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Roman 'well-cisterns', navigational routes, and landscape modifications in the Venice Lagoon and Northeastern Adriatic

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Abstract

Underwater investigations in the lagoon of Venice have revealed a partially preserved structure interpreted as a Roman 'well-cistern'. It is indeed very similar to another, better-preserved building excavated in the same area. The analysis of the mortar, the evaluation of the depth of the structure base in relation to relative sea level, and the absence of foundation poles in the underlying soft lagoon mud support such interpretation. A comparison with other poorly-studied Roman buildings of the same type located along the North Adriatic littoral suggests that they were probably used to supply ships with fresh water. In the Middle Age, similar structures were used in the islands of the lagoon for sustenance of its residents and became a characteristic of the small squares (*campi*) of Venice.

Keywords: Lagoon. Roman, cistern, mortar, underwater

INTRODUCTION

The problematic reconstruction of the Roman settlement pattern in the lagoon of Venice is still debated between scholars who tend either to overemphasize or to belittle the Roman presence in this peculiar environment. Indeed, while we have moved past Dorigo's (1983) reconstruction of a lagoon occupied by a centuriation and, largely, cultivated land, a debate is still ongoing about the nature and density of the occupation of the lagoon of Venice in the Roman Period. A recent theory speculates that the lagoon was crossed by a Roman road now submerged between 4 and 8 m below present mean sea level (MSL) (Madricardo et al., 2021), but unfortunately fails to present any new archaeological and stratigraphic data that may support this hypothesis, nor provides a consistent geological model that can explain the extraordinarily high relative sea level rise that would derive from such an interpretation.

This rather confused research framework is partly due to the practical difficulty of carrying out archaeological investigation in the lagoon, both in terms of traditional archaeological excavations below the groundwater table, and underwater archaeological investigations in very low-visibility water. Additionally, the lagoon of Venice is a very dynamic geomorphic environment, which has been subject to quick, and sometimes substantial, modifications induced by both natural and human processes over the past two millennia (Bondesan & Meneghel, 2004; Primon & Mozzi, 2014). The study of the ancient settlements and landscapes is, therefore, particularly complex and requires an interdisciplinary approach, with much attention on geomorphological and palaeoenvironmental analyses. Finally, it is important to highlight the lack of true research projects dedicated to lagoon archaeology in recent decades. Although many rescue projects have allowed the collection of a considerable amount of raw archaeological data in the past, they have not always produced a significant quantity of historical results, to the extent that the social and economic costs of these activities may be, in some cases, difficult to justify (see also Gelichi, 2006).

In this scenario, the detailed investigation of selected key archaeological sites, such as two sites located along the San Felice Channel (Canale San Felice), can offer precious markers for the study of past settlement patterns, trade routes and resource exploitation of this ever-evolving landscape. We focussed our investigation on what appeared to be among the most prominent underwater archaeological features known thus far in the northern lagoon of Venice, where the very poor visibility and strong tidal currents had previously prevented accurate surveys, leaving many questions unanswered. The location of these structures, interpreted as 'well-cisterns' (similar to the later *pozzi alla veneziana*), in proximity to the Roman and early medieval coastline and tidal inlets, raises further questions concerning their relation to navigation and trade. The specific aim of the investigation was to identify evidence on the aspect, function and chronology of these structures, investigating their technical characteristics through archaeometric analysis of their binding materials and reconstruction of the geomorphological evolution of the sites. A more general aim of the research was to clarify the possible use of these sites as valuable landmarks in reconstructing the Roman settlement pattern in the lagoon, as well as the routes of coastal and inland navigation along the northern Adriatic coast.

THE SAN FELICE CHANNEL SITES FROM PREVIOUS STUDIES

Ca' Ballarin

The underwater archaeological area of Ca' Ballarin was discovered in 1998 along the eastern bank of the San Felice channel, close the village of Treporti, and was investigated several times until 2003 (D'Agostino, et al., 2020, with cited bibliography) (Fig. 1). The area is characterized by the presence of Roman ceramics, especially fragments of Dressel 6A amphorae dating between the second half of the 1st century BC and the end of the 1st century AD (Toniolo, 1991; Gaddi & Maggi, 2017), and the presence of wall remains at a depth between -4 m and -5.50 m below mean sea level (MSL: Italian High-Precision Levelling Network, vertical datum Genova 1942, IGMI - Istituto Geografico Militare Italiano, https://www.igmi.org/en/descrizione-prodotti/elementi-geodetici-1/rete-di-livellazione-di-alta-precisione?set_language=en). The most important and well investigated structures are a filtering cistern with a well and the remains of a probable quay or pier.

The cistern consists of a massive 10 x 9 m base built with rectangular *sesquipedali* bricks of the 'provincial' type whose sides measure on average 44 x 29.5 cm and 7.5 cm in thickness (Bonetto, 2019, p. 319; Previato, 2019, p. 380) (Fig. 2). The southwestern corner is broken and detached from the rest of the building. It now lies inclined on the canal slope at depths between about -250 cm (the top-most preserved course of bricks) and -550 cm (the base of the bricks) MSL. The mortar layers between the superimposed bricks measure 4 and 4.5 cm (with extremes between 3.5 and 5 cm), while the horizontal distance side-to-side varies between 4 and 5.5 cm. The base consists of at least three superimposed levels of *sesquipedali* that directly lie on lagoonal mud, without the use of foundation wooden poles. The walls are preserved to a maximum elevation of more than 230 cm from the present channel bottom. In the lower part, up to 140 cm, the wall bricks are placed cross-wise, resulting in a wall width of 44 cm. In the upper part, bricks are placed length-wise and, consequently, the wall width is reduced to 29.5 cm. This wall structure probably aimed to withstand the lateral pressure exerted by the filling materials and the water stored inside. A thin layer of mortar is spread at the base of the walls (Fig. 3) and on the walls' surfaces, a technique that makes the cistern water-tight. This mortar layer increases in thickness along the internal contact line between floor and walls.

Remains of a well are present in the northern sector of the cistern. The inner diameter of the well is 82 cm while the external diameter is 110 cm. The preserved parts of the well have an overall length of 144 cm and they presently have an elevation of 133 cm from the channel bottom. This structure is built with Roman arched bricks, called *pozzali*, with quite standard measures (45 x 34.5 x 14 x 9 cm) (Cividini & Ventura, 2011). The bottom of the well consists of a concave nodular limestone (*Rosso Ammonitico* rock formation) basin, inserted in the cistern floor; the first four courses of bricks from below were put in place without jointing mortar.

A filling made from sand and gravel (rounded fluvial pebbles, from 1 to 10 cm in size) was still present inside the cistern, especially in the northern sector, less affected by erosion from tidal currents. The gravel was found especially around the well. All these elements allow the structure to be identified as a rainwater filtering cistern, which appears to be a direct ancestor of the so-called 'Venetian wells' (*pozzi alla veneziana*) dating to the medieval and modern periods, a particular type of well that is widespread in the city and its lagoon – where it is not possible to access fresh groundwater (Bortoletto, 2011; Costantini, 1984). The rainwater collected from the surface into the cistern was filtered by the sand-and-gravel fill and could pass inside the well through the *ca*. 2 mm-wide slits between the arched bricks of the first four courses at the well bottom. This allowed fresh and purified water to be drawn from the well.

Several findings from the excavation of the well document the last phase of use and the subsequent abandonment of the water-supply system. Among these, there are common pottery fragments of drinking vessels, two jugs, a walnut pulley and small fragments of rope (probably parts of the water lifting system), small fragmentary oak staves (probable parts of a bucket) and objects that fell or were discharged into the well, such as lead weights for fishing nets, wooden handles of tools with connected iron fragments and three fragments of black-and-white mosaic flooring. These fragments document the relative proximity with some high-status buildings or dwellings. Indeed, 400 m from this site, the presence of a presently submerged Roman villa, currently under investigation by C. Beltrame, is reported (Goti Vola, 2019). A bronze coin of Emperor Philip the Arab (minted AD 244-246) was found. The archaeological materials recovered during the underwater stratigraphical

excavation of the well suggests that this system was in use between the second half of the 1st century AD and the middle of the 3rd century AD, when it was apparently abandoned.
In a recent and valuable article about the medieval '*pozzi alla veneziana*', the Roman cistern of Ca' Ballarin was discussed in a reductive way, citing the uncertainty of stratigraphy, structural evidence and chronology, due to the difficulties of the underwater work (Cianciosi, 2021, pp. 376-377). The archaeological evidence provided by the Ca' Ballarin site is instead clear and well documented, as reported in these pages. The author bases her account on a single short article of dissemination, despite the available published scientific work about the Ca' Ballarin cistern and its functional interpretation (D'Agostino & Medas 2005, pp. 40-44; 2010, pp. 288-289; D'Agostino, et al., 2020).

About 8 m south from the cistern there is a fragmentary, long and narrow structure of concrete made of mortar mixed with blocks of limestone, roughly oriented East-West. The structure was documented during the first surveys of the Ca' Ballarin archaeological area (D'Agostino, et al., 2020). The original structure appears to be segmented in seven portions, each one a maximum of 3 m long, 90 cm wide and 70 to 80 cm high, which originate from the channel bank and are aligned towards the centre of the channel with an overall length of more than 20 m (Fig. 4). The base depths of the concrete layer, set over wooden poles that are still partly visible, increase towards the channel from -360 to -560 cm MSL. Two wood poles were sampled; a first one was a trunk of *Quercus robur* of sub-circular section with a diameter of 18 cm, with preserved *alburnum* that was radiocarbon-dated 1860±60 BP; the second one, sub-circular with a diameter of 19.5 cm, also had the *alburnum* that was radiocarbon dated 1860±60 BP (D'Agostino, et al., 2020). These dates suggest an age of construction of the structure that falls between the second half of the 1st century AD and the 3rd century AD. The structure was interpreted as a pier that likely had a functional relationship to the cistern.

The 'Tower'

This site is located along the San Felice Channel, at a distance of about 2.3 km from the Ca'Ballarin site, 30 m from the northern bank (Fig. 1). The base of the structure lies at a depth between -450 and -300 cm MSL and rises 150 cm above the channel bottom. This implies that the top of the structure is between -300 and -150 cm MSL.
This flat box-like structure, 670 x 770 cm, made only with *sesquipedali* bricks, was discovered in 1984 by F. Tonello, a local diver, who, in collaboration with the Marcante divers' club, created the

first documentation in the years prior to 1988. The structure also gained the attention of Ernesto Canal, who is the pioneer of archaeological survey of the lagoon and who was particularly interested in sites that could be attributed to the Roman Period. The building, because of the shape and of the type of bricks used for its construction, was interpreted by Canal as a 'defensive tower', initially attributed to the 1st-2nd centuries AD (Canal, 1998, p. 74) and then, in a later paper, to the 1st century BC (Canal, 2013, pp. 260-261). In the site a neck of a glass bottle, identified by C. Negrelli as an Isings 50 or 51 (pers. com., 2021), was recovered (Canal, 2013, fig. 113.9b). In July 1988, the local Archaeological Superintendency contracted the private company, Delta sub of Venice, to undertake new detailed documentation, constituting the first activity of underwater archaeology carried out under the coordination of the STAS (*Servizio Tecnico per l'Archeologia Subacquea of the Ministero per i Beni Culturali*).

According to the unpublished illustrated report of the work, made in 1988, among the bricks of which the building is composed it is possible to see an amphora neck which can be identified as *a collo ad imbuto* type, dated between the 1st century and the first half of the 3rd century AD (Mazzocchin, 2009). The site's interpretation as a tower of the Roman Period gained weight among scholars who associated this building, which sometimes was also interpreted as a possible lighthouse, with the navigation and the control of the entrance in the lagoon through the harbour of Lido (D'Agostino & Medas 2005, pp. 44-46; 2010, pp. 289-290; uncritically accepted also by Madricardo et al., 2021).

MATERIAL AND METHODS

Underwater survey and sampling

The underwater surveys were carried out in July and September 2020 with the support of the Idra company of Venice, which specialises in underwater archaeology. All depths MSL of new data acquired in our investigation refer to the Italian High-Precision Levelling Network, vertical datum Genova 1942, by IGMI - Istituto Geografico Militare Italiano (https://www.igmi.org/en/descrizione-prodotti/elementi-geodetici-1/rete-di-livellazione-di-alta-precisione?set_language=en).

After mechanical cleaning, the pier at Ca' Ballarin and the 'tower' were documented with digital photogrammetry by the underwater archaeologist Elisa Costa who used a Nikon Coolpix W300 compact camera with a lens of 24 mm and 4K video. This operation was a real challenge because of the very low visibility (from 0.50 to 200 cm) and of the strong tidal current (especially on the 'tower') which made any operation very complex (Costa, 2022) (Fig. 5).

To produce the complete model of the sites, targets placed on the structures were surveyed using a trilateration computed as a 3D topographic network, following the DSM (Direct Survey Method) technique (Rule, 1989). The targets on the 'tower', thanks to the low depth, were also surveyed with a total station, the base station of which is located on the salt marsh along the channel bank to achieve further control and accuracy (Fig. 6). The pictures were processed with Agisoft PhotoScan software, according to the Structure from Motion technology, and the models produced were 'checked' through Rhinoceros software with the topographical network.

A multi-beam survey with a Reson Seabat 8125 was carried out at the 'tower' by the Elmar Marin Survey company of Venice in the area of the site in order to check the presence of other 'Roman' structures recognized by the Marcante Divers team in the 1980s (Fig. 7).

The Ca' Ballarin cistern was surveyed, and two mortar samples were collected (samples CB_C1 and CB_C2). A corner of the 'tower' was specifically cleaned in order to allow the analysis of its base and the collection of a mortar sample (sample TSF_T9).

Cores CB_c.1C and CB_c.2 D were extracted from the lagoon bottom at Ca' Ballarin and other two cores (TSF_c.A and TSF_c.B) at the 'tower' in order to check the characteristics of the lagoon sediments in the sites. The coring was carried out by scuba divers, through the manual drilling of PVC tubes with the diameter of 3 cm in the lagoonal sediment below and next to the archaeological structures. The cores were from 50 to 60 cm long. Cohesiveness of the silty-clay sediments assured the complete recovery of the core. AS these are soft sediments, some compression during coring operation and minor shortening of the core in respect to the original succession was expected. The sediment cores were later opened and described in the laboratory.

A wood sample was collected from the outer part of one of the foundation poles of the pier at Ca' Ballarin site (sample CB_P1). The sample was stored in aluminium foil to prevent contamination and dried in the oven at 30°C. Radiocarbon dating of the wood sample was carried out at the Laboratory of Ion Beam Physics ETH-Zurich. This radiocarbon date, as well as others from the literature, were calibrated with software OxCal 4.4.2 (Bronk Ramsey, 2020), applying Intcal20 (Reimer et al., 2020) (Fig. 8 and Table 1).

Analysis of mortar

A multi-analytical approach was carried out in order to characterize the mortar samples CB_C1, CB_C2 and TSF_T9 employing X-ray powder diffraction (XRPD), optical microscopy (OM), and scanning electron microscopy coupled with energy-dispersive spectroscopy (SEM-EDS).

Petrographic analyses were performed by OM (Nikon Eclipse ME600 microscope equipped with a Canon EOS 600D Digital single-lens reflex camera) on 30 µm thin sections under parallel and crossed polar light. Furthermore, thin sections covered with an ultrathin graphite coating, were microstructurally and microchemically characterized by CamScan MX2500 SEM equipped with a LaB_6 electron source. The EDS SEMQuant with Phizaf software was used for elemental microanalyses, providing information on both the mineral phases and binder composition. Mineralogical quantitative phase analyses (QPAs) were performed by XRPD using a Malvern PANalytical X'Pert PRO diffractometer in Bragg-Brentano geometry, Co-Kα radiation, 40 kV and 40 mA, equipped with a real-time multiple strip (RTMS) detector (X'Celerator by Panalytical) on powdered fine samples. Data acquisition was performed by operating a continuous scan in the range 3-85° 2θ, with a virtual step scan of 0.02° 2θ. Diffraction patterns were interpreted with X'Pert HighScore Plus 3.0 software by Malvern PANalytical, reconstructing mineral profiles of the compounds by comparison with ICDD and ICSD diffraction databases. QPAs were performed using the Rietveld (1969) method, and refinements were accomplished using the TOPAS software (version 4.1) by Bruker AXS. Both crystalline and amorphous content were calculated by means of the internal standard method with the addition of 20 wt% zincite (ZnO) to the powders.

RESULTS OF THE 2020 INVESTIGATIONS IN THE SAN FELICE CHANNEL SITES

Ca' Ballarin site

Underwater archaeological survey

The underwater survey allowed an accurate documentation of the supposed pier structure, as well as detailed photogrammetric modelling. The good quality of the photogrammetric survey further permitted E. Costa to perform a virtual reconstruction that joins the blocks of the pier, matching together in one image an elongated structure of about 18 m long, 80 cm wide and 50 cm high (Costa, 2022) (Fig. 4). The structure's characteristics fully support its interpretation as a pier that is almost perpendicular to the San Felice Channel's southern bank. The higher elevation of the remains of the pier is -211 cm MSL. It can further be presumed that the top working surface of the pier (not preserved) in the stretch closest to the bank would lie above -200 cm MSL.

Radiocarbon dating of the pier's foundation poles

Radiocarbon dating of the wood sample taken from the outer part of one of the foundation poles of the pier (CB_P1) (see Fig. 4 for location) provided a Cal CE age of AD 15–123. This age estimate probably refers to the period of construction of the pier, which would thus fall between the beginning of the 1st century AD and the first half of the 2nd century AD. The radiocarbon date is consistent with the radiocarbon dating already carried out on other poles of this same structure (D'Agostino et al., 2020, pp. 40-42).

Coring

The two cores extracted at the site (see Fig. 4 for locations), provide information on the sediments on which the pier and the nearby cistern were built.

Core CB_c.1C (length 50 cm) was carried out among the foundation poles of the pier, starting from the channel bottom at the depth of -310 cm MSL. From the bottom, the sedimentary succession consists of soft, grey clay with common shell fragments of marine shells (e.g., *Cerastoderma*, *Chlamys*) passing upward to clay silt, interpreted as subtidal mudflat deposits. At 20 cm depth from the core top, a 5 cm-thick, organic-rich brown horizon with many fine rootlets (diameter <1 mm) is present; several rootlets continue downward to the core bottom. The brown horizon is interpreted as the A soil horizon of a salt marsh. The upper-most 20 cm of the core consist of silty clay with many marine gastropods, indicating subtidal flat sedimentary conditions.

Core CB_c.2D (length 60 cm) is located at a distance of 60 cm from core CB_c.1C but it is outside of the pier structure, at -320 cm MSL. The succession is very similar to that of core C, with clay silt passing upward to silty clay and the A soil horizon at the top. We regard this core as indicative of the subsurface characteristics of the natural sedimentary succession under the cistern, which lies about 7 m to the north of this core.

The sedimentary succession of the investigated area thus developed from subtidal mudflat conditions to a salt marsh with the top at around -32 cm MSL. This was followed by the reoccurrence of subtidal conditions, indicating that the relative sea level rise led to the drowning of the formerly emerged salt marsh. In core C, a thin veneer of lagoonal mud covers the buried salt marsh A horizon. In core C the same A horizon is exposed at the channel bottom in core D site, probably due to erosion by tidal currents in the present San Felice channel. The foundation poles of the pier were drilled through the whole succession. The cistern was dug in these same lagoonal sediments.

Analysis of the cistern's binder materials

The two mortar samples collected in the cistern, both on the corner between the floor and the wall (CB_C1) and on the wall (CB_C2) (Fig. 2), are mainly characterized by lime binder, both silicate and dolomitic sands, and crushed brick and/or ceramic fragments forming a sort of *cocciopesto/opus signinum*. The ceramic is added in order to provide hydraulic properties to the mortar mix (Secco et al., 2020; Ricci et al., 2020; Bertolini et al., 2013). These mortar samples present both powdered ceramics, as suggested by the isotropic texture of binder clusters observed by OM at crossed polars, and millimetric fragments, visible both through OM and SEM observation (see Fig. 9). The inert fraction is fine and well selected, with a unimodal granulometric distribution (maximum dimensions: *ca.* 1 mm; average size: 500 µm), evenly distributed in the mixture and not oriented. Mineralogical investigation by XRPD analyses identified: high aliquots of calcite (up to 43 wt%), due to both the carbonate binder and aggregate; dolomite (less than 2 wt%), ascribable to dolomitic sand used as aggregate in the mixture; quartz (*ca.* 16 wt%), micas, plagioclase and feldspars in low percentages (between 1-6 wt%), attributable to the inert fraction. Furthermore, the presence of diopside (*ca.* 3%wt) is ascribable to brick and/or ceramic fragments fired at high temperature (Jordàn et al., 2001; Trinidade et al., 2009). Paracrystalline phases, such as magnesium-silicoaluminate-hydrates (M-S-H/M-A-S-H phases), were detected (*ca.* 3 %wt), and are probably related to alteration processes and/or partial pozzolanic reaction between the carbonate binder and reactive silicates in a Mg-rich environment (Bernard et al., 2019). Morphological and chemical analyses by SEM-EDS of the cistern's samples showed dissolution and alteration processes of both carbonate and silicate aggregates, and a binder matrix characterized by Ca, Si, Al and Mg, unevenly distributed (Fig. 5). Calcium hydroxide, employed as binder in the mortar mix, and the water salinity provide high pH levels (alkaline pH), promoting the dissolution and alteration of the aggregates such as feldspars, calcite and dolomite (dedolomitization process), releasing Mg, Si, Al and Ca ions forming Ca-Si-Al-Mg-hydraulic phases (Ponce-Antón et al., 2020; Prinčič et al., 2013; Secco et al., 2020). In addition, the Mg-sources are also related to the crushed ceramic fragments, which showed partially vitrified and reacted siliceous-aluminous matrices.

The 'Tower'

Underwater archaeological survey

Our survey indicates that the structure is made of *sesquipedali* bricks in a flat position. The dimension of the bricks is 43.5-46 x 29.5-29 x 6 cm, which is the typical size of the *sesquipedali* of the Po Valley (Bonetto, 2019). They are jointed with a thick layer of mortar along the borders (3 cm) and the sides (2-3 cm). The cleaning of the northern corner has allowed a total number of six preserved courses of bricks to be recognized. They are positioned so as to form steps that extend toward the bottom (Fig. 10). The sixth course forms the first brick course of a side, i.e., a wall. Along the inner corner formed by the unique preserved course of the wall and by the ‘floor’, there is a layer of mortar (Fig. 11). A section of the structure, which was dismantled probably by the impact of fishermen’s anchorage and lies outside the building, could be interpreted as further evidence of a wall. This is composed of four courses of bricks of the wall and two courses of the base (Fig. 12). In the plan made by Tonello, other better-preserved sections of the walls are visible along the corners, but no evidence was found during our survey. The base first course lies between -410 and -430 cm MSL, while the top of the fifth course lies at -370 cm.

The cleaning of the upper part of the structure revealed an amphora Dressel 6A neck as well as fragments of tiles (Fig. 13) cropping out in a hole among the bricks and filled with grey compact silty clay similar in texture and colour to the natural sediments on which the structure rests. Other fragments of presumed Dressel 6A and Dressel 2-4 amphoras, scattered over the site, allow dating of the building and use of this structure as between the Augustan Period and the end of the 1st century AD (Fig. 14) (C. Negrelli, pers. com., 2021).

The extensive multibeam survey of the site did not show any of the supposed ‘Roman’ structures recognized by the Marcante Divers team in the 1980s. As a general remark, we emphasize that the comparison with the documentation made in 1988 by Delta Sub shows a very heavy degradation of the structure from which many bricks were dismantled by the current and by human impact (i.e., anchorage and fishing activities). The impact of anchors of motorboats was also noted during the period of investigation in 2020. The presence of nets, synthetic ropes and modern objects lying on the structure is clear evidence of substantial anthropic impact.

Coring

Two 60 cm-long cores were extracted from under the structure (TSF_c.A and TSF_c.B, see Fig. 5 for locations) so as to check the characteristics of the underlying sediments. The sedimentary succession shows that the bricks of the first course of the structure lie directly on rather homogeneous clay silt, showing some lamination, common marine shells (*Cerastoderma, Chlamys, Cerithium*) and organic flecks. The lithofacies association suggests the interpretation as intertidal/subtidal mudflats. No foundation poles were found under the structure, although the underlying sediments appear very soft and weak (Fig. 15).

Analysis of the mortar sample

The sample of *cocciopesto/opus signinum* mortar TSF_T9 (Fig. 5 for its position) presents coarse ceramic fragments, up to 5 mm (Fig. 16 a), fired at high temperature (1000-1100°C), since diopside was detected (*ca.* 9 %wt) (Jordàn et al., 2001; Trinidade et al., 2009). Calcite (22 %wt), mostly due to the anthropogenic binder, and low aliquots of quartz and other silicates, as part of the inert fraction, were detected by XRPD analyses.

The TSF_T9 sample is characterized by high aliquots of paracrystalline Mg-rich hydrated phases (M-S-H/M-A-S-H), up to 20 %wt, and amorphous phases (up to 32 %wt). The latter are related to both ceramic vitrified phases and siliceous-aluminous amorphous products, as C-S-H/C-A-S-H, formed in the binder fraction due to the pozzolanic reaction. The chemical composition of the binder matrix, investigated by SEM-EDS and shown in Fig. 16, reveals a composition of Si, Mg, Al and Ca (with minor amounts of alkalis and iron), indicating the hydraulic reaction and the presence of M-S-H/M-A-S-H promoted by the simultaneous alkaline pH and Mg-rich reactive additives related to the ceramic fragments (Secco et al., 2020).

ROMAN CISTERNS ALONG THE SAN FELICE CHANNEL

Our investigation, based on a suggestion first made by Eros Turchetto, archaeological diver of the Idra company, shows that there are significant analogies between the cistern at Ca' Ballarin and the so-called 'tower' structure. The main points are:

i) The base of the structure in *sesquipedali* is massive and with a similar rectangular shape, 6.6 x 7.7 m in comparison with the 9 x 10 m of the Ca' Ballarin cistern. The width/length ratio is 0.9 in both cases;

ii) They both lack of poles of foundation even if they lie on soft lagoonal muds. Indeed, the absence of poles in the cistern at Ca' Ballarin can be justified by the fact that it lacked an elevated structure and so it did not need supplementary work on the foundation. The lack of poles under the San Felice structure is not compatible with its interpretation as a tower. The weight of this kind of building on a limited surface would surely have needed the use of foundation poles and planks to let the structure 'float' over the soft lagoonal sediments. The presence of foundation poles under major buildings is a characteristic not only of the buildings in Venice and in the lagoon, but also of other Roman structures close the lagoon, such as at *Altinum*. An example is the monumental gate of the city (with towers), which had foundation poles (Gambacurta, 1992). Furthermore, the building of Roman Period found at Baro Zavelea (Comacchio) in the Mezzano valley in the Po River delta, which was used to interpret the structure of San Felice Channel as a light tower, was built on top of poles (Uggeri, 1978, p. 71, fig. 7; Cesarano & Corti, 2017);

iii) Both structures have mortar at the inner junction between the base and the first course of bricks of the wall. This spread is very similar to the one which was clearly observed, in the same position, in the cistern at Ca' Ballarin. It covered at least the first course of its walls;

iv) Archaeometric analyses confirm the use of *cocciopesto* in the mortar mixes of both structures. *Cocciopesto* mortar was well known and widely used in Roman times, when it was called *opus signinum*, as also reported by *Vitruvius* in the *De Architectura* (VIII, 6, 14), who praises their strength, good mechanical performance and durability. They are hydraulic mortars often used for waterproofing cisterns and waterways, where the pozzolanic additives consist of crushed ceramics and/or bricks partially replacing the inert fraction (Artioli et al., 2019; Weber et al., 2015; Bertolini et al., 2013; Miriello et al., 2010; Chiocchini, 2019). The analysed samples presented in this research are characterized by the use of highly vitrified ceramic fragments and by the presence of paracrystalline and non-crystalline hydrated phases formed due to the pozzolanic reaction between the reactive ceramic components and the lime binder. Furthermore, the precipitation of the poorly crystalline M-S-H/M-A-S-H products was promoted by high alkaline conditions and the availability of Mg in the systems due to crushed ceramics and decomposition of Mg-rich phases (dedolomitization process detected in CB_C1 and CB_C2 samples). The salty water condition had a key role in promoting the precipitation of M-S-H/M-A-S-H products by increasing the pH and, consequently, favouring the dissolution of silicates and carbonates (Bechor et al., 2020). The occurrence of anthropogenic Mg-rich hydrated phases contributes to the strength and durability of the mortar layers. Furthermore, these phases exhibit a negative surface charge, which is compensated by their cation exchange capacity (Bernard et al., 2019), which may improve the conditions of the cisterns preventing any leaks and filtering eventual pollutants, as suggested by Secco et al. (2020);

v) The base of the cistern at Ca' Ballarin is at -410 cm MSL (as per Table 7 in D'Agostino et al., 2020). The preserved walls are 180 cm high (top at -230 cm MSL), and the well is 133 cm high (top at -277 cm MSL). The analysis of benthic foraminiferal assemblages in the small island of San Francesco del Deserto, 5 km to the east (Serandrei Barbero et al., 1997), shows that the Roman relative sea level (RSL) in the 4th century AD was about -215 cm MSL. Assuming a similar RSL at Ca' Ballarin in the 1st-3rd centuries, it appears that the cistern was dug below RSL. This is fully consistent with the existence of an underground cistern. The ground surface should have been at an elevation higher than *ca.* 120

cm MSL (considering an average maximum astronomical tide of 100 cm). At the 'tower' site, the preserved base of the cistern lies at elevations ranging from -420 cm to -375 cm MSL, approximately the same as the Ca' Ballarin cistern and about -200 cm relative to Roman RSL. The position of the foundation below Roman RSL is consistent with its interpretation as a cistern and excludes its interpretation as a Roman building of some sort, be it a 'tower' or a 'lighthouse', as suggested in previous studies (Canal, 1998; D'Agostino & Medas, 2005).

All these elements allow us to propose that the so-called 'tower' of the San Felice Channel is interpreted instead as a cistern. There are no traces of the well, nor of the stone base which is usually present at the bottom of the well. Most probably they were lost due to poor preservation of the structure, or they were intentionally removed in antiquity, leaving no traces of their original presence.

In conclusion, all evidence indicates that this structure was not a 'tower', but a cistern of the Roman Period, although, due to poor preservation, we cannot fully ascertain if it was a well-cistern of the 'Venetian type', such as the one at Ca' Ballarin. It is further highlighted that the elevation relative to Roman RSL is fully consistent with the existence and functionality of these well-cisterns. The previous interpretation of the San Felice structure as a 'tower' or a 'lighthouse', reported also in a recent publication by Madricardo et al. (2021), would imply a highly anomalous local RSL that is not coherent with any geological model for the late Holocene evolution of the lagoon of Venice and the whole Northern Adriatic coast.

ARCHAEOLOGICAL EVIDENCE OF WELL-CISTERNS ALONG THE NORTHERN ADRIATIC COASTAL AREA

Through a review of partly unpublished archaeological excavations carried out in recent decades in the Northern Adriatic coastal area, four sites provide evidence of the presence of cisterns that appear to be similar to those in the San Felice Channel (Fig. 1 and Fig. 17).

Millepertiche (Musile di Piave)

At the site of Millepertiche, in the municipality of Musile di Piave (Venice), a cistern was excavated in 1993 by the Archaeological Superintendency, in collaboration with the Gruppo Archeologico di Meolo, which contracted Co.R.A., a private company.

The cistern is located 400 m south of the Via Annia, a Roman road built in the 2nd century BC (Uggeri, 2012), and very close to a settlement composed of a presumed rural villa and a dock along the bank of a small river channel, dated to the 1st century AD (Croce Da Villa, 2001, p. 278) (Fig. 18). The cistern lies on the southern side of a Late Pleistocene sandy fluvial ridge of the Piave River (Bondesan et al., 2008), at an elevation of about -50 cm MSL on reclaimed land. The site is nearby the inner margin of the Venice Lagoon prior to the cutting of the Sile River canal (Taglio del Sile) in 1684. Assuming a Roman RSL in the northern Venice Lagoon around -140±70 cm (Vacchi et al., 2016), the site was just slightly above sea level during Roman times.

The cistern is composed of a square pit (11.5 x 11.2 m) excavated on the southern side of the alluvial ridge, which was sealed at the base and on the sides by a 70 cm-thick layer of clay (Fig. 19). Close to the north-eastern corner there was a self-supporting well (with an internal diameter of 87 cm), made with *pozzali* bricks, with a curved shape and with a calcareous rectangular stone at the base (Fig. 20). The cornice on this stone suggests it is a reused element. The entire reservoir, 120 cm deep, was filled with well-sorted sand except for a 30 cm-thick layer of gravel which encircled the well. Although the typology of the bricks conserved in one course (which have a standard size of 40 (external side) x 12 x 10 cm) and the pottery found during the excavation are only from the 1st and 2nd centuries AD, the dating of the structure is still not certain (D'Isep, 2002; Vigoni, 2011; M. Davanzo, pers. com., 2021).

Close to this site, at Cascinelle, a structure was possibly identified in aerial photographs as another cistern. It lies few hundred metres from the *Via Annia*, along another relict fluvial channel (M. Davanzo, pers. com., 2021). Though this Cascinelle site would need an excavation test to be fully understood, the spatial relation with the consular road and the palaeohydrography is strikingly similar to the Millepertiche site.

Cittanova (San Donà)

In the site of Cittanova, close the city of San Donà di Piave (Venice), in 1994, an excavation brought to light a rectangular cistern (19.5 x 8 m). The structure is located 30 m to the east of the southern bank of the Piavon palaeochannel, at the present elevation of -50 cm MSL (Fig. 21). The Piavon palaeochannel is a relict channel of the Piave River, that was probably deactivated before the onset of the 2nd millennium BC and that later evolved as a tide-influenced residual channel fed by a small groundwater river (Bondesan et al., 2009). In the Roman Period, this channel entered a wide coastal lagoon that turned into a coastal wetland in the medieval period due to the progradation of Piave River ridges (Bondesan et al., 2004).

The sides of the cistern consisted in a 50-70 cm-thick layer of clay. This reservoir was filled with well-sorted marine sand. A well, located in the northern corner of the cistern, was made of *pozzali* bricks (preserved with a height of 193 cm) encircled by fragments of pottery (Figs. 22-23). The well lay on a circular concave limestone (*pietra d'Istria*?) base, made of two elements jointed by five metal joints (M. Davanzo, pers. com., 2021). There is no information about the dating of the structure because of both the lack of archaeological material in the well and the quality of the rescue excavation.

Aquileia

The cistern of Aquileia was discovered in 1938 by G. Brusin (1939, pp. 70-74 and archival documentation from the Museo Archeologico Nazionale di Aquileia), in the reclaimed area 2 km west of the city, owned by G. Brunner-Muratti. The structure belonged to a complex of Roman Period composed of a small bridge and a building. This latter does not show the typical elements of the Roman house and has been interpreted as a sort of office.

The cistern is close to the wide navigable Anfora Channel that was dug either in the 1st century BC or, more probably, in the 1st century AD, in order to connect Aquileia with the Marano-Grado Lagoon (Bonetto et al., 2020). The present site elevation is around -50 cm MSL; as a 110 to 120 cm minimum RSL rise can be assumed in the area since the Roman Period (Fontana et al., 2017), the site was probably in an alluvial plain setting when functional, though possibly not far from the Roman lagoon inner margin. The cistern had a square shape with 610 cm sides, lateral walls in 30 cm-wide *sesquipedali* bricks, and it was strengthened by three half-pilasters on each side. In the centre it had a well, made of *pozzali* bricks that were not joined by mortar (presumably only in the lowest layers) (Figs. 24, 25). The bricks' dimensions were 39 (external side) x 29.5 x 13 x 9 cm. The well, preserved to an elevation of 125 cm, had a diameter of 73 cm and covers a concave stone slab with a diameter of 96 cm and a thickness of 18 cm. The reservoir was filled with sand while the well was encircled by a 40 cm-thick layer of gravel. Outside of the walls of the cistern the soil was peaty, probably due to the marshy conditions of the area before 20th century land reclamation.

This is of course the structure more similar to the cisterns of the San Felice Channel and the better preserved and documented site.

Piere d'Isela (Lagoon of Marano)

In the Lagoon of Marano, R. Auriemma has documented a square building, dated to the Roman Period, that currently lies at -50 cm RSL which has been tentatively interpreted as a cistern. The floor, with a side 300 cm long, is made with black and white mosaics while the walls are made of tiles and fragments of tiles. Between the floor and the walls there is a layer of 'raw mortar' which could indicate a secondary use of the building as cistern (Florio & Mauro, 2013). Although it has a few technical elements in common with the other noted sites, it is interesting to note its same position along a route of inland navigation.

DISCUSSION

The well-cisterns of the Roman Period presented here can be considered a sort of prototype of the well-known late medieval cisterns which distinguish the public squares (*campi)* of Venice (Fig. 26). As we know, in the Late Middle Ages, well-cisterns occupied almost each open space of Venice and of the islands of the lagoon, both public (in the *campi*) and private (the courtyards inside the palaces), to collect rain water in a territory where the excavation of artesian wells is not easy since the groundwater layer is quite deep (Costantini, 1984, p. 13). As the historian Marin Sanudo (Caracciolo Aricò, 1980) said in the beginning of the 16th century, 'Venice is on the water but without water'. So, the cisterns were regularly filled with freshwater, carried from the Brenta River with special boats (*burci*), to add to the rainwater (Costantini, 1984; Gentilcore, 2021, with references).
The building of well-cisterns in Venice continued in the modern era until the middle of the 19th century when, before the construction of the aqueduct and their definitive fall into disuse, they numbered more than 6000 and occupied the 10% of the surface of the city (http://cigno.atlantedellalaguna.it/maps/47/view; accessed 12/2022).
Three well-cisterns, at Ca' Ballarin, San Felice Channel and Aquileia, fairly accurately dated between the 1st and the 3rd centuries AD, present tanks made of bricks with an internal coating of *cocciopesto* mortar, while others, Millepertiche and Cittanova, without a certain chronology but that could tentatively be proposed to date to the Roman Period, present reservoirs sealed with a layer of clay. Despite the different technique of sealing, the system of functioning appears to be exactly the same. The rainwater entered from the top, that is from the floor surface, presumably through some pierced stones (later called *pilelle*), to fill the cistern. The sand filling the basin filtered the water before it entered inside the well, which was made of bricks. The structures with basins made of a thick layer of clay are more similar to the first known Venetian well-cisterns, which include one excavated at Torcello, dated between the end of the 9th and the 11th centuries AD (Calaon et al.,

2014, pp. 72-73) (Fig. 27), the three recognized during the excavation of the Conterie of Murano (Cozza, 2014), dated between the 11th and the 14th centuries, and the one hypothesized in the excavation of Ca' Vendramin Calergi in Venice, dated between the 11th and the 12th centuries (Gobbo, 2005, pp. 43-50; Cianciosi, 2022). These medieval cisterns differ from those from the Roman Period not only due to the use of clay for the tank (which prevented the rainwater from flowing away and the saltwater from filtering in), but also because of the use of straight bricks, i.e., not of *pozzali*, to build the well. In general, it seems that in the Roman Period the use of bricks was preferred although, of course, building with bricks required more time and material.

Beyond technological aspects, it seems that the Roman well-cisterns investigated may differ from the medieval ones in terms of their use. While the latter mostly served settlements and dwellings, the former appear to be strictly related to waterways. Two cisterns lie along the navigable San Felice Channel, which in the Roman Period probably connected the tidal inlet of Treporti (the 'entrance' to the lagoon) with the harbour of *Altinum*. A cistern is located along the navigable artificial canal *Canale Anfora*, which connected the riverine harbour of Aquileia with the sea (Bonetto et al., 2020), a possible 'traditional' cistern is located in the lagoon of Marano and two 'well-cisterns' are located along paleochannels at Cittanova and Millepertiche.

It is possible, indeed, that the construction of the cisterns along waterways was justified by the necessity to reach them easily by boat in order to recurrently fill them, when rainwater was not enough. However, an alternative explanation is that they were used for providing good-quality freshwater water to be loaded on ships going out to sea. Moreover, it is known that the supply of freshwater has always been essential for navigation in any era. The *Stadiasmus Maris Magni*, a Greek text with marked nautical contents, describes the North African and East Mediterranean coasts (Arnaud, 2017). It is divided in different sections and chronologically stratified between the late Hellenistic and the Augustan Age, but its last assemblage can be dated back to between the 1st and 2nd centuries AD. It also includes information about the practice of freshwater supply, *acquata* in Italian (Medas 2008, pp. 165-168). In particular, the ways used to find freshwater are described, as well as the exact places where it could be found, also specifying its quality. It is interesting to find that among the different freshwater supply sources the *Stadiasmus* mentions the ὕδωρ λακκαῖον (*Stad.M.M.*, 12, Müller 1855) namely 'cistern-reservoir/well water'. In our case, the topographical position of cisterns-reservoirs, which could reach a good capacity ranging between the 85 m^3 of the one in Aquileia (comprising the sand which of course occupied the majority of the volume) to the presumed 358 m^3 of the one of Cittanova, could relate to passage points along waterways along a low coast, functional to the freshwater supply for boats and ships crossing in areas where the rise of salt in the groundwater precluded the possibility of finding other good quality natural water sources.

We know that the well-cisterns documented in our investigation were located either in salt marshes along the banks of tidal channels (i.e., the San Felice Channel sites), or in low-lying alluvial plains at elevations lower than *ca.* +150 cm RSL. In both cases, the near-surface underground water table was most probably brackish and not suitable for human consumption. Surface water in the Piavon and other paleochannels nearby the inner Venice Lagoon margin, as well as in the Canale Anfora near Aquileia, was also possibly brackish during high tide. This suggests that, in such environmental settings, well-cisterns might be the only effective way of storing good quality freshwater that could be provided to seafaring ships for several days or weeks of navigation.

The hypothesis that these artefacts were part of coastal infrastructure in support of navigation still leaves some unanswered questions concerning their presence along the north-western Adriatic littoral. Indeed, it remains to be explained why, apparently, the use of these well-cisterns instead of artesian wells was exclusively in this part of the Empire and not documented elsewhere. Was it a local tradition like the construction of ships using the sewing technique, which is another system used only in the northern Adriatic (Beltrame, 2002)?

CONCLUSIONS

Our program of underwater investigation has uncovered and documented the presence of Roman well-cisterns and related infrastructures on the banks of the San Felice Channel, dating from the 1st to the 3rd centuries AD. Our new photogrammetric survey documents the presence of an 18 m-long pier, almost perpendicular to the channel bank, nearby the well-cistern at Ca’ Ballarin. Radiocarbon dating of one of the foundation poles confirms that the pier was contemporary with the well-cistern and that its construction occurred in the 1st-2nd centuries AD. The new survey, coring and analysis of mortar of a submerged structure located about 2 km to the west of Ca’ Ballarin towards the sea, further allowed to discard its previous interpretation as a ‘tower’ or a ‘lighthouse’, and instead prove that it was another well-cistern dating to the Roman Period.

The remains of the San Felice Channel well-cisterns, as well as other similar structures located nearby the inner margin of the lagoon at Millepertiche and Cittanova and on the coastal plain of Aquileia, were at elevation of maximum +150 cm in respect to Roman RSL. Such low-lying coastal setting implies predominant brackish underground and surface water conditions. In these environmental conditions, well-cisterns were thus an efficient system for storing large volumes of good-quality freshwater, as largely documented in medieval and modern times in the city of Venice and in other late medieval locations (see above).

The San Felice Channel well-cisterns were located along the tidal inlet that was probably crossed by Roman ships from the Adriatic Sea entering the Venice Lagoon to reach the harbour city of *Altinum*. The Millepertiche and Cittanova well-cisterns were close to the consular road *Via Annia*, at the junction between lagoon and fluvial waterways. The Aquileia well-cistern was nearby the Canale Anfora, a Roman artificial canal that linked the city to the sea. Such close connection of well-cisterns with major waterways suggests that they could be dedicated to the supply of freshwater for boats and ships. This interpretation of the well-cisterns as part of a system of nautical infrastructures in support to inland and coastal navigation is further enhanced by their association with the pier at Ca' Ballarin and wooden docks at Millepertiche, that indicate mooring of ships and boats.

The lack of documentation of well-cisterns in other regions of the Roman Empire highlights the possibility that this kind of hydraulic device developed locally, in response to the peculiar environmental and hydrogeological conditions of the low coast and lagoons of the northern Adriatic Sea, and the intense navigation and trading activities that characterized this region. Nevertheless, they can also possibly be a form of local tradition which will be passed on to the later centuries, as the medieval well-cisterns of Torcello and Murano demonstrate.

Authors Contributions

Carlo Beltrame: introduction and conclusions, archaeological investigation of the cistern of San Felice Channel and study of the comparisions with other cisterns; Stefano Medas: the Ca' Ballarin cistern and the *Stadiasmus* for fresh water supply in navigation; Paolo Mozzi: corings and geomorphological aspects; Giulia Ricci: chemical analysis.

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Permissions

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Figure Captions

1. Geomorphological sketch map of the northern lagoon of Venice (modified with permission by Paolo Mozzi from Primon & Mozzi, 2014). In the inset map are shown the locations of the studied sites; the yellow rectangle shows the area covered by the geomorphological map, the red line is the Roman road *Via Annia* with circles indicating main Roman cities and settlements.
2. The well-cistern of Ca' Ballarin (drawing: V. Goti Vola; license by Ministero della Cultura, Soprintendenza Archeologia, belle arti e paesaggio per il Comune di Venezia e Laguna, further reproduction prohibited).
3. Detail of the *cocciopesto/opus signinum* mortar coating inside the cistern of Ca' Ballarin (license by Ministero della Cultura, further reproduction prohibited. Photo: S. Medas).
4. Roman pier of concrete at Ca' Ballarin and position of sampling of *cocciopesto* (samples CB_C1 and CB_C2), wood (sample CB_P1) and sediments (cores CB_c.1C and CB_c.2 D) (processed by E. Costa, Università Ca' Foscari Venezia).
5. Orthophoto of the photogrammetry of the 'tower' of San Felice Channel and position of the cores TSF_c.A and TSF_c.B and the sample of the mortar (TSF_T9) (processed by E. Costa, Università Ca' Foscari Venezia).

6. Multi-beam survey carried out on the 'tower' of San Felice Channel (Università Ca' Foscari-Elmar).
7. C 14 Cal AD analysis on a pole (sample CB_P1) of the Roman pier at Ca' Ballarin (Ion Beam Physics ETH-Zurich).
8. a) and b) Crossed polarized light micrographs in transmitted light of the two samples CB_C1 and CB_C2. c) and d) backscattered electron images (BSI) of the CB_C1 sample and microanalyses of the *cocciopesto* fragment (01) and matrix (02) (photo: G. Ricci).
9. Detail of a side of the foundations, in *sesquipedali* bricks, of the 'tower' (license by Ministero della Cultura, further reproduction prohibited. Photo: S. Medas).
10. Detail of the layer of mortar in the corner between the wall and the base of the 'tower' (license by Ministero della Cultura, further reproduction prohibited. Photo: S. Medas).
11. Collapsed structure composed of four courses of bricks of the wall and two courses of the base of the 'tower' (license by Ministero della Cultura, further reproduction prohibited. Photo: S. Medas).
12. Dressel 6 A amphora trapped in a hole among the bricks of the 'tower' (license by Ministero della Cultura, further reproduction prohibited. Photo: S. Medas).
13. Dressel 6 A (a), Dressel 2-4 (b) amphoras found on the 'tower' (license by Ministero della Cultura, further reproduction prohibited).
14. Detail of the clay silt soil under the 'tower' (without any foundation poles) (license by Ministero della Cultura, further reproduction prohibited. Photo: S. Medas).
15. Crossed polarized light micrographs in transmitted light (a) and SEM-EDS analyses (b) of the TSF_T9 sample. The microanalysis 01 refers to the binder matrix (photo: G. Ricci).
16. The cistern of Millepertiche during the excavation in 1993 (photo with permission: Centro di Documentazione "Giuseppe Pavanello", L. D'Isep and Ministero della Cultura-Soprintendenza ABAP-Ve-Met, further reproduction prohibited).
17. The well with *pozzali* bricks, with a rectangular stone at the base, of the Millepertiche cistern (photo with permission: Centro di Documentazione "Giuseppe Pavanello" and Ministero della Cultura-Soprintendenza ABAP-Ve-Met, further reproduction prohibited).
18. Location of the Cittanova cistern (Regione Veneto, flight 1983, https://idt2.regione.veneto.it/; accessed 01/2023).
19. Sketch of the cistern of Cittanova (drawing, with permission: Centro di Documentazione "Giuseppe Pavanello").
20. ~~The cistern of Cittanova during the excavation in 1994 (photo, with permission)~~
21. Plan of the Roman cistern along the Canale Anfora at Aquileia (license received from the Ministero della Cultura, Dir ezione Musei regionale Musei del Friuli Venezia Giulia, original at the archive of the Museo Archeologico Nazionale di Aquileia, further reproduction).
22. Roman cistern along the Canale Anfora at Aquileia during the excavation of 1938 (license received from the Ministero della Cultura, Direzione Musei regionale Musei del Friuli Venezia Giulia, original at the archive of the Museo Archeologico Nazio nale di Aquileia, further reproduction prohibited).
23. Section of a typical late-medieval Venetian well-cistern (Rizzi, 1976, p. 364, with permission)
24. Section of the 9th-11th centuries AD well-cistern at Torcello, Venice (Calaon et al., 2014, p. 81, with permission).