Environmental setting of the Serra da Estrela, Portugal: a short-note

G. Vieira[1], J. Jansen[2] and N. Ferreira[3]

[1] Centro de Estudos Geográficos, Universidade de Lisboa, Fac. Letras, Alameda da Universidade, 1600-214 Lisboa, Portugal. e-mail: gtvieira@ceg.ul.pt
[2] Department of Ecology, University of Nijmegen, Toernooiveld, 6525 ED Nijmegen, The Netherlands. e-mail: jan.jansen@sci.kun.nl
[3] Instituto Geológico e Mineiro, Rua da Amieira, Apartado 1089, 4466-956 S. Mamede de Infesta, Portugal. e-mail: Narciso.Ferreira@igm.pt

Abstract

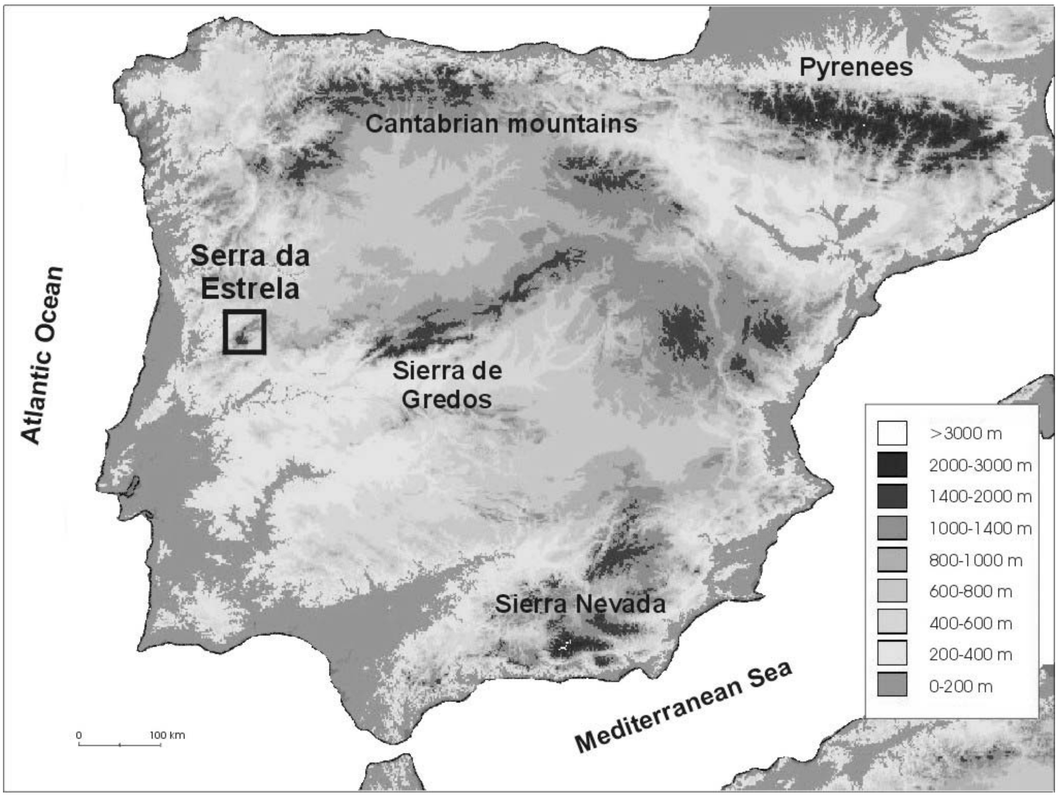
The Serra da Estrela is a granitic and metamorphic mountain range located in Central Portugal (1993 m ASL). The origin of the range is related to events of planation and tectonic uplift that gave origin to a series of plateaus and deep valleys. The most dramatic features of the landscape are probably the Late Pleistocene glacial landforms that mark the upper areas. The vegetation reflects the geographical position and altitude, which induces a complex interaction between the Mediterranean and Temperate bioclimates. A long history of human intervention on the vegetation, through grazing, fires, agriculture and more recently, tourism, amplified even more the complexity of the landscape. It is therefore a very rich area for landscape ecology research. The paper briefly illustrates the general characteristics of its environmental setting.

Introduction

The objective of this note is to briefly describe the general characteristics of the Serra da Estrela, an interesting mountain in the fringe between Atlantic and Mediterranean landscapes, with significant glacial and periglacial landforms and where within a few kilometers one may pass from cryogenic grasslands to evergreen laurel galleries; or from meso-Temperate Pyrenean oak remnants to meso-Mediterranean Holm-oak groves. The range is a large protected area, the Parque Natural da Serra da Estrela and was visited during the Workshop “Landscape Ecology and Management of Atlantic Open Mountain Landscapes” (IALE, ALTERRA and APEP).

The Serra da Estrela (40º20´N, 7º35´W – Fig. 1) is part of the Cordilheira Central, an ENE-WSW mountain range that crosses the Iberian Peninsula and is the highest mountain in Portugal (1993 m ASL – Alto da Torre). Two major plateaus divided by the SSW- NNE Alforfa and Zêzere valleys dominate the relief of the mountain. The Torre – Penhas Douradas plateau (1993 – 1450 m) is located in the western side, and the Alto da Pedrice – Curral do Vento, in the eastern side (1760 – 1450 m). The plateaus are composite, show flat surfaces at distinct altitudes and present a few wide valleys. The mountain flanks in the SE and NW are steep scarps with over 1000 m relief, connecting to the Mondego Platform and Cova da Beira. Other large and deep valleys radiate from the Serra da Estrela (Alvoco, Loriga, Caniça, Alva and Mondego valleys).

Figure 1: Location of the Serra da Estrela

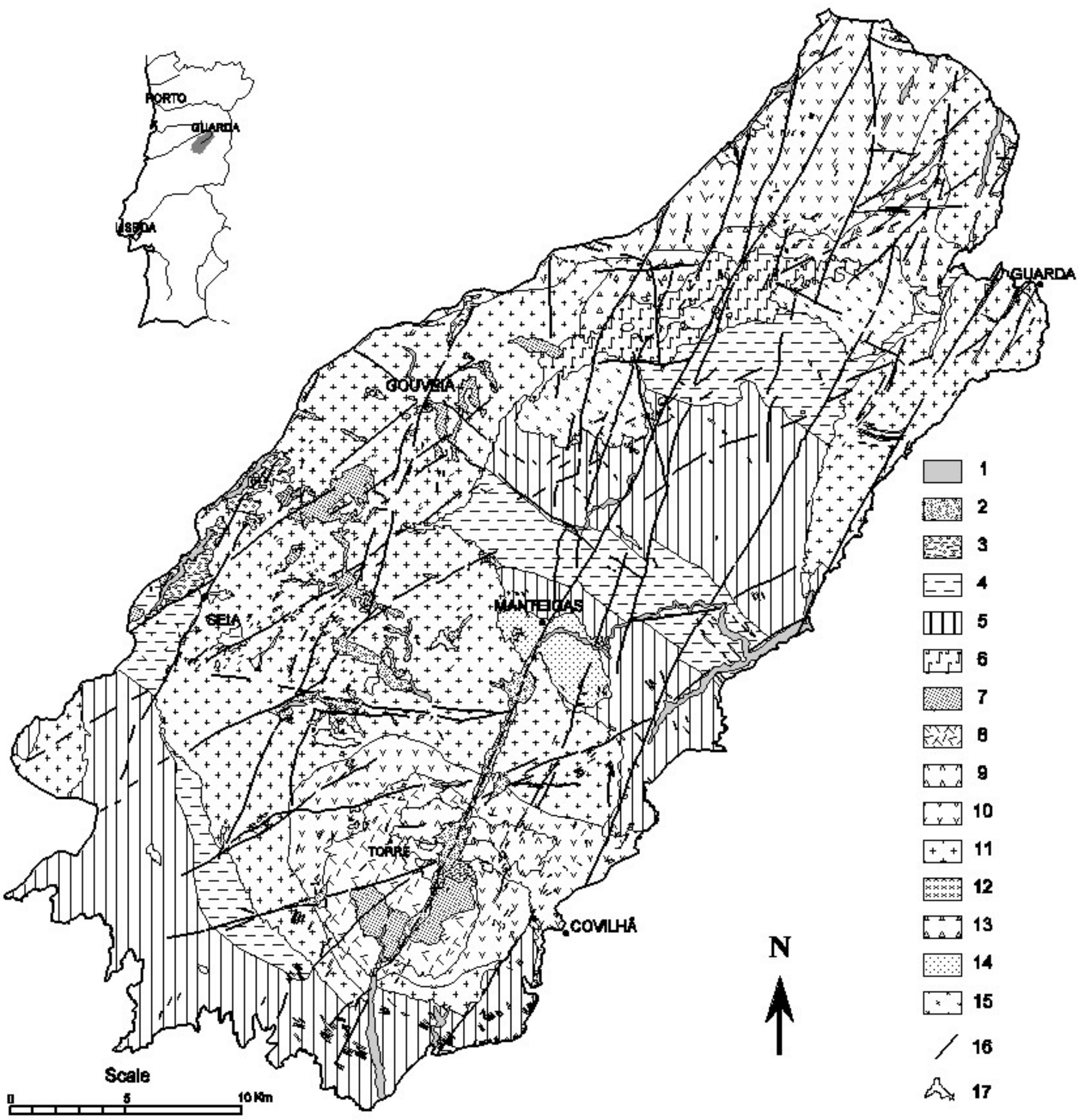


The climate is Mediterranean with dry and warm summers. The wet season is from October to May, with a mean annual precipitation of *ca.* 2500 mm in the summit, while the plateaus show more than 2000 mm. The western side of the mountain presents a larger number of days with rainfall, but a slightly lower total amount than the eastern part, which in turn shows a smaller number of days with rain (Daveau *et al.*, 1978). In the area above 1400 m mean annual air temperatures are below 7ºC and for the Torre plateau, Vieira and Mora (1998) estimated *ca.* 4ºC. Available data on snow is of poor quality and insufficient for purposes of climate analysis. Andrade *et al.* (1992) suggest a median of 40 to 50 days with snowfall at 1400-1600 m. However, there is a large irregularity and snow cover rarely lasts more than a few weeks per year, especially below 1700 m. Wind regimes are complex and show large spatial variations (Vieira and Mora, 1998). The more frequent directions are west and northwest.

Geological setting and evolution

The regional geology of the Serra da Estrela is dominated by Hercynian granites (300 Ma) installed in a schist-metagreywacke sequence of Precambrian-Cambrian age (650-500 Ma) (Fig. 2). This sedimentary sequence of marine origin is essentially turbiditic. Following the Bouma sequences for classic turbidites two formations were identified: the Malpica do Tejo Formation dominated by metagreywackes with some phyllites and metaconglomerates; and the Rosmaninhal Formation, constituted essentially by phyllites with some metagreywacke layers. All the sequence is affected by low-grade regional metamorphism (green schist facies). Hercynian tectonics deformed these metasediments, originating folds with NW-SE axial planes.

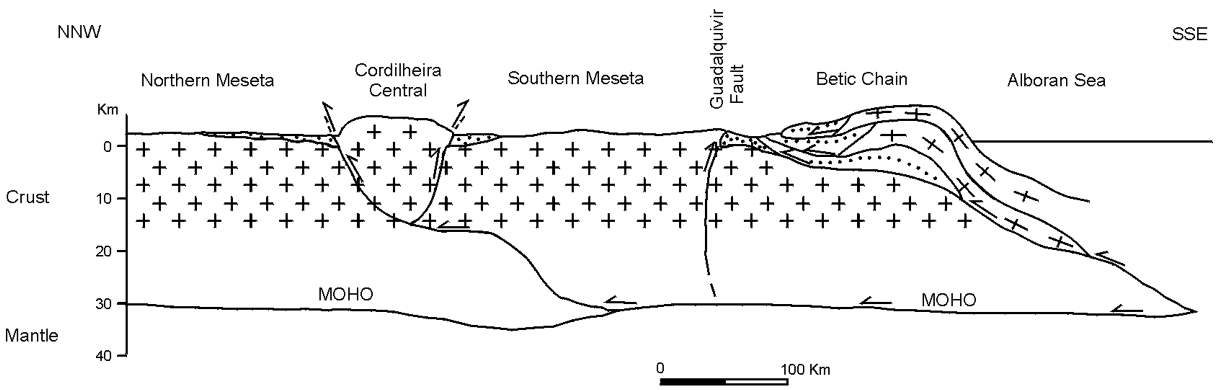
Figure 2: Geological sketch map of Serra da Estrela. 1. Alluvium, 2. Plio-Plistocene deposits, 3. Glacial deposits, 4. Metagreywake with metaconglomerate, 5. Phyllite with metagreywacke, 6. Migmatites, 7. Fine-grained two mica granite, 8. Medium-grained muscovite granite 9. Medium-grained porphyritic muscovite-biotite granite, 10. Medium-grained porphyritic biotite-muscovite granite, 11. Coarse-grained porphyritic biotite-muscovite granite, 12. Fine-grained granodiorite, 13. Medium-grained porphyritic biotite granite 14. Medium-grained granodiorite 15. Medium-grained two mica granite 16. Fault, 17. Reservoirs.



Hercynian magmatism resulted in different granitic facies classified and mapped according to texture, grain size and mineral composition. The coarse-grained porphyritic biotite-muscovite granite in association with granodiorite predominates in the region. In the core of the granitic massif muscovite granite occurs, forming a zoned pluton structure. The granites induced a *ca.* 1 km wide hornfels contact metamorphism aureole in the schist-metagreywacke complex.

A Late-Hercynian strike-slip fault system with NNE-SSW, NE-SW and NW-SE directions affects the region. In the Mesozoic and Cenozoic, the Hercynian mountain range was eroded, followed by crustal uplift and planation. According to Ribeiro (1988) Alpine compressive tectonics reactivated the NNE-SSW and NE-SW Hercynian faults, and uplifted the mountain as a horst in a *pop-up* structure along a parallel fault system in a set of steps architecture (Fig. 3).

Figure 3: Alpine reactivation of the Iberian Variscan basement: décollement along the Moho and pop-up structure in the Cordilheira Central induced by Betic compression (adapted from Ribeiro, 1988).



A note on the Serra da Estrela geomorphology

The more remarkable geomorphological characteristic of the Serra da Estrela is the significance of the glacial landscape, especially in what respects to the erosional landforms along the margins of the highest plateau and in the valleys. Glacial morphology is very well developed, a striking feature, particularly when the southern position and moderate altitude of the mountain range are taken in account.

Cabral (1884) was the first to show the occurrence of glacigenic features in the Estrela, but it was only with Lautensach (1929, 1932) that the glaciation was studied in some detail. Daveau (1971) revised his ideas and presented a more comprehensive account of the glacial geomorphology of the mountain. This remarkable contribution is still generally valid. Most of the glacial features are Weichselian in age and recent observations suggest that small glaciers still existed in the Late Glacial (Van der Knaap and Van Leeuwen, 1997; Vieira *et al.*, 2001a).

At the maximum of the glaciation, an ice field occupied most of the Torre – Fraga das Penas plateau (1993 – 1650 m), in the western part of the mountain, while several glaciers flowed down the main valleys (Fig. 4). The longest was the Zêzere glacier with over 10 km and the ice-front near the village of Manteigas at *ca.* 730 m. In parts of the valley the ice was about 300 m thick (Fig. 5). The glaciated area corresponded to *ca.* 70 km^2 (Daveau, 1971). The plateau of Alto da Pedrice – Poios Brancos located in the eastern side of the mountain at a lower altitude (1760 – 1600 m), was mostly glacier free and shows signs of intense periglaciation (Fig. 6). In the Torre plateau, a landscape of glacial erosion prevails, with polished rock outcrops, roches mouttonées, rock basins, large glacial cirques and lakes; while in the eastern plateau, glacial marks are scarce and debris-mantled surfaces, stone-banked solifluction lobes, cryoplanation benches and blockslopes rule out. In the plateaus at lower

Figure 4: General perspective of the Serra da Estrela from the south. The two plateaus divided by the Alforfa and Zêzere valleys are distinct, as well as the fault scarps along which most of the uplift took place. The white area marks the maximum glacier extent according to Daveau (1971).

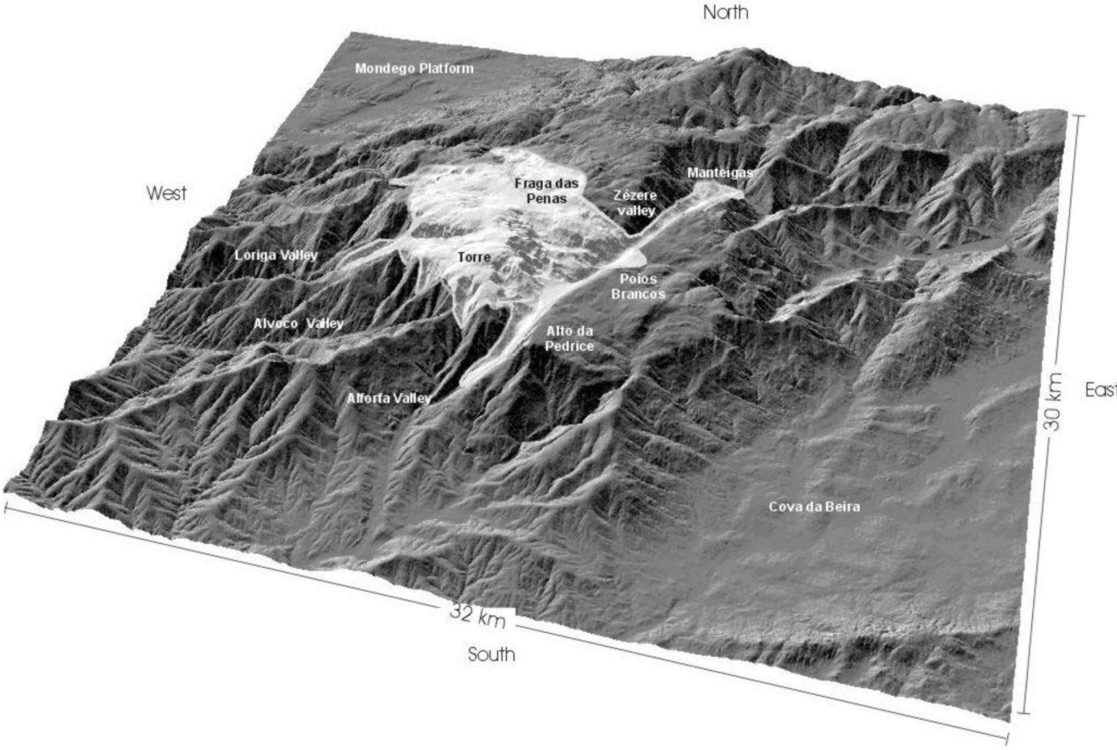


Figure 5: Zêzere valley upstream from the village of Manteigas. Note the U-shape evidencing the effect of glacial erosion. At the maximum of the glaciation the ice filled the valley to the forest on the right side of the picture.

Figure 6: Curral do Vento plateau (*ca.* 1650 m ASL). The flat surface is debris-mantled in some areas. In the skyline it is possible to see tors that are probably genetically linked to periglacial activity.

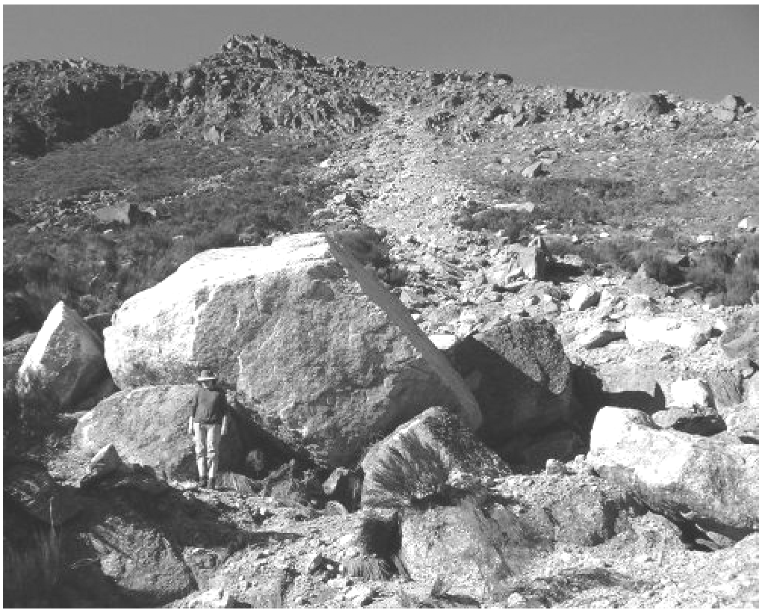
Figure 7: Typical tor morphology in the Penhas Douradas plateau (*ca*. 1500 m ASL).

altitude (< 1600 m) typical tor and bornhardt landscapes dominate and a Tertiary weathering mantle and gruss, very prone to contemporary erosion are present (Fig. 7). The glaciation gave also origin to significant moraine accumulations in the plateau margins and valleys, and to fluvioglacial terraces.

The relict glacial and periglacial landforms and deposits are determinant for the present-day landscape evolution. Glacial erosion was to a large extent responsible for the high gradients of the valley slopes and cirques, and also for the formation and redistribution of non-cohesive materials, that were mostly eroded from the plateau margins and valley-heads and deposited in the valley floors and slopes. This gave origin to a duality between bare-rock surfaces and non-cohesive material (regolith and sediments), which at a general level control the development of the vegetation communities and even land use (e.g. fluvioglacial terraces are popular agricultural locations).

An interesting example of the complexity of factors influencing the contemporary landscape dynamics of the Serra da Estrela is the debris cones that exist in most of the glacial valleys (the Zêzere valley upstream of Manteigas shows more than 30). They are mostly the result of distinct processes, but mainly of debris-flows affecting moraine material and weathered bedrock. The main stage of debris-cone (and talus) formation was certainly paraglacial, when a large volume of glacigenic material was available for remobilization and rock slopes suffered of stress-release processes. However, even today, high magnitude but low-frequency debris-flows occur and influence the landscape dynamics (Fig. 8). They are generally triggered by heavy rainfall events and occur in areas where vegetation was damaged by the fires usually set up by shepherds (which are actors in the cultural landscape).

Figure 8: Debris-flow deposits from December 2002 in the Zêzere valley. Note the person near the boulder for scale.



Recent studies in the Serra da Estrela plateaus show that the present-day geomorphological processes are complex and polygenic, with wash (rainfall and snowmelt) playing a major role, but also with a very significant activity of wind-driven rainsplash-saltation processes (Vieira, 1999; Vieira *et al.*, 2001b, 2003), nivo-eolian corrasion, deflation and cryogenic dynamics (mainly frost-creep and solifluction – Vieira *et al.*, 2002 and microgelivation – Daveau, 1978; Vieira, 1998; Ferreira *et al.*, 2000).

Vegetation

Major landforms and vegetation distribution

In what concerns to the vegetation roughly five landform groups can be distinguished, namely 1) the central plateau, 2) peaks and ridges, 3) the lower plateaus, 4) the slopes and 5) the valleys and rivers. Depending on climate, topography and land use, subdivisions can be made. Note that these landscapes are separately important, but the fact that they occur together in the Serra da Estrela makes them even more.

Central plateau

The central plateau is roughly located above 1600 m, including an extended plateau, some ridges and peaks and the upper slopes. It consists mainly of dwarfshrub formations, grasslands, rock and gravel communities, bogs, rivulets and lakes (Jansen, 2002). Some species and plant communities are strictly endemic. The Central plateau has a long history of transhumance and is the most important area of the Park.

Ridges and peaks

The ridges and peaks are especially important because of their natural vegetation. Moreover, the ridges may have an important corridor function. These generally windswept places have interesting rockfissure vegetation. Good examples are: Serra da Alvoaça (corridor to the Serra do Açor), Forno da Moura, Castelo, the ridge from Taloeiro to Santinha, Espinhaço de Cão, Corredor de Mouros, Sarzedo, Azinha and Cabeça Alta.

Lower plateaus

The lower plateaus are mainly covered with rye fields, grasslands, broom fields and heaths. Together they form a scenery that can be seen as a good preserved European example of the open cultural landscape (see also Jansen and Diemont and Diemont and Jansen, this issue). The traditional agricultural and sylvo-pastoral activities benefit the semi-natural biotopes, like hay meadows, pastures, herb-rich rye fields, heathlands and broom fields. Small irrigation channels add even more quality. In this way the system contributes to other types of landscapes like the central plateau and the slopes. Good examples are Planalto de Videmonte, Alto da Atalaia, Casais de Folgosinho and Serra de Baixo.

Slopes

The slopes are important because they form a gradient from the higher to the lower parts of the mountain, i.e. from one vegetation belt to another and also from one biogeographic region to another (Jansen, 2002). It is worth mentioning that the highest slopes (*ca*. 1600-1900 m) may carry unique primary grasslands and scree communities with many endemic species, some of which are presumed to be of Tertiary origin (see Jansen, 1998). Apart from that, roughly there is a zone from 1200 to 1600 m with mostly degraded stages of Pyrenean oak forest series, but also degraded stages of some potential holm oak, yew, birch or holly forest series, moderate afforestation, no permanent human settlement and moderate human pressure; from 800 to 1200 m, with degraded stages of Pyrenean, pedunculate and holm oak forest series, yew, birch or holly forest series, strong afforestation, permanent human settlement and moderate to strong human pressure; from the foot of the mountain to 800 m, with mainly degraded stages of holm oak forest series, but also cork, Pyrenean, pedunculate oak and holly series, strong afforestation, permanent human settlement and strong human pressure. On gentle slopes below *ca.* 1600 m agriculture may be practiced and for the same purpose on steep slopes numerous terraces have been constructed. Until about 800 m the main crops are rye and potatoes. At lower altitude the importance of olive groves, vineyards and orchards increases.

Valleys

The valleys and the rivers are important for riverine forests, hay meadows, aquatic and riparian vegetation and overall water supply. They have also an important corridor function. Generally, the rivers contain water of extreme high quality. Good examples are the valleys of the Zêzere, the Mondego, the Loriga, the Alvoco, the Alva, the Beijames, a.o.

Altitudinal belts and vegetation distribution

The vegetation of the Serra da Estrela reveals the presence of 5 or 6 altitudinal variants (Jansen, 2002). So far their geographical limits could not be distinguished, mainly because 1) two macrobioclimates meet within its territory; 2) there are too few meteorological data to calculate with; 3) no sufficient bioclimatic research has been carried out; and 4) the existing vegetation is seriously changed by human action. An extra complication is the fact that the vertical extent of vegetation belts is often subject to variation, because relief influences climate and distribution of plants. In many cases the vegetation does not separate into distinct zones, but intergrades or is patchily intermingled. Note for instance that in areas with a Mediterranean bioclimate, a high water table may locally balance summer drought and analogously sunny slopes may compensate summer humidity in a Temperate bioclimate.

Each belt has its own climax formations and the degraded stages of one series frequently differ from those of other series, and so does land use. Because the knowledge of the Estrelean vegetation is not enough to distinguish and attribute all stages of the climax series, the 5 or 6 belts are grouped in to lower, middle and upper belts, a division that has often been made in the past (e.g. Pinto da Silva and Teles, 1986; Rivas Martínez, 1981). The lower includes both meso-belts stretching from the foot of the mountain to *ca*. 800 m; the middle belt includes both supra-belts from *ca*. 800 to *ca*. 1600 m; and the upper one includes the oro-Temperate (from *ca*. 1600 m) to the top and locally, perhaps fragments of the cryoro-Temperate at high and very exposed sites.

Lower belt

Under rather humid conditions, the potential natural vegetation of the meso-Mediterranean belt would mainly be formed by evergreen or mixed evergreen deciduous oak forests dominated by *Quercus suber*; under less humid conditions by *Quercus rotundifolia*. The potential natural vegetation of the meso-Temperate belt would be mainly formed by deciduous oak forests with evergreen elements mostly dominated by *Quercus robur*. More humid soils would have supported *Fraxinus angustifolia* forests and along the rivers *Alnus glutinosa* and *Prunus lusitanica* galleries.

In both meso-belts, human settlement is the densest and disturbance consequently the strongest. All climax forests disappeared and have been replaced by various degraded formations due to human activities like burning, cutting, grazing, ploughing, afforestation, and cultivation. Today there are only very small and incomplete fragments of semi-natural forests left. Degraded phases include small areas covering thickets and large areas covering dwarf-shrub formations, especially those in which *Cistus* species and *Lavandula* species thrive. Further degradation may lead to relatively open grasslands rich in annuals. Locally, on relatively nutrient-rich soils, semi-natural grasslands form linked to human activity (pasturing, hay-making, irrigation). Weed communities originated from arable farming.

Middle belt

The potential natural vegetation of the supra-Mediterranean belt would be formed by deciduous or mixed deciduous evergreen oak forests with *Quercus pyrenaica* and *Quercus rotundifolia*. The potential natural vegetation of the supra-Temperate belt would be mainly formed by forests dominated by *Quercus pyrenaica*. In addition under special climatic and edaphic conditions both *Betula celtiberica* and *Taxus baccata* woods, sometimes mixed with *Ilex aquifolium* would be the final stage in spontaneous forest development. More humid soils would have supported *Fraxinus angustifolia* forests and along the rivers in the valleys *Alnus glutinosa* galleries. Of all these forests only small and incomplete examples remain, mainly as a result of wildfires, and agricultural and sylvo-pastoral activities.

Degradation of the original woodlands mainly led to heathlands, broom fields, or hedgehog-heaths and further degradation to pioneer grasslands or in humid situations to bracken fields (*Pteridium aquilinum*). Through irrigation and haymaking man has produced interesting semi-natural grasslands; Rye cultivation created rich weed communities mounting up to the upper belt.

Upper belt

The potential natural vegetation of the highest belt would be mainly formed by Dwarf juniper formations (with or without *Cytisus oromediterraneus* or *Pinus sylvestris*) and thorn-cushion scrub of *Echinospartum ibericum* subsp. *pulviniformis*. Edaphoclimatic vegetation includes rock, scree and bog communities, formations of small ponds, rivulets and lakes and perhaps some chionophilous (thriving under prolonged snow-cover) or frost-tolerating grasslands. Some of these communities, especially those related to cryogenic processes, show tendencies known from the cryoro-Temperate vegetation belts in the Sierra de Gredos and Montes de Léon in Spain. Burning and summer grazing still produce degraded phases including heathlands, *Cytisus oromediterraneus* broom fields, semi-natural grasslands and pioneer grasslands.

In all belts a number of micro-habitats occur in which mosses and lichens play a major role, but nowhere so conspicuous like in the oro-Temperate belt. Major habitats for saxicolous lichens include cliffs, roches moutonnées, tors, screes and irrigated rocks. Recently a comprehensive survey has been presented of saxicolous, terricolous and epiphytic lichens in the upper belt, including 250 species of which 16 are new to Portugal (Van den Boom & Jansen 2002). A survey of the bryophyte flora of all three belts with more than 400 species is given by Garcia (2002).

Final remarks

The southerly geographical location of the Serra da Estrela, the climatological, geological and geomorphological characteristics, and the present-day vegetation, which is the result of a very long history of human intervention on the natural vegetation, through grazing, fires, agriculture and more recently, by tourist activities, give rise to an original, very dynamic and complex landscape mosaic. The high natural and cultural values of this landscape in the contact area between the Mediterranean and Temperate bioclimates, allied to the accessible location of the range and the existence of an environmental protection framework through the Parque Natural da Serra da Estrela, make it an extraordinary site for landscape science studies (see for example Ferreira *et al.*, 2001).

References

Andrade, E.; Mora, C.; Neves, M. & Vieira, G. (1992) Desportos de Inverno na Serra da Estrela. Contribuição para o estudo da sua viabilidade, *Finisterra* **53-54**: 187-193.

Boom, P. van den & J. Jansen (2002). Lichens in the upper belt of the Serra da Estrela, Portugal. *Österr. Z. Pilzk.* 11: 1-28.

Cabral, F.A.V.P. (1884) Vestígios glaciários na Serra da Estrela. *Revista de Obras Públicas e Minas*, Lisboa: 435-459.

Daveau, S. (1971) La glaciation de la Serra da Estrela. *Finisterra* **11**: 5-40.

Daveau, S. (1978) Le périglaciaire d'altitude au Portugal, *Colloque sur le périglaciaire d'altitude du domaine méditerranéen et abords*, Strasbourg: 63-78.

Daveau, S.; Coelho, C.; Costa, V. G. & Carvalho, L. (1977) *Répartition et rythme des précipitations au Portugal*, Memórias do C.E.G., 3, C.E.G., Lisbon.

Diemont, W.H. & J. Jansen (this issue) Open mountainous landscapes versus lowland landscapes. The case of West-european heathlands.

Garcia C. (2002) *Flora Briológica do Parque Natural da Serra da Estrela. Biodiversidade e Conservação*. Museu Laboratório e Jardim Botânico da Universidade de Lisboa. Instituto da Conservação da Natureza. Parque Natural da Serra da Estrela. Relatório Final.

Ferreira, A. B.; Rodrigues, M. L. & Vieira, G. T. (2000) Manifestações herdadas e actuais de climas frios em Portugal, Peña Monné, J. L.; Sánchez Fabre, M. & Lozano Tena, M. V. (eds.), *Procesos y formas periglaciares en la montaña mediterránea*, Teruel 161-190.

Ferreira, A.B.; Alcoforado, M.J.; Vieira, G.T.; Mora, C. & Jansen, J. (2001) Metodologias de análise e de classificação das paisagens. O exemplo do projecto Estrela. *Finisterra* **72**: 157-178.

Jansen, J. (1998) Übersicht der Silikatschutt-Vegetation in den höheren Stufen der Serra da Estrela, Portugal. *Ber. d. Reinh.-Tüxen-Ges.* **10**: 95-124.

Jansen, J. (2002) *Geobotanical guide of the Serra da Estrela*. Instituto da Conservação da Natureza, Ministério das Cidades, Ordenamento do Território e Ambiente, Lisboa.

Jansen, J. & W.H. Diemont (this issue) Prospects of the open Atlantic mountain landscape of Europe at its southwestern range limit. The possible role of heathland-based farming in living up the obligations of EU Directives in the Serra da Estrela.

Lautensach, H. (1929) Eiszeitstudien in der Serra da Estrela (Portugal). *Zeitschrift für Gletscherkunde* **18**: 324-369.

Lautensach, H. (1932) Estudo dos glaciares da Serra da Estrela. *Memórias e Notícias, Coimbra* **6:** 1-60.

Pinto da Silva, A.R. & A.N. Teles (1986): *A Flora e a Vegetação da Serra da Estrela.* Colecção Parques Naturais. ICN, Lisboa.

Ribeiro, A. (1988) A Tectónica Alpina em Portugal. *Geonovas* **10**: 8-11.

Rivas-Martínez, S. (1981) Sobre la vegetación de la Serra da Estrela (Portugal). *Anal. R. Acad. Farm.***47**: 435-480.

Van der Knaap, W. O. & Van Leeuwen, J. F. N. (1997) Late Glacial and Early Holocene vegetation succession, altitudinal vegetation zonation, and climate change in the Serra da Estrela. *Review of Paleobotany and Palynology* **97**: 239-285.

Vieira, G. T. (1998) Periglacial research in the Serra da Estrela: an overview, in Vieira, G. T. (ed), *Glacial and Periglacial Geomorphology of the Serra da Estrela. Guidebook for the*

field-trip, IGU Commission on Climate Change and Periglacial Environments, 26-28 August 1998, CEG and Department of Geography, University of Lisbon: 49-65.
Vieira, G. T. (1999) Coarse sand accumulations in granite mountains: the case-studies of the serra do Gerês and serra da Estrela (Portugal), *Zeitschrift für Geomorphologie N.F.*, **Suppl.-Bd. 119**: 105-118.
Vieira, G. T. & Mora, C. (1998) General characteristics of the climate of the Serra da Estrela, in Vieira, G. T. (ed), *Glacial and Periglacial Geomorphology of the Serra da Estrela. Guidebook for the field-trip*, IGU Commission on Climate Change and Periglacial Environments, 26-28 August 1998, CEG and Department of Geography, University of Lisbon: 26-36.
Vieira, G.; Ferreira, A. B.; Mycielska-Dowgiałło, E.; Woronko, B. & Olszak, I. (2001a) Thermoluminescence Dating of Fluvioglacial Sediments (Serra da Estrela, Portugal), *Actas VREQUI / I REQUI*, SGP Lisboa: 85-88.
Vieira, G.; Mycielska-Dowgiallo, E. & Woronko, B. (2001b) - Sedimentological analysis of sandy-gravel accumulations, Serra da Estrela Plateaus (Portugal), *Landform Analysis* (in press).
Vieira, G.; Mora, C. & Ramos, M. (2002) Ground temperature regimes and geomorphological implications in a Mediterranean mountain (Serra da Estrela, Portugal), *Geomorphology* (in press).
Vieira, G.; Mora, C. & Gouveia, M. M. (2003) Oblique rainfall and contemporary geomorphological dynamics (Serra da Estrela, Portugal), *Hydrological Processes* (in press).