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THE MAP OF ANCIENT UNDERGROUND AQUEDUCTS: A NATIONWIDE PROJECT BY THE ITALIAN SPELEOLOGICAL SOCIETY

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The project "The Map of Ancient Underground Aqueducts of Italy", started in 2003 by the Italian Speleological Society (SSI), and entirely dedicated to the study and exploration of ancient underground aqueducts, has allowed so far to collect a database of 125 ancient underground aqueducts, distributed in all the Italian regions. Historically, ancient aqueducts have been explored and studied by cavers. Their importance derives from a number of historical, engineering, and environmental reasons. These aqueducts represent a valuable documentation of the skill and engineering techniques of the ancient communities, and due to the mostly underground development, they have often been preserved intact for millennia. Main objectives of the project are: (i) implementation of a detailed inventory of the ancient aqueducts of the Italian territory; (ii) updating of the state of the art on the matter; (iii) encouraging new studies and explorations, in particular by cavers, regarding the ancient aqueducts; (iv) safeguarding and exploitation of these unique works of historical and engineering hydraulic importance.

1. Introduction

Since the establishment of the first settlements, man had to face the issue of water availability. Water was obtained through tapping, transporting and distributing the hydric resources by means of highly specialized works, many of which were actually extremely complex when considering their time of realization. Qanats (from a Semitic word meaning "to dig") are the oldest form of subterranean aqueducts engineered to collect groundwater and direct it through a gently sloping underground conduit to surface canals which provide water to agricultural fields or oases. They represent one of the most ecologically balanced water recovery methods available for arid and semi-arid regions, since do not upset the natural water balance, relying entirely on passive tapping of the water table by gravity. The best evidence (archaeological and written accounts) suggests that qanat irrigation was first invented in the Armenian-Persian region about 600-700 B.C. (LIGHTFOOT, 1996); however, other scholars indicate the first realizations of qanats as dating back to three thousand of years ago (WULFF, 1968). The art of tunnelling, and the expertise in realizing deep shafts and underground canals to transport water, were probably even older, as suggested by the drainage works realized at Kopais, in Boeotia, at the beginning of the 2nd millennium B.C. (KNAUSS, 1991), or by the attempts of the Mycenaean civilization to cross a mountain ridge with an artificial emissary discharging the water toward the sea around the 12th century B.C. (CASTELLANI and DRAGONI, 1997).

Management in drinking water supply has always been of fundamental importance. The need to having available the necessary amount of hydric resources for the populations pushed ancient populations to tremendous efforts in planning, realizing, and maintaining long and complex aqueducts, that developed underground for most, if not all, of their length. To provide just an example, when the engineer Sextus Julius Frontinus was appointed, in AD 79, as imperial water commissioner *(Curator Aquarum)* of the City of Rome, he became responsible for a supply of 800 megalitres daily into the city from nine underground aqueducts, with a total length of 420 km (BONO and BONI, 1996; PIKE, 1999).

Ancient populations (and particularly ancient Romans) understood the relevance of placing the aqueducts underground as a method of protecting their fresh water from external threats, represented by the many enemies. Three main advantages for building the aqueducts underground must be reminded (ASSANTE, 2007; TASSIOS, 2007): (i) to conceal and to protect them from enemies; (ii) to protect them from erosion and

deterioration; (iii) to be less disruptive to life above ground. On the other hand, the main disadvantage was represented by the greater difficulties in maintaining and inspecting the systems (CASTELLANI, 1999, 2001). In many cases the final structure was a mostly underground aqueduct, with intervening sections above ground (Figs. 1, 2). Studying ancient underground aqueducts represents an exciting challenge, that may open new lights toward the capability of man to collect water in the past and, more generally, to work toward a sustainable use of the natural resources (LAUREANO, 1995; BURRI, 2008). On the other hand, the periodic hydrologic crises we experience, often related to over-exploitation and degradation of the water resources, demonstrate that several lessons may be learned from the analysis of ancient hydraulic works (CASTELLANI and DRAGONI, 1991; BURRI, 2003).

Figure 1: Above ground arcade section of an aqueduct near Rome (photo: C. Galeazzi).

2. The Project "The Map of Ancient Underground Aqueducts of Italy"

In 2003, the Italian Speleological Society (SSI) started a project, entirely dedicated to the study and exploration of ancient underground aqueducts, called "The Map of Ancient Underground Aqueducts of Italy." As a matter of fact, ancient aqueducts, as well as other subterranean hydraulic works (lake outlets, cisterns, tanks, etc.), have been since a long time explored and studied by cavers (Fig. 3). Their importance derives from a number of historical, engineering, and environmental reasons:

- they represent a valuable documentation of the skill and engineering techniques of the ancient communities;
- due to the mostly underground development, they have often been preserved intact for millennia;
- they are among the main works that testify the efforts by man to manage the territory, and to develop urban civilizations;
- even though lacking a continuous maintenance, several ancient aqueducts are still working today;
- some aqueducts might be put again at work through low-cost interventions, and constitute an additional water supply in case of droughts or during hydrologic crisis.

Main objectives of the project are, therefore: (1) implementation of a detailed inventory of the ancient aqueducts in the Italian territory, and evaluation of their present state; (2) updating of the state of the art on the matter. Many publications on ancient aqueducts are available in the historical and archaeological literature, but they have never been properly collected and organized so far; (3) encouraging new studies and explorations, in particular by cavers, regarding the ancient aqueducts; (4) safeguarding and exploitation of these unique works of historical and engineering hydraulic importance. Since the Italian territory presents a huge amount of ancient hydraulic works, the database of the project includes all the aqueducts responding to these two time and space requirements

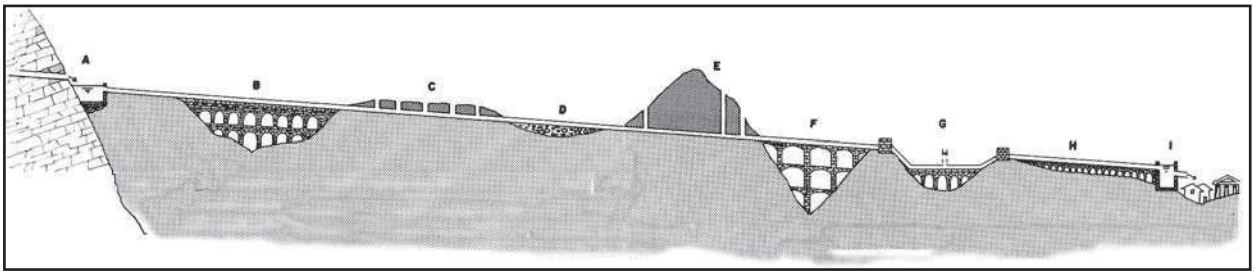

Figure 2: Sketch of a Roman aqueduct (after CASTELLANI and DRAGONI, 1989). Explanation: (A) spring tapping by draining conduits and silting basin; (B) viaduct channel with multiple arcades; (C) underground tunnel at low depth, with several wells; (D) channel on earthfill; (E) underground tunnel at great depth, with few wells, generally at its ends; (F) viaduct with continuous vertical pillars; (G) inverted siphon, realized according to Vitruvio's description; (H) final viaduct; (I) collection and distribution tank.

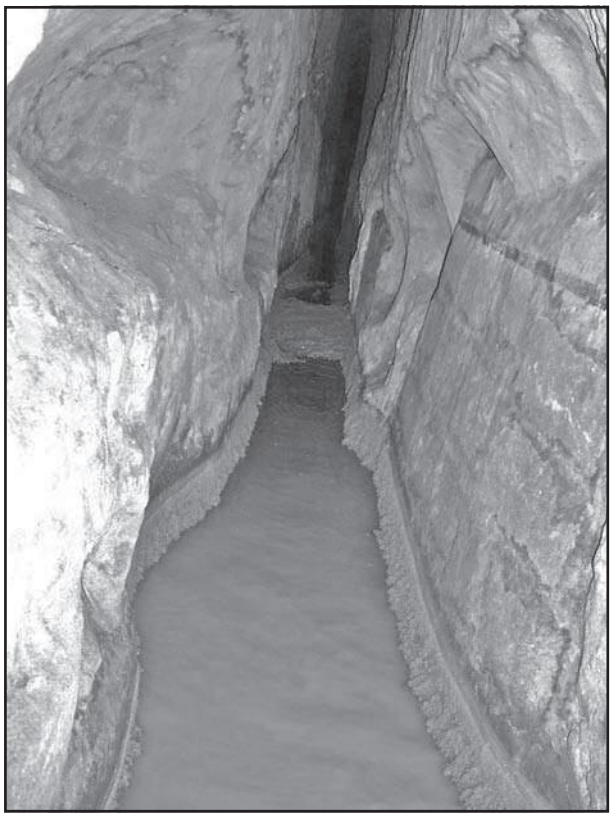

Figure 3: The main tunnel in the Triglio aqueduct (Taranto province, Apulia), one of the longest inventoried aqueducts in southern Italy, with a length of approximately 18 km.

(PARISE, 2007(a): (1) the upper time limit of the aqueduct construction is considered to be the XVIII century; (2) the aqueduct must be at least 400 meters long. As regards the latter requirement, some exceptions have been made, in case of smaller, but historically or hydrogeologically important aqueducts. The aqueducts have been temporally subdivided into three periods: (i) greek-roman time (until VI century B.C.); (ii) byzantine-medioeval time (VII–XIV century B.C.); and (iii) renaissance-modern time (XV–XVIII century B.C.).

In the first phase of the project, a specific form was implemented, in order to facilitate the collection of the main information about each aqueduct. The form, that soon became available in digital format at the dedicated website (address: http://www.antichiacquedotti.it/), consists of three parts: (a) general data; (b) technical data; (c) personal data.

The general data include all the relevant information about name and location of the aqueduct (region, province, municipality), length (with indication of the percentage of subterranean course), and availability of plan and sections. In addition, the present state of the structure, and the possible necessary works for its re-utilization, are also indicated. Eventually, the general data includes all the bibliographic references dealing with that specific aqueduct. The technical data of the form encompasses information about the geological and hydrological setting of the area where the aqueduct develops, with particular reference to geology of the spring area, and any geological (stratigraphic or tectonic) change along the course of the aqueduct. They also include the known notice about age of utilization of the aqueduct. The personal data, eventually, refer to name, address and correspondence of the form's compiler, in order to have the possibility to contact him/her for further requests.

A very important part of the project consisted in putting together, in a unique bibliography, all the references about ancient underground aqueducts, that are often dispersed in many local or sectorial publications, journals or conference proceedings. A thorough work of bibliographical research, and a subsequent phase of cross-checking among the main literary sources, allowed to develop a list of over 1,000 publications (January 2009 update). These were subdivided on a regional basis, and within each region they were in turn associated to each hydraulic work. While the first version has been recently released (PARISE, 2007b), the bibliography is continuously being updated.

3. First Outcomes

Up to date (January 2009) an overall number of 131 forms have been compiled, with a regional distribution of the aqueducts as shown in Figure 4. This number, certainly not a definitive one, expresses the great potentiality of the Italian territory as regards the presence of ancient hydraulic engineering works. The 131 forms correspond to 125 ancient aqueducts distributed over 19 regions of Italy (the only exception being Calabria, where so far no ancient underground aqueduct has been documented). As expected, Latium hosts the great majority of aqueducts, counting 40 hydraulic works (Fig. 4); it is followed by Marche and Campania (13), Apulia (11), Abruzzo (9), and Piedmont (7). A direct consequence of such a regional distribution is the presence of aqueducts in the different Italian provinces: Rome counts 28 aqueducts, and is followed at great distance by Naples (8), Ancona (7), Viterbo and L'Aquila (6), and by many other provinces.

The majority of ancient aqueducts is comprised between 1 and 5 km, but there is a high percentage of aqueducts with a longer course, that is more than 10 km (twelve aqueducts are longer than 30 km). Over four/fifth of the

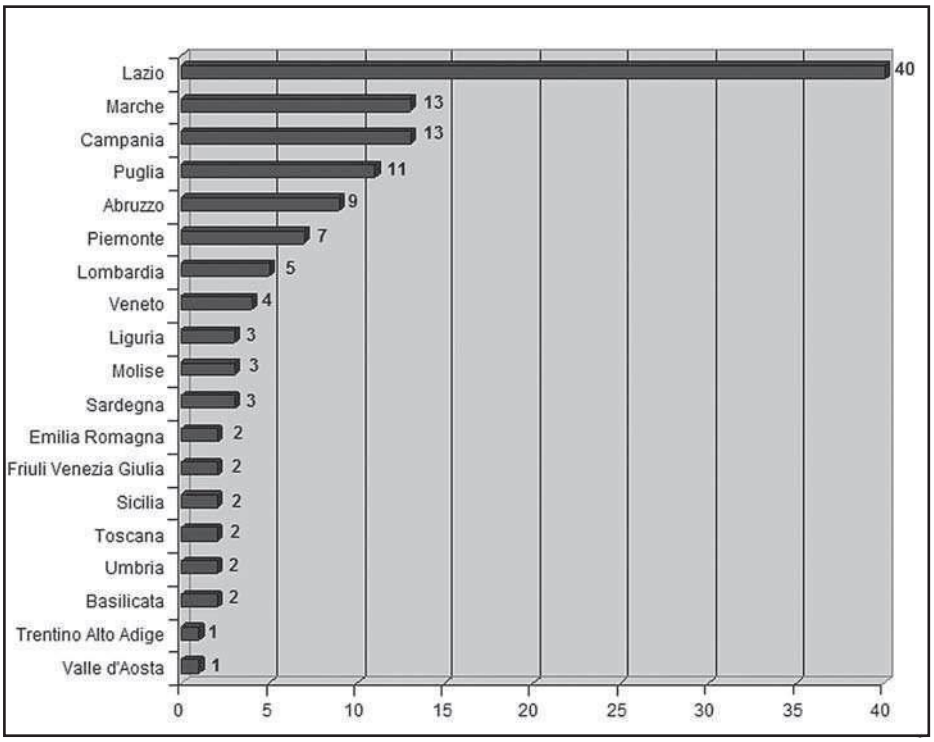

Figure 4: Regional distribution of the ancient underground aqueducts in the database (updated to January 2009).

inventoried aqueducts (precisely, 82%) is of greek-roman age. Only one aqueduct has been catalogued as byzantine-medioeval, but it likely follows an older (roman?) course, not yet documented, however. The remaining (13%) is of renaissance-modern time.

Some considerations have to be done about dating of the aqueducts: the date often comes from historical sources (for example, an ancient author indicates explicitly in the text the date of beginning, or end, of the work, together with the emperor's name); sometimes it is derived from the functionality of the aqueduct (for example, it provided the water supply to a roman colony, thus it is a roman aqueduct); in some case, it is just an hypothesis (for example, it is called roman aqueduct, but actually no documentation which can prove the date is available). Utilization of the aqueducts was rather diversified: they mostly took drinkable water and transported it to *domus*, *villae*, towns, thermal baths, and military camps (GERMANI et al., 2007). In a few cases, the waters were used to irrigate, while in others the hydraulic works drained waters from lakes. There is also one case where the aqueduct supplied water to mills and factories, by providing the purpose-built wheels with the energy for the production process (BIXIO *et al.,* 2007). In most of the cases, the aqueducts are subterranean, completely or in large part.

There is no uniformity in the geological setting of the source areas of ancient aqueducts. In most of the cases, rocks of sedimentary origin (35%) crop out in the areas where the springs are located. These are followed by carbonate (31%) and volcanic rocks (30%), while a much lower percentage interests debris deposits (4%). Analyzing the geology of the area where the hydraulic works are located, and even the difficulties related to the presence of different types of rocks to dig the underground tunnel is a very interesting topic, worth to be thoroughly studied (DEL PRETE and PARISE, 2007). More in general, it has to be noted that the deep knowledge the ancient populations had about hydrogeology, hydraulics and topography, in order to design, and correctly realize, underground aqueducts, is really astonishing.

4. Future Perspectives

The Project "The Map of Ancient Underground Aqueducts of Italy" is still in progress; the amount of sites to study, and where to collect further data, is actually enormous in a country as Italy. The efforts by the Italian Speleological Society have necessarily to be strictly linked to research centres and universities, in order to have the possibility to give continuity to the project and keep working on this subject. As regards the future, already planned, steps of the Project, in the next months the material available so far will be published on the web. This will open the possibility to new collaborations, and, hopefully, some sorts of funds, necessary to start additional explorations and researches, both at the local and the national level.

Recently, aimed at further co-operations with foreign scholars and cavers, a systematic research about bibliographic references to ancient underground aqueducts outside of Italy has also started. The interest on the topic is in fact great even outside the Italian boundaries, and especially in the other countries of the Mediterranean Basin, where many other important ancient hydraulic engineering

works have been built and used during the different epochs. This part of the project, that was started a few months ago, have so far resulted in a list of some hundreds of bibliographical references about underground aqueducts distributed all over the world.

References

ASSANTE, M.J. (2007) *Infrastructure protection in the ancient world.* Idaho National Laboratory Technical Publication, 14 p.

BIXIO, R., A. DE PASCALE, S. SAJ and M. TRAVERSO (2007) Tre acquedotti sotterranei in provincia di Genova. *Opera Ipogea* **1**, 85-94.

BONO, P. and C. BONI (1996) Water supply of Rome in antiquity and today. *Environmental Geology* **27**, 126-134.

BURRI, E. (2003) Antiche opere di regimazione lacustre e di bonifica idraulica nell'Italia centrale. *Ambiente, Società e Territorio* **3** (1-2), 16-24.

BURRI, E. (2008) Le antiche canalizzazioni sotterranee. In GRILLOTTI DI GIACOMO, G. (Ed.) *Atlante Tematico delle Acque d'Italia.* Brigati Ed., Genova, 123-128.

CASTELLANI, V. (1999) *La civiltà dell'acqua.* Editorial Service System, Roma, 256 p.

CASTELLANI, V. (2001) Acqua, acquedotti e qanat. *Opera Ipogea* **2**, 25-32.

CASTELLANI, V. and M. DRAGONI (1989) Opere idrauliche ipogee nel mondo romano. *L'Universo* **2**, 100-137.

CASTELLANI, V. and M. DRAGONI (1991) Italian tunnels in antiquity. *Tunnels & Tunneling* **23** (3), 55-57.

CASTELLANI, V. and M. DRAGONI (1997) Ancient tunnels: from Roman outlets back to the early Greek civilization. *Proc. 12th International Congress of Speleology* **3**, 265-268.

DEL PRETE, S. and M. PARISE (2007) L'influenza dei fattori geologici e geomorfologici sulla realizzazione di cavità artificiali. *Opera Ipogea* **2**, 3-16.

GERMANI, C., C. GALEAZZI, M. PARISE and M. SAMMARCO (2007) Gli antichi acquedotti sotterranei: esempi di uso sostenibile delle risorse idriche. *Proc. Conf. "La crisi dei sistemi idrici: approvvigionamento agro-industriale e civile"*, Accademia dei Lincei, Roma.

KNAUSS, J. (1991) Arkadian and Boiotian Orchomenos, centre of mycenaean hydraulic engineering. *Proc. 2nd Int. Congr. Micenologia*.

LAUREANO, P. (1995) *La piramide rovesciata.* Bollati Boringhieri, 311 p.

LIGHTFOOT, D.R. (1996) Syrian qanat Romani: history, ecology, abandonment. *Journal of Arid Environments* **33**, 321-336.

PARISE, M. (2007a) Il Progetto "La Carta degli Antichi Acquedotti Italiani". *Opera Ipogea* **1**, 3-16.

PARISE, M. (Ed.) (2007b) Bibliografia di base. *Opera Ipogea* **1**, 17-68.

PIKE, E.B. (1999) Drinking water supply – a backward look into the future. *The Environmentalist* **19**, 5-9.

TASSIOS, T.P. (2007) Water supply of ancient Greek cities. *Water Science & Technology: Water Supply*, IWA Publishing **7** (1), 165-172.

WULFF, H.E. (1968) The aqueducts of Iran. *Scientific American*, 94-105.