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THE GALLERIES OF PALMANOVA (FRIULI-VENEZIA GIULIA, NE ITALY)

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Abstract
In the present contribution we aim to provide new documentation regarding Palmanova, a venetian fortress in Friuli-Venezia Giulia, a region in the NE of Italy, in order to promote the preservation and possible exploitation of this historical and architectural site of great value. In the present paper, we will simply outline the working method adopted, describe the instrumentation used (DISTOX) and the methods utilized for mapping, and give a brief description of the main typologies of underground structures existing in that site: venetian countermine galleries of the ravelins, galleries leading to the napoleonic lunettes, fausee-braye galleries and sally galleries of the bastions. The water supply system of the city (aqueducts and water-locks) and the elimination of wastewater are also described and transferred to the Regional Tecnical Map. The plans of the two most important underground systems are superimposed on the ortophoto of the area. A chapter deals with a film taken by one of the authors during the survey.
Keywords: Palmanova, fortress, galleries, DISTOX.

Riassunto
Il grande lavoro svolto nel 2011 dalla Protezione Civile, che ha liberato la zona antistante le mura della fortezza di Palmanova da un'enorme quantità di vegetali che la infestavano da molto tempo, ha riportato alla luce gli ingressi delle gallerie che, partendo dal fossato, si diramano nel circostante sottosuolo. Questa riscoperta ha fatto sorgere negli amministratori comunali il desiderio di averne una conoscenza dettagliata e precisa per finalità scientifico-culturali e di promozione turistica. A tal fine nel febbraio 2012 è stata stipulata una convenzione fra il Comune di Palmanova e la Commissione Grotte "Eugenio Boegan" (CGEB), il più antico gruppo speleologico del mondo ancora in attività (1883), facente parte della Società Alpina delle Giulie, Sezione di Trieste del Club Alpino Italiano. Numerose uscite hanno permesso agli speleologi di esplorare, documentare e topografare circa 4,5 km di gallerie in parte veneziane ("contromine" dei "rivellini", "sortite" dei "baluardi" ed altre tipologie minori), in parte napoleoniche (gallerie di collegamento alle "lunette"), il sistema di rifornimento idrico della città e quello di eliminazione delle acque reflue. I dati per il rilievo ottenuti con il dispositivo DISTOX, che integra un distanziometro laser, una bussola ed un clinometro, trasmessi in tempo reale ad un palmare, corretti per la declinazione magnetica e l'angolo di convergenza reticolo, vengono successivamente esportati in formato DXF su un PC, dove, con l'ausilio di un programma CAD, vengono utilizzati per restituire pianta e sezione delle cavità. L'Amministrazione Comunale di Palmanova ha finanziato una monografia cartacea con annesso DVD, che illustra i risultati esplorativi e li inquadra storicamente con l'intervento di uno studioso locale. Nella pubblicazione ogni galleria è descritta in dettaglio con dati e fotografie, sia amatoriali che professionali, e la pianta è sovrapposta all'ortofoto della zona. Dettagli di particolare interesse sono illustrati con disegni di sezioni realizzati da uno speleologo del team. Nel DVD le piante sono sovrapposte anche alla CTR in scala 1:5000 e vi è inserito un filmato di livello professionale sul lavoro svolto, realizzato da uno degli autori. E già iniziata l'attività di valorizzazione turistica delle gallerie e di promozione culturale anche al fine del richiesto inserimento di Palmanova nel Patrimonio UNESCO. Palmanova, un luogo affascinante da proteggere e valorizzare, nata per la guerra, può diventare crocevia di turismo, conoscenza e pace. Palmanova, la Città stellata, la Fortezza imprendibile, è sorta nella pianura friulana a partire dal 1593, per volere della Serenissima Repubblica di Venezia per contrastare le invasioni dei Turchi e ancor più le mire espansionistiche degli Arciducali, che le avevano sottratto il controllo della fortezza di Gradisca. La sua cerchia difensiva iniziale, circondata da un ampio fossato, fu costituita da nove "baluardi" a forma di freccia collegati da altrettante "cortine" in tre delle quali si aprono Porta Aquileia (o Marittima) a S, Porta Udine a NW, Porta Cividale a NE. Nei lati ben protetti dei "baluardi" si aprono le gallerie di "sortita", dette "poterne", di dimensioni atte al passaggio anche della cavalleria. Le porte, punti deboli delle mura, nella seconda metà del XVII secolo furono protette da tre "rivellini", terrapieni fortificati di forma pentagonale esterni al fossato. In seguito altri sei furono realizzati a protezione di tutte le "cortine" e costituirono la seconda cerchia difensiva. Nel cuore di tali terrapieni furono scavate ed "incamiciate" con muri di pietra e volte di mattoni o pietra, parecchie lunghe gallerie di "contromina" destinate a contrastare le gallerie di mina con cui eventuali assedianti avrebbero potuto far crollare le mura. In un "rivellino" il sistema di tali gallerie è lungo più di 700 m, altre sono molto più brevi. Sono larghe poco più di un metro ed alte poco meno di due. Quando nel 1797 Napoleone, dopo aver posto fine alla Repubblica di Venezia con la sua cessione all'Austria, visitò la fortezza, ne fu affascinato e ritornatovi nel 1806 da Imperatore, iniziò la realizzazione della terza cerchia di fortificazioni, dette "lunette", molto più esterne vista l'aumentata gittata dei cannoni dell'epoca. Ne furono realizzate solo sei. Il nucleo centrale delle lunette è costituito dalle "caponiere", fortilizi a due piani protetti da muri in pietra spessi un metro e mezzo, dotati

di feritoie e che presentano ampie volte in mattoni raccordate con grande maestria. Solo dal piano superiore si può accedere, con due scale a chiocciola e due gallerie inclinate convergenti, alla galleria che collega il fortilizio al fossato. Interessante anche il sistema di drenaggio delle acque dai terrapieni con cunicoli alquanto claustrofobici. Nella parete esterna del fossato (controscarpa) si aprono gli ingressi di tali gallerie veneziane e napoleoniche ed anche numerosi accenni di scavo di altre, anch'esse veneziane, crollate o molto più probabilmente mai realizzate. Nella zona ad E di Porta Udine un sistema di gallerie ed acquedotti in parte monumentali, permetteva, grazie ad un sistema di chiuse, di regolare l'afflusso delle acque in città e nel fossato. Nella zona S di Porta Aquileia un complesso di altre gallerie e chiuse scaricava le acque reflue nel fossato e da qui al canale Taglio, che le portava al mare con un percorso di svariati chilometri. Lo stato di conservazione di molte gallerie sembra generalmente buono anche per merito della dissoluzione del carbonato di calcio della ghiaia calcarea che, concrezionandosi negli interstizi delle volte, le ha consolidate. Alcune invece sono di difficile accesso o del tutto interrotte da imponenti accumuli di ghiaia e terriccio provenienti da parziali crolli e fluitati da importanti flussi idrici nei periodi piovosi.
Parole chiave: *Palmanova, fortezza, gallerie, DISTOX.*

The project "Palmanova Underground"

In 2011 the Italian Civil Protection removed all the vegetation infesting the venetian fortress of Palmanova, a town in province of Udine, in Friuli-Venezia Giulia region, in the NE of Italy, bringing to light the accesses to galleries that branched out from the ditch towards the surrounding underground. This discovery triggered the interest on behalf of the municipal administrators who then desired to acquire a detailed and precise understanding of the galleries for both scientific and cultural purposes and in order to promote tourism.

Thus, an agreement was signed between the Municipality of Palmanova and the Cave Commission 'Eugenio Boegan' (CGEB), one of the first speleological groups (1883) of the world and which is still active, belonging to the Alpine Society of the Giulie, the Italian Alpine Club of Trieste.

Numerous expeditions followed, allowing speleologists to explore, document and produce topographic maps for over 50 galleries of various sizes for a total of about 4.5km. Part of the galleries are Venetian ('ravelin countermines', 'bastion sallies' and other minor typologies) and part are Napoleonic (galleries leading to the "lunettes"). The water supply system of the city and the elimination of wastewater was also investigated.

Cavities were identified with a code (e.g. 4m1), adopting the Civil Protection method, which had divided Palmanova into 9 sectors when cleaning the area, each corresponding to the 'bastions' (b) and sub-areas incorporating the 'ravelins' (r), 'lunettes' (m) and 'fausse-braye' (f). Basically, with rare exceptions, each sector has a ravelin gallery, a lunette gallery, a fausse-braye gallery and a sally gallery. Furthermore there are two similar gunpowder depots, one of which is situated above the ravelin and the other above the lunette.

The publication "The Galleries of Palmanova"

The Town Council of Palmanova decided to fund the monograph by Luca Piani, Fabio Feresin, Silvia Savi and Augusto Diqual (Piani L. *et alii*, 2014), with an attached DVD that included a professional film on the activities carried out. The publication outlines the results of the explorations, placing these in their historical framework with the contribution of a local scholar. The completed product was presented on March 20, 2014 at the Hall of Honour in the Town Hall of Palmanova at the presence of the Vice President of the Friuli Venezia Giulia Region and the local authorities.

Each tunnel is described in detail in the monograph with data and photographs, both amateur and professional, and the plan is superimposed on the orthophoto of the area. Details of particular interest are illustrated with section drawings carried out by one of the team's speleologists.

The plans on the DVD have been overlaid on the Regional Technical Map.

This paper includes the drawings of the most interesting sectors of Palmanova.

Exploitation of the galleries for tourist development and cultural promotion has already started. This was also a requirement for inserting Palmanova in the UNESCO world heritage.

A brief description follows illustrating the structures in the areas which were subject to speleological investigations.

Palmanova

The star-shaped city, an impregnable fortress arose in the plains of Friuli in 1593 at the behest of the Serenissima Republic of Venice in order to counteract the invasions by the Turks and, even more, the expansionist ambitions of the Archdukes, who had taken control of the fortress of Gradisca.

Its initial defensive city walls, surrounded by a wide ditch, was composed of nine arrow-shaped bastions connected by the same amount of 'curtain walls', three of which had gates: the Porta Aquileia (or Maritime) to the S, Porta Udine to the NW and Porta Cividale to the NE. The gates, intentionally monumental in order to symbolize the city's prestige, were soon considered to be weak spots, so that in the second half of the XVII century they were protected by three 'ravelins', fortified pentagonal ramparts placed exterior to the ditch. Later, other six ravelins were built in order to protect all the curtain walls (Fig. 1).

The ravelin and countermine galleries

At the heart of these ramparts many 'countermine' galleries were built with stone walls and brick or stone vaults (Figs. 2 and 3) in order to counteract eventual mine galleries that besiegers could have built to put down the walls; these siege techniques were very common at the time.

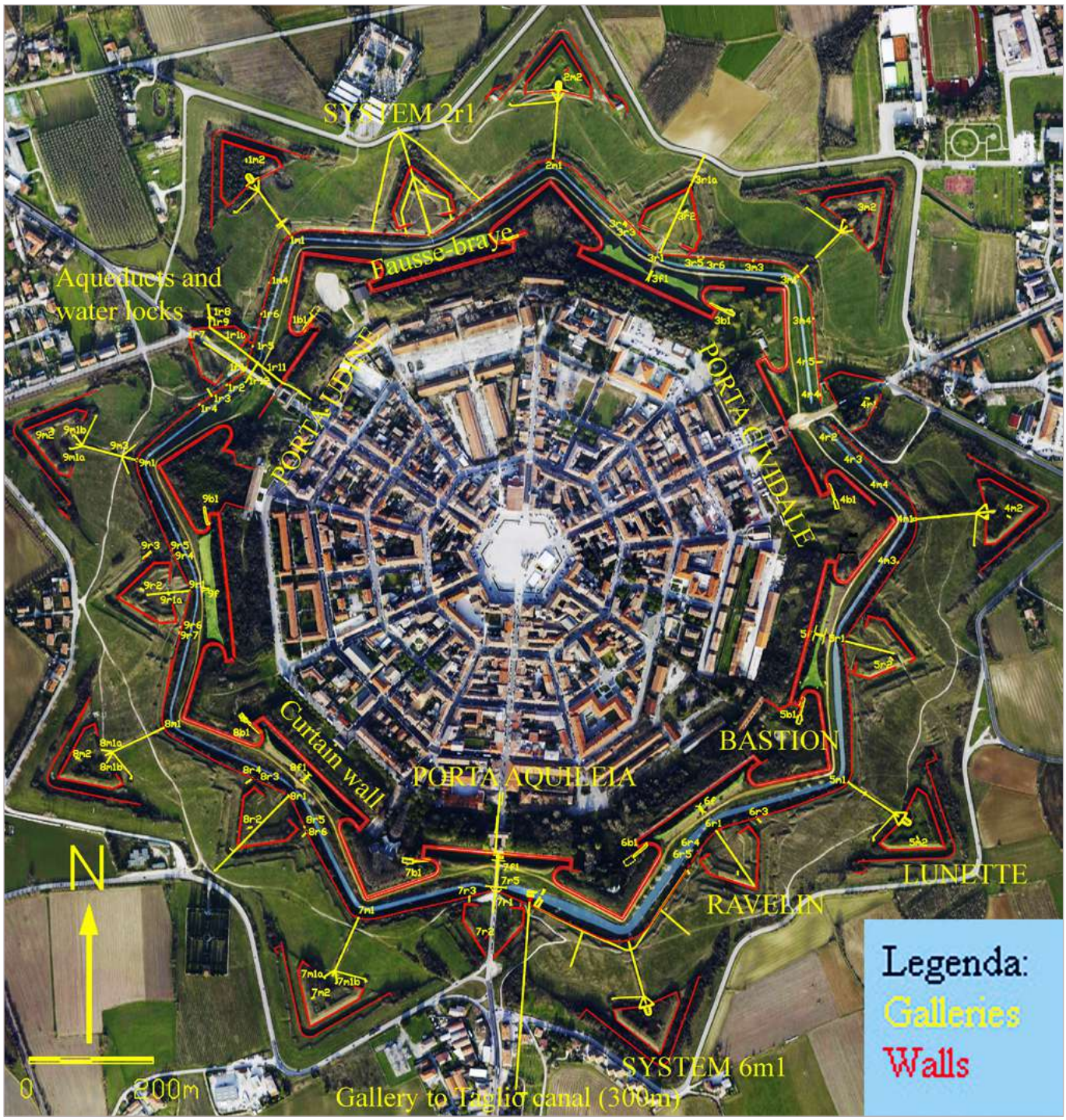

Fig.1: general map of the galleries at Palmanova.
Fig.1: mappa generale delle gallerie di Palmanova.

In a 'ravelin' towards the northern area the gallery system is complex and is over 700m long (Fig. 4); other galleries are rectilinear and their length varies from about 40 to almost 180m. They are slightly more than a metre wide, lower than two metres high, and more or less horizontal.

Galleries leading to the lunette

When Napoleon visited the fortress in 1797, after having put an end to the Republic of Venice by assigning it to Austria, he was overwhelmed by it. When he returned in 1806 as Emperor he began the construction of the third fortified circle of walls, called 'lunette' (Fig. 5) which was situated at a considerable distance due to the increased range of cannon fire. The central core of the lunette is constituted by the 'caponier', a two floored fort, protected by thick stone walls, one and a half metres wide, with embrasures. The rectilinear gallery that leads to the 'lunette' from the ditch, that could also be used to withdraw troops in case of conquest on behalf of the enemy, could be accessed solely from the upper floor by means of two spiral staircases and two converging inclined galleries (Fig. 6). The junction that connected the three galleries is of a fine architectural construction (Fig. 7), similar to the 'caponiers', which have large brick vaults joined

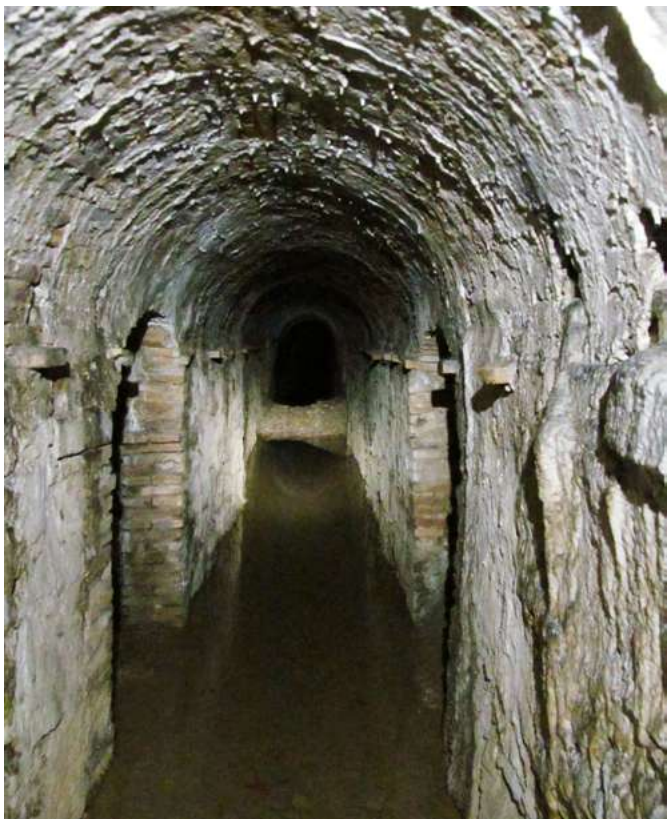

Fig. 2: galleries not ever dry (photo Feresin).
Fig. 2: gallerie non sempre asciutte (foto Feresin).

with great skill. Only six of these were built. The spiral staircases of the other three galleries lead directly to the open air at ground level.
The system denominated 6m1 in the SSE area deserves particular attention. It consists of a lunette gallery connected to pre-existing venetian galleries, some of which run parallel to the ditch, an absolutely unique feature, for a total of 600m (Fig. 8).
The ravelin galleries and lunette galleries alternate on the outer perimeter of the ditch and are interspersed with blind niches that lead nowhere, even though they are surmounted by an elegant arched doorway (Fig. 9). They have been interpreted as excavations that were immediately abandoned. All of these galleries form a series of rays that reach the lunette and extend below the ravelins, as shown in Fig. 1.

The fausee-braye galleries

These consist of short galleries (about 15m long) that cross the fausee-braye, ramparts exterior to and parallel to the curtain walls, that allowed the retreat from the ravelins in the fortress across the sallies, protected from enemy fire.

The lunette drainage tunnels

The water drainage system from the lunette ramparts is also very interesting. It consists of somewhat claustrophobic tunnels, 50cm wide and 70cm high, of

Fig. 3: crossing between countermine galleries (photo Diqual).
Fig. 3: intersezione tra gallerie di contromina (foto Diqual).

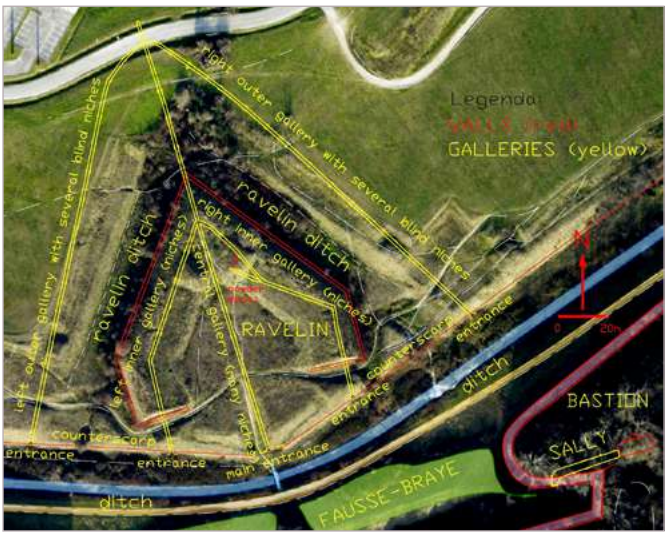

Fig.4: plan of the system 2r1 superimposed on the orthophoto.
Fig.4: pianta del sistema 2r1 sovrapposta all'ortofoto.

variable length but always longer than 50m. In many cases they have been blocked by landslides and air stagnation makes exploration inadvisable.
The tunnels are connected to the galleries next to their junction by three different means: towards the bottom (Fig. 10), the middle and the top.

The water system
E of Porta Udine, a network of galleries and aqueducts (Fig. 11), some of which monumental in structure, regulated the flow of water in the city and the ditch, thanks to a system of water locks (Fig. 12).
S of Porta Aquileia another system of gallery networks and water locks discharged wastewater into the moat and then to the Taglio canal, which, after numerous kilometres, flowed into the sea (Fig. 13).

The sally galleries
The accesses to the inclined 'sally' galleries (Fig. 14), denominated 'posterns' (Fig. 15) are situated along the well protected sides of the 'bastions'; they are approximately 30m long, 3m wide and 5m high. They were also used by the cavalry.

The conservation of the galleries
The galleries are on the whole quite well conserved also thanks to a purely karstic phenomenon: the meteoric waters dissolved the calcium carbonate of the limestone gravel that then became concretion inside the interstices of the vaults, thus consolidating them (see Fig. 2).
Other galleries, on the contrary, are difficult to access or are totally blocked by massive gravel and soil accumulations, due to partial collapses, that then were moved downstream during rainy periods.

Equipment and mapping
In agreement with the Municipality of Palmanova our task consisted in mapping all the existing structures, and in transferring these to the Regional Technical Map. The precision required for this goal was easily achieved by utilizing the modern methods currently used for speleological surveys.

Instruments
An instrument called DISTOX was used for mapping. It consists of a commercial distance-meter within which an additional card is inserted made by the Swiss Beat HEEB that includes the functions of compass and clinometer. The angular resolution is to a hundreth of a degree, whilst the accuracy depended on the calibration that was carried out every time the batteries were changed. This is a rather burdensome activity involving 56 measurements that must be taken in 14 predetermined directions which, if carried out with care, yield measurements that are accurate to a tenth of a degree. This type of measurement was carried out in the Fausse-Braye galleries at Palmanova. The values of all azimuth measurements were corrected in relation to the magnetic declination and

Fig. 5: a "caponier", central core of a lunette (photo Feresin).
Fig. 5: una "caponiera", nucleo centrale di una lunetta (foto Feresin).

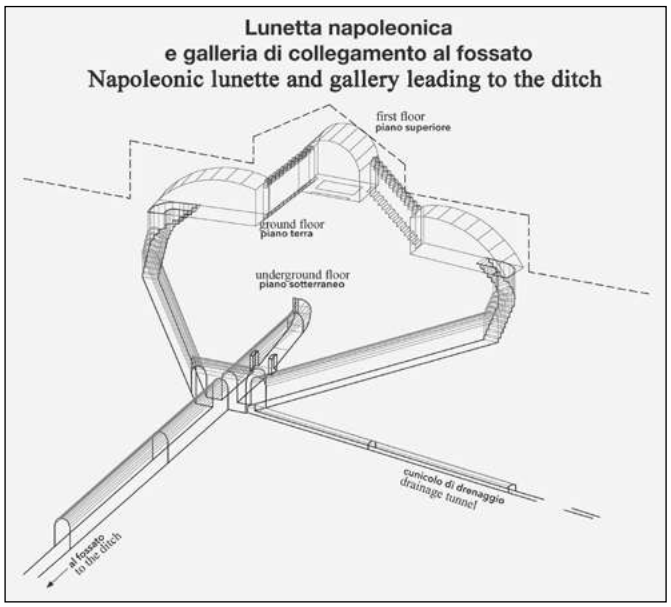

Fig. 6: 3D of a lunette (drawing Diqual).
Fig. 6: 3D di una lunetta (elaborazione grafica Diqual).

Fig. 8: plan of the system 6m1 superimposed on the orthophoto.
Fig. 8: pianta del sistema 6m1 sovrapposto all'ortofoto.

convergence angle of the Regional Technical Map. In order to determine the exact value, we were helped by the fact that over half the galleries have an entrance and one or more exits which are easily identifiable on the topographic map. Therefore, by elaborating the .dxf file of the first galleries and superimposing them on the Regional Technical Map it was possible to determine the value of correction.

In order to verify the validity of the method a couple of closed polygonals were used with an error lower than 0.5%.

In general, stations coincided with particular points such as changes in direction, height, width or with countless niches located along the sides of many of the galleries. Lateral and vertical measurements were taken at these points. No problems arose regarding long-distant measurements for these were unnecessary. The aim to place the gallery entrances via GPS was quickly abandoned for it proved to be much easier and accurate to use the Regional Technical Map.

Mapping by DISTOX

Individual measurements carried out on the field were stored on the device. There followed two choices: to accumulate all the data and then download these on a PC, or to transfer them immediately via Bluetooth to a palmtop computer. The latter method was preferred and the data were directly elaborated using a specific program (Pocket Topo). By using this method it is possible to verify on site the accuracy of the repeated measurements. As a matter of fact the elaboration programme requires that the same measurement should be repeated three times; only then will the number of the station automatically increase, whilst single measurements are interpreted as lateral measurements. Tolereance regarding the identity of the three measurements is rather low, but working contemporarily with a palmtop computer permits the repetition of wrong measurements. To check and correct these measurements in a second phase would have been very difficult. Therefore, the elaboration programme generates the polygonals of the plan and the sections can then be exported in .dxf format. Dxf files can then be transferred to a PC and elaborated with any CAD programme in order to complete the map with all of its details.

Fig. 7: at the junction of three galleries (photo Debelli).
Fig. 7: alla giunzione di tre gallerie (foto Debelli).

Fig. 9: entrance of a gallery with inscription (photo Feresin).
Fig. 9: ingresso di una galleria con iscrizione (foto Feresin).

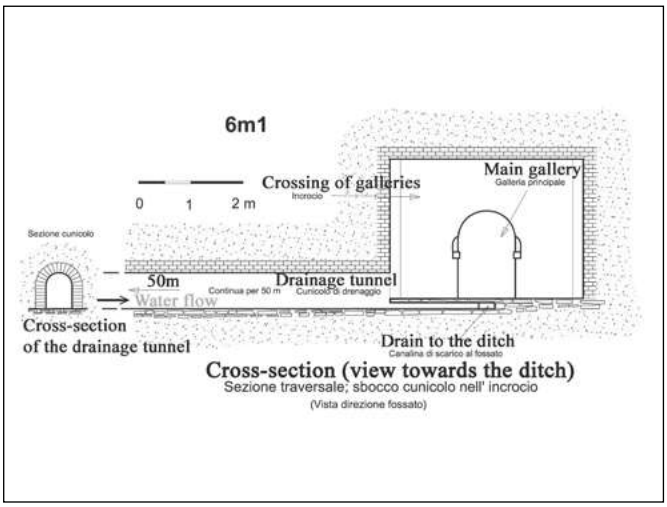

Fig. 10: connection of a drainage tunnel towards the bottom at the junction of three galleries (drawing Diqual).
Fig. 10: collegamento in basso di un cunicolo di drenaggio alla giunzione delle tre gallerie (elaborazione grafica Diqual).

The accuracy obtained is more than sufficient for mapping the galleries and for transferring them on the topographic map at a 1:5000 scale.
We decided to simply delineate the plan of the galleries forsaking the sections which would not have yielded significant information, considering that all galleries are practically horizontal. Two exceptions consist of a lateral view of some peculiarities (e.g. Fig. 10) and the section of a postern with a loggia, shown in Fig. 14.

The making of "Le Gallerie di Palmanova" DVD
The idea
The aim of the short video is to document in moving images the process of mapping the structures and galleries at Palmanova. The plan was to create some footage during the explorations to show how the mapping and exploration was done, but also to explain the reasons of such an impressive and particular construction.

Structure of the video
The structure of the video has to explain every single aspect of the exploration and mapping considering the historical aspect, the working team, the techniques and methods utilised, and also the future development for tourism.
The video starts with the historical definition of Palmanova to frame every historical aspect that can explain the reasons of the construction. After presentation of the whole group working in the project, a general description of the tunnels structure follows. One important aspect was to expose the reason of a huge mapping work, that was never done before, and the future use of the collected data, as well as the further use of the galleries and tunnels as a touristic attraction. A description of the caving group

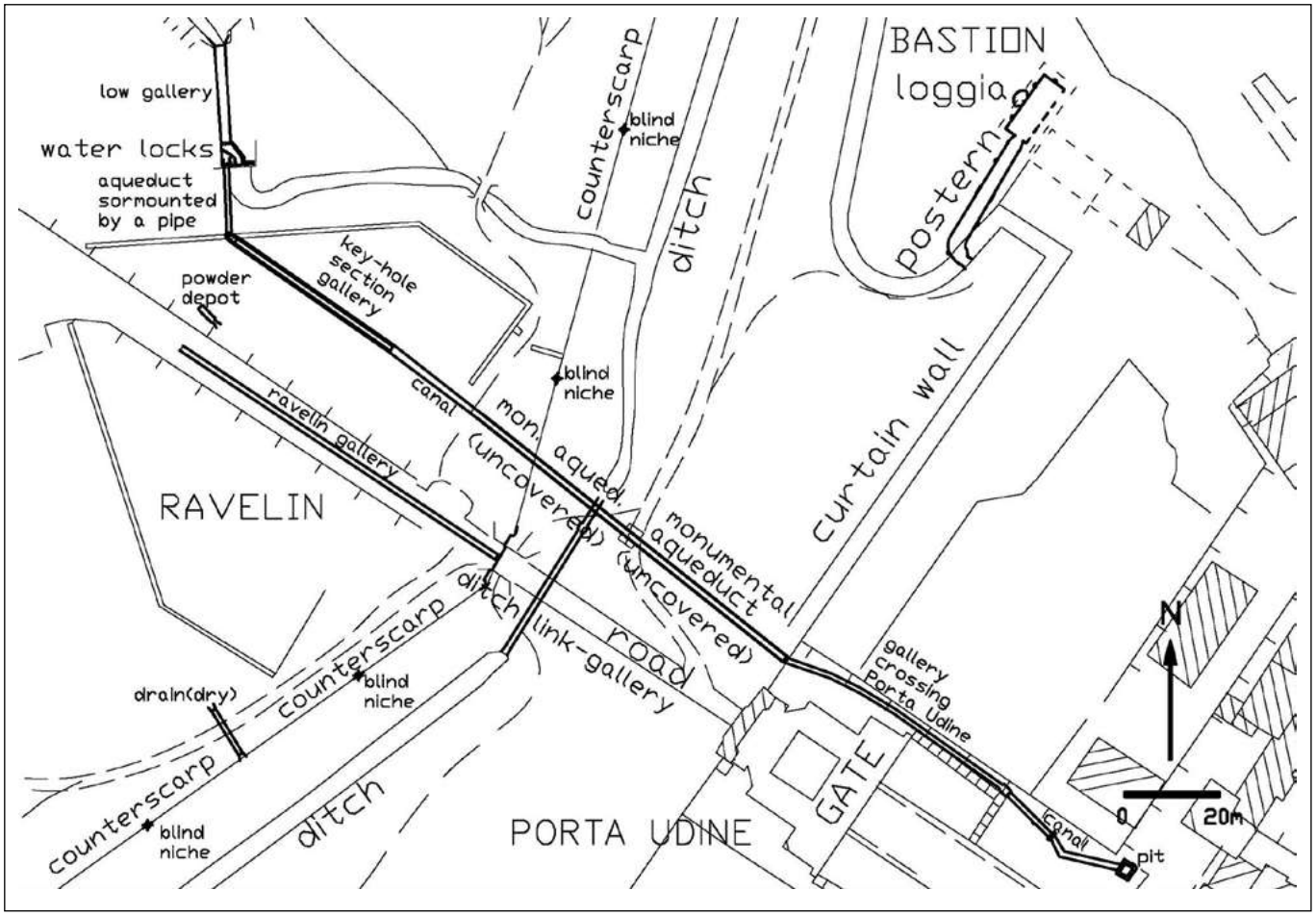

Fig. 11: the water supply galleries and aqueducts.
Fig. 11: gallerie ed acquedotti per il rifornimento idrico.

Fig. 12: aqueduct and water locks (photo Feresin).
Fig. 12: acquedotto e chiuse (foto Feresin).

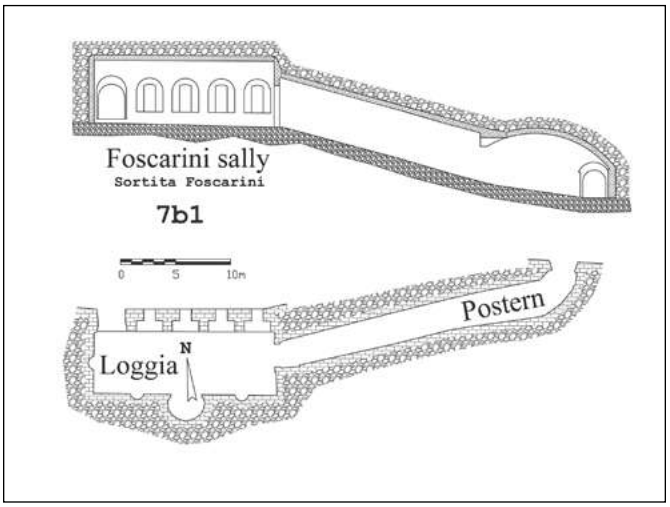

Fig. 14: sally: postern and loggia (drawing Diqual).
Fig. 14: sortita: poterna e loggia (elaborazione grafica Diqual).

Commissione Grotte "Eugenio Boegan" was inserted before the detailed description of the methods and techniques used for the entire mapping including some images of using the DISTOX and the subsequent data insertion and conversion on a computer-aided design system to track on a map the entire survey. All the interviews are mixed with images done during the exploration or the mapping to show to the audience the huge work done and the difficulties encountered. To illustrate in a complete way the whole structure in the history we used some images of the stamps from the municipality archive.

Technical aspect

Due to the difficulty of recording video images in dark environments a Digital Single-Lens reflex camera

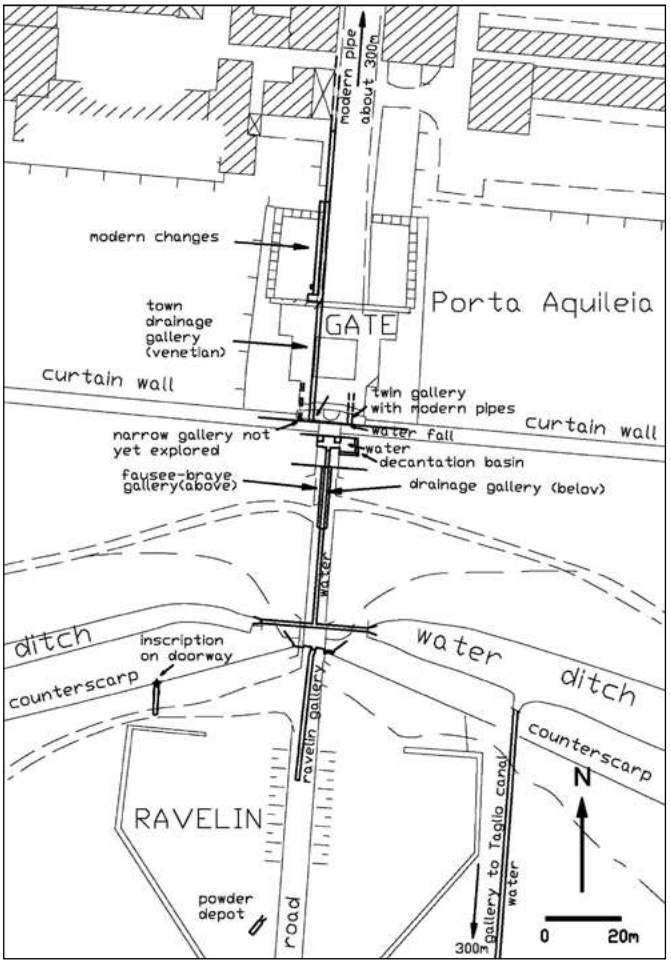

Fig. 13: the system of galleries discharging wastewater at Porta Aquileia.
Fig. 13: il sistema di gallerie di scarico delle acque reflue a Porta Aquileia.

Fig. 15: postern (photo Feresin).
Fig. 15: poterna (foto Feresin).

in video mode with very bright lenses was used. The camera for underground shooting was a Canon 5D Mark II with 50mm 1.4F prime lens and a 28mm 1.4 prime lens. The lighting used was a Manfrotto led display and a custom-made led lamp with lead battery. In most cases the light was used to create a backlight to perceive the length of the galleries or to show some details of the concretions on the walls or at the ground. Although most of the shootings were done by hand, in some cases a Manfrotto tripod with video head was used for some images. All the equipment was covered with protection sleeve to avoid from the humidity and water dropping.
The exteriors and all the interviews were done with a Sony ER1 XDCAM videocamera. The microphones used were a Sennheiser ME 64 and a Sennheiser EW100 wireless system.
The postproduction was made on a HP Video Workstation using the Adobe suite.
The crew during the shootings was composed by two persons.

Results and use

The video was presented at the Italian national caving meeting Spelaion 2012 at San Marco in Lamis (Apulia) and at the Alpi Giulie Festival 2013 in Trieste, and was inserted inside the pubblication DVD. Later, the video was published online and is visible at the following address https://www.youtube.com/watch?v=mJ8wU6nykAs

Conclusions

We would like to point out that the Project "Palmanova Underground**"** can be subject to further development. We have recently identified the partially obstructed entrance to other promising subterranean structures.
We hope to be able to pursue their exploration in agreement with the municipal administration of the city, with which we have always had excellent working relationships.
Palmanova is a fascinating place that must be protected and valorised. It arose due to war but can become a hub for tourism, knowledge and peace.

Acknowledgments

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