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## **Citizen Science and Geoheritage: a Sampling Campaign for Cosmogenic <sup>36</sup>Cl Surface Exposure Dating of Glacial Deposits in Mt Parnassus National Park, Central Greece**

A.D. Leontaritis<sup>1</sup>, K. Pavlopoulos<sup>2</sup>, M. Giorgaras<sup>3</sup>, K. Tsalkoutis<sup>3</sup>, N. Koukis<sup>3</sup>

(1) National Technical University of Athens, Greece / The Greek Mountain Project, Ioannina, Greece. aris.leontaritis@gmail.com (2) Sorbonne University Abu Dhabi, UAE. (3) Nomads Path Adventures- Outdoor Activities Cooperative, Athens, Greece.

### **Research Highlights**

A sampling campaign for <sup>36</sup>Cl dating of Quaternary moraines was conducted in June 2021 with an open call on social media for participation of citizens regardless of their background. The organization was jointly realized by geoscientists and mountain hiking professional guides. A multi-beneficial collaboration both for science and geoheritage was achieved which resulted in a very efficient sampling campaign. At the same time participants and professional guides were actively involved in scientific research thus gaining a deeper understanding of the geoheritage of Mt Parnassus National Park.

### **Paleoclimatic and geomorphological background**

Evidence of former glacier occupation is present across Greece where many mountain regions exceed 2000 m asl (Leontaritis, 2021 and references therein). The most extensive glacial phase in the mountains of Greece took place during MIS 12, as established by radiometric data from Mt Tymphi (Woodward et al., 2004). These studies overturned the initial assumption that, similarly to the Alps, the most extensive glacial phase in the Balkans occurred during the global last glacial maximum (LGM) (27-23 ka). In the contrary, evidence suggests a much more restricted glacier development during the Late Pleistocene, and particularly around the LGM and during the Lateglacial Allard, et al. 2020; Leontaritis et al., 2022. The study of Pope et al. (2017) on Mt Chelmos showed that LGM glaciers were limited to the highest elevations and already in recession at 23-21ka. This is consistent with evidence from Mt Tymphi, where the presence of small glaciers at high altitudes dated to the LGM, correlated stratigraphically with many rock glaciers, has been interpreted as the result of arid climate conditions around the global LGM (Allard et al., 2020).

The Lateglacial (17.5-11.6 ka) in Europe was characterized by at least two cold periods that favored glacial advances: the Oldest (OD) and the Younger Dryas (YD) at 17.5-14.7 ka and 12.85-11.6 ka respectively. In Greece, glacial deposits from the Lateglacial are rare and have so far been dated only on Mt Olympus (OD; 15.7-14.5 ka; Styllas et al., 2018) and Mt Chelmos (YD; 12.6-10.2 ka; Pope et al., 2017). The paucity of OD or YD moraines possibly indicates that relatively unfavorable climatic conditions for glaciers formation continued throughout most of the Lateglacial.

Overall, while several glacial deposits have been identified only some have been successfully dated to the LGM, and Lateglacial. Thus glaciers response to these cold events in Greece remains largely understudied. Traces of former glaciers on the mountains of central Greece (Mt Parnassos, Mt Vardousia, Mt Gkiona) had already been identified by the first pioneer researchers like Mistardis (1937) and Pechoux (1970). The undated (likely) LGM to Lateglacial moraines in the mountains of central Greece could provide the key for testing the precipitation hypotheses of a more arid climate during the Lateglacial in northern Greece compared to the south proposed by Pope et al. (2018) and Leontaritis (2021) based on the observation of decreasing Equilibrium Line Altitudes of paleoglaciers across Greece (North to South).

### **Study Area, approach, and sampling campaign objectives**

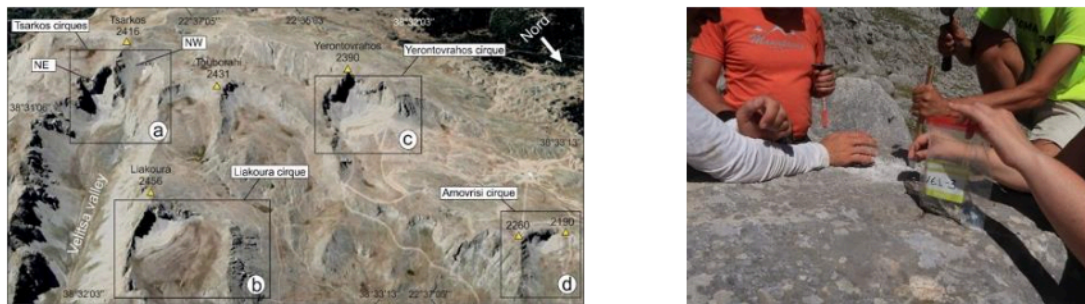
Mt Parnassus is (2457 m asl) is composed of a 1.5-2 km thick Upper Triassic to Palaeocene neretic carbonate sequence, terminating with a typical Palaeocene clastic sequence (flysch) (Kranis and Papanikolaou, 2001). The massif is characterised by U-shaped valleys, headed by well-developed glacial cirques, indicating extensive glacier occupancy(ies) in the past, likely linked to the Middle Pleistocene (MIS 12) (Leontaritis, 2021). Through a dedicated geomorphological field study, Leontaritis (2021) identified a few clear and well preserved, moraines within at least five high altitude (>2000m), north-facing cirques (Figure 1a). The lack of soil and vegetation, limited lichen colonisation and evidence of relatively limited weathering on the surface of these moraines indicate a likely recent (LGM to Lateglacial) age.

The scientific aim of this wider project is to constrain the age of Late Pleistocene glacial deposits on Mt Parnassus, focusing on the LGM and the Lateglacial using the cosmogenic <sup>36</sup>Cl surface exposure dating of glacial boulders - a well-proven method for limestone lithologies. Sampling focused on limestone boulders within moraines in the Liakoura, and Tsarkos NE and NW cirques (Figure 1a). Sites in Yerontovrahos and Arnovrisi cirques (panel c and d in Figure 1a) were ultimately not considered for sampling because of a lack of large boulders and the proximity to the ski runs and lifts.

### **Implementation of sampling campaign in the framework of Citizen Science and geoheritage**

On the 26<sup>th</sup> and 27<sup>th</sup> of June 2021 a joint group of 13 persons collected 18 high quality samples from glacial boulders in

the selected moraines after hard and well-coordinated work (Figure 1b). These samples are currently under analysis in the SUERC AMS facilities in Scotland. The number of participants was significantly affected by a strong heat wave during that period with temperatures reaching 40°C in the lowlands. Several people cancelled their participation due to the prevailing conditions. The group consisted of two geoscientists coordinating and supervising the scientific work, three professional hiking guides taking responsibility of the group safety, the organization of the camp and of advising the 8 participants on tackling the challenges in this hard and remote mountain terrain.



**Figure 1. a) (Left) Satellite image of key sites on Mt Parnassus, b) (Right) Collaborative samples collection**

The workshop started with a short review of the glacial history of Greece and the basic principles of geomorphology and geochronology and the interpretation of landforms with special focus on cryogenic processes. Special attention was given to the sampling principles for cosmogenic nuclides surface exposure dating described in Gosse and Phillips (2001). The training aimed at the understanding of the reasons why samples had to be collected in a certain way, strictly avoiding a series of inexplicable instructions. The participants and the professional guides showed great interest in expanding their knowledge through this geomorphological field study but also posed many questions on other aspects of geoscience such as the orogeny of the Greek mountains, fossils, petrology, tectonics, and geoconservation issues. These matters were openly discussed with the scientific advisors and a participating geologist with specialization in paleontology. In other words, geoheritage as discussed in Papadopoulou et al. (2022) was the focal point of arising discussions.

In summary, this pilot event of citizen geoscience (a process that involves the public in doing geoscience) raised the awareness and perception of the geoheritage of Mt Parnassus and the mountains of Greece for most participants, as it was underlined during the closing discussion of the workshop. Indeed, citizen science has been recognized to increase the participants' understanding of scientific processes and the environment, making them feel recognized and appreciated for their contribution, and potentially making participants more sensitive to and aware of certain socio-environmental issues (Haklay et al., 2021 and references therein). Thus, such actions contribute significantly towards shaping a wider perception of geoheritage and geoethics through the active participation and contribution of citizens in the development of scientific knowledge. Another important aspect is the motivation of outdoor activities professionals towards this direction as they can play a significant role in spreading this geoculture to participants in their commercial activities. The promotion of geoheritage as a natural resource of science, education, and tourism should anyway be among the main responsibilities of geoscientists and outdoor professionals supporting sustainable tourism in protected natural environments.

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