



## **Reconstruction of the Weichselian plateau ice-field and valleys glaciers of the Serra da Estrela (Portugal).**

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The Serra da Estrela is a granite plateau mountain in Central Portugal that rises to ca. 2000m ASL. The general geomorphological characteristics of the Weichselian glaciation of the Estrela are well-known. The plateaus above ca 1,750m are marked by erosional landscapes, with areas of glacial scouring, knob-and-basin morphology and roches moutonnées. The plateau areas between 1,750 and 1,500m show few marks of glacial erosion and present moraines and, in some areas, remnants of the Tertiary weathering mantle. The valleys show the typical geomorphological features of the glaciated valley landsystem, with cirques in the upstream sections, u-shape cross-sections, overdeepenings above ca 1,200 m ASL, kame terraces and different types of moraines. The glaciated area in the Last Maximum of the Serra da Estrela Glaciation (LMGSE) was ca. 66 km<sup>2</sup> and is well-defined by latero-frontal moraines in the valleys and ice-marginal moraine complexes in the plateau. The widespread glacial features in the valleys allow a relatively straightforward reconstruction of the valley glacier topography, especially below the higher lateral moraines. However, above this limit and especially in the plateau, since nunataks are not present, there is no geomorphological evidence allowing the estimation of ice-thickness and glacier topography. The only way for this estimation is through the application of physically based models of the glacier topography. The method developed by Schilling and Hollin (1981) adapts Nye's equation to valley glaciers by including a valley-shape index that influences basal shear stress and is applied in an iterative procedure starting from the glacier front and moving up-valley at constant distance steps. The model runs along the longitudinal profile of the valley and is based on the gradient along the profile, on valley shape indexes (both obtained from topographic maps) and on yield basal shear stresses. These variables influence ice-thickness and therefore, also the slope of the ice-surface allowing for its reconstruction. The key variable is basal yield shear

stress and its value is obtained from a range known to occur in contemporary valley glaciers, varying between 50-150 kPa. Along the valleys, the values of basal shear stress to be used are chosen upon validation of the obtained profile, against existing geomorphological features. Where geomorphological features are absent, a constant value of 100kPa was used. The glacier topography obtained along the valleys is in very good agreement with the geomorphological observations and shows that the model is of good value to the Estrela mountains. The modelling in the plateau is not possible to validate geomorphologically, but since in the valleys the results were very satisfactory, the same is suggested to occur in the upper areas. Other authors have applied the same method with very good results in different parts of the World (e.g. Schilling and Hollin, 1981; Locke, 1995; Evans et al., 2002). In order to enable the estimation of the paleo-equilibrium line altitudes of the glaciers of the Serra da Estrela, several longitudinal profiles along the glaciated valleys starting from the ice-divides, were used. The same was done along secondary flow lines assumed from topography and glacier erosion features. The whole ice-field and valley glaciers were covered in this way by a radiating set of cross-sections, along which ice-thicknesses were calculated. The data was integrated in a GIS package and a manual interpolation of the ice-thicknesses was conducted, in order to obtain the glacier topography. From this, a DEM of the ice surface was calculated and also a ice-thickness map. The DEM allowed the estimation of the hypsometric curves of the different glacier catchments and the calculation of the paleo-ELA's using several methods (Acumulation Area Ratio and Balance Ratio). The values obtained were compared with previous estimation using the maximum altitude of lateral moraines (Daveau, 1971) showing similar results. The analysis of the hypsometric curves allowed to estimate the sensitivity of the different glaciers to ELA variations. The Weichselian glaciers of the Serra da Estrela were very sensitive to minor climatic changes, especially due to the wide extension of the plateau ice-field, and positioning of the ELA's at the maximum glacial extent, close to the altitudes of the plateau margin.