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BATHYMETRIC AND SEDIMENTOLOGICAL CHANGES OF GLACIAL LAKE ŞTIOL, RODNA MASIFF

Marcel MÎNDRESCU[1], Ionuț A. CRISTEA[1] & Simon M. HUTCHINSON[2]
[1]University of Suceava, 13 Universității Sreet, Suceava 720229, Romania, marcel.mindrescu@gmail.com
[2]University of Salford, School of Environment & Life Sciences, Salford, M5 4WT, UK.

Abstract. Lake Ştiol was one of a number of small glacial lakes in the Rodna Massif (Eastern Carpathians). Despite its originally small dimensions, the lake is situated in one of the largest glacial cirques in the Romanian Carpathians. Being positioned at a relatively low altitude and close to major tourist attractions the lake is one of the most visited locations in the area. In 2002, the lake was illegally dammed and linked to the highway network by an access road, although the planned range of leisure facilities at the lake was not eventually established. The building of the dam in September-October 2002 resulted in the artificial increase of the water level of the lake therefore not only the original contours of the lake been destroyed, but also its dimensional and sediments characteristics have been modified. The greatest modifications were in the volume of water and its surface extent. Consequently, the original glacial lake, in the shape of a tear drop and of relatively small dimensions, has effectively been turned into a high altitude pond, with an uncharacteristic shape (human induced) and a chaotic distribution of depth points. Between the creation of the dam (October 2002) and the sediment sampling in July 2006, an approximately 25 mm thick sediment layer has accumulated on the bed of the lake. The rate of sedimentation is this period may therefore be calculated as around 6 mm y^{-1}. The construction of the dam also altered and extended the drainage network of the lake which in addition to riparian erosion due to the raised water level accounts for the currently high rate of sedimentation.

Keywords: changes in dimensions, sedimentary rate, human impact, glacial lake

1. INTRODUCTION

Pleistocene glaciation affected not only sea level but was also a most effective lake-producing agent. As the glaciers retreated numerous water bodies were left behind in the Romanian Carpathians. Some, such as the Bucura and Podragu lakes, located in the Retezat and Făgăraş Mts, (Transylvanian Alps, Romania), were large and deep, but many more were simply small water-filled hollows. Underlain by moraine deposits or rock, these young ecosystems, such as Lake Ştiol, have matured during the course of the Holocene.

These environments are very sensitive to change (Ianoş et al., 2009). There are many land use practices in upland areas (e.g. grazing, fruit harvesting, the use of mountain pine associations for firewood, syrup making or their removal to enlarge grazing areas) which may alter the relationship between a lake and its catchment, however, few impact as directly and as significantly upon a lake body as those observed at Lake Ştiol in 2002.

Four years after the completion of work on the construction of a dam, we report the findings of a series of research campaigns undertaken to assess the impact on this glacial lake. A post dam survey has been undertaken and is compared to the pre 2002 assessment of lake volume by Pişota (1968). We report the consequent changes to the bathymetry and sedimentary regime of a ‘new’ Lake Ştiol.

2. STUDY AREA

Glacial Lake Ştiol was one of a number of small glacial lakes located in the Rodna Mountains (Eastern Carpathians) (Fig. 1). Although relatively small, it is situated in one of the largest glacial cirques in the Romanian Carpathians, the Bistricioara Mare Cirque (Mîndrescu, 2006) (Fig. 2).

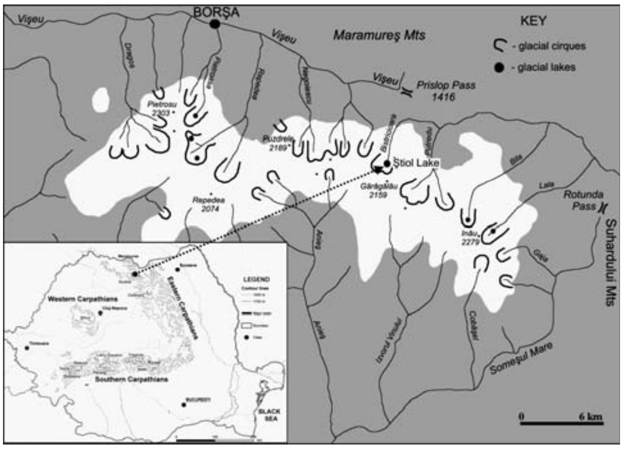

Figure 1. Location of the Lake Ştiol in the Rodna Mts and Romania (insert).

Being located at a relatively low altitude for a glacial lake, it lies en route a number of tourist paths that connect the attractions in the area (e.g. the Waterfall of the Horses, the Borşa Ski Complex, Gărgălău Peak) which has resulted in significant tourist traffic around it. The lake itself represents one of the most visited locations in the Rodna Mountains. Consequently, but without any official approval, a road was built, from Prislop Pass (1416m), directly to the lake. Moreover, in September 2002 the town hall of Borşa determined to erect a dam downstream of the lake in order to increase its surface area and volume.

The aim was also to create a small mountain resort with camping cabins and boating facilities. Although the lake is located in a protected area [Rodna Mountains National Park: Law no. 5/2000 establishes the Rodna Mountains National Park, which defines itself as a protected natural area, of national and international importance, framed under the IUCN (International Union for Conservation of Nature) classification in Category II- National Park – Biosphere reserve, SIT NATURA 2000 (SCI - site of community importance and SPA - s*pecial protection* area)], the dam was erected using bulldozers, this action thus modifying the physical, sedimentary and aquatic characteristics of the lake.

The original basin of Lake Ştiol was excavated in epimetamorphic, sericite-chlorine schists and glacial deposits at the centre of gravity of the Bistricioara Mare Cirque (Fig. 2). The lake sat behind a rock bar and moraine dam deposited during the Würm (LGM - Last Glacial Maximum) at an altitude of 1673m.

Annual average temperatures range between 1.20 C at 1700-1800 m, 00 C at 2000 m and reach -1.50 C at over 2200m. The average number of summer days is 25-30, and that of winter days reaches 130. At an altitude of 1800 m, the rainfall has an annual average of 1312 mm (of which 500 mm are recorded during the winter season) with over 130 days with rainfall annually (Coldea, 1990).

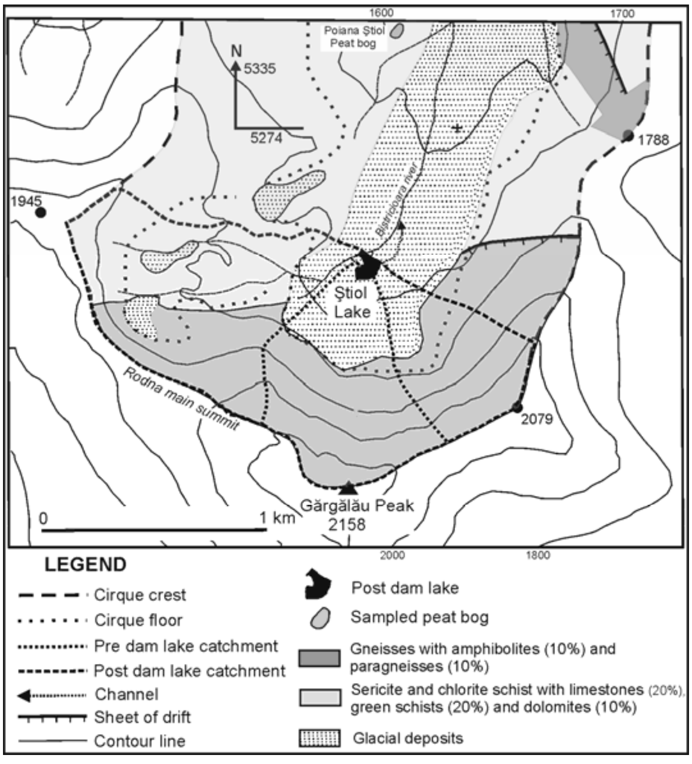

Figure 2. Lake catchment, including the geomorphology and gelogy of the area. (Poiana Ştiol peat bog was sampled by Tanţău *et al.* in 2004)

3. METHODOLOGY

The bathymetric survey of 1968 employed the techniques of the period using a lead line in the field followed by a graphical interpolation of the data points to produce a map of what is also known as Izvorul Bistriței. We opted for the name Lake Ştiol, as this used by the local population However, confusion with nearby peat bogs called Poiana Ştiol should be avoided.

In 2008 a Garmin 525 sounder was used to determine the bathymetry of the lake. The data points in this survey (more than 1000) were registered in the Stereo 70 coordinate system and superimposed on the corresponding orthophoto. This was done in order to verify the accuracy of the topographic mapping and the lake contour extraction. On the perimeter of the lake, points of 0 depth value were automatic ally created, and used later on for a better interpolation. In order to obtain isobaths and the 3D model of the lake basin, a method was selected which caused the least deformation of the measured depths and which represent as exactly as possible the situation on the field. After a review of the methods available in ArcGIS 9.2 data point interpolation and the generation of a digital model of the basin were undertaken using the Topo to Raster method.

In 2007 a HTH gravity corer was employed to sample the sediments of the post dam lake. Three short (<25 cm) cores were taken. In the field the K (volume susceptibility) profile of each core was logged and the cores sectioned at 10mm intervals.

4. PRE DAM LAKE ŞTIOL

Pre dam Lake Ştiol represented a typical glacial cirque lake, circular and with considerable depth (by comparison with its horizontal dimensions) (Fig. 3 and 7 right), that was formed towards the end of the Quaternary glaciations of the Eastern Carpathians. It took shape behind a cirque moraine, whose left 'wing' appears today as a peninsula inside the post dam Lake Ştiol. Its origins were mixed being a result of both glacial erosion processes and moraine related damming. Although it was formed within a large cirque, the pre dam lake was relatively small (approx. 600 m^2 in 1968), and its catchment was only 32% of the surface of the outer cirque, situated above the lake (Tab. 1).

The vegetation history of the area throughout the Holocene has been determined from a peat bog core located within the Bistricioara Mare cirque at Poiana Ştiol (Fig. 2). At the onset of the Holocene the vegetation was dominated by Ulmus together with Pinus, Picea and Betula. The frequencies of the Quercus, Fraxinus and Tilia never exceed 10%. The maximum of Corylus occurred between 8,000 and 6,600 BP (Before present). The local establishment of Carpinus was about 5,000 BP. Its maximum occurred between 4,200 and 3,500 BP. Fagus pollen was regularly recorded from 6,000 BP. Its absolute dominance took place at about 3,000BP. Picea pollen was present throughout the Holocene. The first indications of human activities appear at around 2,000 BP (Pop, 1960; Tanțău & Farcaş, 2004).

The vegetation of the basin is represented by flora specific to high mountain areas. In the areas above the lake, dwarf mountain pine, grouped in the association *Rhododendro myrtifolii:*

- *Pinetum mugi*, characteristic of subalpine environments, can be found. Whereas large scale deforestation of this association which occurred during the last century in order to extend the area for pasture, has considerably reduced their current area, in this catchment's large clusters have survived where access was difficult and the land inappropriate

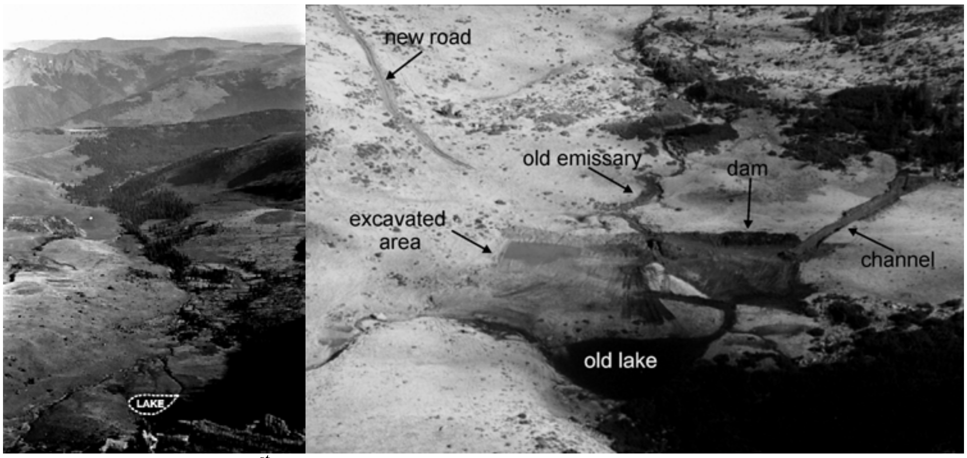

Figure 3: left - Lake Ştiol on 21st September 1975 (photo: Pascu, D.); right - Construction works at Lake Ştiol on the 3rd of October 2002 (photo: Goja L.)

for grazing. The alpine zone (over 2100 m), is characterized by the presence of primary meadow lands from the alliance *Caricion curvulae* (*Caricetum curvulae, Oreochloo- Juncetum trifidi*) and small, oligothermic shrubs belonging to the alliance *Cetrario- Loiselerion*, restricted to a narrow area corresponding to the Gărgălău Peak (Coldea, 1990).

5. POST DAM LAKE ŞTIOL

5.1. Human impact.

The building of the dam in September-October 2002 resulted in the artificial increase of the water level of the lake. The dam is situated at a distance of 80 m downstream from the old lake. Moreover, the materials used for the construction of the dam were taken from the lake basin (Fig. 3 and 4). Furthermore the access road built from Prislop Pass facilitated access to the lake. In time, the lake became a place not only for recreation, but also an area for picnics and camping although, the full plans of the town hall of Borşa were not carried out and a full range of recreational facilities were not established. Nevertheless, this has increased visitor pressure at the site.

Trampling of vegetation is one of the most widespread environmentally degrading repercussions of recreation in the Bistricioarei cirque and can also lead to excessive soil erosion. Numerous studies have been undertaken in the other national parks, which have illustrated the ecological impact of visitors at camping and picnic sites, nature trails and footpaths. In all cases, soil compaction, changes in infiltration rates, soil organic matter, litter and soil moisture content as well as vegetation cover were recorded. Apart from the damage caused by trampling and erosion, long-lasting degradation can occur as a result of burning associated with recreation, e.g. barbecues (Romanians are well know for their love of barbecues at wild campsites). Fire especially when high temperatures are attained, will destroy the above-ground woody biomass and litter and may impair the reproductive potential of plants by reducing the seed bank in the soil (Mannion, 1991). Other studies [e.g. Cole & Fitcher (1983), Stohlgren & Parsons (1986)] have led to the conclusion that the most appropriate management strategy for such wildness areas is to restrict camping to a few designed sites.

5.2. Bathymetric changes

The key parameters of the lake basin are given in table 1.

Table 1. Bathymetric parameters of the two stages of Lake Ştiol

Variable	Pre dam (Pişota, 1968)	Post dam (This study)	Changes
Area (A), m^2	587.5	10600*	> 18 x
Volume (V), m^3	610	20116.7	> 33 x
Maximum depth (z_m), m	2.0	5.7	> 2.85 x
Mean depth ($\check{z}$), m	1.03	1.90	> 1.84 x
Relative depth[1] (z_r), %	7.31	4.90	< 1.50 x
Length, m	40	132	> 3.3 x
Longest line, m	40.6	150.9	> 3.72 x
Maximum width, m	25	125	> 5 x
Mean width, m	14.68	80.30	> 5.5 x
Perimeter, m	120	491	> 4
Shoreline development, degree	1.40	2.70	> 1.92 x
Mean slope, %	1.069	0.1688	< 6.33
Cathment area, ha	49	151	> 3
Elevation range of the Catchment, m	1673- 2158	1667-2158	-
Insulosity, %	0	0.009	-
Lake shapes	subcircular	Irregular	changed
Origin of the lake	Glacial	Anthropic	changed
Origin of the island	-	glacial, moraine top	new island
Origin of the dam	glacial: rock basin dammed by moraine	human induced	changed

* the lake surface area was measured in August 2008 at 12,150 m²

Figure 4. Post dam Lake Ştiol (July 2006) (Photo: Mîndrescu, M).

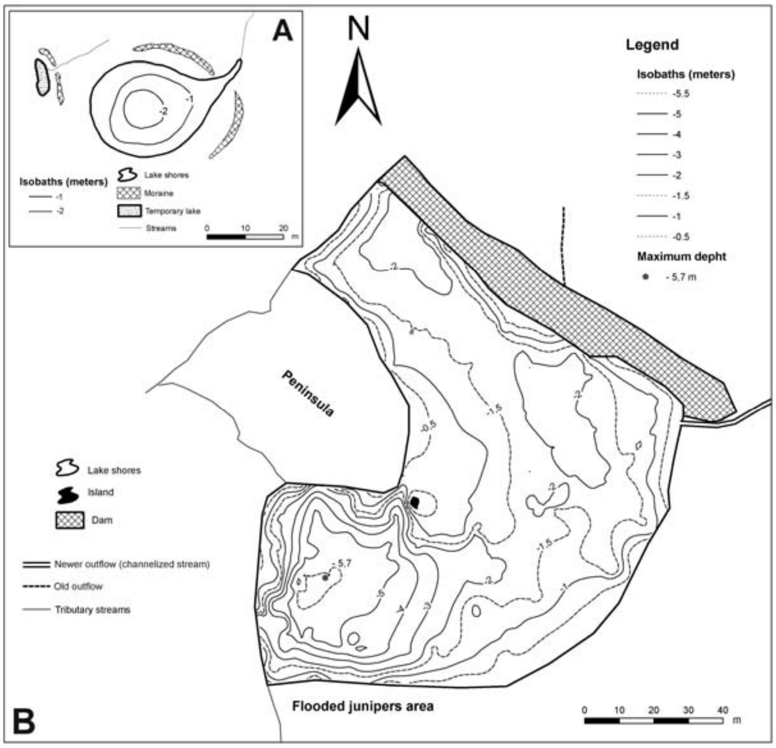

Figure 5. Comparison of bathymetric surveys of Lake Ştiol. A; pre dam (according to Pişota 1968) B; post dam (this report).

By building the dam, not only have the original contours of the lake been destroyed, but also its dimensional characteristics have been modified. Even during the period of dam construction it almost doubled its surface area reaching approximately 1,100m² in October 2002. The greatest modifications were in the volume of water (it grew 33 times) and its surface extent (increasing 18 times). Consequently, the original glacial lake, in the shape of a tear drop and of small dimensions, effectively turned into a high altitude pond, with an uncharacteristic shape (Fig. 4 and 5) and a chaotic distribution of depth points. Moreover, the current lake has significant variations in level, because the depth is controlled by an artificial channel which, due to the high flow events can periodically become clogged. This has led to an increase in the level of the lake surface and the flooding of its banks which were covered with dwarf pine. At a less marked level, the depth, length and width of the lake were also modified. In terms of bathymetry, two areas distinguish themselves, one with greater depths, superimposed on the site of the pre dam lake, and the other with lower depths (under 2 m) situated adjacent to the dam wall. As a result of the increased water level, the lake's shape has been modified, from a circular to an irregular one and a small island has been formed on the ridge of the cirque moraine (Fig. 5). Taking into consideration its new dimensions, Lake Ştiol has become the largest high altitude lake in this part of the Eastern Carpathians, surpassing glacial Lake Vinderel in the Northern Maramureş Mountains (Mindrescu, 2004).

5.3. Lake sediments

Lake basins occurring in the high-mountain areas such as Rodna can form excellent sediment traps for material originating from the denudation of their catchments. Material which is derived from the slopes surrounding a lake or which is delivered by mountain streams is deposited in the lake whilst only a small proportion is lost from the lake in suspension (Brune, 1953).

Consequently these sediments can provide a record of, for example, changes in vegetation cover due to natural or anthropogenic factors. They can therefore act as an archive of environmental conditions in the Northern Eastern Carpathians since deglaciation (Mureşan, 2009). Lake Ştiol has limited contact with any active slopes being relatively distant from the headwall cirque (Fig. 6). Furthermore, delivery of weathered material from these slopes is likely to be reduced as the lake is isolated by moraine deposits and a rocky cirque step located above the lake (between 1750 and 1800 m). Sediments may also have been delivered to the pre dam lake by debris flow (this debris flow fan is located now on the right bank of the post dam Ştiol lake and was noted by Sârcu in 1978) (see Fig. 7) and by dirty snow avalanches and wind.

At Lake Ştiol, the impact of dam building not only modified the physical characteristics of the lake, but also appears to have affected the properties of its sediments and the rate of sedimentation. Figure 8 shows the mineral magnetic properties of a short sediment core. The the subsurface peak in the concentration parameters X (magnetic susceptibility), ARM (Anhvsteric Remanent Magnetisation) and SIRM (Saturated Isothermal Remanent Magnetisation) reflects the impact of the artificial raising in the lake's level.

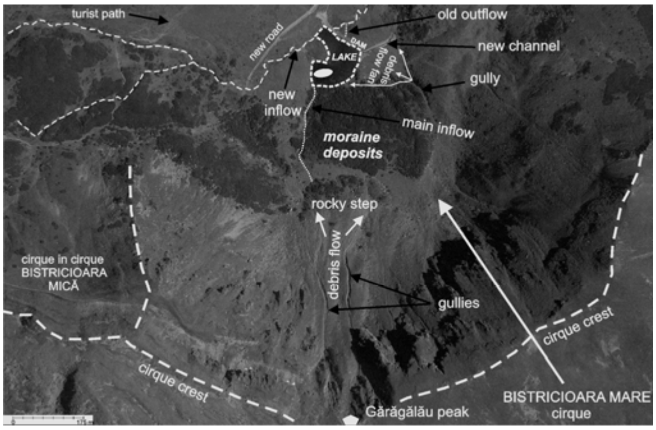

Figure 6. Aerial photo of the post dam Ştiol lake area (2005)

Figure 7: left - Debris flow fan (noted with C.D.); right - Pre dam Ştiol lake shape in 1978, Sârcu, I.

The input of subsurface and, magnetically clean, lake shore material, eroded as the riparian vegetation has died back due to prolong water logging, has effectively buried the magnetically coarse grained concentration and previously sediment surface peak. A mineral magnetic technique had demonstrated the probable influence of atmospheric particulate pollution on the sediments of six lakes in the Maramureş region of the Carpathian Mountains where surface or near surface peaks in magnetic concentration were observed (Hutchinson, 1995; Hutchinson et al. 2008).

Between the creation of the dam (October 2002) and the sediment sampling in July 2006, an approximately 25 mm thick sediment layer has accumulated on the bed of the lake. The rate of sedimentation is this period may therefore be calculated as 6,25 mm y^{-1}. The rate of pre dam sedimentation is unknown, but is likely to have been significantly lower that the estimated post dam rate (Tab. 2). The construction of the dam also altered and extended the drainage network of the lake.

Locally the sedimentation rate for Poiana Ştiol peat bog, which is situated within 1 km at 1560 m has been estimated (Tanțău, Farcaş, 2004). For the Holocene an average rate of approx. 0.37 mm y^{-1} was obtained with a maximum at the beginning of deglaciation (Preboreal and Boreal) and a minimum value near the end of the analysed period, when the rate is only 0.044 mm y^{-1} (Subatlanitic). In the Tatra Mountaisn in the Polish section of the Carpathian Range glacial lake Zielony Staw, situated in the crystalline, granitic part of the mountains at a similar altitude as Lake Ştiol at 1632 m, the mean Holocene sedimentation rate was 0.21 mm y^{-1}, the highest rates in the Little Ice Age (0.36 mm y^{-1}) and the early Subboreal (0.20 mm y^{-1}), while the lowest rates was in the early Subatlantic (0.13 mm y^{-1}) and in the Atlantic (0.18 mm y^{-1}) (Kotarba 1992; Rădoane & Rădoane, 2005).

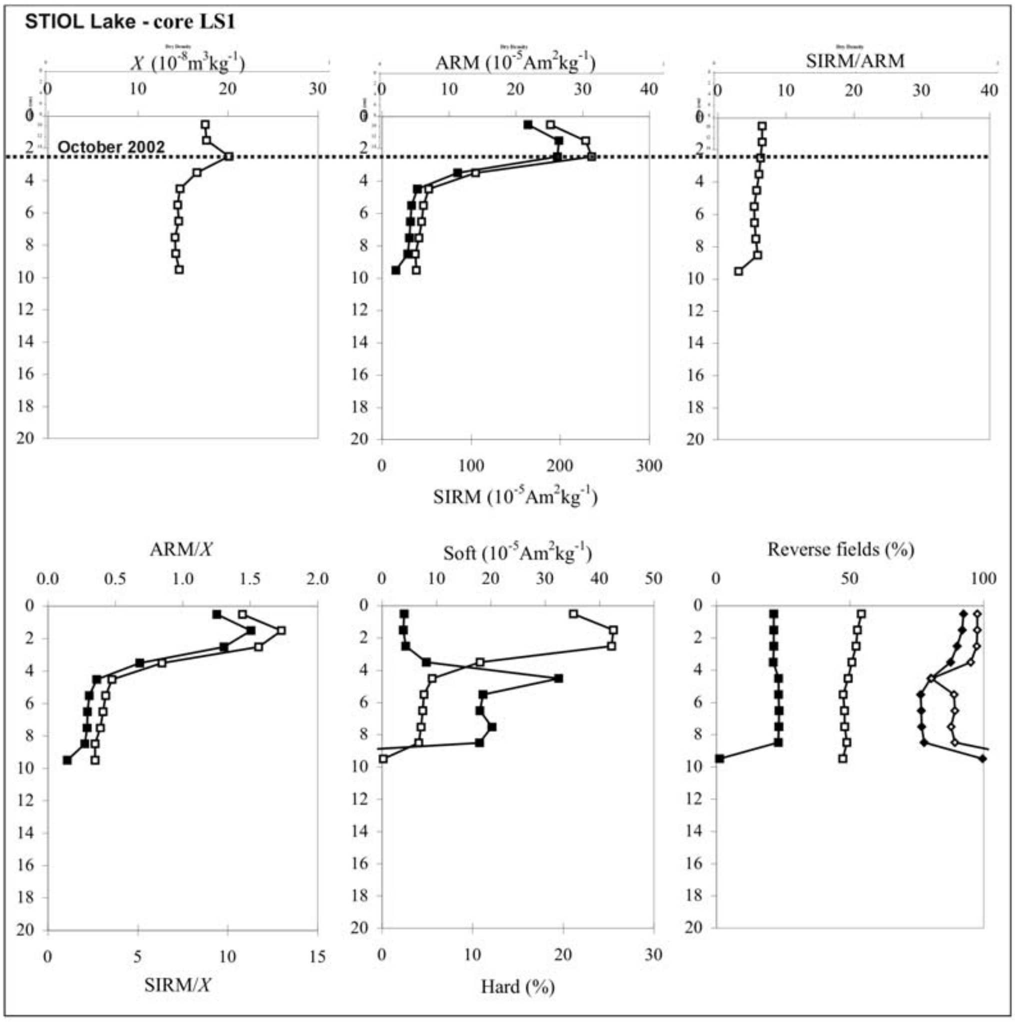

Figure 8. Mineral magnetic properties of a short sediment core from post dam Lake Ştiol (core LS1) (Key: SIRM, SIRM/*X* and Hard shown as solid symbols. Reverse field measurements at -20mT (closed squares), -40mT (open squares), -100mT (closed diamonds) and -300mT (open diamonds).

Table 2. Comparison of sedimentation rates and sediment yield in several sites in the Romanian Carpathians

	Post dam Ştiol	Poiana Ştiol	Iezerul Călimani	Tăul Zănoguţii
Type	glacial lake	peat bog	peat bog	shallow glacial lake
Location	whitin the cirque, Rodna Mts	whitin the cirque, Rodna Mts	on the volcanic plateau, Călimani Mts	whitin the cirque, Retezat Mts
Altitude, m	1667	1540	1740	1852
Peat bog/lake area, m^2	10600	6090	2000	3000
Catchment area, ha	151	7.5	21	53
Latitude	47^0 34' 30''	47^0 35' 12''	47^0 05' 37''	45^0 20' 03''
Longitude	24^0 48' 55''	24^0 48' 49"	25^0 15' 46''	22^0 48' 18''
Rate of sedimentation, mm/y-1	6.25	0.30	0.28	0.30
Sediement yieald, t/ha/y	0.658	0.37	0.040	0.025
Beginning of sedimentation	October 2002	Preboreal, 9,220 y BP	Lateglacial interstadial, 16,750 y. BP	Lateglacial interstadial, 14,800 y. BP

The sediment yield obtained for Poiana Ştiol peat bog over the last 3500 years is 0.0435t/ha/y. In comparison, that calculated for 2002-2006 for Lake Ştiol is 0.658 t/ha/y. Assuming that a comparison between the two sites is realistic it would appear that sediment yield has increased at least 16 times since the creation of the dam (Tab. 2).

6. CONCLUSIONS

Glacial environments in the Romanian Carpathians are highly sensitive to environmental change and human activity can be significant. The importance of glacial lakes can be seen not only from the point of view of landscape, but also through their sediments, as important archives of the environment conditions spanning deglaciation to the present. The construction of a dam in front of Lake Ştiol caused a major modification of its characteristics. The greatest modifications were in the volume of water and its surface extent. Consequently, the original glacial lake, in the shape of a tear drop and of small dimensions, effectively turned into a high altitude pond, with an uncharacteristic shape and a chaotic distribution of depth points.

The analysis of its sediments has shown the deposition a layer of recent sediments, rather different to deposits typical of unmodified glacial lakes, suggesting an increase in the rate of sedimentation and sediment yield. Between the creation of the dam (October 2002) and the sediment sampling in July 2006, an approximately 25 mm thick sediment layer has accumulated on the bed of the lake. The rate of sedimentation is this period may therefore be calculated as 6.25 mm y^{-1} and it would appear that sediment yield has increased at least 16 times since the creation of the dam. The construction of the dam also altered and extended the drainage network of the lake. The actual catchment size of the lake increased three times.

Despite some minor measures of protection, the intensification of tourist activities, if left unmonitored, may lead to further modification of this site.

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