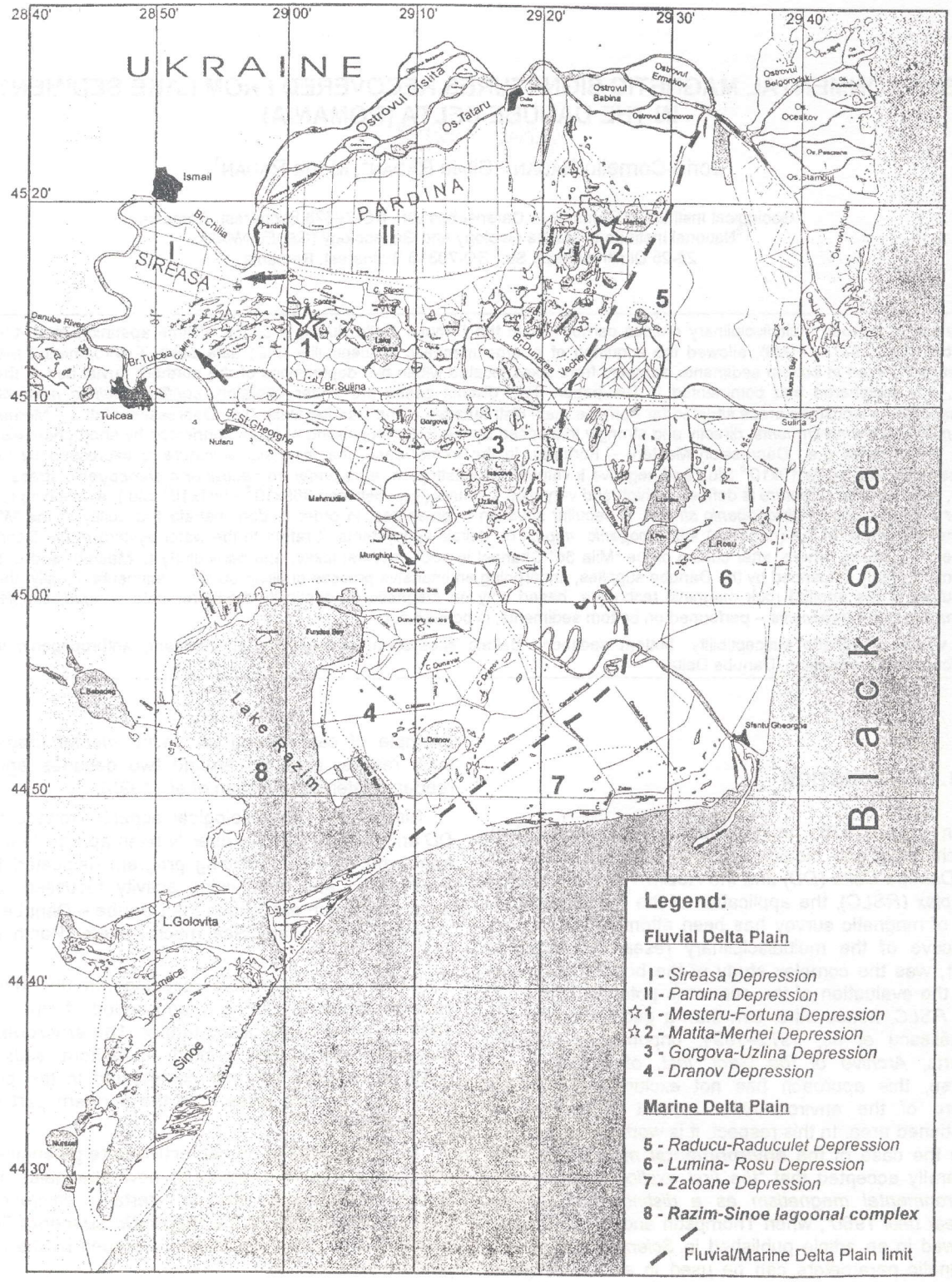

Fig. 1. General map of the Danube Delta and the Razim – Sinoie lagoonal complex. Location of the areas under attention in the paper: 1 - Depression Mesteru – Fortuna; 2 – Depression Matita - Merhei (shown also by stars). *Note*: The two arrows mark the C. "Mila 36" (see text).

susceptibility measurements have usually originated in the first 5 cms below the water/sediment interface.

The *magnetic susceptibility* (**MS**) was measured on KLY-1 and/or KLY-2 Kappabridges ($4.8x10^{-8}$ Slu. sensitivity), in the palaeomagnetic laboratory of the Geological Institute of Romania.

3. RESULTS

During numerous cruises performed after 1977, a huge quantity of magnetic susceptibility data was obtained on various types of sediments (muds, sometimes rich in vegetal detritus, silty muds, silty sandy muds, muddy sands), sampled from all main hydromorphological units of the Danube Delta and the Razim–Sinoie lagoonal complex.

To demonstrate the capability of the ***magnetic susceptibility*** as a *proxy parameter* in distinguishing *confined* and *dynamic deltaic ecosystems*, lakes from two depressions only (i.e., *Mesteru–Fortuna* and *Matita–Merhei*) are chosen here for analysis. Clearly distinct types of connections with the Danube Delta distributaries characterise them. The two depressions are located within the northern *Fluvial delta plain* (**1** and **2**, in Fig. 1; marked also by stars).

Depression Matita–Merhei

The lakes of this depression are situated within the eastern part of the north fluvial delta plain, far from the Delta distributaries (i.e., *Chilia Br.* and *Sulina Br.*) (**2**, in Fig.1). As a consequence, carbonatic-organic sediments prevail, and sediment accumulation rate is very low (Rădan *et al.*, 1997).

The ***magnetic susceptibility***, working as a very suggestive proxy parameter for this type of sedimentary environment, has recorded the most numerous very low **k** values, and equally the lowest, in a suite of lakes within a large sector (actually a depression) of Danube Delta.

Bottom sediments, sampled from lakes showing more confined environments, are rich in subaquatic vegetation (organic muds, porous and slightly cohesive). The **MS** data resulting from the *cruise 1978* reveal very low **k** values – most of them **negative** – particularly in the *lakes Bogdaproste*, *Trei Ozere*, *Polideanca*, *Poludonca*, *Ciorticut* and *Merhei* (Figs 1, 2). Relatively higher magnetic susceptibilities were measured in the *L. Babina* (up to $23x10^{-6}$ Slu.) and *L. Matita* (up to $76x10^{-6}$ Slu.), especially within the channel mouth zones, with coarser muds and sparse in vegetal detritus.

The ***magnetic signature*** – characteristic for these lakes, located within the *Depression Matita-Merhei* – is preserved during the two decades spanning the period since the *cruise 1978* till the *monitoring phase* 1999. The higher **k** values, recorded in several lakes, in some of the monitoring phases (*MPh*), e.g. in the *L. Merhei* ($37x10^{-6}$ Slu., in the *MPh-1995*)), *L. Babina* ($142x10^{-6}$ Slu., in the *MPh-1997*, and $79x10^{-6}$ Slu., in the *MPh-1999*), *L. Trei Ozere* ($71x10^{-6}$ Slu., in the *MPh-1997*) and *L. Bogdaproste* ($75x10^{-6}$ Slu., in the *MPh-1997*), are explained by local causes; particularly, the sampling stations were placed within the channel mouth zones, richer in coarser sediments.

It can be concluded that in this area – situated far from the Danube Delta distributaries – the ***environmental magnetic signature*** has remained basically unchanged. The absence of any *anthropogenic influence* or of a *natural stress* on this deltaic ecosystem is thus magnetically attested.

Depression Mesteru–Fortuna

The lakes of this depression are situated within the western part of the north fluvial delta plain, between *Chilia* and *Tulcea & Sulina Branches* of the Danube Delta (**1**, in Fig. 1).

This area became strongly influenced by the Danube water supply, since 1984, after cutting of a short channel between the *Tulcea* and *Chilia Branches* (*C. "Mila 36"*, marked by arrows in Fig. 1). As a consequence, the *lakes Mesteru, Lungu*, and partially *Tataru* underwent an intensive process of filling up with sediments.

The magnetic susceptibility measurements, carried out on bottom sediments before and after the above-mentioned human intervention, clearly reflect the enhancement of the filling up process in this zone. So, the **MS** determined on samples collected from the *L. Lungu* and *L. Mesteru*, during the *cruise 1980* (Fig. 3), shows **k** values lower than $137x10^{-6}$ Slu., and below $88x10^{-6}$ Slu. (with an exception, locally explained), respectively. The sediments sampled in the two lakes during the *1987 cruise*, therefore after the digging of the channel "*Mila 36*", have yielded **k** values up to $748x10^{-6}$ Slu. (*L. Lungu*), and up to $334x10^{-6}$ Slu. (*L. Mesteru*). A new confirmation of the ***modified*** *magnetic signature*, according to the change of the sedimentary environment, is obtained from the ***MS*** *monitoring phases 1992–1997*. The **k** values determined on bottom sediments, collected during this period, attain $471x10^{-6}$ Slu. (*L. Lungu*), and $450x10^{-6}$ (*L. Mesteru*). This indicates that the depression is an "***area under anthropogenic stress***". The situation is not the same for the *Lake Tataru*, where the magnetic susceptibility has not recorded such important modifications. So, the highest **k** value recorded after 1984 was $114x10^{-6}$ Slu. (*MPh-1998*), in a sector in which the **k** values measured on sediments sampled during the *cruise 1980* have not exceeded $87x10^{-6}$Slu. Actually, the *L. Tataru* is a lake with intermediate conditions , e.g. between the *lakes Bogdaproste, Trei Ozere, Merhei* (see the previous subchapter, concerning the *Depression Matita-Merhei*), and the *lakes Mesteru* and *Lungu*. The magnetic susceptibility values, provided by the bottom sediments, stand for quantitative arguments in this respect.

As regards the *Lake Fortuna*, this receives large amounts of sediments from the River Danube (particularly, from *Sulina Branch*) through a short channel (*Crânjala*) (Figs 1, **4**). The situation is relatively different in comparison with that previously discussed, related to the *L. Mesteru*, *L. Lungu* and the *C. "Mila 36"*; the *C. Crânjala* has existed as a (short) natural channel since a very long time, later being ameliorated for navigation.

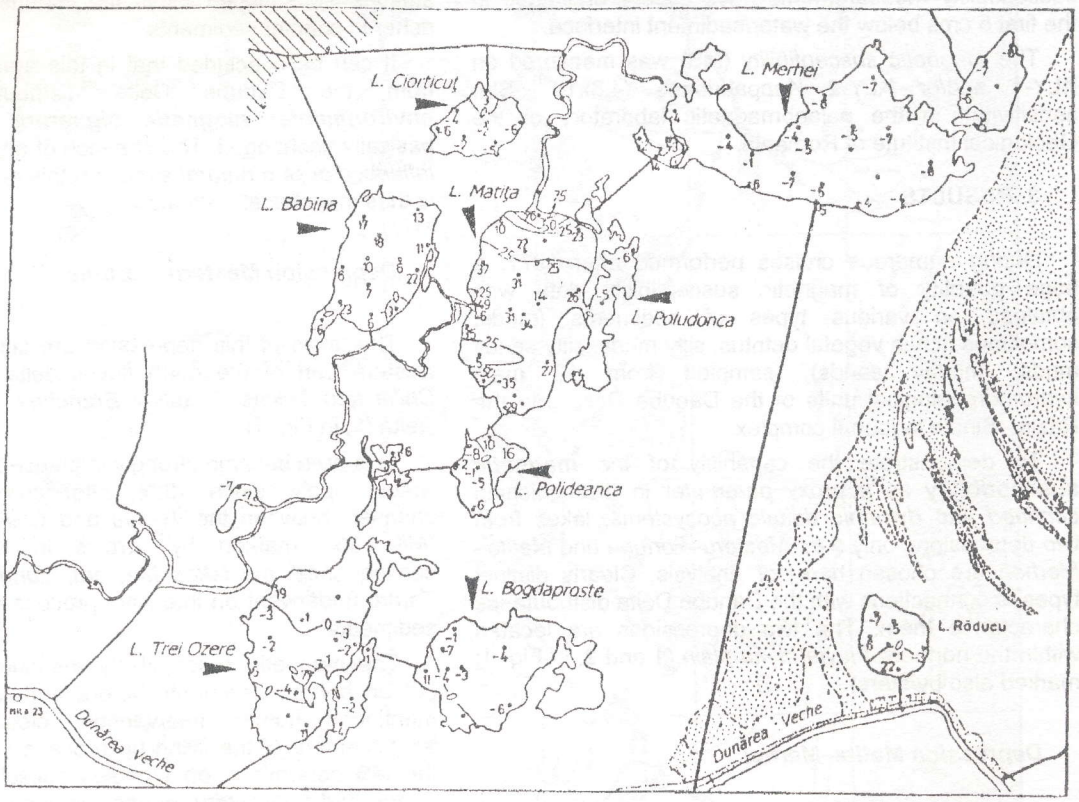

Fig. 2. Magnetic susceptibility (**MS**) data for lakes from the Depression Matita-Merhei (based on bottom sediments sampled during the cruise 1978). *Note*: The **k** values shown on the contours of the **MS** maps or close of the sampling stations must be multiplied by 10^{-6} Slu. (e.g., - $25x10^{-6}$ Slu. - and ○ $31x10^{-6}$ Slu.).

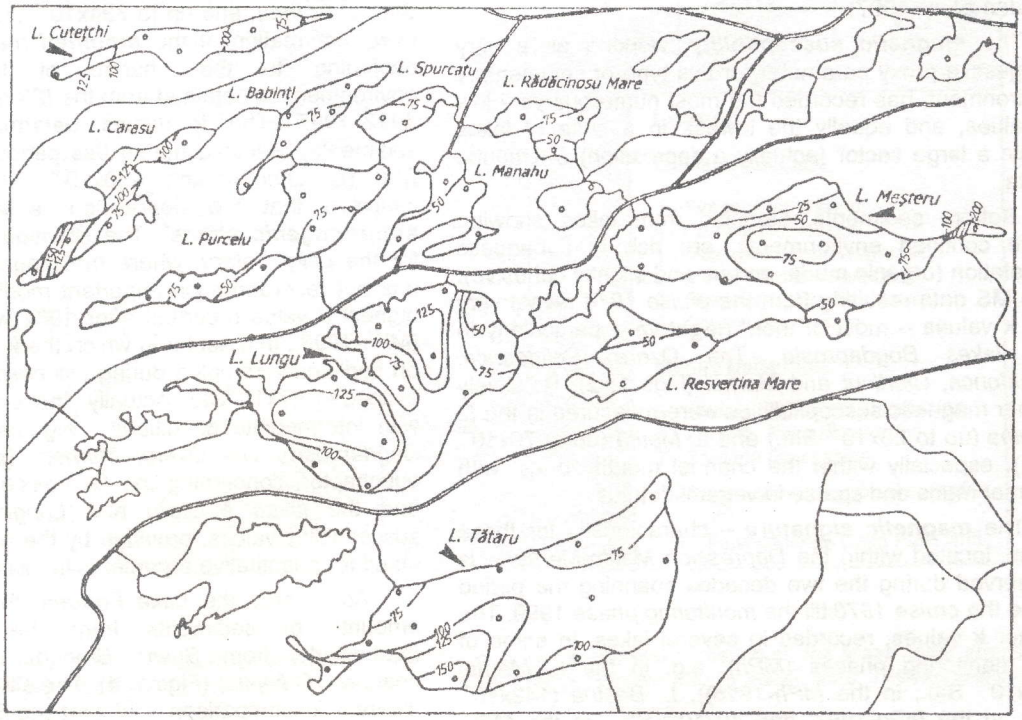

Fig. 3. Magnetic susceptibility (**MS**) data for lakes from the western part of the Depression Mesteru-Fortuna (based on bottom sediments sampled during the cruise 1980). Note: The **k** values shown on the contours of the **MS** maps must be multiplied by 10^{-6} Slu. (e.g.,-$100x10^{-6}$ Slu.-).

The **MS** anomaly (**k** values up to $581x10^{-6}$ Slu.), revealed by the contour map (Fig. 4), constructed on the basis of the 1980 data, clearly reflects the morphology of the underwater fan zone of the solid discharge provided by the *River Danube*, through the *channel Crânjala*.

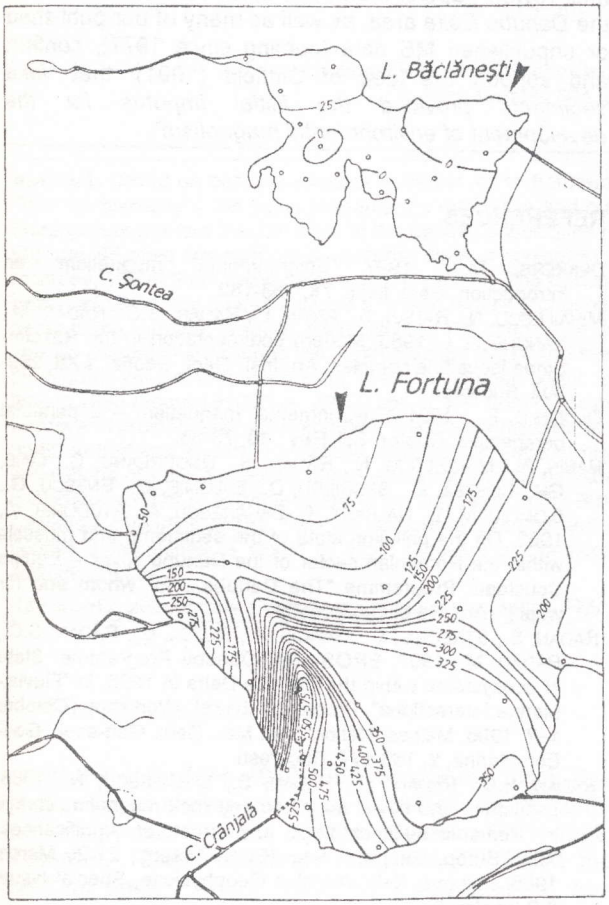

Fig. 4. Magnetic susceptibility (**MS**) data for lakes from the eastern part of the Depression Mesteru - Fortuna (based on bottom sediments sampled during the cruise 1980). *Note*: The **k** values shown on the contours of the **MS** maps must be multiplied by 10^{-6} Slu. (e.g., ---300x10^{-6} Slu.---).

All the other results confirm the main peculiarities of this initial ***MS map***. For example, on the sediment fan developed into the lake at the channel mouth, a **k** value of $454x10^{-6}$ Slu. was recorded in the *cruise 1987*; in the *monitoring phases 1992–1998*, in sampling stations with coarse siltic muds, sometimes fine muddy sands underlying them, high **k** values were determined, too (e.g., $414x10^{-6}$ Slu., in the *MPh-1997*, and $369x10^{-6}$ Slu., in the *MPh-1998*). Therefore, this zone could be considered an "***area under natural and anthropogenic stress***". On the other hand, in the northern part of the *Lake Fortuna*, towards the *channel Sontea*, hence not close of *Danube* direct supplies, all the **MS** results show lower **k** values, between $51x10^{-6}$ - $96x10^{-6}$ Slu. (*cruise 1980* and *cruise 1987*); the data are confirmed by the *MPh legs 1992-1998* (e.g., $94x10^{-6}$ Slu., in the *MPh-1998*, in a station with non-cohesive muds). Moreover, within the *Depression Mesteru - Fortuna* there are several lakes (i.e., *L. Cutetchi*, *L. Durnoi*, *L. Baclanesti*; Fig. 1), which are not significantly affected by the River Danube.

Therefore, a comparative analysis of the **MS** results, obtained on bottom sediments originated in the main types of deltaic ecosystems – related to more confined environments (connected with the forenamed lakes), and to environments strongly influenced by the Danube (with reference to *L. Mesteru*, *L. Lungu* and *L. Fortuna*) – is feasible even in the framework of the same depression. The capability of the **MS** as a *proxy environmental parameter* to differentiate these two categories of lakes is clearly demonstrated by means of the **k** values recorded in sediments collected in the *cruise 1980* or in the *cruise 1987* (*L. Baclanesti*, only), and in the *monitoring phases 1993–1998*. For instance, the sediments rich in fine vegetal detritus, sampled from the *L. Baclanesti* during the *cruise 1980,* indicated negative **k** values, and positive ones up to $45x10^{-6}$ Slu. (see **k** contours, in Fig. 4). Comparable **k** values (with one exception, i.e. $77x10^{-6}$ Slu.) were measured on samples taken during the *cruise 1987*. The ***magnetic signature***, recovered from sediments, reveals its preservation in the period 1993–1997; the ***MS*** *monitoring* confirms a low level of the susceptibilities, with values below $10x10^{-6}$ Slu. In general, the same observations concerning the absence of an anthropogenic impact on the sedimentary environment could be accepted with regard to other two lakes, *L. Durnoi* and *L. Cutetchi*. The ***magnetic signature*** is however expressed by higher **k** values as compared with *L. Baclanesti* (not including the above-mentioned exception). So, the bioturbated loose muds, rich in fine vegetal detritus, sampled in the *L. Durnoi* and the *L. Cutetchi*, have provided **k** values mostly below $61x10^{-6}$ Slu. and $71x10^{-6}$ Slu. respectively, in the *cruise 1980* or in any of the *monitoring phases* (1993–1996, *L. Durnoi*; 1993–1997, *L. Cutetchi*). Concerning the latter, in the *cruise 1980* and in the *MPh-1998*, few higher **k** values were recorded (e.g., $139x10^{-6}$ Slu. and $119x10^{-6}$ Slu.), yet locally explained.

4. DISCUSSION AND CONCLUSIONS

The *magnetic susceptibility* (**MS**) results, selected for presentation in this paper from a large data bank which exists for the *Danube Delta* (*DD*) and the *Razim - Sinoie lagoonal complex* (*RSLC*), represent evidence for the usefulness of the **MS** in studies of lake sediments. And this is so, because this *environmental magnetic parameter*, among others [e.g., anhysteretic remanent magnetisation (*ARM*) and anhysteretic susceptibility (k_{ARM}), isothermal remanent magnetisation (*IRM*) and saturation *IRM* (*SIRM*), saturation magnetisation (M_s), saturation remanence (M_{rs}), coercivity (B_c), coercivity of remanence (B_{cr}), and so on], can be an indicator of temporal variations in deposition of the lithogenous material on lake bottom.

The **MS** measurements performed on sediments, sampled from lakes of two depressions in the northern *fluvial delta plain*, on the occasion of several legs carried out over more than two decades (1977-1999), firstly have proved that the **MS** is a sensitive *sedimentological index*. The connections between the **MS** results and the structure of the surrounding sand ridges, suggesting the continuity below the immerged area – data particularly with regard to the *RSLC* – were exemplified and pointed out in various papers, abstracts and oral presentations (e.g., Rădan *et al.*, 1981, 1988, 1990; Mihăilescu *et al.*,

1983). Two sedimentological aspects have quantitatively been argued here, namely:

- connections between the **MS** values (**k**) and the types of bottom sediments (e.g., muds, muds rich in vegetal detritus, silty muds, fine muddy sands);
- connections between **MS** data and the dynamics and deposition processes in sedimentary environments.

Such connections enable important insights about the deltaic ecosystems and make feasible identification of specific *magnetic signatures*.

Two significant cases have been under attention in the paper. The first of them concerns *confined environments*, represented by lakes located far of the Danube Delta distributaries (e.g., the lakes situated within the *Depression Matita-Merhei*). The ***magnetic signature*** is expressed by low **MS** values (usually, below $10x10^{-6}$ Slu., and negative **k** values). It characterises an "***area not-stressed naturally or anthropogenically***".

The second case regards *environments strongly influenced by the River Danube*: the lakes are connected by short channels to the Delta distributaries (e.g., *L. Fortuna* and *C. Crânjala*, within the *Depression Mesteru-Fortuna*). The ***magnetic signature*** – printed in bottom sediments – is defined by high and very high **k** values (e.g., $369x10^{-6}$ Slu., $414x10^{-6}$ Slu., $454x10^{-6}$ Slu., $581x10^{-6}$ Slu.). This characterises an "***area under natural and anthropogenic stress***".

In addition, the special situation of the *lakes Mesteru* and *Lungu* (*Depression Mesteru-Fortuna*) has been presented. Both lakes are located within a zone which has become strongly influenced by Danube supplies since 1984 only, after cutting of a new channel in the area. This case has yielded an extremely suggestive example of using the **MS** of bottom sediments as source of quantitative information concerning ecological and environmental changes within a lacustrine area. Therefore, *magnetic indicators* of the impact of the human activities on deltaic ecosystems have been detected in lake sediments.

Such a method requires to perform sampling of bottom sediments and **MS** measurements on them, in the same area, in successive phases. The **MS** results, obtained on the basis of the *cruises 1978*, *1980* and *1987*, and of the *monitoring phases 1992-1999*, made this approach possible. Consequently, the ***transformation*** of the area comprising the lakes *Mesteru* and *Lungu* into an "***area under anthropogenic stress***" was revealed. It is a clear example of a ***negative*** impact on a *deltaic environment*, created by cutting of a channel (i.e. "*Mila 36*") between two Delta distributaries (i.e. *Tulcea* and *Chilia Branches*). An increased water circulation has been produced, as well as an enhanced supply of sediments, leading to an intensive process of filling up of the forenamed two lakes.

On the other hand, the **MS** records, practically unchanged in repeated phases performed in lacustrine areas not affected by anthropogenic influences, proved a good resolution for the applied rock magnetic technique.

Finally, it must be added that this investigation instrument, which usually is integrated with other methods of environmental magnetism, is relatively *rapid*, *simple*, *non-destructive* and *inexpensive*, as Oldfield (1991) and Verosub & Roberts (1995) pointed out in their review papers. Moreover, these results achieved in the *Danube Delta* area, as well as many of our published or unpublished **MS** data (coming since 1977), confirm and support the idea of Oldfield (1991), that "*lake sediments provided the initial impetus for the development of environmental magnetism*".

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