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THE EVOLUTION OF HELIOTHERM PHENOMENON IN THE KARSTOSALINE LAKE URSU FROM SOVATA, ROMANIA

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Abstract: In the present study we have set to highlight some interesting aspects regarding spatial and time distribution of heliotherm phenomenon in one of the most representative lakes in Romania, namely Lake Ursu (Bear) in Sovata. After some details regarding natural processes of existence and evolution of the mentioned lake, we have presented a few methods and techniques used in data collection and analysis. The extended period of time (nearly 10 years) of the current research, combined with the ones achieved before, have made it possible to interpret the heliotherm phenomenon in many ways: on short-term (daily), seasonal and multiannual one, for mid and long-term. We can observe a clear dependence of the intensity of the phenomenon not only on solar radiation but also on salt distribution, season and anthropic influence. Also, in contrast to the beginning of the 20th century, an unquestionable decrement of the phenomenon over time can be seen. Using GIS model in the case of Lake Ursu has made it possible for the identification of the heliotherm horizon not only in longitudinal but also on three-dimensional profile. The conclusions reveal the necessity of taking some measures to protect lacustrine environments and the perpetuation of the heliotherm phenomenon by using better ways of extracting resources and doing seasonal surveys.

Key words: karstosaline lake, halocline, temperature, heliothermy, GIS, spatial evolution, conservation

1. INTRODUCTION

The study of physico-chemical parameters, and especially of the heliotherm phenomenon in the case of different categories of salt lakes has been a priority to many scholars because of the economic potential (touristic and balneary valorification) and the medical one (treatments and recovery in the case of different diseases).

At the end of the 19th century it was approached the salt waters heating phenomenon with observations made on a salt basin near Besançon, France, where at a depth of 1.35 meters there was a temperature of 62°C, without any scientific explanation for this kind of phenomenon (Telegdi-Roth, 1899).

Afterwards, Kalecsinszky experimentally proved and explained the way in which salt waters heat under the effect of solar radiation, realising a series of observations and measurements on Lake Ursu (Sovata) for the first time in 1901 (Kalecsinszky, 1901). Unlike previous researchers, he has demonstrated that the existence of a thin layer of freshwater or slightly salty at the surface of the lakes lying on the hipersaline horizon from deepness, was the compulsory condition for the significant growth of temperatures at 1.5-3 meters deep. The researcher has named Lake Ursu and other salt lakes from Sovata heat "reservoirs" or "hot lakes".

Later on, there have been unfolded a series of terrain surveys and measurements regarding this phenomenon and used different locations and salt lakes in Transylvania (Maxim, 1929, 1931, 1937, 1942). He was the first one who confirmed the existence of this phenomenon and named it "heliothermy".

In 2002, Touchart defined the existence of a warmer water layer between two layers with lower temperatures "paradoxical structure" or "thermal anomaly".

On a global level, researches have emphasised the presence of heliotherm lakes on all continents, with a higher frequency between the parallels of 30°S and 67°N (Sonnenfeld & Hudec, 1980). One of the heliotherm lakes has appeared in **warm climates** of the Globe because of water evaporation and saline concentrations (Smith, 1947; Eckstein, 1970; Melack & Kilham, 1972; Por, 1972; Cytryn et al., 2000).

Other lakes have appeared in the **temperate zone**, connected with either the salt massifs (karstosaline and anthroposaline lakes – salt mines or other fallen minerals) or water evaporation and salt concentration.

Heliotherm lakes have been identified in Central, Western and East Asia: in Siberia – Lake Kuchuk in the Kulunda Steppe; in the Karakum Desert – Lake Sultan-Sandzhar; in the area of inferior Volga river – Lake Chapchachi; in the Tuva region – Lake Dus-Khol; on the eastern side of Lake Baikal – Lake Selenga; in the Aralo-Caspian Basin – Lake Inder; in the Republic of Kazakhstan – Lake Shunet, Lake Tuzluk and Lake Razval. The last three lakes are the most representative heliotherm lakes, being situated on the ancient exploitations from the saliferous massif of Ilek (Dzens-Litovskii, 1953, 1968; Sonnenfeld & Hudec, 1980; Gâştescu & Breţcan, 2009). Also, the heliotherm lakes in Japan were studied by Yoshimura & Miyadi (1936), Yoshimura (1937) – Lake Sinmiyo and Miyake, or by Touchart & Ishiguro (1999), Touchart (2002) – Lake Kaiike.

In *America* there has been many lakes from this category recognised in the Province of British Columbia (Hudec & Sonnenfeld, 1974, 1980; Northcote & Hall, 2010), in the United States of America (Hot Lake formed in abandoned sulphate mine), or in Venezuela (Laguna Pueblo).

In *Europe* there are many highly mineralized lakes, with a frequency on the salt massifs from Former Yugoslavia (Sonnenfeld & Hudec, 1980), Germany, France, Romania, etc. (Gâştescu & Breţcan, 2009), with some of them developing the heliotherm phenomenon.

There were also identified heliotherm lakes at **high latitudes** on the Globe, such as the ones in northern Canada, including the islands – Ellesmere Island etc. (Sonnenfeld & Hudec, 1980) or the ones in Antarctica (Wilson & Welllman, 1962; Ragotzkie & Likens, 1964; Goldman et al., 1967; Bydder & Holdsworth, 1977; Spigel & Priscu, 1998; Gibson, 1999; Gibson & Andersen, 2002).

In *Romania* the salt lakes come under some particular genetic categories, such as *anthroposaline lakes*, *karstosaline lakes* (these two types of lakes being situated in saliferous areas – Har et al., 2010), *lakes formed due to climatic conditions* (water evaporation and salt concentrations) and *maritime limans* (with high salinity levels because of the marine waters and climatic conditions).

Only the first two categories of lakes are found in the geographic area of the Transylvanian Basin, as the above-ground appearances of salt are quite frequent: the areas from Sovata, Ocna Sibiului, Ocna Mureş, Turda, Cojocna, Sic, Ocna Dej, Jabeniţa. Nowadays, there are 41 salt lakes in these zones, seven of them being karstosaline ones (five in Sovata and two in Ocna Sibiului), and the other 34 being situated in ex-underground or surface salt mining areas (Fig. 1).

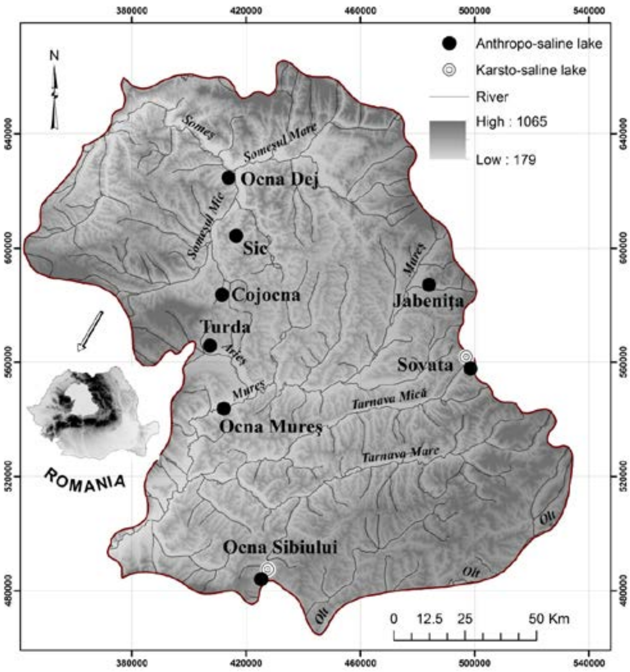

Figure 1. Location of saline lakes in the Transylvanian Basin.

The presence of heliotherm phenomenon was observed in the case of many salt lakes diapirs in the Transylvanian Basin, whether they are anthroposaline or karstosaline kind of lakes. However, the amplitude of this phenomenon remains quite low in many cases (up to 5°C). On the other hand, the karstosaline Lake Ursu (Sovata) remains probably one of the most important heliotherm lakes in Europe. The difference in temperatures between the heliotherm layer and the surface of the lake exceeds in each estival season 12^{o}C, and even reaching 25°C.

The studies concerning the quality of saltwater lakes has started a little bit later (19^{th} century). These were performed by physicians, chemists and biologists, at the request of salt mines administration, aiming towards the planning of tourist or treatment units. There were analysed several physical and chemical parameters (temperature, salinity) or the biotic composition of water in the saline lakes (Maxim, 1929, 1931, 1937; Gâştescu et al., 1985).

In the first half of the 20^{th} century, researches were intensified: Kalecsinszky (1901 – Sovata), Schafarzik (1909 – Sovata), Viski (1911 – Turda), Maxim (1929, 1931, 1937, 1942; Sovata, Sic, Ocna Sibiului, Turda) etc. Most of these researches concentrated on the study of physical and chemical parameters, but also on the dynamics of lake basins.

In the second half of the 20th century, the first complex study was published by Gâştescu (1963 and 1971) and later by Alexe et al., (2006), Alexe (2010). Other studies, concerning the dynamics of lake basins and salt massifs, were written by Pişota, (1960) and Popa (1960) at Sovata, Bobeică (1969 - Ocna Sibiului), Panait & Bobeică (1968 - Sovata), Panait et al., (1969 - Sovata), Pânzaru (1970, 1971, 1974, 1975, 1977, 1982, 1986a, b - numerous locations in Transylvania), Trică (1983 - Sovata), Şerban et al., (2005).

2. STUDY AREA

The basin of Sovata is a combe developed and formed by erosion along the diapiric anticline, as a result of the epigenetic sinking processes of the Târnava Mica River and its tributaries in the diapiric folds (Fig. 2).

Because of the lithostatic pressure, salt has migrated to the edges, where the thickness of the deposits and vertical stress were lower. Thus, in its ticklish path to the edges and to the surface, salt has emerged the Quaternary cover deposits, sometimes to a vertical position, forming the so called diapiric folds (Fig. 2). These folds are well emphasised on the eastern border of the basin, running north-west and south-east on the alignment of Şieu-Sovata-Praid-Odorheiu Secuiesc localities, with a spectacular outcropping bed in the case of ”Salt Mount from Sovata”.

The basin from Sovata-Băi, which includes not only the lakes but also the salt massif, is drained by Pârâul Sărat (the Sărat Rivulet), which collects all defluent discharges from the lacustrine complex Ursu - Aluniş. The Topliţa and Auriu rivulets, as well as the Paraschiva rivulet, partially supply and maintain the briny water layer at the surface of Lake Ursu. These three rivulets were stabilized and taken in the sewage network of the facility, so that they should not unbalance the peculiar phenomena in Lake Ursu and avoid its silting.

The karstosaline types of salt lakes (dissolving salt and land subsidence) formed on the diapir from Sovata are Lake Roşu, Lake Verde, Lake Ursu and Lake Aluniş. We can add the isolated reservoirs with a dissolution sinkholes origin, such as Lake Mierlei and Lake Şerpilor (at present a eutrophic swamp).

Lake Negru is the only anthroposaline lake and it is situated on the southern side of the Salt Mount, having its origin in an old excavation from the roman period.

Upstream Lake Ursu there were established two freshwater lakes for recreation and fishing (Lake Paraschiva and Lake Tineretului), the latter being drained because of the accelerated salt dissolution and freshwater seeping in 1997. Regarding the formation of Lake Ursu in the second half of the 19th century, there was a grass land at the confluence of Topliţa and Auriu rivulets. Alongside the individualization of the Sărat rivulet water-course and the deepening of the two forementioned rivulets led to the contact between water and the underground salt. The accelerated salt dissolution created a huge abruption, causing a landfall.

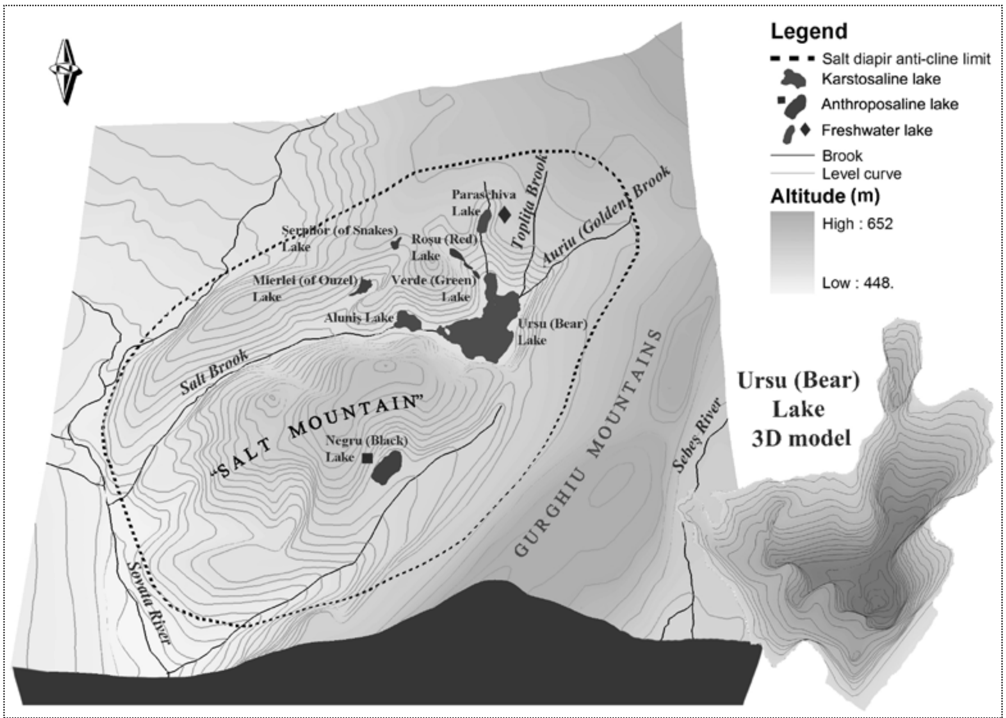

Figure 2. Diagram of the diapiric anticline from Sovata.

Table 1. Morphometric elements of Lake Ursu from Sovata.

Elem. / Year	S (m^2)	L (m)	B_m (m)	B_{max} (m)	h_m (m)	h_{max} (m)	A (m)	a (m)	P (m)	C_s	V (m^3)
1955 (by Pişota, I.)	41702	457.53	91.14	183.81	12.65	18.90	366.76	243.05	1257.27	1.74	489966
2002	41270	455.95	90.51	204.61	11.84	18.20	366.02	238.78	1223.33	1.70	488675

S, surface; L, length; B_m, average width; B_{max}, maximum width; h_m, mean depth; h_{max}, maximum depth; A, big axis; a, small axis; P, perimeter; C_s, sinuosity coefficient; V, volume.

The two rivulets filled up this gap, giving birth to the actual lake (the shape of a bear skin). There is an uncertainty concerning the year when this lake took its final shape; some sources from that time period recorded the years 1875 and 1879 as being the ones when the lacustrine basin took birth. Instead, the only certain fact is that the cadastral evidence from 1873-1874 did not mention about the existence of any lake (Lengyel, 1898).

According to researches, Lake Ursu is one of the largest salt lakes in Transylvania and Romania, with a surface exceeding 4 ha, a maximum depth of 18.20 m and a total amount of water around 0.5 million m^3 (Table 1).

3. METHODS

Over the past 10 years of research, several terrain campaigns were carried out, beginning with topo-bathymetric surveys and then gathering water samples and hysic-chemical analyses. For that purpose there were used total stations, GPS terminals and sounders. We used only 3 years (2002, 2004, 2012) because we considered them the most representative in showing us the differences in variation of parameters to highlight the processes and phenomena that have occurred.

For the study of hysic-chemical parameters portable multiparameter cases Hanna 9828 were used, comprising sensors capable of measuring the values of 12 parameters (such as transparency, temperature, pH, conductivity, dissolved oxygen, salinity, resistivity, oxygen saturation) and Hanna 98713 turbidimeter. The connection cable (30 m long) between the thermostat bulb and the transducer was set up to measure the desired parameters in extreme conditions (e.g. hipersaline water, profundity).

When determining salinity the appropriate way is considered to be estimated from SC using the following empirical equation based on data presented by Williams (1998):

$$C_{NaCl} = 12.856 + 0.1609 \times SC + 0.0046 \times SC^2$$

where C_{NaCl} is the concentration of NaCl in g l^{-1} (range 21–311 g l^{-1}) and SC is the specific conductance of the water sample in mS cm^{-1} (range 30–225 mS cm^{-1}).

The saline medium used for the accomplishment of the desired measurements induced disturbances and considerable alteration in the spatial distribution of the other physical and chemical parameters. Thus we considered the use of some diagrams to underline these aspects as important.

The pieces of information were centralized and processed using a computer, with the following statistical and GIS software: Microsoft Office; CurveExpert; SPSS; The Scientific Software Group's "Groundwater Modelling System-GMS"; ESRI ArcView 3.x; ESRI ArcGIS/ArcINFO 9.x.

4. RESULTS

In the case of Lake Ursu, the development of the heliotherm phenomenon is determined by other elements besides the favourable morphometric conditions. All in all we can observe that the lacustrine basin is situated in a reservoir with a protective microclimate and a southern exposition, gaining solar heat in the metalimnion (Fig. 2).

Furthermore, an important role plays the controlled water inputs from the two rivulets (Topliţa and Auriu), which maintain the brackish water at the surface. As other conditions we can add the salt jump layer, called the halocline (Touchart, 2002) and an unalterable hipersaline solution, evolving between 2 and 4 meters, respectively from 4 meters to the bottom of the lake. In fact, the lower part of this halocline layer represents the boundary to which the thermal diffusion currents are propagated. From this point, heat transfer decreases and occurs through thermal conductivity (Fig. 3A).

The A component in the above charts indicates the most relevant profile from the eight ones measured at noon and shows the vertical distribution of parameters. We had a clear sky during measurements.

After 10 years of field campaigns and researches, we have stored an important amount of raw data regarding the qualitative and quantitative parameters of salt lakes and digitally arranged them in strings to statistically process spatial or attribute data. The purpose of these inquiries was to point out the evolution in time and space of the heliotherm phenomenon during the whole four seasons, as well as covering short periods of time before and after balneary activities.

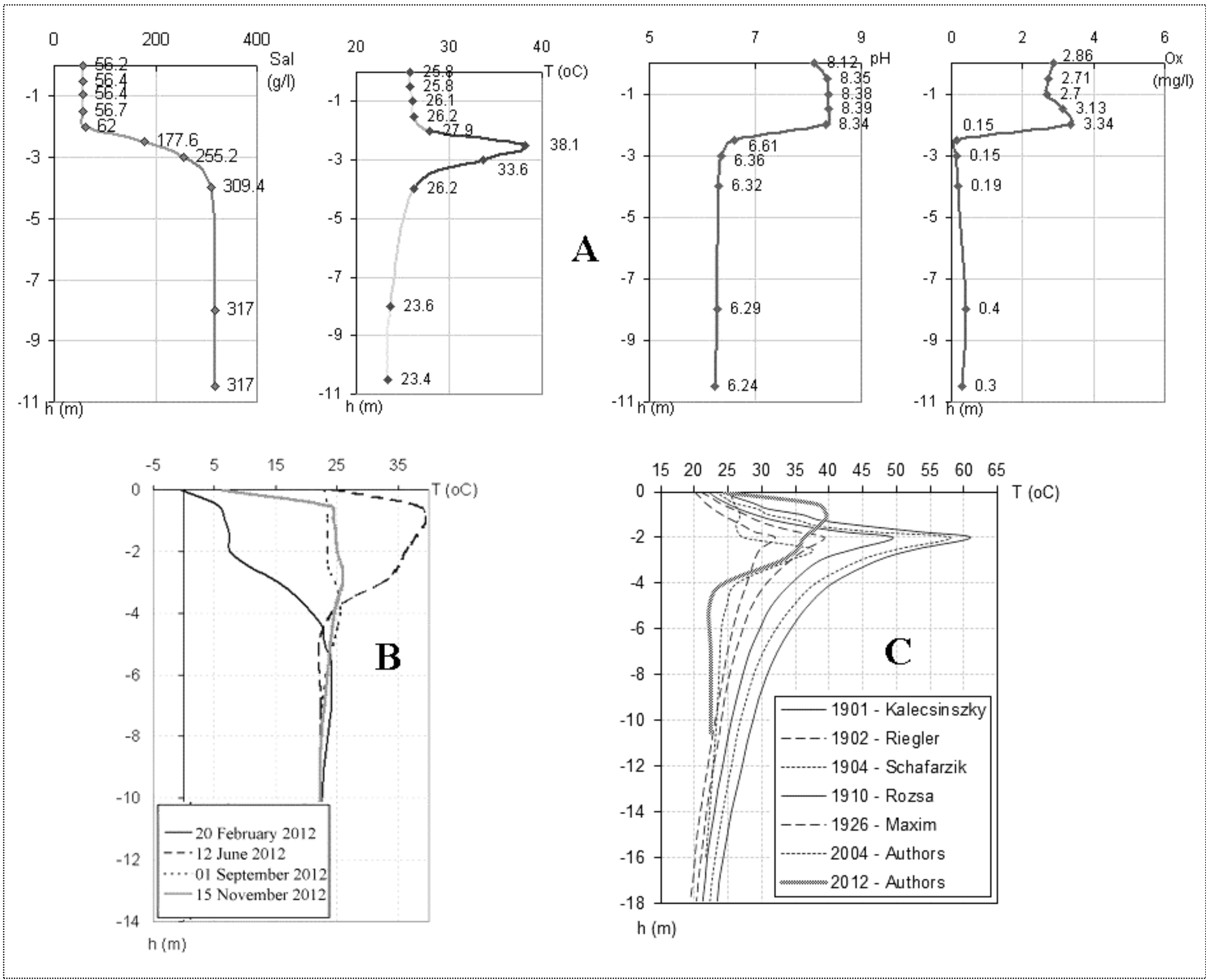

Figure 3. Distribution of physical and chemical parameters on vertical (**A** – July 2004); seasonal discrepancies on vertical changes in temperatures taken at 12.00 o'clock P.M. (**B**); temporal evolution of the heliotherm phenomenon (**C**) - measurements: the 5th of July 2004, 2 P.M., clear sky; the 12th of June 2012, 1 P.M., clear sky. The years used in legend represent the years of measurements; they differ frequently from the year of research publishment.

Thus, in the months of May (more and more a month with aestival features in Transylvania) and June (the first half), before balneary season, there were observed situations with utmost development of this phenomenon, water being under 40°C in the mezzo-thermal horizon (Fig. 3 A and C).

After the summer season, during autumn, it is possible that heliothermy should be maintained or reappear, but the differences in temperatures being reduced compared to the previous season. In the second half of this period, we can often observe inverse thermal stratification or homothermy, water having rather high temperature values (over 20°C) than in the case of artificial lakes or other types of lakes from the temperate climate (Fig. 3 B).

Winter season distinguishes through the presence of an inverse thermal stratification, which was set up by the ice bridge, and maintaining a rather high temperature under the salt jump horizon (around 20°C – Fig. 3B).

Spring begins with the same inverse stratification and sometimes maintains it until April. Then, in the second half of April and in May, follows a relatively sudden warm up of air temperatures and consequently water becomes warmer in the superficial layer, leading to the heliotherm phenomenon (Alexe, 2010).

National and international importance of Lake Ursu lies not only on its therapeutic qualities of waters and sapropelic muds but also on the presence of the heliotherm phenomenon. In fact, this lake represents an ecosystem and reveals a peculiar potential, which has come to many scholars attention over time.

A significant information gathering about temperatures and heliotherm phenomenon has left the possibility to follow the temporal evolution of it for a long time. Among the first writings about the maximum temperature values of the heliotherm layer we can mention the ones of Telegdi-Roth in 1899. He managed to record temperatures higher than 60°C

(09.22 ... 66.2°C, 09.23 ... 67.5°C, 09.25 ... 69.5°C). Also, in the summer of 1900, there were recorded temperatures up to 70-71°C, the maximum value recorded in reference materials and literature (Kalecsinszky, 1901).

Subsequently, at the beginning of the 20th century we can observe a diminishment of this phenomenon from 61°C (Kalecsinsky, 1901) to values between 58°C (Schafarzik, 1909) and 32°C (Maxim, 1929). Recent measurements have revealed significant water temperature dropping to 40°C in all cases (Fig. 3C). The main problem seems to be the intense exploitation of waters through bathing and treatment centers. Until recently, in the case of Lake Ursu, a great water volume was collected and restored in larger quantities, having low salinity, which led to the perturbation of natural water stratification. The existence of some influxes from the upstream Lake Tineretului seems to be another reason for water stratification changes; finally this fresh water lake was drained in 1997.

The salt jump layer, which provides the greatest heat storage, induces important modifications in the vertical distribution of other parameters, with a major importance in the development of processes and phenomena in the lacustrine environment. Thus, water pH turns from alkaline to acid all of a sudden and the dissolved oxygen drops from survival values of freshwater aquatic organisms to ones close to zero (Fig. 3A).

5. DISCUSSIONS

Relying on the researches performed from the birth of this lake and the desire to protect the heliotherm and therapeutic qualities, national authorities and local agents have established Lake Ursu a natural reserve. Also, local administrators have begun by using conservation methods to set up a daily bathing programme, with a two hours break (13.00-15.00) and to limit bathing areas only in the southern section of the cuvette. These rules are meant to keep the quasi-nonaltered characteristics of the lacustrine system in the northern compartment and to reestablish the normal distribution of water layers in the other section.

During balneation, anthropic element influences the above analyzed phenomenon by keeping the maximum values for temperatures under the specified limit and slightly dropping the heliotherm layer (1 m deeper). At the end of the three hours break, we (the authors of this paper) have noticed a recovery of the heliotherm layer (Alexe et al., 2006; Alexe, 2010). With the stored pieces of information, GIS model made it possible to plot temperatures on a longitudinal profile in the lake's water mass. Thus, we can clearly distinguish an undisturbed water horizon (heliotherm one) just looking at the two profiles shown below (Fig. 4).

If one cannot doubt the continuity of the horizon we can remark instead on some valoric discrepancies in different sections of the cuvette. Therefore, the northern apophysis of the lacustrine cuvette (profile 1 - north) is characterized by a slight decrease in temperature amplitudes between 2 – 4 m, as a result of a permanent hipersaline water contribution from the Roşu and Verde lakes. Due to the exposed salt their shorelines present many limestone pavements and specific landforms. Thanks to this, we can observe a vertical homogenization of salinity, rather favourable to the development of a widespread heliothermy, an aspect that can be encountered in the case of other natural and anthroposaline lakes in the Transylvanian Depression. A distinct intensity of the phenomenon can be seen in other lacustrine units than are mentioned above. Thus, we can observe a vertical development of the maximum temperature layer together with a slight decrease in temperatures inside the layer because of water incomes from Topliţa and Auriu rivulets on the north-eastern apophysis (profile 2 – NE).

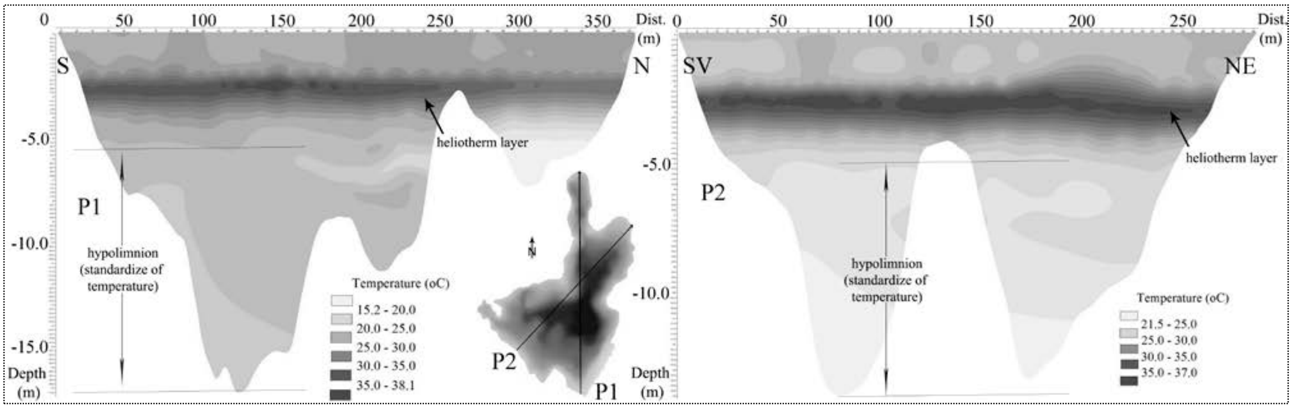

Figure 4. Localisation of the heliotherm layer on longitudinal profile – Lake Ursu (June 2012).

This situation is determined by freshwater infiltrations, which reduce salinity and generate a perturbation in the thermal stratification and distribution of other physico-chemical parameters (pH, dissolved oxygen, electrical conductivity etc.).

In the hypolimnion we can see a quasi homogenization of temperatures, in the limiting values of 15-20°C, due to salt concentrations over 300 g/L and lack of convection currents between the layers. In the case of Lake Ursu, the halocline acts as a real screening – sealing element. In other words, all the year round, this situation maintains its properties and the impact on the hipersaline environment influences other physico-chemical parameters (pH – acid element, dissolved oxygen – almost 0 mg/L and high quantities of hydrogen sulphide).

The above mentioned properties concerning water temperatures were confirmed by the use of a three-dimensional model in Arc Scene 9.x, which allowed us to go beyond the halocline and heliotherm layer (Fig. 5).

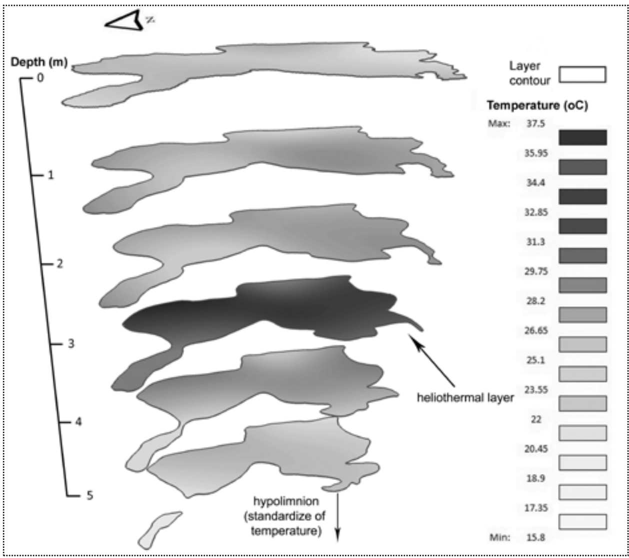

Figure 5. Three-dimensional distribution (layer) of water temperatures in Lake Ursu (July 2004).

If the differences in temperature are more than obvious in the vertical profile, we have low changes in temperatures in the case of the same water layer (maximum 2-3°C). As a matter of fact, these things occur due to a rather small lake surface (approximately 4 ha) and the lack of superficial water currents because of the steep slopes nearby. On the contrary, as the water depth increases, the surfaces of the layer decreases, which combined with the lack of deep water movements, produce undistinguishable differences in temperatures 1-2°C). Over the decades, in the case of Lake Ursu, the presence of the heliotherm phenomenon, in other seasons than winter, has been constantly sustained by observations, measurements and books published by different scholars.

6. CONCLUSIONS

Even if the proportions of the heliotherm phenomenon have diminished in time (from 70°C to about 40°C), Lake Ursu probably remains the most important heliothermal lake in Europe and the whole world. The morphological, morphometrical, climatic and hydric conditions made easier the installation and perpetuation of this phenomenon in the stored water mass.

The balneary and therapeutic potential of sapropelic muds and salt waters will transform this lacustrine unit in a permanent attraction for tourists and for all kind of investors.

On the other hand, aggressive and irrational exploitation of resources may produce major unbalances in the lacustrine unit. It is because of this that we have to monitor it and implement some principles of tourist and ecological sustainability.

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