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Fossil debris-covered glaciers in Demanda Sierra (Northern Spain): geomorphological research and 10Be cosmogenic exposure dating

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The Demanda Sierra, at altitudes above 2000 m.a.s.l., is located in the Iberian Range (Northern Iberian Peninsula, 42º15' N). The main divide extends from west to east between 3º25' W and 2º52' W. The most relevant evidences of Pleistocene glaciation are found in small cirques above 1800 m a.s.l., most of them in the northern face. These cirques hosted small-size glaciers with ice tongues <1 km in length that deposited moraines composed of angular blocks with scarce fine matrix. Several rock glaciers were identified in previous papers. Nevertheless, recent fieldwork suggests the reinterpretation of the large chaotic angular block accumulations without fine matrix as fossil debris-covered glaciers. To elucidate such a complex issue, two north-facing cirques in the Mencilla Peak (42º11'11" N, 3º18'45" W; 1932 m a.s.l.) and a southeast-facing cirque in the San Lorenzo Peak (42º14'28" N, 2º58'31" W; 2261 m a.s.l.) have been selected as they host similar block accumulations. The aim of this paper is: 1) to identify the debris-covered glacier features in such block accumulations; 2) to present the chronology obtained for the first time from debris-covered glaciers and to put them in the context of deglaciation in the Iberian Range and in the Iberian Peninsula and the Mediterranean mountains; 3) to analyze the glacier evolution during the deglaciation.

To carry out these objectives, different methodological approaches and techniques have been applied: 1) detailed geomorphological mapping at 1:1000 scale over stereoscopic pairs, high-resolution LIDAR Digital Elevation Models and fieldwork to identify glacial and debris-covered glacier features (e.g. moraines, ridges, furrows, etc.); 2) Cosmogenic Exposure Dating (CED), 10Be, applied to 18 quartzite samples taken from stable boulders over moraine ridges or fossil debris-covered glaciers; 3) glacier reconstruction for modelling the glacier evolution at different stages; 4) Equilibrium Line Altitude (ELA) calculation. The results obtained show that the large chaotic block accumulations are fossil debris-covered glaciers given the numerous longitudinal ridges and furrows. These fossil debris-covered glaciers consist of a relatively thin debris mantle (<2 m thick), deposited over the residual ice masses, which partially cover the adjacent moraines. The CED analysis indicated a minimum age of 17.8 $\pm$ 2.2 ka for the outermost moraine in the San Lorenzo cirque, attributed to the Last Glacial Maximum (LGM) or even prior glacial stages, and an age of 16.5 ka (GS-2a stadial, Oldest Dryas) for small moraines located close to the cirque headwall. Thus, the debris-covered glacier developed in the intense deglaciation occurred between the LGM and the Oldest Dryas. The isolating effect of the debris mantle over the ice masses enabled them to endure for thousands years, especially in the western Mencilla Cirque, which melted during the Holocene Thermal Optimum, favored by its northern aspect, whereas the San Lorenzo debris-covered glacier did it earlier during the Late Pleistocene. The ELAs fluctuated between 1673 and 1807 m a.s.l. (Mencilla Peak) and between 1904 and 2007 m a.s.l. (San Lorenzo Peak) within the three/four glacial stages identified in the cirques.

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