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WATER TUNNELS OF GÜVERCINLIK VALLEY (CAPPADOCIA – TURKEY)

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In memory of Jean-Pierre Mairetet who explored the tunnel in 1984.

Abstract
The region, known as Cappadocia and, located in the borders of four provinces of Turkey today, has witnessed continuous settlement up to now. Tuffaceous rocks spewing out of the active volcanoes in the late Pliocene and Pleistocene period in the region were used for many different purposes such as houses, barns, churches, burrowing by the locals. There are also underground cities for shelter and hiding. Water and irrigation requirement of the local people has also been solved by troglodyte methods. Because there is not enough water on the plains of Cappadocia, only dry agriculture can be carried out. Water exists only in the valleys and the main agriculture lands are inside those valleys. In ancient times, the need of water for irrigation was provided by the tunnels within tuffaceous rocks in those valleys. At first sight, it may seem illogical to take the water flowing on the surface into a long tunnel on the wall of a valley which needs a tremendous effort to dig. But, apart from having a continuous and controlled water supply and irrigation of the agricultural lands, those tunnels should also have been excavated to decrease the surface water flow in order to widen the efficient agricultural lands in the valleys which are already narrow and also to protect the valleys from the floods. There is probably at least one water tunnel in each valley of Cappadocia but only four of them have been extensively explored up to now. The water tunnels system, located in Güvercinlik (Pigeon) Valley in Uçhisar is probably the last of two (or possibly three) different water tunnels excavated in different dates in this valley besides being the longest one known. With a total length of 3600 meters, 51 separate surface connections and several side tunnels, that main water channel is a marvelous example of hydraulic engineering of Middle Ages or older times.
Keywords: Cappadocia; hydraulic tunnel; water tunnel; underground channels

Riassunto
La regione conosciuta come Cappadocia, situata al confine di quattro province dell'odierna Turchia, è testimone di insediamenti ininterrotti fino ad oggi. Le rocce tufacee, prodotte dai vulcani attivi nel tardo Pliocene e Pleistocene nella regione, sono state scavate dalle popolazioni del luogo ed utilizzate per diversi scopi, come abitazioni, fienili, chiese e città sotterranee realizzate per riparo e nascondiglio. Anche la necessità di acqua per irrigare è stata superata e risolta con "metodi trogloditici". A causa della carenza di acqua, sulle pianure della Cappadocia possono essere impiantate solo coltivazioni a secco. L'acqua scorre solo nelle valli, dove si trovano i principali terreni agricoli. Nei tempi antichi la necessità di acqua per irrigare è stata risolta con la realizzazione di cunicoli scavati all'interno delle rocce tufacee in quelle valli. A prima vista può sembrare illogico prelevare l'acqua che scorre sulla superficie immettendola in un lungo cunicolo sulla parete di una valle, per gli enormi sforzi connessi alle operazioni di scavo. Ma in tal modo si otteneva l'irrigazione continua e controllata delle terre destinate all'agricoltura e le gallerie erano anche funzionali a diminuire la portata dell'acqua di superficie, al fine di ampliare la superficie destinata a coltivativo e proteggere le valli dalle inondazioni. Oggi tutte le valli della Cappadocia conservano uno o più cunicoli, ma solo tre di essi sono stati fino ad ora estensivamente esplorati. Il sistema delle gallerie idrauliche della Valle di Guvercinlik (Piccionaia), a Uchisar, è probabilmente l'ultima di due (o forse tre) gallerie idrauliche scavate in date differenti in questa valle, oltre ad essere la più lunga attualmente nota. Con una lunghezza totale di 1840 metri, 14 collegamenti con la superficie e diverse gallerie laterali, il condotto principale rappresenta un meraviglioso esempio di ingegneria idraulica di epoca medievale.
Parole chiave: *Cappadocia, galleria idraulica, canali sotterranei.*

Introduction

Hundreds of underground aqueducts from roman period have been explored in Italy (Parise, 2011; Parise et al, 2009, 2013) and in the other Mediterranean countries. The longest one is the Qanat Firaun that extends on 170 km from Dille (Syria) to Gadara (Jordan) with a 94 km long tunnel and several other undergrounds sections (Döring, 2006). In Cappadocia region of Turkey (Fig. 1), the thickness of ignimbrites, which spread to a surface of about 25 000 km^2 as a result of eruptions during Upper Miocene and Pliocene periods, have reached a height of 400 m in various areas. The compressibility of these ignimbrites, which were already low, has been more and more decreased by rainwater due to micro porosity (Topal & Doyuran, 1998). These rocks have created thousands of fairy chimneys through rapid erosion together with thermoclastic effects beside hydraulic effects. Such a formation which is vulnerable to erosion was rapidly carved by rivers flowing on the surface and formed deep and

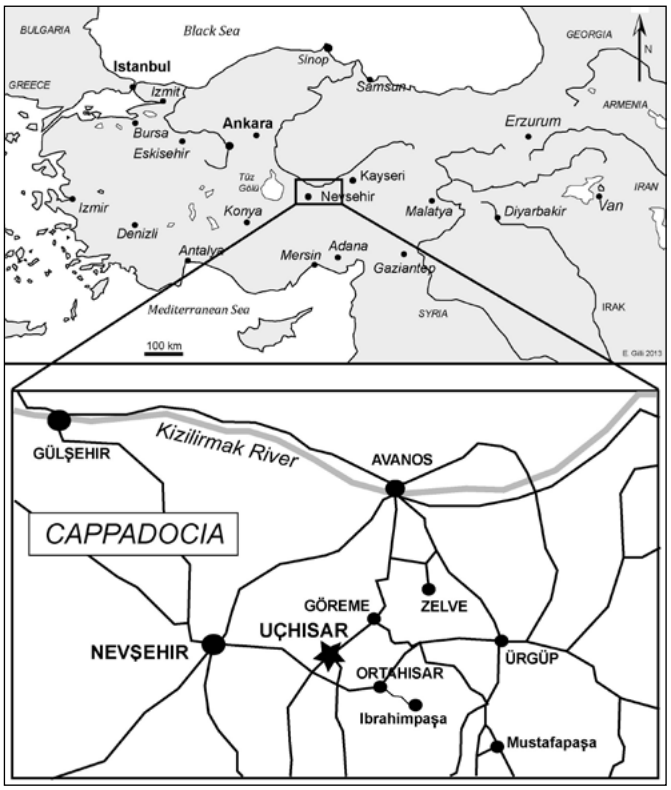

Fig.1: location map of Cappadocia (drawing A. Yamaç).
Fig.1: localizzazione della Cappadocia (elaborazione A. Yamaç).

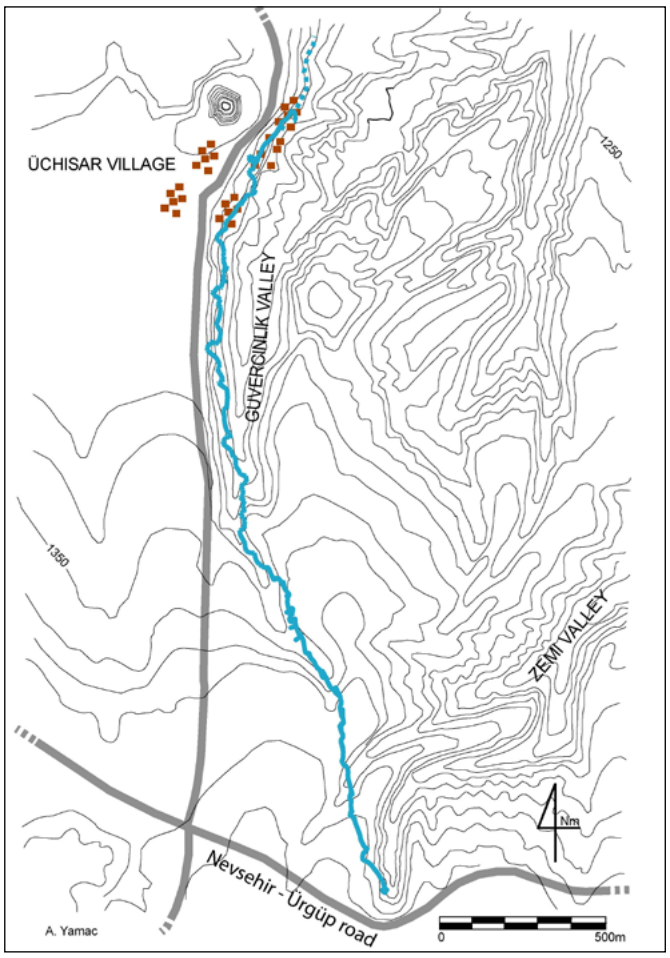

Fig. 2: map of Güvercinlik Valley water tunnel (drawing A. Yamaç).
Fig. 2: mappa dei condotti idraulici della Valle di Güvercinlik (elaborazione A. Yamaç).

narrow valleys in the region. Those deep and branched valleys, formed among broad planes and plateaus, are subject to a same rapid erosion, even today.

There are long water tunnels dug on the valley walls in several valleys in Cappadocia. Because there is not enough amount of water available on the planes over the valleys, only dry agriculture can be carried out. Furthermore, the volcanic based soil fed by alluviums in the depth of valleys is a complete arable land and there are rivers in all the valleys. At first sight, it may seem illogical to take the water flowing on the surface into a tunnel by digging long and difficult water tunnels on the wall of a valley where there was already a river inside. However, there are important reasons for such an effort:

- to feed underground cisterns and fountains in troglodytes settlements;
- to reduce evaporation during the dry season;
- to manage irrigation of the agricultural lands;
- to decrease the surface water flow in order to widen the efficient agricultural lands in the valleys;
- to avoid erosion of the valley slopes and to protect crops in the valleys due to fast discharge of meteoric waters.

Those ancient water tunnels generally catch groundwater or collect the water from the springs and/or reservoirs from the beginning of the valley. Due to the continuous erosion, new tunnels were required to be dug because of the corruption of the previous tunnels through the ages.

As the time passed, several new water tunnels were dug in the same valley. Today, looking at the remains from the surface, it is impossible to detect how many times this process was repeated. Similarly, to date what is left of these tunnels is also nearly impossible.

In this article, we describe the results of our exploration and survey of water tunnels in Güvercinlik (Pigeon) Valley, near the town of Uçhisar in Cappadocia. This tunnel system, that was discovered and partially explored in 1979 (Gilli, 1984), shows great similarity with water tunnels in other nearby valleys. Researches were executed in Meskendir Valley (Castellani, 2002; Burri & Petitta, 2005), Zemi Valley (Bukarenko *et al*., 2011), Kılıçlar Valley and Göreme Valley (Bixio *et al*, 2012) When compared with these other tunnels, Güvercinlik (Pigeon) Valley Water Tunnel System catches the attention not only by being the longest, but also by having two and even three different tunnels dug in different periods in the same valley. It is also still used by locals to feed underground cisterns in Uçhisar village and contains perfectly preserved terracotta pipes and jars. Some unexplored portions feed small cisterns or reservoirs in the agriculture lands.

Güvercinlik Valley water tunnels

Güvercinlik Valley starts at a point near to the main road at 2.5 km south of Uçhisar Village. At that site the two valleys made a fork; Zemi Valley to the east and Güvercinlik Valley to the west. The name of the latter valley comes from the dovecotes on both walls of

Fig. 3: end cistern of Güvercinlik Valley water tunnel (photo E. Gilli, A. Yamaç).
Fig. 3: cisterna terminale dell'acquedotto della Valle di Güvercinlik (foto E. Gilli, A. Yamaç).

the valley at the northernmost part, near Uçhisar. All of the old houses of Uçhisar Village, located at the end of the valley, were built on the valley walls. The valley begins with a mild slope in the south with depth about 6-10 meters whereas the depth near Chinar Village reaches 40 meters.
The main water tunnel starts from the southernmost part of Zemi Valley, south from the place where Güvercinlik Valley starts. It takes its water from two underground reservoirs very close to the main road (N38° 36.513'; E34° 48.629', elev. 1381 m). The tunnel continues for 3600 meters, with an average slope of 1%, through the western wall of the valley (Fig. 2) and reach the troglodytes settlements of Uçhisar to feed a group of cisterns (Fig. 3) and fountains. It was surveyed on 3500 m and ends on a collapsed zone, close to an exit (N38°37.881'; E34°48.462'; elev. 1309 m). Several parts remain unexplored and the total length is certainly close to 4 km. This length makes it, not only in Cappadocia but in Turkey, one of the longest ancient water tunnels explored and surveyed till now. The main line of the tunnel is continuously 1.40-1.80 m high and its width varies 50-80 cm (Fig. 4). In several parts of the tunnel, two terracotta pipes are observed on the basement. The older one, which is destroyed, is bigger than the most recent one which was probably still in use at the beginning of the 20th century. Those terracotta pipes should probably have been installed in order to prevent ignimbrites erosion and to use at least some amount of water, when the tunnel was no longer benefitted efficiently. Two plastic pipes are now visible, a destroyed white PVC one and a still in use black one. There are 51 surface connections and several branches in the tunnel. It is obvious that the surface connections were used to dig the tunnel. They were probably used for the maintenance of the aqueduct but most of them were closed by important wall to prevent intrusions. The branches were realized for increasing the amount of water in the tunnel by catching groundwater from various directions. More interestingly, in addition to the cisterns in Uçhisar Village, there are four different small reservoirs inside the tunnel. On those points the tunnel is blocked by a wall with a height of half of the total height of tunnel to provide a water accumulation. Those structures should have been thought as a solution to the low amount of water in summer times. Another important observation in Güvercinlik Valley is that several water tunnels portions, dug in the valley at different times, can be seen together and from very close points. Despite many processes of maintenance and restoration, it is certain that ignimbrites are sensitive to erosion, thus the tunnels become unusable after a period of time (Bicchi *et al*, 1995).
For instance, on the north part of the valley, another water tunnel is located on the opposite wall of main water tunnel. Remainings of that other tunnel which can be observed in places, have almost been vanishing completely because of erosion. A small part of it, which is older than the main tunnel and where there are subsidiaries of previous water tunnel located also on the east wall, has been explored and surveyed (Fig. 5). South of this area, it is mostly certain that the holes observed on the completely eroded east walls of the valley belong to another water tunnel (Fig. 6).
Further, it is unclear if those water tunnels, which are located on the east walls of Güvercinlik Valley and which are completely eroded, are follow ups of the old tunnel (partially mapped in Fig. 5) or a third water tunnel. Similar eroded holes also exist in Meskendir Valley (Castellani, 2002) and another hypothesis is that in addition to the underground aqueducts, drainage tunnels were dug to collect rain water and prevent the erosion of crop zones (Burri & Petitta, 2005).
We have no argument to date both the main water tunnel and the older ones. Some studies (Burri, 1996; Burri & Petitta, 2005) suggest the water tunnels in the valleys were excavated between 7th to 13th centuries, but the human settlement in the region dates back to millennia ago (e.g. 11000 years in Aşıklı Höyük village). Thus, roman or older ages are possible. Dating is difficult as no architectural peculiarity or artifact is present to characterize a period time. Furthermore,

Fig. 4: Güvercinlik Valley water tunnel and terracota pipe (photo E. Gilli).
Fig. 4: tunnel idraulici della Valle di Güvercinlik e tubi di terracotta (foto E. Gilli).

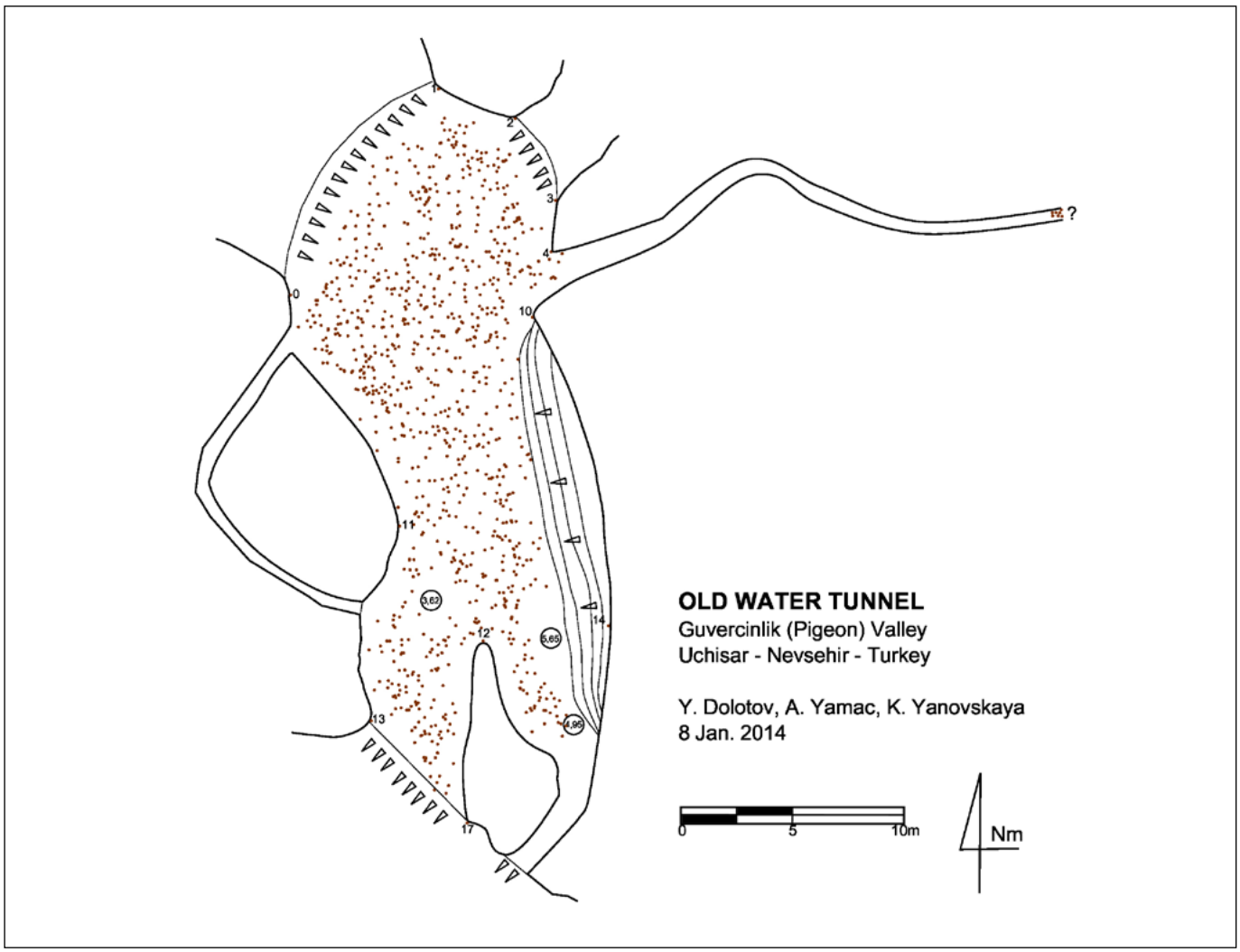

Fig. 5: plan of old water tunnel (drawing A. Yamaç).
Fig. 5: planimetria dell'antico tunnel idraulico (elaborazione A. Yamaç).

such underground structures have been continuously used, repaired and rehabilitated for centuries. The oil lamps used to dig and check the tunnel deposited soot, thus ^{14}C dating could be envisaged in some places.

Techniques

Local people had developed a troglodytes civilization and used to live and work underground. Lighting was provided by oil lamps whose homes are visible in the tunnel. Bigger niches allowed hosting of oil jars (Fig. 7-A). In front of almost each surface connection, the modern pipe is interrupted by a utility hole made of a jar or a pipe element (Figs. 7-A, 8). These places formed sediment traps, windows on the water flow or pressure compensation units.

Digging such an underground structure poses no particular problem because the ignimbrites are easy to excavate and have good geotechnical properties. The two main problems are the cuttings removal, and especially the positioning. Indeed, digging an underground structure whose main axis is more than 3600 meters requires a considerable precision for calculating the directions and slopes.

Engineers have solved both problems by constructing the tunnel by successive portions 50 m long (Fig. 7-B). Based on a precise surface survey, using for instance chorobates, inclined conduits were dug from the bottom of the valley till the desired depth, then the aqueduct was dug upstream and downstream, to reach the next portion. It is possible that the jars, installed on the pipes as utility holes, made it possible to check the water level during the digging work. In most cases, the connection was perfect, but some junctions have been problematic, with vertical or horizontal positioning errors. The workers then had to dig vertical passages or horizontal meanders to reach the neighboring portion. Cuttings were spread in the valley where they contributed to form arable soil. Their volume is estimated to 4000 m^3.

The same techniques was described for Qanat Firaun, but the roman surveyors, made a number of miscalculations, and the water arrived in Gadara slightly too low to feed the cisterns which is easy to understand after a 170 km long distance (Döring, 2006).

Geology

Cappadocian Volcanic Province (CVP) is one of the major volcanic provinces of Turkey. The CVP, terminated and partly transacted by major fault zones, extends for about 300 km southwest-northeast and is surrounded by tectonic basins and massifs of the

Fig. 6: eroded holes on the East wall of Güvercinlik Valley, possibly remnants of an old water tunnel (photo A. Yamaç).
Fig. 6: fori di erosione sulla parete Est della Valle di Güvercinlik, probabili resti di un antica struttura idraulica (foto A. Yamaç).

central part of the Anatolian block (Toprak et al., 1994). Tectonic movements intensively seen in the region caused various volcanic phases with basaltic and andesitic lavas and later ignimbrite deposits which explains the continuous stratigraphic changes of the adjoining areas. There were numerous eruptions during Upper Miocene and Pliocene in the area and the rocks observed around Güvercinlik (Pigeon) Valley belong to the Akdağ-Zelve Ignimbrite formation whose age is around 7.6 million years. Fallout thickness, size and amount of lithic clasts, depositional facies and flow directions of the deposits shows that the source area of this pyroclastic flow is about 6 km north-northeast of Kaymaklı Village and covers a total area of 1.200 km^2 (Schumacher & Mues-Schumacher, 1997; Innocenti *et al*, 1975).

Conclusion

Güvercinlik Valley water tunnel gives valuable information on the difficulties people had for managing water and on the solutions they had developed. Some works are still used today but the lack of maintenance and the absence of integration in local development plans endanger this heritage and restrict the knowledge local people and tourists should have concerning the habits of people living in the region in ancient times towards nature and water use. The diversity of Cappadocian underground water works

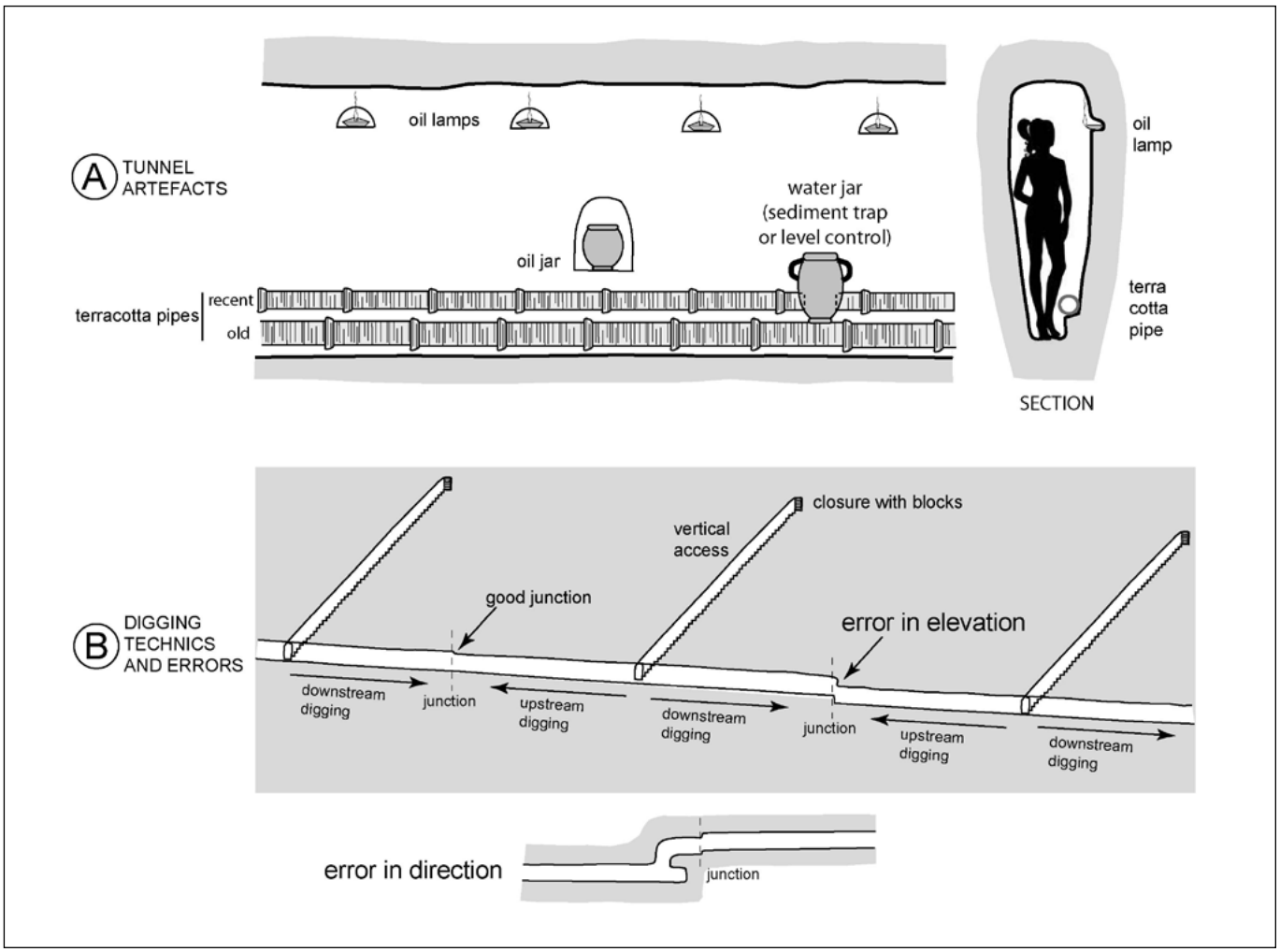

Fig. 7: A) tunnel artefacts like oil lamp niches and terracotta pipes. B) digging technics and some errors at the junctions (drawing E. Gilli).
Fig. 7: A) manufatti scavati, come nicchie per lampade a olio e tubi di terracotta. B) tecniche di scavo e alcuni errori nei raccordi (elaborazione E. Gilli).

(spring catchments, wells, aqueducts, cisterns) should be inventoried and classified. Unfortunately, the water usage techniques of people in Cappadocia, whose history has been evaluated by thousands of years, have not been investigated comprehensively up to now. There are hardly any scientific researches available other than few limited resources about the subject. They need comprehensive scientific surveys and should be protected and carried into future as far as possible. Indeed, in addition to their historical interest, they have an environmental and economical interest by making it possible the preservation of a local agriculture which is an important factor for the environment protection that could benefit to the touristic Cappadocia. Further studies on Güvercinlik Tunnel could focus on a more accurate survey of the valley right wall to determine the exact number of old tunnels and to determine their relative chronology. Dating is also an important objective but this will remain very difficult.

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Fig. 8: jar used as a utility hole on the terracotta pipes (photo E. Gilli).

Fig. 8: vaso utilizzato come pozzetto di ispezione nel tubo di terracotta (foto E. Gilli).

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