

Article

Remote Sensing and Geo-Archaeological Data: Inland Water Studies for the Conservation of Underwater Cultural Heritage in the Ferrara District, Italy

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Abstract: In the southern area of the Ferrara District, Italy, remote sensing investigations associated with geo-archaeological drilling in underwater archaeological studies, have helped to broad our understanding of the historical evolution and cultural heritage of inland waterways. In working on prototype sites, we have taken a multidisciplinary approach of surveillance and preventive archaeology, and have collaborated with archaeologists, geologists, hydro-biologists, and engineers. In this area of research, often lakes, lagoons, and rivers are characterized by low visibility. Some Quaternary events have deeply modified Ferrara's landscape. Analysis of preserved samples from micro-drillings, underwater direct and indirect surveys, and the cataloguing of historical artefacts, are giving to the researchers a remarkable ancient chronology line. Recent studies confirmed anthropization sequences from the 1st Century B.C. to the 6th Century A.D. Waterscape archaeology, a multidisciplinary science devoted to the study of the human use of wetlands and anthropological connection with the water environment, testifies the ways in which people, in the past, constructed and used the water environment. In this article, we describe underwater cultural heritage research using 3D side scan sonar surveys and artifacts analysis, comparing data from direct diving investigations and stratigraphic data from micro-geological drillings on sites of Lago Tramonto, Gambulaga, Portomaggiore (Ferrara).

Keywords: underwater cultural heritage; palaeo-watercourses; geo-archaeology; remote sensing; Late Roman; Ferrara

1. Introduction

The Project *Underwater Archaeology of the Inland Waters- Investigations at Lago Tramonto Gambulaga (FE-Italy)* is a collaboration between *Federation ITA F07-CMAS Diving Center Italia*, *Confédération Mondiale des Activités Subaquatiques* and Superintendence of Emilia Romagna, Archaeology sector, directed by who is writing with the scientific supervision of the Functionaries of the Superintendence F. Berti, V. Nizzo, M. Cesarano, C. Guarnieri.

This research utilized an experimental approach and new methodologies regarding the surveillance archaeology of inland waters, including underwater and landscape research. In Italy, legislation requires that preliminary archaeological studies, defined as “preventive verification of potential archaeological interests and surveillance during excavations”, follow the United Nations Educational, Scientific and Cultural Organization (UNESCO) conventions for underwater cultural heritage (for more information on the Italian Legislation see <http://www.archeologiapreventiva.beniculturali.it/rifelegi.php>; or for the UNESCO conventions, see <http://www.unesco.org/new/en/culture/themes/underwater-cultural-heritage/2001-convention/>). Archaeology is a discipline connected to geo-resources, oil and gas, and big engineering works. Geo-resources, especially

geo-technic and quarry studies, are involved in the stratigraphic evolution of territory, as well as archaeology. Methodologies, techniques, and new approaches to territory are the same for all of these disciplines, and are orientated to the preservation of cultural heritage.

The sand quarries of Ferrara are diffuse. They are projected, by geologists and engineers who undertake sedimentological and hydrogeological research, before, during, and after excavations. Pianura Padana is a late geological structure, crossed by big rivers, of which, some still survive and have become palaeo-watercourses, filled by sediments [1,2].

Palaeo-watercourse systems are mainly evidenced by old traces of the Po River. From satellite and aerial photos, the ancient courses are still highly visible. Our first analysis, with geologist collaboration, is dedicated to the examination of such ancient courses, including their morphology and their flow.

The southern branch of the Po is subdivided in the direction of the Reno River, parallel to the Sandalus (ex river), to divert a small fraction to a municipality in Portomaggiore, Gambulaga [3–5], which is an area with old geo-resource poles, now converted into naturalistic oasis lakes (Figures 1 and 2).

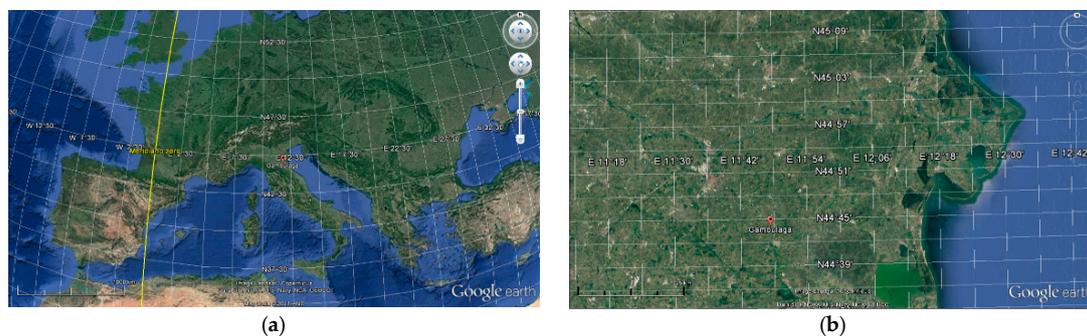


Figure 1. Satellite images of Gambulaga, Portomaggiore (Ferrara District (FE), Italy): (a) Position of the site; (b) River Po Delta (Google Earth Satellite Images, accessed on 22 January 2018).



Figure 2. Satellite images of Gambulaga, Portomaggiore (FE, Italy): (a) Lago Tramonto and Lago Alba (Google Earth Satellite Image, accessed on 23 November 2017); (b) Sunset at Lago Tramonto, panorama from Northeast side.

The lakes are inside a palaeo-alveo, which meanders in a northeast direction, with a northern margin characterized by high elevation (2.5 m above sea level). The lakes were excavated by dredge during the decade 1980–1990.

The excavations of the *Fadieni necropolis*, close to the north side of Lago Tramonto, (Figure 3) underline the archaeological interest in this area, which is connected to life in Roman and Late Roman Periods, attested by its proximity to *Vicus Aventiae* or Voghenza (FE) [6].



Figure 3. Evidence of the archeological interest in Gambulaga, Portomaggiore (FE, Italy): (a) Artifacts found via excavation of the *Fadieni necropolis* site http://www.archeobo.arti.beniculturali.it/mostre/settimana_cultura_06.htm; (b) Permanent exhibition of the artifacts found at the castle, Delizia del Verginese <http://www.archeobologna.beniculturali.it/mostre/gambulaga.htm>.

The underwater investigations described in this study began in 2009 [7–9] and continued until 2016.

In 2014, we performed two sections of remote sensing investigations. In 2015, we made a complete inventory of the artifacts found since 2009 (180 findings) and, during the summer of 2016, we organized two underwater inspections, which were characterized by extraordinary visibility (due to exceptional droughts and the absence of rain that would usually drain clay into the lake). During 2017, we made two geo-archaeological drillings to investigate the stratigraphy of the North and South sides of Lago Tramonto, whose sedimentology was only partially individuated during underwater direct surveys.

Following the stratigraphic sequences that were found in 2009 from diving surveys and after having carried out a polygonal background of 250 m in length along the northern shore of the lake, sporadic objects were found on the bottom of the lake between a depth of 3–4.5 m. These objects were heterogeneous ceramic fragments, orange and yellow amphorae pieces, and fragments of bricks and tiles. We conducted studies that would extend this past research. In 2016, we performed new underwater surveys and re-examined the old geological documentation that was preserved in the regional online database. In 2017, we made new geo-archaeological drillings, with particular analysis of the local stratigraphy. In this paper, we illustrate new archaeological discoveries and their connection to new methodological applications.

2. Materials and Methods

2.1. Remote Sensing Surveys

Indirect surveys were performed in collaboration with Hydrosynergy (a spin-off of Alma Mater Studiorum University of Bologna, Bologna, Italy) during 2013. Thanks to an integrated instrument, echo sound scan sonar *Humminbird 1198c SI Combo*, and the software, *Dr. Depth*, set on an aluminum small boat with an electric powered engine, we completed a sequence of 20 parallel swaths, as well as perimeter scanning, beginning from the East side of Lake Tramonto. This hydrographical survey permitted us to draw, in scale, seven 3D plan-views (see Figure 4a for example) and two 3D sections (North–South and West–East, as shown in Figure 4b), showing the maximum extension of the lake, the maximum depth, and the most dangerous area to avoid during underwater inspections (for more about safety in underwater quarry investigations see [7]). The echo scan records latitude and longitude coordinates for later examination; and depth information for each coordinate value is stored differently for each khz beam from the transducer. The recorded files are stored in two formats, directly, when recorded. The first format is a general allocation file for a *Humminbird* unit (.DAT files, which recall spatial information and connect this to depth information). The second format is .SON and this is located in the folder associated with the waypoint that started the original recording track (depth

information from each kHz). The software, Dr. Depth, for bathymetric mapping, utilizes a multi-staged anisotropic smoothing spline algorithm to pair depth and location data into a 3D bathymetric map. Maps and sections are drawn per as isobaths, with sloping contours from 0 to 20 m in shades of blue to red, respectively, integrated with metric reference and orientation (Figure 4) data, georeferenced on Google Earth.

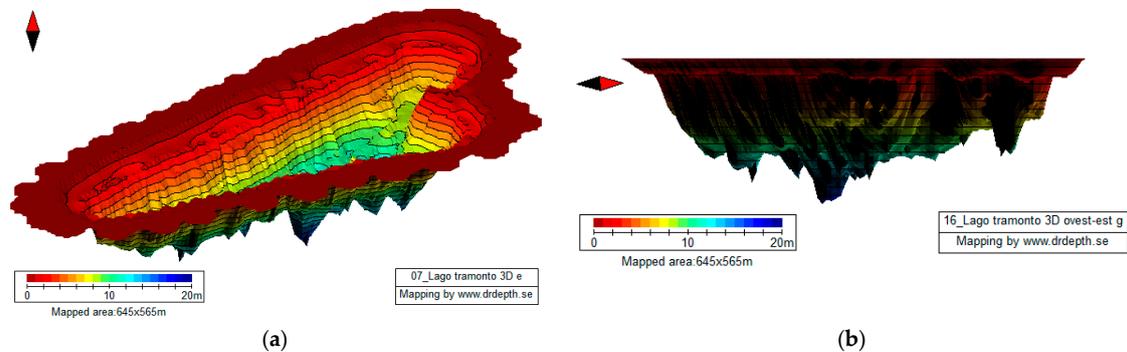


Figure 4. Tridimensional elaborations of Lago Tramonto in Gambulaga, Portomaggiore (FE, Italy): (a) 3D bathymetry; (b) 3D section West-East (using Hydrosynergy).

From the database of the scanned lake-bottom, we detected 25 anomalies, both natural and artificial. The archaeological evidence was concentrated predominantly in the northern sector of the lake, at a depth between 4–12 m (Figure 5a,b).



Figure 5. Lago Tramonto in Gambulaga, Portomaggiore (FE, Italy): (a) A view of the georeferenced bathymetrical plan, with an indication of the underwater site; (b) Positioning of the main ancient anomalies (yellow oval).

The instruments detected ancient and modern anomalies. The criteria for identification of anomalies was the comprehension of peculiar shapes and shadows, identified by watching the *DAT* side and down image files on the computer, displayed by the software, Hum Viewer. Examining the recorded echo scan track files, we isolated the presence of natural downslopes from the settlement of sediment (after quarry excavation), tree trunks belonging to an ancient phase of forestry [1,5], wood poles, and some accumulations of bricks and fragments of pottery. The shapes of the artifacts with sharp edges were evident on the sediment bed. Viewing the images, we identified collapsed horizontal poles due to their length and morphology, with circular sections. A vertical wood system was clear from the echo scan recorded files when changing the chromatics of the file track shadows.

With site surveys, we had the chance to check evidence and collect diagnostic data, concentrated in the northwest area (Figure 5a,b). We detected that the northern bank of the ancient river was made of compact clay, with quite vertical excavated margin and micro-depositional levels of clay and silt, visible on *.DAT* files as a long dark rectilinear shadow running West–East (Figure 6).

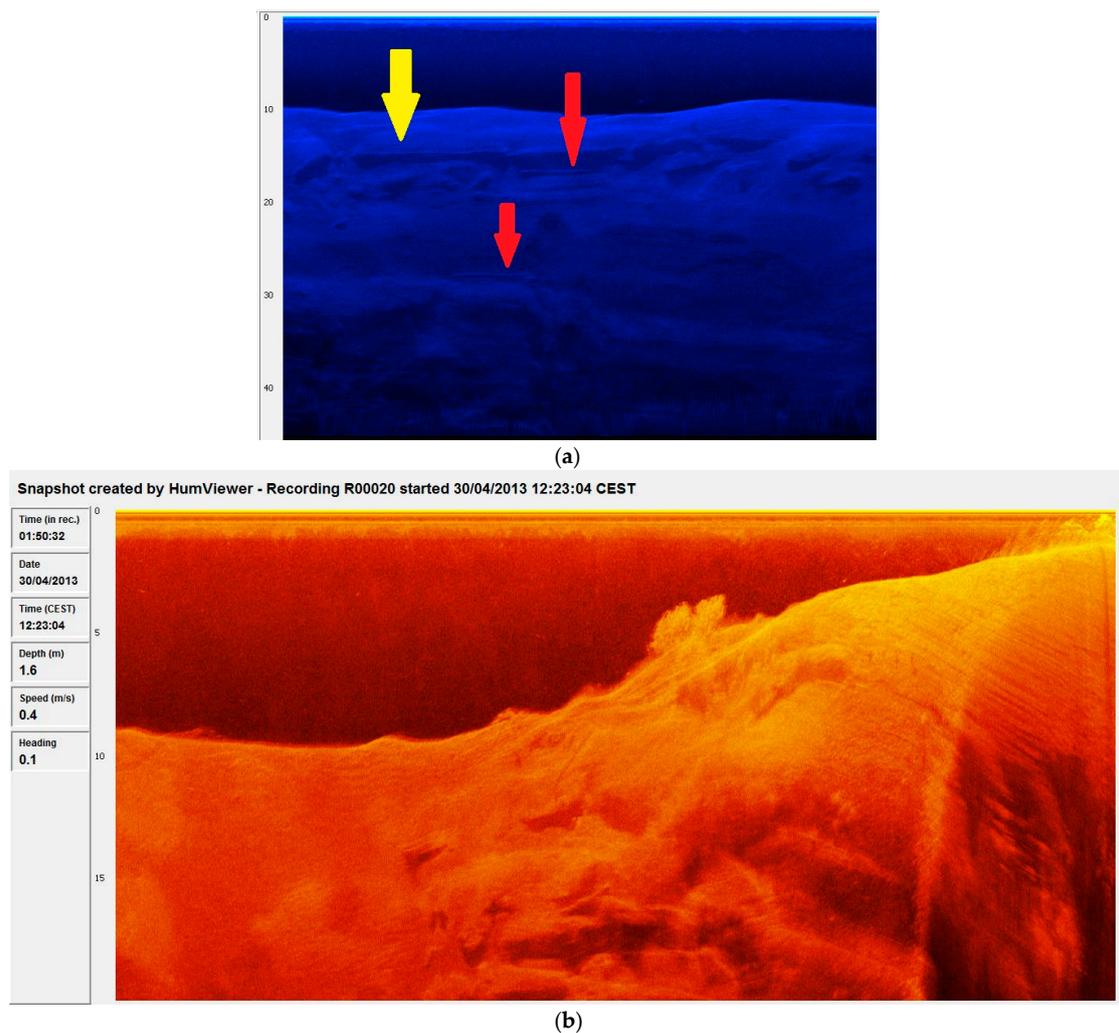
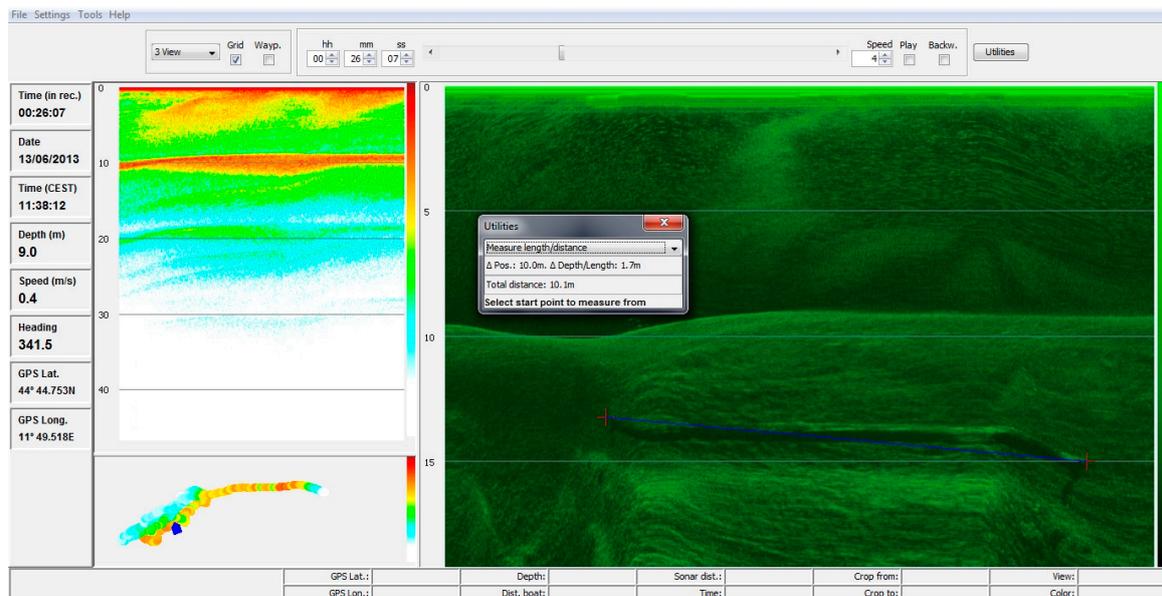
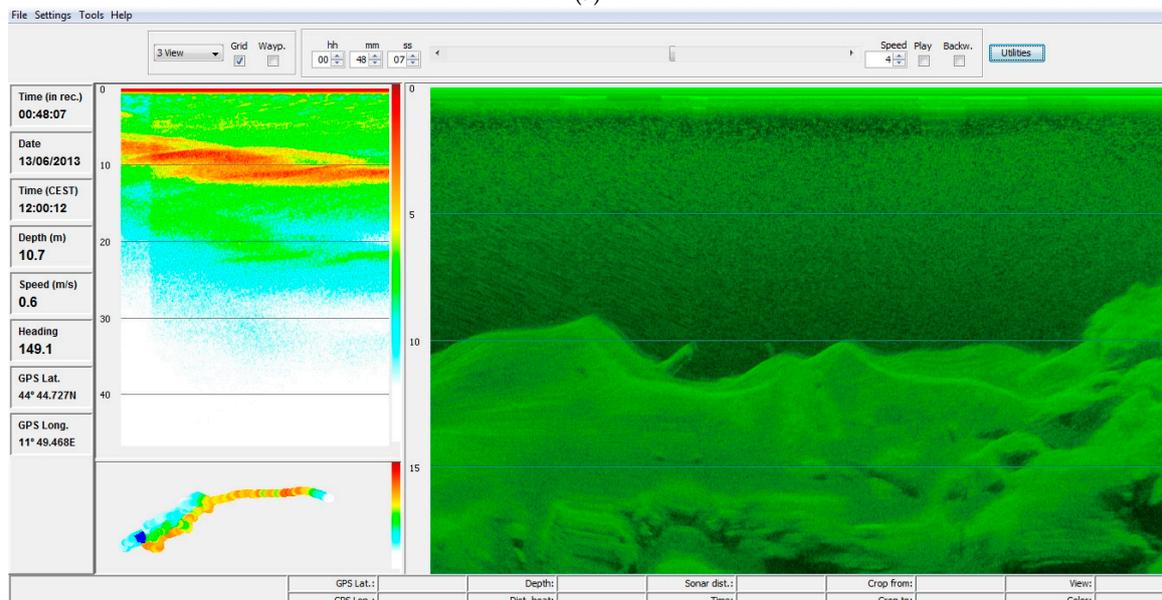


Figure 6. Visualization of the echo side scan sonar snap shots with Hum viewer software, in Lago Tramonto, Gambulaga, Portomaggiore (FE, Italy): (a) Down image of the northern, ancient riverside (indicated by yellow arrow) with fallen posts (red arrows); (b) Down image of mudslide and collapsed structures.

As visible in the Arcgis photo in Figure 9 (see Section 2.2), and the echo side scan sonar, the northern edge of the river coincided perfectly with the bank of compact clay we documented underwater in the direct surveys, as well as with remote sensing investigation, with a better long distance perspective. We also found trees, cut wood, bricks, and tiles. Many downslopes and partial bank collapses were located along the same direction, South–West to North–East, following the direction of the river flow. Post-processing analysis of the echo side scan sonar data allowed us to take measurements of the big trunks laying on the silty clay, close to the northern river bank, that were almost 10 m in length (Figure 7).



(a)



(b)

Figure 7. Visualization of the echo side scan sonar snap shots with Hum viewer software, in Lago Tramonto, Gambulaga, Portomaggiore (FE, Italy): (a) Bottom, down image and position with metrical reference of a big trunk; (b) Bottom, down image and position of anthropic traces.

A tiny current could still be detected in the alveo because of the natural course of the falda water, following the morphology of the ancient hydrographical context.

We also saw traces of the quarry excavations that were better understood with immersion on-site (Figure 8a,b).



Figure 8. Underwater surveys from 2016 in Lago Tramonto, Gambulaga, Portomaggiore (FE, Italy): (a) Clay banks cut by the dredge; (b) A vertical hole caused by the fixing pile of the dredge (photo by Giovanna Bucci).

2.2. Geological and Geo-Archaeological Drillings

We analyzed 18 local geological drillings and three penetrometric tests performed in 1990, preliminary to the quarry excavation.

Documentation from this preliminary investigation related to a sand quarry project are available online, on the geological webgis cartographical database of Emilia Romagna (<http://ambiente.regione.emilia-romagna.it/geologia/cartografia/webgis-banchedati>).

Perforation No. 204060 P4242 Comune di Portomaggiore Dato R/7 SONGEO (position 9.7 in Figure 9a), after 3 m of silt alternated to gray sand, shows a level of grey medium sand with wood at a depth of 6.8–7.7 m (from the ground level). The presence of wood gives a useful comparison to our database, coming from direct investigations. This data, compared with the lake-bottom measures, coincides with our main, detected archaeological, underwater findings. The falda level at the time of the 1990 drillings and penetrometric analysis was found to be 2.5 m, which means the archaeological level was at a depth of 5.5 m. As visible from the Arcgis photo below (Figure 9b, blue arrow), the palaeo-alveo is partially obliterated, exactly in coincidence with the archaeological site. As we can see from Figure 9c, geologists isolated a flow in this area. The Google Earth elevation section (Figure 9d) shows the fluvial palaeo-bank of the river with anthropic traces.

There was a big flow, that has already been studied by geologists, at the southeastern side of the lake [5], which likely modified the local landscape at the time of the event. Our research suggests this catastrophe of Late Quaternary happened at the beginning of the Early Middle Ages (see Section 5). The chronology, as we already know, concerns Roman and Late Roman—Early Mediaeval Cultural Heritage.

The geo-archaeological drillings of 2017 were dedicated to providing a better understanding of the local stratigraphy, giving special attention to the presence of palaeo-soils and ancient anthropization, and looking for an untouched, well-preserved stratigraphy, close to the fluvial anthropized bank. We positioned the drillings at the South and North sides of the lake to make a section of the western area of the palaeo-watercourse (Figure 9c,d).

The lower part of Figure 9d shows the elevated section of the sedimentary deposits along the old river. The north side shows the biggest depositional bump inside the meander, while the South side is the most erosive side, as visible from the red arrows indicating the right side of the palaeo-watercourse. The lake is not as wide as the river. We confirmed this by analyzing the stratigraphy data from the first, 2017 drill (Figure 10).

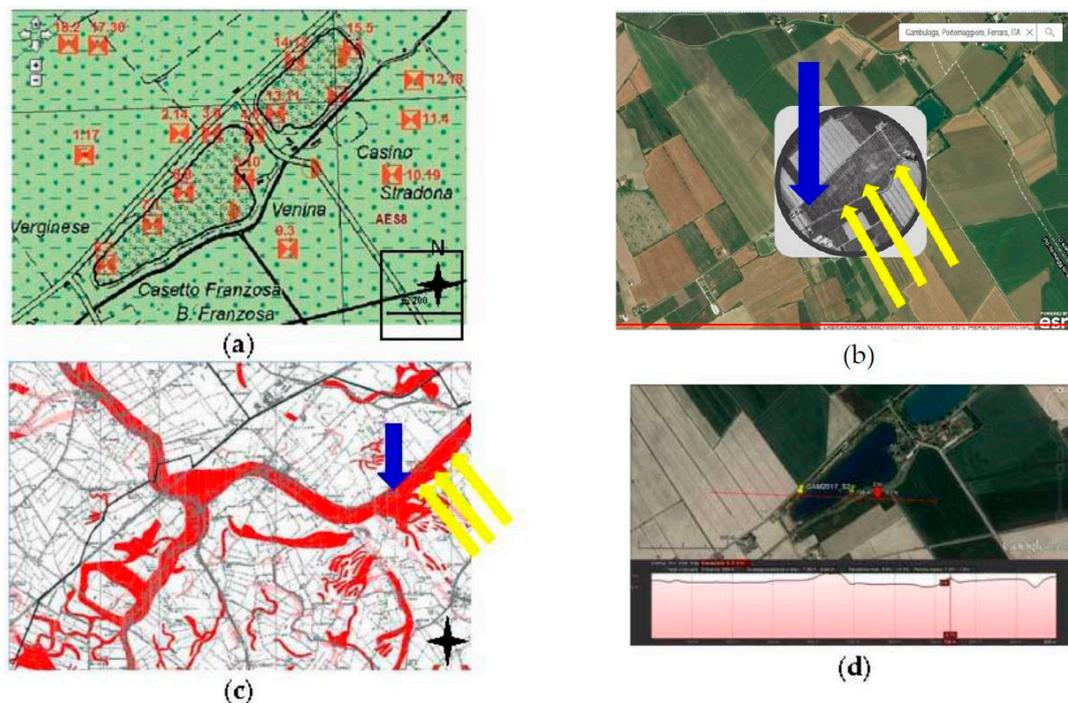


Figure 9. Lago Tramonto, Gambulaga, Portomaggiore (FE, Italy): (a) Extracted plan view from <http://ambiente.regione.emilia-romagna.it/geologia/cartografia/webgis-banchedati> (accessed on 30 November 2017) with the positioning of the 1990 drillings; (b) Palaeo-watercourse of the River Po on the site of the future quarry (1989), extracted from <http://www.arcgis.com> (accessed 1 December 2017), where the blue arrows indicate the archaeological site and the yellow arrows indicate the palaeo-alveo traces; (c) Palaeo-watercourses and floods (extracted from [3]); (d) Google Earth Image with position of the 2017 drillings and 1km altitude section crossing the two points of the drill.



Figure 10. Drilling No. 1 in 2017 in Lago Tramonto, Gambulaga, Portomaggiore (FE, Italy): (a) The drilling machine; (b) Work in progress while drilling, sediment check (photo by Giovanna Bucci).

Drill No. 1/2017 reached 5 m depth and presented the following stratigraphy (expressed in meters): from 0 to 0.60 there was beige silt, 0.60–1.25 sandy silt (beige and orange), 1.25–1.55 grey silty sand, 1.55–1.80 grey coarse sand, 1.80–2.20 grey sand, 2.20–3.10 beige lightly silty sand, and from 3.10–5.00 there was grey coarse sand (see Appendix A and Figure A1).

The second drill, on the North shore, was 8 m deep and showed the following levels (expressed in meters): from 0–0.50 there was beige silty clay, 0.50–1.35 brown mottled silty clay with vegetal traces, 1.35–2.40 beige orange mottled clayey silt with traces of reeds, 2.40–3.15 beige silt, 3.15–3.65 grey clay (palaeo-soil), 3.65–4.30 grey–light blue silt, 4.30–4.50 grey clay with micro fragments of torba, 4.50–5.10 grey sand, 5.10–5.40 grey clay with a nucleus of CaCO_3 , 5.40–5.60 violet clay with

micro-carbonaceous cores and vegetal traces (palaeo-soil), 5.60–6.10 grey silt with vegetal traces and malacofauna, 6.10–7.40 violet silty clay with micro-carbonaceous cores and vegetal traces (palaeo-soil), and from 7.40–8.00 there was violet silty clay with torba micro levels (see Appendix A and Figure A2).

The two investigations concerned two different depositional situations. To the South side we have the river itself with its “clean” sediments, and to the North side there are traces of ancient human settlements, confirming all our preceding research.

There were some extra considerations regarding the second drilling. The area was covered by beige silty clay that lay on a brown mottled silty clay with vegetal traces, concerning the last centuries (see Appendix A for a graphic depiction) Stratigraphic Units 1, 2, and 3. A natural alluvial level of beige silt (US 3) covered the first palaeo-soil, connected to a downslope of the river bank. The natural matrix of grey clay included micro-fragments of bricks belonging to the Roman and Late Roman Periods.

There were a couple of typical inland water layers, with gray and light-blue silt, possibly indicating a slow phase of the watercourse from palaeo-soils or beds of inland waterscapes.

The sedimentological characterization of the samples performed during 2017 [10] supported the presence, in many samples, of seeds belonging to *flora palustris*, typical of inland waters: *Nymphaea alba*, *Apium inondatum*, *Typha latifolia*, and *Sparganium erectum*. Isotopic analysis confirmed the presence of organic components.

2.3. Underwater Surveys

The 2016 dive session was dedicated to the documentation of the submerged site of Lago Tramonto, in light of the data collected by echo side scan sonar in 2013.

The underwater surveys were performed thanks to a team of divers, using simple diving equipment with 12 or 15 l tanks, filled with air, fitted with double first stage, separated primary and secondary regulators, together with all of the safety equipment required by current legislation. The use of compasses was fundamental, along with canonic topographical instruments, including a total station Leica 1205 reflector (settled at the edge of the lake), capable of positioning our reference buys on the surface and connecting our measures to a local topographical grid (Figure 11a,b).



Figure 11. Photographs of the underwater survey operation in Lago Tramonto, Gambulaga, Portomaggiore (FE, Italy): (a) Setting of the equipment before the survey; (b) Pegging the underwater topographical reference point (photo by Antonio Duccoli and Paolo Farina).

There were three main underwater surveys. Table 1 reports the main data with satellite Google Earth positioning of the main tracks performed.

The first survey, carried out in May 2016, took place in the west sector of the lake and along the eastern edge; the second survey took place in August along the circumnavigation of the lake; and the third survey focused on the northwest area of the basin, where we have documented traces of frequentation and the sporadic presence of artifacts. Excellent water visibility between August and September 2016 made it possible to take videos and photographs, bringing to light new information about cultural heritage.

Table 1. The underwater surveys recording sheet, which includes the number of the survey, date, length of the track, diving time, maximum depth, temperature of the water, remarks, and Google Earth GPS mapping of the surveys.

S No.	Date	Track [km]	Diving Time [h]	Max Depth [m]	T [°C]	Remarks	Satellite Photo-Plan Google Earth with Survey Track
1	22 May 2016	0.57	01:02:05	7.4	16.4	Very poor visibility, absence of archaeological findings	
2	15 August 2016	1.27	02:50:50	7.8	24.4	Good visibility, documentation of the archaeological site	
3	15 September 2016	0.38	01:05:20	6.9	26.3	Very good visibility, documentation of the archaeological site	

Material emerged from the bottom of the lake due to local underwater sediment landslides has increased the knowledge of the site, the possibility of new investigations, and has expanded the chronology of attendance.

From a methodological point of view, research was carried out using the parallel swath system (method of crossbars or parallels), even over the longer distance by remote sensing. We proceeded by following the best visibility and anthropic traces. For the most evident structures, on which we concentrated our work, we provide a double topographical net connected to the old one made between 2009 and 2010 [9], with a polygonal line on the lakebed and new parallel grid of investigation oriented with compasses, meters, and “floating GPS”. Positioning was achieved using a GPS receiver in a watertight container, placed in the sub-marks buoy and equipped with appropriate housing.

The underwater photographic and video documentation was undertaken with a *Nikon Coolpix AW110* digital camera and a *Go Pro Hero3 Black*.

3. Results

Surveys number 2 and 3, in 2016, were designed to discriminate objects for the interpretation of the archaeological history of the lake.

We documented part of the ancient natural bank of the river, made of very compact gray–beige clay and a palisade. This natural structure was well-identified thanks to the echo side scan sonar investigation. Natural achievement of the resting angle of the sediments and perhaps also the earthquake of 2012, gave rise to a small landslide, with a sandy matrix, in the vicinity of an area already highlighted in previous studies [7–9]. Part of the outcropping clay material could be traced back to Late Antiquity. We found a different typology of the amphora: *Late Roman 3* and *Late Roman 5* (Figure 12a,b).



Figure 12. Fragments of Late Roman Amphorae found during underwater surveys in Lago Tramonto, Gambulaga, Portomaggiore (FE, Italy): (a) Foot and part of the body of *Late Roman 3*; (b) Handle of *Late Roman 5* (photo by Giovanna Bucci).

These are also fragments of *dolia*, tableware and kitchenware (Figure 13a,b).



Figure 13. Fragments found during underwater surveys in Lago Tramonto, Gambulaga, Portomaggiore (FE, Italy): (a) *Dolium*; (b) Fragments of pottery (photo by Giovanna. Bucci).

Together with the pottery findings, three animal bone fragments were collected: two belonging to horses and a swine jaw. These finds were in the same matrix as wood, logs, and other non-diagnostic ceramic pieces.

Particularly interesting was the finding of a *Roman Common Ware* money box, which had evidently emerged from the stratigraphy shortly before the survey and could be seen in the large area not covered by calcareous encrustations. The small object was laying on the East side of the underwater landslide. Close to this area, there were piles driven into the lake-bottom (Figure 14a,b).

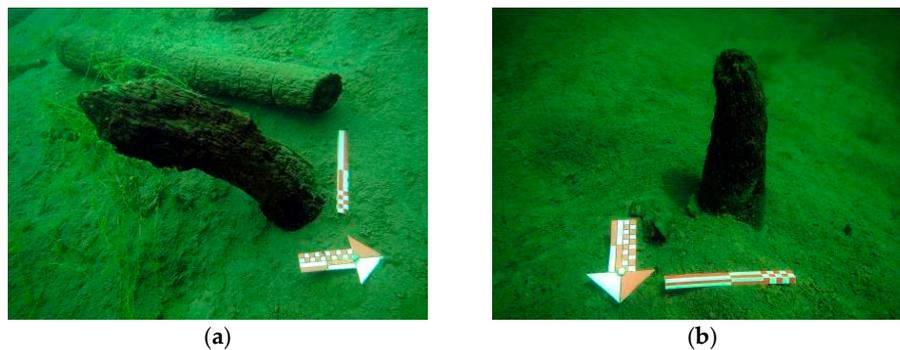


Figure 14. Silty clay bumps during underwater surveys in Lago Tramonto, Gambulaga, Portomaggiore (FE, Italy): (a) Standing pole and tapered pole with engraved lines; (b) Standing pole (photo by Giovanna Bucci).

Beside this area, there were numerous poles in the secondary laying, partially worked: some tapered, ending in a truncated cone, and others partially or completely cut, with bricks and tiles dispersed (Figure 15a,b).

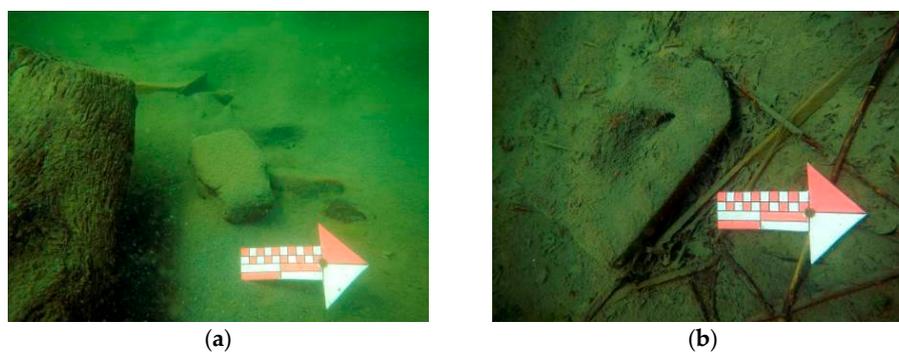


Figure 15. Silty clay downslopes during underwater surveys in Lago Tramonto, Gambulaga, Portomaggiore (FE, Italy): (a) Cut trunk, bricks, and tiles; (b) fragment of brick (photo by Giovanna Bucci).

Survey No. 2 also highlighted the presence of fragments of monoxyl pirogues laying at an average depth of 4 m, near the North bank. The presence of many pieces of pirogue and, importantly, the finding of a bow or stern (Figure 16a) of this kind of boat along with parts of the boards (Figure 16b), is testimony of the ancient navigation of the river Po.

A few meters West of the bow, there was one trunk, cut along its length (Figure 17a), and another one partially internally excavated (Figure 17b).

Other fragments of piroga sides were dispersed close to the surviving North bank. The pieces with work in progress support archaeological evidence of a small center of pirogue production.

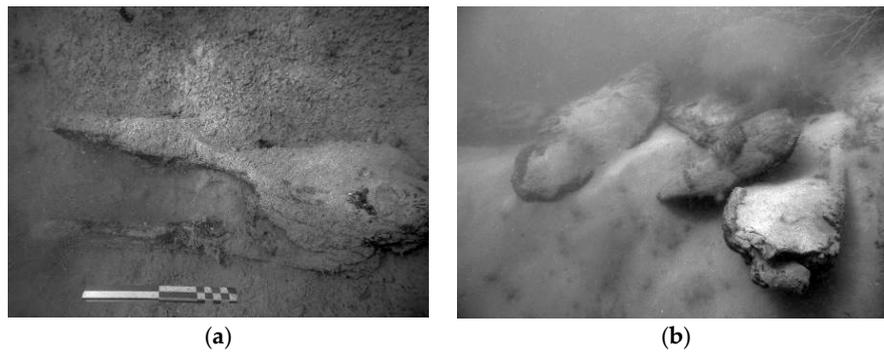


Figure 16. Fragments of piroga found during underwater surveys in Lago Tramonto, Gambulaga, Portomaggiore (FE, Italy): (a) Stern or bow; (b) Hull (photo by Giovanna Bucci).

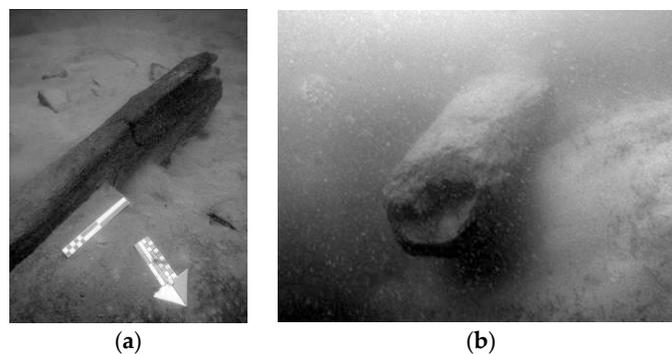


Figure 17. Partially processed trunks found during underwater surveys in Lago Tramonto, Gambulaga, Portomaggiore (FE, Italy): (a) A trunk cut to its maximum length with metrical references; (b) A trunk, partially excavated inside (photo by Giovanna Bucci).

4. Discussion

Remote sensing for underwater archaeology is mostly used for large-scale, extensive projects in the sea (deep water) [11,12], in combination with photogrammetry, and 3D recording and modelling (see <https://www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XL-5-W5/index.html>), with a lot of international attention dedicated to wrecks. Archaeology of inland water is a new area of research, where we must introduce new methodologies and techniques of investigation. In marine deep-water archaeology, much research is performed with excellent instruments and boats. What is still missing, is the introduction of small remote sensing instruments for everyday archaeology fields, such as surveillance archaeology.

Freshwater-scape and underwater-scape archaeology remain the best approaches. Influential research by Westley and Mcneary [13], published two years ago, described archaeological applications of low-cost integrated side scan sonar/single-beam echo sounder systems in Irish Inland Waterways. They explained how areas of “potential archaeological interest” could be detected by instruments like echo sounders, if used by archaeologists with the necessary experience. Inland waterways may be a significant archaeological resource that is often poorly recorded and quantified.

In the ambit of preventive and surveillance archaeology of inland waterways, the use of echo side scan sonar gives excellent results. It is an instrument capable of working in low visibility, for example, in very cold or polluted water, and it allows for oversight of the lake/river bottom without the need for diving. Completing a 3D bathymetry before direct investigation is an important step, not only on the side of scientific results, but also in term of safety for the immersions. Knowing the exact focus point of the main archaeological evidence (position, geomorphology, and depth) gives the possibility of organizing and managing direct surveys or avoiding them if there are too many risks for people.

Underwater visibility of inland waters is always very poor because of suspended clay (during and after quarry excavations). Very often, the maximum distance of perspective is 50 cm. Low visibility and frequent landslides create dangerous situations. The actual Italian legislation forbids any kind of immersion while dredging work is in progress, but sometimes dredges pick up findings and we need to check if it is only a dispersed artifact or if it is the signal of larger evidence, like a wreck, an ancient anthropic phase of the local history, or a palaeontological finding. The image files of the scan could be very useful to detect an array of objects or structures.

We would also like to emphasize that remote sensing bathymetrical survey with our instruments is a low-cost investigation with zero impact on the ecosystem (we used a silent, electric engine on a small aluminum boat). Of course, however, this research involved a small area and shallow water environment.

Archaeology of the Inland Water is an experimental project dedicated, not only to the investigation of ancient rivers, but to a new kind of approach to archaeology in artificial lakes.

The combination of geological and geotechnical studies offers the possibility of full comprehension of a hydrographic story and aids in the conservation of local cultural heritage.

The depositional system of artificial lake banks creates a soft layer of very light clay, which hides the stratigraphy, also often with tiny algae covering all the lakebed. In these cases, micro-geoarcheological drillings give us the chance to isolate particular sedimentary and anthropic levels, offering a guide for the matrix.

On the historical side, studying and making comparisons to ancient cartography from 1400 to 1785, we remark that the river likely survived until the 17th Century. Retracing the cartographical data, we see that the big meander of the River Po is always attested with continuity in the same places. This means that it was frequented, potentially, until the Estense Period. Here, we show six plan views of the area, extracted from an essay by F. Cazzola [14], to demonstrate, using the documentation of cartographers of the 17th and 18th Centuries, the persistence of the river in post-antique periods (Figure 18).

On the maps of G.B. Aleotti (*Corographia dello Stao di Ferrara*, 1603), Penna (1658), L.F. De Rossi (*Legazione del Ducato di Ferrara*, 1709), G.F. Bonfadini (*Topografia dello Stato di Ferrara*, 1709; https://www.igmi.org/carte-antiche/stati_preunitari/carta-14), A.F. Facci (*Geografia dello Stato di Ferrara*, 1716), and A. Baruffaldi (*Geografia del Ducato di Ferrara*, 1758), the name of the Estense Castle of Verginese is clearly attested, close to the course of the Po River. The Renaissance Structures are about 500 m away from the lake, with Roman and Late Roman cultural heritage evidenced (to read more about the Castle, see <http://www.ferraradeltapo-unesco.it/delizie/verginese>). The “end of the river” could also be connected to the land reclamation that began in the Renaissance Period.

The cataloguing of 200 artifacts, including the last findings of the *Late Roman Amphora*, discriminates two different periods: Roman Proto-Imperial and Late Antiquity–Early Middle Ages. Of the artifacts found, 83% were pottery (amphorae, cooking, or tableware), 13% were tiles (wing tiles, often with trademarks), 3% were glass (bowls or goblets), and 1% were fragments of lithic artefacts. Actually tiles and pottery were the chronology indicators.

The first *terminus post quem*, indicated by the *Pansiana Tiles* [15], was found to be from the first and the second century A.D. (Figure 19).

The finding of a small part of *Dressel 2–4 Amphora*, with a double-listel handle (Figure 20), could show the continuity of use of the site during the third and fourth century A.D.

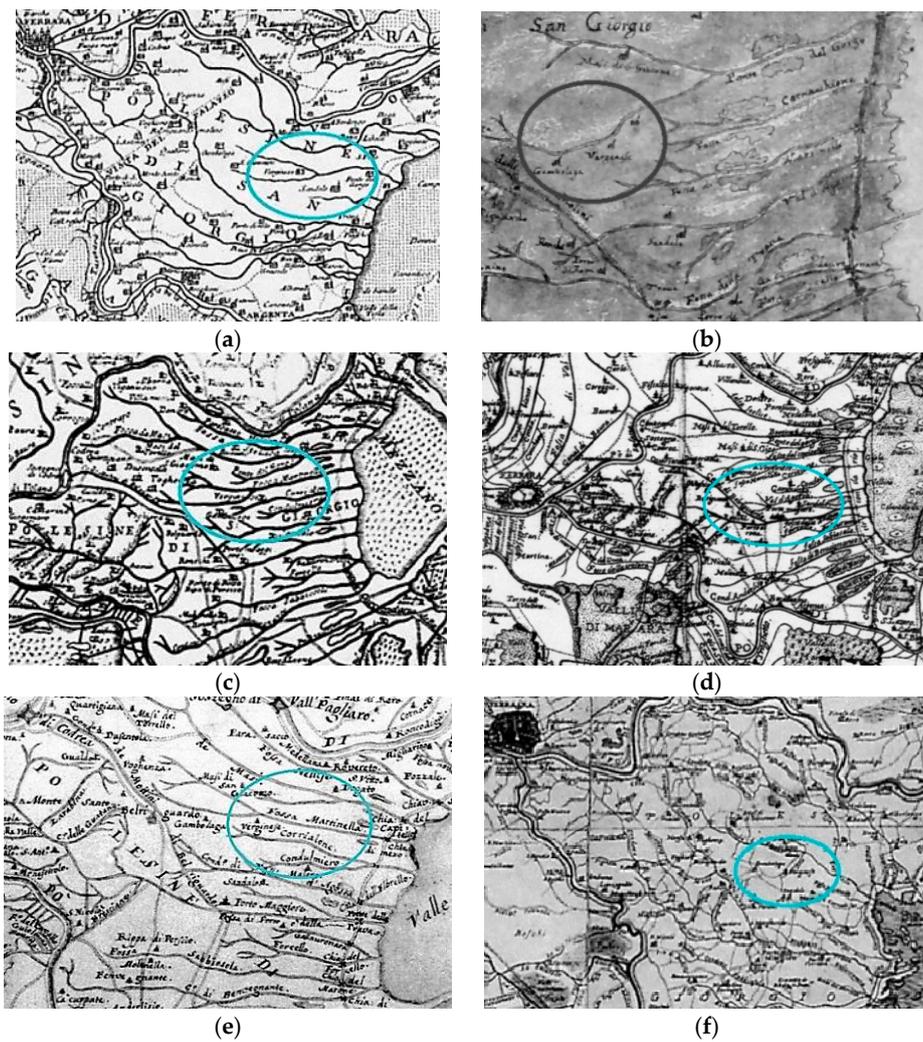


Figure 18. Extracted maps from ancient Ferrara cartography with attested rivers (North to the top) and, in the circle, the Po River with the course running close to Verginse Castle, Gambulaga: (a) Aleotti 1603; (b) Penna 1658; (c) De Rossi 1709; (d) Bonfadini 1709; (e) Facci 1716; (f) Baruffaldi 1758.

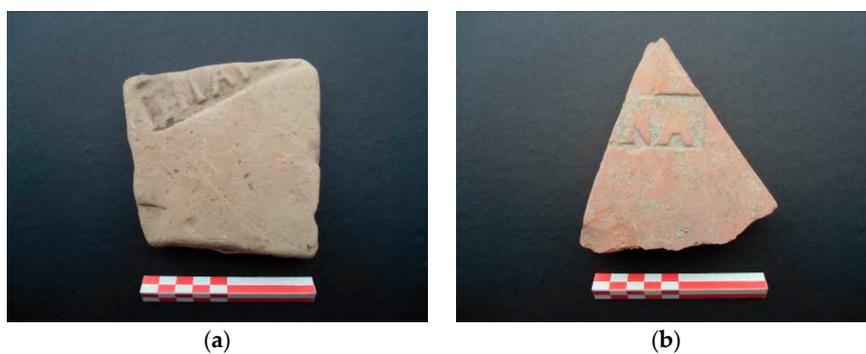


Figure 19. Fragments of *Pansiana* tiles found in Lago Tramonto, Gambulaga, Portomaggiore (FE, Italy): (a) *Incipit* of the stamp TIPAN [siana]; (b) *Explicit* of the stamp NA [Tipansia] (photo by Giovanna Bucci).

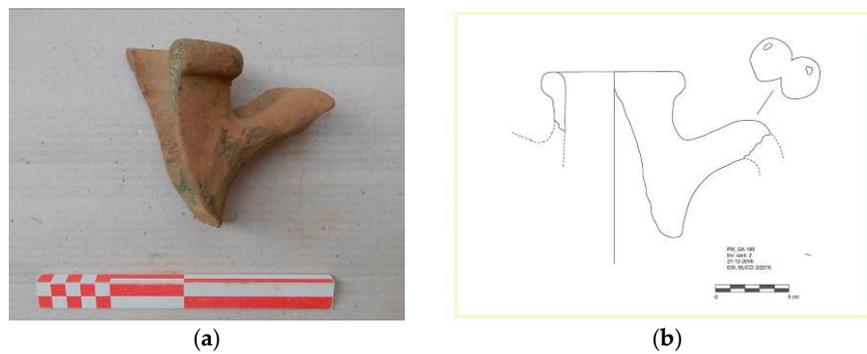


Figure 20. Fragments of *Dressel 2–4 Amphora* found in Lago Tramonto, Gambulaga, Portomaggiore (FE, Italy): (a) Photo with metric reference; (b) 1:1 draw (by Giovanna Buccì).

There is second *terminus post quem* to comprehend the time of the destruction of the archaeological settlement. It is attested by the neck with handle of *Late Roman Amphora No. 5* (Figure 21) and some fragments of Early Mediaeval Cooking Ware (Figure 22).



Figure 21. Fragments of *Late Roman Amphora* found in Lago Tramonto, Gambulaga, Portomaggiore (FE, Italy): (a) Photo with metric reference; (b) 1:1 draw (by Giovanna Buccì).

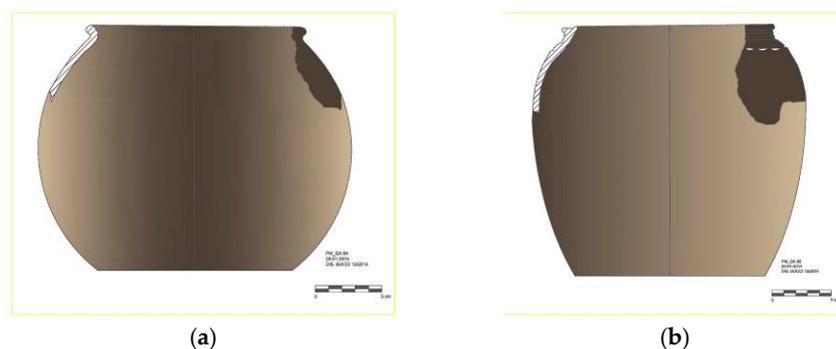


Figure 22. Digital reconstruction from diagnostic fragments of Late Roman-Mediaeval cookware found in Lago Tramonto, Gambulaga, Portomaggiore (FE, Italy): (a) *Olla* with a round lip and spherical body; (b) *Olla* with a flat lip and geometrical decorations on the shoulder (Giovanna Buccì).

5. Conclusions

Through the use of 3D side scan sonar surveys, direct diving investigations, geo-archaeological drillings, artifact analysis, and historical research, great contributions have been made to the comprehension of the Lago Tramonto archaeological panorama.

Studies of waterscape archaeology analyze the anthropological connections of inland water environments, showing the way in which people between the Roman and the Early Middle Ages constructed and used their territory (i.e., a river bank with wooden structures). Some piles are identifiable, for example, a structure to support the river embankment (linin piles running West–East), and others connect with buildings, for example, a watchtower with a square plan view. The hypothesis of the watchtower is related, also, to the topographical location of high geomorphological sites and to the late attested Italian toponym, “La Vedetta”, which is the watchtower/observation point.

Reading from east to west in the archaeological sequence (not necessarily in phase with each of the elements indicated here) we find the following context: there was a sandy boulder, with four poles driven into the ground and south of the hind, at a greater depth, a beam with four rectangular hollows was found (already previously detected and attributable to a watchtower at a depth 6 m, approximately). A tree trunk with bifurcation was found towards the center of the lake, next to landslide, with fragments of Roman and Late Roman pottery, bricks, tiles, and animal bones. Finally, a tree trunk with long bifurcation was found towards the center of the lake, with three perpendicular trunks. The ancient riverbank edge, made of compact clay and partially structured with vertical piles on the western side, continues to survive, with pieces of monoxyl pirogues and dispersed pieces of semi-finished wood boats found there (depth about 3.5 m ca.). At the center of the lake, in a deeper sector (more excavated from the dredge, southern to the individuuated structures), outcropping at 7.9 m, a semi-fossilized tree trunk rises straight from unseen palaeo-soil, potentially belonging to Subsynthema AES8a [3].

The direct surveys, No. 1 and No. 2, allowed us to verify the absence of anthropogenic traces on the eastern and southern sides of the lake, as already documented in the first on-site research. The area of greatest archaeological interest is, therefore, confirmed to be near the northern side of the palaeo-watercourse, in the West sector.

As a result of this research and the various methodologies employed (underwater direct investigation No. 3, remote sensing hydrographic surveys, and stratigraphic data from geo-archaeological drillings), it is possible to hypothesize that a catastrophic event of a hydrogeological nature, like violent flooding, along the Po branch in particular, caused the demolition of nearby structures on the northern bank. The large bifurcated trunks were iso-oriented and sub-parallel to the direction of the river current and they were oriented like the steles of the necropolis of *Fadieni*, knocked down from natural events, as evidenced by the stratigraphy. The presence of archaeological elements, predominantly in dispersion and deposition, is determined not only by quarrying and dredge work, but, above all, by older natural events, perhaps the *deluuium aquarum* described by Paulus Diaconus in *Historia Langobardorum*. III.23: *Eo tempore fuit aquae diluuium in finibus Venetiarum et Liguriaie seu ceteris regionibus Italiae, quale post Noe tempore creditur non fuisse.*

Archaeometrical analysis of some of the pottery fragments demonstrated the local production of the vases [16]. Additionally, the tiles were produced a few kilometers away from the *Fadieni* site (Gambulaga), in the *Vicus Aventiae*, Voghiera (FE), where there are traces of Roman Furnaces in relation to the *figlina Pansiana* [16]. The data establishes the archaeological site as covering the Ancient Delta Roman and Late Roman Contexts, in the great hydrographical system that crossed the Oriental side of Pianura Padana [17,18].

The next step in our research is to concentrate on archaeobotanical analysis of the wooden findings, actually preserved on site, underwater, on the lake bed, as UNESCO Conventions suggest. In the Ferrara District, the main discoveries of pirogues are related to the Mediaeval Period, with quite similar boats: two pirogues from Valle Volta, Massafiscaglia, one from Iolanda di Savoia, one from Valle Ponti, and two from Valle Isola, Comacchio [19]. Archaeobotanical studies might help us to isolate the chronology of the boats.

In the ambit of valorization and preservation of the Underwater Cultural Heritage, we are working also on a project of a virtual reconstruction of the Roman Site visible on a digital totem placed on the welcome area and night projection with holograms directly on place of the archaeological site. This

program will we performed step by step in collaboration with students of the University of Ferrara and Padova. It would be a didactic explaining performance dedicated to “public archaeology”. Actually people can explore the area with an underwater track with specific diving guide lines.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Drilling No. 1.

Site Code GAM 2017		Area	South Sector
		Drilling No.	1
Topographical Data Gambulaga (FE), Via Bargellesi	District Ferrara	GPS position	11°49'35.9"E
			44°44'44.2"N
		Elevation [m]	+2.50
Context Ex sand quarry lake			
Photo 1: Site	Photo 2: Work in Progress	Photo 3: Sediment	
			
Photo 4: Sediment	Photo 5: Sediment	Photo 6: Samples	
			
Levels [m]		Stratigraphic Data	
from	to		
0	0.60	Beige silt	
0.60	1.25	Sandy silt (beige, orange)	
1.25	1.55	Grey silty sand	
1.55	1.80	Grey coarse sand	
1.80	2.20	Grey sand	
2.20	3.10	Beige lightly silty sand	
3.10	5.00	Grey coarse sand	
Day 1 February 2017		Supervisor: Giovanna Bucci Technical Assistant: Fabio Facchini	

Table A2. Drilling No. 2.

Site Code Gam 2017		Area	North Sector
		Drilling No.	2
Topographical Data Gambulaga (FE), Via Bargellesi	District Ferrara	GPS position	11°49'25.5"E 44°44'44.3"N
		Elevation [m]	+2.10
Context Ex sand quarry lake			
Photo 1: Site	Photo 2: Work in Progress	Photo 3: Sediment	
			
Photo 4: Sediment	Photo 5: Sediment	Photo 6: Samples	
			
Levels [m]		Stratigraphic Data	
from	to		
0	0.50	Beige silty clay	
0.50	1.35	Brown mottled silty clay with vegetal traces	
1.35	2.40	Beige orange mottled clayey silt with traces of reeds	
2.40	3.15	Beige silt	
3.15	3.65	Grey clay (palaeo-soil)	
3.65	4.30	Grey-light blue silt	
4.30	4.50	Grey clay with micro-fragments of torba	
4.50	5.10	Grey sand	
5.10	5.40	Grey clay with nucleus of CaCO ₃	
5.40	5.60	Violet clay with micro-carbonaceous cores and vegetal traces (palaeo-soil)	
5.60	6.10	Grey silt with vegetal traces and malacofauna	
6.10	7.40	Violet silty clay with micro-carbonaceous cores and vegetal traces (palaeo-soil)	
7.40	8.00	Violet silty clay with torba micro-levels	
Data 1 February 2017		Supervisor: Giovanna Bucci Technical Assistant: Fabio Facchini	

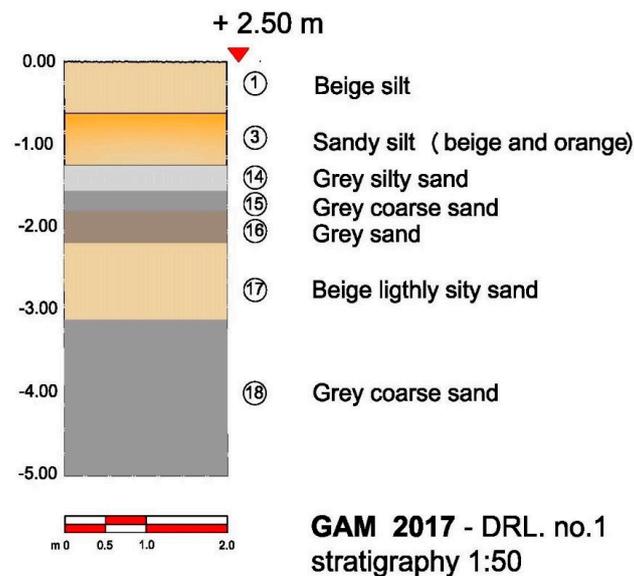


Figure A1. Graphic depiction of drilling No. 1 in 2017 in Lago Tramonto, Gambulaga, Portomaggiore (FE, Italy).

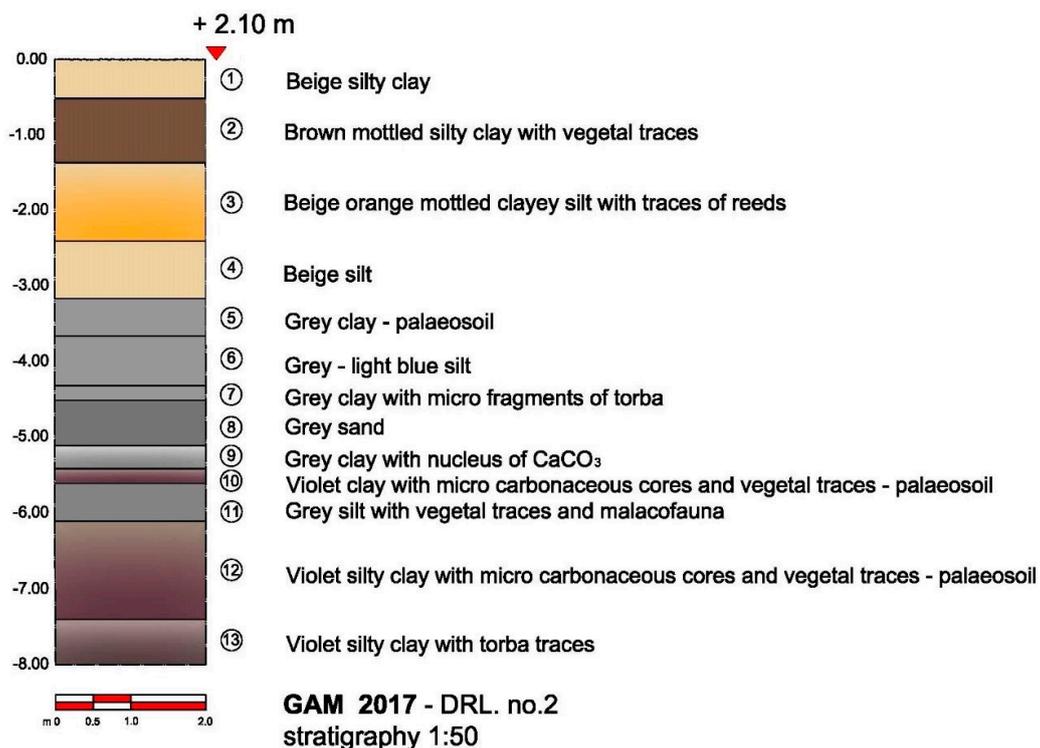


Figure A2. Graphic depiction of drilling No. 2 in 2017 in Lago Tramonto, Gambulaga, Portomaggiore (FE, Italy).

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