NEOTECTONICALLY CONTROLLED QUATERNARY SEDIMENTATION IN THE LĂPUŞ BASIN (MARAMUREŞ COUNTY, ROMANIA), DEMONSTRATED BY SEDIMENTOLOGICAL AND GEOCHEMICAL ANALYSES

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Abstract. An alluvial plain of about 25 km^2 is situated on the upper segment of the Lăpuş River between Târgu Lăpuş town and Răzoare, Borcut and Dumbrăvița villages. It covers a tectono-erosive basin, which was formed and evolved under tectonic forces, *i.e.* by the movement of blocks of the pre-Quaternary basement.

Based on the results of previous morphological, geological and geophysical research and the recently performed sampling and analytical data, the character and the amplitude of these movements, as well as the environmental evolution of the site, from the beginning of Late Pleistocene until present days, can be determined. For this purpose, apart from previous borehole and mining data, the grain size distribution, the palynological content and the geochemical analysis of the sediments from shallow boreholes were processed. In this case, the heavy metal content of the samples originated from the hydrothermal ore bodies of Băiuț area were used as "markers" in the sediment columns.

Key words: Geomorphology, geological setting, Holocene sediments, palynology, grain size, heavy metals, neotectonic events

1. INTRODUCTION

The research area is situated close to Târgu Lăpuş town (Maramureş County, Romania), in the north-western part of Transylvania. Over the last five years, Doroțan (one of the authors of the present paper) has been studying the state of the environment, the water quality and the soils from the adjacent area in the upper and middle segment of the River Lăpuş. A lot of analytical data was gathered, which can be used both for environmental and geological purposes.

In this paper, we try to decipher the history of the sediment filling of the small "tectono-erosive" Lăpuş basin, which appears as a small depression in the front of Preluca regional fault system. The main question is whether this tectonic basin is still moving or whether it has been stabilized. For this purpose, apart from our data, we also utilize the partly unpublished mining, geotechnical and geophysical results of previous research, mostly acquired during the exploration of the Răzoare Fe-Mn ore deposit.

The Lăpuş River transports various mineral and rock fragments, including those of hydrothermal ores related to Neogene metallogenic processes, characterized by a heavy metal content, originating both from natural and mining activities, the latter causing an increased inflow of heavy metals, transported by water flows in solution and as rock fragments.

This river crosscuts various rock types of the geological background both in the mountainous area and in the hilly zone called "*Ţara Lăpuşului*" (Lăpuş Land), and discharges them in a large alluvial plain, prior to rushing into the wild Lăpuş canyons.

2. PREVIOUS GEOLOGICAL STUDIES

The geological study of the mountainous area started at the end of the 19th century (Pošepny, 1862; Gesell, 1891, 1892; Woditska, 1896) and continued in the first half of the last century by Mihăilescu (1934), Anton (1943) and Mezősi (1948). During the regional geological mapping (Dimitrescu & Bleahu, 1955; Mutihac, 1955; Bombiţă *et al.*, 1972), the overlapping structure of the Paleogene Flysch zone and the intrusive and effusive character of the igneous bodies were defined. In Băiuţ-Poiana Botizii Area, the hydrothermal mineralization and the ore accumulations related to the Neogene magmatic activity were studied by Dimitrescu & Gheorghiţă (1962), Pomârleanu *et al.* (1968), Manilici & Kalmár (1973), Achim & Ciolte (1991) and Chioreanu & Fülöp (2000). The mineralizations were included in the Baia Mare metallogenetic district (Borcoş *et al.*, 1976; Mariaş, 2005). The last cartographic image of the whole Oaş–Gutâi–Ţibleş belt, including that of the Băiuţ–Poiana Botizii area was the result of a 25 years mapping activity performed by a team of IPEG Maramureş. The map series was printed between the years1983 and 1986 (Edelstein *et al.*, 1986).

The hilly area between Văratec–Ţibleş belt and Preluca Mts. was studied by Dumitrescu (1957), Paucă (1955, 1963), Bombiţă (1972), Mészáros & Ghergari (1979), Macovei (1994) and Kalmár & Macovei (2011), while the eastern part of the Preluca Mts. and the Ineu horst were investigated by Kräutner (1937), Dimitrescu (1963), Kalmár (1971, 1981) and Kalmár & Lelkes-Felvári (1991). There are also unpublished reports on the Răzoare Fe-Mn ore body, elaborated between 1975 and 1988. The geomorphology of the Lăpuş Basin is mostly discussed in the works of Mihăilescu (1934) and Posea (1962), as well as in other unpublished studies.

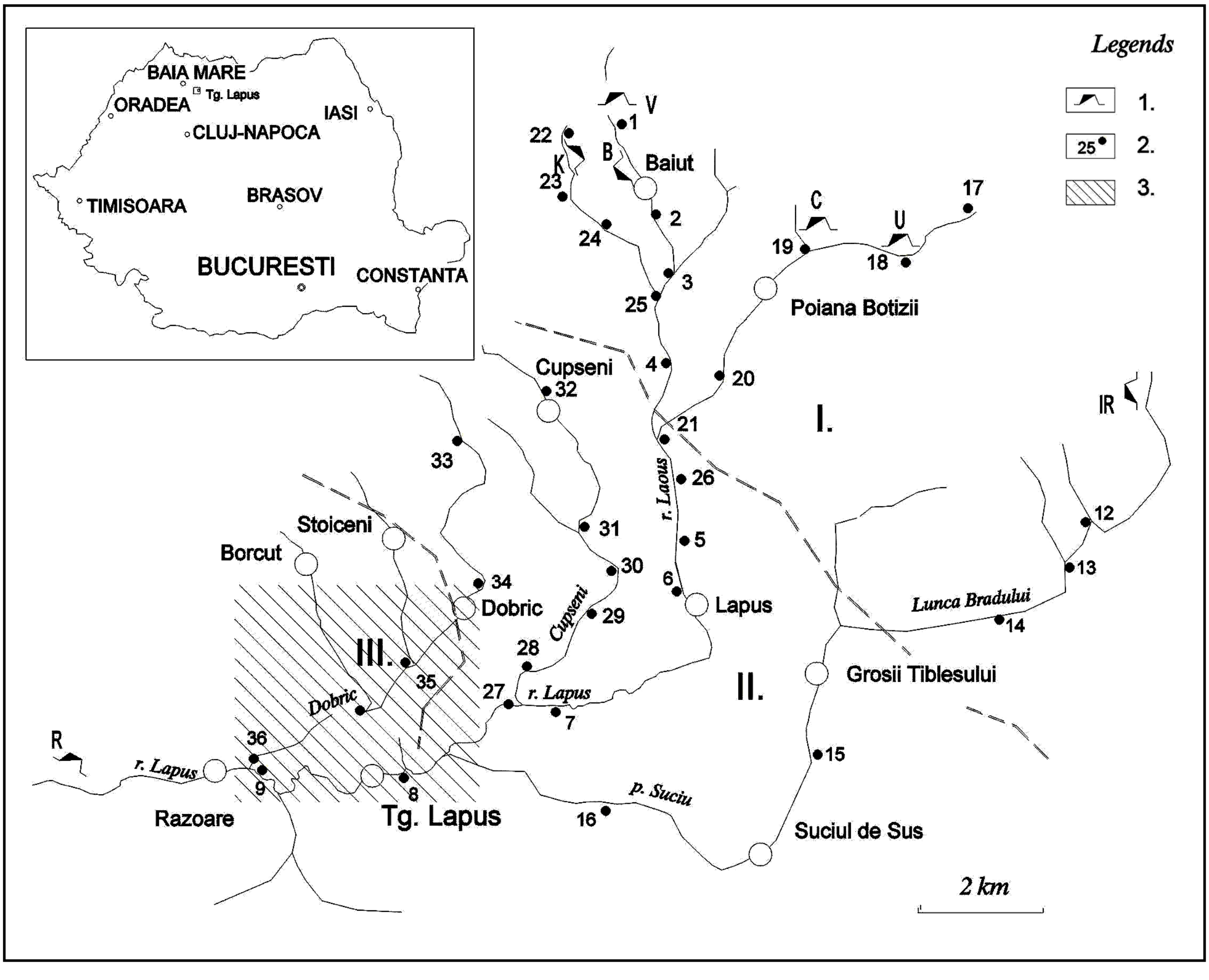


Fig 1. The drainage basin of the upper segment of Lăpuş River. Morphological units: **I** – Mountainous area; **II** – Hilly area; **III** – Floodplain area. *Legend*: **1** – Major mining works: **B**. Breiner-Băiuţ; **C**. Cisma-Poiana Botizii; **IR**. Izvorul Rău-Ţibleş; **K**. Kelemen-Strâmbu; **R**. Răzoare; **V**. Văratec-Băiuţ; **2** – Shallow boreholes; **3**. – Study area.

3. MATERIALS AND METHODS

In addition to previous geological, geophysical and mining data, in this paper, stream sediments and sediment samples of shallow boreholes were also used, totalizing 36 sampling points (Fig. 1). These sediments consist of a natural mixture of fine to coarse grained sand, silt and clay, with, or without, coarser (gravelly) particles. The boreholes were carried out using *Eijkelkamp* drilling rigs, both on the flooded bank of the river, and on so called floodplain terraces, including the lower level of the 1st terrace of the Lăpuş River. Our sampling covers the whole drainage basin of the upper segment of this river.

Grain size and geochemical analyses were performed on the sediment samples, both in laboratories of Faculty of Environmental Science and Engineering of Babeş-Bolyai University, Cluj Napoca and of the former Geological and Geophysical Institute of Hungary, Budapest. In two sediment samples, the microfloristic association was determined by Dr. Elvira Bodor, senior palynologist of the Hungarian Geological Institute. The paleontological data were completed by an older (unpublished) report about a fossil bone, signed by Dr. P.-M. Samson and Dr. C. Rădulescu, mammal paleontologists at the Institute of Speleology of the Romanian Academy in Bucharest.

The sedimentological and geochemical analytic data were grouped based on morphological criteria (*i.e.* mountainous, hilly and floodplain areas) and, respectively, as riverbed, riverside and terrace sediments. The data were treated separately, mainly using statistical methods. Our target was to make a spatial and temporal model of the sediment transport and deposition from the mountain area to the large Lăpuş-Dobric floodplain. We used as "markers" the behaviour of the heavy, toxic metals – generated continuously by cropping out base metal and gold-silver-bearing mineralizations of the igneous belt Văratec-Ţibleş, as well as by historical and industrial mining activity. The microfloristic and paleontological analyses permitted us to establish the relative (chronostratigrapical) age of the main sediment-forming events and integrate them in the neotectonic evolution of the study area.

4. RESULTS AND DISCUSSION

4.1 The natural background

Geographical and geomorphological setting. The natural – geographical, geological and geomorphological – background of the hydrological basin of the Lăpuş River, upstream of Răzoare village, can be divided into three sectors, which, at the same time, correspond to the three morphological units (Fig. 1).

The mountainous area begins at the river sources and extends up to the mouth of the Poienii rivulet (south of Poiana Botizii). The hilly area, comprising the Lăpuş River with its tributaries, starts at the confluence with Valea Poienii and ends at the confluence with Valea Morii, a small brook on the right side of the Lăpuş River (close to Tg. Lăpuş). The floodplain area extends from the Valea Morii to the mouth of the Dobric rivulet, *i.e.* to the first micaschist cliff of Preluca Mts.

In the mountainous area, the water flows have linear character, with V-shaped valley section (Plate I, Photo 3), and a marked longitudinal slope. Here and there, narrow banks of coarse-grained alluvial deposits appear.

In the hilly region, the Lăpuş River flows in a 200–500 m wide valley. The riverbed is incised in a 2–5 m thick "meadow terrace" (gravel, sand and silt deposits). Posea (1962) correlates the different segments of these terraces, successively with the third, the second and the first (Pleistocene) terraces of the river Lăpuş. In this segment, the river shows a linear and branched character, with slightly elevated gravel and sand banks, representing small "islands" inside the riverbed.

In the floodplain area, the River Lăpuş forms even bigger meanders down to the confluence with the Dobric rivulet. This rivulet and its tributaries on the right side (Borcut, Dumbrava and Stoiceni rivulets) form complex meanders, small oxbow ponds and marshlands (Fig. 2). Note that all of these rivulets and even the River Lăpuş have been regulated, thus they flow in rectilinear channels.

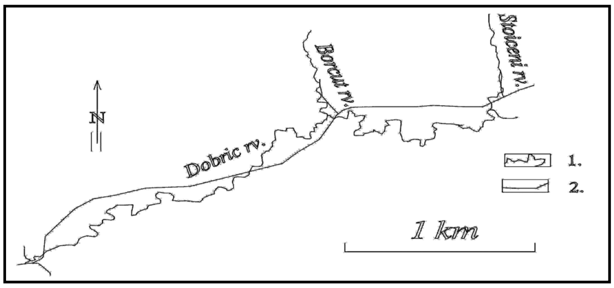


Fig. 2. The meandering Dobric rivulet before (**1**) and after (**2**) regulation.

Geology. The Văratec Mountains, the area from where the River Lăpuş and its tributaries (Strâmbu, Văratec and Poiana) originate, are extended as far as the Someş-Tisa watershed (Roata-Prislop-Roşia-Văratec Peak-Secu line). The mountain range represents one of the eastern segments of the Oaş – Gutâi – Ţibleş igneous belt of the Eastern Carpathians.

The geological structure of this area is complicated by the presence of the Botiza Flysch Nappe System – the Botiza and the Wild Flysch nappes (Late Cretaceous-Eocene), which overlap the Late Oligocene Valea Lăpuşului Autochtone (Dimitrescu & Bleahu, 1955; Bombiţa *et al.*, 1972). The post-tectonic cover is represented by Miocene (Badenian, Sarmatian and Early Pannonian) sediments. The Quaternary cover is made of scarce alluvial valley fillings and, on the slopes, by thick diluvial and colluvial, heterogeneous deposits (Fig. 3).

The igneous rocks of Văratec Mts. pinch out and cover the sedimentary succession by Pannonian (9–10 Ma) andesite lavas, microdiorite plugs and other subvolcanic bodies, often with large contact-metamorphic rims, hydro-metamorphic areas and hydrothermal epithermal base metal and Au-Ag ore bodies (Dimitrescu & Gheorghiță, 1962; Manilici & Kalmár, 1973; Chioreanu & Fülöp, 2000).

The hydrothermal mineralizations were opened by mining works in four major mineralized structures: Kelemen-Strâmbu, Breiner, Văratec and Cisma-Coasta Ursului.

The mineralization forms large, often branching lodes, stockworks, lens-like bodies and extended impregnation zones. The metallic minerals are represented by pyrite, pyrrhotite, marcasite, chalcopyrite, arsenopyrite, galenite, sphalerite (Plate I, Photo 4), wurtzite, antimonite, realgar and orpiment, sulphosalts such as tetrahedrite, bornite, bournonite, jamesite etc., as well as iron oxides and oxyhydroxides (magnetite, hematite, goethite, lepidocrocite). Native gold, silver and cooper occur mainly on the upper zones of the mineralization. The non-metallic minerals are represented by quartz, calcite, dolomite, siderite, baryte and clay minerals. On the outcropping oxidation zones, large "iron caps" were formed which have been partly exploited as limonitic iron ore.

According to historical documents, the mining activity began in 1473. The industrial exploitation dates from the end of 19th century (Woditska, 1896) and lasted until the closure of the Băiuț plant (2003). In that area, the former mining activity left sites of high environmental risk, such as a lot of opened mine works, unprotected waste rock dumps and tailing ponds (Plate I, Photos 1 and 2).

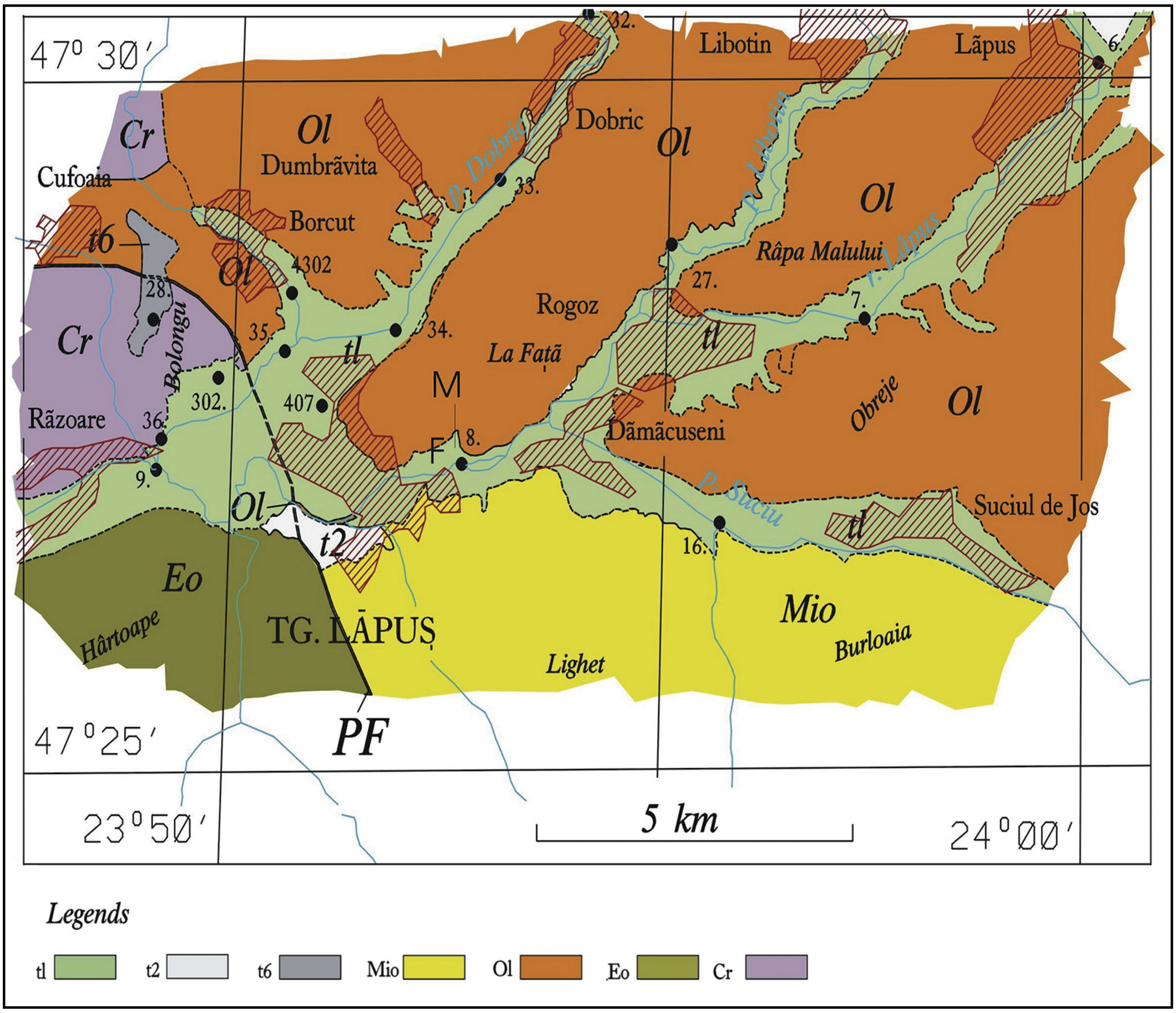


Fig 3. The geological background of the Lăpuş floodplain (modified after Edelstein *et al.*, 1986). **t1**: Holocene floodplain; **t2**: *La Țărm* – terrace II of the River Lăpuş; **t6**: Bolongu hill, with the terrace VI of the River Lăpuş; **Mio**: Late Miocene Hida-Măgura Giurgiului Formation; **Ol**: Late Oligocene Vima and Valea Lăpuşului Formations; **Eo**: Late Eocene Valea Nadăşului and Piatra Cozlei Formations; **Cr**: Metamorphic rocks of the Preluca and Inău Cristalline Islands; **PF**: Preluca Fault; **M.** Morii rivulet; **F**: location of the bone fossil found; • Shallow boreholes.

The hilly area is composed of largely folded Late Oligocene marls and sandstones (Valea Lăpuşului–Şetref Formation), covered by the coarse sand and gravel levels of the Miocene (Carpathian stage) Hida-Măgura Giurgiului Formation.

Extended terraces of the Lăpuş-Suciului valleys system have been developed on this area. Without paleontological or radiometric data, their age is presumed to be from the Early Pleistocene till the Pleistocene-Holocene boundary.

The Lăpuş-Dobric floodplain, which is in the focus of this paper, is surrounded northward and eastward by the Oligocene Valea Lăpuşului Formation, southward by the Late Eocene Valea Nadăşului Formation, the Oligocene Vima Formation, and by the Miocene Hida-Măgura Giurgiului Formation, and westward, by the micaschists and quartzites of the Preluca Formation, and by the Valea Lăpuşului Formation (Fig. 3). The Vima marls are covered by the 7–10 m thick sand and silt deposits of the terrace level II of the Lăpuş River, which forms the *La Ţărm* plateau.

Thereinafter, we will examine the role of this tectonic pattern in the development of the floodplain, *i.e.* the passive or the active role of the Preluca Fault in its evolution.

The Quaternary filling of the basin is visible along the trenches of the regulated riverbed of the River Lăpuş and it was also crossed in some urban geotechnical boreholes. Thus, due to the intensive exploitation of the gravel as building raw material, in the riverbed at a depth of 2-3 m, the removal of the Quaternary sediments exposed sandstone banks of the Valea Lăpuşului Formation. West of them, in the ore exploration boreholes on the East Dobric Ore Field, the micaschists and quartzites are covered by 2–3 m thick coarse sandy gravel or gravelly, coarse to medium-grained sand with limonitic lenses (riverbed sediment facies). They gradually pass into fine, silty sand and clayey-silty sand, forming the floodplain facies of the alluvial deposits. On the other hand, in the geotechnical boreholes close to the Tg. Lăpuş – Baia Mare highway and in wells deepened for mineral water exploitation (Borcut No. 5, 6 and 7), the thickness of the gravel reaches 8 m. In the above-mentioned seismic profile, the same thickness of the so called "low-velocity level" appears. The thickness of the Quaternary sediments suddenly increases to north-east to the Preluca Fault line (Fig. 3).

In several boreholes, at the base of the south-western part of this depression, crystalline rocks appear (with a thin cover of red breccias), while other drillings intercepted the Quaternary over the Oligocene deposits, respectively, the Vima and Valea Lăpuşului formations. The boundary between these two basement units is the south-eastward curved wing of the regional Preluca Fault. Close to the western boundary of the basin, the borehole No. 28 traversed quartzite and paragneiss series, 32 m thick, followed by 15 m thick fault breccias and 20 m thick Eocene red sands of the Valea Nadăşului unit. The aforementioned series is underlain by another quartzite and paragneiss series, which has been intercepted to the top of the borehole (Fig. 4). The reverse character of the Preluca Fault is clearly seen on the northern segment of the Dealul Mare – Dobric seismic profile (Fig. 5). Based on the results of magnetic ΔT measurements for Mn–Fe ore, other secondary faults, such as parallel and radial lines, were identified out of the outcropping area. One of them was traversed in the Dobric East directional gallery, horizon 220 of the second Răzoare pit.

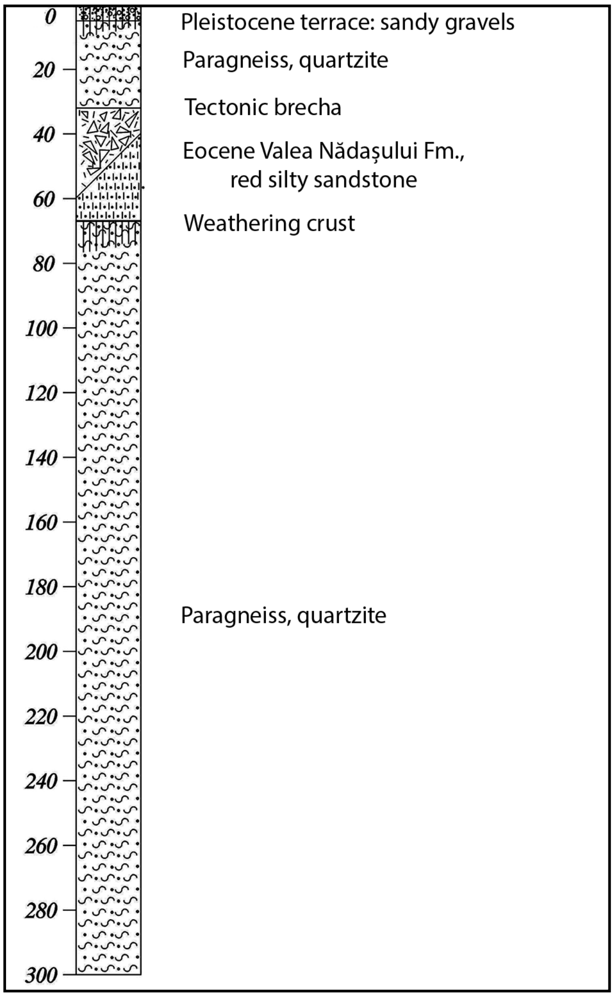


Fig. 4. Lithologic column of exploration borehole No. 28 Bolongu - Răzoare

By modelling the sediment filling of the Lăpuş Basin using both sedimentological and geochemical criteria, we tried to find out (i) the relative time scale of the different levels, and (ii) what type of sediments have been transported by the River Lăpuş and its tributaries in the past and in the present.

4.2. Quaternary chronostratigraphic data

Two palynological and one paleontological samples were analysed in the studied area, as follows:

The oldest sampled level is placed on the outcropping scarp of the *La Ţărm* plateau, on the left side of the River Lăpuş, close to the gas pipeline crossing. Here, an embedded layer 35 cm thick of grey, sandy silt appears in the upper half of the fine-grained, yellowish-grey, silty sand of terrace deposit, *i.e.* that of the 2nd terrace level (Posea 1962). The sporopalinological content of the sample is the following:

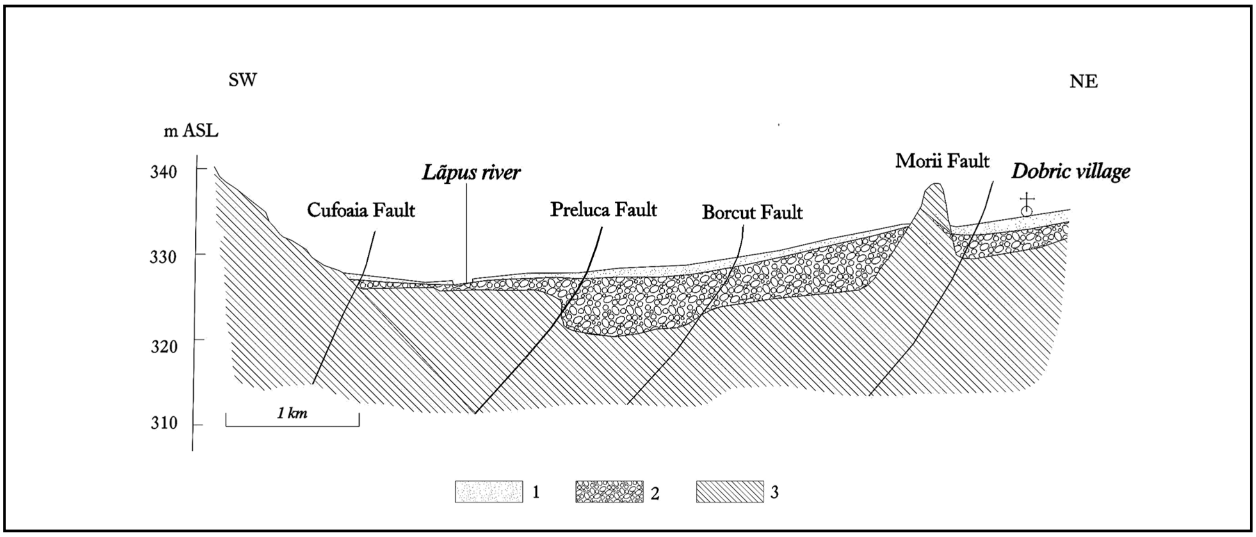


Fig. 5. Cross section of the Lăpuş basin, following the northern segment of the seismic profile Dealul Mare – Dobric (after IPEG Maramureş data). **1**. Fine-grained, sandy-silty level; **2**. Coarse-grained, sandy-pebbly level; **3**. Pre-Quaternary formations.

Fungi sp.	5 ex.
Aneura sp.	1 ex.
Ophioglossum vulgatum	7 ex.
Polypodium vulgare	11 ex.
Pinus silvestris	20 ex.
Abies sp.	5 ex.
Picea sp.	8 ex.
Artemisia vulgaris	2 ex.
Artemisia sp.	10 ex.
cf. *Riccia* sp. (corroded)	3 ex.

In this sample, a poor and scarce sporopolinic association was described, in which ferns and conifers dominate. Together with the *Artemisia* species, these plants imply cold and dry climate and may originate from the end of the Late Glacial Period. Lacking other chronostratigraphical data, we consider these sediments to belong to the upper part of the Würm stage.

The dark brown clayey silt sample from borehole 34 (0.4–1.2 m) was taken from the upper half of the floodplain sediment. Here, the following sporopolinic association was identified (Plate II, photos 3, 4, 5 and 6):

Fungi sp.	785 ex.
Ciliates	46 ex.
Algae:	
Botryococcus braunii	2 ex.
Spirogyra sp.	6 ex.
Concentricystes sp.	138 ex.
Bryophyta:	
Plagiopus sp.	14 ex.
Filicales:	
Lycopodium annua	4 ex.
Botrychium sp.	4 ex.
Polypodium sp.	1 ex.
Asplenium sp.	1 ex.
Cystopteris fragilis	2 ex.
Gymnospermae:	
Pinus silvestris	2 ex.
Picea sp.	4 ex.
Angiospermae:	
Typhia latifolia	*5* ex
Carex sp.	*3 ex.*
Scirpus lacustris	*2 ex.*
Phragmites cf. australis	*5 ex.*
Corylus avellana	*35 ex*
Alnus glutinosa	*15 ex*
Salix fragilis	*5 ex*
Fagus silvatica	*10 ex*
Quercus robur	*3 ex*
Ranunculus sp.	2 ex.
Sedum sp.	4 ex.
Scabiosa columbaria	3 ex.
Linaria vulgaris	1 ex.
Lycopus europeus	1 ex.
Inula sp.	2 ex.
Achillea millefolia.	2 ex.
Sinapsis arvensis	1 ex.
Cardaminae sp.	3 ex.
Plantago lanceolata	1 ex.
Artemisia campensis	1 ex.
Artemisia vulgaris	2 ex.
Tragopagon sp.	1 ex.
Carduus sp.	5 ex.
Centaurea sp.	10 ex.
Panicum cf. *millaceum*	3 ex
Cirsium sp.	1 ex.
Arenaria sp.	1 ex.
Polygonum aviculare	2 ex.
Chenopodium album	3 ex.
Chenopodium bonus-henricus	4 ex.
Chenopodium sp.	2 ex.
Atriplex tatarica	1 ex.

Comparing the aforementioned association to similar palynological profiles such as the Bócsa borehole, East Hungary (Borsy *et al.*, 1991), both hydrophilic (as *Typhia, Carex, Phragmites, Salix, Alnus* and a rich Bryophyta population) and grassland plants (*Arenaria, Chenopodium, Plantago, Polygonum*) are represented. Among tree pollens, the Thermophyta species prevail, the dominant form being the hazelnut and, sub-dominantly, *Quercus robur* and some herbaceous plants (*Centaurea, Chenopodium bonus-henricus, Plantago, Atripex* and *Tragopagus*). These taxa indicate the „Hazelnut climatic optimum" on the Atlantic phase (4.5–5 Ka B.P.), with transitional palynomorphs to Subboreal (*Polypodium, Asplenium, Linaria, Achillea, Polygonum* and the Chenopodiaceae). The tree and some grassland pollen grains show evident transport traces, indicating repeating floods, which covered the actual floodplain with fine-grained sediments.

The three pollen grains of *Panicum* (panic-grass) and the high number of *Concentricystes* algae forms indicate disturbed, trod, pastured soils, probably linked to the human presence and activity in this region.

The paleontological data come from the limonitized sand level (Plate II, Photo 2) below the silty-sandy floodplain deposit close to the mouth of the Morii Valley (see Fig. 3). The 70 cm long reddish bone was examined by specialists in Quaternary mammal palaeontology, Dr. Petre-Mihai Samson and Dr. Costin Rădulescu. According to their opinion, the fossil remain is the left femur of a *Bos primigenius primigenius* specimen. In their short (unpublished) reports, the scientists assume that the auroch probably weighed more than a ton. Such remains have been found in Mesolithic sites (8–9 Ka BP), but this species became extinct in Europe far before the Bronze Age. The small-tailed aurochs, *Bos primigenius*, from which European cattle is thought to have descended directly, was domesticated in the Near East. It appeared on East European grasslands later (5–6 Ka BP) (Kyselly, 2008; Edwards *et al.*, 2010). Thus, the sandy-pebbly level of the Lăpuş Valley is presumably younger than the last floods of the Late Glacial Period – *i.e.* the Pleistocene–Holocene boundary interval.

Therefore, the Quaternary sediments of the Lăpuş Basin are older than the Late Pleistocene-dated terrace II. The basin was filled with coarse, gravely-sandy sediments during the Mesolithic (8-9 Ka B.P), while the fine-grained floodplain sedimentation culminated during the climatic optimum at the Boreal-Subatlantic transition of the Holocene (4.5–5 Ka B.P.), when human presence is also to be assumed. To note that the uppermost 20–30 cm of the floodplain sediments in which historic and recent garbage is found belongs to the late floods, before the regulation of the river and its tributaries.

4.3. Dynamics of sediment transport and deposition – grain size analysis

The grain size distribution of the sediments was analysed in 102 samples from 36 shallow boreholes and stream sediments for the whole Upper Lăpuş hydrographical basin.

Since the distribution of the different grain size classes might be characterized by using numerical methods, either for the type of transport or the sedimentation, their variation was studied both along the river, from the spring till the discharge in Lăpuş–Dobric floodplain, and across the valley, from the riverbed to the floodplain or the first terrace level.

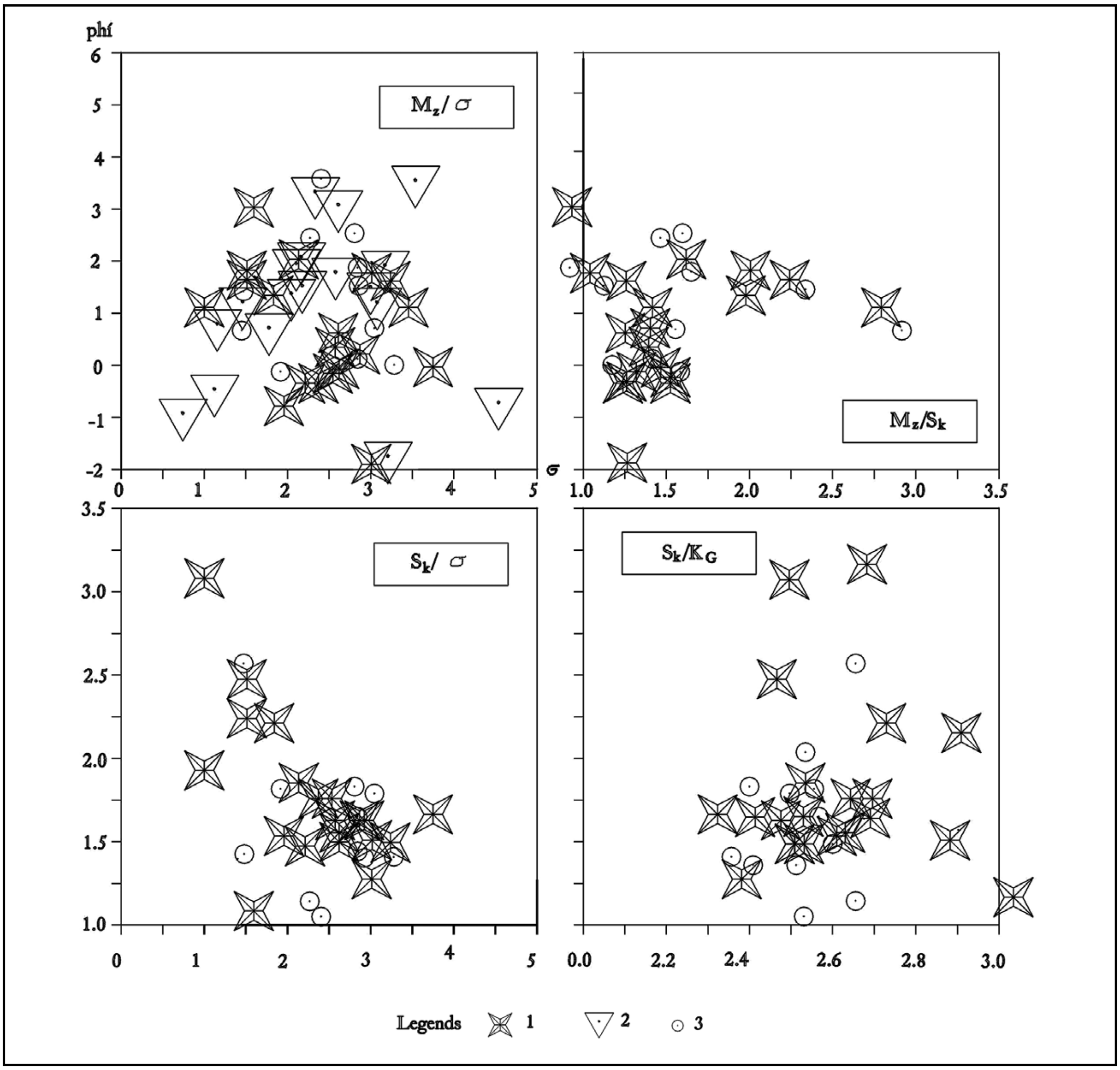
It is generally known that such a sediment sample is a heterogeneous set of grains of different sizes, from the finest (clay) particles to coarse-grained (gravel, pebble or block) elements. However, in natural material, grain size population is represented closely by normal or log-normal (Gaussian) distribution. For this reason, the grain size distribution was characterized using the four main parameters: 1) the mean grain size M_z, 2) the dispersion σ, 3) the skewness $S_{k,}$ and 4) the kurtosis K_G, each one with its genetic significance.

The mean grain size M_z describes the type of the sediment (clay, silt, sand etc.). The dispersion σ shows how large is the size variation below and above the mean size, *i.e.* the degree of grain sorting. The skewness S_k indicates deviation toward the fine size domain (left or negative skewness) or toward the coarse one (right or positive skewness), while the kurtosis K_G indicates the excess of grains close to the mean size, measuring the amplitude of the fluctuations during the sedimentary process.

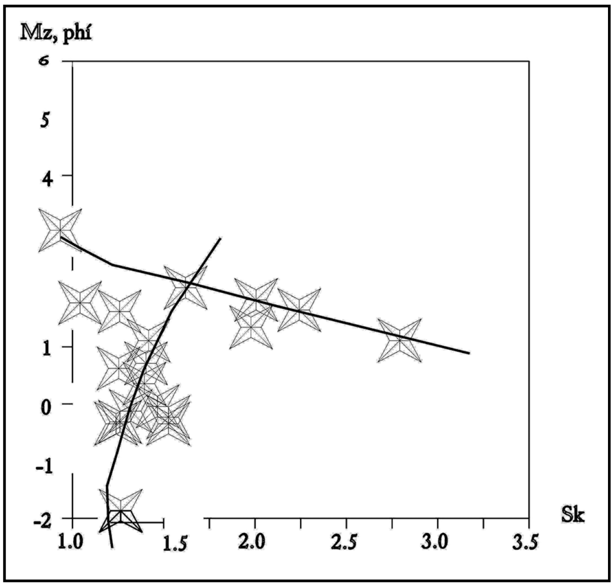
On the φ grain size scale ($\varphi = - g \log 2$, in which g is the grain diameter measured in mm), using the formula of Folk & Ward (1957), these parameters can be easily calculated. Friedman (1971) highlights, that a combination of the pairs of these parameters (M_z/σ, M_z/S_k, S_k/σ and $S_k/K_{G)}$ bears genetic significances, *i.e.* they indicate some peculiarities in the transport and sedimentation.

These parameters were calculated for the sediments of the mountainous, the hilly and the floodplain segments of the River Lăpuş and its tributaries. The shape and density of the parameteres of the three groups on Friedman diagrams differ, confirming the differences between the sediment transport and sedimentation for the studied water flow segments (Fig. 6).

It can be concluded that in the mountainous zone, the speedy, turbulent creeks gather the sediments through (active) slope processes and the sediment transport occurs in a narrow, irregular, rocky riverbed. In this zone, there are only small, temporary banks, characterized by coarse, slightly sorted and unabraded sediment (Plate II, Photo 1). In the studied samples the coarse-grained sediments are characterized by unsorted character, thus with a large variation of parameters; as a consequence, they occupy extended fields in these diagrams. Metallic minerals that



▲ **Fig. 6.** Friedman diagrams for the mountainous (**1**), the hilly (**2**) and the floodplain (**3**) segments of the Lăpuş River and its tributaries.



◀ **Fig. 7.** Positive correlation between the mean grain size M_z and the skewness S_k for heterogeneous sediment input from the slopes *versus* inverse correlation for selected, moving sediments of the riverbed in the mountainous segment of the River Lăpuş.

contain heavy, toxic metals may get into the sediment in this segment of the river.

In the hilly segment, the energy of the water along with the gradient of the riverbed decrease. The characteristic flow type is laminar, and the sediment input is limited to the lateral erosion of older terraces or of Oligocene and Miocene formations. During flood periods, the sandy and silty materials are spread and accumulated on the banks. Apart from the gravels and pebbles which roll and/or are fixed in the riverbed, the samples from a finer, more or less sorted material of the banks and terraces show a more regular, defined field on the diagrams.

Finally, in the meandering, often stagnant segments of the Lăpuş River and of its tributaries, the transport of the fine, silty–clayey fraction is limited to the flood periods. The relatively homogeneous character of these sediments and the quiet sedimentary condition appears on Friedman diagram as a small centred field (Fig. 6).

More detailed aspects of these diagrams show some peculiarities of the sampled material. For instance, in the samples from the mountainous segments, two opposite M_z/S_k correlation are visible, because the heterogeneous lateral (slope) sediment input is mixed with the washed, coarse riverbed material (Fig. 7). In the case of the samples from the alluvial filling of the basin, however, the skewness is prominent because the accentuated energy oscillation during the floods results in „strudel dough"-like fine sand–silty clay structures within the sediment (Fig. 8).

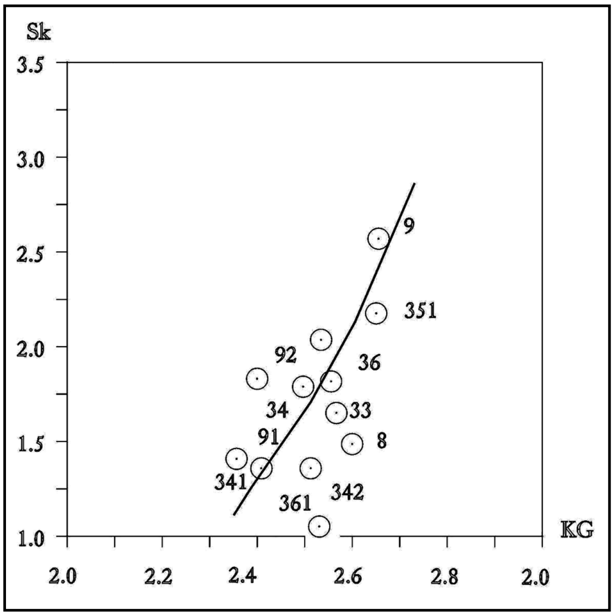


Fig. 8. Positive correlation between skewness Sk and kurtosis K_G due to the repeated and intensive changes of the sedimentation regime in the floodplain alluvium during flood periods

The same samples were grouped by site location, *i.e.* riverbed, riverside and floodplain/terrace sediment sites. This grouping makes it possible to participate in a real journey through time – from the present days to the Late Pleistocene (Fig. 9).

The actual stream sediment consists of sand, locally associated with pebbles and a small amount of fine-grained material. As a result of the continuous washing of the sediment material, the stream sediment samples – containing heavy, metallic mineral particles (Plate I, Photos 5 and 6) released from waste rock dumps and tailing ponds – appear on the Mz/σ diagram as a well-grouped field. The negative correlation between skewness and dispersion indicates a sediment transport dominated by saltation (Fig. 10).

The riverside sediments were mainly formed in the historical past; the sedimentation took place during the withdrawal of the muddy water of floods. These samples have been plotted on an extended area in Mz/Sk and Sk/σ diagrams. The scarce values of the skewness and the K_G of these sediment samples indicate quiet sedimentation under low energy regime.

The samples taken from the upper levels of ancient floodplains and from the terraces show similar characteristics due the accentuated amount of coarser grain fractions. It seems likely, that during the wet periods of the Early Holocene and Late Pleistocene the transport energy was higher than in the present and in the historical past.

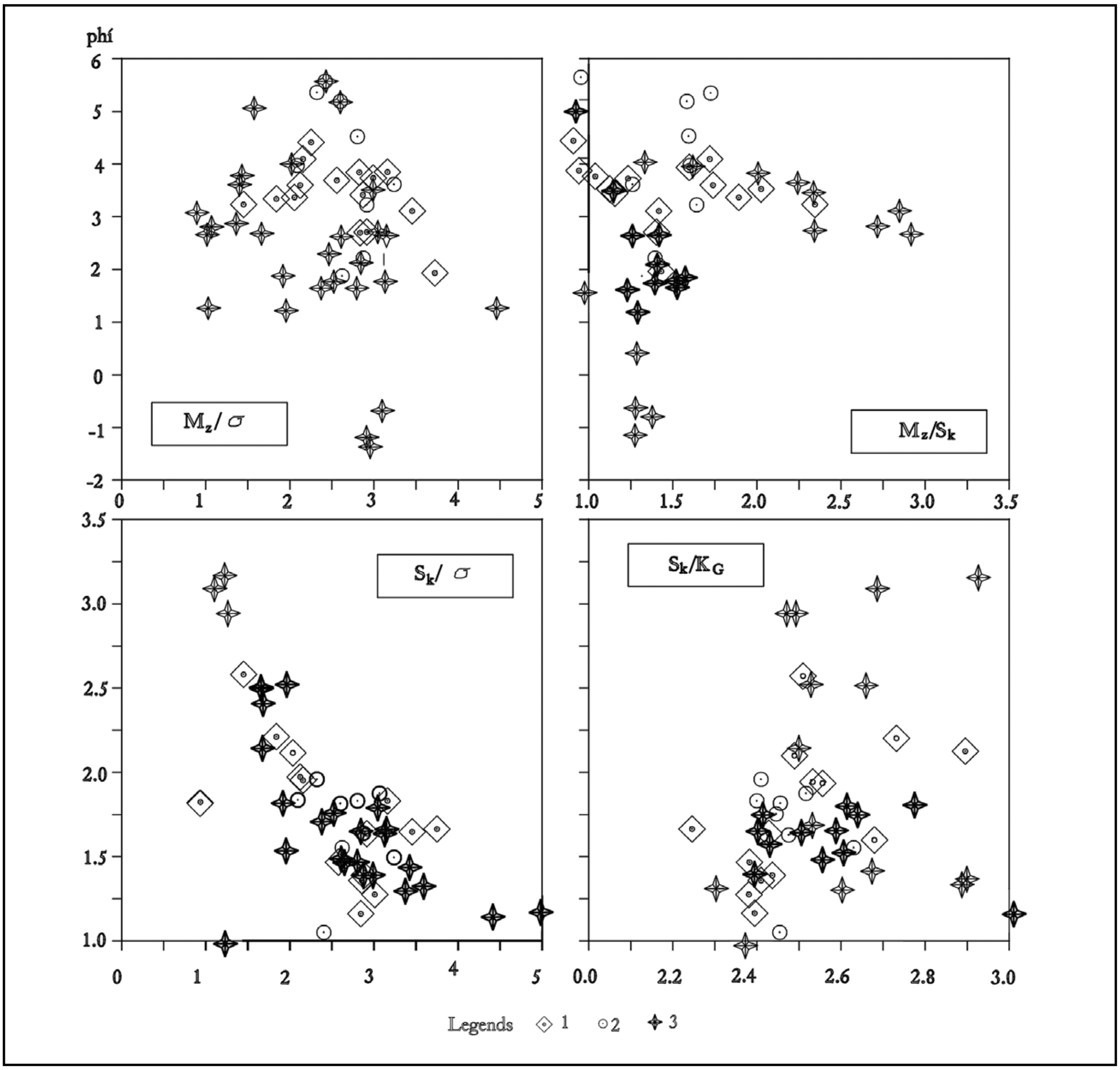
The statistical grain size analysis of the sediment samples led us divide the sediment types similarly according to the geomorphologic criteria. Because all types of these sediments contain grains of metallic minerals, this separation permits to reveal the heavy metal risk in time, for each sediment type.

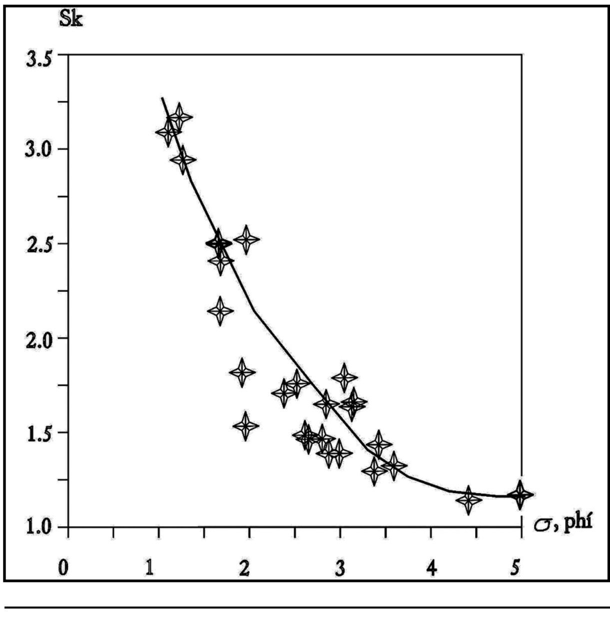
4.4. Transport, sedimentation and movement of heavy, toxic metals

To verify the conclusions of the grain size analyses, we have to examine the behaviour of the toxic, heavy metals – as chemical–mineralogical „markers" – in each type of sediment. On this purpose, the same samples were used both for grain size and geochemical analysis. Therefore, it s possible to decide whether the geomorphological setting is reflected in the distribution of certain elements in these sediments or not. Apart from visual comparison of the analytical results, suitable conclusion are drawn using statistics, *e.g.* the Student`s t-test for all the seven heavy, toxic metal contents of the samples.

In case of normal or lognormal distribution, the Student`s t-test verifies, that in set M and N, the X{x, y} variable (*i.e.* the concentrations of the respective element) belongs to the same set, or forms two significantly different sets. For this, the following relation will be applied:

$$t = \frac{x - y}{\sqrt{(n-1)s_x + (m-1)s_y}} \sqrt{\frac{nm(n+m-2)}{n+m}} \quad [1]$$





▲ **Fig. 9.** The Folk-Ward diagrams for floodplain/terrace (**1**), riverside (**2**) and stream (riverbed) sediments (**3**).

◀ **Fig. 10.** Negative correlation between skewness S_k and dispersion σ: the saltation of the sand grains dominates within the actual stream sediment processes.

in which *m* and *n* are the number of the samples of the sets M and N, *x* and *y* the mean value of the concentration in each set, and *sx* and s_y their dispersion. If the result is that $t<t_{adm}$ (*i.e.* the value established for the number of pairs and the desired significance level), the hypothesis H=0 is verified, there are not significant differences between these groups; in the opposite case, the groups differ from each other. In this study, the Student`s t-test was applied for Cu, Ni, Zn, Cd, Pb, Cr and Fe, at 0.05 significance level.

First, the distribution of these elements among the mountainous, hilly and floodplain segments were calculated (Table 1).

Excepting Cd values (where measured concentrations are close to the detection limit), the Cu (relation hill/basin) and Ni ones (relation mountain/hill), heavy elements do not fulfil the H=0 criteria, thus their groups show significant differences between the geomorphological type of their sampling sites.

Since the data sets of the elements significantly differ, the question is what happens with them along the river? Comparing the mean concentration values (in ppm), both positive and negative differences appear. To note that positive difference implies accumulation, while the negative difference indicates the dilution (or loss off) of the respective element (Table 2).

From natural and/or anthropogenic sources, a continuous supply of Cu, Zn, (Cd?) is assured, whereas Ni, Pb, Cr and Fe (*i.e.* the elements of the pyrite deposits in the flotation ponds) are discharged from the mountainous area toward the hilly zone and mainly to the basin area. Finally, all of these heavy metals (including Ni and Cr, the main trace elements of pyroxenic andesites) accumulate in the basin. According to the geological-geophysical data, the grain size and the geochemical observations, a local depocenter is outlined inside the idiographic Lăpuş Basin.

4.5. Neotectonics: local and regional evidences

The main tectonic element of the studied area is the Preluca Fault, a regional disjunctive line drawn first by Hoffman (1888), described by Kräutner (1937) and largely commented by Paucă (1962). The exploration boreholes in Copalnic Basin were studied by Macovei (1994), who referred to the role of the Preluca Fault in the evolution of this area. By exploration borehole No. 28 (Bolongu hill, Răzoare) the reverse character of the western segment of this fracture was confirmed.

Kalmár & Ionescu (1968), analysing the geometry of Preluca Fault and certain secondary faults, demonstrated that the Ţicău and Preluca crystalline islands are coupled like two cogwheel pieces: the Ţicău Mts. pursue a clockwise rotation, while Preluca Mts. an anticlockwise rotation, stretching the so-called Chioar Couloir between them. For this reason, starting from the Ştiurdina valley (Copalnic Mănăştur), the character of the Preluca Fault is changing from a normal to a reverse fault. At the same time, the E–W oriented fault line is curved to NW–SE and, finally, to N–S direction (Figs. 3 and 11), producing a more than 150 m horizontal displacement of the lithological limits, detail which was also observed and mapped by Mészáros & Ghergari (1979). Numerous mineral and normal water springs mark the route of the major fault lines and the secondary fractures. It seems like these fractures are still active, causing the deformation of the water flow network and the formation of small, local and active depocenters. The Lăpuş River basin is one of them.

The formation of the Preluca Fault and the major adjacent tectonic lines began in the early Badenian, when the tension field on the northern Preluca Highs was discharged by the falling down of the Baia Mare – Copalnic – Lăpuş zone. This pull-apart movement was followed by explosive volcanic activity of 16 Ma (K/Ar dating) in the Coaş zone (Kalmár & Ionescu, 1970). The differences in the thickness and lithology of the Sarmatian

Table 1. The Student`s t-test for heavy metal contents from mountain, hill and floodplain segment of Lăpuş River.

Segment		T values for heavy metals							t admissible
		Cu	Ni	Zn	Cd	Pb	Cr	Fe	
Mountain	Hill	24.591	**1.073**	209.943	4.458	15.10	4.252	18.7357	2.412
Mountain	Basinet	19.301	7.7338	114.856	**0.395**	8.501	9.375	22.369	2.861
Hill	Basinet	**2.129**	5.758	36.506	**2.838**	3.831	5.209	6.702	2.861

Table 2. Distribution of heavy metal contents between several segments of Lăpuş River

Segment		Difference between the mean contents (in ppm)						
		Cu	Ni	Zn	Cd	Pb	Cr	Fe
Mountain	Hill	80.199	**-1.284**	1387.748	1.350	**-42.013**	**-3.299**	**-38.089**
Mountain	Basinet	8.865	8.991	296.858	1.568	**-15.791**	5.611	16.219
H8ill	Basinet	71.334	10.275	1090.890	0.218	26.222	8.910	54.311

and Pannonian deposits eastward, to Baia Mare, prove that the Preluca Fault was repeatedly reactivated in the Miocene and in the Pliocene periods, and continues the uplifting of the Early and Late Pleistocene terraces of river Lăpuş on the back of the crystalline island at more than 50 m in some sites.

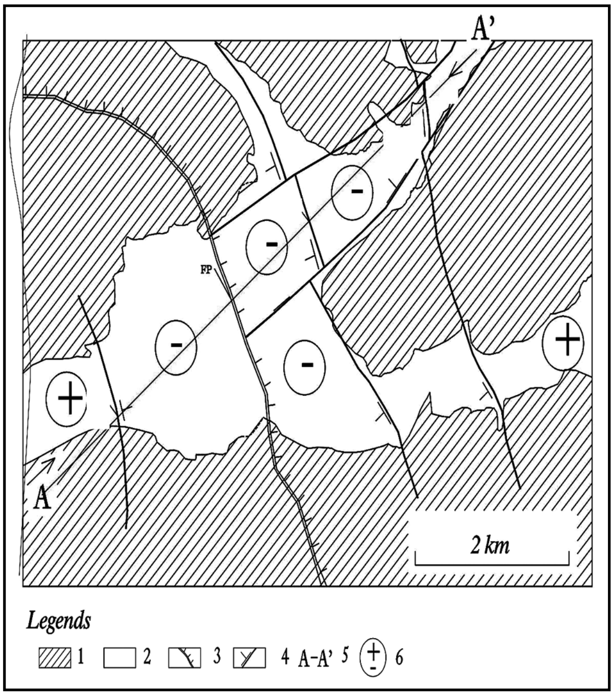


Fig. 11. Tectonic sketch of Lăpuş Basin. **1**. Pre-Holocene background; **2**. Holocene alluvial filling; **3**. Preluca Fault; **4**. Secondary faults with dip direction; **5**. The location of the Dealul Mare–Dobric seismic profile; **6**. Uplift (+) and sinking (-) of the blocks.

We assume that the starting of the turning of the Preluca crystalline block began around the Pleistocene–Holocene boundary, when the big aurochs *Bos primigenius primigenius* lived. The Preluca block pushes the Dobric block to NE and weighs it down. The here formed depression was filled up with coarse, sandy–pebbly sediments carried both by the River Lăpuş and by the Dobric rivulet and their tributaries. The tectonic activity was reactivated during the „hazelnut period" (4.5–5 Ka B.P.) and it seems to continue during historical times and nowadays, too. The increased heavy metal content in the upper levels of the basin proves that its sinking was active during the „historical" mining activity (14^{th}–18^{th} centuries).

The local neotectonic activity in the studied area can be integrated into the larger Pleistocene and post–Pleistocene movements of the whole Pannonian Basin (Thamó-Bozsó *et al.*, 2002; Timár, 2003; Nádor *et al.*, 2007; Gábris & Nádor, 2007). It involved on the present as the main moving stages of the Eastern Hungarian blocks in the Late Glacial (10–12 Ka B.P.) and during the Atlantic/Subboreal transition (4.5–5Ka B.P.). Within the frame of the global and regional movements, these neotectonic events have activated the Eastern border of the Pannonian Composite Terrain, including the basement of the Lăpuş basin.

5. CONCLUSION

The upper part of the discharge basin of the Lăpuş River (NW Transylvania, Romania) collects the watercourses mainly from the mountainous area, traverses the hilly zone and discharges in a large floodplain. The floodplain was formed by the progressive filling of the depression in front of the Preluca Fault. Based on palynological and paleontological data, we assumed that the depression was „carved" in the Late Pleistocene landscape, including some terrace deposits. During the Mesolithic time, it was filled at first by coarse sandy-gravelly sediments. The last important input of fine, silty-clayey sediment occurred at the Atlantic/Subboreal boundary. Based on the analyses of the grain size distribution parameters of the samples from shallow boreholes and stream sediments, the mountainous source area of the sediments, the hilly – considered mainly transport segment – and the floodplain, as area of sediment accumulation, were defined. The same features allow the characterisation of the stream sediments, the riverside sediments and the sediments of older floodplain terraces and Pleistocene terraces.

Beside the mineral grains and rock fragments, water flows also transport different minerals coming from natural hydrothermal ore accumulation and from products remaining from the historical and industrial mining activity. The results of the grain size study were verified by the statistical analysis of the toxic heavy metal contents of the samples. Though the heavy metal element transport from the source area was characteristic also before the mining activity, the main inflow, both in riverbed and in the riverside sediments, took place in the last hundred years of industrial mining. The balance of the mean concentrations indicates that these elements are generated continuously and transported during the most important floods from the mountainous source area with opened waste rock dumps and tailing ponds, through the hilly area, toward the sedimentation sites: the riverside and the floodplain. Nowadays, by the regulation of the Lăpuş River and its tributaries, the sediment charge of the river is discharged directly into the Lăpuş canyons.

The Lăpuş basin was formed and evolved to reach its present state by the moving Preluca Fault, an important tectonic line with repeated reactivation periods, including those of the Late Pleistocene–Holocene. Tectonic activity still continues today.

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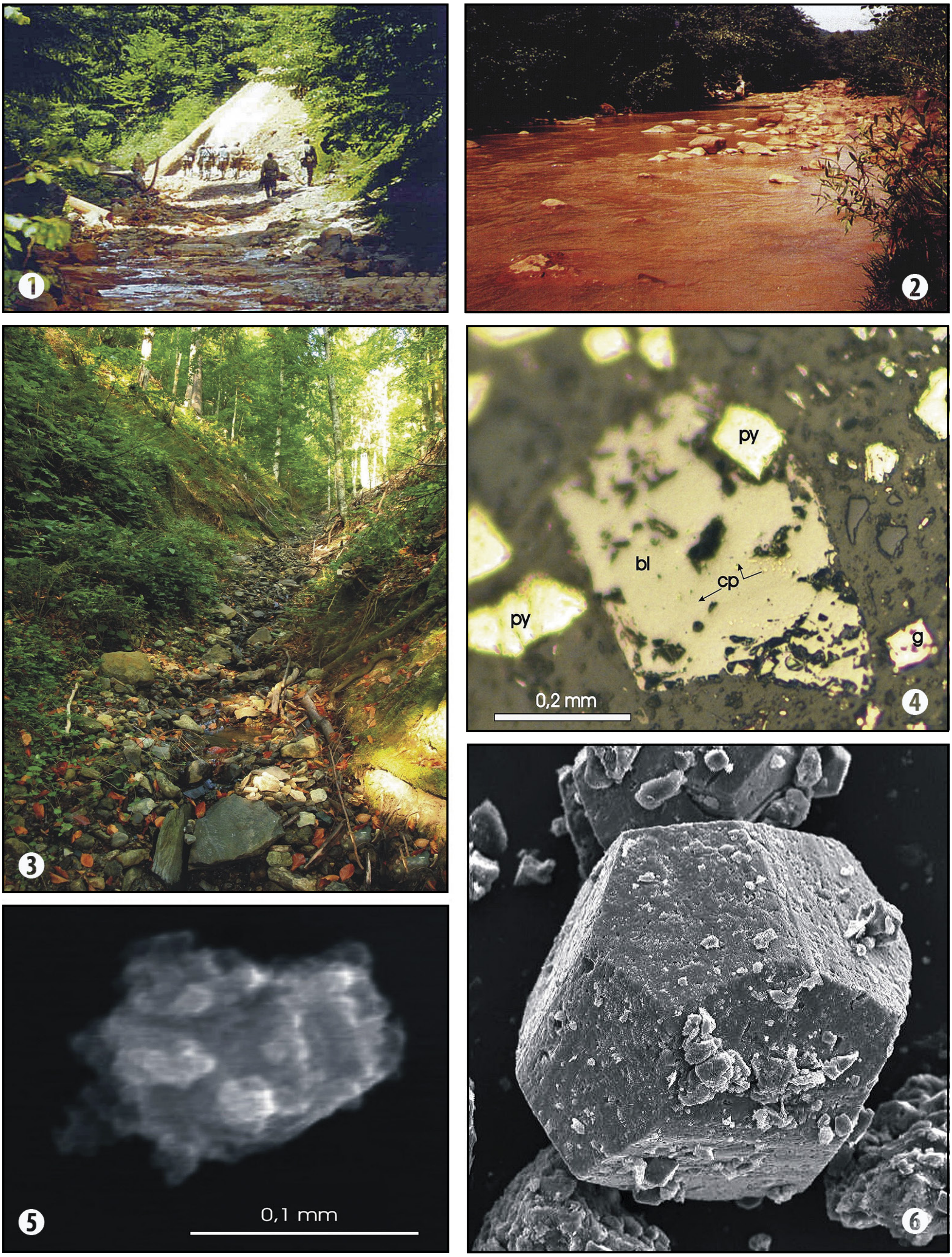

Photo 1. Conciu Valley, Băiuţ: an unprotected heap of Breiner mine. **Photo 2**. Red flood caused by mine water eruption in Breiner mine. **Photo 3**. Neagra valley, Băiuţ, V-shaped valley transporting coarse-grained alluvia. **Photo 4**. Sulphide ore with pyrite (py), galenite (g), sphalerite (bl) with chalcopyrite inclusions in quartz gangue; polished section from Coasta Ursului heap, Poiana Botizii. **Photo 5**. Galenite grain from the stream sediment of Lăpuş River, Rogoz; SEM microphotograph. **Photo 6**. Pentagonal dodecahedron pyrite crystal from the stream sediment of Lăpuş River, Rogoz; SEM microphotograph.

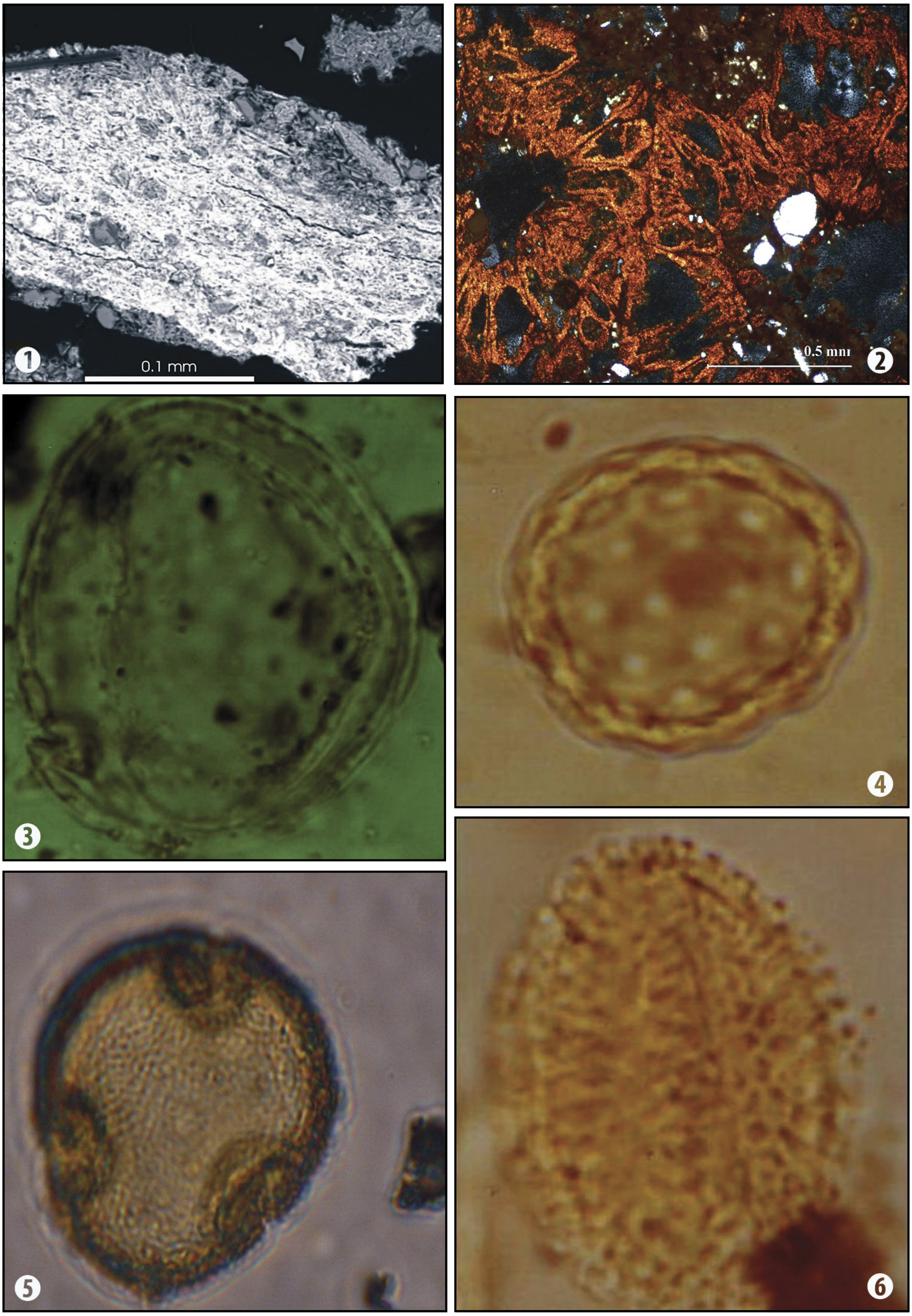

Photo 1. Unabraded clayey siltstone fragment from stream sediment (Strâmbu valley); SEM microphotograph. **Photo 2**. Fibrous ferrihydrite cementing the coarse-grained sand (mouth of Morii rivulet, Tg. Lăpuş); thin section, unpolarized light. **Photos 3-6**. LM microphotographs of pollen and spore grains from shallow borehole No. 34 (1500x magnification): **3**. *Concentricystes* sp. **4**. *Chenopodium bonus-henricus*. **5**. *Fagus sylvatica*. **6**. *Salix* sp.

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