

## Thermoluminescence Dating of Fluvioglacial Sediments (Serra da Estrela, Portugal)

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*Keywords:* Thermoluminescence dating, Glaciation, Serra da Estrela, Portugal.

*Abstract:* Recently new subglacial till and fluviglacial deposits were identified in the Serra da Estrela. The latter were subject to thermoluminescence dating and the results, which are the first absolute dates on the Estrela glaciation, are presented here. The thermoluminescence datings obtained for the Estrela sediments are all included in the Last Tardiglacial, a result that agrees reasonably with the geomorphological evidence of the glaciation.

### INTRODUCTION

Vasconcelos Pereira Cabral first reported the glaciation of the Serra da Estrela in 1884, but a detailed study came only after Lautensach (1929, 1932). Forty years later Daveau (1971) restarted the investigations and achieved new results. Only recently new studies on the subject were undertaken, mainly in the framework of a doctoral thesis (GV). That study focuses mainly in the systematic survey of the area in order to identify the sedimentological remnants of the glaciation, a methodology that has not been followed before.

With the exception of the moraines contemporaneous to the glacial maximum, glacial deposits are scarce in the Serra da Estrela. Recently new subglacial till and fluviglacial deposits were identified. The latter were subject to thermoluminescence dating and the results, which are the first absolute dates on the Estrela glaciation, are presented here.

### NEW SEDIMENTOLOGICAL OBSERVATIONS AND THERMOLUMINESCENCE DATINGS

The recent sedimentological research in the Estrela revealed the existence of diamicton outcrops with similar facies to the subglacial tills of the Serra do Gerês (Vidal Romani *et al.*, 1990). The diamictons are of granitic origin and are formed by heterometric silty-sandy material with gravels and boulders, massive and compacted, in some cases with injections of the finer matrix into joints in the bedrock. Although the micromorphological analysis was not performed yet, we interpret these deposits as subglacial tills. In some sites there are sand lenses and laminations related to subglacial melting, similar to the ones observed in the Serra do Gerês. In other deposits, probably supraglacial, which are constituted by coarse-grained diamicton, frequently clast-supported, the genesis is not so clear. They are interpreted as supraglacial or ablation tills when integrated in a more complete sequence, for example, if a subglacial till is present in the lower section of the exposure.

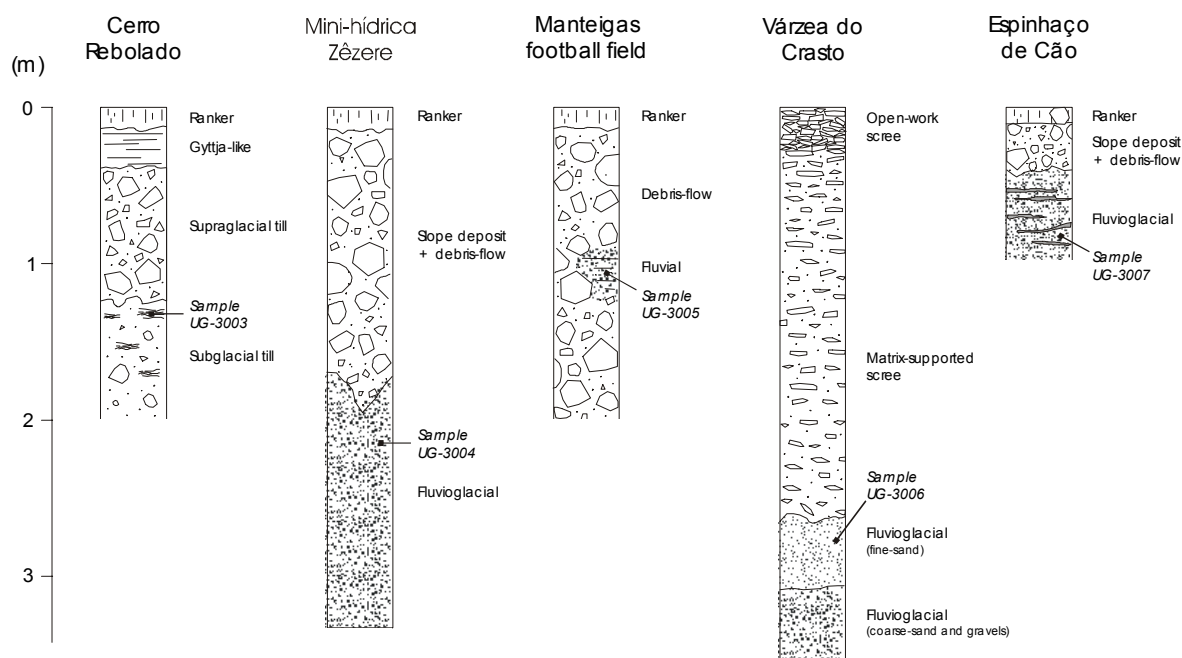
Most of the outcrops interpreted as till were found in the Zêzere valley. There, besides the gravel accumulations located between Covão da Caldeira and Lameiro do Grilo that are still not completely understood (Daveau *et al.*, 1997), stratified silty-sandy deposits have been identified. The geomorphological setting and sedimentological characteristics indicate that they are fluviglacial.

Five samples were taken from different outcrops, four of which fluviglacial and one from a debris-flow deposit (figure 1). The samples are silty-sandy and collected from *ca.* 20 cm depth from the exposure wall. Proximity to boulders was avoided and a distance of *ca.* 20 cm was respected in order to minimize possible contamination of the sample material. The thermoluminescence dating was performed at the laboratory of the University of Gdansk.

As can be inferred from table I the TL ages indicate the Last Tardiglacial. These results are however underestimated due to the relatively high radionuclide concentrations (Ra, Th and K) in the sediments. The samples from Mini-hídrica Zêzere and Várzea do Crasto present values of Ra above 50 Bq/kg, the ones from Manteigas football field and Espinhaço de Cão above 100 Bq/kg and the one from Cerro Rebolado above 200 Bq/kg. In what respects to the Th high values (more than 100 Bq/kg) were obtained in the samples from Cerro Rebolado, Mini-hídrica Zêzere and Manteigas football field. Finally, K concentrations above 1000 Bq/kg were measured in all samples and in the case of Cerro Rebolado the value was higher than 1700 Bq/kg. Based on these numbers, we estimate that the obtained TL ages are *ca.* 20% younger than the real age of the sediments, a value that can be even larger in the case of the Cerro Rebolado that shows very high radionuclide concentrations. The TL ages presented in this paper should be interpreted with relative caution and should not be used, without further datings, individually for the determination of fine chronologies inside the Tardiglacial.

Location	nr	Type of deposit	Equivalent doses, Gy	Total dose rate, Gy/ka	Age TL, ka
Cerro Rebolado	UG-3003	Fluvioglacial	166,63	12,720	13,1 ± 2,0
Mini-hídrica Zêzere	UG-3004	Fluvioglacial	139,28	8,441	16,6 ± 2,5
Manteigas football field	UG-3005	Debris-flow	102,73	9,692	10,6 ± 1,6
Várzea do Crasto	UG-3006	Fluvioglacial	88,65	6,926	12,8 ± 1,9
Espinhaço de Cão	UG-3007	Fluvioglacial	84,91	6,739	12,6 ± 1,9

**Table I – Thermoluminescence datings of sediments from the Serra da Estrela.  
(Datagens por termoluminescência das amostras da Serra da Estrela.)**



**Figure 1 – Studied sections and location of the samples for TL dating.  
(Cortes estudados e localização das amostras para datagem por TL.)**

**Cerro Rebolado** - The Cerro Rebolado area marks a clear geomorphological limit between the glaciated plateaus to the south and the glacier-free areas to the north. The studied exposure is ca. 150 m long and shows a recession sequence related to the Conde valley glacier (fig. 1). It represents the more complex till found up to date in the Estrela. The deposit, located at ca. 1590 m asl presents three sedimentary units. The lower unit is a very compact diamict, in some sectors sandy-silty and in others more coarse-grained. Stratified sands related to subglacial melting are frequent. Silt and clay injections in joints in the bedrock have also been observed. This unit is interpreted as a subglacial till but presents significant amounts of fluvioglacial sands. The intermediate unit is a coarser and poorly consolidated diamicton. It presents no organised structure and is constituted by angular to sub-angular cobbles and boulders within a sandy matrix. It is interpreted as a supraglacial till deposited during glacier recession. The upper unit is a gytja-like deposit, an organic rich sandy accumulation, with stratification in some sectors. Above this unit a more recent mountain ranker exists. The sample collected for dating purposes (UG-3003) was taken from the fluvioglacial material present in the lower unit.

**Mini-hídrica Zêzere** - During the construction works of an electric power dam in the Zêzere valley at an altitude of ca. 1080 m an exposure some 3-4 m high and 20-30 m long was opened in the western slope of the valley (fig. 1). The lower section of the exposure revealed a fluvioglacial deposit, some 2.5 m thick, constituted by sandy-gravel material with silt. The material showed a crude lamination. Above it exists an upper unit of

poorly consolidated diamicton with sandy-silty matrix supporting sub-rounded to sub-angular boulders and gravels. This deposit fills small gullies that incise the lower unit and is interpreted as a mixture of remobilised morainic material from the slopes and debris-flow deposits. The sample UG-3004 was taken from the fluvioglacial material, some 2 m from the top of the exposure. Unfortunately the exposure does not exist anymore.

**Espinhaço de Cão** - The Espinhaço de Cão outcrop is located in a small non-paved road that runs in the eastern slope of the Zêzere valley, just in front of the Espinhaço de Cão moraine at an altitude of ca. 1150 m. The sediment outcrops in irregular sectors along the road for about 50 m. It consists of poorly-sorted sandy-gravel sediments with silts and sub-rounded cobbles, showing gentle downvalley stratification (fig. 1). Compact greyish silty layers 1 to 2 cm thick, with small deformations occur intercalated with the sandy-gravel material. The deposit is interpreted as a fluvioglacial sequence, probably reflecting a position very near the ice-margin (valley train). The fine silty layers resemble the typical "glacial flour" silts that form in present-day mountain glacial environments. It is also possible that there were short-lived over-ridings of the deposit by the ice-mass that could be responsible for compaction of the sediments. Above the fluvioglacial deposit lays a polygenic slope deposit, with boulders supported by a sandy-gravel matrix. The surficial layer is a poorly developed ranker. The sample UG-3007 was taken from a sandy-silty sector of the fluvioglacial material.

**Várzea do Crasto** - The exposure located in the Zêzere alluvial plain near Várzea do Crasto (ca. 640 m asl), downstream of Manteigas, shows a fluvioglacial deposit with massive poorly-sorted coarse sands and gravels in the lower part (fig. 1) and massive well-sorted fine sands in the upper part. On top of the fluvioglacial material lays matrix supported scree material constituted by angular hornfels cobbles and boulders. The upper part of the exposure is open-work scree material. The sample for TL-dating (UG-3006) was collected from the fluvioglacial fine sands.

**Manteigas football field** - Daveau (1971) first described the deposit located at the Manteigas football field and considered it a kame terrace. The deposit is a non-sorted heterometric accumulation of sub-rounded to angular granite boulders with a silty-sandy matrix (fig. 1). In some sectors infilled-gullies are present and also thick silty-sandy inclusions with a crude stratification. Daveau *et al.* (1997) raise some problems concerning the kame genesis and suggest that the deposit is a fan related mainly to debris-flow activity. The sample UG-3005 for the TL analysis was taken from the silty-sandy material described above and that is present in the left part of the exposure.

## DISCUSSION

The major limitation for determination of the chronology of the glaciation in Portugal is the very small number of absolute datings. The glacial forms and deposits of the Estrela and Gerês ranges have been attributed to the Last Glaciation (Würm in the classical alpine chronology). Recent datings based on the formation of cosmogenic nucleids in glacially polished surfaces, both in Queixa (Galice, Spain) and in Gerês, suggest that there, the Pleniglacial is much older (Vidal Romani *et al.*, 1999). In the Gerês, a sample (X-1) was dated 130 kyr BP and another sample (X-2), representing the Pleniglacial, was dated 238 kyr BP. Once this method indicates the minimum ages, because the polished surfaces are exposed only during the glacier recession, the latter sample would be included in isotopic stage 8 (Vidal Romani & Fernández Mosquera, 2000). In terms of the regional variations of glacier ice volume, reflected in the isotopic stratigraphy, the age of the sample X-2 indicates that the maximum in the Serra do Gerês would be close to Termination III (following Broecker & Denton, 1990, *in* Lowe & Walker, 1997, p. 152).

In what respects to the Serra da Estrela, no datings exist for the Pleniglacial. Nevertheless the Pleniglacial stage of the Estrela glaciation is well defined by the lateral moraines, like the ones of Poio do Judeu and Lagoa Seca in the Zêzere, which reflect a glacier thickness of more than 300 m in the valley. Another example is the 4.5 km long Covão do Urso moraine (the longest of the Estrela range) that marks the northern limit of the ice cap. The kame-terraces in the valleys are Pleniglacial too. Also, as shown by Daveau (1971, p. 15) the analysis of the boulder accumulations in some of the valley floors enables the identification of several stadial moraines.

The thermoluminescence datings obtained for the Estrela sediments are all included in the Last Tardiglacial, a result that agrees reasonably with the geomorphological evidence of the glaciation. Three samples were obtained from fluvioglacial deposits located near the Zêzere valley bottom, two of which (Espinhaço de Cão and Mini-hídrica) located much below the maximum thickness of the glacier during its maximum extent. For the Espinhaço de Cão an absolute age for a relatively well-known position of the glacier was obtained. The age obtained for the Manteigas football field deposit suggests that it cannot be considered a kame terrace. An alluvial

fan seems more likely, probably formed in distinct episodes during the Tardiglacial or even during the postglacial. The only result that raises some doubts is the Cerro Rebolado sample, for which an older age would be expected, once the deposit has been interpreted before as Pleniglacial (Daveau *et al.*, 1997). Even considering that the age of the fluvioglacial material is more than 20% older than suggested by the TL, it is possible to confirm that glacier ice occupied the Conde valley until recent times and that probably the Pleniglacial in the Estrela is much more recent than in the Gerês.

The more significant information from these first TL datings of fluvioglacial sediments from the Serra da Estrela, point towards a confirmation of the existence of glacial activity during the Tardiglacial. These results are in agreement with the palynological studies that indicate the absence of peat sedimentation in the mountains of NW Iberia before the Older Dryas (Ramil Rego *et al.*, 1995; Vidal Romaní *et al.*, 1995). Also, for the Serra da Estrela, Van der Knaap & Van Leeuwen (1997) showed that the lacustrine sediments of Charco da Candieira, a site at 1400 m asl in a hanging valley tributary of the Zêzere, do not contain organic deposits before the pollen zone LG1 (14,8 - 14,3 cal kyr BP). The authors interpret the result as due to the occurrence of a glacial and periglacial morphogenesis in the catchment. The site was only occupied by a *Betula alba* forest during pollen zone A1a (11,6 - 11,5 cal kyr BP).

#### ACKNOWLEDGEMENTS

This research was supported by the bilateral cooperation between the Universities of Lisbon and Warsaw. Vieira and Ferreira were also supported by the ESTRELA Project (Praxis/C/CTE/11153/98 - Fundação para a Ciência e a Tecnologia). The Natural Park of the Serra da Estrela is thanked for the logistical support during fieldwork.

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