



Use of Drill Cuttings for Hydrogeological Water Well Logging Reconstruction: A Practical Approach

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Abstract

In hard rock terrains, down-the-hole hammer drilling is a method commonly used. Consequently, it is a destructive method, and the resulting drill cuttings are crushed rock and rock dust. A low-cost and valuable methodology to reconstruct the water well logs from drill cuttings is presented. That approach encompasses lithological, mineralogical, geo-structural, and hydrogeotechnical data. A comprehensive study of the site's geology, engineering geology, and hydrogeology constraints supports the water wells design at an early stage. The cuttings were systematically collected and described during the drilling process, and they were registered hydrogeological field parameters for every 3 m drilled. The drill cutting samples were carefully described at the laboratory with a binocular microscope's assistance. The design of the water well potentially intersects the fracture zone trending NNE-SSW. The groundwater flow seems to be associated preferentially with this orientation. That was confirmed in the drilling data and related to the productive groundwater zones. The synthesis and integration of this information allowed a significant improvement in the hydrogeological conceptual site model, thus contributing to efficient groundwater resource management.

Keywords

Water well • Log reconstruction • Drill cuttings • Hydrogeotechnics • NW Portugal

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1 Introduction

In hard rock terrains, the down-the-hole hammer (DTH) method is commonly used to drill water wells and other boreholes (e.g., Bresson 1977; Atlas-Copco 1979; Plote 1985; Driscoll 1986; ADITC 2015; Missstear et al. 2017; Glotfelty 2019, and references therein). Several button bits could be mounted at the end of the drill pipe, combined with a down-the-hole air percussion hammer to cut the rock. Then, high-pressure air is pumped through the drill pipe to lubricate the cutting surfaces and blow the broken-down rock material (cuttings) to the surface. The drill cuttings consist of rock dust and fragments up to 3 cm in diameter (e.g., USACE 2001; Sterrett 2007; Marjoribanks 2010). These destructive drilling methods are well described in the scientific and technical publications (e.g., Davis and Turk 1964; Summers 1972; Bresson 1977; Plote 1985; Driscoll 1986; Clark 1988; Hartman 1992; Yin and Brook 1992; USACE 2001; Doesburg 2005; Eustes et al. 2009; Ahmed et al. 2014; ADITC 2015; Rix et al. 2019; Zhang 2016; Missstear et al. 2017; Dassargues 2019; Patel 2019; Glotfelty 2019). Still, systematic sampling is not treated with equal importance. Nevertheless, Harvey and Lovell (1998), Marjoribanks (2010), Monnet (2015), and Kyzym et al. (2015) highlight the sampling and logging procedures for destructive drilling methods, clearly stating that it is only possible if undertaken when the water well is being drilled.

This preliminary study shows how a low-cost and prompt methodology greatly supports the water well log reconstitution from drill cuttings. Furthermore, that comprehensive approach based on lithological, mineralogical, geo-structural, and hydrogeotechnical data is reliable. This data has crucial importance for the development of the hydrogeological conceptual site model.

The geology of the study site—Noninha, Montemuro Mountain, North Portugal—is dominated mainly by granitic rocks (Fig. 1). At the bottom of the Noninha stream valley, some alluvia deposits are also present. Additionally, quartz

veins outcropped the granite bedrock and quartz hornfels (Teixeira 2011). The granitic rocks are dominated by two major fault sets, mainly trending to NNE-SSW and conjugated systems, NW-SE to WNW-ESE. The field studies conducted in the area have integrated geological, morphostructural, and hydrogeological data to support a series of exploration works. In the former S. Pedro das Meadinas spring vicinities, two exploration sub-horizontal (5° dip) water wells were drilled, trending $N160^\circ E$ and $N90^\circ E$, respectively (Fig. 1).

2 Material and Methods

At the Noninha site, was carried out a comprehensive hydrogeological study. Field surveys, such as regional and local geological mapping, morphotectonical, hydrogeological inventory, and hydrogeotechnical surveys. Besides, desk studies and laboratory analysis were performed, namely GIS (Geographical Information Systems) mapping and hydrogeochemical analysis. Therefore, was design two sub-horizontal exploration water wells (5° dip) and drilling with the DTH method. Figure 2 presents a practical methodology for water well logs reconstruction based on drill cuttings in hydrogeological studies to support the conceptual site model.

The studies performed at the investigation site were structural geology and geomorphology mapping, on-site fracturing scanline surveys, hardness testing evaluation on exposed rock surfaces, and hydrogeological field surveys. In addition, the suggested methods for characterisation and testing of rock masses proposed by ISRM (1981, 2007, 2015) were followed. This information was necessary to design the water wells, later integrated with the data collected during the drill cuttings sampling and log reconstruction stage.

The water wells were drilled using the down-the-hole hammer (DTH) method, employing 3 m drill pipes mounted with button bits. The cuttings sampling was made during the drilling process, following the methodology proposed by Marjoribanks (2010). The collected samples for every 3 m drilled are stored in a wooden box (Fig. 3a). Several parameters were recorded from the drill cuttings, namely: Depth (or length, since the water wells are sub-horizontal), Geological description (lithology, mineralogy, colour, grain size, among others), Weathering grade (W) and Fracturing degree (F). At the end of the drilling works, the samples were packaged and labelled into individual plastic bags to be carried out to the laboratory. Also, during the drilling process, other hydrogeological parameters were recorded, namely the measurement of flow (L/s), pH, temperature ($^\circ C$), and electrical conductivity ($\mu S/cm$) of the water. To accomplish this task were followed several recommendations, highlighted, for example, by Clark (1988), CFCFF (1996), Assaad et al. (2004), Doesburg (2005), Brassington (2017), Rix et al. (2019) and Kowalska et al. (2020).

The samples were carefully analysed in the Laboratory of Cartography and Applied Geology—LABCARGA (School of Engineering ISEP, Polytechnic of Porto). A macroscopic characterisation was carried out, with an accurate scale observation of rock/mineral cutting samples (description, identification, and evaluation) and a binocular microscope (10 and 30 x magnification) observation and description. For each sample, were taken three photos: real scale, 10 x magnification and 30 x magnification (Fig. 3b, c, and d). Complementary mineralogical tests and geochemical evaluation were also carried out, such as handheld XRF spectrometer, X-ray fluorescence spectroscopy technique, chemical, and pyrognostics tests. The collected information supports the water well logging process, namely lithological reconstruction and description with geological, geotechnical, and hydrogeological data.

Fig. 1 Location of the Noninha stream valley: schematic geological profile and FH2 horizontal water well position (adapted from Teixeira 2011)

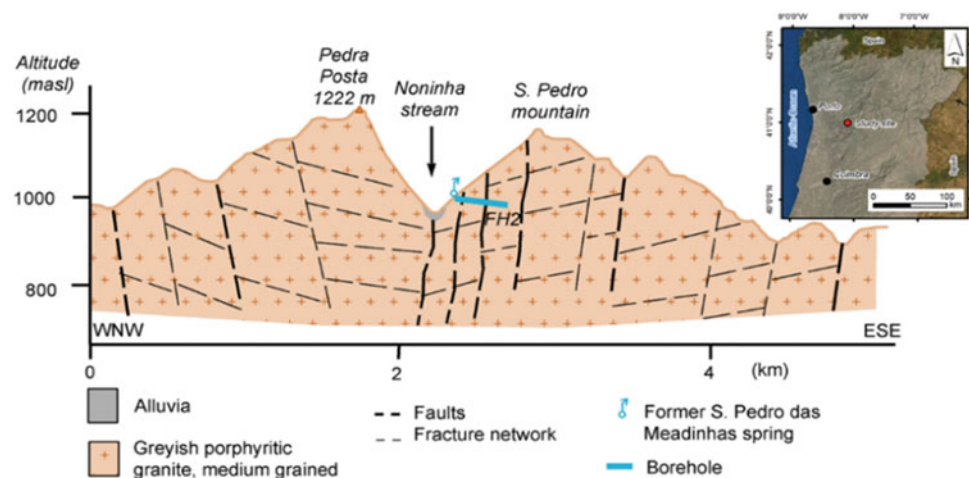
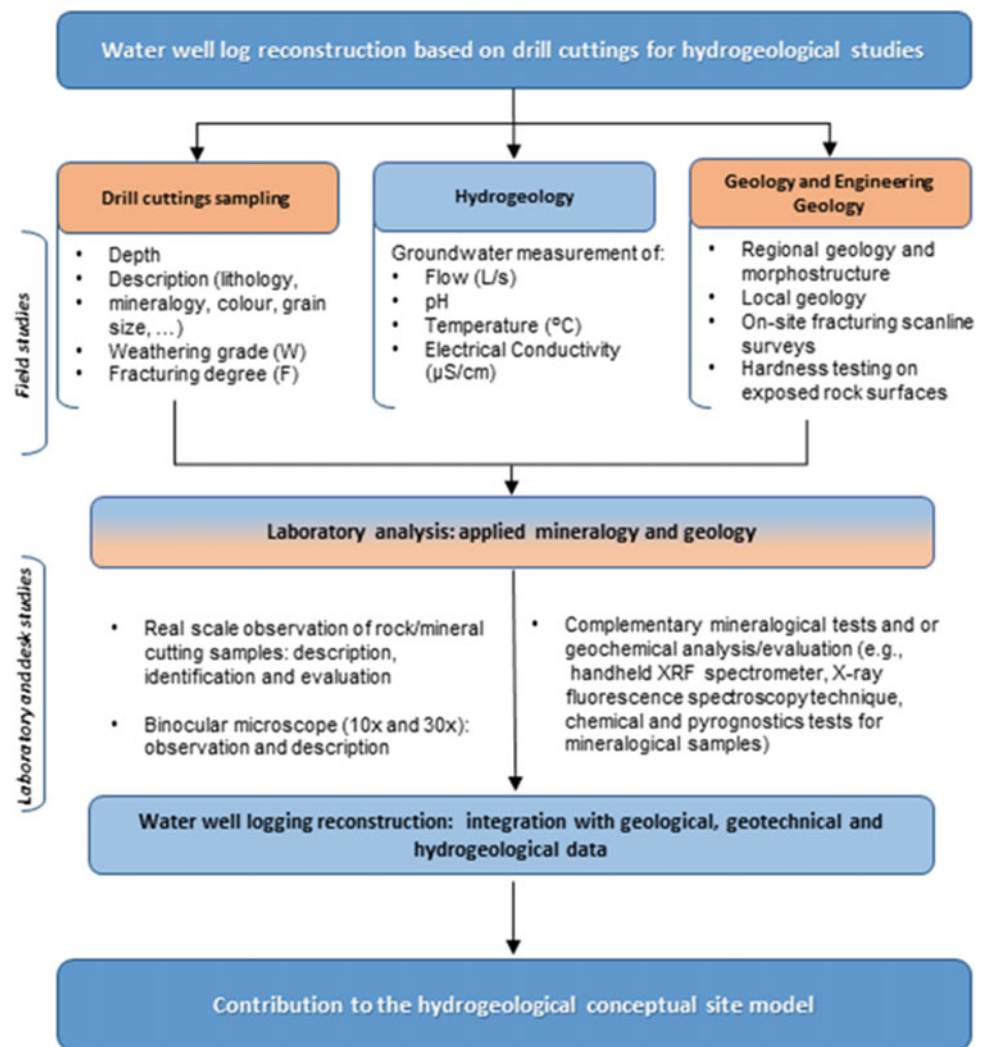


Fig. 2 Practical methodology for water well logs reconstruction based on drill cuttings



3 Results

The hydrogeological inventory in the area has shown that most groundwater manifestations (springs, fountains, dug wells, wells, and others) are in the granitic rocks. That highlights a thick horizon of weathered granite (W_{4-5}) to a residual soil (W_6). This weathered horizon is sometimes over 20 m and plays an essential role in improving the quantity of groundwater stored in this shallow aquifer system. Locally, when geo-structural conditions are favourable, this groundwater flows to the deeper aquifer system. The area's water manifestations also seem to be highly correlated with tectonic lineament nodes or some preferential orientations at a local scale, and mainly near the valleys' bottom. The tectonic lineaments primarily trending NE-SW and ENE-WSW appear to be the most important hydrogeological traps. Therefore, the water wells were designed to intersect these geostructures (Teixeira 2011).

Figure 4 shows the database created with comprehensive information that permits the water well log reconstruction. Also, it added a photo of each sample. The log drawn was also added to the database. Thus, the collected data allowed the reconstruction of the logs of FH1 and FH2 water wells. At the FH1 water well, some alternating zones of fresh to slightly weathered granite (W_{1-2}) with highly weathered granite zones (W_{4-5}), up to 81 m. The identified fractures belong to the specified NNE-SSW orientation and are also present mainly until 81 m. The main productive groundwater zones (where the drilling flow increases significantly) were determined at 50 and 120 m.

Additionally, the FH2 water well has similar characteristics, and the alternating zones of fresh to slightly weathered granite with zones of highly weathered rock mass (Fig. 4) go up to 120 m. Still, the fracture density is higher until 50 m. The productive groundwater zones were identified at 30 and 70 m. The gravitic groundwater flows measured after the drilling process finished is 4–6 L/s for each well.

Fig. 3 Field samples in the wooden boxes, collected during drilling (a); Sample from a fractured zone (b); Aspect of some muscovite crystals (c); Portion of chlorite crystals, seen through a binocular microscope with 10 × magnification (d). (Images adapted from Teixeira 2011)

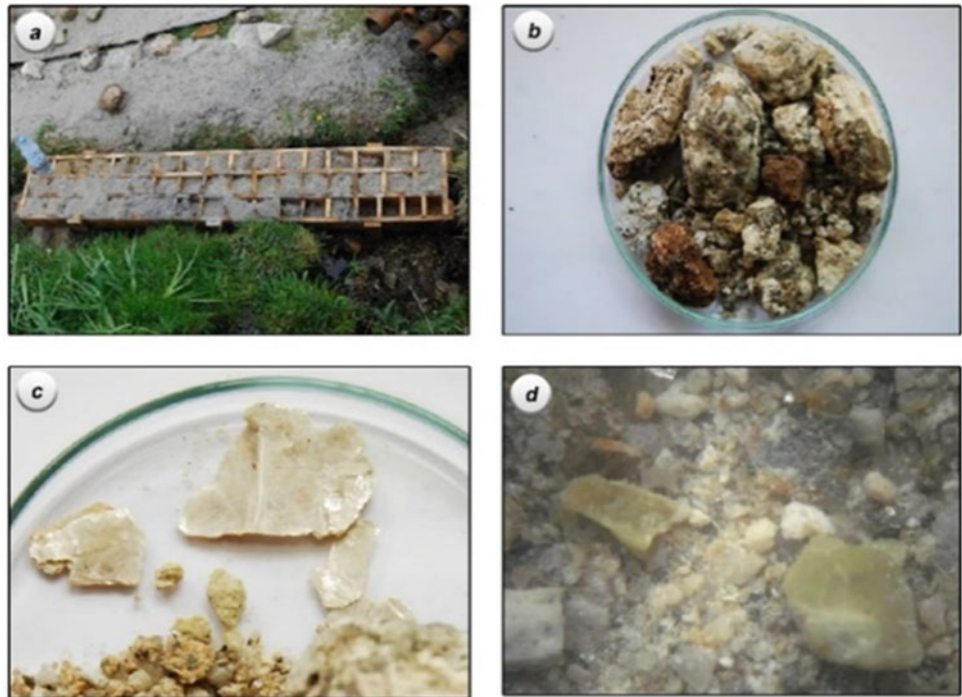


Fig. 4 Extract of the database and the final result of the log reconstruction for water well FH2

| Depth (m) | Lithology | Minerals | | Colour/ton | Granularity | | | | | | Weathering | | | | | | Observations | Schematic log | Photo |
|-----------|------------------------|--------------------------------------|----------------------------|--------------------|-------------|---|---|---|----|---|------------|-----|----|---|----|--|--------------|--|-------|
| | | Essential | Accessory | | VC | C | M | F | VF | I | II | III | IV | V | VI | | | | |
| 3 | Medium grained granite | Quartz, Feldspar, Biotite, Muscovite | | Yellowish | | | | | X | | | | | X | | | | | |
| 6 | Medium grained granite | Quartz, Feldspar, Biotite, Muscovite | | Yellowish | | | | X | | | | | | X | | | | Large muscovite grains | |
| 9 | Medium grained granite | Quartz, Feldspar, Biotite, Muscovite | | Yellowish | | | | X | | | | | | X | | | | | |
| 12 | Medium grained granite | Quartz, Feldspar, Biotite, Muscovite | Tourmaline, chlorite? | Yellowish, greyish | X | X | X | | | | | | | X | X | | | Large muscovite grains, slickenside lineations on rock surface cuttings, highlighting probable fractures | |
| 15 | Medium grained granite | Quartz, Feldspar, Biotite, Muscovite | Tourmaline, chlorite? | Yellowish, greyish | | | X | | | | | | | X | | | | | |
| 18 | Medium grained granite | Quartz, Feldspar, Biotite, Muscovite | Tourmaline (few minerals) | Greyish | X | | X | | | | | | | X | | | | slickenside lineations on rock surface cuttings, highlighting probable fractures | |
| 21 | Medium grained granite | Quartz, Feldspar, Biotite, Muscovite | Tourmaline, chlorite (few) | Greyish | | | X | X | X | | | | | X | | | | | |
| 24 | Medium grained granite | Quartz, Feldspar, Biotite, Muscovite | Tourmaline, chlorite (few) | Greyish | | | | X | X | | | | | X | | | | | |
| 27 | Medium grained granite | Quartz, Feldspar, Biotite, Muscovite | Tourmaline, chlorite (few) | Greyish | | | | X | | | | | | X | | | | | |
| 30 | Medium grained granite | Quartz, Feldspar, Biotite, Muscovite | Tourmaline, chlorite (few) | Greyish | X | | X | X | | | | | | X | | | | Fractures? | |
| 33 | Medium grained granite | Quartz, Feldspar, Biotite, Muscovite | Tourmaline | Greyish | X | | | X | | | | | | X | | | | Quartz vein? Fractures? | |
| 36 | Medium grained granite | Quartz, Feldspar, Biotite, Muscovite | Tourmaline | Greyish | X | | X | X | | | | | | X | | | | Iron oxide? Quartz vein? | |

The in situ hydrogeochemical studies revealed hyposaline water and sodium bicarbonate facies. However, during the rainy season and relatively short residence times, the Non-inha's waters turn to sodium chloride facies. As a result, the analysed waters' silica/total mineralisation ratio is around 30–35%.

4 Concluding Remarks

The practical methodology applied to reconstitute water well logs from drill cuttings and the database created has proven reliable. That integrates the lithological, mineralogical, geo-structural, and hydrogeotechnical data. The discontinuity orientations were confirmed in the interpretation of the drilling data, characterised in the drilling logs carried out, and correspond, in general, to the productive groundwater zones of the water wells. Combining and integrating this information allowed a substantial improvement in the hydrogeological conceptual site model, thus contributing to more efficient water well completion and groundwater resources management.

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