Exploring Late Pleistocene and Holocene linkages between different geomorphological domains in the SE Carpathian Basin

Brief overview

The primary aim of the research is to improve local or sub-catchment scale datasets into an integrated catchment and sub-basin scale model of Late Pleistocene – Holocene geomorphological evolution in the SE part of the Carpathian Basin. The work could be organised around four major topics which were arranged into 2 major research activities: 1.1) What is the dynamic relationship between the Late Pleistocene fluctuations of glaciers in the Southern Carpathians and the reconstructed coeval channel development on the alluvial fan of the Maros River? 1.2) How did sedimentation rate change at the apex of the Maros Alluvial Fan and how could these changes contribute to significant avulsions revealed formerly? 2.1) How alluvial and aeolian processes can be linked to loess deposition on the Danube-Tisza Interfluve and its surroundings? 2.2) To what extent can different dating methods, applied at the same study area, verify each other?

In order to assess these questions, several field campaigns were made in the study area and beyond, thus research questions were extended in space. The research activity can be summarised by the following data.

The number of study areas included: 14 (Hungary, Romania, Serbia)

The number of samples collected: 189 (OSL, C-14, TCN)

The number of conference abstracts: 14

The number of papers published by indicating NKFI: 5

The number of manuscripts not published yet, but submitted by indicating NKFI: 4

The number of papers related to the research but not indicating NKFI: 4

The research in our opinion can be regarded successful, as several papers could be published by the research team already during the research period, and there are still papers that are submitted, or even reviewed and wait for final decision and publication.

Results

Methodological developments

Beside geomorphological research in the SE Carpathian Basin several methodological investigations were also made, practically on a basin scale, to study the OSL behaviour of fluvial and aeolian sediments. The questions that were addressed were the following: What unwanted OSL phenomena and to what extent can affect the dating of fluvial sediments? How efficient is sunlight in bleaching fine and coarse grain sediments in a river system, i.e. to what extent residual doses can affect the results of OSL dating? Is there a remarkable difference in the luminescence sensitivity (i.e. the luminescence intensity emitted in response to a given radioactive dose) of fluvial sediments from different parts of the Carpathian Basin? Can luminescence sensitivity be applied as a proxy for sediment tracing later? How OLS sensitivity values change along a river? How alpha sources mounted in luminescence readers can be best cross-calibrated? What effect this can have on values routinely applied during the dating of aeolian loess sediments?

Investigations were primarily focused on the Danube, Tisza and the Maros Rivers. Major results achieved and conclusions made were the following:

Tests on both coarse and fine grain sediments proved that as a matter of thermal transfer, the virtual equivalent dose of Danube sediments increases considerably if preheat temperature is set above 200°C. Although the use of a hot bleach decreases the scatter of recovered doses, it also introduces a considerable degree of thermal transfer, which differs from sample to sample. (Tóth et al. 2017)

Bleaching of medium sand sized coarse grain sediments is fairly complete along the investigated river reach, consequently the mean and standard error of residual dosed is 0.10 ± 0.01 Gy. Therefore, it is suggested that regarding younger sediment deposits from the investigated area equivalent dose results should be corrected by this value. Besides, in terms of Danube related palaeo-sediments the effect of incomplete bleaching on the measured equivalent doses seems to be of low significance if a proper statistical treatment is applied, (Tóth et al. 2017)

As expected, concerning fine grain sediments incomplete bleaching can be considerable, the mean and standard error of fine grain residual doses along the studied section of the river is 2.34 ± 0.72 Gy. on the lower reaches this fraction cannot be applied safely for palaeo-sediments in the usual age range of fine grain quartz OSL dating (Tóth et al. 2017).

Based on luminescence tests, both coarse grain and fine grain samples have adequate properties for the application of luminescence dating on fluvial sediments in the Lower Tisza region. Nevertheless, coarse grain samples have poorer characteristics, and therefore extensive measurements are required to have sufficient number of aliquots passing OSL rejection criteria (Sipos et al. 2016).

According to the comparative analyses made by dating both the fine and coarse grain fraction of several samples, the resetting of fine grain sediments in the Tisza system is obviously less efficient than that of coarse grains, and in average a 1.5 ka overestimation can be attributed to the ages obtained by fine grain silts. However, overestimation is not general. Therefore, in the given time range, fine grain ages can still provide valuable data for identifying trends, but on their own they are not suitable for drawing sound conclusions (Sipos et al. 2016).

In spite of the limitations of using multi-grain measurements for quartz sensitivity measurements analysis, the detailed sensitivity analyses of fluvial samples from some major catchments of the Carpathian Basin (Danube, Upper Tisza, Lower Tisza, Maros) have shown for the first time that the sensitivity of Alpine and Carpathian origin quartz extracts is remarkably different even in a lowland environment, several hundred km downstream of the upland catchments where the sediment is produced (Bartyik et al. 2021).

When considering different types of sensitivity parameters, total LM-OSL intensities and fast component ratios showed the least variation within one group of samples, therefore it is claimed that in the Carpathian Basin these parameters can be used best for sediment provenancing. This was also supported by the fact that using a total LM-OSL vs. fast component ratio plot the samples of the investigated regions could be separated relatively well (Bartyik et al. 2021).

Based on our results, geomorphological drivers might also affect the sensitivity parameters of coarse grain quartz samples, e.g. by the better mixing of grains the distance of sediment transport can have a positive effect on the scatter of sample mean sensitivity values. More systematic analysis needs, however, to determine whether age vs. CW-OSL relationships have a geomorphic meaning or not. At the present number of samples this cannot be unambiguously stated (Bartyik et al. 2021).

In terms of fine grain luminescence dating the assessment of the efficiency of α radiation is an important parameter, which can significantly affect the age obtained. When applying five calibration procedures, using different samples, different protocols and different α-sources to cross-calibrate the built-in α-source of a RISØ TL/OSL DA-20, regardless of the applied procedure, the calculated α-dose rates with one exception gave similar results, thus the calibration process was successful (Sipos et al. 2021b).

Although comparable results were obtained when using quartz OSL and polymineral $pIRIR_{290}$ measurements, the issue of fading and the high level of residual doses decrease significantly the precision and possibly, also the accuracy of polymineral MAR IR_{50} measurements. However, the application of the $pIRIR_{290}$ signal can be a feasible option if lower residuals are achieved and bright samples are applied. Quartz, on the other hand, seemed to be a more reliable material for cross-calibration if the results of a natural aeolian sample are considered: different bleaching procedures, and the use of different known dose rate α-sources and protocols ended up in almost identical results (Sipos et al. 2021b).

Even though the α-source dose rates, determined by the different procedures, are practically interchangeable at the uncertainty values of luminescence dating, it is highly recommended to use more samples and/or more protocols during the calibration process. This way it is at least possible to compare the precision of results, and to increase the reliability of the dose rate finally applied (Sipos et al. 2021b).

Within our multi-procedure approach, the performance of the fine grain RISØ calibration quartz as a potential material for α-source cross-calibration could also be assessed. Compared to a natural fine grain quartz extract, the calibration material, artificially ground, shows a remarkably early signal saturation in response to α-dosing. It seems that weaker than present γ-dosing would be more feasible for α-source calibration purposes in the future. Finally, if the a-value of the fine grain RISØ calibration quartz would be determined in more laboratories, then the mean value would provide a simpler way to calibrate built in α-sources with unknown dose rate (Sipos et al. 2021b).

Research activity 1 (temporal linkage between glacial and fluvial processes)

The research activity focused on the first hand to the catchment of the Maros River and the potential linkage between upland and lowland events in the Late Plesitocene and at the onset of the Holocene. Consequently, study sites were located in the Retezat Mountains, the Haţeg Basin and on the terraces and alluvial fan of the Maros River. The main results of these investigations were the following:

When going more upstream the luminescence behaviour of quartz grains can exhibit high variations as experienced in the case of the sediment samples originating from the Rau Mare and Gura Zlata valleys, Western Retezat Mountains. The quartz samples collected from a glaciofluvial terrace, related to the Gura Zlata valley were especially bright, whereas quartz grains collected in relation with the Rau Mare valley were extremely dim, allowing only the use of feldspar grains for dating (Sipos et al. 2018).

Ages obtained from sandy deposits around boulders located on the surface of the investigated glaciofluvial terrace showed Early Holocene ages, and place fluvial activity to around 10 ka. As no direct ages were obtained from the boulders themselves, it is suggested that the sand was transported there after the glacially deposited boulders. Still, the incision of the Gura Zlata can be dated to the onset of the Holocene (Sipos et al. 2018).

Using exclusively feldspar dating sand deposits from below large glacial boulders at the mouth of the Gura Zlata valley, $pIRIR_{290}$ ages place the deposition of boulders to the end of the penultimate glacial. Consequently, this was the first time glacial sediments older than LGM were numerically dated in the region. This also suggests that at some locations the length and extension of Riss glaciers could be larger than LGM ones (Sipos et al. 2018).

The deglaciation chronology of the S-SW exposure Bucura and Lapusnicu valleys in the Retazat mountains shows that here maximum ice extent was synchronous with the LGM, which was followed by a fast glacier recession during the Lateglacial. On the basis of the ^{10}Be data the final deglaciation occurred around ~14 ka, a date supported by independent paleoclimate reconstructions as well. Hitherto, no evidence of a Younger Dryas (GS-1) or Holocene glacial advance has been recorded in the study area (Ruszkiczay et al. 2021).

The presence of inherited cosmogenic ^{10}Be in moraines, glacial boulders and bedrock samples of the cirque region hinders the age determination of the last and penultimate deglaciation phases. This nuclide inventory must have accumulated during exposure(s) prior to the last glaciation, which points to the limited erosional efficacy of cirque glaciers during the last glacial phase. Modelling of the depth of glacial erosion suggests that 1.1–1.7 m of rock was eroded by the glaciers from the cirque area, at a glacial erosion rate of 20–29 mm/kyr during the last glacial period (MIS4-2). The absence of inherited 10 819 Be inventory from the lower/older moraine samples suggests that carving of the glacial troughs during the LGM and early Lateglacial periods was deep enough to remove the cosmogenic nuclides from previous exposures. During these phases of extended glaciation most probably the cirque region was conserved under cold-based ice (Ruszkiczay et al. 2021).

The limited glacial erosion in the cirques during the LGM suggests that the development of these landforms must have taken place during several subsequent glacial phases, providing an indirect piece of evidence for repeated Quaternary glaciations in the Retezat Mts. The apparent absence of pre-LGM landforms is most probably the consequence of LGM glaciers overriding the previous glacial features and/or the difficulty of recognising the severely eroded remnants of a possibly more extended previous glaciation in the lower valleys (Ruszkiczay et al. 2021).

The alluvial fans in the Hateg Basin, recording the transportation of glacial sediments form the valleys of the Retezat Mountains with a Northern exposure, record a coarse grain gravel aggradation phase during the last glacial, which can be attributed to MIS3 or the beginning of the LGM at latest. However, no significant aggradation can be identified on these alluvial cones during to the peak of the glacial. Finer cover sediments are loess derivates and fine grained fluvial deposits, and are mostly dated to the Late Glacial (Sipos et al. 2018)

Based on the results, the two identified generations of alluvial cones have been dissected by the incision of rivers from the beginning of the Holocene probably in several phases, as the minimum ages of cover sediments over LGM deposits vary from around 10 ka to 5 ka. The deposits on the present floodplain is dated to the be 1.0-1.2 ka old, and correspond to floodplain development during the onset of the medieval warm period, suggesting that there was a potential increase in human impact as landuse became more intensive, which could affect in turn fluvial processes and sedimentation in the Hateg Basin.

Going more downstream, the terrace development of the Maros River at Deva also exhibits climatic triggers, however in slightly different way as it is supposed on the basis of general models. Channel deposits identified 5-6 m above the present day floodplain were dated to be of 33-36 ka old and resembling therefore a MIS3 coarse grain gravelly sediment pulse in the valley of the river. Here, just as in case of the Hateg Basin the LGM is characterised by rather fine grain deposits, being a mixture of loess derivates and fluvial silt.

Two incision events could be reconstructed on the basis of terrace sediments the age of cover sediments. The first occurred around 27-26 ka at the start of LGM and can be explained by the decrease of evapotranspiration and temporal increase of surface runoff. The second phase was dated to the 14-10 ka period, thus to the onset of the Holocene. The results refer to the complex genesis of terraces, and the significance of climatic transitions in generating incision events.

Investigations at the apex of the large alluvial fan of the Maros River, using OSL and C-14 dating of channel deposits and subfossil tree trunks refer to a very dynamic aggradation and fluvial activity where the river leaves its upland catchment. Sampling several sites oldest deposits were only a few centuries old, even at a depth of 5-6 m. The measurements also proved that the two methods provided consistent ages when compared (Kern et al. 2018).

Research activity 2 (temporal linkage between fluvial and aeolian processes)

Fluvial processes were investigated along the Hungarian Lower Danube (Kalocsai-sárköz), the Upper and Lower Tisza, Somes and Crasna rivers, while Aeolian processes were investigated at the Illancs Dunefield, the Deliblato Sands and the Novo Orahovo loess section. The research activity focused on the temporal relationships between the lowland incision of rivers and the intensification of aeolian processes.

The evolution of alluvial areas on the Danube Plain was reconstructed using OSL dating and geomorphological mapping. On the upper alluvial level (floodplain level 2), sampled at Lake Kolon, the single aliquot equivalent doses of sampled sediments exhibited a significant skewness, just like in the case of fluvial samples, referring to a limited aeolian transport. These samples yielded ages of 23.60 ± 1.18 ka and 17.38 ± 0.60 ka. Thus, it is suggested the Danube formed its upper floodplain level at maximum till the Last Glacial Maximum. Later the Danube incised into this floodplain level, but the exact date of this event could not be defined (Tóth 2019).

By a 3 m incision the lower floodplain level was formed, which can be separated to three units based on their elevations and ages. Floodplain level 1/3 could be preserved in the western front of the 2 floodplain level. Based on the results, this part of the lower floodplain was formed until 7.5 ka ago. Subsequently, the Danube created the floodplain level 1/2, which level has higher elevation than the level 1/3, indicating that it was formed by intensive aggradation processes. The rate of this aggradation however continuously decreased in downstream direction, as the elevation of two floodplain levels are close to each other on the downstream end of the study area, moreover in the southernmost area, the 1/2 level shows even the signs of incision. The 1- 1.5 m incision of the Danube into the 1/2 level created the 1/1 level, where sediments were deposited at 5.3-5.5 ka ago by the Danube (Tóth et al. 2017).

The longitudinal slope of the floodplain levels along the Danube is mostly divergent, indicating that these floodplain levels formed by headward erosion probaly induced by the subsidence of the southern part of the area. However, the possibly Late Glacial and Holocene abandonment of the upper floodplain also refers to a climatic trigger to some extent. Therefore, it is not entirely obvious whether climatic or the tectonic processes had larger effect on the development of floodplain levels evolution.

Most probably tectonic movements had a more significant role in the development of the floodplain levels, but climate changes might enhance these processes (Tóth 2019).

Concerning the Lower Tisza River, the point bar series of large meanders, situated on the upper floodplain and on an intermediate morphological level in between the upper and lower floodplains, were investigated. Results support the Late Pleistocene – Early Holocne development of the intermediate floodplain level. This also means, that the lower floodplain itself developed in the Holocene. The gradual incison identified (upper, inetrmediate, lower levels showing an approximate 1 m elevation differnece) suggests that the process is rather controlled by tectonic subsidence (Sipos et al. 2016).

The dating of several pointbars also allowed to assess the dynamics of meander evolution. The first phase of evolution on the upper floodplain can be related to a high discharge period during the Bølling-Allerød interstadial. Nevertheless, a relatively low intensity of development is inferred, which may refer to the significance of vegetation control under a warm and humid climate. The second phase and the start of the incision process can be related to the Younger Dryas, which obviously brought much lower discharges and although vegetation control was limited also, meander development was slow. The slight Younger Dryas incision, however, underlies the importance of tectonic forcing over climatic control in the development of floodplain levels along the river (Sipos et al. 2016).

In terms of the Upper Tisza new morphological, morphometric, sedimentological and chronological data on paleofluvial remains from the Someș Alluvial Plain and the Ier River suggest that the Tisa River already held its previous NE-SW position, along Ier River valley, 173 ka ago and abandoned this course at a minimum 53 ka ago (Persoiu et al. 2021).

After the avulsion of Tisa, the Someș Alluvial Plain was formed in three distinct phases, conditioned mainly by the location and timing of distinct tectonic movements in the area. The first phase comprises the late MIS 4 or MIS 3 remains of the Upper Tisa, flowing in the northern part of the alluvial plain. The avulsion of Upper Tisa further to the north marks the second phase, which lead to the shifting of the Lower Someș River to the NNW edge of the study area ca. 31 ka ago. The third phase, Late Glacial to present, corresponds to the reorientation of the Lower Crasna and Lower Someș Rivers to the NW in response to the most recent subsidence in the area (Persoiu et al. 2021).

A new perspective on river adjustments to Late Quaternary climate change along rivers draining the Hungarian Great Plain is provided by two outcomes of our regional synthesis: (1) the Tisa River maintained a dominantly meandering pattern over at least the last 53 ka, with only a short incision phase followed by a braided pattern between ca. 37 - 32 ka. (2) The lower reaches of the tributaries of the Tisa River (e.g. Someș - this study; Mureș, previous studies) maintained large scale meandering and/or multi-branching, or even braiding patterns during Early Holocene, with a significant reduction in their size only after ca. 5 ka (Persoiu et al. 2021).

Turning to aeolian processes, previously available OSL data of Aeolian activities were summarised and analysed. In total nearly 150 age data were considered from 18 sites, representing four large sand dune areas, that were developed on the alluvial deposits of the Danube (Somogy Alluvial Fan, Danube-Tisza Interfluve, Deliblato Sands) and the Tisza River (Nyírség Alluvial Fan). Beside interpreting the total distribution of the dataset, ages were grouped in time according to the climatic phases. The strength of the aeolian signal for each phase was determined by the number of coinciding data, the number of sites affected and the rate of deposition where it was calculable. Although results correspond to the general framework of aeolian history in the region they also underpin the significance of local events especially in the Holocene and in relation with human activities (Sipos et al. 2019).

However, the detailed analysis of a large dune form situated in the Illancs Dunefield has shown the major phases of Aeolian activity since the LGM. The development of the investigated dune could be separated into five phases. The base the 1.5 km long dune form developed up till the Older Dryas Period. Subsequently, the dune became significantly higher throughout several minor phases of Aeolian activity in the Younger Dryas, the Boreal, Early Subatlantic and Late Subatalntic Phases. These periods correspond fairly well to those identified on other dunefiekds of the, especially the Deliblato Sand (see later).

Aeolian processes on the Deliblato Sands, once claimed to be the Desert of Europe, has not been investigated before by numerical dating methods. Based on the morphology and the height condition of dunes, the majority of the dune field is dominated by elongated, hairpin like parabolic dunes, referring to a relatively low sand supply during their formation. However, another set of dunes, predominantly of filled parabolic type, are superimposed on the previous ones and resemble a much higher sand supply (Gavrilov et al. 2018, Sipos et al. 2021a).

Subsequently, another phase of dune formation could take place in the Younger Dryas period up till the Boreal Phase of the Holocene, with periods of stability and interdune soil formation. By the beginning of the Atlantic Phase the present landscape on the NW part of the dune field had been fixed by vegetation. Therefore, on most of the Deliblato Sands the dunes are older and more stable than previously assumed on the basis of morphological studies (Sipos et al. 2021a).

Meanwhile, on the SE part of the high dune field sand was undoubtedly remobilised during historical times. As part of the present research the last phase of aeolian activity could be identified, which is dated to 0.2 ka and corresponds well to the data of written records. Nevertheless, earlier events in historical times, regularly observed on other Carpathian Basin dune fields, cannot be excluded to occur, even though, on the basis of their geomorphological position and obtained OSL ages the young dune forms are directly superimposed on the Late Glacial, Early-Holocene deposits (Sipos et al. 2021a).

Conclusions

The numerous results of the project are still under evaluation, however by synthetising the results listed in brief above, it is possible to make some general conclusions.

various earth surface processes could be interconnected on the Maros River catchment both in time and space. In the light of the research results, the importance of warming periods between glacial and interglacial climates should be underlined, as at the beginning of these a large amount of sediment is mobilized in the upland catchment, which is then followed by general erosion as vegetation stabilizes the slopes. Upstream sediment pulses arrive to the lowland section of the river with considerable delay up till the Atlantic Phase of the Holocene.

The channel development of large alluvial rivers in SE part of the Carpathian Basin, especially concerning incision and avulsion events is largely affected by tectonic subsidence, inducing a general process of headward erosion and down cutting, which is modulated by climatic transition periods. Within the framework of the present research, we found only a partial relationship between the westward translation of the Danube on the Danube-Tisza Interfluve and the intensification of aeolian processes in SE Carpathian Basin. Concerning the investigated loess section at Novo Orahovo, grain size of the sediment inevitably increases at 40-50 ka, which can be an indicator of increased sand availability northwest of the deposition site, however no difference was found in terms of dust accumulation rates.

Regarding the dunefields of the area it has become clear that extensive, regional scale dune formation lasted till the Older Dryas period, with a potential peak at the LGM, which can be scarcely investigated due to the recycling of the sediments during subsequent aeolian events. In later periods first the decrease in precipitation rather than temperature governed the initiation of dune development, as there are several pieces of evidence both from the cold Younger Dryas, and from the warm Boreal Phase for aeolian activity. However, it is true that during these periods dune formation was more limited than before. A change in this pattern can be observed by the intensification of human activity in historical periods, when blown sand movement could occur potentially at any kind of climatic regimes from the Subboreal Phase, since these events were triggered by landuse practices.

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