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Geological Materials as Cultural Markers of Water Resources †

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Abstract: Water has always been a critical resource for humans and climate change could aggravate supply problems. In this context, groundwater could be an important reservoir of water, especially given the dispersion of places where it can be obtained and the widespread occurrence of surface marks (springs). Historically, places where groundwater is available have been marked by humans using built structures, with stone materials having a major role. These cultural objects tend to become a part of the collective memory and the historical record (when available) and frequently they stay on the original site along time (hence "marking a spot" for groundwater). However, the development of major water supply structures, especially in the 20th century, promoted the negligence of these ancient water sources. We present a general defense of the importance of recording and preserving cultural stone related to water sources, preferably in the original sites. Conservation of groundwater-related structures could help in the future exploration of this geological resource and converge with historical information on the fountains' discharge, with geological studies of the terrains and geochemical features of the groundwaters involved, in order to characterize the hydrogeological systems and their potential future use (including the preservation of water quality and properties). These studies could promote a synergetic conservation of both heritage and water.

Keywords: groundwater; water supply; climate change; conservation of cultural stone; historical and archaeological sources of information; urban planning; synergetic conservation

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1. Introduction

Water has always been a critical resource for human groups, and climate change could aggravate supply problems.

This is an issue that could have affected humanity in the past and it has been postulated that human development at the end of the Bronze age in some areas was affected by their increased aridity [1].

In this context, groundwater could be an important reservoir of water, especially given the dispersion of places where it can be obtained (namely springs) and in many places the multitude of historical structures built with the aim of allowing water consumption.

Historically, places where groundwater is available have been marked by humans using built structures, with stone materials having a historically major role. These cultural objects tend to become a part of the collective memory and the historical record (when available) and frequently they stay on the original site along time (hence "marking a spot" for groundwater).

However, the development of major water supply structures, especially in the 20th century, promoted the negligence of these ancient water sources.

Nonetheless, there are several examples showing the present pertinence of these dispersed water supplies (not limited to stone structures) such as a recent study (2019) regarding water quality in fountains [2]. In their short history of fountains, Juuti et al. [3] mention the spread since the beginning of the present century of "water kiosks" that aimed to provide public drinking water and which could help to reduce plastic waste. There are even examples in the general press, as this example from the Washington Post discussing environmental and health issues associated with the decline of trust in public fountains [4].

One can find diverse works relating water resources to heritage such as the already mentioned work by Juuti et al. [3], several works presented in [5] and the Water Shapes project [6], which will be cited on several specific points of our discussion in the next section.

We attempt to present here a general defense of the importance of recording and preserving cultural stone related to groundwater sources, focused on examples from Braga (NW Portugal) and surrounding places. Braga is a town with a rich historical past from Roman times (when it was known as *Bracara Augusta*) and with a wide-ranging heritage among which one can highlight the Braga cathedral (41.55° N, −8.43° W). It is placed mostly on granite terrains, and granite is an important material in heritage elements (as will be illustrated here in relation specifically to groundwater). More historical information on Braga focused on water supply to the town can be found in Martins et al. [6].

The results of the discussion presented in the next section will be the basis for our proposals for stone heritage preservation presented in the final considerations.

2. Discussion

We are considering here geological materials in a very wide sense, comprising both the terrains that are the water source or through which water structures are placed, as well as those materials used for building the water supply structures, with a special highlight on natural stone, a material with a particular importance in water-related historical structures. While we will essentially focus on stone/rock structures, due to our global (geological) research interests, the considerations presented here will be also pertinent for structures with many other materials.

The assessment of ancient information on water resources needs to consider both the material evidence and the written sources, as illustrated by the discussion concerning water supply to Braga presented in Martins et al. [6]. Here we are concerned with the special importance of the material record, given our research experience. However, we might add that historical documents can be affected by human features, e.g., second-hand information that might not only be inaccurate but even fantasized. In relation to the elements of the material evidence, one can expect that they will be "free of intentional misrepresentation", to adapt a sentence used by Lyell for geological bodies [7].

However, geologists must be aware, in relation to this subject, that some elements of the material record (namely fountains) can be misleading when they are not in the original place and there is no documental record of their displacement. In contrast with traditional geological studies, the displacement of these materials will frequently not be due to geological phenomena, except where those displacements related to, for example, earthquakes, tsunamis, sea rise and mass movements (in these cases there is, generally, other evidence of the geological action).

The material record concerning groundwater includes diverse structures such as wells, fountains, aqueducts, etc., made in stone and other geological materials that can persist over time. In Braga, for example, there is a wide assortment of water fountains and a major water distribution system. Water supply was frequently celebrated and the very elaborated stonework that is found in many fountains (as shown in Figure 1) is a memento of that importance. Some examples can be found in the middle of intense urban development. One of the most interesting examples is the Idol's fountain, which is believed to have existed since before the Romans [6], and where there are carvings on a granite outcrop around a spring. These carvings have been related to the cult of a local deity [6]. One can also find more recent examples associated with religious motifs (Figure 1b).

(a) (b)

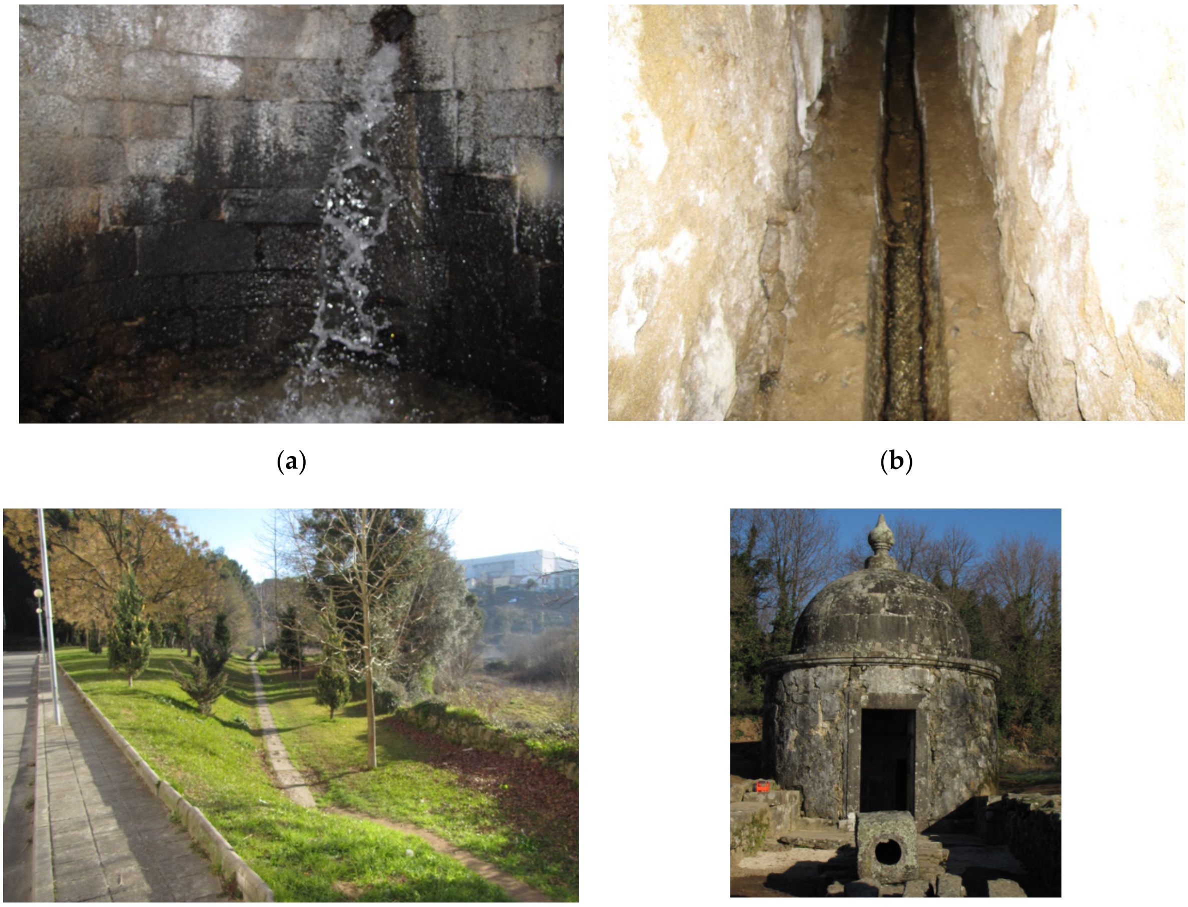
Figure 1. Examples of fountains in Braga, showing elaborated stonework in granite and its presence in the highly developed urban context (**a**) and association with religious context (**b**), which is also located in a highly urbanized setting (not visible in the image).

It was also possible in the context of a project of the first author to recognize the existence of several wells in the center of Braga (albeit we do not make the distinction of those that were made in stone).

A more complex example is the water distribution system known as "Sete Fontes" (seven fountains), which is hypothesized to be based on a previous roman structure and much developed afterwards (see historical information in [6]). This water system collects water from several groundwater sources and presents an extensive and diverse stone heritage, including underground reservoirs, galleries, and surface stone channels (see Figure 2). Martins et al. [6] highlight that the many works in the seven-fountain water distribution system and its resilience to the present day show the potentialities in the area regarding water resources (related to groundwater sources). The persistence of the water supply from this system could have helped to preserve it (personal communication from Ricardo Silva) in an area that was expected to be subjected to intense urban development.

Besides these major water distribution systems, one can also find small structures scattered among human settlements, as illustrated by the water structure shown in Figure 3. Some of them seem to be currently abandoned, but the materials used (stone) and perhaps their position in small settlements have helped to ensure their preservation. There are more modern examples of water systems that were closed and then recovered, such as the Old Croton Aqueduct in New York, which was closed in 1955 and partially reopened in 1987 [8]. There have been cases, such as the so-called "ferrous waters" in Fraião, Braga (NW Portugal), that were dismounted and relocated, keeping the water supply; however, this last case might be illustrative of the problems associated with this, as it seems that the present water supply has very different characteristics from the previous ones, characterized in Lima et al. [9].

These different structures for water supply could be useful for chemical and physical characterization and monitoring of groundwater quality and quantity, especially those linked to in situ water occurrences such as wells and fountains linked to springs. According to Meran et al. [10], Humboldt, during his voyages in Venezuela, hypothesized that the drying of springs and drought in a region could be related to its deforestation.



(**a**) (**b**) (**c**) (**d**)

Figure 2. Illustrative images of the seven-fountain water system in Braga (NW Portugal), showing an extensive use of stone for collecting water in underground reservoirs (**a**), and underground (**b**) and surface distribution channels (**c**). The image in (**d**) shows a detail of the stone pieces used for surface water channels and one of the stations used for the control and manutention of the system known locally as "Mãe d'água" (there have been conservation interventions in these stations, but this older image illustrates the extensive use of stone on these structures).

(**a**) (**b**)

Figure 3. Small water structure in stone located in the outskirt of the town of Braga (**a**) with detail of its inside (**b**).

In Braga, the Idol's fountain is a clear reminder of the sensitivity of water resources; it had plenty of water at the beginning of this century but has dried up since then. The historical wells in Braga were included in the geochemical characterization of the urban groundwater of this town, albeit in the perspective of assessing their potential impact on the historical built heritage in stone [11]. The water distribution system of the seven fountains has allowed the preparation of studies of the groundwaters that feed this system concerning both the hydrodynamical characteristics [12] and the geochemistry and water quality [13].

There are several examples of synergetic conservation proposals for ecological resources [14,15], as well as for energy and water [16]. There are also examples involving the perspectives of geological heritage, mineral resources and the structures used for their exploitation [17]. This synergetic conservation approach could be useful for the conservation of geological resources such as groundwaters and the terrains that hosted them, as well as for the historical heritage that was made to supply these hydric resources, as is illustrated by many examples around the world, such as, for example, those considered in the references mentioned previously in this work.

3. Final Considerations

Hopefully, the present work has contributed to the development of a synergetic conservation approach to geological objects, in this case, geological materials used for building historical water supply structures and the groundwater resources that fed or feed them.

The last case is especially interesting since water supply use will be perhaps the best safeguard against the destruction by urban development of this kind of heritage. Hence, searching for and developing uses for the water resources in these structures could be a key element in their conservation. In fact, as some examples in Braga illustrate, historical structures related to groundwater exploitation could be integrated in the urban development and contribute to valuing it.

Groundwater-related heritage can be seen as a potential exploration tool for hydric resources that were used in the past and that might be recovered for future use. This should converge with historical information both on location (since some built elements could be presently displaced in relation to the original site) and on the systems' discharge, with geological studies of the terrains and geochemical features of the groundwaters involved, in order to characterize the hydrogeological systems and their potential future use (including the preservation of water quality and properties).

These issues should be vital factors in urban planning for the future in order to preserve water resources and related structures that might become essential due to climatic alterations.

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