Subsidies on Geomorphological and Geological-Structural Elements for the Knowledge of Deep Aquifer Systems of Hot Sulphurous Groundwaters in the Meda Region (Portugal)

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Abstract

The Meda region is a territory in the interior of Portugal, made up of essentially rocky terrain of the Hercynian granite type and the ante-Ordovician schist type. The local population lives mainly from agriculture; only a small percentage lives from services, commerce, and other residual activities. The supply of drinking water to the population is provided from surface water, rainwater, stored in the Ranhados Dam, on the Torto River. The most common groundwater is essentially used for agricultural activities and is abstracted from surface aquifer systems, mainly in granite massifs, up to around 100m deep. The waters of these systems have hydrogeochemical characteristics typical of short underground circuits, shallow, with an acidic pH of around 6, total mineralization generally less than 300 mg/L, with the dominant anion being bicarbonate and the dominant cation being sodium and/or calcium. However, there are some occasional occurrences of groundwater, which although very rare, are very important due to their specific characteristics These rare groundwaters are sulphureous, with the presence of reduced Sulphur species, are alkaline due to their pH generally being higher than 8, have total mineralization between 300 mg/L and 600 mg/L, belong to the sodium bicarbonate facies, have significant concentrations of silica, with SiO_2 between 25.0 mg/L and 63.5 mg/L, have fluoride values higher than 10 mg/L, and also have the presence of carbon dioxide (total CO_2); present several trace elements with relevance to Boron (B), Rubidium (Rb), Strontium (Sr), Cesium (Cs), and Tungsten (W). There is also the particularity that the latter waters are warm, resurfacing to the surface at temperatures higher than normal in the region (≥ 15ºC), with the highest temperature at the Well AC1A of the Longroiva Medical Spa, with 47.4ºC. Geothermometer studies indicate reservoir temperatures of around 78ºC for Águas do Graben, 84ºC for Areola and 115ºC for Longroiva, which are the three main natural discharge sites for these deep aquifer systems. The potential use of these special waters is for thermalism activities and geothermal exploitation, as is already the case at the Longroiva Medical Spa. Therefore, in order to promote the exploration of those waters and new applications, it is necessary to know as accurately as possible the geohydraulic model of the circuit of those waters, and the geomorphological and geological-structural aspects are absolutely central to this process. So, this article, after a brief introduction, presents the main geomorphological and geological-structural characteristics of the region and explains the various details that led to the compartmentalization of the region into three potential exploitation poles: Longroiva Medical Spa, Areola Medical Spa, and Águas do Graben. Finally, some conclusions and final notes are presented on proposals for new studies to support detailed knowledge of the geohydraulic models of each Pole and other potential locations to explore water from the deep aquifer system.

Keywords: *Deep aquifer, Hot groundwaters, Geological-structural elements, Geohydraulic models*

1. Introduction

The city of Meda is the seat of the municipality which has a global area of 286 km2, a total population of 4630 inhabitants, with around 1987 inhabitants residing in the city itself, with emphasis on the trend in recent years of decreasing population. The main activity is agriculture, and this alone cannot motivate people to settle down, and thus reverse the decline in the population, which currently has a population density of just 16.2 inhabitants/km2, in relation to the municipality total [1]. Tourism is an activity that is beginning to take off and is on the rise. In this sense, it is understood that if the special sulphurous groundwater that occurs in this territory is harnessed [2,3], it could result in flourishing activities in the field of thermalism, the wellness sector, aqua-ludic activities and others, which will help to stimulate tourism. There are three poles with natural springs of the sulphurous water type (Figure 1): the Longroiva Medical Spa Pole, the Areola Medical Spa Pole, and the Águas do Graben Pole.

On the other hand, those sulphurous water have geothermic potential [4], if they are captured at depth, being able to reach temperatures that will allow geothermal uses, a situation that also favors thermalism activities, like the entire region, with the use of energy alternative to fossil fuel energies that are currently predominant. In particular, the buildings that support thermalism and neighborhood hotels could be heated, in addition to heating their domestic hot waters, boosting these activities throughout the year, at more modest costs, given that winters in this region are slightly harsh. It should also be emphasized that for the Longroiva zone, there is even the potential to produce electricity from very hot sulphurous water, provided it is captured at great depth, at temperatures of around 115ºC [5].

In order to make the resource available in quantity and at a temperature that makes compensatory investments possible, it is necessary to make new abstractions, which, when they reach the depth of the theoretical reservoir, around 2 to 2.5 kilometers, will make it possible to reach temperatures of around 78ºC, 84ºC and 115ºC, for the Águas do Graben, Areola, and Longroiva poles, respectively [6,7]. Rigorous knowledge of the hydrogeological model of those waters is fundamental, not only to estimate the available water reserves, such as the flow rates to be exploited and the expected temperature, but also to optimize the appropriate location for the new boreholes/wells, by that, the knowledge of the geomorphological and geological-structural elements is important in this regard. Therefore, the objective of this article is to present the geomorphological and geological-structural elements that are understood to be fundamental in conditioning the hydrogeological models of the various thermal poles in the municipality of Meda.

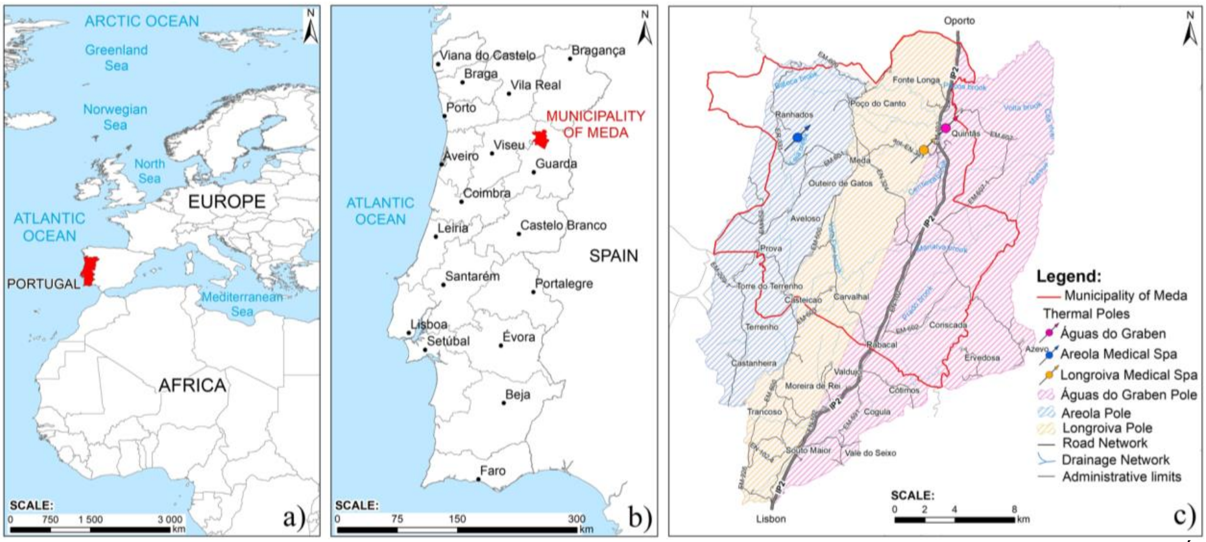

Fig. 1. Geographical context of the Municipality of Meda (a,b), and location of the resurgences of the three thermal poles: Águas do Graben, Areola Medical Spa, and Longroiva Medical Spa (c).

2. Methodological Aspects

This article is part of an extensive research project, the main objective of which was to contribute to the knowledge of the hydrogeological models of the waters of the deep aquifer system in the municipality of Meda [6]. Overall, it involved a very broad methodology, and it should be noted that after an initial part of bibliographical research, fieldwork followed, with geological mapping and the collection of rock, groundwater, and rain samples to be analyzed in laboratories, followed by the processing of the results. In processing the results, the graphic presentation of the various elements was fundamental, as well as the creation of numerous maps, namely those with geomorphological and geological components, presented in this article. To obtain those maps, topographic bases were used at various scales [8-10], using various software, namely ArcGIS [11].

3. Results

The main results used in this article are organized into essentially graphic and cartographical information, in the following areas: geomorphological, geological-structural, and hydrogeological aspects. Below they are presented in a synthetic way, however, those aspects are developed in detail in the work of Coelho-Ferreira [6], and with sectoral situations, in several works already published [2-5, 12-14].

3.1 Geomorphological Aspects

As a starting point, there is the site of the resurgences or springs, which are the natural discharge points for sulphureous waters (Figure 2): SA, SL e SG. In the past, the springs at Longroiva Medical Spa and Areola Medical Spa were used for thermalism activities, using the flow rates of the resurgences, which were less than 0.5 L/s.

That flow rate was sufficient according to the requirements of the time. Meanwhile, in the case of Longroiva, hydrogeological prospection work and subsequent studies [15-17] have recently shown that from a well (Well AC1A) drilled near the old spring, it is possible to obtain artesian sulphurous water with a flow rate of 6.3 L/s. That flow rate, which is constant throughout the year, has already made it possible to build a bathhouse that complies with current regulations [18]. The aim of these studies, as already mentioned, is to contribute to the knowledge of the hydrogeological model of each pole, but it should be noted that this is fundamental for the successful construction of new wells, to increase the potential of Longroiva and launch the other poles.

In a normal situation, after recording the locations of natural springs, on topographic maps, the boundaries of the hydrographic basin associated with these springs are delimited, particularly upstream of them. If the terrain were homogeneous, based on the basin boundaries, the water recharge for depth could be easily calculated, and new wells would be located with some ease, looking for lower altitude areas.

However, in the region under study, there are rock masses with immense heterogeneities, including extensive faults and veins, which can result, respectively, in barriers or conduits for underground flows and consequently, there are transfers of groundwater between hydrographic basins.

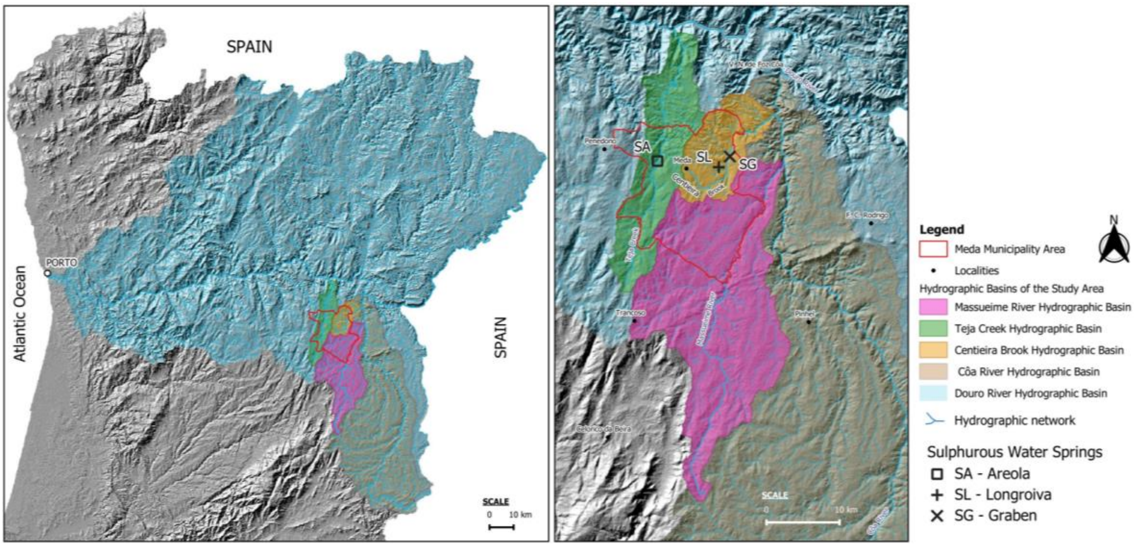

Fig. 2. Framing of the hydrographical basins of the study area in relation to the main places of natural discharge of water from the deep aquifer systems in the Meda region: S_A- Areola, S_L- Longroiva, e S_G – Graben.

Therefore, to try to clarify these situations in the region under study as best as possible, Figure 2 shows the hydrographic basins associated with the three thermal poles. It should be noted that the sub-basins of the study sites are integrated within the Douro River Basin, which is an international river that begins in Spain and with its mouth in the city of Porto, Portugal. It can be seen that SL and SG both belong to the Centieira Brook basin, but it should be noted that they are located in small sub-basins geomorphologically separated from each other. SL is associated with a small watercourse that converges with the Centieira Brook on the left bank, while SG occurs in a very small watercourse too, but it converges with the Centieira Brook on the right bank. SA is near the right bank of the Teja Creek. The Strahler classification [19] for the SA site is 6, while for the SL and SG cases it is only 3. The altitudes for the SA, SL, and SG cases are 550 m, 370 m, and 280 m respectively. It should be noted that the maximum altitudes, which occur south of the basins, are around 800 m for the Centieira Brook case, and around 980 m for the other cases.

The Figure 2 also shows other sub-basins, namely the Massueime River, and even outside the territory of the municipality of Meda, since, as will be shown later, the recharge zones occur mainly in the same area, and there are clearly transfers of groundwater between basins. Table 1 shows the main geometric characteristics of the main hydrographical basins. It is worth noting that the Centieira Brook basin, with two sulphurous water springs, has the smallest area.

Tab. 1. Geometric characteristics of the main hydrographic basins that are related to the deep recharge of the aquifer systems that supply the thermal poles in the municipality of Meda.

Parameter	Units	Teja Creek	Centieira Brook	Massueime River
Area (A)	km^2	201.6	112.1	524.4
Perimeter (P)	km	95.4	54.9	151.5
Maximum watershed length (L)	km	36.5	17.3	47.8
Maximum watershed width (W)	km	8.4	9.7	22.4
W/L ratio	-	0.23	0.56	0.47
Main channel extension (l)	km	49.5	26.0	61.9

3.2 Geological-Structural Aspects

The geological map of the region studied is shown in Figure 3. From the outset, it is important to say that although the target of the study was the municipality of Meda, it was understood from the outset that in order to understand the aquifer systems that supply the sulfurous waters that resurface in the municipality's territory, it would be necessary to study wider regions, therefore, outside the municipality of Meda, namely to the south, near Trancoso, in areas of higher altitude, particularly in the Teja Creek basin, in the case of S_A. According to the studies carried out, with the main support of the geological map of Portugal, at 1/50000 scale [20], complemented by the elements of the Map at 1/500000 scale [21], in addition to the fieldwork, in the study region, the following geological units occur, from the oldest to the most recent:

. CXG - Schist-Greywacke Complex, made up of schist rocks of various types of Cambrian age (De, Pi, Ri);
. γ - Granitic rocks, of Hercynian age (γGπg, γmt, γg, γπm, γ´g, γ´m,γ´f, γ´Δ, γI1);
. γ_F - Philonian Rocks, late and post-Hercynian (γμ, q, γa. γp, TT);
. T - Very consolidated sedimentary deposits, of the Tertiary (QP, vi);
- Q - Sedimentary deposits, of the Quaternary (a, v).

It is emphasized that it is the Granitic Rocks unit (γ), which is most representative in the study area, and on the other hand, sedimentary deposits (Q) are almost non-existent. It is worth highlighting the occurrence of the extensive faults that cross the region, especially the Vilariça Fault (VF), which divides the study area into two large blocks. That fault, with a global direction of NNE-SSW, is characterized by being a strike-slip deformation structure, with about 5.5 km of horizontal displacement and that triggered a parallel fracturing in a range of 0.5 to 1km wide, which with the unevenness of the extreme blocks and subsidence of the central block originated the Longroiva Graben - LG [22], essentially filled by arkoses (vi) of the Unit T. It's important to mention the uniqueness of the occurrences of sulphurous water springs in the granites (γ), but with the CXG formations nearby, on the downstream side (Figure 3b,c,d), i.e. on the side with the lowest altitude. Those springs occur for several reasons; one is the proximity of the CXG formations, which have a much lower permeability than granites and act as a barrier to underground flows from granites at higher altitudes. Another reason is that they are associated with very long fractures, which cut across large areas of the territory and cross several sub-basins, favoring underground flows coming from far away. From Figure 3a, the situation associated with the S_L pole is more evident, where the CV-MF Fault in higher altitude areas to the south, evolves to the NE, leading to the LF Fault, which passing over SL, continues to the NE to the CXG formations. The notion of this type of situation is reinforced by the observation of Figure 4, particularly in the strip of the central zone, with a global direction of NE-SW, between the CV-MF fault and the C-CF fault; as a whole, this territory functions as a system of fractured rocks that favors the evolution of underground flows through various sub-basins, naturally converging towards S_L. Figure 4 also shows that there are three large families of faults, being the most extensive, one of the most frequent, and with a global direction of NNE-SSW.

A detailed survey of the various fractures at a local level, in the area of each sulphurous spring and nearby surroundings, led to the results shown in Table 2. From those results, it is observed that fractures with a global NNE-SSW direction continue to occur in the vicinity of the springs, being associated with evidence of regional tectonic movements, which are understood to be harmonized with the movements of the great main fault, the Vilariça Fault (VF), which continues to be active at present.

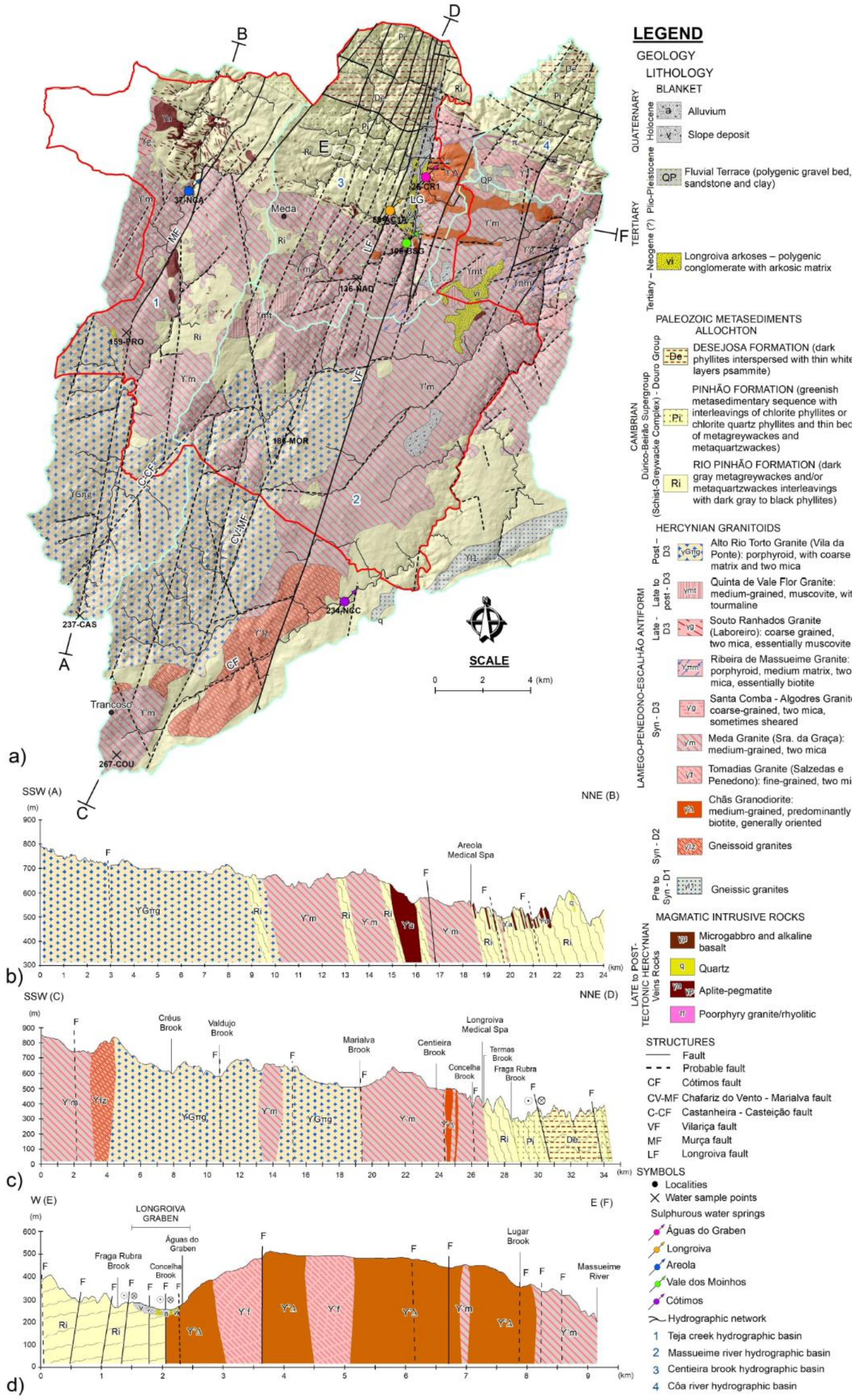

Fig. 3. Simplified geological map (a) and some geological sections, passing through the area of the sulphurous springs: S_A (b), S_L (c), and S_G (d).

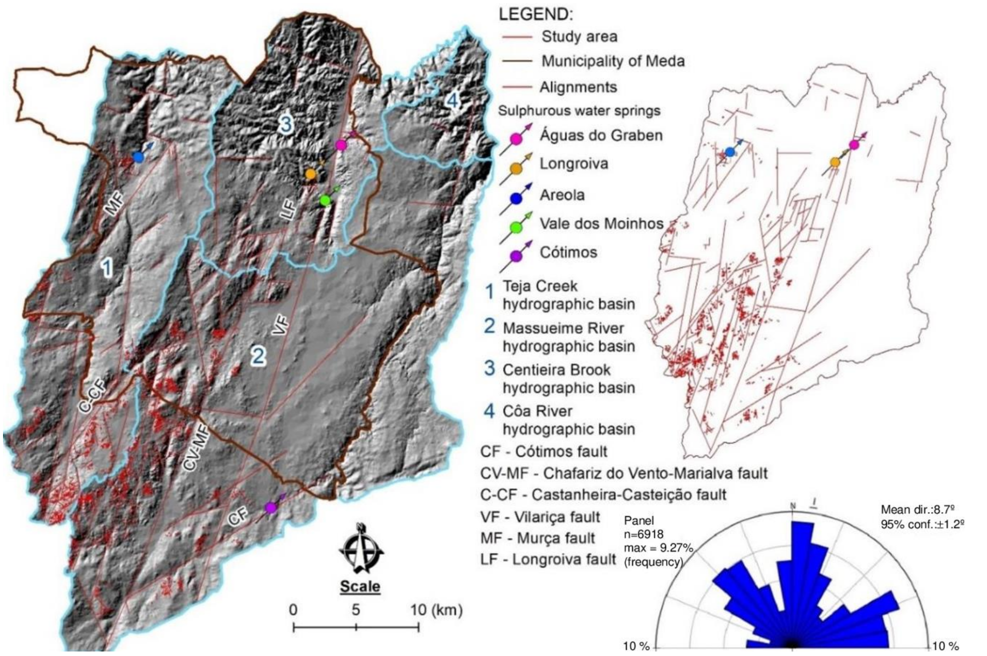

Fig. 4. Map of the main lineaments in the area under study.

Tab. 2. Synthesis of the local fracturing of each thermal pole under study.

Thermal Pole	Group	Direction	Inclination	Occurrence	Observations
S_A	F1	NNE-SSW	77ºNW	+++	Left-lateral strike slip; occur near thermal springs.
	F2	NNW-SSE	64ºWSW	++	-
	F3	ENE-WSW	75ºSSE	+	-
S_L	F1	NW-SE	70ºNE	+++	Shear zones with flower structures.
	F2	NW-SE to NNW-SSE	80ºSW-WSW	+++	-
	F3	NE-SW	80ºSE	++	-
	F4	NNE-SSW to NE-SW	70ºNW	+++	Left-lateral strike slip; occur near thermal springs; Shear zones with flower structures.
	F5	E-W	80ºN	+	Existence of left movement striations.
S_G	F1	NW-SE	75ºNE	++	Extensive fractures; they are associated with centimetric to decimetric shear structures.
	F2	NNE-SSW to NE-SW	65ºNW	+++	Vertical movement, of the normal type, producing steps descending from E to W along the brook.
	F3	NNE-SSW to NE-SW	65ºSE	++	-
	F4	N-S	≈ 90º	+	-

a) + infrequent, ++ frequent, +++ very frequent

According to some authors [22, 23], the VF, known globally as the Manteigas-Vilariça-Bragança fault, is one of the great tectonic structures of NE Portugal; it corresponds to a left-handed strike-slip fault, with a NNE-SSW direction and an approximate length of 220 km, and in the central segment of Vilariça the maximum value of 9 km of strike-slip is reached, the result of several phases of movement from the Variscan orogeny to the present day, of which 1 km is attributed to the upper Pliocene to Quaternary.

Based on the global tectonic elements available for the Eastern Trás-os-Montes region [23], where the region under study is included, Figure 5 shows the regional stress system and the kinematic behavior of the main fracture families, as well as a block diagram with the orientations of the main fracture families and the movements of the faults according to the current stress system. It is noteworthy, in particular, the existence of Fractures (1) strike-slip fault and (3) reverse fault, which together are admitted to favor the resurgence of underground flows, namely through reverse faults.

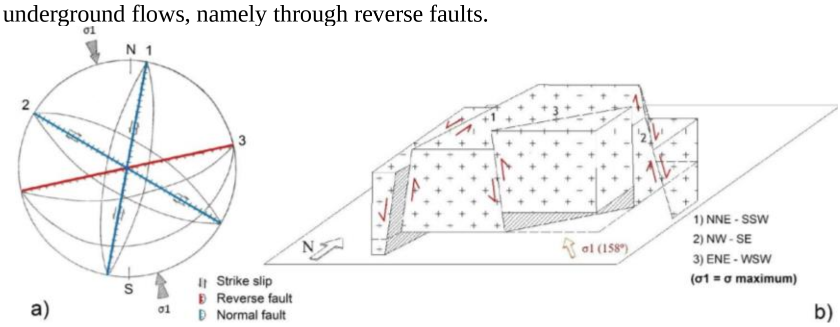

Fig. 5. Structural elements of the region under study: a) stress system and kinematic behavior of the main fracture families in eastern Trás-os-Montes; b) diagram block with the orientations of the main fracture families and the movements of the faults according to the current stress system.

3.3 Hydrogeological elements

Various hydrogeological studies have been carried out at various stages in order to get to know the aquifer system associated with each of the 3 main sulphurous water springs in the municipality of Meda. Table 3 shows the basic physical parameters that characterize the water from the main sulphurous water abstraction at each Pole.

Priority was given to studying the SL situation in detail, for political reasons, to try to legalize the resource for thermalism applications, as has already been mentioned, resulting in various works in the 1990s [15-17], including the Well AC1A, with a flow rate of 6.3 L/s, in artesian use.

Due to the quantity and quality of groundwater obtained, it was quickly certain that the water from Well AC1A could not have originated from precipitation in the small hydrographic basin where it is located, which is only grade 3 in Strahler's classification [19]. Thus, the key to the issue in the first phase was to analyze the relationship between the main fractures and the global geomorphology, leading to a global study area much larger than the municipality of Meda itself, as shown in the various maps in the various figures presented. In that global territory, with a total area of 258 km2, a survey was carried out of the main underground water points (holes, wells, perennial springs, mines, and others) with a total inventory of 286 points, with records of basic physical parameters, such as those shown in Table 3, and presented in great detail in some works [3,6].

Tab. 3. Physical-chemical parameters of the main emergencies in the poles under study.

Parameter	S_L Pole Well AC1A (ID-59)	S_A Pole S_A (ID-37)	S_G Pole Well CR1 (ID-26)
Artesian flow - Q (L/s)	6.30	0.24	0.28
Temperature - T (ºC)	47.4	20.0	19.8
pH	8.40	8.22	7.77
Redox Potential- Eh (mV)	-141.2	-128.6	-101.7
Electrical Conductivity - C (μS/cm)	589.4	407.0	615.0
Total Mineralization - M_T (mg/L)	551.7	376.4	565.8

From the various studies carried out, and crossing geological elements, it was possible to systematize in hydrogeological terms, the following units:

- Unit Al: alluvial aquifers, of the porous type, free, and associated with the drainage network, almost without expression, due to their small thickness (< 8 m), essentially of interest for local subsistence agriculture.

- Unit G_{sup}: shallow granitic aquifer systems; they are associated with granitic rocks in the uppermost approximately 100 m, being essentially of the fissure type, but sometimes also of the porous type, in zones with a greater degree of weathering; these aquifer systems are of the free type, and sometimes constitute interesting bodies of water, used essentially for agriculture and human consumption.

- Unit G_{depth}: deep granitic aquifer systems; they are associated with granitic rocks, in zones with depths greater than 100 m, and with associated veins, with circulations at depths generally greater than 1 km, which discharge superficially in some cases in springs due to the geological-structural framework. These aquifer systems are of the fissured type, semi-confined to confined, and have unique waters, corresponding to the groundwater that is the subject of this article. The use of these waters, when properly used, is within the scope of thermalism and geothermal, and, in places that are not explored in those applications, they are used in agriculture.

- Unit CXG: Shale aquifer systems, being of the fissured type and essentially of the free kind; although occasionally, they allow abstractions to be obtained with some productivity, in the proximity of G_{sup} and G_{depth} they function as a barrier, constituting an aquiclude.

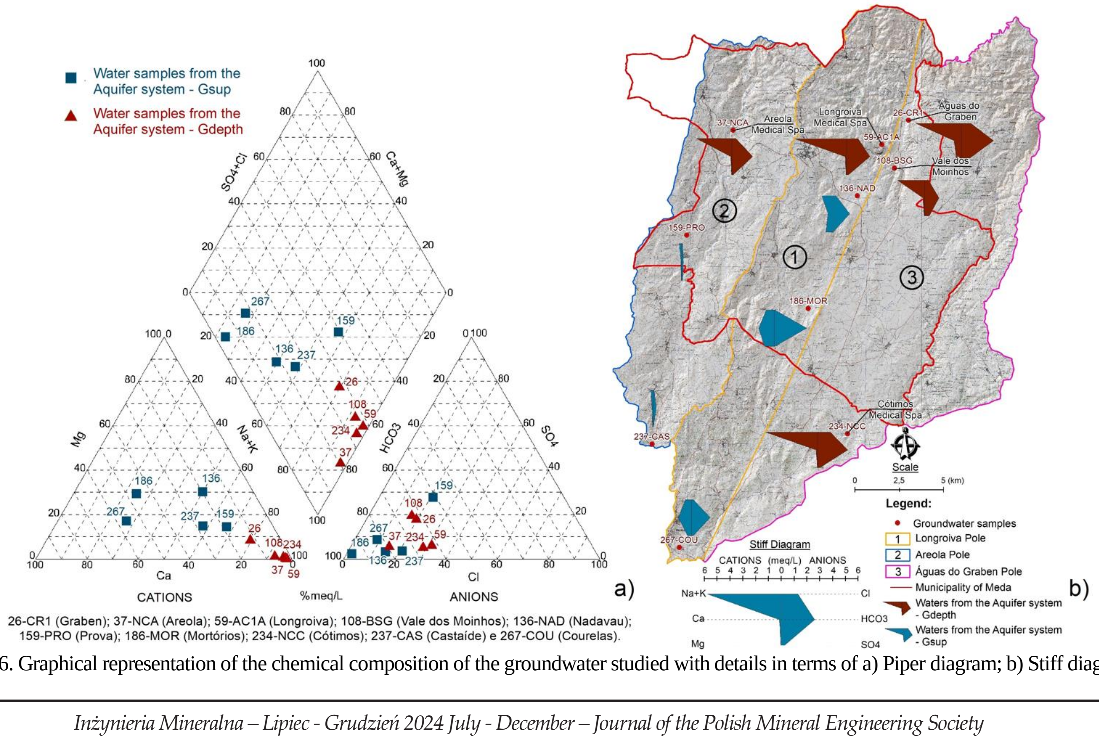

Fig. 6. Graphical representation of the chemical composition of the groundwater studied with details in terms of a) Piper diagram; b) Stiff diagram.

To get to know the granite aquifer systems as best as possible, 10 samples of groundwater were selected, namely those that were certain to be sulphurous, to be analyzed in chemical terms in detail. The main results are presented in Figure 6 in terms of Piper and Stiff diagrams. From Figure 6, without any doubt, it can be seen that the waters of S_A, S_L, and S_G and also the waters of Vale dos Moinhos (S_M) and Cótimos (S_C), already in the neighboring municipality (Trancoso), show a lot of similarity, being It should be noted that they are all sulphurous, as they even present the occurrence of Total Sulphuration (I_2 0.01N), with values of 40.3, 9.0, 12.0, 6.1, and 17.6 mL/L, for water from S_L, S_A, S_G, S_M, and S_C respectively. The S_M water that occurs in a very small resurgence is thought to have some mixture of surface waters.

Thus, considering the waters of S_L, S_A, S_G, and S_C, they are all very rich in Sodium ion (Na^+ > 89 mg/L). When analyzing in detail the various major elements [6] it appears that there are some differences between them, with S_G water being the one with the highest total mineralization (M_T= 507 mg/L), the one with the most bicarbonate (HCO_3^-= 231mg/L), and less Fluoride (F^- = 10.4 mg/L), with the particularity of the latter (S_G) having Ca^{2+} (16.1 mg/L) and Mg^{2+} (6.7mg/L), while the others only present for these elements residual values.

On the other hand, all those sulphurous waters contain some trace elements, namely Boron (B), Cesium (Cs), Rubidium (Rb), Strontium (Sr) and Tungsten (W), with the particularity of S_G water having a higher content of B (381 µg/L), Sr (191 µg/L) and W (169 µg/L, and S_L water has a higher content of Cs (128 µg/L) and Rb (84 µg/L). There is also the uniqueness of S_G water being the only sulphurous water that registers Zn at 7.7 µg/L.

Detailed analyzes of its chemistry, including multivariate statistical studies, commonly called Principal Component Analysis [24], led without any doubt to state that in the granite rocks of the area under study there are two distinct aquifer systems, as previously stated, the G_{sup} and G_{depth}. The G_{sup}, generally up to a maximum depth of 100 m, with waters typical of short, shallow underground circuits, with an acidic pH around 6, M_T generally below 300 mg/L, with HCO_3^- as the dominant anion, and Na^+ and/or Ca^{2+} as the dominant cation. G_{depth}, constituting aquifer systems whose waters have reached great depths in their path, generally more than 1 km, with very extensive paths, eventually emerging in very specific geological-structural contexts, locally forming aquifer zones even at small depths. G_{depth} waters are sulphurous, with the presence of reduced sulphur species, alkaline due to their pH generally being higher than 8, have M_T between 300 mg/L and 600 mg/L, significant concentrations of silica (SiO_2) between 25.0 mg/L and 63.5 mg/L, have the presence of carbon dioxide (total CO_2), and belong to the sodium-bicarbonate facies. The latter is also hot, emerging to the surface at temperatures higher than normal in the region (15ºC), with the highest temperature in Well AC1A, at 47.4ºC.

Detailed studies using geothermometers [4,6] show that all the sulphurous waters under study have long depths and high reservoir temperatures; the highest temperature was obtained for S_C water (115.5°C), followed by S_L water (115.4°C), S_M water (108.8°C), then S_A water (83.7°C) and with the lowest value S_G water (78.2°C).

Isotopic hydrology studies (^{18}O and ^{2}H) applied to the G_{depth} waters [6] showed that they have a meteoric origin and entered the underground system at altitudes of the order: 770-809 m for the S_L Pole; 591-715 m for the S_M waters; 803-808 m for the S_A Pole; 727-769 m for the S_G Pole; and 671-702 m for the S_C water.

These latest studies, both of geothermometers and isotopes, definitively point to the recharge of meteoric waters over great distances and at altitudes much higher than those of the discharge zone, leading to the systematization of the study territory into three poles, generically organized as shown in Figure 1c. The following elements were fundamental in this systematization (see Figures 3 and 4):

i) positioning of the Vilariça Fault (VF) with a global direction of NNE-SSW, which due to its characteristics is admitted to be very thick, with clayey filling, and impermeable, leading to independent underground circulations to occur to the east and west of the same;

ii) positioning of the CV-MF and LF faults system, also with a global direction of NNE-SSW, converging directly with S_L in Longroiva; this structure, globally, will have a role that favors the evolution of fluids from south to north, and in particular those coming from its western sector, including the territory upstream of the Teja Creek hydrographic basin, in the higher altitude zones, up to the C-CF fault (see Figure 4).

Thus, the most complex case is the definition of the territory that contributes to S_L, which generally corresponds to the strip between the VF Fault and the C-CF Fault (with continuity through the ridge zone of the Teja Creek hydrographic basin). It is admitted that very detailed studies for the future will constitute the territory between the VF and CV-MF faults, as a new pole of the Vale dos Moinhos spring (S_M).

Concerning the territory that contributes to S_A, the situation is simpler, as it generically corresponds to the Teja Creek hydrographic basin, excluding the most upstream territory, the East of Fault C-CF, which, as shown above, is included in the S_L Pole.

Regarding the territory that contributes to SG, it is clearly east of the VF Fault up to the ridge zones at the limit of the Centieira Brook, in addition to including some plateau areas of the Côa and Massueime rivers hydrographic basin.

It should also be noted that in hydrogeological terms, there is the Cótimos Sector, clearly marked by the CF Fault (Figure 4), but because it is outside the municipality of Meda it has not been the subject of detailed studies.

4. Conclusions

The main conclusion is that the municipality of Meda has three main poles of potential exploitation of special groundwaters, of the sulphurous type and potentially very hot, which, in addition to thermalism activities, aquatic recreational and wellness uses, could allow for energy uses in the future, since the utilization of heat to the production of electricity, depending on the temperature to be obtained in new abstractions. The poles in question are: The pole associated with the Longroiva Medical Spa, the pole associated with the former Areola Medical Spa, and the pole associated with Águas do Graben. These studies leave open the possibility of a new pole in the future, in the area associated with the Vale dos Moinhos spring, near the southern end of the Longroiva Graben. These studies also point to interesting potential, in the same sense, in the Cótimos zone, but already in the neighboring municipality (Trancoso).

Knowledge of the geohydraulic model of each pole is fundamental to assessing the available water and geothermal reserves, as well as to locate the position of new abstractions for the exploitation of the resource. To do this, it is very important to know in detail the water recharge zones. Knowledge of the occurrence of several extensive fracture systems that intersect various hydrographic basins, in harmony with the geomorphology of the territory, are absolutely fundamental to understanding these models. In the present work, several results are presented to structure the territory associated with each pole, however, it will be important in the future to have studies in the field of deep geophysics and others to map the rigorous position of the various fractures. Studies on isotopic hydrology extended to the various waters of the region will also be important to consolidate and refine the elements already advanced on the recharge territories of the deep aquifer systems.

Finally, how important it would be to carry out deep mechanical drilling work, to refine the knowledge of the productive zones of the excellent resource, which are the hot sulphurous waters of deep granite aquifer systems.

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