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pod redakcją

Małgorzaty Frydrych i Damiana Moskalewicza



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# **Youth Symposium "Geomorphology in Quaternary Research"**

Borucino, Poland, 27.06.–1.07.2022

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## Introduction

The youth symposium "Geomorphology in Quaternary Research" will be held from 27.06 to 01.07.2022 in Borucino (Northern Poland). The symposium will be organized under the auspice of the INQUA TERPRO Commission, the International Association of Geomorphologists and the Association of Polish Geomorphologists. It is the first Peribaltic Working Group meeting dedicated to Early Career Researchers.

Peribaltic Working Group (PWG) is a part of the Terrestrial Processes, Deposits and History INQUA Commission (TERPRO). It is a long-term association of researchers from countries located around the Baltic Sea. PWG started in the early 1990s and comprises scientists interested in Quaternary research. Currently, PWG is defined as a formal Working Group in INQUA-TERPRO structures. The main research topics of the group are: paleogeography of the Peribaltic region, quaternary geology and stratigraphy, chronology and dynamics of Pleistocene Scandinavian Ice Sheet, glacial geomorphology, reconstructions of climate change, paleoecology, interactions of natural environments with early human activities. The results of the studies are presented during annual conferences and field trips organized in different countries in the Peribaltic region. They are usually published in Quaternary International Journal in a dedicated post-conference volume. The last PWG meeting took place before the pandemic, in 2019 in Greifswald, Germany.

The symposium programme includes participants' research presentations, workshops, and field trips. The symposium aims to broaden participants' knowledge about geomorphology in Quaternary



research. Participants will take part in workshops on important and developing methods used in Quaternary research (dating using TCN, microcomputed tomography in Quaternary deposits, handheld gamma-ray spectrometry). During the field trips, the organizing committee will present five study sites with Quaternary deposits. Participants will get to know the results of recent research in Kashubian Lakeland, focused on glacial, fluvio-glacial, lacustrine sedimentation and deformation. In the coastal zone of the Baltic Sea, participants will be introduced to natural hazards subject comprising contemporary sea level rise and storm flood deposition.

The crucial goal of the Youth symposium is to allow ESRs to get to know each other, have time to discuss different topics and create a space where they can share their experiences and ideas. The meeting is vital when contacts became limited during the pandemic. The youth symposium "Geomorphology in Quaternary Research" is organized by ECRs from PWG for ECRs. We believe that this first meeting will initiate a new tradition of periodic events under the auspice of the INQUA. We hope the symposium will promote our research and working group, and bring new members to our community.





## Programme of the meeting

### Monday 27.06.2022

15:00 – Registration

19:00 – Dinner and ice breaker

### Tuesday 28.06.2022 – Lectures and field trip

10:30–13:00 – Introductory lectures

10:30 – *Damian Moskaiewicz* – The opening of symposium

10:35 – *Wojciech Tylmann* – The welcoming of guests by the Deputy Dean for Research and Development at the Faculty of Oceanography and Geography at the University of Gdańsk

10:45 – *Robert Jan Sokołowski* – Quaternary Stratigraphy of Poland

11:30 – *Piotr Paweł Woźniak* – Introduction to Pleistocene geology and geomorphology of the northern Poland

12:10 – *Maurycy Żarczyński* – Research of lake sediments in Polish Lowlands

13:00 – Lunch break

14:00–18:30 – Field trip (hike) – *Karol Tylmann* – “Geological structure and glaciogenic landscapes of the Kashubian Lakeland”

~19:00 – Evening gathering

### Wednesday 29.06.2022 – Presentations and workshops

10:00–13:00 – Participants research presentations

10:00 – *Markas Kazlauskas* – Megafloods and floodscapes of LGM

- 10:20 – *Inese Grīnbauma, Kristaps Lamsters* – Landforms of the Lubāns ice lobe in the Atzele elevated plain
- 10:40 – *Olga Reutt, Damian Moskalewicz, Piotr Paweł Woźniak* – Seeking indicators of tills weathering: How can we exploit geophysical and geochemical methods?
- 11:00 – *Beáta Farkas* – Relict sand wedge sites in Hungary – a sedimentological case study
- 11:20 – Coffee break
- 11:30 – *Shashi Shekhar Shukla, Padmini Pani* – Insights from the Palaeo-Geomorphic Features of the Central Ganga Plain, India: Past to Present
- 11:50 – *Anna Tołoczko-Pasek, Régis Braucher, ASTER Team, Michał Makos* – Determination of the age of carbonate rocks by the cosmogenic chlorine-36, in the valleys of Miętusia and Mała Łąka
- 12:10 – *Marin Mićunović, Sanja Faivre* – Remote sensing applicability in geomorphological investigations of beaches
- 12:30 – *Maciej Kossowski* – Possibilities for the use of drone data in geomorphological analysis of river deltas, based on the delta of Jeziorsko Reservoir
- 13:00 – Lunch break
- 14:00 – *Damian Moskalewicz* – Workshop “Handheld gamma-ray spectrometry”
- 15:30 – Coffee break
- 15:40 – *Karol Tylmann* – Workshop “Dating using TCN”
- ~18:00 – Outdoor geocaching game

### **Thursday 30.06.2022 – Field trip**

9:00–18:00

1. Mechelinki – *Karolina Leszczyńska et al.* – Storm surge deposits at the coastal area (key points: Sedimentological features of storm deposits, reconstruction of palaeostorminess, storm-related landforms)

2. Rzucewo #1 – *Łukasz Elwinski et al.* – Debris flows in a lacustrine basin (key points: Debris flow and lacustrine sedimentary structures, lithic and soft-sediment clasts distribution, microtomography)

~13:00 – Lunch break

3. Rzucewo #2 – *Piotr Paweł Woźniak et al.* – Geomorphological conditions of early settlement (key points: Holocene evolution of the Puck Lagoon area and their influence on settlement, changes in the availability of local natural resources, stone tool and dugout canoe manufacturing)
4. Dmuchowo – *Aleksandra Jobska et al.* – Weichselian tills with the extraordinary boulder (key points: Glacial sedimentation and deformations, weathering of tills)

~19:00 – Evening gathering

### **Friday 01.07.2022 – Workshop and closing meeting**

9:00 – *Łukasz Elwinski* – Workshop "Microcomputed tomography in Quaternary deposits"

11:00 – INQUA ECR and PWG perspective

11:30 – Lunch

12:30 – Back to Gdańsk





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## Field trips

Kashubian Lakeland and Kashubian Coast are natural regions located in the northern Poland. The landscape of these regions was shaped in the Quaternary period, during the past 2.5 mln years. Subsequent glaciations in the Northern Hemisphere resulted in the expansion of large continental ice sheets, including the Fennoscandian Ice Sheet (FIS) in Europe. Consequently, the area located within the extents of the FIS was covered with tens to over a hundred meters thick sequence of siliciclastic deposits. The Last Glaciation (Weichselian) contributed to the formation of the contemporary landscape, abundant in, e.g., moraines, sandur, and glacial channels (tunnel channels/valleys or marginal channels) occupied by lakes. The decay of the FIS at the turn of the Pleistocene and the Holocene resulted in the formation of lakes and peatlands, as well as the Baltic Sea and coastal environments. The geological history of the Kashubian regions makes them unique in terms of diversity and abundance of Quaternary landforms and related deposits.

### *Glaciogenic landscapes at Borucino*

Borucino village (54.25°N, 17.98°E) is located within the Kashubian Lakeland natural region, which was formed as a result of cyclic transgressions and recessions of ice sheet during the Quaternary. The



thickness of Quaternary deposits is very diversified and rather high there, ranging from 80 to 308 m. Present-day morphology was shaped at approximately 17–15 ka BP during the Pomeranian phase of the Weichselian glaciation. The landscape comprises moraines, sandurs, tunnel-valley lakes, peatlands, and deeply-incised river valleys. The highest absolute elevation point reaches 329 m a.s.l., while the lowest is at 123 m a.s.l. Such a huge contrast appears between morainic plateaus and deeply incised glacial channels that are contemporary occupied by lakes or are part of a river drainage network. The genesis of deeply incised valleys might probably be related to Pleistocene vertical crust movements along pre-Quaternary thrusts planes, sub-glacial erosion during subsequent glaciations and fluvial erosion during drainage network evolution after deglaciation. Deposits that form contemporary landscape may be studied at several exposures, including, e.g., Łączyno or Puzdrowo gravel pits.

#### *Storm deposits at Mechelinki*

Mechelinki site (54.62°N, 18.51°E) is located approximately 30 km NW from Gdańsk at the coastal area of the Puck Lagoon (western part of the Gulf of Gdańsk). The coast comprises a shallow clastic bay, gravelly sand beach, low foredunes with small washovers, and wide peatland. The back-barrier environment is an archive of coastal evolution, extreme storm events and related coastal flooding that occurred in the past. Storm deposits are characterised by sharp erosive bottom boundary, increased grain size diameters, and distinguishable heavy mineral assemblage. A high frequency of coastal flooding was present ca. 3600–2900 BP and has been present currently for approximately 700 years. Coastal geomorphology, the resilience of the coastal dunes after storm activity, and climate change are the main factors that influence coastal flooding at the Mechelinki site.

#### *Subglacial deposits at Dmuchowo*

Dmuchowo site (54.799°N, 18.078°E) is located approximately 75 km NW from Gdańsk, in the steep edge zone of the moraine plateau near Żarnowieckie Lake. The outcrop shows several till layers intercalated with fluvio-glacial deposits. A significant part of them shows various deformation structures. The upper, Late Weichselian till is 3 m thick and heterogeneous. The lower and upper part of the till layer differs in till fabric and petrographic composition. The upper part of the profile

also shows marks of weathering expressed in vertically decreased content of low-resistant rocks and minerals. Additionally, a massive erratic boulder is embedded in the till. The boulder is intact and partially uncovered, its estimated height is 2 m, and the perimeter is around 20 m.

### *Debris in glaciolacustrine deposits at Rzućewo*

The study site (54.681°N, 18.466°E) is located at the cliff coast south of the Rzućewo village. Glaciolacustrine deposits are up to 15 m thick and are exposed in natural outcrops along the Puck Lagoon coast. Most of the deposits comprise fine-grained lithofacies. However, they are multiply intercalated with diamictos (debris), resulting from debris flows on the subaqueous slope. The thickness and frequency of debris decrease from the proximal to the distal part of the glaciolacustrine subaqueous fan. Their inner composition also changes, indicating selective sorting and erosion of lithic and soft-sediment clasts. The top of glaciolacustrine succession is covered by Late Weichselian till.

### *Early Neolithic settlement at Rzućewo*

Rzućewo settlement site (54.695°N, 18.467°E) is located several hundred meters north of the Rzućewo cliffs. It is a well-known archaeological site which contains remnants of past settlements from around 6500 years. The development of the first human activities was highly supported by the unique geomorphological features of the surrounding area. For several thousand years, rivers in incised valleys and lakes developed on the post-glacial landscape were the primary source of fresh waters for early communities. The site was also very close to the Puck Lagoon, which increased its area in the Holocene – a place for seal hunting and fishing. Glaciolacustrine fine-grained deposits exposed in the neighbourhood were used to craft ceramics. Gravels and boulders from glaciogenic and fluvio-glacial deposits were used to rise constructions and manufacture stone tools, including axes, chisels, polishing slabs and grinding tools. Some of them were used to regularly process different materials, like wood for dugout canoes.







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## Workshops

Workshops are dedicated to three innovative methods that are increasing in importance in Quaternary geology. Each of them is useful in sedimentological interpretations or may be used to determine the age of the deposits. hGRS (handheld gamma-ray spectrometry) is the field equivalent of the GRS method used in well logging applications to investigate lithological properties of sedimentary rocks. TCN dating is an analytical technique used in age estimation of ground surfaces or deposits exposed to cosmogenic radiation.  $\mu$ CT (microcomputed tomography) is a novel method used mainly to analyse the internal structure of sediments in undisturbed samples. Each workshop comprises theoretical background, possible applications presentation, and exercises for participants.

### *hGRS- handheld gamma-ray spectrometry*

The method uses a portable device based on scintillation spectrometry. The device is put directly to the outcrop wall in an approximately perpendicular position. Measurements are usually performed with an interval of 0.2 m and last 120–180 s. Natural radiation from the target volume reaches the device. Then, based on built-in algorithms and calibration data, the spectrometer provides information about radioactivity. The method helps derive the concentration of natural radioactive elements, artificially introduced radioisotopes, or monitor



radioactivity changes in various applications. In geology, it is mainly used to calculate total gamma radiation GR and provide concentrations of, e.g., potassium-40, uranium-235 and 238, thorium-232, cesium-134 and 137. The data obtained is useful in e.g. discriminating basic lithologies and sedimentary environments, tracking weathering processes and palaeoclimate changes, supporting stratigraphic interpretation and correlations, and recognising radiogenic hazards.

#### *TCN dating- terrestrial cosmogenic nuclide dating*

This dating technique uses cosmogenic nuclides (e.g.,  $^{10}\text{Be}$ ,  $^{26}\text{Al}$ ,  $^{36}\text{Cl}$ ) produced *in-situ* in rocks exposed to cosmic radiation due to nuclear reactions occurring within crystal lattice of minerals. The “shower” of secondary cosmic rays reaches the surface of the lithosphere and produces cosmogenic nuclides within exposed rocks. The production rate (atoms per year) of a particular nuclide can be estimated, and the concentration of a particular nuclide may be measured in a rock sample, so the exposure age of rocks may be calculated. Surface exposure dating with TCN is widely used in glacial geomorphology and geology, mainly to constrain the timing of glaciers/ice-sheets retreat. Glacial chronologies may be constructed by sampling the surface of stable, intact erratic boulders resting on moraines and/or glacially eroded bedrocks. TCN dating may also be used to investigate the chronology of other geological processes, such as: tectonic movements, mass movements, and volcanic eruptions. In fact, in all cases where the duration of rocks surfaces, exposition is relevant. If cosmogenic nuclides produced *in-situ* within rocks are unstable and have their characteristic radioactive decay, their concentration within sediments profiles may be used as an indicator of burial time for deposits – i.e. age of deposition.

#### *$\mu\text{CT}$ - microcomputed tomography*

Microcomputed tomography or microtomography ( $\mu\text{CT}$ ) is a powerful 3D-imaging technique that obtains a remarkably high-resolution reconstructed image using a small radiation spot. Sedimentary rock samples (monoliths) are collected in aluminium containers ( $10 \times 10 \times 10 \text{ cm}$ ) and are scanned using a computer microtomograph. The  $\mu\text{CT}$  method allows acquiring the data without disturbing the original structure of the monoliths collected. These samples may be used later for multiple analyses (e.g., macroscopic or micromorphological analysis). A 3D volume of the sample representing the x-ray attenuation (sensitive to composition

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and density) is produced, allowing observation and quantification of various components and textures. In the three-dimensional image, using dedicated  $\mu$ CT software, areas that differ in density and structure can be distinguished and studied. It is possible to determine the size, area, volume or directional features in collected monoliths. Computer microtomography is a developing method and, in the future, may become a key research analysis used in Quaternary geology and geomorphology.





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## Landforms of the Lubāns ice lobe in the Atzele elevated plain

In this study, a 1 m digital elevation model (DEM) derived from airborne LiDAR data was used to analyse the glacial geomorphology of the Atzele Elevated Plain (AEP), in eastern part of Latvia. The study area is located in the SE sector of the Scandinavian Ice Sheet (SIS) where the Lubāns Ice Lobe (LIL) operated. The glacial geomorphology of the study area provides an excellent opportunity to study subglacial processes and ice streaming/surging.

The aim of this research is to determine morphology, origin, development of glacial landforms in AEP, and reconstruct the dynamics of the LIL. To fulfil this aim, the following objectives were addressed: (1) mapping of glacial landforms; (2) analyses of their morphometric parameters and arrangement.

The geomorphic imprint left by the LIL range from mega-scale glacial lineations (MSGs) to small transverse geometric ridge network and glacial meltwater landforms (eskers, meltwater channels and tunnel valleys). Geomorphological mapping revealed 216 streamlined bedforms, many of which were identified mostly in the northern part of the study area. They have NE–SW orientation indicating the LIL flow direction. Majority of MSGs are segmented indicating postglacial fluvial erosion. The mean length of the separate segments is 2 km (max 20 km), height – 5 m and width – 580 m. MSGs are superimposed by low-amplitude transverse ridges, which are interpreted as crevasse squeeze ridges (CSRs).



In the central part of the study area, CRSs (~4903) have orientation mainly perpendicular and oblique to the ice flow direction. Individual segments are between 0,5 m and 13 m (mean – 1,52 m) high, 10 m – 550 m (mean 151 m) long and 8 – 155 m wide. Also, prominent ridges with ‘zig-zag’ appearance have been observed.

The landform assemblage provides the evidence of the surging behaviour of the LIL in the AEP during the deglaciation. CRSs in the AEP were likely produced by till squeezing upwards into basal crevasses when the deformable sediments (subglacial till) were saturated either during or immediately after a surge. Thus, the CRSs imprint in paleo-glaciated terrain can be used as indicator of surge behaviour in paleoglaciological reconstructions. Eskers and tunnel valley systems give clue to understanding how large subglacial meltwater drainage operated under LIL.



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## Seeking indicators of tills weathering: how can we exploit geophysical and geochemical methods?

A detailed insight into weathering processes may deliver not only historical data, but it can also provide a better understanding of the long-term evolution of soils and contemporary landscapes in general. Geophysical and geochemical methods are widely applied in various geological settings and, in relation to weathering, they can help in identifying the range and intensity of this process, which ultimately supports any other sedimentological research and palaeogeographical reconstructions. However, as far as tills are concerned, there seems to be a large research gap, which eventually triggered our study project.

Our main research activities are: (1) major and trace elements content analysis using ICP-MS (Inductively Coupled Plasma – Mass Spectrometry) and XRF (X-Ray Fluorescence), (2) geophysical logging of till profiles with handheld gamma-ray spectrometry (GRS) which yields the concentrations of K, Th, U and total gamma-ray signal (GR), (3) correlation of weathering indices obtained by geochemical analyses with geophysical logging results.

Four study sites in the northern Poland are planned to conduct the research. All of them are located within the ice-sheet extent during LGM (the Last Glacial Maximum) and the exposed profiles feature at least one Weichselian (MIS 2) till layer with various susceptibility to weathering. The profile in Dmuchowo site consists of massive till with sandy interbedding in its lower part. There are visible signs of



weathering in the top part. In Gdynia Babie Doły site the till profile is protected by paralimnic sands and silts, and debris-flow diamicton, but its top bears signs of initial erosion. The till profile in Gdynia Orłowo site reveals intense weathering in the top part and lastly, the till profile in Polskie Gronowo site does not show any apparent signs of erosion and weathering with the upper part protected by glaciolacustrine silty-clayey deposits.





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## Relict sand wedge sites in Hungary – a sedimentological case study

Thermal contraction cracks are well known proxies of frost action, both in recent and relict environments. A sedimentological analysis was carried out on relict sand wedges from two study sites (Kemeneshát and Mogyoród area) in Hungary, in order to investigate past periglacial processes in the Pannonian Basin. After adequate sample preparation, the grain size distribution of sand wedge infillings (N=82) was determined, and descriptive statistical analysis was carried out using GRADISTAT software. 470 quartz sand grains were examined by using a scanning electron microscope. Thereby, the roundness of the grains was determined and grain surface microtextures were analysed.

The results show that every sample from the Kemeneshát area exhibit poor sorting values and mainly polymodal distributions, while the Mogyoród samples are exclusively unimodal and moderately sorted. SEM investigation reinforces the abovementioned statements with the Krumbein's scale results. Most of the studied grains are angular, which refers to the short transportation time of the sediment. Crystal overgrowth was often found on the grains, which suggests sandstone or metamorphic origin for the infilling material. Intensively weathered grain surfaces mark lots of changes in the palaeotemperature. Fresh, sharp edges, as well as big, unaltered conchoidal fractures and breakage blocks indicate intensive frost weathering processes during the last damaging cycle of the sediment.



These results help us to reduce the arising uncertainties in the paleoenvironmental reconstruction of the Pannonian Basin during Late Pleistocene.



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## **Insights from the palaeo-geomorphic features of the Central Ganga Plain, India: past to present**

The Ganga Plain is one of the largest alluvial tracts of the world consisting of rivers of different types and sizes. The domination of the fluvial process has evolved the different kinds of fluvial landforms on this plain. The palaeo-fluvial features have a significant presence in the region but are less explored/mapped. Palaeo-fluvial features are remanent of the past that are disconnected from the process that forms them. The palaeo-fluvial landforms on distant interfluvial surfaces of the Central Ganga Plain are disconnected from the present rivers. The major palaeo-fluvial landforms observed in this region are palaeo-channel and associated oxbow lakes, meander scars *etc.* The evolution of such features is still not understood properly. These palaeo-fluvial features are a possible result of changing past climatic and geologic conditions in the region. The landscape memory of such features could be very important to understand the climatic and tectonic changes of the past. Apart from that, they do control several physical-cultural aspects of the region. The large-scale mapping of such features is very important to locate the old path of flow, the direction of channel changes, events of river capturing, and the evolution of contemporary rivers. The study of such features is required to understand the past evolution of the Ganga plain and to understand the impact of such features on the present physio-cultural setting.



Although the palaeo landforms of the region are buried or in the process of burial, still they show different kinds of signatures that can be traced for identifying and mapping them. The available high-resolution remote sensing datasets are very helpful for identifying and studying them. It is found that automatic extraction techniques are not useful for the selected study area due to diverse surface conditions. The mapping of these palaeo-fluvial features has been done using visual image interpretation and manual onscreen digitization on the moderate to high-resolution datasets. Mainly Landsat MSS images are used along with the high-resolution Google Earth imageries available on the Google Earth Pro platform. The sedimentological and geochronological analysis is also important along with mapping to understand the history of the past.

The several networks of palaeo-channel with associated landforms are mapped in the study. It is found that there are signatures of lost rivers on the interfluvial surfaces of the Ganga Plain. This mapping has also solved the problem of the presence of large lakes in the study area. The dense network of palaeo-fluvial features suggests that in the recent geological past, the fluvial activity was very active and rivers have frequently changed their paths. Some river capturing events also have been identified in the study. This study is very important in highlighting the influence of these remanent landscapes of the past on the present physio-cultural setting.



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## Determination of the age of carbonate rocks by the cosmogenic chlorine-36 in the valleys of Miętusia and Mała Łąka

The Mietusia and Mała Łąka valleys were glaciated at the turn of the Holocene and Pleistocene, with the maximum extent during the Last Glacial Maximum (LGM). This was one of the assumptions of the project, which we wanted to prove by dating glacial forms. Both valleys are situated in the Western Tatras. This part of the Tatra Mountains is much less studied in terms of the age of glacial and postglacial forms compared to the forms from the High Tatras. We used the cosmogenic <sup>36</sup>Cl because of the geological structure of the study area, which consists mainly of Triassic dolomites and limestones with very limited meade of gneiss and other metamorphic rocks at the highest picks (Krzesanica 2122 m a.s.l., Małolączeniak 2096 m a.s.l., Ciemniak 2096 m a.s.l.).

The Tatra Mountains (Western Carpathians) are the northernmost alpine orogen which was glaciated in the Pleistocene. Therefore, they are a kind of palaeoclimatic link between the area of southern Europe and Scandinavia and Central – Eastern Europe. For this reason, the reconstruction of the palaeoclimate for these glaciers seems to be a necessity.

The Tatra Mountains are situated at the junction of continental and oceanic climate, which causes high temperature amplitudes and the highest precipitation in the summer months. The high amount of



precipitation, especially in warm months, causes high erosion rates (including chemical erosion) and a rapid rate of change in glacial forms (especially in the lower parts of the valleys).

In the course of this study, we obtained 32 dates based on the measurement of cosmogenic  $^{36}\text{Cl}$  produced *in situ*, derived from boulders building maximum and recession moraines, and from the floor of the valleys. Dates from morainic boulders range from  $20.7 \pm 0.8$  ka to  $8.8 \pm 0.4$  ka, with a high standard deviation for one moraine. Bedrock dates are:  $16.7 \pm 0.7$  ka and  $18.8 \pm 1.1$  ka. From the obtained results it is very difficult to determine a reliable moment of glacier stabilization and the age of the entire form especially for the LGM moraines. Unfortunately, this makes it difficult to use these glaciers as a palaeoclimatic source of information, as we cannot put climatic conditions into a specific time frame.

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## Remote sensing applicability in geomorphological investigations of beaches

Beaches are coastal forms consisting of unconsolidated material of varying sizes. Since they are formed on the seashore, processes from both the land and the sea, combined with anthropogenic influences, affect their morphological changes. Beaches have an important socio-economic significance for tourism, so it is necessary to take care of their stability. Beach monitoring has proven to be one of the most appropriate methods for studying their morphological changes. It is usually carried out with the help of remote sensing techniques, which are increasingly used nowadays and may provide a huge database of relatively high-quality images. If the UAV images are connected with a GNSS data, sub-centimetre precision can be obtained. This paper revealed the accuracy of remote sensing methods and their application in the study of beach evolution on the island of Hvar in Croatia.

Measurements were carried out at 20 sites over a 10-year period (2011–2021) using Google Earth Pro, the Croatian State Geodetic Administration geoportal and fieldwork (UAV and GNSS receiver). Since the models generated by photogrammetric techniques from the UAV are the most precise, they were used as reference values, so the measurements from different remote sensing data sources were compared with them. By comparing the measurements from all data sources, a strong correlation was calculated ( $r^2=0.98$ ). It was found that the average RMSE for beach area was 7.2% and length was 2.5%, a relatively accurate measurement that can be used for beach surveys when the calculated error is taken into account (Mićunović *et al.*, 2021).



In order to study evolution of beaches using archival data (maps, photographs and orthophotos) and more recent remote sensing data several beaches were selected. The oldest, the Franciscan cadastre, dates from 1834, photographs and orthophotos from the mid-20<sup>th</sup> century, and more recent remote sensing data (UAV and satellite) from 2021. All beaches had the largest area in the 19<sup>th</sup> century, which gradually decreased until recent period. There is a trend towards severe erosion of the beaches. On average, beaches have lost 32% of their area. For example, the pebble beach Lučišće has lost 45% of its area while Mola Milna 27%.

Various remote sensing data sources proved to be very good for accurate beach measurement surveys. In combination with archival data, they provide useful information for the study of beach evolution which is necessary for further sustainable coastal management.

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## **Possibilities for the use of drone data in geomorphological analysis of river deltas, based on the delta of Jeziorsko Reservoir**

The annual lowering of the water level in Jeziorsko Lake in autumn and spring provides an opportunity to observe interesting changes related to bottom morphology and riverbed evolution, especially in the unstabilized northern part of the delta. This is the period when about 50% of the bottom is exposed. During this period, it is possible to observe and analyse changes shaped by water currents. The aim of this study is to prove the usefulness of carrying out photogrammetric flights using drones to analyse the evolution of deltas of water reservoirs. The muddy and boggy wetland of the exposed bottom of Jeziorsko Lake poses a problem for ground surveys, so unmanned aerial vehicles were used to conduct the research. The surveys produced four orthophotos at intervals ranging from a few days to several months in succession, thus depicting the exposed section of the unstabilized delta. Initial observations of the photogrammetric imaging revealed variability of morphological forms of the bottom of Jeziorsko Lake, which is visible in overlapping parts of the imaging. In particular, a dynamic evolution of riverbeds draws attention. Changes in their positions reached up to about 1.5 m in two days. Other observations include changes in water level, increased overgrowing of exposed fragments of the bottom by vegetation in the period from the end of April. The study also revealed increased anthropogenic activity, which may lead to degradation of the frequented area, especially where lowering of the water level revealed



peninsulas facilitating access from the shore. Nadir aerial photographs in jpg format were used for the analysis. The photogrammetric flights were conducted at altitudes of 110–120 m AGL (above ground level). The photographs were then processed in Dji Terra and Agisoft MetaShape photogrammetric software in order to create an orthophoto map. The GPS navigation system ensures the accuracy of geolocation of the photographs, the measurement of which was additionally corrected using the RTK system. Location correction using the RTK system was necessary so that the survey without any photopoints could be carried out with as much precision as possible. The decision not to measure the photopoints on the surface of the mapped area was made because it was not possible to set up measuring points on the optimum surface of the study and the study was conducted over unstable ground.