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Contribution to the Knowledge of the Geothermal Potential of the Municipality of Meda (Portugal)

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ABSTRACT

Geothermal energy is presented as an increasingly viable alternative for the production of energy. Currently, in Portugal, municipalities are engaged in finding alternatives to the classical methods of energy production for environmental and economic reasons and the Municipality of Meda is no exception. Therefore, it is important to analyse in more detail the geothermal potential of the entire municipality, which is rich in granitic massifs with some springs of sulphurous thermal waters. This work presents the main geological elements of the municipality, the inventory roundwater points whose temperature is recorded and gives particular attention to wells that are associated with deep geohydraulic models, putting forward their reservoir temperatures and depths respective. We emphasize the occurrence of three major sectors with geothermal potential: Longroiva, Areola and Graben. From the results of physicochemical analyzes of mineral water at each sector, using geothermometers, we evaluate the maximum temperature of 113.2°C, 84.2ºC and 78.9ºC, at correspondents reservoir depths of 2000m, 2200m and 2500m, respectively to the sectors of Longroiva, Areola and Graben. Finally, we highlight the fact that the sector Longroiva present a local geothermal gradient of 0.0762 ° C / m, which is higher than the average value of the earth's crust (0.033ºC/m).

1. INTRODUCTION

Conventional energy associated with hydrocarbons triggers pollutant gases, particulate matter, polluted rain, among others, which as a whole contribute to the greenhouse effect. According to Prates (1998), the buildup of greenhouse gases in the atmosphere generated by human activity will increase the greenhouse effect causing the surface temperature of the Earth to rise from an estimated 1 ºC to 3.5 ºC by the year 2100, which will change the climate, with all its consequences, possibly catastrophic. According to the JOUE (2005) the issue of energy resources and its relation to greenhouse gas emissions becomes even more problematic considering that the world's energy needs are expected to double or triple the current levels by 2060 because of population increase and economic progress in the least developed countries. Thus, a paradigm change is required toward the use of alternative and/or renewable energy, thereby leading to benefits to environmental protection. It should be stressed that geothermal energy could play an important role in achieving these goals.

The present study falls in the domain of low-enthalpy, with the potential use of geothermal fluids at temperatures below 100 ºC, particularly suited for heating buildings and greenhouses and providing domestic hot water. This is possible due to the favourable geological setting of the study area, because there are large granitic massifs associated with extensive and deep faults, which together favour the occurrence of relatively deep hot water aquifers. Although a few locations with such features are already known in the municipality of Meda, the ongoing project from which this paper is drawn is intended to derive a more consolidated knowledge on the subject.

This paper is the result of a project carried out in the context of the doctoral thesis by the first author, which aims to contribute to the interpretation of the geohydraulic model of the hot sulphurous waters of the Meda region. Some of these waters resurface with anomalous temperature and chemical composition, which enables to map areas of high geothermal potential and use geothermometers to estimate their temperatures in the reservoirs.

The Municipality of Meda is a small region with 286 km^2, located in Northeast Portugal which is turn is located in Southwest Europe (Fig. 1).

2 GEOLOGICAL AND GEOMORPHOLOGICAL SETTINGS

The study area lies in the Old Massif, which corresponds to the western part of the Iberian Peninsula morphostructural unit called Hercynian basement (Fig.2) with obvious episodes of extensive magmatic intrusions. With respect to the geomorphology, the region is constituted by large plateau areas spaced at various altitudes, with some areas of high slope. It stands out the occurrence of the tectonic accident of the Vilariça fault (Bragança - Manteigas) which compartmentalises the region of Meda in two large blocks, and is characterized by a horizontal displacement of about 5.5 km that triggered a parallel fracturing across a strip 0.5 to 1 km wide, which with the unevenness of the rim blocks and subsidence of the central block originated the Longroiva graben (Fig. 3). This fracturing has not developed a symmetrical morphology on both sides of the Vilariça fault. On the eastern side there is a 150-200 m high fault escarpment and the current surface corresponds to the Meseta tilted NW toward the Douro River and partially carved by the deep canyons of the Côa River and the streams of Massueime, Pisco and Aguiar, a result of regressive erosion from the Douro River. It should be noted that residual reliefs stand out from the surface of the meseta such as: extensive veins of quartz (Seixo, 604 m), an ordovician quartzite inselberg (São Gabriel, 652 m and the western pericline synclinorium of Poiares, 742 m). On the western side tectonic levels occur until about 650-750 m, where the city of Meda lies. West of the Teja stream, altitudes range between 800 m and 950 m in the granitic area through which the Torto River flows. This rugged relief, with planation surfaces at different altitudes, is the result of intense fracturing and differential erosion, associated with the fitting of the hydrographic network of the left bank of the Douro River (Ferreira da Silva and Ribeiro, 1991).

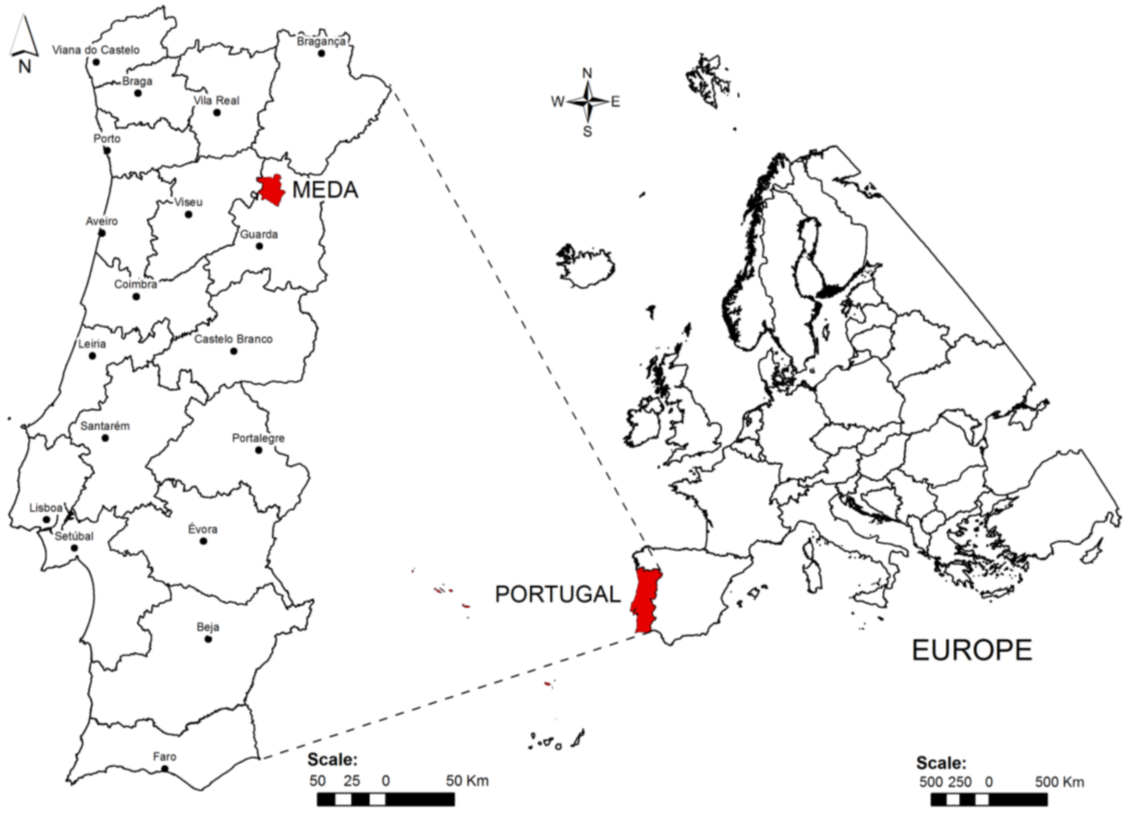


Figure 1: Location of the study site – Municipality of Meda.

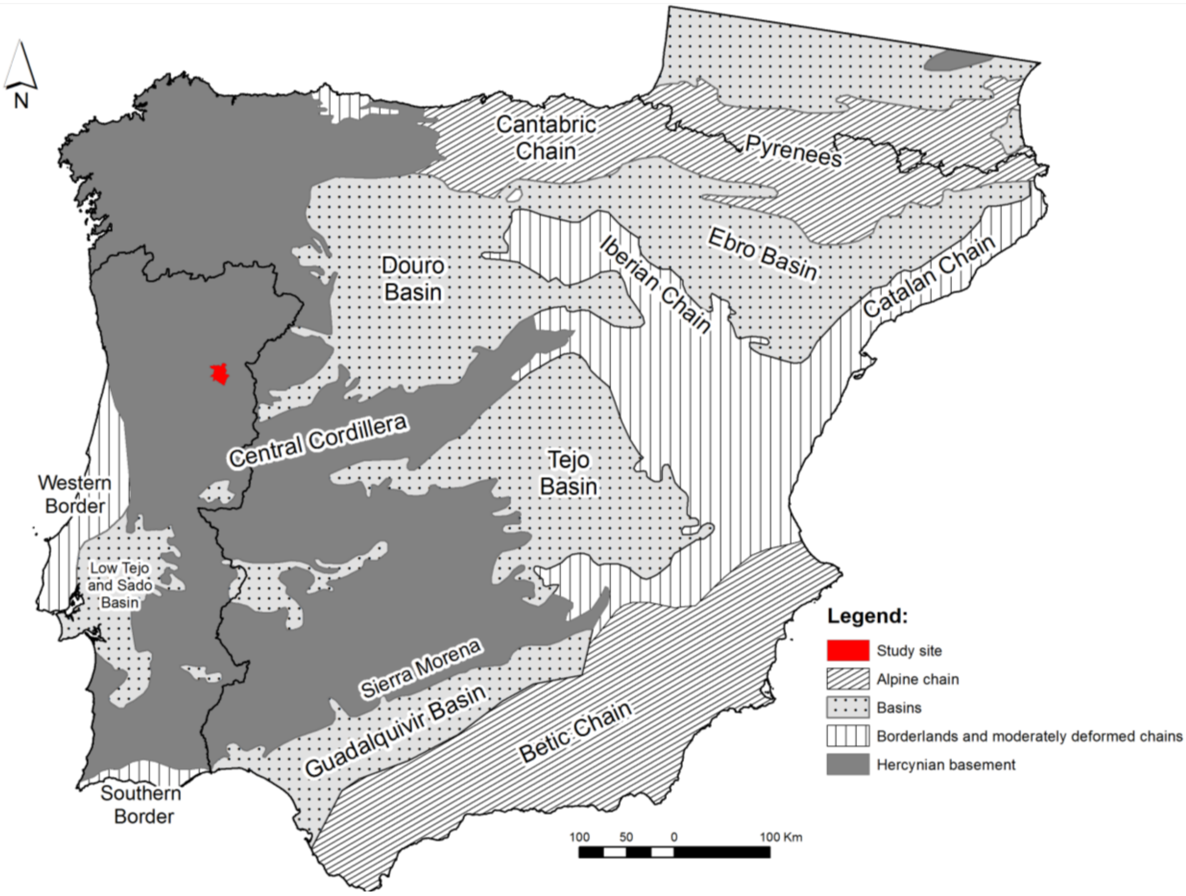


Figure 2: Location of the study site in the geomorphologic units of the Iberian Peninsula (Ribeiro *et al.*, 1979).

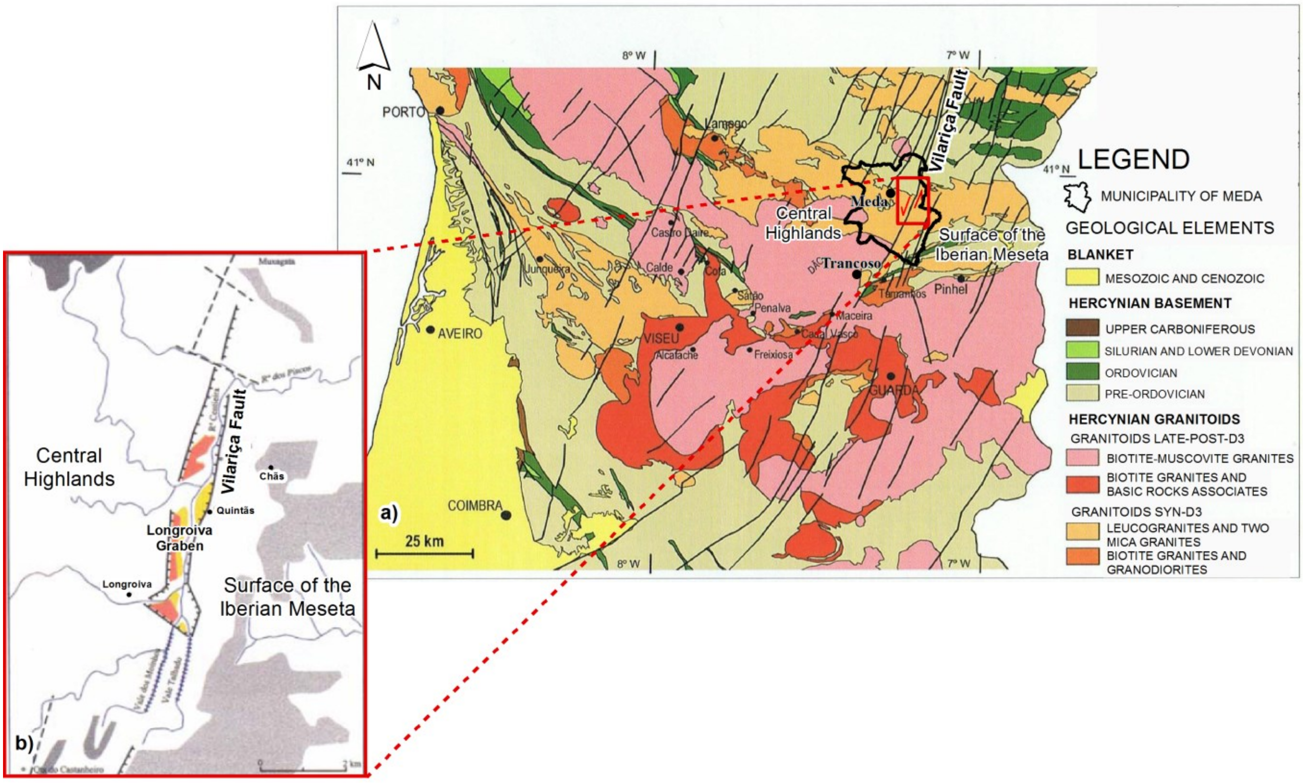


Figure 3: a) regional geological setting of the study site (from Azevedo and Aguado, 2012); region of the graben (from Cunha and Pereira, 2000).

A relevant element to this study at geomorphologic level is a mountain range with an average altitude of 750 m (granitic plateau about 35 km long and 4 km wide) extending from Trancoso NNE - SSW along the longest axis and across the entire study area. On the eastern part a vast plain unfolds reaching up to 350 m altitude. The drainage systems that starts along that mountainous central range (ridge line) is dendritic and unfolds for Northeast, feeding the streams of Massueime and Centieira towards the Côa River, and Northwest feeding the Teja Riverside, both tributaries of the left bank of the Douro River (Fig. 4).

The geology of the region is dominated by old Cambrian, Ordovician and Permo-carbonic formations, topped by newer Tertiary and Quaternary formations (Fig. 5). The geological units are organised into the following main groups:

i. Schist-Greywacke Complex: schist rocks, pre-Ordovician (≈550 Ma),

ii. Hercynian granitoids (260-220 Ma), and filonian masses,

iii. Sedimentary deposits of coverage:

   a. Vilariça arkoses, Tertiary-Neogene;

   b. Slope deposits, Holocene;

   c. Alluvial deposits, actual age.

The geologic unit that supports the geothermal potential aquifers is composed of granitoids. However, it is the whole geological, structural and morphological setting that favours the natural ascension of groundwater that is of most interest to this work. Figure 5 presents the locations of the major springs. It should be noted that these are unique, rare elements in the region, accounting for around 0.1 % of the whole of perennial springs of the municipality. These are sulphurous springs as shown in the following point.

3 HYDROLOGIC AND ENVIRONMENTAL ELEMENTS

3.1 Climate Elements

Some climatic aspects are introduced because they form the basis for assessing hot groundwater recharge. It is also considered important to provide the ambient temperatures in the region to highlight the necessity of using geothermal energy in particular for heating buildings in colder periods of the year.

Table 1 shows the characteristics of weather stations relevant to the calculation of the water-balance in the region. It is important to mention that although there is sufficient number of stations with records of precipitation in the area of interest to the municipality, the same is not true for the stations with records of temperature, and therefore the records of the nearest stations (Table 2), i.e. Figueira de Castelo Rodrigo, Moncorvo and Guarda, are presented. The location of those stations in Portugal and their relationship with the municipality of Meda are shown in Figure 6. The values of temperature, precipitation as well as the main results of the calculation of the water-balance of the municipality of Meda are shown in Table 3. The water-balance generally followed the methodology presented by Thornthwaite and Mather (1957). The precipitation values correspond to the weighted precipitation evaluated based on the area of influence of each weather station determined from Thiessen polygons (*in* Dunne and Leopold, 1978), and admitting only areas of the municipality of Meda as illustrated in Figure 7. Figure 8 shows the graphical representation of the water-balance for the region of Meda.

Among all the results, we highlight the annual water superavit (SH) of 197.36 l/m^2. In principle, this value suggests a modest aquifer recharge. However considering a recharge area commensurate with the municipality of Meda characterised by generally modest slopes, with much altered and usually very fractured large granitic massifs, as well as taking into account a frequent vegetation of forest and bush, a significant portion of SH is estimated to infiltrate and recharge the aquifers of the region. Thus, SH = R+G=197.36 l/m^2 being the sum of surface runoff (R) and groundwater inflow (G), and considering the ratio "G/SH" = 35% as representative for the study site, annual infiltration rates of 69.1 l/m^2 are obtained to recharge the aquifer reserves, which for a total area of 286 km^2 allows an average annual recharge of 19.8 x10^6 m^3.

Such value corresponds to a continuous annual discharge of 627.9 l/s. Although assuming that most of it will ultimately discharge into shallow water springs, there will be a component that reaches greater depths, especially in the granitoid area, which will result in underground hot water with a temperature dependent on the local geothermal gradient.

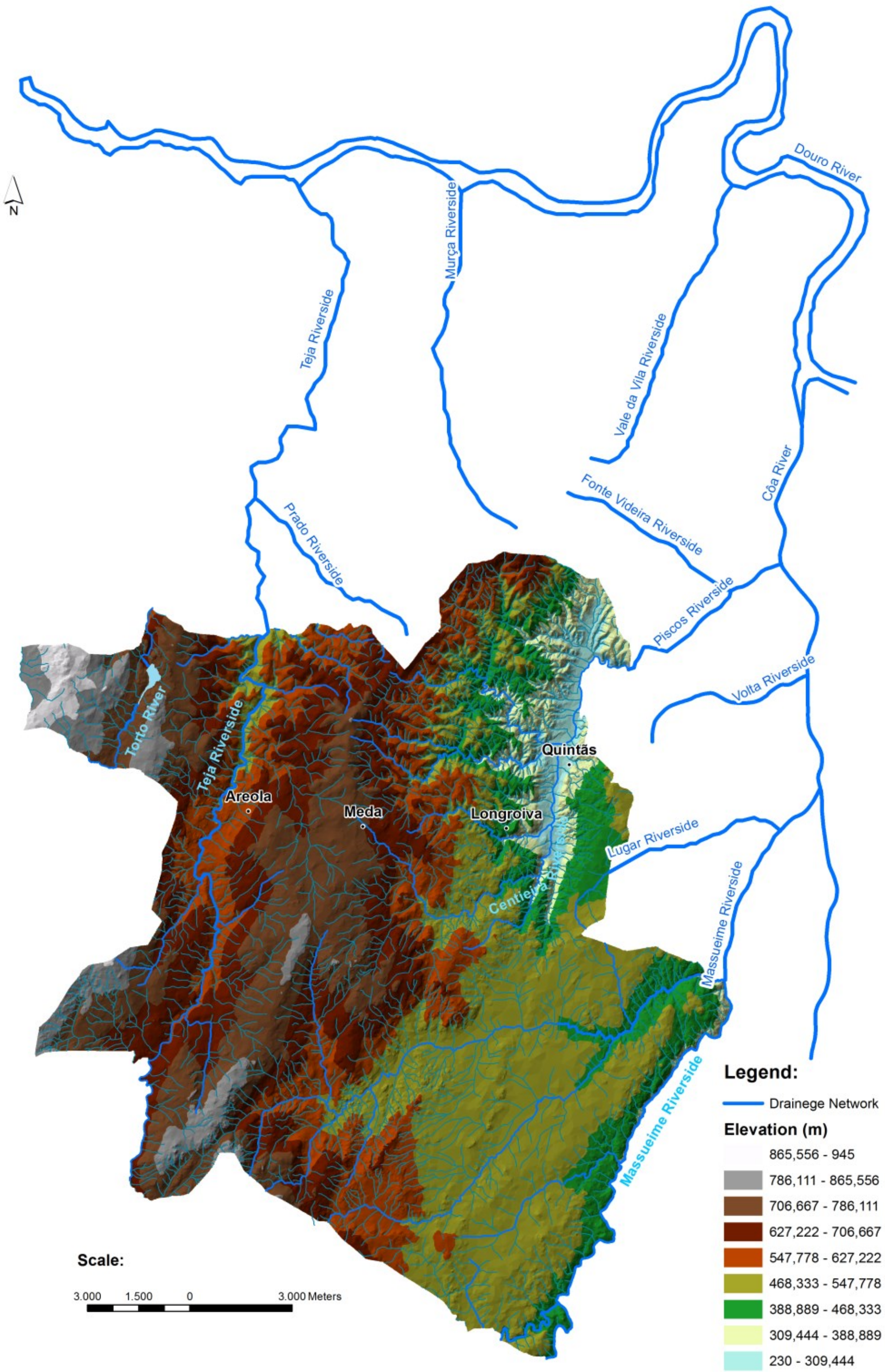


Figure 4: Digital model of the terrain of the municipality of Meda and its integration in the regional drainage system.

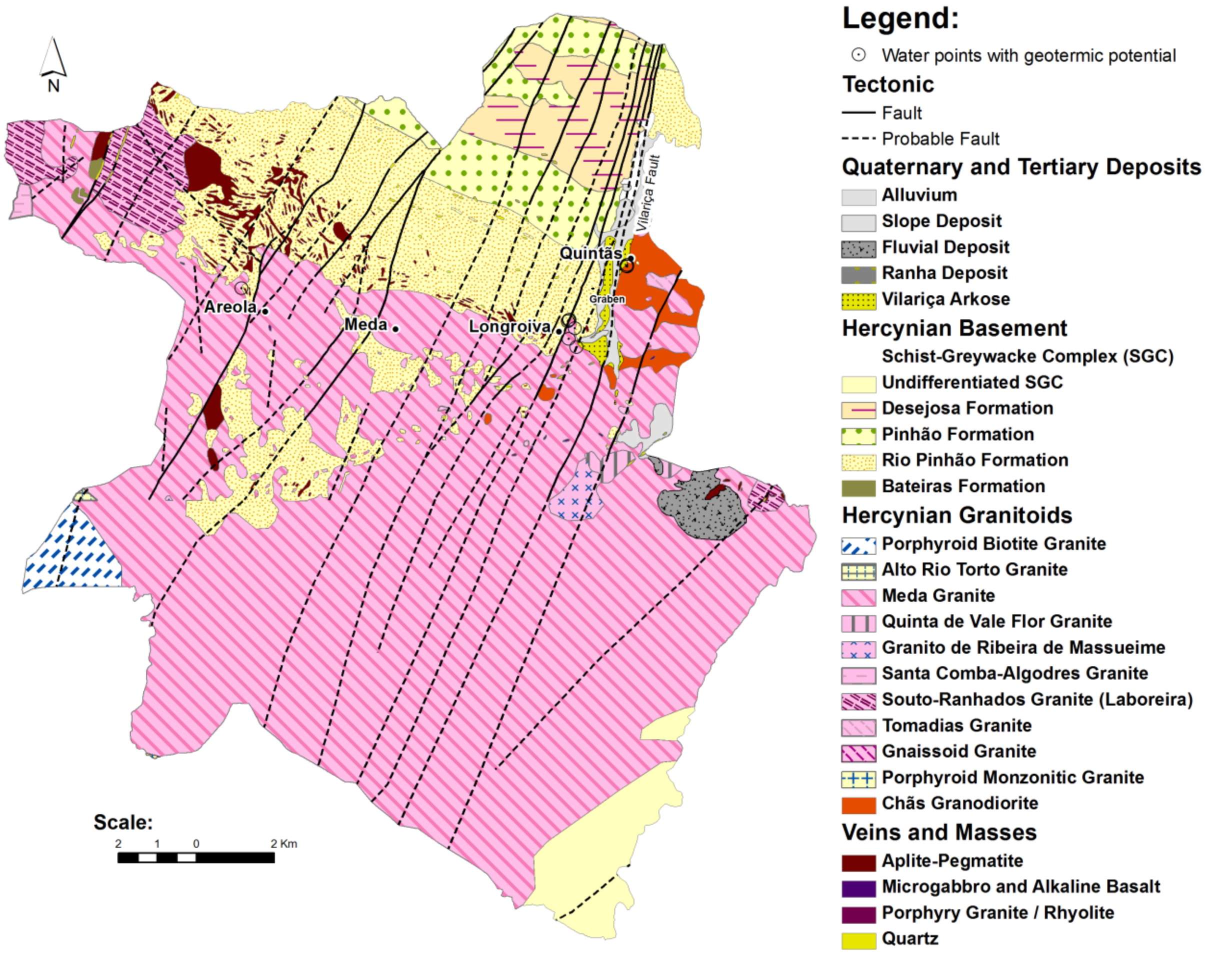


Figure 5: Geological Map of the municipality of Meda with implantation of the main groundwater points with geothermal potential.

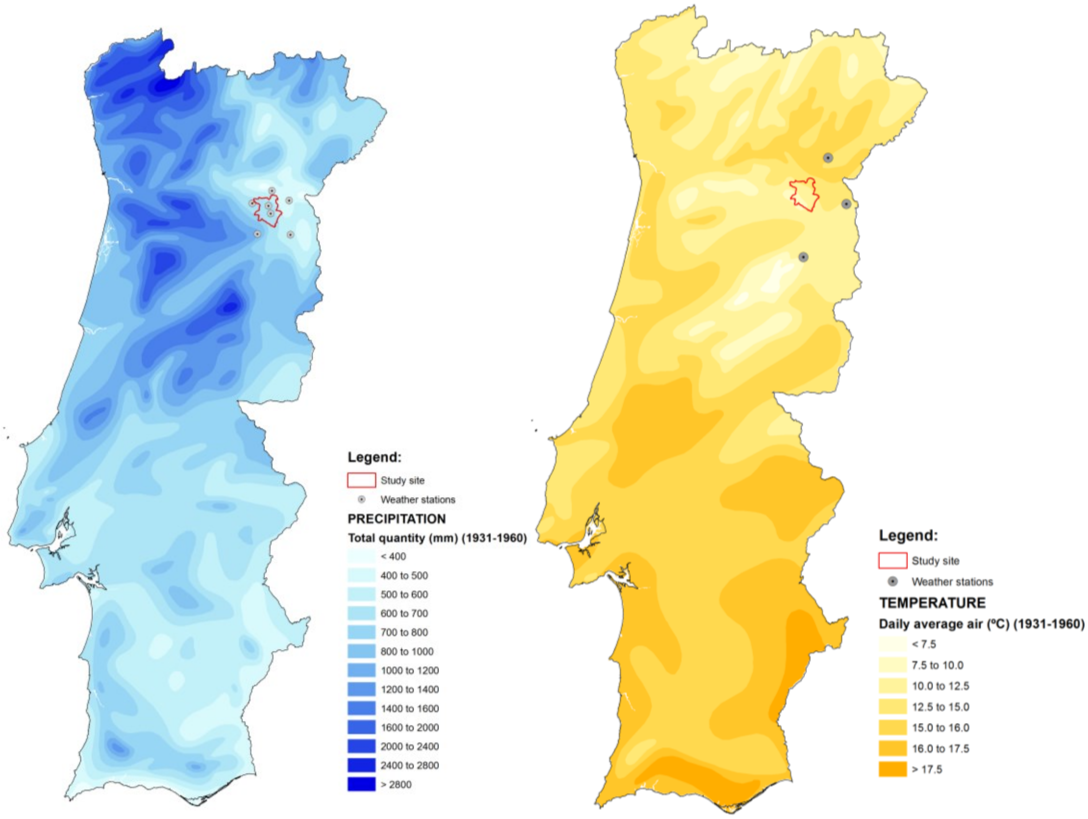
Table 1: Characteristics of the weather stations relevant to the municipality of Meda (in Ferreira, 1970).

Station	Meda (1)	Marialva (1)	Freixo de Numão (1)	Trancoso (1)	Penedono (1)	Moncorvo (2)	F.C.Ro-drigo(2)	Guarda (2)
Latitude	40.965N	40.913N	41.065N	40.778N	40.984N	41.165N	40.866N	40.530N
Longitude	7.251W	7.232W	7.218W	7.350W	7.393W	7.051W	6.900W	7.270W
Altitude	671	558	563	853	957	408	635	1019
Period	1936-60	1960-09	1936-60	1933-60	1933-60	1925-54	1951-80	1931-60
Influence area (*) (%)	36.5	49.1	4.8	0.1	9.6	-	-	-
Influence area (km^2)	0.364	0.491	0.048	0.001	0.096	-		-

(*) based on Thiessen polygons. (1) stations with records of precipitation; (2) stations with records of temperature.

Table 2: Temperatures (T in oC) recorded in various stations in the region of Meda (in Ferreira, 1970).

Mon-th	Moncorvo					Fig.de Cast. Rodrigo					Guarda				
	Monthly T			Pontual T		Monthly T			Pontual T		Monthly T			Pontual T	
	ave.	max.	min.	max.	min.	ave.	max.	min.	max.	min.	ave.	max.	min.	max.	min.
Jan.	6.4	9.3	3.4	18.4	-4.8	4.7	8.8	0.6	17.0	-12.6	3.4	5.7	1.0	16.7	-8.0
Feb.	8.2	12.1	4.4	19.8	-5.7	6.0	10.6	1.5	23.5	-9.1	4.2	7.0	1.3	17.8	-12.3
Mar.	11.4	15.7	7.1	26.5	-2.2	8.3	13.4	3.2	25.3	-9.6	6.6	9.8	3.5	20.6	-8.8
Apr.	14.0	18.8	9.1	32.8	2.0	10.5	16.1	4.8	28.0	-5.6	8.8	12.6	4.9	25.6	-5.1
May	16.7	21.9	11.5	35.6	3.1	14.1	20.6	7.7	40.2	-4.1	11.3	15.4	7.2	29.1	-1.3
June	21.6	27.6	15.7	39.0	6.5	18.1	25.2	10.9	38.0	2.1	15.9	20.7	11.1	32.2	2.4
July	24.2	30.7	17.8	41.8	10.5	21.3	29.5	13.1	38.0	4.5	18.8	24.2	13.4	35.0	6.1
Aug.	24.4	30.9	17.9	41.4	11.1	20.8	29.0	12.7	38.0	5.5	18.9	24.1	13.7	33.6	4.9
Sept.	21.2	26.8	15.6	37.9	7.5	18.1	25.5	10.8	37.0	1.6	16.2	20.5	11.8	31.5	1.8
Oct.	16.2	20.8	11.5	32.8	2.1	13.3	19.1	7.5	31.0	-4.6	11.4	14.5	8.2	25.0	-0.4
Nov.	10.6	14.0	7.2	21.9	-2.5	8.0	12.7	3.2	24.0	-8.1	6.8	9.3	4.3	21.0	-5.3
Dec.	7.2	10.2	4.2	20.9	-4.0	4.9	8.8	1.0	18.5	-9.6	3.8	6.2	1.5	16.5	-10.4
Year	15.2	19.9	10.4	41.8	-5.7	12.3	18.3	6.4	40.2	-12.6	10.5	14.2	6.8	35.0	-12.3



a) b)

Figure 6: Climatologic framework of the study site: a) total annual precipitation; b) average annual temperature (from APA, 2014).

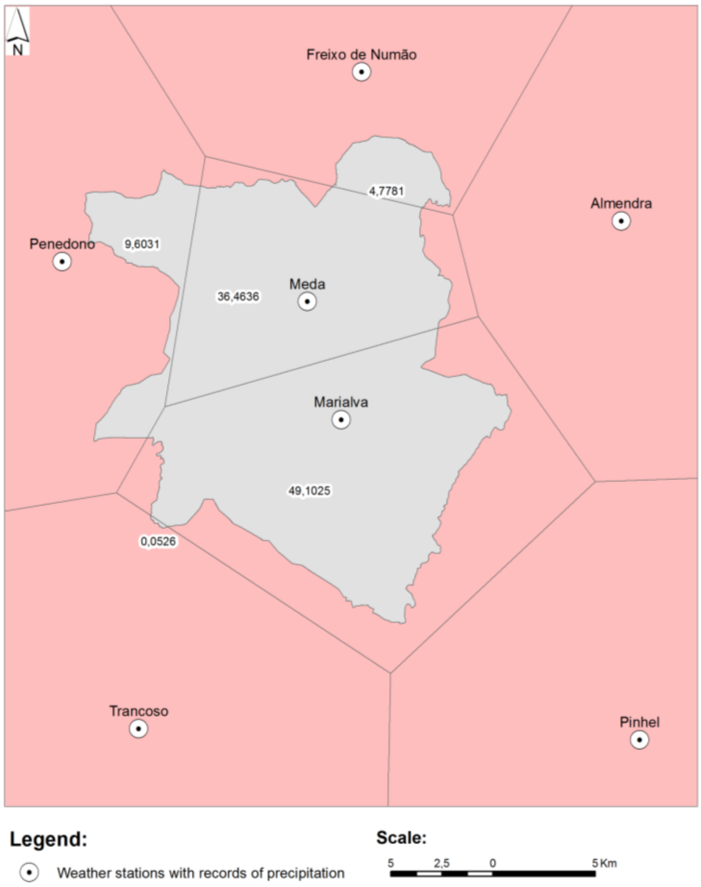


Figure 7: Optimisation of the influence area of each weather station based on Thiessen polygons.

Table 3: Monthly water-balance for the municipality of Meda (*).

Month	Jan.	Feb.	Mar	Apr	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
T (ºC)	4.7	6.0	8.3	10.5	14.1	18.1	21.3	20.8	18.1	13.3	8.0	4.9	-
P	89.9	78.8	64.8	49.4	44.0	30.7	9.5	9.4	28.2	56.3	75.1	72.7	608.9
PET	11.66	17.76	29.97	45.04	71.76	103.02	124.96	113.32	85.71	51.59	23.96	12.00	690.8
RET	11.52	17.75	29.91	44.89	68.23	69.73	34.66	16.93	29.97	51.59	23.96	12.00	411.15
DH	-	-	-	-	3.52	33.29	90.29	96.38	55.75	-	-	-	279.24
SH	78.28	61.03	34.87	4.35	-	-	-	-	-	0.00	0.00	18.84	197.36

(*) the capacity usable by plants (nu) was assumed to be complete at the beginning of the dry season, i.e., nu = 100 mm in April.
T – monthly average temperature; P – monthly average precipitation, weighted for the recharge area, based on Thiessen polygons, admitting only areas of the municipality of Meda; PET and RET potential and real evapotranspiration; DH – water deficit; SH – water superavit.

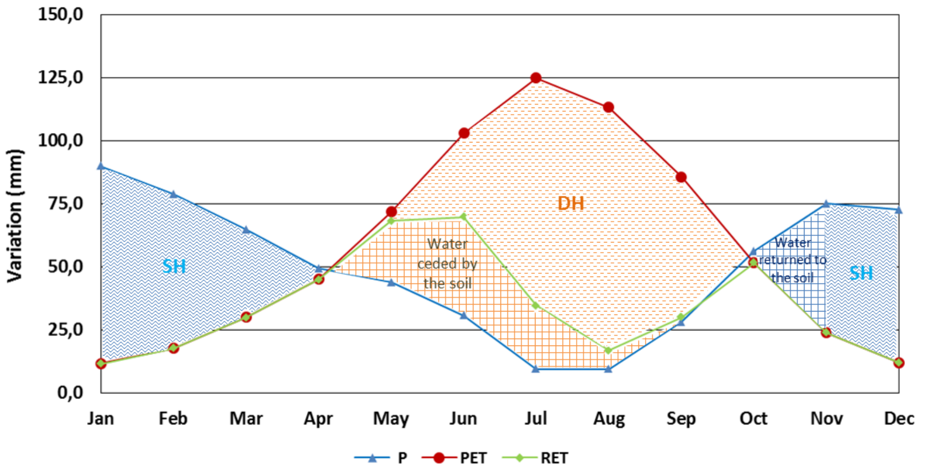


Figure 8: Graphical representation of the water-balance for the municipality of Meda (P – weighted precipitation; PET - potential evapotranspiration; RET - real evapotranspiration, SH – water superavit; DH – water deficit).

3.2 Groundwater Points

In order to clarify the hydrogeology of the area a wide survey of all water points, including natural springs, traditional shallow wells, and boreholes, among others, is underway. At present, it has been verified that water points with geothermal potential occur on granitic rocks. The main points identified are shown on the geological map in Figure 5; some of their features are summarized in Table 4. It should be noted that they correspond to three distinct major sectors with resurgences or wells being located nearby contacts with schistose rocks. Generally, the water infiltrates granitoids in elevated areas and then moves deeper until slamming into schists which act as in-depth barriers. However, natural resurgences are favored by relatively deep faults that cause water to rise is some cases with temperatures clearly anomalous for the region concerned.

The anomalous records fall into three distinct sectors: i) Longroiva ii) Ribeira Teja, and iii) Graben-Quintãs. One of the highlighted sectors corresponds to Longroiva Spa where the naturally warm groundwater is already harnessed to heating buildings and sanitary water. This sector is associated with the set of faults of the Vilariça system which favours the percolation of water from Trancoso on the south to the Spa and other locations to the north. The Ribeira Teja sector corresponds to the currently inactive Areola Spa generally associated with a fault approximately coincident with Teja riverside, which also allows the percolation of groundwater flows from the south to the north. Finally, a new sector is identified on the east border of the Graben of Longroiva, whose underground percolation occurs from the east to the west until bumping into the graben.

Table 4: Main groundwater points with geothermal potential in the municipality of Meda.

Ponto	Tipo	Q (L/s)	T (ºC)	C (µS/cm)	pH	Eh (mV)	TDS (mg/L)	Elevation (m)	T_E (º)	Sector
N north-Spa	natural spring	0.15	21.6	595.8	8.87	-153.7	549.0	376	13.3	Longroiva
N south-Spa	natural spring	0.28	29.3	621.8	8.69	-145.8	570.4	376	13.3	
AC1-A Spa	Well (212 m depth)	6.30	47.4	593.6	8.73	-153.3	545.9	376	13.3	
28 – Gricho	natural spring	0.13	21.3	462.0	7.85	-	-	375	13.3	
33 - Faião	natural spring	0.08	17.0	468.0	8.83	-	-	338	13.2	
47 Coitada	natural spring	0.16	22.8	408.0	8.20	-	-	361	13.3	
NT- Areola	natural spring	0.24	20.0	506.0	7.98	-	-	530	12.0	Rib.Teja
NT Negrilhos	natural Spring	0.09	17.0	590.0	7.24			274	13.3	Graben - Quintãs
CR1	Well (178m depth)	0.28	19.8	614.7	7.77	-101.7	565.8	277	13.4	
CR2	Well (55m depth)	0.08	19.2	612.0	7.72	-99.8	563.2	277	13.4	

Q - Approximate average annual water flow; T – Maximum temperature recorded in water; C- Conductivity; Eh - Potential Redox; TDS - Total Dissolved Solids; T_E – Approximate average ambient temperature in the region.

The groundwaters in question are of the basic type with pH higher than 7.0, redox environments (negative Eh), conductivity between 450 and 700 µS/cm, temperature above 17.0 °C reaching the maximum value of 47.4 °C in the AC1A borehole with 212 m deep. The normal temperature of the groundwaters in this region is below 15 ºC. Other characteristics of these waters are that they naturally smell of hydrogen sulfide (rotten eggs) and when resurging they develop a typical whitish biogel.

4 QUALITY OF GROUNDWATERS

For better understanding of the special waters of the region and in particular to investigate the geothermal potential of the main sectors, the chemical analysis data of the water of the main catchments of each sector were organized as shown in Table 5. According to the corresponding Piper diagram presented in Figure 9, these are classified as sodium-bicarbonate waters. In any case, these waters are commonly referred to as sulphuric waters due to the particularity of being rich in sulphur species usually represented by significant values of Sulphuration, which according to Fetter (1994) corresponds to the total ionic water content of S_2- species, including simple and complex sulphur forms.

Table 5: Results of physic-chemical analyses of the groundwaters of the main water points in the various sectors with geothermal potential in the municipality of Meda.

Parameters		NT (N south-Spa) Longroiva (Almeida e Almeida, 1975)	AC1-A Longroiva (IGM 2000 in Ferreira Gomes 2001	CR1 Graben (IST, 2010a)	CR2 Graben (IST, 2010b)	NT Areola (Almeida e Almeida, 1975)
pH		8.79	8.85	7.97	7.67	7.92
Conductivity (μScm^{-1})		630	637	563	496	-
Hardness (p.p.$10^5 CaCO_3$ - ºf)		-	-	78	115	-
Sulphuration (I_2 0.01N) - ml/L)		14.0	46.3	16	10	-
Total CO_2 (m mol/L)		-	2.50	-	-	-
Silica (mg/L)		65.9	67.5	26	29	39.2
Total solids (to 180ºC (mg/L)		403.6	395.0	-	333	258.8
Total mineralization (mg/L)		-	457.0	481	437	-
Cations (mg/L)	Na^+	125.6	125.0	112	79	91.3
	Ca^{2+}	3.2	2.6	18.4	26	-
	K^+	5.04	4.3	2.6	3.0	1.8
	Mg^{2+}	0.24	0.04	7.7	12.1	1.7
	Li^+	0.56	0.78	0.59	0.44	-
	NH_4^+	-	0.58	0.43	0.22	-
	Fe^{2+}	0.08	<0.03	<0.03	<0.03	0.08
Anions (mg/L)	HCO_3^-	159.8	146.0	209	205	144.0
	Cl^-	51.8	45.4	45	36	16.3
	Br-	0.05	-	-	-	-
	SO_4^{2-}	14.9	12.7	45	37	20.7
	F^-	8.7	24.0	11	8	17.0
	CO_3^{2-}	8.7	6.9	<2	<2	-
	NO_3^-	-	<0.38	<0.3	<0.3	-
	NO_2^-	-	<0.02	<0.01	<0.010	-
	HS^-	0.86	7.6	2.4	1.4	0.54
	$H_3SiO_4^-$	-	13.1	<1	<1.0	-
Secondary elements ($x10^{-3}$) (mg/L)	Ag	-	<0.5	<1	-	-
	Al	-	<12	<3	-	-
	As	-	<3	17	36	-
	B	-	288	0.41	-	-
	Ba	-	107	<0.03	-	-
	Be	-	<1	0.4	-	-
	Cd	-	<1	<1	-	-
	Co	-	<6	<2	-	-
	Cr	-	<6	<1	-	-
	Cu	0.02	<2	<2	<2	-
	Hg	-	-	<0.2	-	-
	Mn	0.03	1.1	0.09	-	-
	Mo	-	<4	<5	-	-
	Ni	-	<4	<5	-	-
	Pb	-	<6	<3	<3	-
	Sb	0.05	<3	<1	-	-
	Se	-	<3	<0.4	-	-
	Sn	-	-	<5	-	-
	Sr	-	88	0.2	-	-
	Tl	-	-	<2	-	-
	V	-	<2	<0.02	-	-
	W	-	82	-	-	-
	Y	-	<1	-	-	-
	Zn	0.01	<2	<0.05	<0.05	-

5 GEO-ENERGETIC ELEMENTS

The water chemistry reflects the type of rocks traversed along the underground flow throughout their geohydraulic circuit. Some chemical elements of its composition are particularly useful in inferring what temperature was the water subject to along its path. If the temperature of the reservoir and the respective local geothermal gradient are known, it will be easier to program hot groundwater catchments in order to facilitate their use.

Thus, taking into account that the groundwaters presented in Table 5 have a relatively deep circulation, using their chemical composition, the reservoir temperature (Tr) can be calculated based on geothermometers. From the various solutions available in the literature, only equations that are based on silica and the ratio of Na/K (Table 6) are used in this work, because they are deemed the most appropriate to the waters concerned. The results obtained are summarized in Table 7 with the Longroiva sector having the highest values with average temperatures of around 113 °C. The other cases show a Tr lower than Longroiva but nonetheless with very significant and important temperatures for low enthalpy uses.

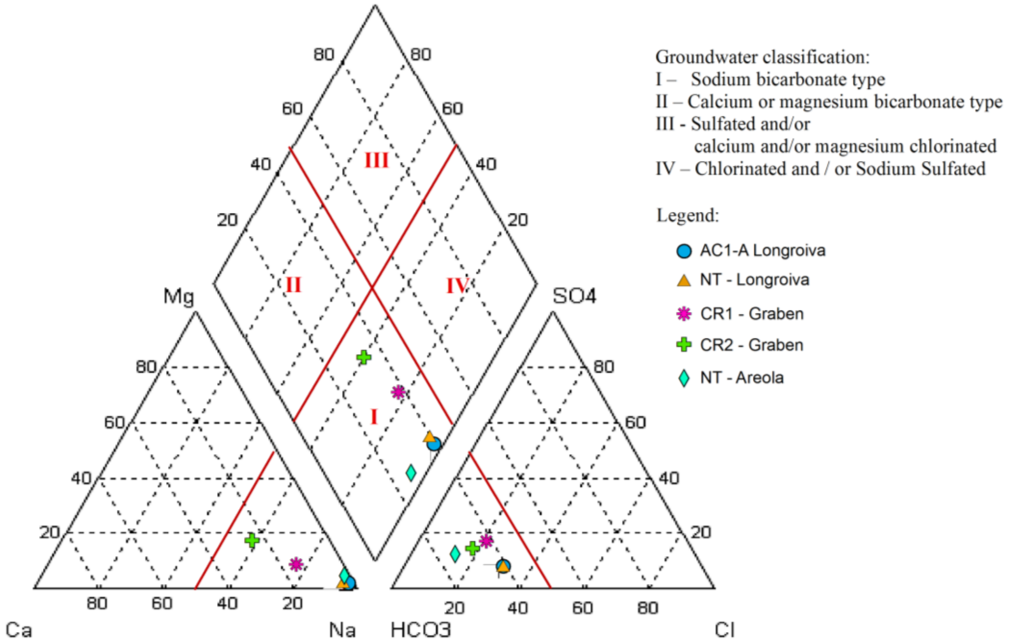


Figure 9: Piper diagram for groundwater with geothermal potential in the municipality of Meda (ions in% of mEq/L).

Table 6: Equations to estimate the reservoir temperature based on the chemical composition of mineral waters (in Ferreira Gomes *et al.*, 2014).

Geothermometer		Equation	Limitations	Author
Conductive quartz (silica)	1	Tr = 1309/(5.19-log C)-273.15	Tr= 0 - 250ºC	Fournier (1981, 1991)
	2	Tr=1164/(4.9-log C)-273.15	Tr=25 - 180ºC	Arnórsson (1983)
Adiabatic quartz (silica)	3	Tr = 1522/(5.75-log C)-273.15	Tr= 0 - 250ºC	Fournier (1981, 1991)
	4	Tr =1498/(5.7-log C)-273.15	Tr=25 - 180ºC	Arnórsson (1983)
Na/k	5	Tr = 855.6/(log D + 0.8573)-273.15	Tr=100-275ºC	Truesdell (1976 *in* Fournier 1981)
	6	Tr=883/(log D + 0.78)-273.15	-	Tonani (1980 *in* Fournier 1991)
	7	Tr=933/(log D+0.993)-273.15	Tr=25 - 250ºC	Arnórsson (1983)
	8	Tr=1217/(log D+1.483)-273.15	Tr > 150ºC	Fournier (1981, 1991)
	9	Tr=1178/(log D)+1.47)-273.15	Tr=25 - 250ºC	Nieva and Nieva (1987 *in* Fournier,1991)
	10	Tr = 1390/(1,750+log D)-273,15	-	Giggenbach (1988)

C= sílica in mg/L; D= Na/k, with Na= sodium, K = potassium, both in mg/L.

Table 7: Reservoir temperature (Tr in ºC) based on equations by several authors for the three sectors associated with deep geohydraulic models in the region of Meda.

Equation (Table 6)	1	2	3	4	5	6	7	8	9	10	average (*)
Longroiva AC1A	116.4	105.9	115.0	113.9	95.5 (*1)	120.4	106.7	139.9 (*1)	128.4	90.0	112.2
N south-Spa	115.1	104.6	114.0	112.8	106.5	132.5	117.3	149.5(*1)	137.8	88.9	114.7
CR1 Graben	73.6	60.9	77.9	76.4	70.3(*1)	92.6	82.0	117.3(*1)	106.3	51.4	78.9
CR2 Graben	78.0	65.5	81.8	80.4	102.5	128.1	113.4	146.0(*1)	134.4	55.4	98.8
NT Areola	90.8	78.9	93.0	91.6	60.7(*1)	82.2	72.6	108.6(*1)	97.9	66.9	84.2

(*) the calculation of the average did not include the values with (*1) because the equations do not apply in those cases as shown in Table 6.

Due to the fact that the Longroiva Spa sector shows more potential, it is where more studies have been carried out. This have led to the AC1-A Borehole. This hole was drilled by rotopercussion and artesian flows with temperatures being recorded during the drilling that have led to the evolution presented in Figure 10. The following equation is obtained from the graphical analysis of the records:

$$T = 25.598 + 0.0762\ D \qquad (1)$$

with D being the depth in meters, and T the temperature in °C.

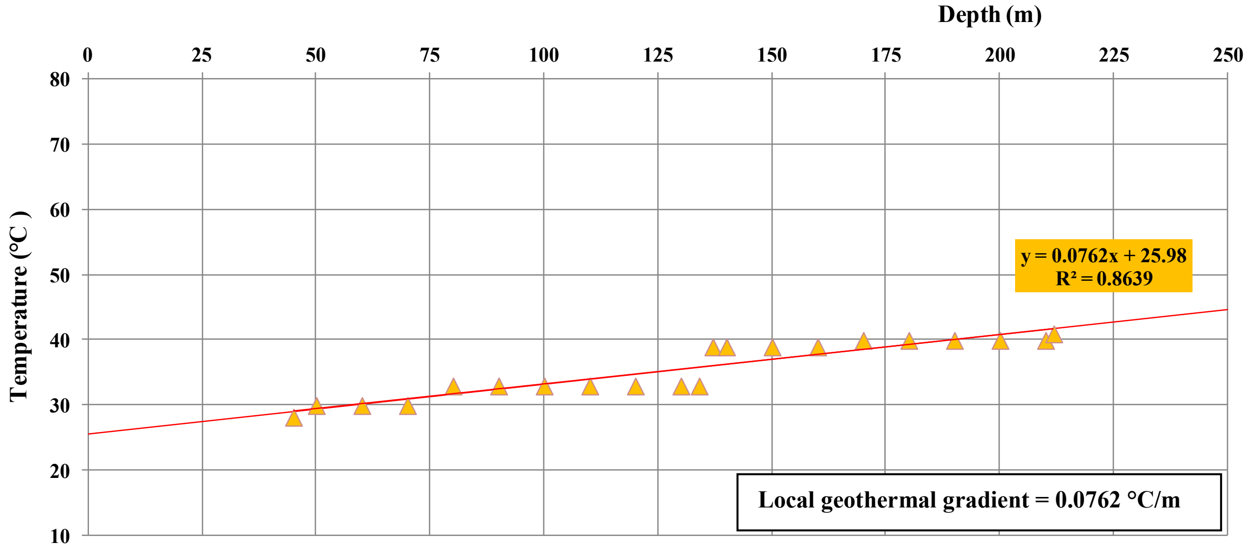


Figure 10: Evolution of the temperature in depth in the granitic massif in the area of Longroiva based on records of the AC1A borehole, as it was being drilled in 1999.

Thus, it is seen that the local geothermal gradient is 0.0762 °C/m, valor above the average geothermal gradient of 0.033 °C/m attributed to the continental crust (IGM, 1999). According to Pomerol and Ricour (1992) the normal geothermal gradient in granitic massifs is only 0.0125 °C/m. The case of Longroiva is definitely worth mentioning because it suggests an interesting geothermal potential at relatively modest depths.

From the previous results, considering that the potential temperature of natural resurgence of this type of water in the granitic massif of Longroiva is 25,6 °C, as equation 1 suggests, it means that the temperatures shown in Table 8 are likely to be obtained. Taking into account the temperatures obtained for the reservoir presented in Table 7 in the Longroiva sector, it can be assumed in this way, that the reservoir is at an approximate depth of 1200 m.

Table 8: Estimated temperatures (T) at different depths (D) for the granitic massif of Longroiva, based on the geothermal gradient observed in the AC1A borehole.

D (m)	0	50	100	200	300	400	500	700	1000	1200
T (ºC)	25.6	29.8	33.2	40.8	48.5	56.1	63.7	78.9	101.8	117.0

Another interesting element in the Longroiva sector is that over time the temperature has increased significantly as shown in Table 9. This is explained by the fact that initially there was a considerable exchange of heat between the water of the borehole and area adjacent to wall of the borehole. Also, the fact that the borehole is continuously exploited has caused the heating of the adjacent area and thus the fluid reaches the surface with temperatures more similar to those recorded at the bottom of the borehole. It should be noted that since the borehole was drilled (with T = 41 ºC) the water has increased ΔT = 6.4 ºC in about 13 years, being currently at 47.4 ºC.

Table 9: Temperature of the water of the AC1A borehole over time in the Longroiva sector since the borehole has been drilled (1999).

Data	1999/02	1999//04	1999/05	2000/10	2005/08	2007/08	2009/07	2012/0
T (ºC)	41.0	43.9	44.2	45.4	46.8	47.0	47.2	47.4

In order to further research the depth of the reservoir, the methodology proposed by Rybach was applied (1990). According to this author, thermo-mineral waters in deep circulation, such as the cases concerned, require models that explain the loss of heat from water as it is being brought to the surface. The models take into account the reservoir temperature (Tr) the discharge temperature (Ts), the discharge flow rate (Q) and maximum depth (Dr) of the hydrothermal-mineral circuit. The loss of heat is estimated base on one expression of the type: Tr-Ts = f (Q, Dr, Geometry). Introducing a dimensionless variable, θ, simplifies the mathematical calculation according to the expression (Rybach,1990):

$$\theta = (Ts-T_E)/(Tr-T_E) = f\,(Q, Dr, Geomety) \qquad (2)$$

where T_E is the average annual surface temperature in the region of ascent.

The models tested by Rybach (1990) apply to the geological context of the present work. There are two models: vertical pipe (cylindrical conduit) model and plane fracture (plane conduit) model.

Considering the results available from the main water points concerned and calculating the parameter θ (Table 10), using the suitable Rybach models, the results shown in Figure 11 are obtained, i.e., reservoir depth (maximum depth of the hydrothermal-mineral circuit) for: i) Longroiva, Dr ≈2000 m; Graben, Dr ≈ 2300 m; and Areola, Dr ≈ 2200 m.

In the case of Longroiva, it is important to mention that the Dr obtained is higher than the extrapolation based on equation 1 that points to approximately 1200 m. In economic terms the highest value should be taken into account but only a drilling with such a depth would allow more certainty.

As for the Dr for Graben and Areola being adequate, considering the reservoir temperatures and the other elements listed in Table 10 the temperature gradient for both locations is around 0.028 ºC/m. It would be interesting and useful if both locations could be drilled in order to determine these situations.

Table 10 – Parameters for calculation of the θ variable to estimate the depth reservoir of the mineral waters considering the thermodynamics models used by Rybach (1990), for the main thermal water points of the municipality of Meda.

Mineral water point	Q (L/s)	Ts (ºC)	Tr (ºC)	T_E (ºC)	θ
Longroiva- AC1A	6.30	47.4	113.2	13.3	0.341
Graben- CR1	0.28	19.8	78.9	13.4	0.099
Areola - NT	0.24	20.0	84.2	12.0	0.111

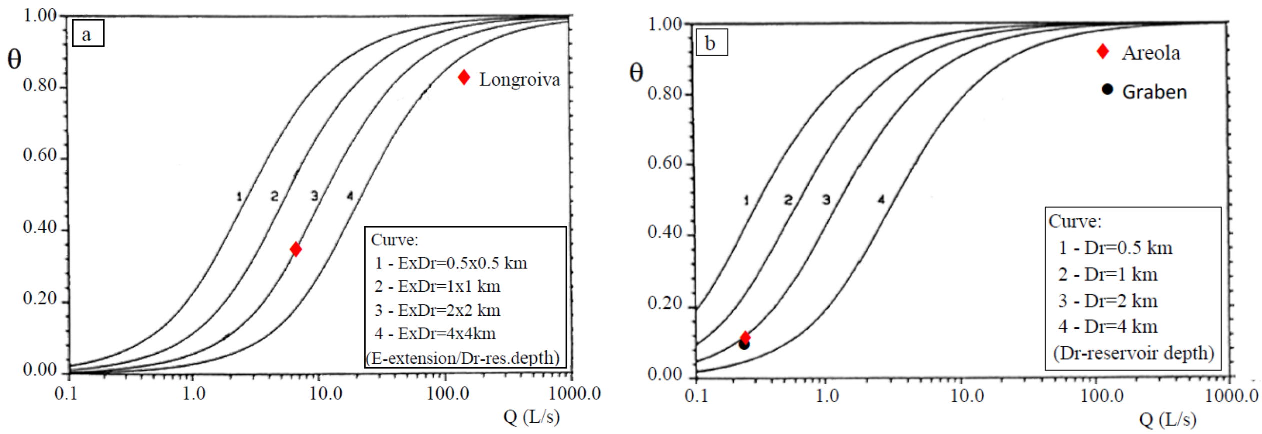


Figure 11: Diagram with master curves: a) for plane fracture (plane conduit) model for the Longroiva mineral water; b) for vertical pipe (cylindrical conduit) model for the Graben and Areola mineral waters (after Rybach, 1990).

6 CONCLUSIONS

The main conclusions of this work are the following:

i) three sectors with geothermal potential were identified in the municipality of Meda: a) Longroiva; b) Graben; and c) Areola; all of the above sectors occurring in granitic hercynian rocks. Large areas of these massifs occur upstream of the natural resurgences that are close to schistous rocks, in addition to the fact that there is a special structural setting with faults relatively deeps; the waters of these resurgences are sulphurous, bicarbonate-sodium, alkaline, with temperatures higher than the temperatures of common waters of the region;

ii) based on the geothermometers used, the reservoir temperatures (Tr) estimated for each sector are as follows:

Longroiva	Areola	Graben
Tr = 113.2 ºC	Tr = 84.2ºC	Tr = 78.9ºC

iii) according to Rybach (1990) model based on Tr, Ts (discharge temperature), T_E (surface temperature at the location of catchment), on Q (discharge flow rate), the reservoir depths (Dr) are estimated as follows:

Longroiva	Areola	Graben
Dr = 2000m	Dr = 2200m	Dr = 2300m

based on a 212 m probing carried out in the Longroiva sector, the local geothermal gradient is 0.0762 ºC/m, which if confirmed would lead to a Dr of 1200 m. This highly beneficial situation corresponds to a geothermal gradient higher that the mean value of the earth's crust (0.033 ºC/m) and is a consequence of the local unique geological and structural situation. Given the impossibility of determining the local geothermal gradients of the other sectors, they were estimated for the case the Tr and Dr mentioned in ii) and iii). Considering the temperatures of natural resurgence, the Graben and Areola have gradients of the 0.026 ºC/m and 0.030 ºC/m, respectively.

Finally, it is important that boreholes with 1000 m deep were drilled in the sectors concerned. Based on the results presented, we believe that there would be an increase in both the groundwater flow and in their temperature thus enabling low enthalpy geothermal uses. That would provide much needed economical benefit to the region of Meda which is eager to find new ways to consolidate the life of its citizens.

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