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Güllüdere and Kızılçukur:
Rose Valley and Red Valley in Cappadocia

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Underground hydraulic systems and anthropogenic cavities in Cappadocia

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Studies into hydraulic systems

A key aspect that should be borne in mind by all investigations into ancient settlements is the availability of water for domestic use and irrigation, and consequently the hydrography of the places and the relative water collection, transport, storage and distribution structures required to meet the water demand during the period of site occupation. This important topic is now well documented with regard to various regions in the Near and Middle East, as well as in central Asia where there are numerous studies on water supply systems using underground channels like *karez* or *qanat*, many of which still in use today. However, few sources deal with the ancient water management structures of Cappadocia, where they are widely present in a variety of forms.

Irene Beldiceanu, a researcher at the Centre national de la recherche scientifique (CNRS) and expert in Ottoman history, has written in general about extremely elaborate irrigation works documented in the Ottoman period consisting of dykes forming large artificial lakes called *sughla* that fed channels carrying water to the fields.[1] She believed that the system dated to before the Ottoman conquest and may have been introduced by the Seljuqs, inspired by Iranian models. However, after comparing the different sources, she came to the conclusion that the irrigation systems in this region probably dated to the Byzantine era. It should be pointed out, though, that Beldiceanu makes no specific mention of networks of underground channels like those found in the Göreme area. She does, however, provide important information regarding farmers' use of meltwater feeding the *sughla.* As we will see, this technique is key to explaining the functioning of the tunnel-cisterns identified during the most recent investigations carried out in the Göreme site.

Although a 5th-century account by Herodotus[2] mentions ambitious hydraulic works carried out on the River Halys (now Kızılırmak) in Cappadocia by Thales of Miletus for Croesus in about 550 BC, concrete evidence of an underground tunnel built to divert a stretch of this important water course was not obtained until 1984 following investigations carried out by Eric Gilli.[3] In the interim, there were occasional minor references to underground water supply systems: in the late 19th century by William Mitchell Ramsay[4], and in the early 1900s by Georges Cousin,[5] G.E. White[6] and Guillaume de Jerphanion.[7] It was not until very recent times that specific studies were carried out by the Centro Studi Sotterranei, Genoa:[8] between 1992 and 2000, under the patronage of the Turkish Ministry of Culture, and then between 2012 and 2014, in the context of the missions organized by the Università della Tuscia and directed by Maria Andaloro. A short study was also carried out by Alexandra V. Bukarenko[9] in 2008 followed by further investigations by Eric Gilli and Ali Yamaç[10] in 2015.

These investigations revealed the presence throughout Cappadocia, and in the district of the erosion valleys around Göreme, in particular, of highly effective and ingenious underground water systems adopting the 'negative construction' techniques peculiar to this region. Over the centuries, such techniques have produced an impressive number of rock-cut sites in the faces of tablelands, cliffs, badlands, pinnacles comprising churches, tombs, dwellings, agricultural works, and above all, underground refuges protecting local inhabitants from raids as well as from the extreme climatic conditions.[11]

Types of water supply systems

Rock-cut hydraulic works vary according to the strategies adopted by the local inhabitants to ensure optimal water use on the basis of the climate and lithology in these areas, which are typically lacking in surface water resources.

p. 2 The most common type of water supply system consists of wells created by digging vertical shafts through the bedrock as far as the aquifer ('snow-pits' belong to a different category).[12] The shaft can be circular or more often square, with an average cross section of 70 centimetres. Footholes dug into the sides make it possible to chimney through the shaft both during and post construction for maintenance purposes.

Such wells are frequently found in underground shelters, ensuring their self-sufficiency for long periods, such as during the frequent and systematic Arab raids that took place between the 7th and 10th centuries.

Depending on the area, they can reach depths ranging from 10 to 40 metres although Ramsay[13] briefly describes a well that is "300-feet" deep (around 90 metres) in an unnamed village that may correspond to Çekme, which lies not far from Derinkuyu, and whose well is still in use today.

There are also numerous underground cisterns comprising chambers entirely dug out of the rock, found both as isolated structures in the countryside, where they are used for local irrigation, or integrated within other underground structures, some of which suspended, located at the highest levels of cliffs. They may be fed by springs, rainwater or meltwater, by groundwater extracted from wells or by tunnel-cisterns, like those described below.

There is also a unique system, which uses 'funnels' consisting of small troughs dug out along the edges of a cliff to collect the rainwater and meltwater and convey it via a vertical downpipe going through the rock bank to the reservoir below where it can be drawn from a hole in the bottom.

In addition to these water collection points, there are also underground aqueducts made up of tunnels dug out in the rock to convey the water between two points lying at varying distances from each other. The water was either conveyed through free surface flow – i.e. directly through the tunnel – or through a pipe line laid in the channel. In Uçhisar there is a system of channels over 3,600 metres long containing two terracotta pipes from different periods.[14]

Another integrated underground water system comprising drainage tunnels and tunnel-cisterns was identified in a rather small, highly anthropized area corresponding to the valleys around the ancient Byzantine site of Korama, now the site of the Göreme Open Air Museum (Açık Hava Müzesi). The area features a surprising number of rock-cut churches and dwellings, eighteen defensive structures as well as refectories, grape presses, dovecotes, and at least fourteen beehives, all dug out of these evocative rock formations.[15]

Drainage tunnels

Drainage tunnels are designed to drain off excess water. Although virtually no longer maintained, they still have the function of reducing and distributing the water load produced by rainfall and of containing flashfloods, thus permitting the cultivation of the land on the bottom of the deeply incised, narrow valleys characterizing the entire region.

These tunnels, some over 300 metres in length, were obtained by using multiple teams to dig sections from both ends until they met in the middle. They were dug out of the rock walls below the level of the riverbed, parallel to the hydraulic route and intercepted by shafts or short cross-tunnels delivering the runoff flows (dissipators). The water is drained off at various points, protecting vast stretches of the valley bottom from erosion as well as from the accumulation of sediments, and permitting the construction of wind-protected terraces for the cultivation of fruit and vegetables (although such plots are gradually disappearing).

The tunnels originally had a rectangular cross section with a height of 100-180 centimetres and a width of about 80 centimetres. The erosion action of the water over the centuries has widened them, sometimes giving them a bell-shaped or elliptical cross section, probably produced by overlapping crioclastic phenomena.

Some of the galleries are up to 5 metres in height and 3 metres wide, while in the Zemi Valley (Zemi Vadisi) they are over 10 metres high.[16] Nearly all of them have a small channel cut into the floor to convey the minimum flow.

Tunnel-cisterns

In the Valley of Swords (Kılıçlar Vadisi) – a deep canyon next to the Göreme valley, which contains one of the drainage systems described above – recent investigations have documented another type of tunnel that is contiguous yet independent, and mostly flooded, which is clearly intended to supply water for the irrigation of the plots of land obtained thanks to the reclamation of the valley bottoms.

p. 3

One of them, a 60-metre long tunnel known as Traforo, conveys the water from one valley to the next, passing below the ridge separating the two valleys. It is fed by a sole absorption point consisting of a weir across the bottom of the Valley of Swords and uses a minimal fall in height to collect the water and convey it to the opposite side, in the midst of a dense group of structures carved out of the rock walls and pinnacles. Looming over them is Tokalı Kilise, one of the most important rock-cut churches in the area, which is surrounded by a group of abandoned dug-out spaces that may have belonged to the original monastery complex, and at least six underground refuges protected by the characteristic millstone doors.[17]

The use of such tunnels to convey water is secondary, while there is a marked vertical oscillation in water levels due to filling and emptying actions: in fact, their primary purpose is to collect water during the rainy months and, above all, meltwater from the snow, which can then be drawn off to supply various needs throughout the rest of the year. Not aqueducts in the strict sense of the term, they act as reservoirs and consist of a long and narrow underground tunnel, often with a larger capacity than the usual chamber cistern. They can be either rectilinear or ramified and are known as 'linear cisterns' or tunnel-cisterns.

Another unique feature of these tunnel-cisterns is their unexpected use of an ingenious yet simple feeding system based on trenches filled with loose stones that has revolutionized water collection systems in the region, offering an alternative water source to springs or aquifers.

Tunnel-cistern excavation method and sequence

By analyzing the systems identified, we were able to reconstruct the probable design and construction procedure.

After identifying the points most suitable for surface runoff harvesting in relation to the site where water was to be drawn off and distributed in the area to be used for cultivation, work began on digging the entrances at either end of the system (or at several ends in the case of ramified systems). The first was usually a trench or vertical shaft, 2 to 4 metres deep while the second could also be horizontal. The excavation work proceeded inwards from each tunnel entrance – possibly at the same time – and niches for lamps were cut into the walls at regular intervals. The tunnels were dug out from both sides until the opposite faces met; this point can usually be identified by a shift in the centre line, leading to a vertical or horizontal offset. As a result, the tunnel tends to proceed in a slightly winding manner.

Once the excavation of the tunnels had been completed, the upper trench was filled with loose stones of various dimensions, eventually supported by tuff slabs, thus creating a point of absorption allowing infiltration of rainwater and runoff to feed the underlying tunnel-cistern.

At the opposite end was the plant for the outlet and distribution of the water resources collected in the tunnel system. This plant generally consisted of an intake chamber separated from the tunnel-cistern by a rock wall, left in place during the excavation work, that was either open on top (weir) or closed (screen). In the first case, the intake chamber was created in line with the tunnel-cistern and had an access crossing the weir (for inspections and maintenance). In the second case, the entrance to the tunnel system was obviously separate from the intake chamber and could even be located at some distance from it.

Water was drawn off via a through hole, with a diameter of approximately 10 centimetres, bored through the bottom of the rock wall. It was regulated by a wooden bung or a valve on an iron tube inserted into the hole itself. Distribution took place through a series of small channels dug into the floor that went from the intake hole to the plots of land. They are now all filled with soil and in a couple of cases have been replaced by fixed pipes or temporary rubber tubes.

Pilot-holes

Where intake holes were made in the rock wall (screen) of the intake chamber, we documented an interesting method used to identify the exact point in which to position the conduit so as to ensure the best possible water supply during the minimum flow rate, without risk of overflow during times of maximum flow rates. The sequence can thus be illustrated:

1. Two groups of diggers excavating from either end – from the tunnel-cistern and from the intake chamber – would attempt to get as close as possible to each other by using the noise and vibrations transmitted through the rock by their tools.

2. Once they were at a reasonable distance from each other, the first hole was bored, probably using a form of drill, in order to check the thickness of the remaining rock, as well as the altitude and alignment of the two opposite faces, so as to make any adjustments necessary for the correct placement of the intake hole. This pilot hole was drilled high up in the wall, probably so as to avoid compromising the definitive position of the extraction hole, which needed to be placed low down, as near as possible to the bottom of the chamber.

3. In case the first pilot hole failed to reach the tunnel because it was placed too high up and too far to the side, a second attempt was made, eventually expanding the intake chamber, involving a new pilot hole that was drilled in a lower, more central position and succeeded in reaching the opposite face.

4. Thanks to this new reference point, it was possible to further reduce the thickness of the screen, without risking its collapse, and to dig the extraction hole near the bottom of the wall, in the point held to be most suitable for drawing off water from the tunnel-cistern.

The loose stone trenches

As mentioned above, the loose stone trenches (or the loose stone shafts) comprise a long and narrow vertical shaft (sometimes with a circular cross section) extending down from the land surface to the depth where the tunnel-cistern was to be built. Investigations so far have revealed depths ranging from 2 to 4 metres.

The resulting rock-cut container was filled with rubble allowing the runoff from the surrounding land to percolate downwards through gravity and end up in the cistern below. In this way, the water collecting in the various branches of the tunnels would be distributed uniformly throughout the system of underground galleries as if in a single reservoir, gradually diminishing whenever water was drawn off. For this reason, water circulation was prevalently vertical, along with a secondary horizontal flow caused by the movement of the water towards the extraction hole, as is the case also in chamber cisterns. As a result, the gradient of the tunnels plays no great role. In fact, in one case (Belvedere tunnel-cistern) there was difference in height at the meeting point between the uphill and downhill sections, evidently caused by a slight error in the digging of the opposite faces, which the tunnel builders had not considered worth correcting.

Methods and sources of water supply

As far as the formation of water reserves are concerned, the results of the investigations carried out in Cappadocia by the Centro Studi Sotterranei over the past twenty-five years, combined with the most recent local rainfall statistics suggest that water was accumulated throughout the year over relatively short periods of time, especially in spring due to the thawing of the snows in late March, as already suggested by Beldiceanu,[18] and to the peak rainfall in late April. The region experiences early winters with extreme temperatures and heavy snow, while there is very little rain during the summer. We therefore think it is likely that the main purpose of these absorption trenches was to capture meltwater, and only occasionally rainwater, which was collected directly or as surface runoff. Considering the different climate conditions over the centuries, which included periods of drought, it is probable that the tunnel-cisterns were designed to collect a sufficient volume of water to meet supply needs during periods of low precipitation which coincided with the highest demand for water. The maximum capacity was probably reached in early May and would have gradually decreased over the summer, when there would have been little or no additional incoming water, reaching minimum levels in October, when rainfall increased again, until about 20th November. Once irrigation needs were reduced and the first snows fell (sometimes from early October onwards), there was also a fall in the demand for water, which was used mainly for domestic use and for livestock, reaching a new minimum level in the following spring. We should also consider the fact that the locals would spent most of their time in their underground dwellings "until the winter passed and the snows had melted".[19]

It is possible that some of the water at least came from the condensation of moisture from the air circulating in the tunnels due to the difference in altitude (even minimal) between the absorption trenches and the downstream access points. Contrary to what one might initially think, it is clear that this water system was not fed by existing aquifers but directly from surface runoff following brief and/or intermittent periods of precipitation.

Lastly, we would like to point out that no trace of plaster has been discovered in the galleries of the tunnel-cisterns, suggesting that the lithological characteristics of the tuff in which they were excavated ensured that water dispersion was negligible once the rock was saturated. It is also evident that there was no surface evaporation of the water stored in the underground reservoir, ensuring no water loss.

1. Beldiceanu-Steinherr 1981, pp. 108-110.

2. *Histories*, Book i, 75.

3. Gilli 1984.

4. Ramsay 1897, pp. 244-246.

5. Cousin 1905.

6. White 1904 (p. 68), mentions the presence of 'snow-pits,' one of which may be located opposite the Göreme Open Air Museum (Açık Hava Müzesi). Snow-pits or 'icehouses,' also widely known in Italy where they were in use until fairly recent times, consist of pits that were filled with compressed snow that would turn into ice though regelation and that would last throughout the summer. The blocks of ice removed from these pits were mainly used to preserve food.

7. Jerphanion 1925.

8. See, for example, Castellani 1994, Bixio et al. 2017.

9. Bukarenko-Dolotov-Kovalev 2011.

10. The ancient underground aqueduct of Uçhisar was first documented in Gilli-Yamaç 2015.

11. For an extensive examination of the different types and of underground refuges, in particular, see, for example, Bixio-Castellani-Succhiarelli 2002, Bixio 2012, Ousterhout 2017.

12. See here, note 6.

13. Ramsay 1897, pp. 244-246.

14. Gilli-Yamaç 2015, pp. 202-207.

15. Refuges and refectories have been documented thanks to various collaborations. See, for example, Lucas 2003 and Bobrovskyy-Grek 2013.

16. See Bukarenko-Dolotov-Kovalev 2011.

17. Millstone-doors are heavy wheel-shaped monoliths, very widespread in Cappadocia where they were used in the event of attacks, along with other defensive devices, to block access to underground refuges and isolate single chambers or entire zones (see Bixio-Castellani 2002).

18. Beldiceanu-Steinherr 1981.

19. From a 13th-century chronicle mentioned by SATHAS 1894 and cited by JERPHANION 1925, p. 7.

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