***Unveiling the Past, Safeguarding the Future:***

***Exploring Environmental Radioactivity for Geochronology Advancements and Understanding Earth Science Processes***

The study of environmental radioactivity holds a dual significance, contributing not only to the health and well-being of our environment but also playing a pivotal role in the development of nuclear dating methods. These two facets are deeply intertwined, offering valuable insights into the past and present.

On one hand, understanding and monitoring environmental radioactivity are essential for safeguarding the health of humans as well as the health of our environment (Begy et al., 2023a, Dicu et al., 2021). These studies enable us to detect and assess the presence of radioactive pollutants, both natural and anthropogenic, in various environmental matrices such as soil, sediment, water, and air (Savin et al., 2023, Begy et al., 2023a, Ganea et al., 2023, Begy et al., 2022a,b, Tunyagi et al., 2020). EURATOM directive no. 59 /2013 on safety standards regarding exposure to ionizing radiation introduced for the first time legal requirements on protection against exposure to natural sources of radiation and mandated all EU member states to establish national action plans in this regard.

On the other hand, the field of environmental radioactivity, including studies regarding natural and artificial radioactivity by gamma, alpha, and beta spectrometry all hosted by our research center, has been instrumental in the development of nuclear dating methods. The natural decay of radioactive isotopes in the environment, such as Pb-210 dating, provides us with a natural clock that allows us to determine the age of materials and sediments. Pb-210 dating is particularly valuable for dating recent sediments, spanning the last 200 years. We utilize the Pb-210 dating method to establish precise chronologies of sediment deposition in natural sedimentary archives (Begy et al., 2024, Begy et al., 2021, Szabo et al., 2020, Haliuc et al., 2020). These chronologies serve various purposes, including studying effects of land use changes on soil erosion processes, historical assessments of water quality, and monitoring atmospheric pollution involving heavy metals, organic pollutants, and radioactive emissions. Recent studies have also proven the potential of using the method for dating peatlands with great implications for the pivotal role these have in CO2 sequestration, underscoring the urgency of preserving these ecosystems (Begy et al., 2023b, Longman et al., 2021). We also contribute to developing the methodology of the analytical procedures involved in these technique (see e.g. Kelemen et al., 2023, Begy et al., 2022a).

For going beyond the recent past, trapped charged techniques such as luminescence and electron spin resonance (ESR) dating are methods that rely on the effect natural radioactivity has over the point defects in mineral grains in time. These methods have significantly contributed in the last decade to paleoclimate research addressing the timeframe of the Quaternary by providing accurate absolute ages, aiding in the reconstruction of past environmental conditions (del Valle et al., 2024, Peric et al., 2022, del Valle et al., 2022, Avram et al., 2022, del Valle et al., 2021, Faur et al., 2021, Mirea et al., 2021, del Valle et al., 2020a,b, del Valle et al., 2019). The study of paleoclimates is the key to unlocking the past, enabling us to better understand the present, and providing essential insights for predicting and mitigating the challenges of future climate change.

At present the Babeș-Bolyai University (BBU) luminescence dating laboratory is the sole fully operational facility of its kind in Romania. During recent years we expanded our capabilities by introducing electron spin resonance dating at BBU (Timar-Gabor et al., 2020, Benzid and Timar-Gabor, 2020, Gabor et al., 2019). The combined use of these trapped charge dating methods is a rare practice, limited to just a few laboratories worldwide. As such, we conducted luminescence and electron spin resonance dating studies in various sedimentary environments, with implications for various scientific disciplines, including geology (Constantin et al., 2019, Tecsa et al., 2020), archaeology (Handel et al., 2020, Groza et al., 2019) and environmental science (del Valle et al., 2019). Apart from the applicative studies our research goal is to enhance the precision, accuracy, and age range of these dating methods, delving into the behavior of point defects in minerals under natural factors (see e.g. Timar-Gabor et al., 2020, Benzid and Timar-Gabor, 2020).

The members of the Environmental radioactivity and nuclear dating center, Babeș-Bolyai University (BBU) recently successfully finalized INTERTRAP project,funded under Horizon 2020 (2016-2021). INTERTRAP was a innovative initiative in the field of Physical Science and Engineering. It was supported by the European Research Council. Grants funded by the European Research Council (ERC) are synonymous with excellence and represent the pinnacle of prestigious research funding in Europe, fostering groundbreaking discoveries and innovation in frontier science. This project was the first of its kind in the field of Earh Sciences in Romania, as well as the first in its host institution, focusing on integrated dating methods for studying past climate using trapped charge techniques. The project was instrumental in setting up a cutting-edge luminescence and electron spin resonance (ESR) dating laboratory at BBU, with an investment exceeding 1 million Euros in research equipment.

The project had a global reach, spanning four continents (North America- see for example Tecsa et al., 2020, Asia-see for example Avram et al., 2022, Europe-see for example Sacaciu et al., 2020, and Oceania-see Avram et al., 2022, Brezeanu et al., 2021, Micallef et al., 2021) and addressing both geological (see e.g. Constantin et al., 2021) and methodological challenges (Lawless et al., 2023, Benzid and Timar-Gabor 2020, Kabacinska and Timar-Gabor 2022, Biernaka et al., 2022) in dating sediments and paleoclimate studies. One aspect of INTERTRAP's paleoclimate approach involved deriving high-resolution luminescence ages and paleoclimate proxy records in loess deposits, particularly around the Pleistocene/Holocene climate transition. These records were compared across continents and with global key records to investigate the synchronicity of climate change. Notably, the project revealed that magnetic susceptibility, often used to correlate loess palaeosol sequences, indicated a gradual shift from the Last Glacial to the Holocene. This shift began around Termination 1 (around 17,000 years ago in the North Atlantic) but preceded the Pleistocene/Holocene transition observed in ice core records, dated 11.7 thousand years ago. Additionally, the project challenged previous interpretations of embryonic soils in relation to Greenland interstadials, suggesting that they reflected regional hydroclimate variability rather than global events. This underscored the importance of considering absolute age control when correlating climate events in different archives (Constantin et al., 2021). The methodological aspect of INTERTRAP aimed at enhancing dating methods for sediments older than approximately 40,000 years by incorporating ESR alongside luminescence techniques. Our work introduced ESR dating of sediments as a new research avenue in Romania. Single grain analysis revealed that brighter grains yielded more accurate results, suggesting that using coarse grains and selecting the brightest ones could lead to better chronologies. Our fundamental research in luminescence and electron spin resonance, using different grain sizes and minerals has unequivocally defined the accurate temporal limits of different methodologies used in trapped charge dating (Kabacinska and Timar-Gabor 2022, Kabacinska et al., 2022, Avram et al., 2020).

In 2022, the core of the INTERTRAP team achieved a significant milestone by securing a second European Research Council (ERC) grant. Obtaining two consecutive grants is a rare achievement at European level, as the ERC encourages diverse and innovative research rather than continuous funding. PROGRESS, as part of Horizon Europe, will run from 2023 to 2027. The project, titled "Reading provenance from ubiquitous quartz: understanding the changes occurring in its lattice defects in its journey in time and space by physical methods," currently develops methods for determining the origin of quartz samples by studying atomic-level changes in quartz over geological time. The primary goal of PROGRESS is to advance our understanding of quartz-based provenance methods by conducting complex investigations on samples of various types with ages spanning over an extended geological time. Most of the provenance studies using trapped charged methods target minerals grains deposited in sinks and focus only on observing the characteristics of signals displayed by different samples, followed by clustering. As such, there is a gap in the knowledge regarding quartz luminescence signals in rocks. Without directly examining the signals of the potential rock sources, these studies are not proving a cause-effect relationship. PROGRESS team members currently tackle this gap by investigating the luminescence sensitivity in rocks with varying crystallization ages that go beyond 1 Ga, selected from locations throughout the world, from our country to North America, Africa, and Australia. These investigations will contribute to the development of a quartz fingerprint method that can have a significant impact on quantitative provenance studies. In other words, PROGRESS will develop a quartz based forensic fingerprinting method for geological applications. Our preliminary results show that indeed luminescence and electron spin resonance methods have the potential for such methods to be developed (Timar-Gabor et al., 2023, Dave et al., 2022a,b). This project will significantly expand our research capabilities by incorporating cutting-edge equipment valued at over 1.5 million Euros, most of it already purchased and installed. It will involve combining luminescence and paramagnetic electron resonance dating techniques with spectrally resolved cathodoluminescence, based on scanning electron microscopy as well as other spectroscopic methods such as Fourier transformed infrared spectroscopy. Although these methods are known for other applications, there are only a handful of laboratories worldwide that integrate these experimental approaches for applications in earth sciences. By incorporating microscopic and cathodoluminescence techniques with trapped charge dating techniques, the BBU laboratory will gain a competitive advantage in the luminescence and paramagnetic electron resonance dating community worldwide.

Our research group boasts a global network of collaborations. However, as seen from our publication list below, the place of origin of the vast majority of our publications remains our group, emphasizing our leading role in the research we carry out. Our members are present in the scientific committees of the main conferences in our field. Our papers, cited over 2000 times in all major databases during the last five years have been listed many times as most cited/downloaded in Radiation Measurement, Quaternary Geochronology and Boreas Journals in the last years. Both senior, early career scientists and students of our team have received international accolades. The members of our center have been honored not only to attend prestigious international events but also to host visits from numerous international scientists and are active in various actions that aim transferring our know how to society as well as actions that aim at increasing the participation and success rate of Romanian researchers in ERC funding schemes. To conclude the Environmental and Nuclear Dating Centre stands as exceptional in Romania, for its excelent capabilities in the study of natural radioactivity, precision dating of the last 200 years using Pb-210, unique luminescence and electron spin resonance dating facilities for the young Quaternary period, and its pivotal role in advancing fundamental research, generously supported by the European Research Council.

Last but not least, with over a dozen PhD students graduating in the last decade, the Environmental and Nuclear Dating Centre is a nurturing ground where aspiring young students are cultivated and trained into the scientists of tomorrow.

**References: Articles published in the last 5 years in indexed journals by current team members and alumni (undergrad students, PhD students and post-docs) of the Environmental Radioactivity and Nuclear Dating Center and marked in bold.**

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**Projects implemented in the last 5 years by members of the Environmental Radioactivity and Nuclear Dating Center**

1. European Research Council Grant 101043356, Horizon Europe, “Reading provenance from ubiquitous quartz: understanding the changes occurring in its lattice defects in its journey in time and space by physical methods (PROGRESS)”, 2023-2027, PI Alida Timar-Gabor.

(value 2 657 000 Euro)

European Research Council Grant 678106, Horizon 2020, „Integrated dating approach for terrestrial records of past climate using trapped charge methods (INTERTRAP)”, 2016-2021, PI Alida Timar-Gabor. (value 1 500 000 Euro)

1. EEA-RO-NO2018-0126, „Cave deposits as archives of climate and environmental changes. A Center of Excellence in speleological research”, grant coordinated by Silviu Constantin,” Emil Racovita” Speleology, 2019-2023, BBU partner PI Alida Timar-Gabor. (value 200 000 Euro)
2. PN-III-P3-3.6-H2020-2016-0016, „Premierea H2020 Integrated absolute dating approach for terrestrial records of past climate using trapped charge methods”, 2016-2021, PI Alida Timar-Gabor. (value 375 000 Euro)
3. PN-III-P1-1.1-TE-2016-0814, „Studies on the effects of land use changes on soil erosion and increased sedimentation using radionuclides”, 2018-2020, PI Robert Begy. (value approx. 100 000 Euro)
4. PN-III-P1-1.1-TE-2021-0213 ″Carbon sinks or sources: assessing the impact of climate change and anthropic activities on peat development in SE-Europe over the last 150 year (CLIMPEAT)” 2022-2024 PI Robert Begy. (value approx. 100 000 Euro)
5. PN-III-P1-1.1-PD-2019-0895, „To what extent can uncertainties on luminescence ages be reduced: a field study on the variability of ages obtained on coeval sedimentary samples (PRECLUM)”, 2020-2022 PI Daniela Constantin. (value approx. 50 000 Euro)

**Awards received by members of the Environmental radioactivity and Nuclear Dating Centre during the last 5 years**

**2023-** Grigore Moisil award for exact sciences Virtus Excelsior Gala, under the patronage of Romanian Academy, first edition, 2023 (Alida Timar-Gabor)

**2022**- Universitaria Award “Gândit în România”, 1st edition 2022 (Alida Timar-Gabor)

**2021-** Martin Aitken prize for Fundamental research (best Oral presentation) at the 16th International Luminescence and Electron Spin Resonance Dating (LED) Conference (Aditi Dave)

**2020-** Best Oral Presentation award at the German LED Conference, Leipzig (Aditi Dave)

**2020**- Young Profession Award, VII. Terrestrial Radioisotopes in Environment International Conference on Environmental Protection Conference, Institute of Radiochemistry and Radioecology, University of Pannonia, Veszprém, Hungary (Șerban Grecu)

**2019**- Best Poster award at the U.K. LED Conference, Copenhagen. (Aditi Dave)