

THE SANGEMIL SPA AND THE DÃO FAULT SYSTEM

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ABSTRACT

Thermal manifestation along the Dão fault system is expressed by thermal springs issuing at different temperatures, but with chemical compositions remarkably similar for practically all major and many trace elements. Due to its temperature and special chemical components, these thermal waters have long ago been used for medical purposes.

Sangemil Spa is the aim of this paper who presents a summary of geological and hydrochemical (including isotope measurements) studies carried out in the area. A model is proposed for the circulating water in the thermal circuit.

1. INTRODUCTION

Hydrothermal activity in Northern and Central Portugal is represented by thermal springs of low enthalpy associated with a network of faults, some formed during Hercynian Orogeny and reactivated at recent geological times (Alpine Orogeny), in a main morphostructural entity called Hesperic Massif. The ante - mesozoic Hesperic Massif is composed mainly of granites and metapelites of lower Paleozoic age.

Like areas of prevailing cristalline rocks with a normal or near normal heat flow, the occurrence of hydrothermal systems is controled by the tectonic development of a large and deep faults making possible the downward circulation of groundwater and subsequent surface return.

A group of three thermal springs with moderate temperature (Cavaca - 28 °C; Alcafache - 48 °C and Sangemil - 49.5 °C) emerge along the Dão river valley defining a tectonic lineament which, undoubtedly, can be recognized as a large fault striking NE-SW - the Dão fault. Chemically these thermal waters are similar. With a moderate content of total dissolved solids (< 480 mg/l) they are alkaline (pH around 8) and of sulphidic and sodium - bicarbonate type. Two other cold mineral springs occur on or near the Dão fault (Sezures - 18 °C; Granjal - 16 °C) with the same hydrochemical typology.

2. PHYSICAL SETTING

Sangemil region is located at Viseu district (Central Portugal). Characterized by a moderate summer and winter has an average rainfall of 1305 mm. and a mean annual temperature of 13 °C. It is a mountainous country with the geomorphology dominated by the encase of Dão river with a general direction NE-SW. Near the right bank but at the river bed there are waters spouting at a temperature of 49.5 °C with a mean discharge of 2 l/s.

3. GEOLOGICAL AND TECTONIC SETTING

The thermal waters spring from coarse porphyritic late - Hercynian granites at the intersection of two faults trending N40° - 50°E and N25°W. The former, which is the principal structure, is called "Thermal Fault", which regional expression is the Dão fault, and the second promotes the resurgence. Geological map of Sangemil region is shown in figure 1.

There is no other hydrothermal manifestation within the studied area, if we exclude the water from a well 30 m deep, about a 100 m NNW from the thermal spring. It presents a variable temperature (max. 23 °C; min. 18 °C). Available information on geological and hydrochemical features supports the statement that it is occurring a mixture between thermal and cold water of subsuperficial circulation.

In effect, probable hydraulic connection between the fractures existing in thermal spring domain and particularly in its uppermost section will make possible the existence of subsurface discharge points. At those sites, the mineral - thermal water might be mixed with the regional waters as to form "hybrid waters" slightly abnormal both for its hydrochemistry and temperature.

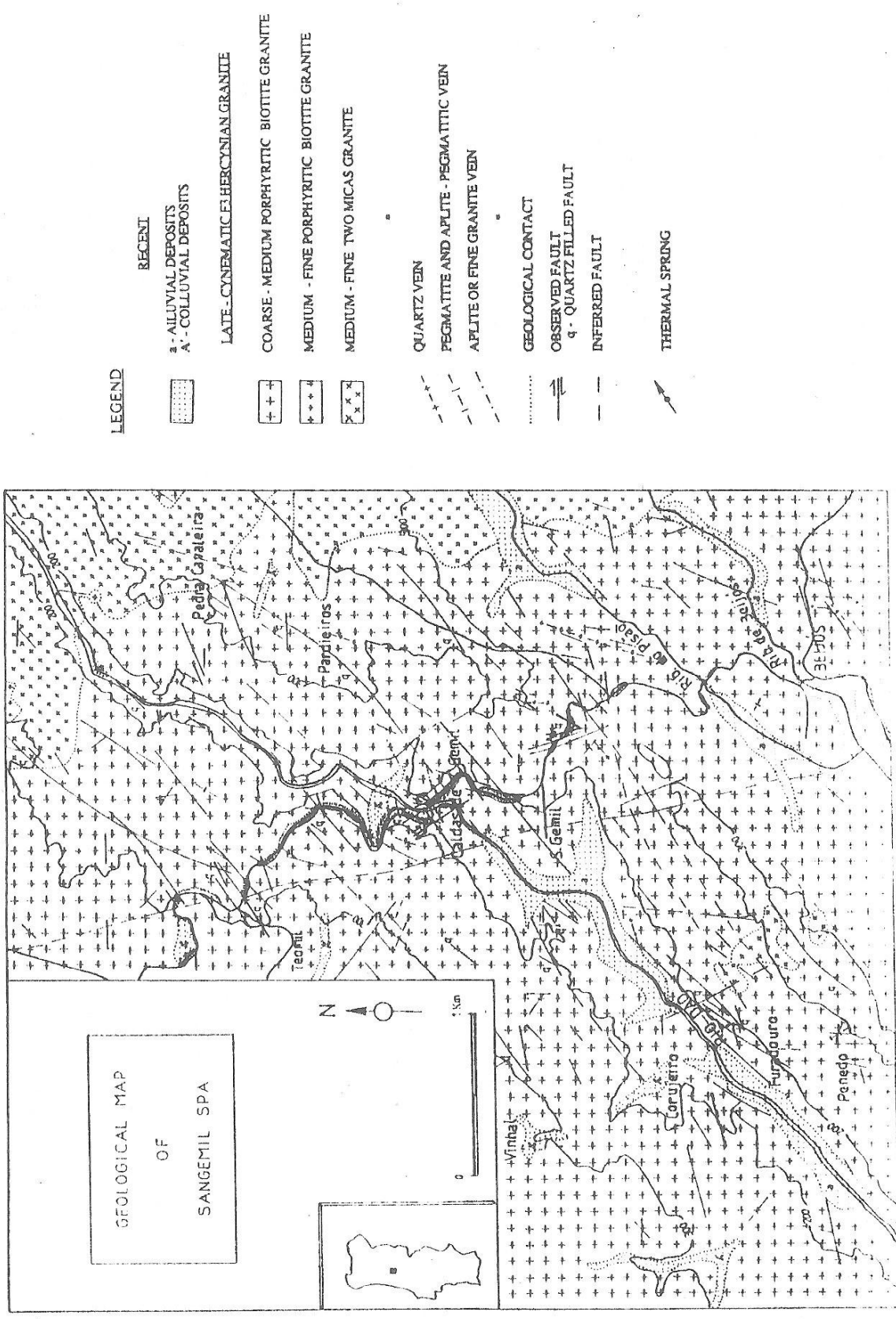


Fig. 1 - Geological map of Sangemil Spa.

4. HYDROCHEMICAL DATA

The chemical composition of Sangemil thermal water is characterized by:

- Total dissolved salts = 474.6 mg/l
- pH = 8.55 (at 27 °C)
- Cations dominated by Na⁺ (90% of total cations), with alkaline earths representing only 4%. Cationic sequence is rNa >> rCa > rMg.
- Anions dominated by HCO₃⁻ (62% of total anions), followed by Cl⁻ (21%). Anionic sequence is rHCO₃ > rCl > rSO₄.

Is classified as alkaline sodium - bicarbonate water.

From the chemical composition presented in table 1 we also may point out the presence of reduced sulphur species as the HS⁻ and the S₂O₃²⁻ ions. Reducing character of this water (calculated Eh = - 295 mv) inhibits the existence of nitrogen species at elevated oxidation states as nitrite and nitrate. Reduction of nitrate it is a possible explanation for the occurrence of NH₄⁺ (0.36 ppm). For major ions other interesting concentrations are given by fluoride (17.2ppm) and Li⁺ (1.5 ppm). These water also show a great variety of metals and nonmetals elements as minor and trace constituents (cf. chemical analysis).

Chemical quality of thermal water differ markedly from the shallow non-thermal groundwater. This is showed from chemical analyses representation on the triangular diagram (after Piper) in figure 2. Cold spring waters scatter widely in the diagram whereas thermal water occupies a very distinct position.

Most significant conclusion to be retained from hydrochemical interpretation based on ion ratios and the results of factor analysis of major ion data is the admission of distinct processes in acquisition of mineralization of thermal water versus local cold waters. Hot water issue from a dynamic system where the dissolution of elements from rocks, naturally favored by temperature, changes the chemical equilibria, whereas ion exchange and precipitation of alteration minerals tend to reestablish the system equilibrium. The final result is the admittance of a general equilibrium of the thermal water in the reservoir adversely to the shallow non equilibrated cold groundwater.

5. GEOTHERMOMETRY

Reservoir temperature have been estimated from data analysis of surface discharge, using a selected number of chemical geothermometers with strict observance to the specified temperature range for which the equations are valid.

Table 1 - Results of chemical analysis for Sangemil thermal water.

Date: June/85					
Temperature (°C)		49.5			
pH (at 27 °C)		8.55			
Eh (mv ; calculated)		- 295			
Conductivity (µS/cm ; at 24 °C)		522			
Total dissolved solids (mg/l)		474.6			
SiO ₂ (mg/l)		89.4			
CATIONS (mg/l)			ANIONS (mg/l)		
Na ⁺	112.9	HCO ₃ ⁻	158.0		
K ⁺	4.56	Cl ⁻	53.3		
Ca ²⁺	4.7	SO ₄ ²⁻	4.1		
Mg ²⁺	0.85	F ⁻	17.2		
Li ⁺	1.5	CO ₃ ²⁻	4.8		
NH ₄ ⁺	0.36	NO ₃ ⁻	<0.07		
		NO ₂ ⁻	<0.002		
		HS ⁻	5.9		
		S ₂ O ₃ ²⁻	8.7		
MINOR AND TRACE ELEMENTS (µg/l)					
Phosphate	17	Beryllium	0.87	Iodine	0.9
Aluminum	20	Lead	9.2	Arsenic	9
Manganese	10	Silver	0.05	Tungsten	82
Bromine	67	Chromium	0.4	Copper	6.8
Boron	2380	Iron	6	Zinc	17.4
Molybdenum	3				
Elements below the detection limit: Cd, Ni, V, Sn, Y, Nb and Co.					

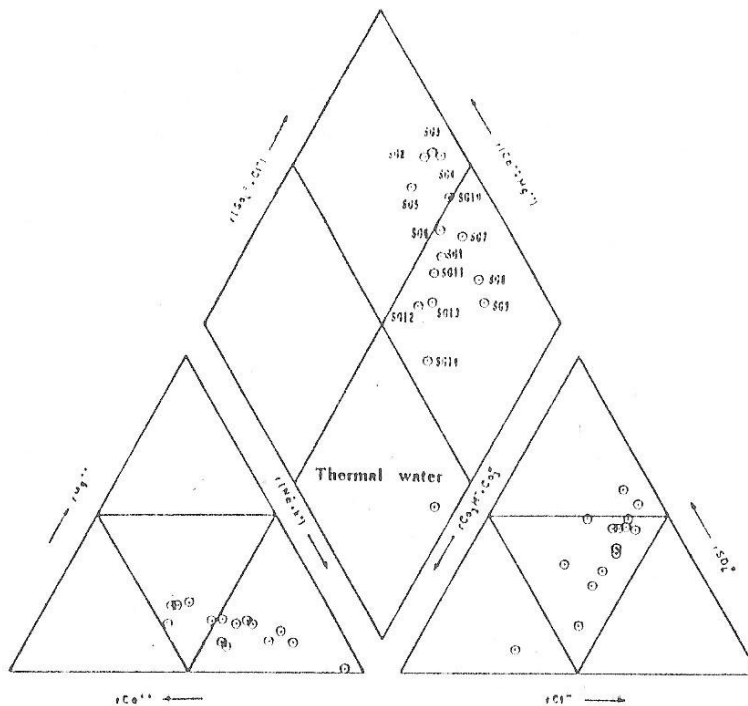


Fig. 2 - Triangular diagram for natural waters in the study area.

From table 2, one can see that silica geothermometer assuming equilibrium of the water with quartz provide temperatures between 122 °C and 132 °C. Lower and more unchanging values are predicted by different equations that assumes control of aqueous silica by chalcedony (102 °C - 104 °C). The ratio Na/K being temperature dependent function furnish a mean temperature of 108 °C, and the Na-K-Ca geothermometer gave a value of 108 °C (for B=4/3) and 141 °C (for B=1/3), which drops to 95 °C and 127 °C respectively, using the magnesium correction. Finally Albite - Anortite geothermometer yield a temperature for the storage system of 110 °C.

Alternatively to exhaustive utilization of the considerable number of chemical geothermometers presented we selected particularly those calibrated and tested in areas of low enthalpy geothermal systems, as the equations proposed by Arnórsson. These conduct to a mean value for the base temperature of Sangemil thermal water of 110 °C ± 10°C.

Another attempt to estimate temperature of deep reservoir supplying the thermal spring is done using the evolution of the saturation indexes with temperature for a set of minerals that we may admit occur in the deep part of the geothermal system. Figure 3 shows the evolution of saturation indexes of some minerals (quartz, chalcedony, microcline, albite, fluorite, muscovite and laumontite) vs temperature, for the spring of Sangemil. For this group of minerals the saturation indexes become zero in a range of temperature from 85 °C to 120 °C. Although relative dispersion (many possible causes contribute to that) and lower values regarding temperatures obtained before, the idea left by these figures is to support the validity of chemical geothermometers temperature. On the other hand oversaturation at spring temperature regarding these and other minerals, can be explained by absence of significant chemical reequilibration during ascent of the thermal water from the reservoir to the surface.

6. ENVIRONMENTAL ISOTOPES

Three samples of different cold waters and two samples of thermal water were analysed to measure the content in stable isotopes (^{18}O and D). The interpretation of the data allows to verify that isotopic relations for thermal water (mean value: $\delta^{18}\text{O} = -5.86$ ‰; $\delta\text{D} = -34.4$ ‰) are close to the values obtained for cold groundwater (mean value: $\delta^{18}\text{O} = -5.32$ ‰; $\delta\text{D} = -32.7$ ‰).

From the plot δD vs $\delta^{18}\text{O}$ (figure 4) we can visualize the position of those waters regarding the "meteoric water line". Significantly the projection of mean isotopic composition for cold

Table 2 - Estimated reservoir temperatures based on chemical geothermometers (°C).

QUARTZ	Temp. (°C)
Siever, 1962	122
Fournier & Truesdell, 1974	131
Truesdell, 1976	131
Tardy, Dubessy & Plot, 1977	127
Michard, 1979	132
Arnórsson, 1983	122

CHALCEDONY	Temp. (°C)
Fournier & Truesdell, 1974	104
Truesdell, 1976	102
Michard, 1976	103
Arnórsson, 1983	103

Na - K	Temp. (°C)
White & Ellis, 1970	108
Fournier & Truesdell, 1976	99
Michard & Pouillac, 1976	107
Michard, 1979	109
Arnórsson, 1983	118

Na - K - Ca	Temp. (°C)
b=4/3	108
Fournier, 1981	
b=1/3	141

Na - K - Ca - Mg	Temp. (°C)
b=4/3	95
Fournier & Potter, 1981	
b=1/3	127

ALBITE - ANORTITE	Temp. (°C)
Albert - Béltran, 1973	110

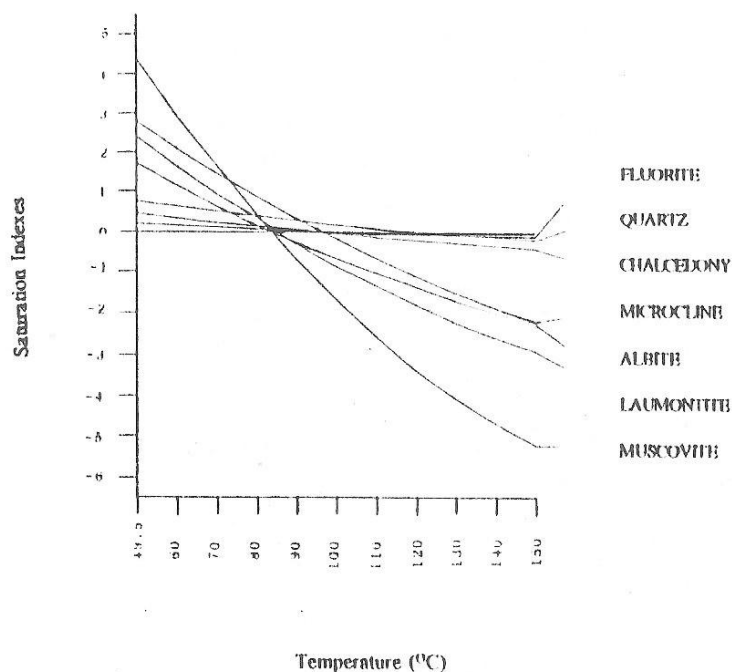


Fig. 3 - Evolution of the saturation indexes with temperature.

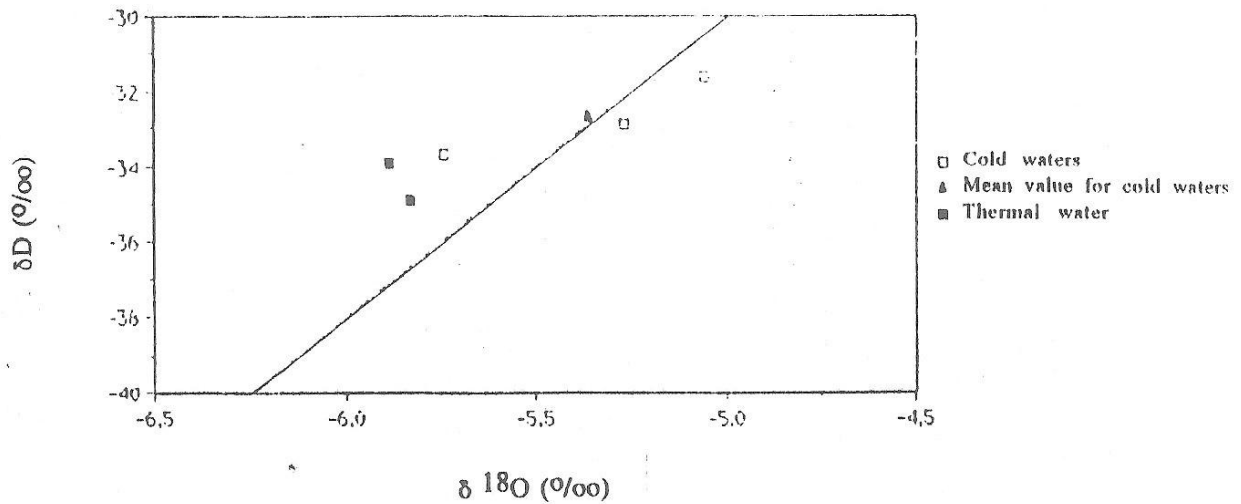


Fig. 4 - Values of $\delta D / \delta^{18}O$ for cold and thermal waters of Sangemil (Solid line shows the "meteoric water line").

waters, fall upon the line $\delta D = 8 \delta^{18}O + 10$. Values for thermal water are plotted above and at small distance from that line. This shows that the Sangemil thermal water has a meteoric origin.

Thermal water presents a depletion in both the heavier isotopes, ^{18}O and deuterium, comparatively to the cold waters. A possible explanation for this observed shift may be the localization of the recharge area for the thermal circuit. For the interior and at increasing altitude, rainfall will be characterized by a higher isotopic lightness. The small difference between δD figures for thermal and cold waters proclaims for a near recharge area.

A tritium measurement on a sample from Sangemil thermal spring yielded a low value (0.3 T.U.), which suggests a long period of circulation and indicates that mixing of deep high temperature water with cold near surface water is not likely in the hydrothermal upward path.

7. CONCLUSIONS

From consideration of the chemical, hydrogeological and thermal behaviour, a conceptual model is proposed, which assumes a relatively simple story for Sangemil thermal water.

Rain water at the recharge area (perhaps not far away from emergence) begins a downward movement until it reaches a compatible depth with estimated temperature of ± 110 °C. As it enters the circuit, the infiltrating water changes its chemical composition owing to

water/rock (granite) interaction. Chemical identity of thermal water is obtained in the descending circuit.

After a long time and deep circulation in a homogeneous geological environment, thermal water attains equilibria which depends on the temperature. With volume expansion due to heating, the ascending current becomes efficient and the water leaves the reservoir towards the surface where it emerges as thermal spring, at a point of lower altitude than the recharge area.

During the ascending path, thermal water don't go through expressive changes in chemical composition and loses heat by conduction.

8. ACKNOWLEDGEMENT

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SELECTED REFERENCES

Aires-Barros, L. (1989). Geothermal resources in Portugal. Anais da UTAD, vol. 2 (1), p. 11-22.

Albert-Beltrán, J. F. (1975). El equilibrio albita-anortita como termómetro hidrogeotérmico en zonas graníticas. Acta Geológica Hispánica, tomo x, nº 5, p. 170-174.

Arnórsson, S. (1983). Chemical equilibria in Iceland geothermal systems - implications for chemical geothermometry investigations. Geothermics, vol. 12, nº 2/3, p. 119-128.

Carvalho, M. R. (1989). HIDSPEC, um programa de especificação e cálculo de equilíbrios água /rocha. Aplicações. Dissertação apresentada à Univ. de Lisboa para obtenção do grau de Mestre em Geologia Económica e Aplicada, Lisboa, 238 p.

Carvalho, M. R. , J. V. Cruz, C. Almeida, M. O. Silva (1990). Hidrogeoquímica da águas dos granitos hercínicos das Beiras. Geolis, vol. IV, fac. 1 e 2, p. 229-248.

Ferreira, M. Portugal, J. M. Carvalho, J. L. Mendonça (1984). Águas minerais na Zona Centro-Ibérica (Sector de Portugal): Metodologia, Tipologias. Congreso Español de Geologia, tomo IV, p. 317-330.

Fournier, R. O. (1981). Application of water geochemistry to geothermal exploration and reservoir engineering. In "Geothermal systems: Principles and case histories", L. Rybach, L. J. P. Mufler (Eds.), a Wiley - Interscience Publication; p. 109-143.

Machado, M. J. C. (1988). O quimismo das águas sulfúreas portuguesas. Estudos, Notas e Trabalhos, D.G.G.M., tomo 30, p. 37-49.

Michard, G. (1979). Geothermomètres chimiques. Bulletin du B.R.G.M., 2^a série, secção 3, nº 2, p. 183-189.

Michard, G., C. Fouillac, D. Grimaud, J. Denis (1981). Une méthode globale d'estimation des températures de réservoirs alimentant les sources thermales. Exemples du Massif Central Français. Geochimica et Cosmochimica Acta, vol. 45, p. 1199-1207.

Michard, G., E. Roekens (1983). Modelling of the chemical composition of alkaline hot waters. Geothermics, vol.12, nº 2/3, p. 161 - 169.

Morais, M. J. F. (1990). Termas de Sangemil - Um estudo hidrogeológico. Dissertação apresentada à Univ. de Coimbra, no âmbito das "Provas de aptidão pedagógica e capacidade científica", para progressão na carreira docente universitária; Coimbra; 214 p.

Truesdell, A. H., J. R. Hulston (1980). Isotopic evidence on environments of geothermal systems. In "Handbook of environmental isotopes", Ed. P. Fritz, J. C. Fontes, cap. 5, p. 179-225.