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Origin of highly mineralised waters in a semi-arid area of the South Portugueses Zone (Portugal)

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ORIGIN OF HIGHLY MINERALISED WATERS IN A SEMI-ARID AREA OF THE SOUTH PORTUGUESE ZONE (PORTUGAL)

António Chambel¹ and Carlos Almeida²

¹Department of Geosciences, University of Évora, Apart. 94, 7001 Évora codex, Portugal

²Department of Geology, University of Lisbon, Edif C2, Campo Grande, 1700 Lisboa, Portugal

ABSTRACT

Part of southern Portugal is included in a geo-structural domain consisting of metamorphic rocks of Hercynian age, known as South Portuguese Zone (SPZ). The Pyrite Belt, one of the geological units of the South Portuguese Zone, consists of low metamorphic rocks that have evolved from sedimentary and volcanic rocks containing massive sulphides. It is composed of alternating decimetric to metric layers of acid and basic volcanic rocks, shales, graywackes, quartzowackes, siltstones, pelites, quartzites, sandstones, rare conglomerates and limestones.

The groundwater, in the South Portuguese Zone, has a deficient quality, presenting high values of electrical conductivity, reaching 20,000 $\mu\text{S}/\text{cm}$, with Sodium-chloride as dominant hydrogeochemical facies. The origin of this high salt content may be related to the migration of connate waters due to tectonic stresses. The deep mineralized waters would ascend mainly through the highly fractured rocks of the Pyrite Belt.

The increase of water mineralisation towards depth and some ionic ratios, e.g. Cl/Na , Cl/Li , and Cl/K observed in a pyrite mine in the Pyrite Belt are consistent with that hypothesis. A reverse trend in mineralisation can be observed in certain areas, where spring waters and waters produced by large diameter wells can be two to four times more mineralized than waters produced from wells ranging from 30 to 100 meters deep. This is probably associated with high rates of evapo-transpiration allowing an abnormal concentration of salts on the upper layers of the soil.

INTRODUCTION

The study presented on this article is based on two investigation projects with the overall co-ordination of the "Co-ordination Commission of Alentejo Region", a regional agency of the central government, supported by National and European Community funds. The aim of these projects is to provide a better understanding of the groundwater resources and create instruments that will allow the proper management of the water resources and improve the territory administration.

The *Study of Groundwater Resources of the Alentejo Region*, is the most important of the two projects which involve a region corresponding to a third of the Portuguese territory. This \$2,000,000 USD project started on the fourth quarter of 1996 and will continue to 1999 and has been executed by 4 regional and national entities, including the University of Évora. The other project, *Groundwater of Mértola Region*, a \$220,000 USD project, occurred between 1991 and 1994, under the technical supervision of the University of Evora.

GEOLOGY

The Iberian Massif, an important part of the Iberian Peninsula, consists mainly of metamorphic and igneous rocks of Precambrian and Palaeozoic age, partially covered with more recent sediments. Occurring by the end of the Palaeozoic times, the Hercynian Orogeny molded the geo-structure of this massif, resulting on a NW-SE orientation of the geological and geo-structural features. The Hercynian compression created several domains identified in figure 1 with the southernmost of these domains being the South Portuguese Zone (SPZ), located in south-eastern of this overall structure and corresponding to the southern part of Portugal and part of the south-west of Spain.

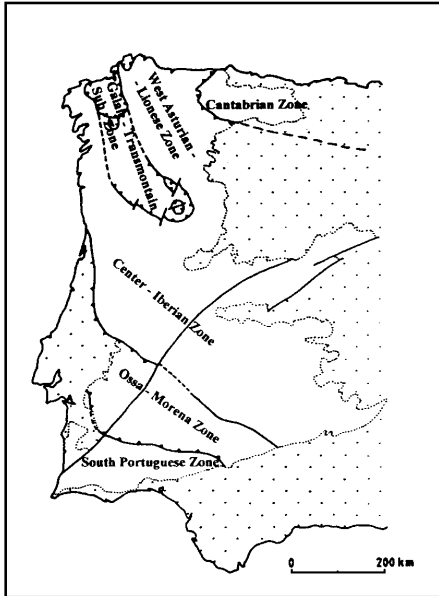


Fig. 1- Sub-divisions of the Iberian Massif according to Lotze (1945), Julivert *et al.* (1974) and Ribeiro (1979).

According to the geo-dynamical model of the Hercynian Chain evolution, Bard *et al.* (1980) defined the SPZ as an intra-continental basin, formed by the collision of the "middle Europe" and "North Europe/South Iberia" continents accompanied by the closing of a Palaeozoic ocean just North of the SPZ. The SPZ lies over the continental crust of the "North Europe/South Iberia" continent and consists of metamorphic rocks which derived from the upraised and compressed sedimentary and volcanic rocks during the orogeny in sequence of the collision of those continents. Therefore, in the SPZ, the rocks are more recent from north to south.

The collision was oblique and created an important left shear zone that forced, by transtension, the opening of grabens and the bimodal volcanism of one of the units of SPZ, the Pyrite Belt (fig. 2). This geological unit consists of original sedimentary and volcanic rocks containing massive sulphides. It is composed of alternating decimetric to metric layers of acid and basic volcanic rocks, shales, graywackes, quartzowackes, siltstones, pelites, quartzites, sandstones, rare conglomerates and limestones and other types of rocks.

North of the Pyrite Belt is the Pulo do Lobo Sub-Zone, the oldest of all the units of the SPZ, consisting of phyllites, quartzites and some levels of acid and basic

volcanic rocks. South of the Pyrite Belt there are the most recent sediments of the SPZ, a turbiditic sequence corresponding to the Baixo Alentejo Flysch Group.

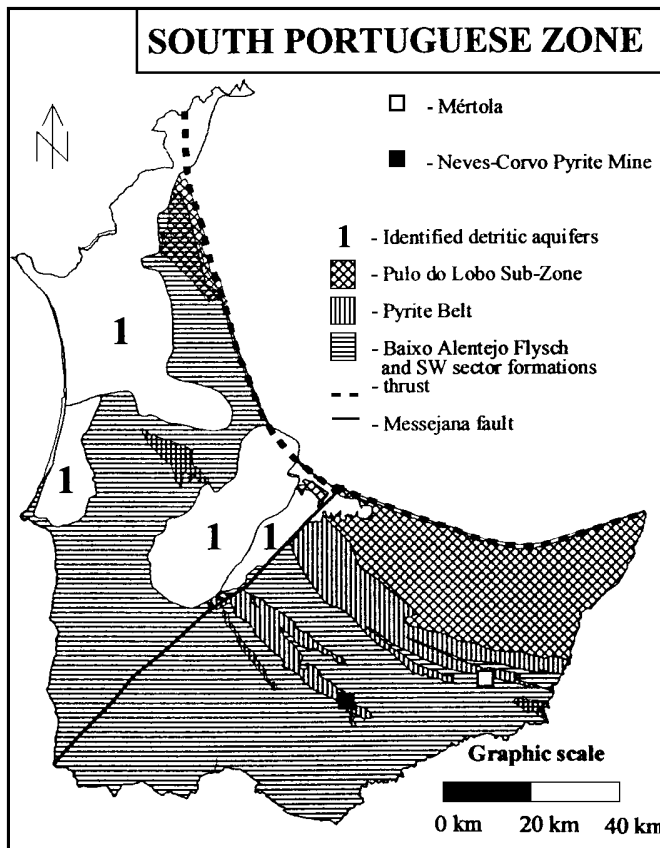
With great diversity of high competent rocks, the Pyrite Belt is the domain more affected by tectonic forces. The results can be seen both in the field and in the existent detailed geological cartography.

CLIMATOLOGY

In Portugal, the SPZ is characterized by semi-arid climatic conditions, with the exception of the western coast, which is considered to be a sub-wet area. The annual mean precipitation in the continent's interior, the eastern part of the figure 2 map, can go as low as 450 mm and rarely surpasses 600 mm (considering a sampling period of 40 years), with the precipitation occurring mainly during winter. The graphic in figure 3 shows that in the town of Mértola (see location in figure 2), more than 75% of this 455 mm of precipitation mean occurs in only six months, between October and March.

The high temperatures occurring during summer, sometimes over 40° C, give raise to very high values of potential evapo-transpiration, surpassing 700 mm, mainly during the period from July to September.

Fig. 2. The three major set of units of the South Portuguese Zone in Alentejo (Base: Geological Map of Portugal at scale 1:500000).



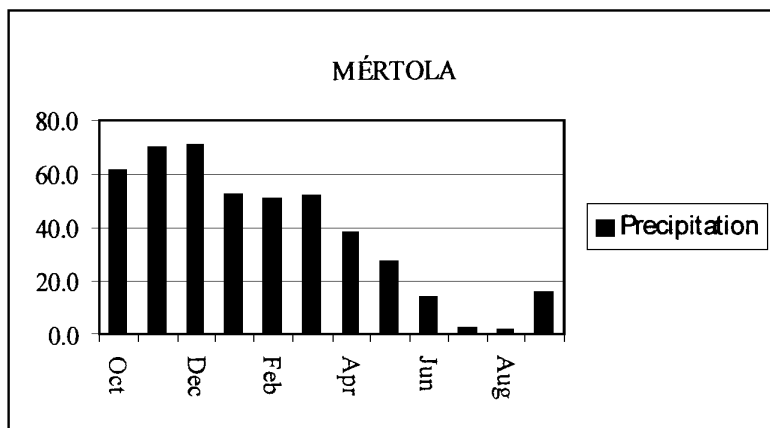


Fig. 3. Precipitation distribution (mm) for a period of 40 years in the town of Mértola, Southeast Alentejo.

HYDROGEOLOGY

The rocks representative of the described geological settings are characterised by low permeability but the structural characteristics of the Pyrite Belt allows higher values. In fact the massive sulfides mine of Neves-Corvo (see location in figure 2) developed in the 80's suffered severe problems with huge amounts of water due to the excavation of the access decline. Considering that the mineralised masses are located 300 to 700 meters deep, it was initially assumed, that the metamorphic rocks were

sufficiently impermeable to avoid water problems during the excavation. Subsequent investigation proved that the induced infiltration, created by the lowering of the levels, can represent important losses for superficial streams (Fernández-Rubio and Carvalho, 1993; Fernández-Rubio *et al.*, 1994). The Oeiras river, that passes nearby, lost 40 to 50 m³/hour in dry periods and much more in rainy periods, albeit not quantifiable (Fernández-Rubio *et al.*, 1994).

The conceptual hydrological model applied to this area could probably be used in the overall of the SPZ. Taking into account the lithological, structural and hydrogeological differences between the different units (Fernández-Rubio and Fernández Lorca, 1985, 1987, 1990; Fernández Rubio *et al.*, 1988; Carvalho *et al.*, 1990) three systems are proposed: (1) a superficial water table aquifer on a weathered and fractured zone in the first 50 meters, (2) a intermediate one, characterized by low permeability, but with widely spaced vertical fractures that, with the lowering of the levels, can function as high conductive channels and (3) a deeper system, related with highly fractured pyrite masses and involving rocks. When the access decline intersect the deeper system, the change of the hydraulic head leads to the interaction of all three systems proving that even the low permeability intermediate system can be of extreme importance as a channel connecting upper and deeper systems. In places where the mineralized masses are absent only the first two systems will be present.

A striking feature in some areas of the SPZ, seen in area of Mértola in the Alentejo province (fig. 4), is the high concentration of dissolved salts (Chambel, 1996; Chambel and Almeida, 1998). Among the three geologic units, that can be identified in this region, the Pyrite Belt is the one whose waters are most mineralized. Table 1, shows some statistics of the electrical conductivity (EC) of water from the three geological units. It can be seen that the median and mean in the Pyrite Belt reach more than twice the values of the same statistics in the Pulo do Lobo Anticline and in the Mértola Flysch Formation, being the latter with the lowest values.

By leaching some crushed samples of several rock types of the Pyrite Belt with demineralised water it can be proved that the salts present in the rocks were sufficient to justify high amounts of dissolved salts, essentially on more thin sediments, like the shales. It seems that the most fractured rocks of the Pyrite Belt allow the ascension of briny deep waters, probably from more than 1000 meters deep. The high pressures at these deeper levels may cause the slow upwelling of the denser deep waters to the surface along fractures and on its way up the salts are absorbed by different rocks exposed to the fractures, with the shales being more affected. The extremely high water mineralisation recorded on some places needs another explanation: it occurs mainly on very flat and swampy areas of the more fractured rocks of the Pyrite Belt. On surface they suffer the influence of the high ratios of evapotranspiration and the successive dry/wet cycles create on the upper part of the soils the high concentrations that are observed. During the summer white caps of salt can be observed on this areas. On rainy times the simple dissolution of this salts is sufficient to increase the EC values to levels of several thousand of $\mu\text{S}/\text{cm}$. After the initial precipitation, that causes this increase, the continuing precipitation will dilute the solution. The level of dissolution depends on the days with precipitation. The inverse process occurs when rain stops: the EC increase and when temperature reaches higher values the salt will be deposited again.

The remote origin of the mainly Sodium-chloride waters must be due to the origin of the rocks themselves: during the closure of the paleo-ocean North of this area the brine migrated to points of less pressure, as shown by Garven (1995) and Bethke and Marshak (1990). Figure 5, shows clearly the brine migrations that can occur when the tectonic compression and thrusting produce large overpressures in the orogenic belts (Garven, 1995). In the SPZ case the migration must have tended to South. During the compression theoretical calculations suggest flow velocities between 0.1 and 1 m/year, although these rates will dissipate quickly when stress relaxes (Garven, 1995). This origin is also supported by Fernández-Rubio and Fernández Lorca (1987) studies in the reports about Neves-Corvo Pyrite Mine, pointing to fossil waters responsible for the high mineralisation registered. The conclusions are based on the ionic ratios of several ions, like Cl/Na, Cl/Li and Cl/K, that agree with the hypothesis that the origin is marine water or evaporitic salt deposits disseminated on rocks.

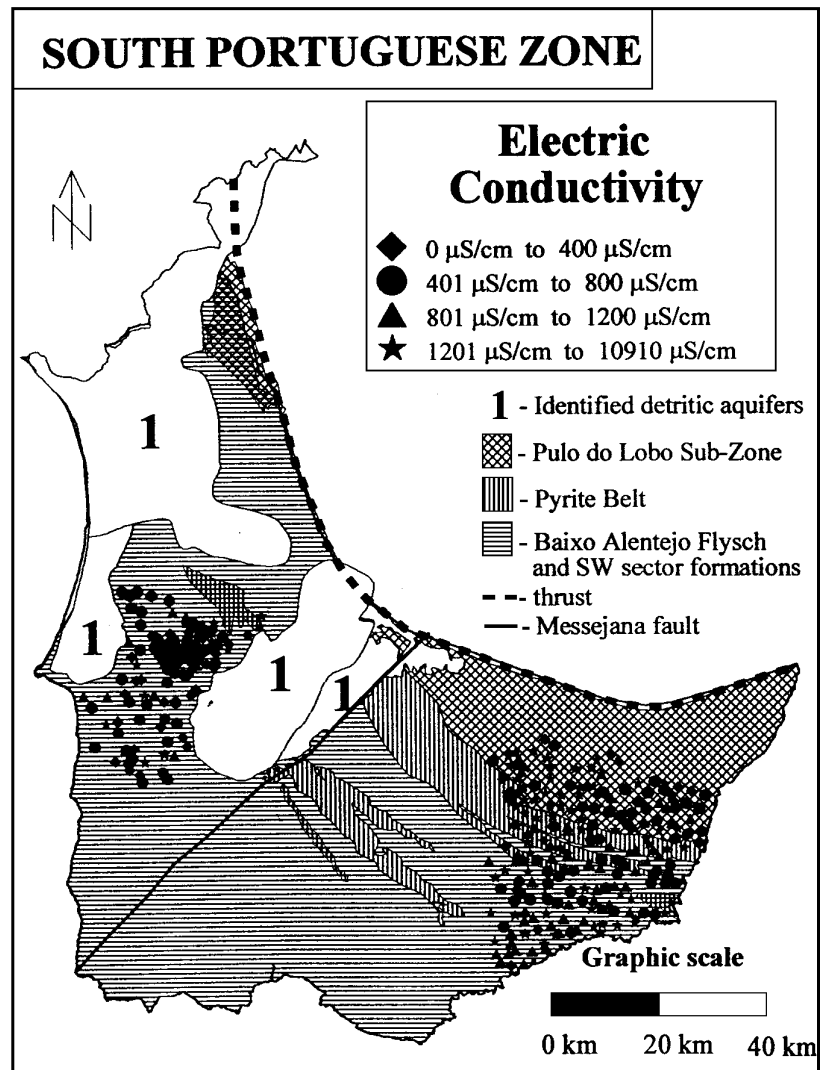


Fig. 4. Water points already investigated in the South Portuguese Zone.

Table I – Electrical Conductivity ($\mu\text{S/cm}$) statistics of the three main divisions of the South Portuguese Zone.

	Pulo do Lobo Anticline	Pyrite Belt	Mértola Flysch
Samples size	65	36	116
Mean	1284	2823	1109
Standard deviation	952	2361	516
Minimum	254	376	164
Lower quartile	630	1147	770
Median	1030	2145	984
Upper quartile	1738	3835	1365
Maximum	4570	10900	3020

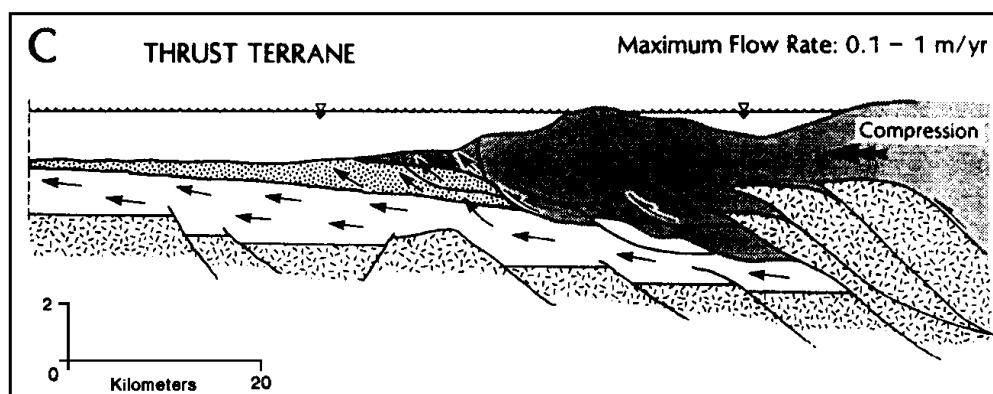


Fig. 5. Tectonically driven flow in a fold-and-thrust belt (Garven, 1995) similar to the evolution of the South Portuguese Zone. The figure shows the flow, whose general direction is depicted by arrows, through two permeable layers, between an underlying impermeable substract and an impermeable overlying aquitard.

The actual situation of the Pulo do Lobo and Pyrite Belt, near the point of maximum compression, and the known evolution of all of this area, corresponds to this model. The presence of high competent rocks and the presence of the thrust belt, with all the fractured structures associated, creates the conditions for the ascension of these brines. The lower mineralisation levels in the Baixo Alentejo Flysch will be related with less competent rocks associated with lower levels of compression, due to higher distances to the tectonic compression environment.

CONCLUSIONS

The geostructural domain of the South Portuguese Zone, on the southern part of Portugal, corresponds to metamorphic rocks. Their sedimentary and volcanic origin and its evolution created the conditions to the presence of high mineralised Sodium-chloride waters, mainly by effect of the migration brines associated to the closure of a paleo-ocean north of these area. This is supported by an independent investigation in the area of the Neves-Corvo Pyrite Mine, mainly by the study of the depth evolution of the groundwater quality and some observed ionic ratios. The ascension of the waters is due to the high deep pressures registered and the high ratios of fracturation that occurs mainly in the Pyrite Belt and Pulo do Lobo Sub-Zone.

The high electric conductivity values registered in the groundwater collected near the surface is explained by the high ratios of evapotranspiration that occur in this area. This allows the concentration of salts in the upper layers of the soils and in fine-grained rock layers like shales.

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