

Hydrogeology of hard-rocks in the Portuguese Iberian Massif: Porto urban area and Serra da Estrela mountain region

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Abstract An integrated multidisciplinary approach will be adopted in order to carry out a broad characterisation of the groundwater in the Porto urban area and Serra da Estrela mountain region (Iberian Massif, Northern and Central Portugal). Such an approach will contribute to improve groundwater management and protection, under the sustainability framework. Research will include the following main tasks: a) presentation of a geologic, morphotectonic, hydrologic and climatic outline; b) hydrogeologic inventorying and definition of a network of surface and ground water monitoring points; c) fieldwork campaigns, in order to collect water samples for chemical and isotopic analysis.

Key words Groundwater, Hard-rocks, High-mountain Hydrogeology, Iberian Massif, Northern and Central Portugal, Urban Hydrogeology.

INTRODUCTION

The increasing worldwide pressure on water resources under conditions of global anthropic and climatic change often requires an integrated multidisciplinary approach to address the scientific issues involving water resources. The multidisciplinary approach proposed here is adequate in order to identify the hydrogeological processes and their dynamics. Furthermore, both surface water and groundwater resources are handled as a whole in their assessment,



development and management. These studies are strongly connected to some of the most crucial water-related research issues at the present time, such as the UNESCO International Hydrological Programme (*e.g.*, Aureli 2002): a) “High Mountain Hydrology”, especially the “High mountains as country’s water towers” item; b) “Water and Society”, in particular the “Land habitat hydrology in urban areas” subject. The referred topic is based on the fundamental principle that groundwater is as essential to sustainable development as it is to life and that water, beyond its geological, hydrochemical, biological function in the hydrologic cycle, has social, economic and environmental values that are inter-linked and mutually supportive.

This paper attempts to synthesise, under a multidisciplinary perspective, the importance of geology, morphotectonics, palaeoweathering and climate on the hydrogeology of two sectors of the Portuguese Iberian Massif: Porto urban area (Northern Portugal) and Serra da Estrela mountain region (Central Portugal) — Fig. 1. Both study areas are located in the vicinity of major regional active faults (Ribeiro 1988, Brum Ferreira 1991). Porto urban area is intersected by the Porto-Coimbra-Tomar shear zone (Gama Pereira 1998, Chaminé 2000), while Serra da Estrela mountain region is intersected by the Bragança-Vilarica-Manteigas-Unhais da Serra fault zone (Ribeiro *et al.* 1990).

GEOLOGICAL AND HYDROGEOLOGICAL SETTING

Porto urban area

In the urban area of Porto, the second most important conurbation of Portugal, there is a human load of about 1 million inhabitants. The city is one of the oldest in Europe, dating back to the 12th century (Oliveira Ramos 1995) and has been developed on the granitic hillslopes of the Douro valley. Porto urban area (Fig. 2) is located in a complex geotectonic domain of the



Portuguese Iberian Massif — on the so-called Ossa-Morena Zone and Central-Iberian Zone boundary (Chaminé *et al.* 2003).

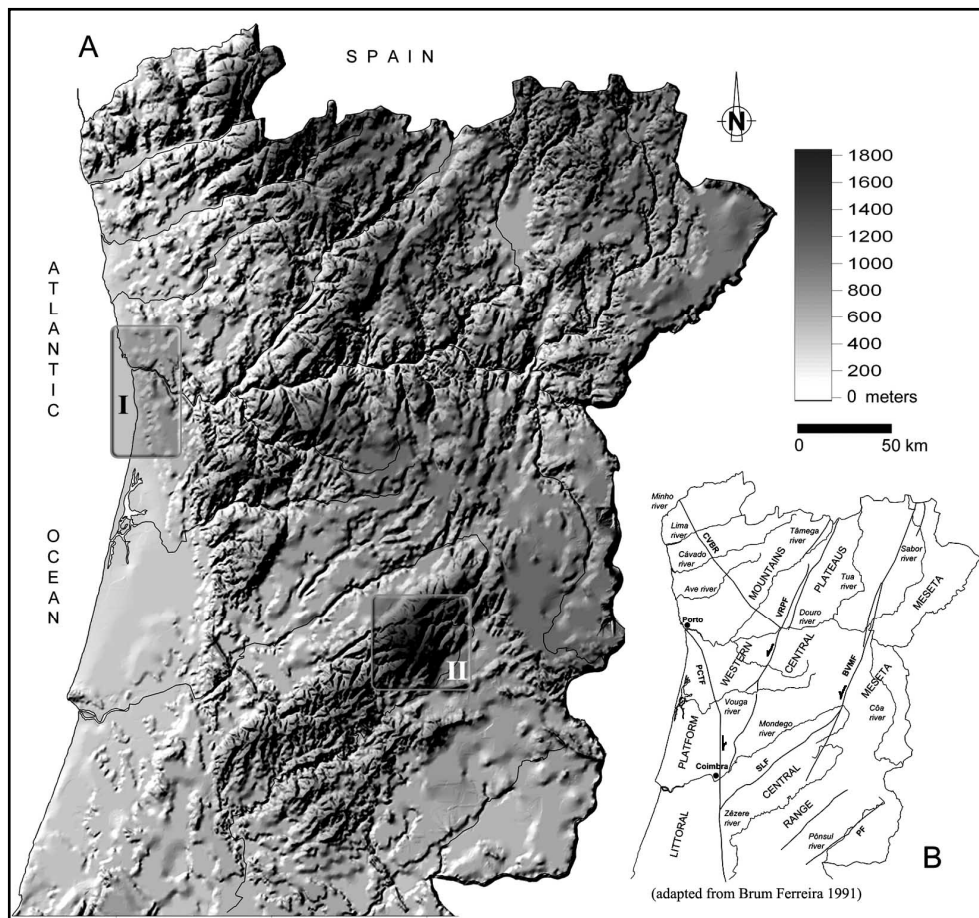


Fig. 1 – Morphostructural features from Northern and Central Portugal, with the two key-sectors studied (I- Porto urban area; II- Serra da Estrela mountain region). A: Digital elevation model (DEM) of Central and Northern Portugal, based on “Atlas do Ambiente de Portugal” (1/1000000); B: Main rivers and regional morphotectonic units (adapted from Brum Ferreira 1991); major faults: PCTF – Porto-Coimbra-Tomar strike-slip shear zone; CVBR – Vigo-Vila Nova de Cerveira-Régua fault zone; VRPF – Verin-Régua-Penacova fault zone; BVMF – Bragança-Vilarica-Manteigas-Unhais da Serra fault zone; SLF – Seia-Lousã fault zone; PF – Pónsul fault.

The topographic configuration of Porto region (*s.l.*) consists of a littoral platform showing a regular planation surface that deepens gently to the West and culminates around 120m a.m.s.l. (Araújo *et al.* 2003), which is East bounded by a series of hills rising to 250-300m a.m.s.l. on the top. Deeply incised river valleys cut the platform, particularly the Douro river valley, which shows a regional tectonic control. The regional geotectonical framework of Porto urban area comprises a crystalline fissured basement complex which is composed of strongly deformed and overthrust metasedimentary rocks and granites (*e.g.*, Carrington da Costa



1958, Chaminé *et al.* 2003). The Upper Proterozoic/Palaeozoic substratum complex is mainly composed of phyllites, black schists, garnetiferous quartzites, micaschists, migmatites and gneisses, whereas sedimentary cover rocks are dominated by post-Miocene alluvial and Quaternary marine deposits (Chaminé *et al.* 2003, Araújo *et al.* 2003). Igneous rocks include pre-orogenic and syn-orogenic Variscan suites, which occupy a large exposure of granitic rocks.

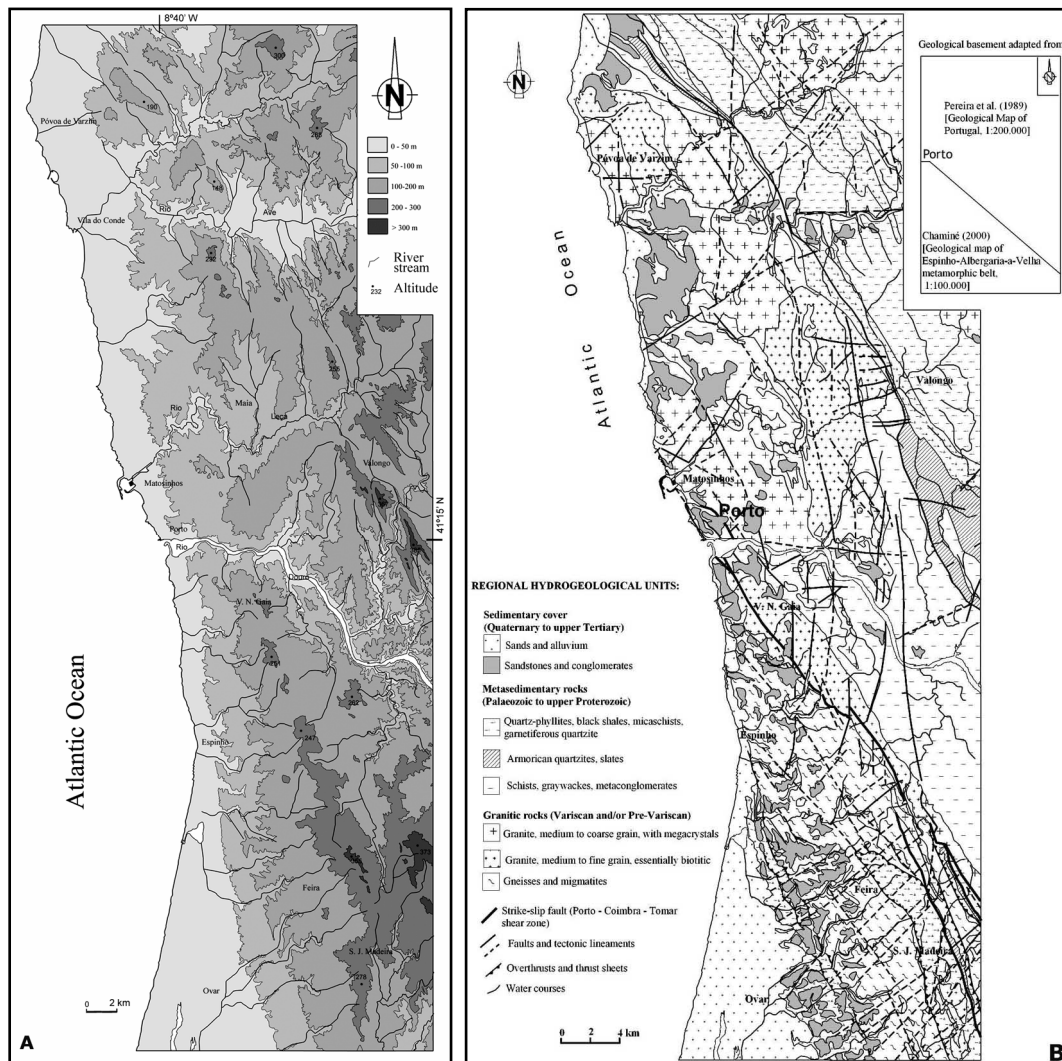


Fig. 2 – Hypsometric (A) and hydrogeological features (B) from Porto urban area.

Porto urban area has an Atlantic mild temperate climate, with a mean annual precipitation of 1152mm and mean air temperature of 14°C (Afonso 2003). These climatological conditions, as well as the geological and morphostructural features determine the existence of



groundwater resources (e.g., Carvalho 1996, Carvalho *et al.* 2003, Afonso *et al.* 2004). The hydrogeological data are still scarce in the study area (Afonso 2003) and therefore, the proposed regional hydrogeological groups correspond roughly to the main geological features (Table 1): a) sedimentary cover (post-Miocene), including alluvium and fluvial deposits; b) metasedimentary rocks (upper Proterozoic-Palaeozoic metamorphic belt), which include schists, graywackes, quartz-phyllites and quartzites; and c) granitic rocks (Variscan and/or pre-Variscan), including two-mica granites, medium to coarse grained, with megacrystals; biotitic granites, fine to medium grained; gneisses, migmatites and gneissic granites.

Table 1 – Main hydrogeological features from Porto urban area.

| Regional Hydrogeological Groups | Hydrogeological Units | HYDROGEOLOGICAL FEATURES | | | | | | | | | | |
|---------------------------------|---|--------------------------------------|---------|----------|---------------|-----------------|---------------|----------------|--------|-------|---------------------------------------|-----------|
| | | Connectivity to the drainage network | | | Type of flow | | Weathering | | | | More suitable exploitation structures | |
| | | with | without | possible | porous medium | fissured medium | low thickness | high thickness | clayey | sandy | dug-wells, galleries and springs | boreholes |
| Sedimentary cover | sands and alluvium | x | | | x | | n. a. | n. a. | n. a. | n. a. | x | |
| | sandstones and conglomerates | x | | | x | | n. a. | n. a. | n. a. | n. a. | x | |
| Metasedimentary rocks | quartz-phyllites, micaschists and black shales | | | x | | x | x | x | | x | | x |
| | quartzites and slates | | x | x | | x | x | | | x | | x |
| | schists, graywackes and metaconglomerates | | | x | | x | | x | x | | | x |
| Granitic rocks | granite, medium to coarse grain, with megacrystals | | | x | | x | | x | | x | x | |
| | granite, medium to fine grain, essentially biotitic | | | x | | x | | x | | x | x | |
| | gneisses and migmatites | | | x | | x | x | x | | x | x | |

n.a.= not applicable



Serra da Estrela mountain region

The Serra da Estrela mountain area presents specific geomorphologic, climatic (associated with a maximum altitude of 1993m a.m.s.l.) and geotectonic characteristics that play an important role and impact on groundwater recharge and circulation.

The study area is the river Zêzere catchment upstream of the village of Manteigas (Fig. 3) and its surroundings, corresponding to *ca.* 28 km².

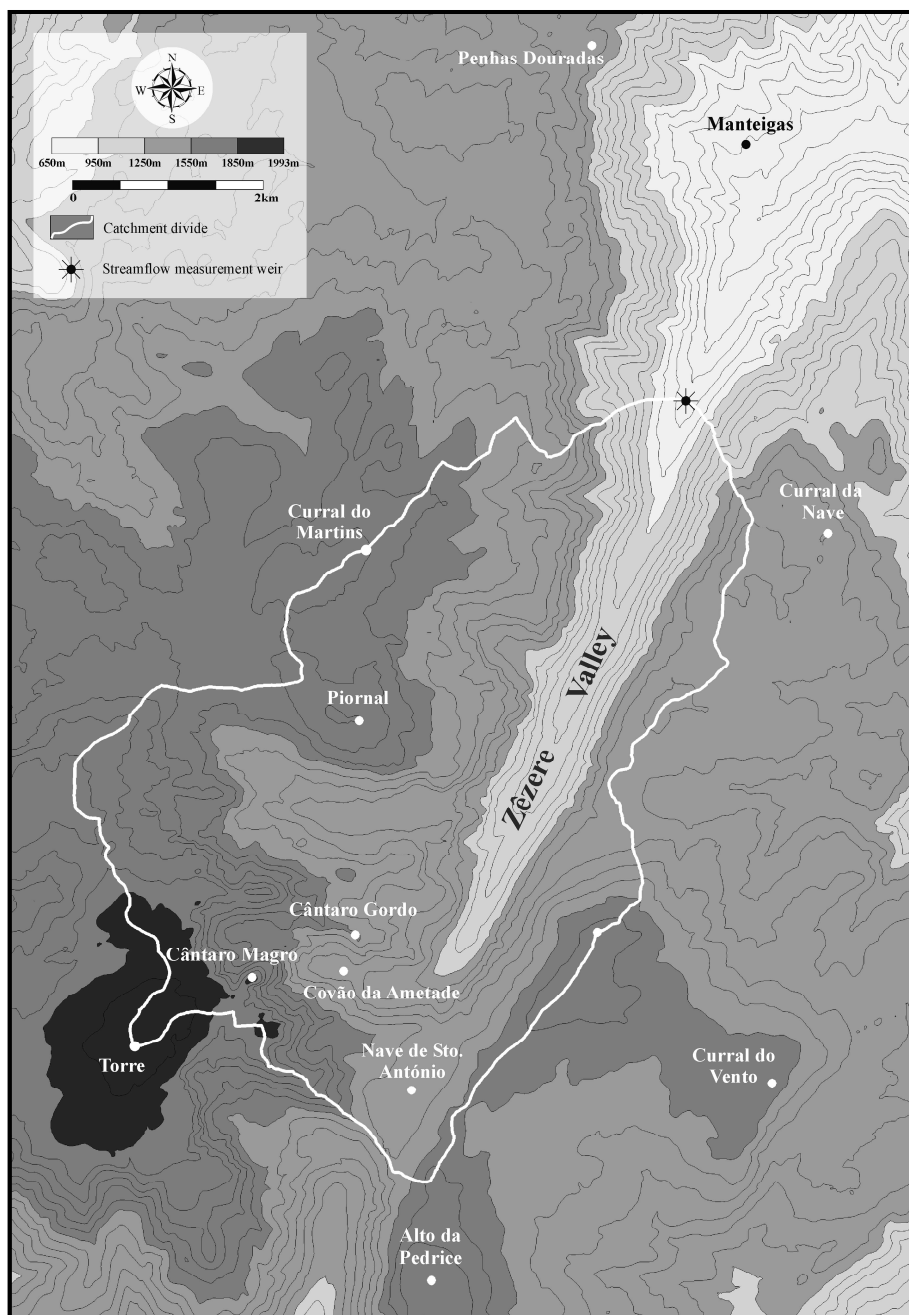


Fig. 3 – Hypsometric features from Serra da Estrela mountain region.



The altitude of the catchment ranges from 875m a.m.s.l., at the streamflow measurement weir of Manteigas, to 1993m a.m.s.l., at the Torre summit. The most important lithotypes consist of Variscan granites; Precambrian-Cambrian metasedimentary rocks; alluvium and Quaternary glacial deposits. The main regional tectonic structure is the NNE-SSW Bragança-Vilariça-Manteigas-Unhais da Serra fault zone, which controls thermomineral occurrences. This structure is part of a late-Variscan fault system that was reactivated by the alpine compressive tectonics and originated the uplift of the mountain as a horst in a pop-up structure (Ribeiro 1988, Ribeiro *et al.* 1990). The relief of this sector of Serra da Estrela is dominated by two major plateaus, separated by the NNE-SSW valley of river Zêzere: the Torre - Penhas Douradas plateau (1450-1993m a.m.s.l.), located in the western side, and the Alto da Pedrice – Curral do Vento plateau (1450-1760m a.m.s.l.) — Vieira *et al.* (*submitted*). Late Pleistocene glacial landforms and deposits are a distinctive feature of the Zêzere catchment, since the majority of the plateau area was glaciated during the Last Glacial Maximum (*e.g.*, Daveau *et al.* 1997, Vieira *et al.* *submitted*). According to Daveau *et al.* (1997) and Vieira & Mora (1998), the Serra da Estrela climate has a Mediterranean regime with a high mean annual precipitation that reaches 2500mm in the upper areas. Mean annual air temperatures are below 7°C in most of the plateau area and, in the Torre vicinity, they may be as low as 4°C. The proposed regional hydrogeological units correspond nearly to the main geological characteristics (Table 2): a) sedimentary cover, including alluvium and fluvio-glacial deposits; b) metasedimentary rocks, which include schists and graywackes; and c) granitic rocks.

STUDY TASKS AND METHODS

A regional geologic, morphotectonic, hydrologic and climatic framework will be developed in order to outline the main features conditioning the water cycle related processes.



Table 2 – Main hydrogeological features from Serra da Estrela mountain region.

| Regional Hydrogeological Groups | Hydrogeological Units | HYDROGEOLOGICAL FEATURES | | | | | | | | | | |
|---------------------------------|---|--------------------------------------|---------|----------|---------------|-----------------|---------------|----------------|--------|-------|---------------------------------------|-----------|
| | | Connectivity to the drainage network | | | Type of flow | | Weathering | | | | More suitable exploitation structures | |
| | | with | without | possible | porous medium | fissured medium | low thickness | high thickness | clayey | sandy | dug-wells, galleries and springs | boreholes |
| Sedimentary cover | fluvioglacial deposits | x | | | x | | n. a. | n. a. | n. a. | n. a. | x | |
| | alluvium deposits | x | | | x | | n. a. | n. a. | n. a. | n. a. | x | |
| Metasedimentary rocks | schists, graywackes and metaconglomerates | x | | x | | x | | x | x | | | x |
| Granitic rocks | granitoids | x | | x | | x | x | x | | x | x | x |

n.a.= not applicable

The hydrogeologic importance of the fracture network will be considered, with particular emphasis in understanding the fault system geometry, processes of opening and sealing of fractures, stress fields and seismic pumping. For this purpose, scale studies from outcrop to satellite imagery will be accomplished. In particular, Geographic Information Systems (GIS), remote sensing and tectonic analysis will be used to characterise the main tectonic lineaments. Data obtained from computational analysis of digital terrain models and from geological structures are complemented by field data acquired using traditional mapping methods.

An hydrogeologic inventory and the definition of a network of surface and ground water monitoring points (springs, boreholes, shallow wells and streams) will be carried out. Subsequently, fieldwork campaigns will be conducted in order to collect water samples for chemical and isotopic (oxygen-18, deuterium, tritium and carbon-14) analysis. Hydrogeochemical information (major and minor element composition) will be applied to estimate geochemical evolution of groundwater, including its origin and interaction between water and the aquifer rock minerals.



In order to understand groundwater's recharge and circulation related phenomena, infiltration and recharge areas will be identified and delimited by means of hydrogeochemical, isotopic and hydrogeomorphologic criteria. In addition, groundwater circulation paths will be characterised and groundwater contribution to streamflow will be estimated. Thus, lithology, water chemistry, morphostructure, climate, soil type and land use should be considered in this issue.

Specific tasks and particular study methods are required in order to attain the objectives established earlier. The most important ones, related to the Serra da Estrela mountain region, are presented and described as follows:

a) Soil physical, geochemical and mineralogical features are especially relevant in hydrologic studies, because they contribute to control both the quantity and the chemistry of the waters in the hydrologic systems. The main soil physical properties considered are texture, structure, bulk density, particle density, porosity, colour, water retention and hydraulic conductivity. Other properties considered are pH, organic matter content, cation exchange capacity and exchangeable cations. Soil geochemical analysis will consider 36 chemical elements. Soil and gouge materials geochemistry and mineralogy will mostly consider the clay studies.

b) The Serra da Estrela mountain region is characterised by the existence of strategic groundwater resources which also seem to be strongly dependent on geomorphology (recharge areas) and tectonics (active faults responsible for groundwater circulation). The study area supplies high quality drinking water for a bottling industrial unit and for domestic use at Manteigas village. The presence of important thermomineral water resources made possible the creation of the Manteigas Spa. Furthermore, the groundwater contribution to the river Zêzere flow is added to the storage at the Castelo do Bode large dam, the main source for Lisbon's water supply.



c) Since the snowfall above 1700m a.m.s.l. may represent a significant fraction of the annual precipitation, the aquifer recharge from snowmelt will be estimated, especially through the use of isotopic methods and mathematical modelling.

d) The information collected during the earlier study phases, together with data from Manteigas and Penhas Douradas meteorological stations, will be used to model the water balance in the soil, the unsaturated zone and the aquifers, making possible to estimate the aquifer recharge in the catchment. For this purpose, the Visual Balan V.2.0 computer code will be the main tool (*e.g.*, Samper *et al.* 1999, 2000).

CONCLUDING REMARKS

Crystalline rocks, particularly granites and metasedimentary units, dominate the two key-regions, *i.e.*, Porto urban area and Serra da Estrela mountain region. The hydrogeological characterisation of this kind of hard-rocks is complex, due to the high heterogeneity and anisotropy of the fracture network that stores and conducts the water. It is usual to consider that the flow-paths are mainly governed by the fissured medium hydraulic conductivity, faulting and weathering, resulting on non-continuous productive zones. Nevertheless, it is clear that in the Variscan Iberian Massif, lithology and structure play a major role on the productivity of regional hydrogeological units and related water wells.

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