A multitechnique approach to the dynamics of thermal waters ascribed to a granitic hard rock environment (Serra da Estrela, Central Portugal)

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Introduction

In this presentation is dedicated to high mountains and their role and impact on surface water/groundwater interaction (Fig. 1).

The results obtained were used to increase knowledge on the hydrogeologic conceptual model of Caldas de Manteigas thermal waters, trying to understand the:

i) recharge and discharge processes and,
ii) role of snowmelt as a source of groundwater resources.

Fig. 1 – Morphological features showing the location of Serra da Estrela region (Portugal Central, Iberian Massif).
The study area

Corresponds to Serra da Estrela National Park region, including the Zêzere river drainage basin upstream of Manteigas village (Fig. 2), with an area of about 28 km².

This region presents specific geomorphologic, climatic and geotectonic characteristics which contribute to control the recharge and flow paths of Caldas de Manteigas thermal waters (issue temperature of about 42ºC).

Fig. 2 - The location of Serra da Estrela National Park region (Portugal Central, Iberian Massif).
The study area (cont.)

The Serra da Estrela climate:

- mean annual precipitation reaching 2500 mm in the most elevated areas (Fig. 3),

- mean annual air temperatures are around 8°C in most of the plateau area and in the Torre vicinity they may be as low as 4°C.

Fig. 3 - Hypsometric features of the river Zêzere drainage basin upstream of Manteigas.
Geology and tectonics

The geology is dominated by (Fig. 4):

- Variscan granitic rocks,

- Precambrian - Cambrian meta-sedimentary rocks,

- alluvium and quaternary glacial deposits.

-The main regional tectonic structure is the NNE-SSW Bragança-Vilariça-Manteigas fault system.

Fig. 4 - Geological map of Serra da Estrela region (adapted from Geological Map of Portugal, 1/500.000, SGP, 1992).
Methodology

Water samples for geochemical and isotopic analysis were collected from river waters, shallow cold dilute groundwaters (spring waters – “normal” waters) and from the Caldas de Manteigas thermal waters.

Temperature (°C), pH, Eh (mV) and electrical conductivity (μS/cm) of the waters were determined “in situ”.

Chemical analyses of waters were performed at the Laboratório de Mineralogia e Petrologia of Instituto Superior Técnico (LAMPIST - Portugal).

The δ²H and δ¹⁸O measurements (vs. V-SMOW, Vienna - Standard Mean Ocean Water) were performed by mass spectrometry at the Instituto Tecnológico e Nuclear (ITN - Portugal).

The ³H water content (reported in Tritium Units, TU) was also determined at ITN.
Examples of sampling sites
Results and discussion

Hydrochemistry

Local “normal” groundwaters (surface waters and shallow cold dilute groundwaters):

i) $\text{HCO}_3^-\text{-Na-type}$ waters (low total dissolved solids).

The higher mineralization detected in some of these spring waters could be ascribed to a long underground flow path.

ii) $\text{Na-Cl-type}$ waters (also characterized by relatively low mineralization).

The strong Na-Cl geochemical signatures of some of these waters could be ascribed to the use of NaCl to promote snowmelt in the roads.
Results and discussion
Hydrochemistry (cont.)

The thermal waters (45°C) are characterised by the following main features:

i) relatively high pH values (≈ 9),

ii) TDS values usually in the range of 160 to 170 mg/L,

iii) HCO₃-Na type waters,

iv) the presence of reduced species of sulphur (HS⁻ ≈ 1.7 mg/L),

v) high silica values (usually around 50 mg/L),

vi) high fluoride concentrations (up to 7 mg/L).
Results and discussion
Hydrochemistry (cont.)

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Fig. 5 – Stiff diagrams for the studied waters
Estimation of geothermal reservoir temperature and depth

Using reservoir temperatures (between 98°C and 103°C) given by the quartz geothermometer applied to Caldas de Manteigas AC2 and AC3 borehole waters, and considering a mean geothermal gradient of 25°C/km (IGM, 1998), we can estimate a maximum depth of about 3.7 km reached by the Caldas de Manteigas thermal water system. This value was obtained considering that:

\[
\text{depth} = \frac{(\text{Tr} - \text{Ta})}{\text{gg}} = \frac{100.5 - 8}{25} = 3.7 \text{ km}
\]

where \(\text{Tr}\) is the reservoir temperature (°C), \(\text{Ta}\) the mean annual temperature (°C) and \(\text{gg}\) the geothermal gradient.
Isotope hydrology ($^{18}$O and $^2$H)

Fig. 6 - $\delta^2$H vs $\delta^{18}$O diagram for the studied waters.
The “Altitude Effect”

The δ\(^{18}\)O isotopic gradient in the study area is -0.10 \(^\circ\)/\text{o}_{oo} /100 m of altitude (Fig. 7).

Considering the mean isotopic composition of the thermal waters (\(\delta^{18}\)O\(_{\text{mean}}\) = -7.8 \(^\circ\)/\text{o}_{oo} vs. V-SMOW),

the upper valley of Zêzere river, with altitudes ranging between 1600 and 1800 m a.s.l., should be faced as a potential catchment area of this thermal water system.

Fig. 7 - Relation of δ\(^{18}\)O to altitude of sampling sites (springs). Alt stands for recharge altitude.
Conceptual Model

As indicated by the morphostructural and isotopic data, the main recharge areas should be (Fig. 8a,b):

i) the NNE-SSW section of the Zêzere valley,
ii) the Nave de Santo António col,
iii) the Covão de Ametade and Candeeira valleys, corresponding to conjugate faults of the main structure.

The thermomineral waters discharge area is located ca. 800 m a.s.l.,

The water ascending from the deep reservoir spurts in a location with distinct tectonic features: the intersection of the main NNE-SSW structure by WNW-ESE structures.

Fig. 8a - Hypsometric features of the river Zêzere drainage basin upstream of Manteigas.
Conceptual model (cont.)

Fig. 8b. Scheme of the thermomineral aquifer recharge: a conceptual hydrogeological model.
Isotope hydrology ($^3$H)

- $^3$H (TU)
- Na (mg/L)
- Cl (mg/L)

- "normal" waters (Summer)
- Thermal waters (Summer)
- "normal" waters (Winter)
- Thermal waters (Winter)
- Surface waters (Winter)
Concluding remarks

The results of studies performed under the scope of HIMOCATCH Project will be used to help the preservation of thermal water quality, based on the identification of:

i) recharge areas,

ii) underground flow paths,

iii) sources of pollution and,

iv) the processes affecting natural hydrogeologic conditions.

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Many thanks
for your attention