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**RECONSTRUCTION OF FLUVIAL PROCESSES IN THE MAROS
RIVER BASIN, WITH PARTICULAR REFERENCE TO THE
APPLICABILITY OF OSL SENSITIVITY**

Summary of PhD thesis

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1. Introduction, aims

To reconstruct fluvial processes, explore and understand the dynamics of surface processes, it is essential to place geomorphological changes in a numerical time frame. Optically stimulated luminescence (OSL) is a widely used technique in this field. It can be used to study the quartz and potassium feldspar mineral fractions of various sediments. However, the applicability of the technique is largely determined by the luminescence properties of the minerals used in the measurements.

Recently, it has been shown that the luminescence properties of minerals, in particular quartz, can be used as an indicator of fluvial erosion and/or sediment origin for various fluvial processes (e.g. Gray et al. 2019). One of these properties is the so-called luminescence sensitivity of quartz grains, i.e. the intensity of the luminescence response per unit dose. Laboratory tests have shown that the magnitude of luminescence sensitivity can vary in response to light and heat exposure and radioactive radiation (e.g. Stokes 1994). Thus, in nature, high sensitivity has been associated with a high number of sediment cycles and low sensitivity with their absence (e.g. Moska and Murray 2006, Preusser et al. 2006). In addition, it has also been shown that the lithological background of quartz, i.e. the source area, can also be a crucial factor, so luminescence sensitivity can be used for the analysis of sediment provenance (e.g. Tsukamoto et al. 2011). Overall, however it is still questionable whether it is the inherited properties of source rocks (as primary factors) or the sedimentary history (as a secondary factor) that determine the luminescence sensitivity of sedimentary quartz.

While luminescence dating is an important tool in quaternary geomorphological research, luminescence sensitivity studies can further increase the range of processes that can be explored.

Although the reconstruction of the Late Pleistocene evolution of the lowland alluvial fan of the Maros River using OSL dating has been done before, such studies have not been carried out in the middle and upper section of the river. The Retezat Mountains in the mountainous catchment of the river are one of the members of the Carpathians that were heavily glaciated during the Pleistocene glaciations (Urdea 2004). Changes in the glaciation and deglaciation phases in the area may have affected the ability of river to work downstream. Thus, sediment accumulation in the Hateg Basin in the foothills of the Retezat may be related to deglaciation. The terraces of the Middle Maros may also reflect these phases. In addition, a number of paleochannel patterns can be identified on the prominent alluvial fan of the lowland area of the Maros River. Their temporal and spatial displacements, water yields and channel types are indicators that the sediment discharge and sediment

transport capacity of the river increased significantly from the Late Glacial to the Early Holocene and was higher than the present (e.g. Kiss et al. 2013).

The doctoral thesis and the objectives can be divided into two main, interdependent parts. Since luminescence sensitivity studies have not yet been carried out on the sediments of the Carpathian Basin, the first step of the research is to investigate the potential of the technique.

Exploring the methodological potential of luminescence sensitivity parameters:

- Laboratory tests to develop a suitable measurement protocol for quartz grains (90-150 μm) of fluvial origin.
- Determination and comparison of the luminescence sensitivity parameters of quartz grains from the main rivers of the Carpathian Basin (Danube, Tisza, Maros).
- Investigation the luminescence properties of recent fluvial samples collected along the Maros and its main tributaries and exploration the surface lithology and geomorphological correlations.

The second main objective of the research is related to the reconstruction of the Late Pleistocene geomorphological processes in the upland catchment of the Maros River Basin and along the Middle Maros. Mainly through OSL dating and luminescence sensitivity studies.

Exploration of the late Pleistocene geomorphological processes in the middle section of the Maros:

- Reconstruction of the geomorphological processes using OSL age dating methods in the Retezat Mountains, Gura Zlata and Râul Mare valley, Hateg Basin and the young terraces of the Middle Maros.
- Use of the correlations identified in the first part of the thesis in the geomorphological reconstructions.
- Exploration of the temporal and spatial relationships between the geomorphological events identified in the studied areas.

The results of this thesis can answer the following questions: What the further possibilities for are investigating the luminescence sensitivity of Carpathian Basin fluvial samples? What are the factors and methodological problems to be expected in future research in this field?

How might late Pleistocene climatic changes have influenced the formation of the alluvial fan of the Hateg Basin and the terraces that can be recognised in the middle section of the river? Did tectonic processes in this section of the river possibly override climatic geomorphological processes? Lastly, how do the changes observed in the alluvial fan relate to the processes observed in the upland section?

2. Material and methods

The research was carried out on fluvial sediments from the Carpathian Basin. In the first instance, coarse-grained (90-150 μm) fluvial quartz from the main rivers in the area, such as the Danube, Tisza and Maros. In the second phase of the research, the sedimentary materials of the Retezat Mountains, the Hateg Basin and the terraces along the Middle Maros were investigated.

Optically stimulated luminescence dating (OSL) was used to reconstruct the temporality of geomorphological processes, complemented by a luminescence sensitivity analysis of the quartz samples. To analyse the relationship between luminescence sensitivity and source rock, surface lithological maps were prepared, while geomorphological maps were also prepared to select OSL sampling sites and the reconstruction.

2.1 Compiling maps

To investigate the relationship between the lithological background and the OSL properties, the "Global Lithological Map Database v1.0" (GLiM) overlays compiled by Hartmann and Moosdorf (2012) were used as a basis. The database identifies 12 lithological classes for the study area. The data were processed and displayed in ESRI ArcMap 10.4.1. For the separation of the main lithology units for the Maros catchment, the map section of 1:200 000 scale *Harta geologică a R. S. România* map sections of Romania, 1967, were used, on basis to isolated 31 types. In order to select suitable sampling sites and study the surface evolution of the Hateg Basin and the Middle Maros terraces, prepared geomorphological maps based on 25 m resolution EUDEM (E50N20, v11) SRTM relief models. As part of further refinements, also used the 1:200 000 scale geological maps of Romania and, for the terraces, the more detailed 1:50 000 scale map of the area.

2.2 Luminescence dating and sensitivity measurements

The SAR protocol (Murray and Wintle 2000) was used to determine the equivalent dose for OSL dating for the quartz fraction, while for the potassium feldspar fraction, the pIR₅₀IR₂₉₀ protocol described by Buylaert et al. (2012) was used. Basically applied the so-called multi-grain (MG) measurement method for both mineral types, but single-grain (SG) measurements were also made in the case of potassium feldspar. Before each equivalent dose measurement, test measurements also performed to identify the optimal measurement setup. To determine the different natural bleaching of quartz and potassium feldspar minerals, applied a residual dose test on samples collected from the Gura Zlata valley in the Retezat Mountains.

To facilitate future comparability, the luminescence sensitivity tests were only performed on coarse-grained (90-300 μm) quartz grains. Nearly

identical (~6 mg) amounts of quartz grains were used for the measurements. To explore more complex relationships, were also investigated the sensitivity parameters using continuous wave optically stimulated luminescence (CW-OSL), thermoluminescence (TL) and linearly modulated optically stimulated luminescence (LM-OSL) techniques. For each technique, the signal response to a dose of 24 Gy was investigated using identical measurement settings (preheating at 210°C, and the same stimulation time as the technique). Artificial laboratory sensitisation of samples was also carried out.

Dose rate determinations, always essential for OSL age calculations, were performed using a Canberra XtRa Coaxial germanium detector gamma spectrometer.

3. Summary of results, theses

3.1. Luminescence characteristics

1. thesis: *The sensitivity of Alpine and Carpathian fluvial quartz in the lower section of the catchments show clear differences in terms of CW-OSL, TL 110°C peak and LM-OSL techniques.*

The analysis of the luminescence sensitivity of quartz grains of fluvial origin from different areas of the Carpathian Basin (Danube, Tisza, Maros catchments) has shown for the first time that the luminescence sensitivity of Alpine and Carpathian samples differs significantly even in the Great Hungarian Plain, hundreds of kilometres away from the source area. Accordingly, the quartz fraction of the sediments associated with the Danube had significantly lower values for all sensitivity parameters (CW-OSL, TL 110°C peak, LM-OSL fast component, total LM-OSL) than sediments from other rivers. Based on the data, it is clear that the below-average sensitivity may be typical for the whole Hungarian stretch of the Danube. The studies also showed that in the case of the Tisza, samples from the upper and lower section of the river behave similarly, so the data do not allow a clear conclusion on the actual downstream variation in sensitivity. This, and the role of tributaries, requires further investigation.

2. thesis: *Among the sensitivity parameters, the results of total LM-OSL and fast component ratio is the most applicable for the separation of sediments with different provenances.*

Among the different sensitivity parameters, the total LM-OSL intensities and the ratio of fast components showed the largest variation within a given group of samples. This leads to the conclusion that these parameters are the most useful in the Carpathian Basin for determining the source area of fluvial quartz grains. The results thus suggest that, in addition to the CW-OSL sensitivity, the component ratios in the OSL signal may also be a tool for the

future discrimination of river sediments with different lithological backgrounds.

3. thesis: *The sedimentary quartz grains of the Danube show a higher sensitivity with increasing age, while the Maros shows a lower sensitivity with increasing age.*

By comparing luminescence sensitivity and the age of the samples, only regional correlations could be detected. Thus, in the lower Danube, an increase in luminescence sensitivity is observed with the decreasing age of the samples. This may be due to repeated reworking of the sediment, as the Danube significantly reworked the area during the Late Pleistocene and Holocene, and thus the repeated natural bleaching may have increased the sensitivity of the grains. However, the opposite trend is observed in the case of the Maros, where the sensitivity of the quartz grains increases with age. On the surface of the Maros alluvial fan, recurrent avulsion events have resulted in less reworking of sediments by the river concerning a single channel. In addition, the water and sediment yields of the river increased significantly over the time interval studied (18-5 ka) so that the grains were transported to their final deposition sites more rapidly, with fewer cycles of sediment transport. These suggest that, in the longer term, geomorphological processes can significantly impact the luminescence sensitivity of quartz grains.

4. thesis: *In the case of the Maros River, luminescence parameters are strongly influenced by sub-basin and river section scale factors. No general trend in the variation of the different sensitivity parameters is observed over the 565 km stretch studied.*

Based on the analysis of recent sediment samples, an increase in the sensitivity of quartz grains can be observed along the Maros in the following cases: 1) the inflow of sediments associated with the Arieş River, which is partly derived from the degradation of granitoids and paragneisses; 2) in sections where no major tributaries are connected, and the river sediments can be repeatedly permeated with increasing distance. In addition, a clear decrease in values can be observed: 1) below estuary of the Târnava, a river that mainly transports Neogene sandy sediments, whose quartz fraction is moderately sensitive; 2) in the alluvial fan sections where quarrying from in channel. Therefore, it can be shown that the influence of both lithological, geomorphological, and anthropogenic factors on quartz susceptibility can be locally significant. Accordingly, no general trend in the different sensitivity parameters can be observed over the whole river section studied (565 km).

5. thesis: *Along the Maros, the residual dose from quartz grains shows a clear downstream decrease, but the trend may be broken by tributaries and erosion.*

For the residual doses measured from quartz grains, in agreement with the general model, the values show a decreasing trend with increasing transport distance due to repeated reworking and multiple bleaching. The results suggest that the increase in values over local and shorter river reaches may be due to: 1) the join of short tributaries carrying a limited number of sediment cycles; 2) increased erosion of paleosediments and sedimentary rocks by the Maros, which may be due to natural or anthropogenic factors (quarrying). All these processes introduce grains with a high equivalent dose into the sediment mixture of the river, which then increases the measured residual dose.

6. thesis: *Overestimation of age due to inadequate natural extinction in potassium feldspar samples - isolated and prepared with simple tools - can be eliminated by single-grain IRSL measurements in glacial and fluvial samples in the Maros catchment.*

Residual dose test measurements on samples from the Gura Zlata and Răul Mare valleys confirmed that the potassium feldspar samples have a slower trap discharge during natural exposure than the quartz samples, i.e. a much higher residual dose. For this reason, the multi-grain (MG) potassium feldspar ages differ significantly from the luminescence ages measured. However, the results of the single-grain (SG) potassium feldspar measurements, which were carried out with simple tools to avoid this, were within error of the ages measured from the quartz fraction for both the Gura Zlata valley and the Hateg Basin samples. This observation, suggests that SG potassium feldspar measurements can be used reliably in cases where periods beyond the quartz measurement limit need to be investigated or where quartz grains prove unsuitable for OSL measurements.

3.2. Geomorphological reconstruction of the study areas

7. thesis: *The MIS 3 stage in the Maros catchment was dominated by coarse-grained, gravel-sand sedimentation.*

Summarising the geomorphological processes revealed in the different study areas and taking into account their temporal scale, it can be concluded that the intensive coarse-grained sedimentation, i.e. the valley filling, can be dated to the MIS 3 stage (40-32 ka) in the high mountain catchment, in the pre-mountain basins and the middle section of the Maros. It can be assumed that this period was the period when most of the sediment was moving through the whole catchment and that the system was characterised by a surplus of

sediment that exceeded the sediment transport capacity of the watercourses. This suggests that the milder but highly variable climate associated with the MIS 3 stage created favourable conditions for the mobilisation of sediment and the initiation of sediment pulses throughout the catchment.

8. thesis: *A higher degree of fluvial incision in the middle catchment of the Maros was observed during the MIS 3-MIS 2 and the MIS 2-MIS 1 transition.* The studied sections show a strong, multi-area incision during the MIS 3-MIS 2 transition period (~30-27 ka), which is well-aligned with the terracing models that emphasise climatic transitions. Thus, during this period, the capacity for transporting sediment exceeded the amount of sediment entering the fluvial system with a simultaneous decrease in evaporation and an increase in surface runoff. Furthermore, the data suggest that the Râul Mare valley was also incised during this period. Overall, the MIS 2 stage has therefore achieved a balance between the amount of available sediment and the sediment transport capacity of the watercourses in the whole catchment. The data suggest that this equilibrium was only broken in the Late Glacial when a new incision event was observed in several sample areas from ~14 ka onwards.

9. thesis: *Based on the data obtained, fluvial processes along the Middle Maros were mainly influenced by climatic conditions.*

The results show that the major accumulation and erosion activities occurred in approximately the same period in different areas of the Maros catchment. Given that these periods coincide with climatically variable or transitional periods, it can be concluded that the observed processes are most likely to be primarily climatically driven. Although longer-term tectonic influences are observed in some sample areas, their direction is unlikely to have changed over the last 30 ka, and vertical displacements have determined the rate rather than the direction of geomorphological processes.

10. thesis: *In the Retezat valleys and the Middle Maros terraces, the luminescence sensitivity of some quartz grains shows significant differences, which may indicate a different source area.*

Measurements in the valleys of the Retezat Mountains show that there are large differences in the luminescence properties of the quartz fraction over a relatively small area. The quartz fraction of the samples from the fluvio-glacial terrace system was completely insensitive, while the samples collected at the terrace surface were highly sensitive. This suggests that the origin of the two sedimentary materials may be different, suggesting that the insensitive samples are probably related to the Râul Mare valley, while the highly sensitive samples are related to the Gura Zlata valley.

In the case of terrace T2/2, there are also quartz fractions of cover sediments showing a luminescence sensitivity more than two and a half times higher than elsewhere along the Maros, i.e. the most sensitive of all the samples studied. The large difference indicates another source area for the sediment, i.e. the floodplain sediments overlying the gravel material are most likely associated with the Boholt Stream, a tributary of the Maros.

11. thesis: *There is no temporal relationship between the deglaciation phases in the Retezat Mountains and the water yield of the paleochannels of the lowland alluvial fan, but the sediment mobilised by the increase in precipitation may have influenced the channel pattern of the lowland section.* The activity of the lowest water yield paleochannels defined on the Maros alluvial fan coincides with the M1 (~22-20 ka) and M2 (~18-17 ka) deglaciation periods of the Retezat glaciers. These suggest that the most intense glacial retreat has not significantly impacted the geomorphological processes in the Maros catchment, either in the middle section of the river or in the lowland alluvial fan. At almost the same time, i.e. during the deglaciation phases M3 (~16-15 ka) and M4 (~13.5 ka), paleochannel with significantly higher discharge rates appeared on the Maros alluvial fan, indicating a large increase in runoff values in line with the significantly more precipitated climate associated with the interstadial GI-1 (~14.5 ka), which also resulted in elevated discharge rates in other Carpathian Basin rivers. In the upper and middle stretches of the catchment, the sediment resources that were stable in MIS 2 became unstable, and the coarse-grained sediment pulses released by the incision led to the formation of Late Glacial and Early Holocene braided pattern channels in the lowland alluvium of the Maros. However, it is not clear from the data how dominant the sediment pulses from the Retezat were in the catchment.

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