

Historical, biological and morphological aspects of the Roccarainola qanat in the district of Naples, Italy

G. De Feo, S. De Gisi, C. Malvano, D. Capolongo, S. Del Prete, M. Manco, F. Maurano and E. Tropeano

ABSTRACT

A qanat is an underground channel consisting of vertical shafts connected at their bottom with a sub-horizontal tunnel bringing water from an aquiferous stratum, with a slight downward slope useful for the water tapped to run down it and into the open air by gravity. Qanats were first developed in Kurdistan as a side result of mining activity by the early millennium B.C. at the latest. Qanats exist in more than 34 countries all over the world, but most are concentrated in present day Iran. In Italy, Sicily is usually cited for its “Ingruttati”, but also in the Campania Region, there are some qanats (“Qanate”). As a matter of fact, this paper describes the historical, biological and morphological aspects of the Roccarainola qanat located in the district of Naples, in Southern Italy. It dates back to the Roman Ages, but currently the hypogean environmental condition misrepresents its ancient state. The animal species discovered forty years ago in the Roccarainola qanat were substantially small sized arthropods, a planaria and some species of bats. The Roccarainola qanat is composed of three branches for a total length of 786 m, with a drop of 9 m. The tunnel slope varies from around 1.70 cm/m to 5.20 cm/m. However, original slopes have been modified due to accumulation of debris and waste. Seventeen vertical shafts (not internally covered) with a circular section were found along the hypogeum. On the average, the shafts are spaced 36.5 m apart.

Key words | biological, drainage tunnel, historical, morphological, qanat, Roccarainola

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INTRODUCTION

A qanat is an underground channel consisting of vertical shafts connected at their bottom with a sub-horizontal tunnel bringing water from an aquiferous stratum (Moosavi 2006; Stiros 2006). The tunnel has a slight downward slope useful for the water tapped to run down it and into the open air by gravity (Hodge 2002). Since the tunnel is underground (hypogeum) evaporation is kept to a minimum and water remains cool even through a hot desert summer (Foltz 2002). In practice, qanats are a form of subterranean aqueduct (Lightfoot 1996).

The term “qanat” comes from an ancient Semitic word meaning “to dig” (Stiros 2006). There are several variations of the name including “Aflaj”, “Cuniculi”, “Falag”, “Falej”,

“Foggara”, “Fogger”, “Ingruttati”, “Kahriz”, “Kareez”, “Karez”, “Kariz”, “Khattara”, “Khattava”, “Madjira”, “Mayon”, “Negoula”, “Qanate”, “Rhettava”, depending on location. In addition, there are numerous differences in spelling (Hodge 2002; Tolle-Kastenbein 2005; Javan *et al.* 2006; Moosavi 2006).

Foltz (2002) stated that qanats were first developed in Kurdistan as a side result of mining activity by early 1000 B.C. at the latest. As a matter of fact, they are mentioned in the records of Sargon II for 714 B.C., who destroyed them but then adopted the technology for use throughout his empire (Foltz 2002). Under the Persian Achaemenids, their use spread to the Mediterranean, Arabia, and

doi: 10.2166/ws.2010.115

Central Asia. Later, from the eight century onwards, Muslims built qanats in Morocco, Spain and Sicily (Foltz 2002; Tolle-Kastenbein 2005).

Therefore, the invention of the qanat is almost certainly to be seen as a by-product of mining, rather than agriculture or irrigation (Hodge 2002; Moosavi 2006). Moosavi (2006) tried to investigate other possible ideas of qanat invention: consecutive excavation of spring outlet after a long drought period, seepage of groundwater into deep diversion channels, drop in piezometric surface of artesian well, mine drainage and spontaneous invention (Moosavi 2006).

A qanat system can be composed of several branches joined forming a network. A single branch is defined on the basis of the following technical parameters: tunnel length, tunnel width, tunnel height, tunnel slope, tunnel roof, tunnel trampling plane, tunnel lateral raceway, tunnel drainage chamber, chamber drainage niches, shafts spacing, shafts height, shafts diameter, flowrate, water quality, stratigraphical settings, etc.

A typical tunnel slope used is 0.5 m/Km (or 0.05 cm/m). While a minimum tunnel section is 0.6×1.2 m, determined by the need of human access (Hodge 2002). A tunnel can be very long. For instance, the Zarch qanat in Iran is 71 Km (Javan *et al.* 2006).

Although the tunnel is the heart and *raison d'être* of the qanat, vertical shafts have most outward and visible manifestation (Hodge 2002). The shafts are usually spaced 20–40 m. Some examples include 28.5 m for the Vazvan qanat in Iran, 33.6 m for the Zarch qanat in Iran, 40 m for the Ocana qanat in Spain, 42.4 m for the Moon qanat in Iran (de Bustamante *et al.* 2006; Javan *et al.* 2006). The Gonabad qanat in Iran is an exception from this standard with 77 m of shafts spacing. Moreover, the Gonabad qanat is also the deepest qanat. As a matter of fact, the depth of the mother shaft is 300 m (Javan *et al.* 2006).

It is difficult to generalise on the outlet flowrate of a qanat (Hodge 2002), but some average values can be pointed out. For instance, Javan *et al.* (2006) furnished several average values for Iranian qanats: 32 L/s for the Vazvan qanat, 50 L/s for the Moon qanat, 150 L/s for the Zarch qanat and Gonabad qanat, 350 L/s for the Dehno qanat.

Qanats exist in more than 34 countries all over the world, but most are concentrated in present day Iran, which

has about 30,000 active systems with a total annual discharge of about 9 billion m³ (Moosavi 2006).

In Italy, Sicily is usually cited for its “Ingruttati”, but there are some qanats (“Qanate”) in the Campania Region, even though they were not known. As a matter of fact, in this paper the historical, biological and morphological aspects of a qanat located in the district of Naples, in Southern Italy are described.

The investigated qanat is in the Village of Roccarainola which is located along the south slope of the Partenio massif, in the Campania Region. The Authors performed a speleological exploration of the Roccarainola qanat realising a detailed map and profile of the several branches of the qanat.

This is a preferential point of view because it dominates the Campania Plain between Campi Flegrei and Vesuvius. Pyroclastic deposits from Somma-Vesuvius volcanic activities diffusely cover the limestone slopes, both as primary fall deposits and reworked pyroclastic deposits. The Roccarainola qanat is northeast oriented in relation to the village. It is developed along the piedmont of Monte Maio carbonate relief (altitude of 972 m). Regarding the stratigraphical context, the qanat tunnel an alternate sequence of pyroclastic deposits, reworked pyroclastic deposits and alluvial fan, sometimes with the presence of paleosol horizons (Figure 1).

HISTORICAL ASPECTS

In the District of Naples, the Roccarainola qanat is locally known as “*Acquedotto delle Fontanelle*” (“Small Fountains’ Aqueduct”). It has been very important for local communities for a long time. As a matter of fact, it has been the only drinking water resource until to the ‘50s of the last century when a modern aqueduct was constructed. The qanat has a small fountain of water located near its entrance as well as two other small fountains connected to a brickwork tank, in the principal square of Roccarainola.

Nowadays it is no longer possible to admire the tank because it was knocked down, but only the little fountain on the hill, near the qanat entrance, continues to slowly supply water. Unfortunately, since the intensive activities surrounding the qanat as well as the bad internal

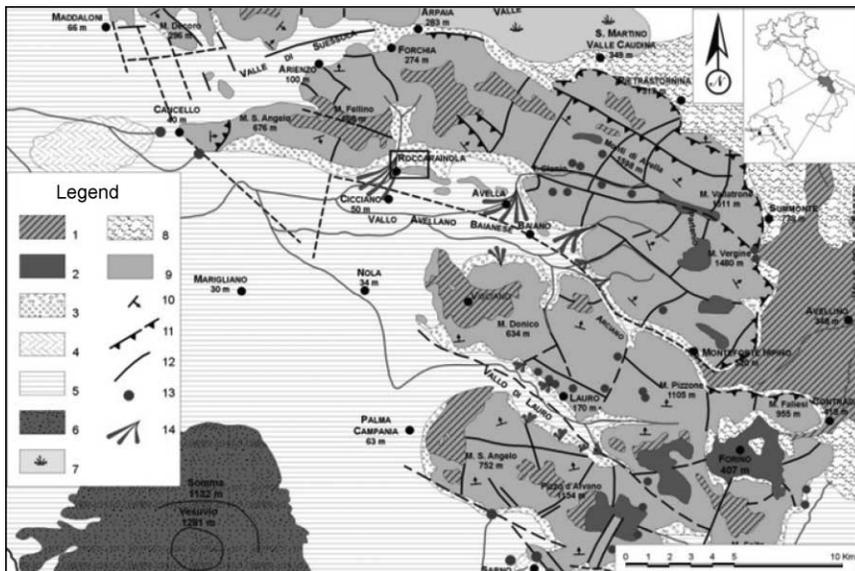


Figure 1 | Geological sketch map of Partenio and Sarno massif (Civita et al. 1970). Legend: 1) pyroclastic deposits; 2) endoreic deposits; 3) slope deposits; 4) travertine; 5) marine, pyroclastic and alluvial deposits; 6) volcanic deposits of Somma-Vesuvius; 7) lacustrine deposits; 8) miocenic flysch; 9) Mesozoic limestone; 10) bedding; 11) reverse fault; 12) fault; 13) spring; 14) fan. The squared area is refer to the location of aqueduct.

environmental quality and the heavy groundwater pollution, the water of the small fountain is not drinkable.

In a little village, an aqueduct plays a fundamental role, especially in a rural area. As a matter of fact, the Roccarainola qanat has had several pages of local history written about it.

The Roccarainola qanat appeared for the first time in literature in a treaty of hydraulics at the beginning of the last century. In fact, Masoni (1924) presented the Roccarainola qanat as a Roman aqueduct, highlighting the ability of the Romans in obtaining water both from surface sources (river, lakes, springs) and groundwater by means of drainage tunnels.

D'Avanzo (1943) stated that the Roccarainola qanat was probably not constructed by the Romans but during the Middle Ages in order to furnish the nearby Norman castle. D'Avanzo (1943) based his statement on the fact that in the Roman Ages near the area of the qanat there were not any important cities. Moreover, the nearby city of Avella and Nola were furnished by other aqueducts (De Feo & Napoli 2007).

Capolongo (1967), in a biologic dissertation, reported the statement of D'Avanzo as well as a first detailed description of the Roccarainola aqueduct, with a schematic plan of tunnels and distribution of vertical shafts. Five years

later, in another biological study of the same underground environment (Capolongo 1972), the same Author recognized in the Roccarainola tunnels the typical structure of a qanat. Finally, in 1976, Capolongo (1976) definitively dated the Roccarainola qanat back to the Roman Ages because it was realized in an area (of medium altitude) with an intensive agricultural activity, but without any natural springs. As a matter of fact, several ruins of *villae rusticae* as well as other archaeological materials were found in the same area which was also crossed through by the important pass of "Vado di Carpine" between via Appia, in the north, and via Popilia, in the south (Figure 2).

BIOLOGICAL ASPECTS

The biotic community (biocoenosis) of the Roccarainola qanat was studied between 1960 and 1970, when the tunnels were sufficiently clean and maintained. As a matter of fact, at that time people usually took water from the continuous flow of the little fountain near the qanat entrance (Capolongo 1967).

Nowadays, it is impossible to take biologic samples because the underground tunnels are in a derelict state, with a lot of materials and waste dumped inside the qanat.

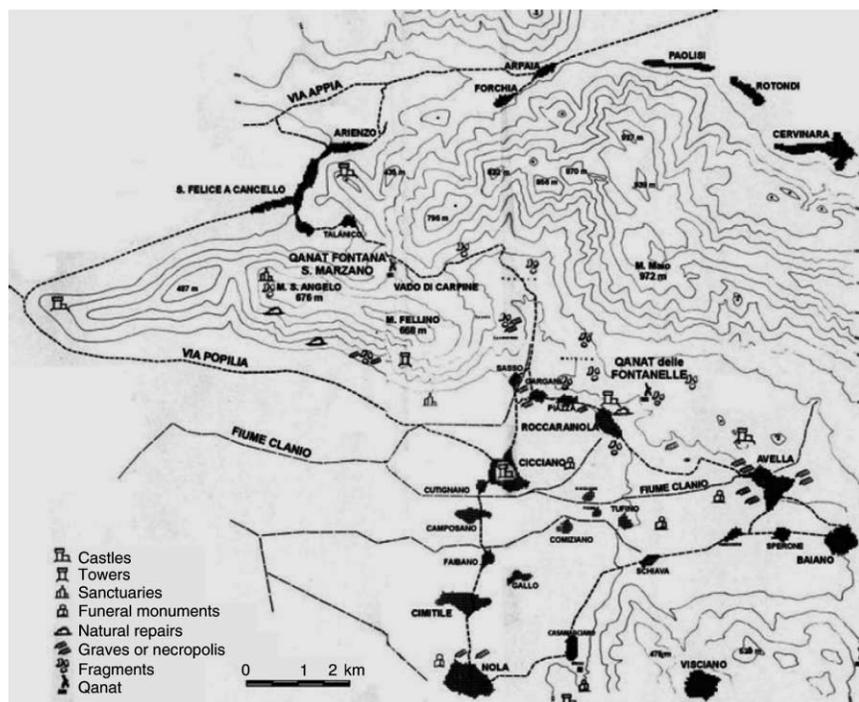


Figure 2 | Archaeological map of Roccarainola area (Capolongo 1976).

Moreover, several branches of the qanat are almost completely flooded due to the accumulation of discards in correspondence of the vertical shafts. In other words, the hypogean environmental condition misrepresents the ancient state of the Roccarainola qanat. Finally, the absence of a shutter in correspondence to the entrance produces several air flows due to the vents of the vertical shafts.

The animal species discovered forty years ago in the Roccarainola qanat were substantially small-sized arthropods, a planaria (in the clear and slowly flowing water) and some species of bats. In particular, the following species were found:

- (a) coleopteran (carabid coleopteran *Actenipus acutangulus* Schauf., tenebrionid coleopteran *Blaps gibba* Cast., sylvph coleopteran *Choleva sturmi* Ch. Brisout);
- (b) orthopteran (*Dolichopoda geniculata* Costa, *Gryllo-morpha dalmatina* Ocsk.);
- (c) caddis fly (*Stenophilax mucronatus* Mc. L.);
- (d) diplopoda (*Callipus sorrentinus* Verh.);
- (e) opilionid (*Trogulus* sp., *coriziformis* C. L. Koch);
- (f) spider (*Amaurobius ferox* Walk., *Meta* sp., *Tegenaria parietina* Four.);

- (g) planaria (*Dugesia* sp.);
- (h) chiropteran (*Rhinolophus ferrumequinum* Schreber, *Rhinolophus hipposideros* Bechstein).

The composition of the biotic community pointed out the presence of a self sufficient ecosystem, with predators and preys. It is important to underline troglomorphy of the most part of species discovered, usually present in ancient underground caverns as well as in vestibule zones of natural caves and an underground environment.

The most diffuse specie was the *Dolichopoda* grasshopper, roving on the walls with its long legs and horns. On the other hand, bats were hung on the tunnel vault, wrapped in their loose patagium.

MORPHOLOGICAL ASPECTS

The Roccarainola qanat is schematically composed of two principal branches. One branch is developed in a north-northeast direction (“North branch”), while another branch goes east (“East branch”) (Figure 3). Another branch starts from the “East branch” and heads in a northeasterly direction

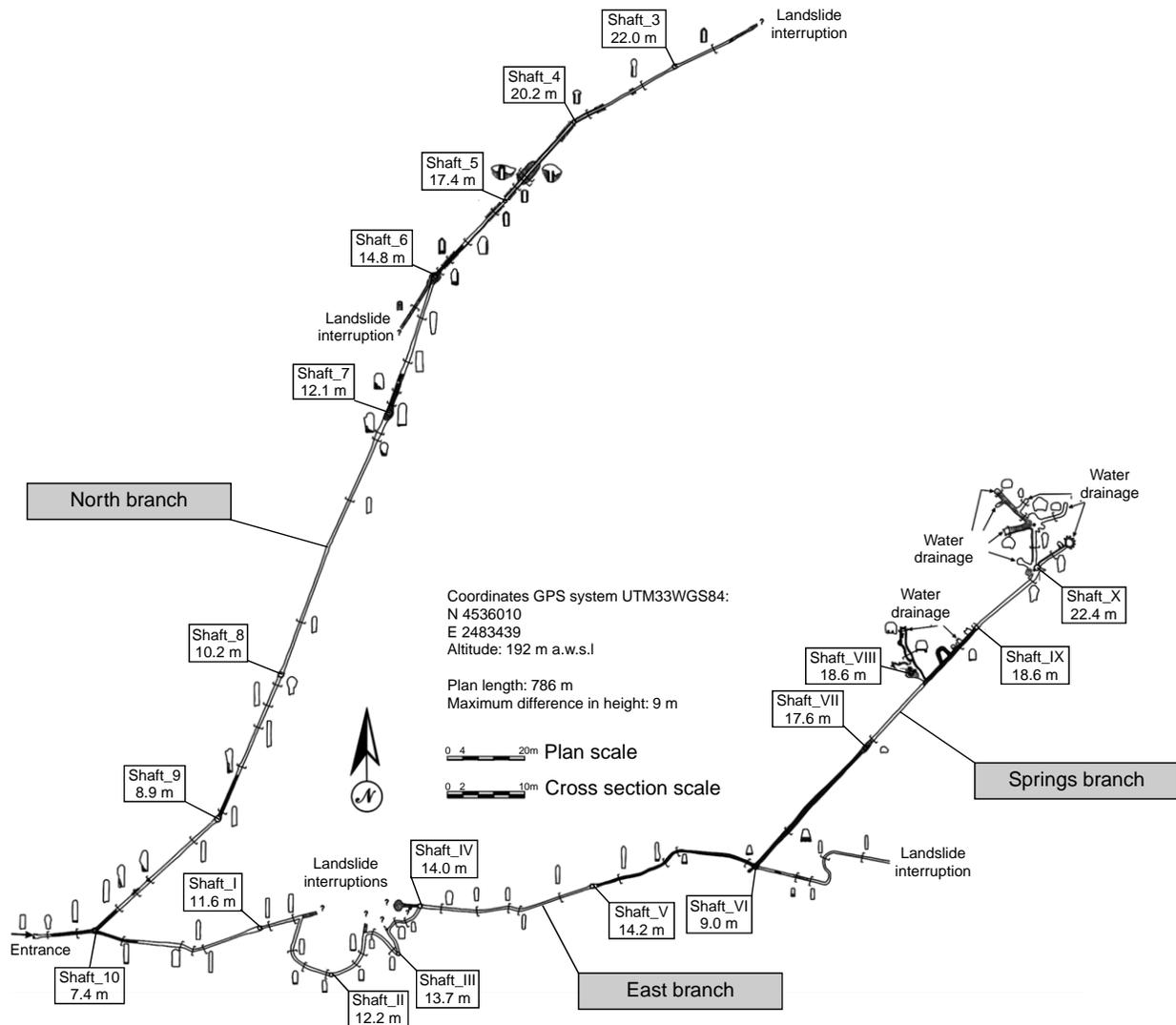


Figure 3 | Roccarainola qanat map (Modified from Capolongo *et al.* 2008).

(“Springs branch”). Globally, the hypogea has a total length of 786 m, with a drop of 9 m. However, the presence of some landslide obstructions probably indicates a greater length.

Since water flows into an open channel, the slopes are low. In particular, slope values vary from around 1.70 cm/m in the “East branch” and in the “Springs branch” to 5.20 cm/m in the “North branch”. However, original slopes have been modified due to accumulation of debris and waste, especially in the “North branch” (Figure 4).

Seventeen vertical shafts with a circular section were found along the hypogea. They are not internally

covered. The primary deposits are mainly constituted of the several (continuous or not) pumice and ashy layers that combine in extremely variable stratigraphical settings. While the secondary deposits (reworked by sheet wash, mass-wasting and fluvial processes) are mainly found as debris. Obviously, the pyroclastic deposits originated from the explosive phases of the Somma-Vesuvius volcanic complex activity.

On average, the shafts are spaced 36.5 m apart. While the maximum distance is 73.2 m between shafts number 8 and 7 (in the “North Branch”) as well as the minimum distance is 17.8 m between shafts number III and IV

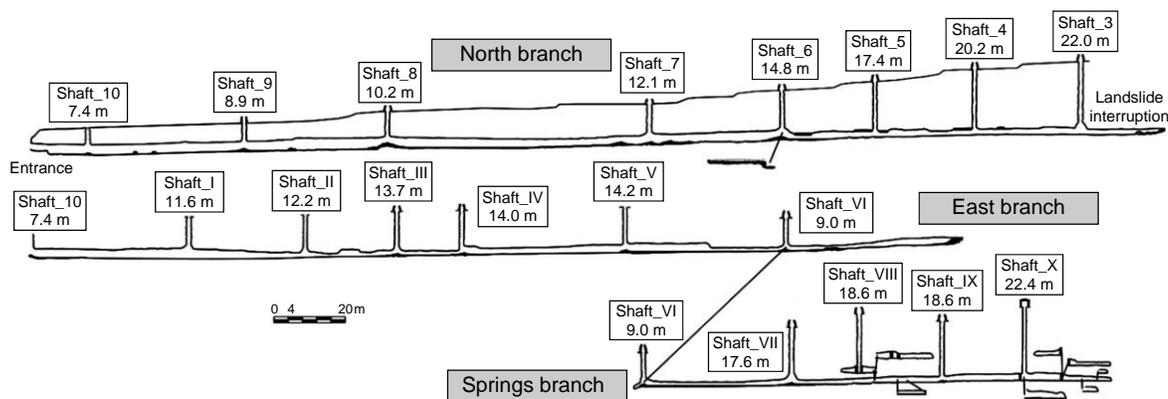


Figure 4 | Roccarainola qanat profile (Modified from Capolongo et al. 2008).

(in the “East branch”). It is worth noting that the average distance between the two subsequent vertical shafts is equal to 35 m which is the spacing value recommended by *Vitruvius* for a Roman aqueduct (Hodge 2002). The depth of the shafts increases progressively going further from the outflow, the last one being the deepest. As a matter of fact, shaft number 10 (the nearest to the entrance) is only 7.4 m deep, while shafts number 3 (the last one of “North Branch”) and X (the last one of “Springs branch”) are respectively 22.0 m and 22.4 m deep. On average, the shafts are 14.7 m deep.

On the ground, the brickwork mouth of the vertical shafts are well preserved. Angular mouths have been recently redone, while truncated cone and circular pseudo-vault mouths are the oldest (Figure 5a).

Over the collapsed stretch of the “North branch”, other two vertical shafts were found on the ground, already reported in Capolongo (1967). In particular, all the vertical shafts have been numbered according to Capolongo (1967).

The “North branch”

Fifteen meters over the qanat entrance, there are the interceptions between the “North branch” and “East branch”, in correspondence to shaft number 10. As shown in Figure 5b, there is a diffuse environmental degradation. Water is conveyed into a stretch, which cannot be inspected, through a PVC piping probably furnishing the small fountain near the entrance. Over the waste deposited in correspondence to the base of shaft number 10, the roots

of a fig-tree along the shaft walls are creating serious problems to the stability to the tunnel.

As shown in Figure 5c, the first part of the “North branch” has a regular section with the walls and full-centre arch vault which is not covered. The average height is 2,7 m, while the width is 60–70 cm. The trampling plane is covered by microgours (typical speleothems due to the water run off on the floor of hypogean) which also clogged the lateral raceway for the water run-off. Near shaft number 8, the height of the tunnel is less, with traces of an enlargement of the original section being similar to other points.

In correspondence to each shaft base, there is always waste dumping. There are falling rocks from the walls between shafts number 7 and 6, probably due to soil pressure discharge. Lithology is characterised by pyroclastic deposits (affected by paedogenesis) occasionally with clay.

In correspondence to shaft number 6, debris obstructs a tunnel not found before in Capolongo (1967). This newly discovered stretch is 30 cm in height with a width of 50 cm and goes on for 16 m. It is not clear whether it is a lateral branch collapsed or simply a mistake during construction. The new stretch is separated from the principal branch by means of a low dry-wall and this means that it was probably used as a stocking deposit for excavated materials.

As shown in Figure 5d, from shaft number 6 towards the end of the “North branch”, both the walls and vault were covered due to the bad lithological condition. This technical solution was adopted only in this part and it is present neither in the “East branch” nor the “Springs branch”.

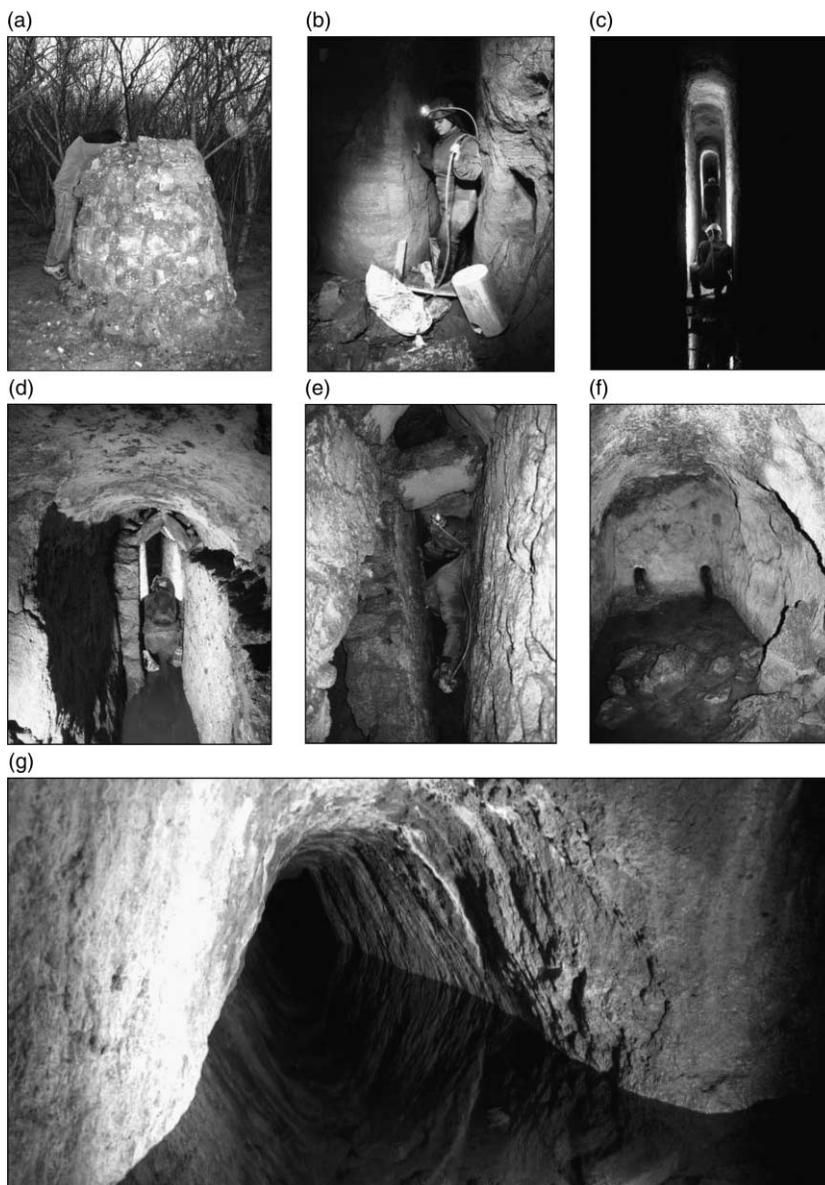


Figure 5 | (a) Ancient walling shaft along the path of North branch; (b) Intersection between North branch and East branch under shaft n. 10; (c) Typical cross section of North branch early sector; (d) Contact between the sector of aqueduct without walling and the sector with walling and gabled roof; (e) Aqueduct wall break and collapse of the vault at the bottom of North branch; (f) Niche for drainage of watertable; (g) View of initial sector of Springs branch (Capolongo *et al.* 2008).

Starting from this point, the dimensions of the sections dramatically diminishes (1.4 m height, 40 cm width). In correspondence to some sections, there is a narrowing at the base probably due to lateral clay earth pressure. The tunnel has a gabled roof and the walls are covered brickwork. Both the roof ashlars and wall bricks were realized with autochthonous materials excavated from the tunnels.

Between shafts number 5 and 4, there is a lateral widening of the section where the “skeleton” of the brickwork covering is partially insulated and not held on the trampling plane, while the roof is locally shored up with block piles.

As shown in Figure 5e, the brickwork covering is ruined and partially occupies the section due to lateral earth pressure. After some meters, the tunnel is completely obstructed due to a landslide.

The “East branch”

The first part of the “East branch” has a regular section. Both the roof and walls are not covered. The tunnel section is 2.3–2.7 m high with a width of 50–90 cm. At the base of the section, the lateral raceway for water run-off is almost completely obstructed from calcite crust. Occasionally, the tunnel has a pseudo-glabled roof, while the section narrows in this stretch.

As shown in Figure 5g, the tunnel becomes a narrow passageway with a width of 50 cm and 1 m high. There are several interruptions due to local landslides that probably led the constructors to modifying the original designed path. Starting from the first obstruction on the main branch, the tunnel suddenly deviates south-southwest and after gradually describing a huge arch that goes north-northeast. A second obstruction forces a new marked southeast deviation for around ten meters as far as shaft number III where the tunnel rotates about 270° northwest. After 6 m another obstruction causes a new significant deviation heading northeast as far as the main branch in correspondence to the vertical shaft number IV. On the west side of shaft number IV, there is the obstruction set in correspondence to the extension of the main branch towards shaft number I.

After the described narrowing of the tunnel, the section assumes dimensions useful for the passage of a person in an erect position (1.8–2.4 m in height, 60 cm in width) with slight deviations for the following 100 m as far as the interception with the “Springs branch”. From shaft number VI, heading northeast, there is the “Springs branch” (Figure 6), while heading east, there is a dark airless alley which ends interrupted by a landslide after 50 m.

The “Springs branch”

The first 40 m of the “Springs branch” have a trapeze section as far as shaft number VII, with a maximum height of 1.3 m and a base of 1.2 m. After around 30 m, on the right side of the tunnel there is a chamber and then, on the main branch, there are several niches intercepting water. From this point onward, water seepage and drainage sketch start. Over the chamber, there is shaft number VIII. In particular, the chamber has an irregular form with several niches and holes in correspondence to the walls base realized in order



Figure 6 | (a) Chamber under the shaft number X with the drainage tunnel of last sector of the Springs branch; (b) Particular of the drainage chamber (Capolongo *et al.* 2008).

to increase the drainage surface. Analogously, in the main branch, as far as shaft number IX, there are 4 niches and a small lateral meander. The niches are around 1 m in width, with a height of 0.9–1 m and with two rectangular holes on the bottom reaching over two meters in depth. Walls of the niches are often covered by a limestone stratum (Figure 5f).

After 50 m, there is the final stretch of the qanat under shaft number X. The final stretch ends in a chamber with several drainage tunnels and niches dug into the rock similar to those described above (Figure 6a). One of these drainage tunnels ends in a little ellipsoidal chamber with 8 holes near the walls base conveying water in the lateral raceways (Figure 6b).

CONCLUSIONS

The aim of this work was to investigate the historical, biological and morphological aspects of the Roccarainola qanat in the District of Naples, in Southern Italy.

The following particular outcomes can be stated:

- The Roccarainola qanat dates back to the Roman Ages because it was realized in an area with an intensive agricultural activity, but without any natural spring as well as several ruins of *villae rusticae* being found;
- Currently the hypogean environmental condition misrepresents the ancient state of the Roccarainola qanat;

- (c) The animal species discovered forty years ago in the Roccarainola qanat were substantially small-sized arthropods, a planaria and some species of bats;
- (d) The Roccarainola qanat is made up of three branches with a total length of 786 m, with a drop of 9 m. However, the presence of some landslide obstructions probably indicates a greater length;
- (e) The tunnel slope varies from around 1.70 cm/m to 5.20 cm/m. However, the original slopes have been modified due to the accumulation of debris and waste;
- (f) Seventeen vertical shafts (not internally covered) with a circular section were found along the hypogeum. On average, the shafts are spaced 36.5 m apart.

While, the following general outcomes on qanats can be pointed out:

- (g) Qanats were first developed in Kurdistan by early 1000 B.C. at the latest;
- (h) The invention of the qanat is almost certainly to be seen as a by-product of mining, rather than agriculture or irrigation;
- (i) Qanats exist in more than 34 countries all over the world, but most are concentrated in present day Iran, which has about 30,000 active systems;
- (j) In Italy, Sicily is usually cited for its “Ingruttati”, but also in the Campania Region there are some qanats (“Qanate”) even though they were not known of.

ACKNOWLEDGEMENTS

The authors wish to thank dr. Sacha A. Berardo for his precious contribution.

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