# L'importance de la présence de dykes et filons de quartz fracturés pour la recherche d'eau dans les roches métamorphiques argileuses

# The importance of the presence of fractured quartz dykes and veins in groundwater prospecting in metamorphic clayish rocks

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## I. INTRODUCTION

In semi-arid regions groundwater plays an important role in economic and human development. However, in areas where groundwater is a limiting factor due to very hard hydrogeological conditions, all human development is constrained by groundwater availability. The region analysed in this document is located in Alentejo region, South Portugal (see figure 1). Alentejo is a plain region with a Mediterranean climate, where the main activities are agriculture and livestock, both of them highly dependent on water availability to be profitable. Areas without water or less water do dry cultures or grow rustic cattle. Areas with good water availability can be used to implement crops that are much more productive, like corn, rice, soybean, etc., or even green pastures for cattle, allowing the increase of the number of animals per hectare. The water sources are mostly superficial (dam lakes) and groundwater, or both of them combined, once there are just a few permanent rivers in this area. The most important income from agriculture is based in irrigated cultures; so, farmers try to get water as a way to increase the production or to grow new kind of crops in order to diversify the offer. Being the morphology so flat, not all the proprieties are suitable to construct dams, so the pressure to use groundwater is incrementing, which reflects in a recurrent prospecting, drilling and construction of new wells.

Representing around one fourth of the Portuguese territory, Alentejo has only 5% of the Portuguese population, and it's an area of big propriety (hundreds of hectares each one), still with large regions without any drilled well. So, the investigation and hydrogeologic knowledge has been slow in all this area.

This document intends to show that the increase in the demand of new wells needs to be followed by further investigations, and the results of these drillings can strongly help to improve the previous hydrogeological knowledge. The study area is located north-east of Estremoz, in a metamorphic hydrogeological context.

## II. GEOLOGICAL FRAMEWORK

The area is included in the geostructural divison of the Iberia Peninsula called Ossa-Morena Zone (OMZ), composed by pre-Carboniferous Palaeozoic sedimentary rocks. The Silurian of this area corresponds to a condensed sequence (maximum thickness 80 m) that comprises, from base to

top, the uppermost quartzitic levels of the Colorada Formation (?), the black cherts (lydites) and black schists of the Schists with Nodules Formation (equivalent to "Ampelitas y Liditas Negras" Formation of Quesada & Cueto, 1994 and to the "Alumn shale and chert" Fomation of Giese et al., 1994) and part of the alternating dark schists and siltstones of the Schists Raiados Formation. The Schists with Nodules Formation comprises 5 to 8-10 m of alternating black schists and lydites where black cherts predominate, overlain by 20 to 30 m of black schists, whitish when strongly weathered, with rare lydite levels. The uppermost levels of the Schists with Nodules Formation pass up gradually into laminated dark siltstones, alternating with thin (1-2 mm) sandy lenses, which correspond to the Schists Raiados Formation (30-40 m). All this formations layers are most sub-vertical, tilted to NE.

The study area is located in middle Ordovician/Silurian rocks (figure 1). Geologically, the area is integrated in a main syncline structure that includes Neoproterozoic till Devonian rocks. These Silurian rocks correspond to Terena Synclinal (Lopes, 2003). At SW occur the Estremoz Marbles which are worldwide known as ornamental rocks, and are inserted in a Cambric metamorphosed limestone and dolomite geological framework, corresponding to one of the most important karst aquifers of Portugal (Estremoz Carbonate Aquifer – ECA).

## III. HYDROGEOLOGICAL SETTINGS

Climatologically, the region has a temperate climate, moderately rainy with multi-year droughts. The average annual rainfall is 637 mm/year and the annual average temperature is 16.2 ºC.

From the hydrogeological point of view, this region is integrated in a hard rock media context, which means generally very low permeabilities and transmissivities and low yields. The region is part of the Low Productivity Aquifers of South Portugal, where the average productivity is normally around 1 L/s. These evidences are well studied regionally (Chambel & Duque 1997; Chambel et al. 1998; Chambel, 1999; Duque & Jan, 2000; Carvalho, 2000; Almeida et al. 2000; Chambel et al. 2002; Chambel & Duque, 2006; Chambel et al. 2007), but there are always references to exceptional yields in specific geologic/tectonic environments.

The schists are very clayish and are characterized by a low density of fractures. There is a tendency for fractures filled with clay materials or by calcite and limonite precipitation. The most common water points are old large dug wells, able to support the livestock water demand. Drilled wells are more usually used to support water supply to houses in the proprieties and for cattle. In the study area, the main rocks are metamorphic, namely schists, with some thin layers of lydites and quartzites associated with the presence of quartz dykes.

## IV. HYDROGEOLOGY OF THE STUDIED AREA

But, in recent years, a slow but deep transformation in landscape, motivated by large investment in vineyard plantations, boomed by the construction of a large dam in the region (Alqueva dam), motivated the farmers who were not involved in the lake water network to invest in water and get a better profit from the high quality of the regional wines. Most part of the rivers in the region are temporary, with no flow in summer, so farmers invest in little dams, where it is possible, and in drillings.

On the past, irrigation was managed according the water availability, and not according the plant's demand. Grape production was very low but with a good alcoholic grade. But increased

productivity is only possible with water and the wells in the area are normally drilled in the most extensive outcrops of the geologic formation called Schists Raiados Formation. Most of this boreholes were positioned without any hydrogeological criteria, being the locations defined according the position of the irrigation systems, proximity of electricity, along rivers, near roads, etc.

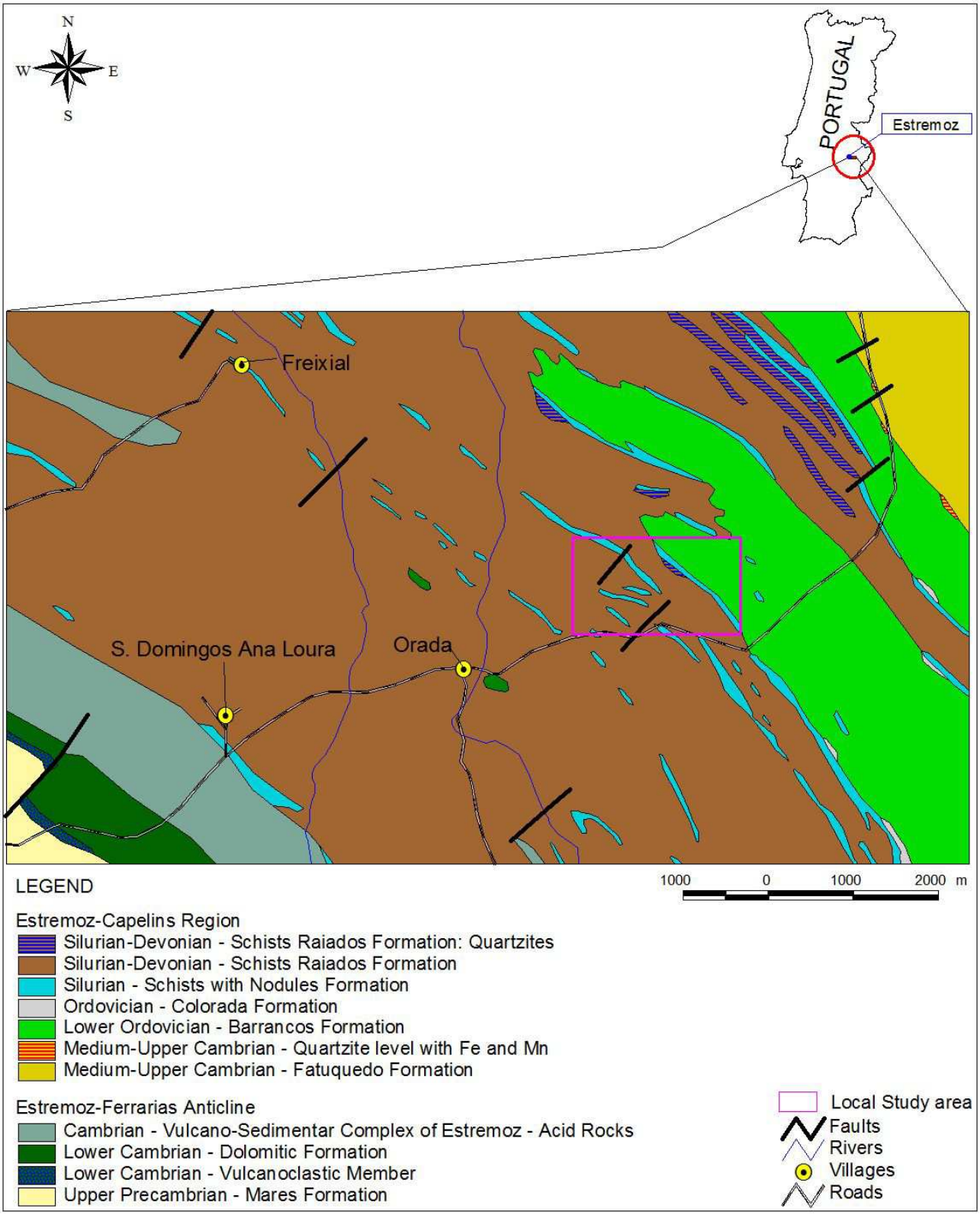


Figure 1 – Geological framework of the region of NE of Estremoz in the Syncline of Terena.

In 2013, after a geological approach and field work, a well (RA1) was performed in a thin outcrop of the Schists with Nodules Formation. The yield of this well was 19 L/s measured with compressed air in the end of drilling, and the litologies crossed were black schists and lydites, where black cherts dominate. In the study area this kind of rocks are related to the occurrence of long white quartz dykes, highly fractured and limonitized. The shape of the relief is also intimately associated to black schists and lydites with quartz occurrence. Being rocks with much more silicate components than the metamorphic silts of Schists Raiados Formation, the erosion is deeper in Schists Raiados Formation than in Schists with Nodules Formation. So, hills are aligned with the Schists with Nodules Formation with quartz fractured veins and dykes. Figure 2 shows the presence of this formation, important to define the hydrogeological potential of this area. The well RA1 was drilled in the top of one of the highest hill, in the NE flank of Schists with Nodules Formation layer. In the field, an occurrence of a metric quartz dyke is visible, and several lydite and quartz evidences are also detected in the soil. The borehole is 148 m deep. It crossed also psammites and graphitic schists. At the deep of 90 m, a 12 m quartz dyke with productivity of 2 L/s was crossed. Between 100 and 108 m and between 120 and 147 m deep, lydites and heavy fractured and limonitized quartz mixed with lydites and greywackes were also crossed. At this stage the groundwater yield reached 19 L/s, using the compressed air in the end of drilling. A 24 h aquifer test was performed with a submersible pump, using a 12 L/s pumping flow. The static level was 49.54 m and the dynamic level was 51.07 m (specific capacity of 680 $m^2$/day).

Meanwhile, between 2013 and 2015 many neighbours around this Orada Vineyard propriety did several wells inside the Schists Raiados Formation. The results were not positive and the productivity varied between 0 and 1.5 L/s. In the beginning of 2015 another well (RA2) was drilled in the same Schists with Nodules Formation alignment. This new well has 151 m deep, and is located more than 330 m NW of RA1. The rocks crossed were psamites and graphitic schists, and, at 60 m deep, a 9 m quartz dyke was cut, producing 2 L/s. Between 86 m and 98 m, 113 and 128 m, and 133 and 137 m deep, a highly fractured lydite, with white limonitized quartz was crossed. In a total of four productive levels, yield reached 28 L/s using compressed air. A 24 h aquifer test using a submersible pump was done, with an abstraction of 15 L/s. During this aquifer test, the water level in RA1 was monitored. There wasn't any level variation in RA1, which means that there aren't any hydraulic contact between those two wells. The aquifer test in RA2 showed that the static level was 50.4 m and dynamic level 55.3 m (completely stabilized after 8 h of pumping), which reach a specific capacity of 264 $m^2$/day. The difference between the 28 L/s measured by compressed air and the 15 L/s obtained in the aquifer test was due to the reduced diameter of casing (200 mm) and to the water pump availability to do the job.

Figure 3 shows the projection of RA1 and RA2 wells, as well as other low productive wells made around the study area. Here it's possible to see the projection of Schists with Nodules Formation and interpreted fractures. Fractures are mainly NE-SE and conjugated NW-SE. Fractures NE-SW seems to play an important role, doing some compartment of dyke's structures, or even increasing the grade of fracturing of these dykes.

## V. CONCEPTUAL MODEL OF THE SCHISTS WITH NODULES FORMATION AND ASSOCIATED QUARTZ DYKE AND VEINS

The occurrence of high yields in the Schists with Nodules Formation when compared with the surrounding rocks (metamorphic siltites of Schists Raiados Formation) can have a repercussion on water management and in water for irrigation. Schists with Nodules Formation are intimately

associated to the NW-SE hercynian compression phase, as well as those fractures which are parallel to the hercynian direction related to Terena Syncline deformation. The conjugated NE-SW fractures are linked to the Alpine Orogeny, reported in Portugal as marginal, but with a strong influence in the presence of decompression faults with NE-SW direction, increasing the secondary permeability. The fractured and limonitized quartz present is a proof of that.

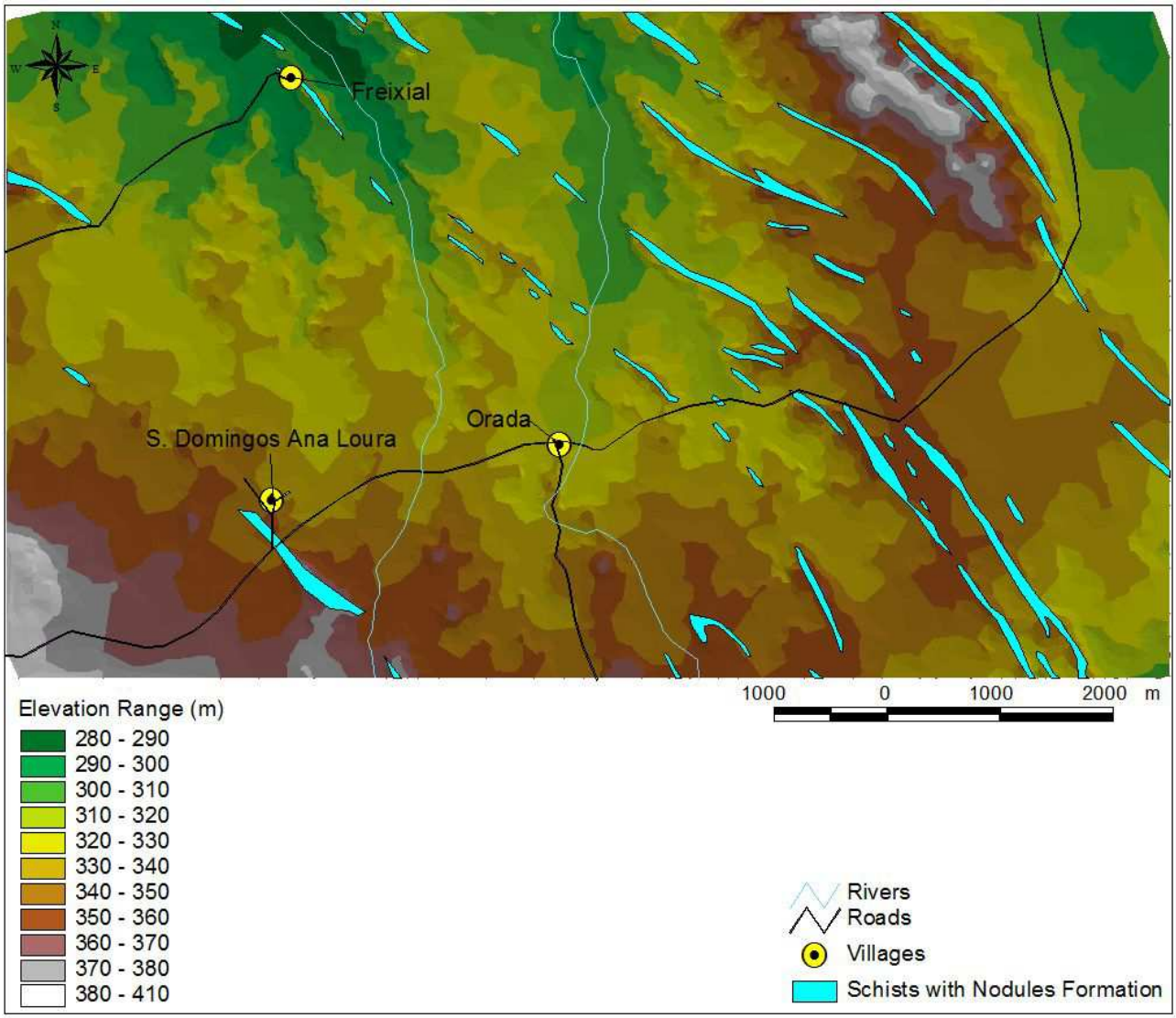


Figure 2 – Relation between altitude and localisation of Schists with Nodules Formation complex.

The Schists with Nodules Formation are sub-vertical, slightly tilted to NE. The more productive wells are only drilled in the NE flank of the formation, allowing the intersection of the fractured zones in a more deep position. However, this structural genetic condition can't be the only justification for the high yields. Admitting that recharge occurs only along the outcrops of the formation and the associated quartz dykes, infiltration based in precipitation would be limited, due to the reduced extension of the outcrops. The conceptual model that justify the high groundwater potential in these formation and associated structures is that it behaves as a mega deep drainage sub-vertical structure, draining the lateral pseudo-impermeable rocks (metamorphic siltites and other clayish metamorphic rocks) of Schists Raiados Formation. And this will work both for the secondary as for the primary porosity of these less permeable rocks, linking

faults, fractures, including diaclases, and the intrinsic porosity of these rocks to a main conduit where water can drain more easily (see figure 4). It means that these structures can "collect" water from other less permeable formations, through a vast double surface extension cutting the rocks underground. At surface the Schists with Nodules Formation seems to have no spatial continuity and seems to be cut by several fractures. However, it's probable that the dykes have a real spatial continuity in deepness along NW-SE direction or at least can be linked by some NE-SW faults.

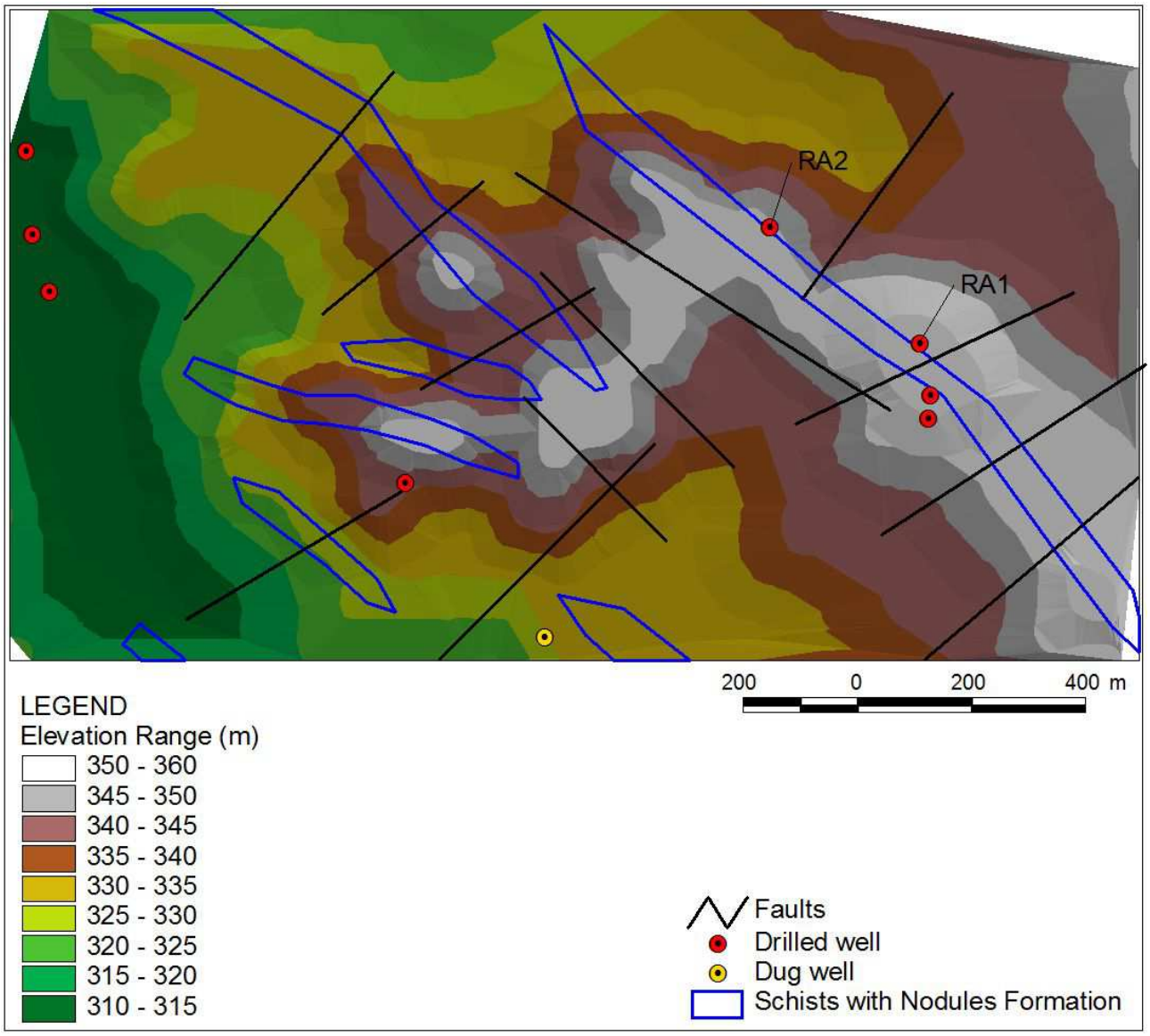


Figure 3 – Projection of wells and other groundwater abstraction structures, interpreted fractures and Schists with Nodules Formation in the study area mentioned in figure 1.

## VI. FINAL REMARKS

Groundwater prospection in a hard rock context in rural areas of South Portugal is mainly dependent on private investment and agricultural trends. The evolution of the hydrogeological knowledge in the area depends on field work, inventory of wells and identification of their characteristics, and the tracking of drillings. This was the case of this investigation. Two drillings (RA1 and RA2) in a favourable hydrogeological environment (Schists with Nodules Formation with

fractured quartz dykes) allowed yields of 19 and 28 L/s (measured with compressed air) in these two wells. The recommend yields were 12 and 15 L/s, respectively, based on flow tests, even so limited by the diameter of the wells and the capacity of the pumps. In fact, as can be seen by the drawdown on both of them after 24 h (1.53 and 4.9 m respectively for RA1 and RA2), the maximum yield will surely be superior to the defined values. The specific yield was respectively 680 and 264 $m^2$/day.

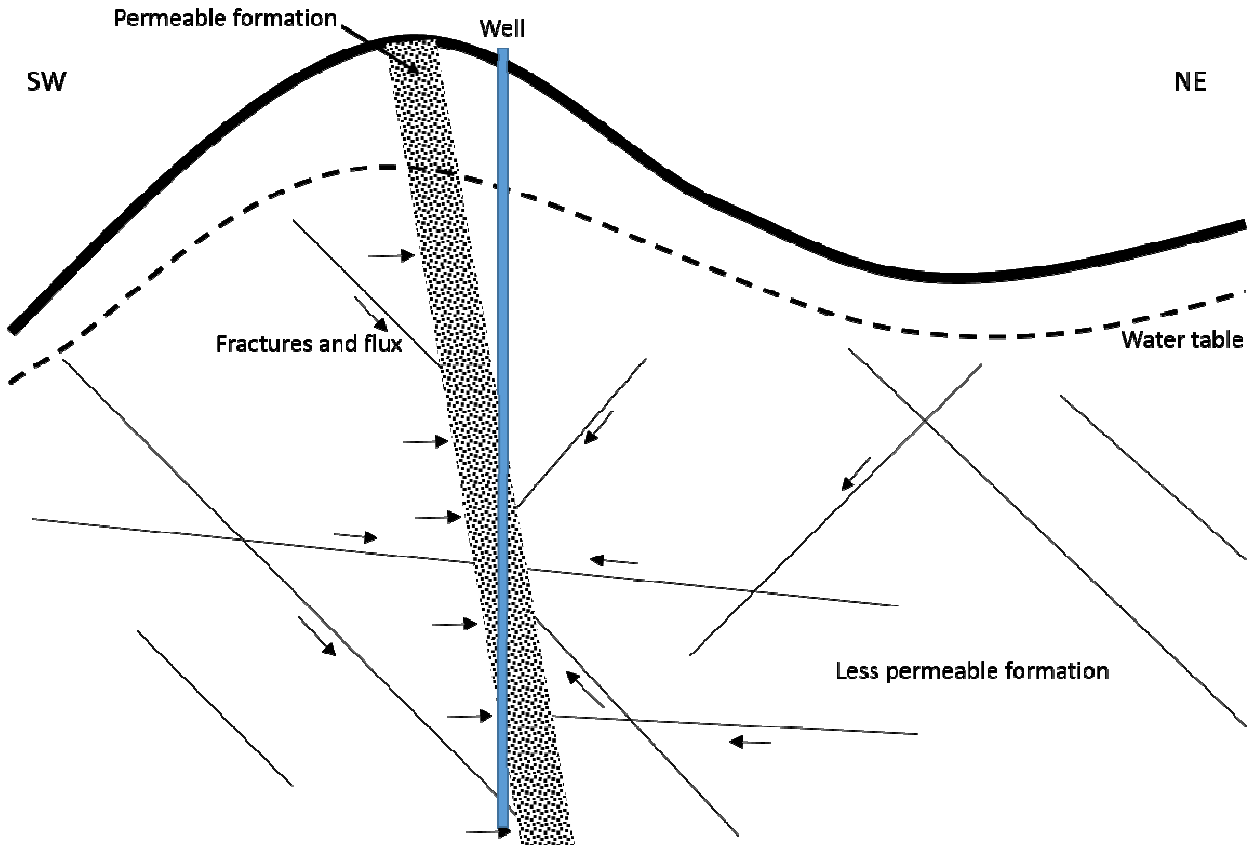


Figure 4 – Conceptual model for the Schists with Nodules with quartz dykes.

The conceptual model for this kind of tabular sub-vertical aquifers on specific formations with quartz dykes implies an important recharge, which can be explained by the large are area of contact between these more porous formations and the surrounding less permeable ones. This will allow that lots of little fractures in the less permeable rocks drain water from secondary and primary porosity origin to the more porous fractured media of the Schists with Nodules Formation. The lydites and quartz dykes will behave like conduits draining the water from neighbouring formations.

Once this wells are recent, there is not yet the perception for how long time these structures can be reliable before any drawdown on the water levels and in productivity can be noticed.
More attention must be paid to new prospecting along the Schists with Nodules Formation, in order to understand if the hydrogeological behaviour is the same in all places. And the investigation of new wells must also be focused in other similar structures, like quartz veins and dykes cutting the main structures, or greywackes and quartzite formations, which occur in other places of Alentejo.

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