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Austrian Journal of Earth Sciences | Vienna | 2019 | Volume 112/1 | 01 - 19 | DOI: 10.17738/ajes.2019.0001

Geoarchaeological evaluation of the Roman topography and accessibility by sea of ancient Osor (Cres Island, Croatia)

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KEYWORDS Adriatic Sea; Croatia; geoarchaeology; airborne laser bathymetry; sea-level change

Abstract

We combine geoarchaeological investigations with high-resolution airborne laser scanning (ALS) topographic and airborne laser bathymetric (ALB) measurements to reassess the topography of the Roman city of Apsorus (modern Osor, northeastern Adriatic Sea, Croatia), which has generally been interpreted as important nodal point of Roman maritime traffic. Apsorus is located at the isthmus connecting Cres and Lošinj islands, which is 90 m wide at the narrowest part and dissected by a canal of supposed Roman age. A conspicuous low-lying wetland north of the city has been suggested to be a former sea passage and harbour area. Geoarchaeological coring, sedimentological analysis and radiocarbon dating suggest that this depression was already silted up with terrestrial sediments some 6,000 years ago and, especially in combination with the lower sea-level at that time, could not have been a Roman harbour. The combination of the ALS/ALB topographic data with lower sea-levels reconstructed for the Roman period challenges the traditional view which places ancient Osor on a small island and allows for new interpretations of the accessibility of Osor by sea.

1. Introduction

Safe anchorages and harbours are imperative for shipping and thus their locations are crucial for the position and prospering of ancient as well as modern coastal centers. Hence, there is a plethora of literature about the relationship and co-evolution of ancient coastal sites and their harbours (e.g. Kraft et al., 2000; Morhange et al., 2014; Draganits et al., 2015; Giaime et al., 2016; Giaime et al., 2018). However, most of these studies focus on the eastern and central Mediterranean with less attention given to the Adriatic. Here, we investigate Apsorus (Starac, 2000) (modern Osor, Kvarner Gulf, northeastern Adriatic Sea, Croatia), located on a small ridge at the isthmus connecting Cres and Lošinj (Figs. 1, 2), which, together with the islands of Krk and Rab, form the most northern group of Croatian Adriatic islands. Ancient Osor was a coastal center at the Croatian coast, flourishing during the Iron and Roman ages (Faber, 1982). However, hardly any details are known about its coastal setting and landscape during those times.

The city wall, which had its origin in prehistoric times (Mohorovičić, 1956; Blečić Kavur, 2015), encloses an almost circular area with a diameter of 300 m (Fig. 3). The circular layout of the city-wall was modified in the 16th century (Sušanj Protić, 2015), when a newly built wall cut off half of the circle in the north-south direction. While the western half of the city remained populated, the eastern half of was abandoned and left to decline. This is a clear sign of a decreasing population – a process that was already in progress in the 16th century and continues to this day (Stražičić, 1981).

In the south, west and north, the city is bound by the sea, while in the north-east and east, the settlement area is limited by a conspicuous swampy depression, measuring ca. 110 x 40 m, with only a 10 m narrow possible connection towards the sea (Figs. 1, 3-5). In the southwest of the city, a 10.2-11.4 wide channel (Croatian: *Kavada, Kavauda,* Italian: *Cavanella*) separates Cres and Lošinj (Figs. 1, 2) and it is widely accepted that the channel is artificial (a canal). Based on observations during excavations, Faber (1982) argued for its construction no later than Roman times, due to the finding of a Roman sewage drain that emptied into the canal. From the first investigations of Osor up to now, the existence of the canal has always been regarded as crucial for seafaring and the location of Osor has been connected with controlling the sea route between the islands and trading ports (Benndorf, 1880; Mohorovičić, 1954; Stražičić, 1995).

The position of the canal is obvious, but the location of its former harbour(s) is not (Figs. 1, 2). In fact, most studies argue for two harbours, one in the north of Apsorus, located in the bay of Bijar, facing towards Istria, and one south-east of Osor in the Bay of Jaz (Fig. 1) (Faber, 1982). In this context, note the fundamental differences between anchorages, harbours, and ports (e.g. Tartaron, 2013, p. 4). Finds of submerged boat moorings (Faber, 1980) and archaeological material in Bijar bay (Ettinger Starčić, 2012) support the idea of a harbour there. Archaeological

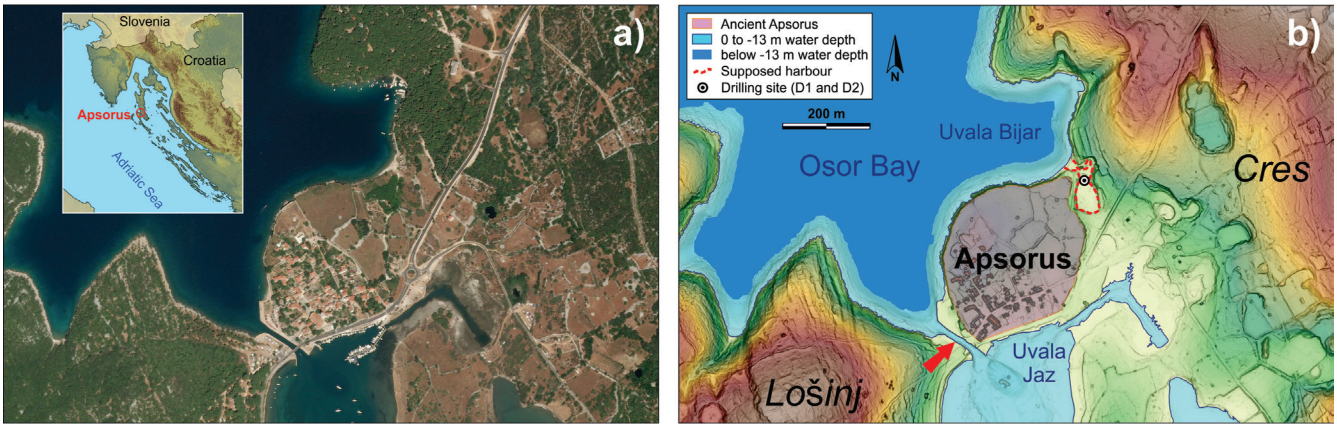

Figure 1: Overview of the isthmus and canal at Osor (ancient Apsorus), between Cres Island and Lošinj Island. a) Satellite imagery from ESRI ArcGIS world imagery basemap. b) High resolution (0.5 x 0.5 m) airborne laser bathymetry (ALB) and digital terrain model (DTM); visualization is a combination of color-coded altitude and hillshade; altitude range from -13 m below sea-level (depth limit based on the applied configuration of airborne laser scanner) to 55 m above sea-level. The Osor canal is indicated by a red arrow. Label 1 and dashed red outline indicates the supposed harbour site in the present-day wetland northeast of Osor. Additional supposed harbour sites include the bays of Uvala Bijar and Uvala Jaz. The L-shaped extension northeast of Uvala Jaz is modern and less than 1 m deep.

Figure 2: Oblique aerial photography of Osor towards the northwest. In the foreground the Kampa Peninsular, Osor in the center with the narrow canal south of the town and the Bay of Bijar in the background; 02101101_007©Michael Doneus.

evidence for a harbour in the Bay of Jaz (Fig. 1) is still lacking (Ettinger Starčić, 2012).

Even the topographic situation of Apsorus is in discussion, as to whether Osor was – at any point in its long history – a small island (Mohorovičić, 1956; Faber, 1980) or not (Stražičić, 1981). The swampy depression northeast of the city (Figs. 1, 3), which was decisive for the location and orientation of the city walls (Doneus et al., 2017, fig. 18) was interpreted as a former seaway connecting the bays of Bijar and Jaz (e.g. Faber, 1980) and consequently ancient Osor would have been completely surrounded by sea.

The goal of this paper is to combine (i) geoarchaeological investigations, including outcrop evaluation, coring, stratigraphy, reconstruction of the depositional

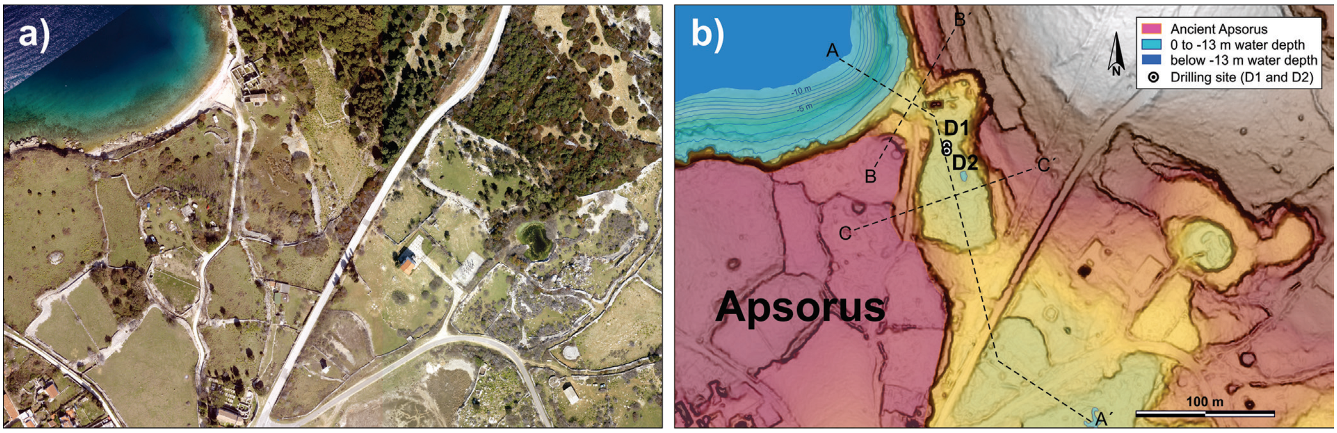

Figure 3: Detail of the study area showing the depression northeast of ancient Osor which is a swampy area just above sea-level, ca. 110 m x 40 m in size, and was suggested as silted former harbour (e.g. Faber, 1980). a) High-resolution ortho-photo acquired in March 2012 with 8 cm ground sampling distance. b) High-resolution airborne laser scanning bathymetry and topography, 0.5x0.5 m resolution; visualization is a combination of color-coded altitude and hillshade; altitude range from -13 m below sea-level to 21 m above sea-level; locations of topographic profiles shown in Figure 4 indicated.

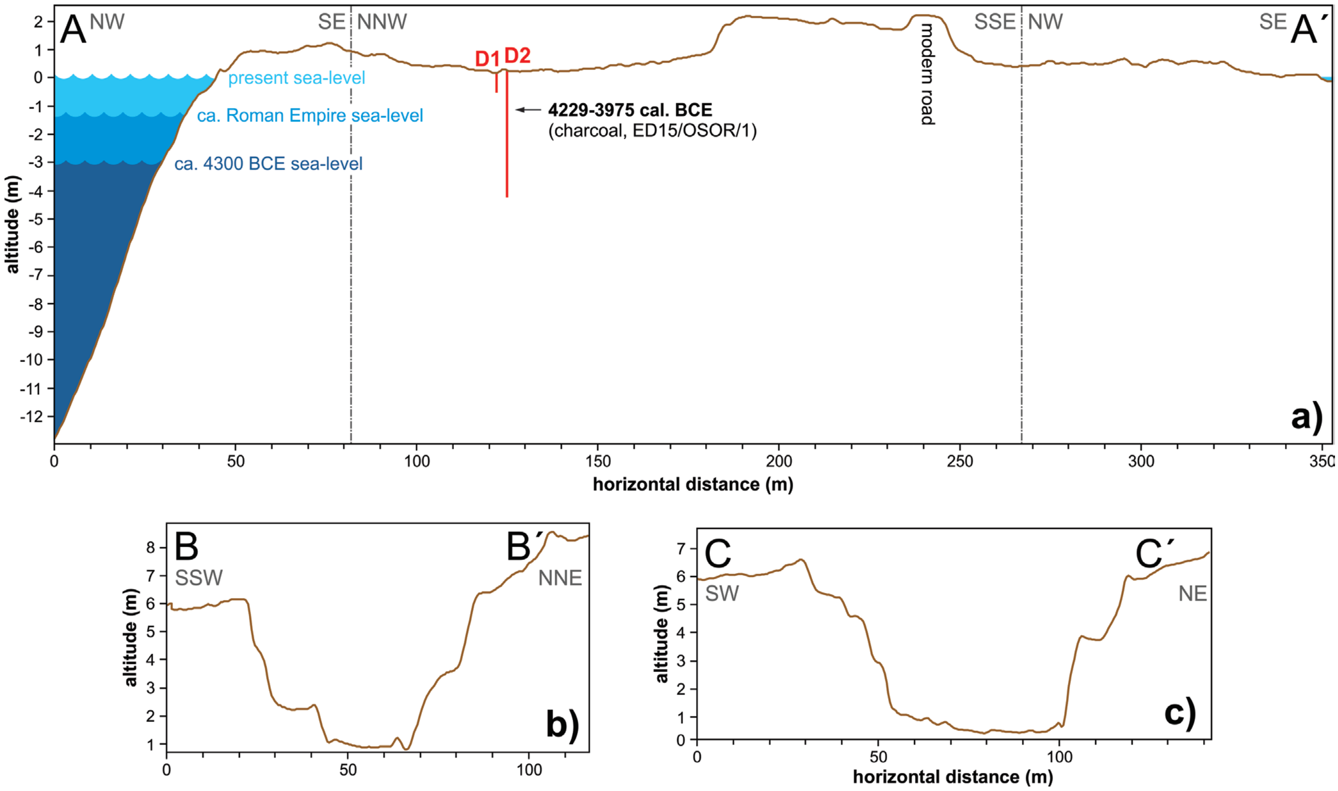

Figure 4: Topographic profiles based on high-resolution bathymetric and altitude data from airborne laser scanning in the area of the supposed harbour; see Figure 3 for location of the specific profiles. a) Ca. 350 m long profile starting -12 m below sea-level, crossing the whole depression and ending at sea-level in the excavated area at Uvala Jaz; note the two kinks in the profile. Present-day sea-level as well as reconstructed Roman Empire sea-level (after Faivre et al., 2010) and reconstructed ca. 4300 BCE sea-level (after Brunović et al., 2019) are indicated. Location of coring sites and coring depth of D1 and D2 are indicated in red, as well as the depth of the dated charcoal fragments from 117-125 cm below present-day sea-level (see Table 1). b) and c) show the shape of the depression in south-southwest-north-northeast and southwest-northeast orientations, respectively.

environment and radiocarbon dating, with (ii) the evaluation of local sea-level changes and with (iii) high resolution topography and bathymetry from airborne laser scanning, aiming for a better understanding of the topography and accessibility by sea of Roman Apsorus.

2. Archaeological background

In the past, archaeological investigations at ancient Osor have mainly concentrated on single aspects of its (pre)history. The excavation of the prehistoric and Roman necropolis outside the city wall was among the first archaeological efforts to investigate the city in context with its surroundings (Blečić Kavur, 2015). During the 1950s, interest focused on the architectural monuments and the layout of the Roman town, including its road system and the city center (Mohorovičić, 1953). Small-scale excavations along the city wall in the 1970s revealed its complex stratification (Faber, 1972; Faber, 1974). After

Figure 5: Situation in the supposed harbour in the wetland area northeast of Osor. Red arrow indicates location of the two drillings; monastery ruin from the 11th century in the back ground. Water surface (fresh water) is more or less at sea-level. The floor of the monastery church is just 0.9 m above present-day sea-level.

2000, a Croatian-French team started to investigate the monastery of Saint Peter (*Sv. Petar*), applying ground penetrating radar (GPR) and systematical excavation of its remains (Bully et al., 2015). Christian monuments generally play an important role in the investigation of Osor; the oldest currently known remains date from late antiquity and are situated next to the church of St. Mary on the Cemetery (*Sv. Marija na groblju*) (Turković and Maraković, 2005).

A new integrative approach for investigating Osor in its environmental context started in 2012, with the use of large-scale archaeological prospection. The combined airborne laser scanning (ALS) and airborne laser bathymetry (ALB) data acquisition was carried out on the Cres-Lošinj archipelago (Doneus et al., 2013), covering, amongst others, Osor and parts of its hinterland at Punta Križa. In the Hinterland of Osor, abundant information (dry-stone walls, limekilns, prehistoric hillforts, historic settlements, barrows etc.) was obtained on human occupation in today's densely overgrown areas (Doneus et al., 2015a). At the same time ALB has proven to be a valuable tool for rapidly scanning underwater topography in shallow water. In 2014 and 2015 large-scale archaeological geophysical surveys took place in the eastern part of ancient Osor, which accommodates settlement remains from prehistory to the Middle ages. The use of high-resolution ground penetrating radar systems allowed the documentation of buildings and streets from Roman and post-Roman periods (Doneus et al., 2017).

3. Geoarchaeological and geological setting

The geodynamic setting of the Central Mediterranean is dominated by still ongoing collision between Africa and Europe. At a more local scale, the study area is situated in a tectonically active region consisting of the Adriatic microplate, in between the Apennines and the Dinarides, both being an expression of the Alpine orogeny (D´Agostino et al., 2008). Geologically, the Croatian coast between Rijeka and Šibenik and its offshore islands belong to the so-called "High Karst Unit", a tectonic unit of the External Dinaridic Platform (Schmid et al., 2008), dominated by Cretaceous carbonate sediments. The Kvarner Islands are no exception (HGI, 2009; Korbar, 2009). Cres comprises dominantly Cretaceous carbonates, which have been thrust along north-northwest-south-southeast striking reverse faults on top of Cretaceous and sometimes Paleogene sediments, which are more abundant on the islands of Lošinj, Unije and Srakane. Quaternary sedimentary cover is thin and noteworthy occurrences are on Unije and especially Susak (Fuček et al., 2014). For a recent summary of the geology of the study area see Brunović et al. (2019 and references therein). Because of the abundance of carbonate rocks, karst (Ford and Williams, 2007) represents a very important landform shaping process in the study area (Bognar et al., 2012). Based on the data of the tide gauge at Mali Lošinj (http://www.hhi.hr/en/tide/index/ML) the study area is characterized by a microtidal environment (Hayes, 1979).

The Croatian coast with its 79 islands – defined as piece of land surrounded by the sea, larger than 1 km^2 (Duplančić Leder et al., 2004) – is a spectacular islandscape but this has not always been the case. During the Last Glacial Maximum (LGM), ca. 26.5-19.0 kilo years before present (BP) (Wirsig et al., 2016), the global sea-level was about 125-130 m lower than today (Lambeck et al., 2014), leaving dry most of the area towards the latitude of Split (Vai and Cantelli, 2004). The Po River discharged about 300 km towards the southwest from its present day delta, slightly northwest of Svetac otok (Vai and Cantelli, 2004). At this low sea-level of the LGM Palagruža and Sušac, as well as Jabuka islet, were the only islands in the Adriatic Sea (Forenbaher and Kaiser, 2011). According to Lambeck et al. (2004), the Roman global sea-level was only about 20 cm lower than today; however, at a local scale, crustal movements, among other processes, can modify the global sea-level trend considerably.

The global sea-level rise in the last millennia was quite a slow process (Lambeck et al., 2014). However, vertical tectonic movements may result in episodic rapid local sea-level changes (e.g. Faivre et al., 2011; Marriner et al., 2014; Benjamin et al., 2017). According to the data of the International Seismological Center in Thatcham (UK), which is collecting, archiving and processing seismic data from ca. 130 seismic networks and data centers around the world, the Kvarner Gulf is characterized by occasional shallow earthquakes (http://www.isc.ac.uk). Sea-level changes, and especially local sea-level changes, are a crucial factor in the reconstruction of past environments in coastal settings (Draganits et al., 2015; Giaime et al., 2016) and local sea-level changes have to be investigated in detail at local scales.

Measurements of present-day active tectonic movements by continuous GPS networks indicate tectonic lowering of the crust in the Kvarner Gulf (Altıner et al., 2006), which is supported by tectonic subsidence in the order of 0.63-0.89 mm/year interpreted from Roman fish tanks (Florido et al., 2011). A comparison of continuous GPS data with tide gauges at the eastern Adria coast by Buble et al. (2010) show a fairly uniform local sea-level rise from tide gauge data of 0.84 ± 0.04 mm/yr, which is a factor of about 4 lower than the global average sea-level rise from satellite altimetry data (Nerem et al., 2018, http://sealevel.colorado.edu). Active vertical crustal displacement from continuous GPS data show variations from about -1.7 ± 0.4 mm/yr in southern Adria to 0.0 ± 0.4 mm/yr in northern Adria (Buble et al., 2010). The local sea-level rise in the western Mediterranean during the last 10,000 years has been reviewed recently by Vacchi et al. (2016). Brunović et al. (2019) used cores from submerged dolines in the Lošinj channel to reconstruct -3 m for the local sea-level at around 4,300 BCE. Faber (1980) estimates an almost 2 m lower local sea-level in antiquity. According to Antonioli et al. (2007), the Adriatic coast from the Gulf of Trieste to the southern tip of Istria has tectonically subsided by about 1.5 m since Roman times. Faivre et al. (2010) concluded that the sea-level in the Istria-Kvarner area during the first and second century Common Era (CE) was about 1.0-1.5 m lower than today.

Apsorus/Osor is located at a narrow isthmus linking Cres with Lošinj (Figs. 1-3) and thus lies in a long tradition of harbour sites in such an advantageous geomorphological position, allowing for landing on opposite sides and different wind directions, like many Phoenician harbours, including Nora and Tharros on Sardinia (e.g. Bonanno, 2005) and also Greek harbours in the Aegean (e.g. Draganits, 2009). The isthmus at Osor itself is about 350 m wide, while at the narrowest and lowest area southeast of the city it is less than 90 m wide (Figs. 1, 2). There, the isthmus is cut by a canal, which, according to HHI (2003), is today 10.2 m wide and 2.4 m deep. However, the minimum depth of the canal, measured by ALB, is ca. 3.5 m and we refer throughout the paper to this depth. The bathymetry on either sides of the isthmus is very different (Figs. 1, 6). While the northwest side, the Osor Bay, deepens rapidly fast from the coast, reaching > -30 m depth in less than 100 m distance from the coast, the southeastern side, the Lošinj channel, is very shallow and narrower and hardly reaches -4 m water depth ca 1 km southeast of Osor (HHI, 2003; Doneus et al., 2017, fig. 7).

4. Methods and techniques

4.1 Aerial photography, airborne laser scanning topography and bathymetry

Airborne laser scanning of Osor and parts of its hinterland at Punta Križa was carried out on 29th March 2012 using the hydrographic laser scanner VQ-820-G (RIEGL Laser Measurement Systems GmbH), yielding ground sampling distances less than 0.5 m. Setup included very short laser pulses (1 ns) with small footprints (0.45 m at 450 m flying height) and a high effective measurement rate (ca. 200 kHz), allowing up to one Secchi depth penetration performance. The scan angle was set to the full field of view of the instrument (60 degrees) (Doneus et al., 2015b).

Data processing included (i) echo detection and generation of a 3D point cloud from the scanner, GNSS and IMU data, (ii) strip adjustment and quality control, calculating a water surface model for subsequent refraction correction, (iii) range and refraction correction of water echoes based on the water surface model, (iv) classification of surface and off-surface points (within and outside the water body), (v) DTM interpolation (Doneus et al., 2015b). Data processing was carried out using the software RiPROCESS. The resulting total point cloud (including all echoes) was at least 10 points per square meter. Difference between ellipsoid- and geoid height was calculated at 43.2 m (see also Bašić and Bjelotomić, 2014).

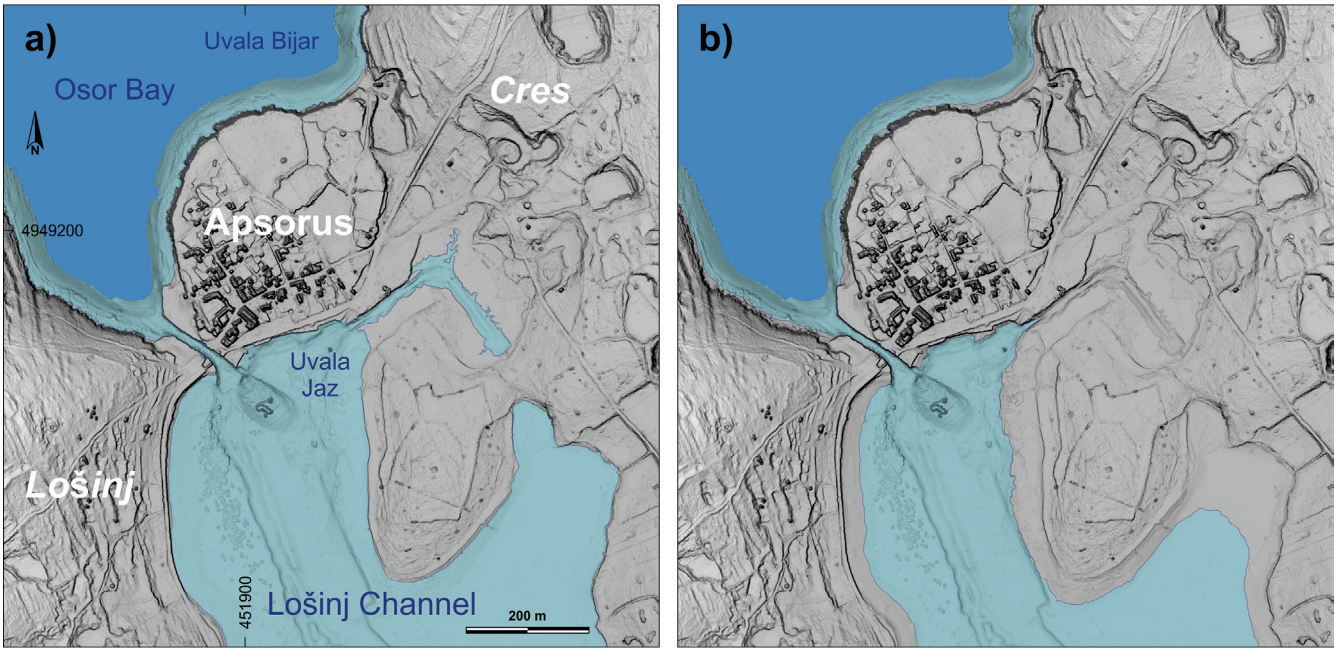

Figure 6: Modelled coastline change in the study area; ALS/ALB data visualized as combination of DTM in greyscale with 50% transparent hillshade and 50% transparent slope. a) Modern coastline. b) Reconstruction of the coastline ca. 2,000 years ago at 1.5 m lower sea-level.

Digital vertical aerial photographs were acquired simultaneously with the airborne laser scanning using an IGI Digicam H-39 (39 megapixel @ 6.8 microns pixel size). The high-resolution images were ortho-rectified using the digital surface model from the airborne laser scan, resulting in ortho-images with a ground sampling distance of 8 cm.

4.2 Coring and sedimentary analysis

Two sediment cores were taken in the depression to the north of the ancient city (Figs. 3, 5) with a vibracoring system using a gas powered Atlas Cobra breaker and steel window sampler with 80, 60 and 50 mm diameter, respectively. Core D1 was located at 452117.7 m E, 4949394.9 m N (UTM33), 0.24 m above sea-level (asl); core D2 was located at 452117.6 m E, 4949391.6 m N (UTM33), 0.23 m asl (Figs. 1, 3-5). Sediments were described directly in the field, including properties like sedimentary structures, color by using Munsell Soil Color Charts (2000 edition), and grain size by utilizing standard comparison charts (U.S. GeoSupply Inc.). Wet sieving was carried out using stainless steel test sieves (Retsch GmbH) with mesh sizes 0.063 mm, 0.125 mm, and 0.250 mm. Sieving aimed for the microscopic investigation of the sediments and documentation of organism remains. The different grain size fractions have been inspected by a Nikon SMZ-2B binocular.

Mineralogical composition was established using X-ray diffraction (XRD) with a Panalytical X'Pert PRO diffractometer (Cu Kα radiation, 40 kV, 40 mA, step size 0.0167, 5 s per step). The samples were loaded in the sample holders as oriented powder. X-ray diffraction patterns were interpreted using the Panalytical software "X´Pert High score plus". Three samples of core D2 were measured. Samples ED15/Osor/4 and ED15/Osor/9 were measured as bulk samples, while ED15/Osor/1 was sieved at <63 µm to remove coarse limestone particles. Additionally, the clay fraction of the three samples was separated and analyzed.

For clay mineral analysis, the samples were first disaggregated with diluted H_2O_2, to remove the organic matter, and subsequently treated with a 400 W ultrasonic probe for 3 min. The < 2µm-fraction was separated in an Atterberg cylinder, where the suspension was drained after a settling time of 24 h 33 min (formula after Stokes, from Köster, 1964) and dried at 60°C. Oriented clay samples were prepared by pipetting the suspensions (10 mg sample in 1 ml of distilled water) onto glass slides and air dried. Oriented XRD mounts were analyzed saturated with Mg and K ions, and after saturation with ethylene glycol (EG) and glycerol (Gly) at 60 °C for 12 h. The saturation with ethylene glycol and glycerol was carried out to identify expandable clay minerals such as smectite and vermiculite (Moore and Reynolds, 1997). Additionally, the samples were heated to 550 °C to destroy kaolinite and expandable clay minerals (Moore and Reynolds, 1997).

4.3 Radiocarbon dating

Organic material was only found in ED15/OSOR/1 at 140-145 cm depth of core D2 (*i.e.* 117-122 cm below present-day sea-level) (Figs. 4, 7). They comprise very small charcoal fragments that were too small for any botanical evaluation (pers. comm. Otto Cichocki, 2016). Hand-picking from 125-250 and 250-500 µm wet-sieving fractions under a binocular provided nearly 2 mg, which were radiocarbon dated at the Vienna Environmental Research Accelerator (VERA) in Vienna by Accelerator Mass Spectrometry (AMS) technique. Sample preparation procedures of the VERA laboratory (Steier et al., 2017) were used to extract carbon from the charcoal. Calibration has

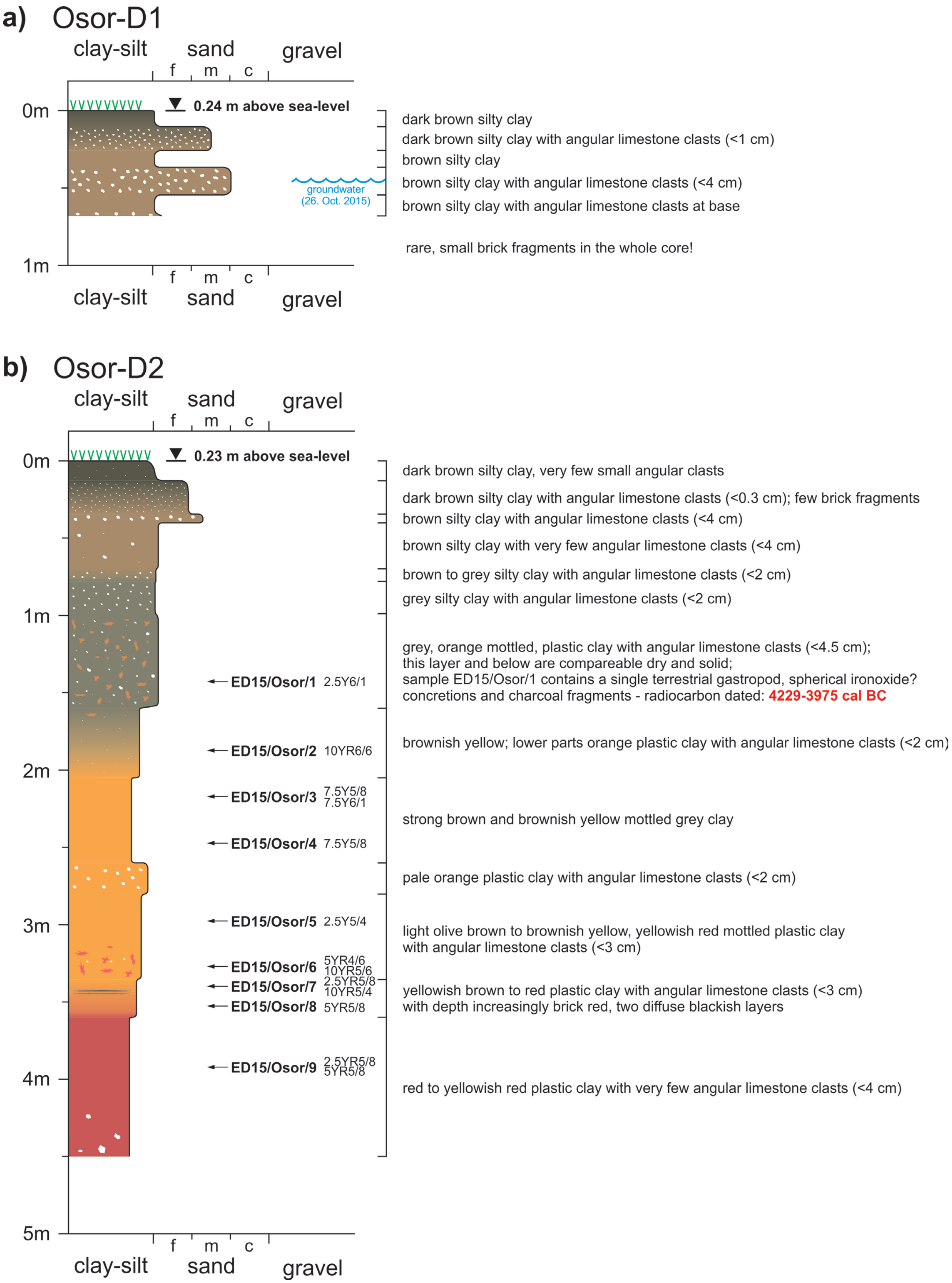

Figure 7: Lithostratigraphic profiles of the cores. a) In D1 core, ca. 0.1 m thin dark brown soil layer is underlain by brown silty clay with varying amounts of angular limestone clasts. A few small brick/ceramic fragments are found throughout the core. b) Generally, in D2 core the grain size was fine to very fine and decreased from silty clay in the uppermost 1 m with common angular limestone clasts, to highly plastic clays in the lower part with only a few angular limestone clasts. No sharp bed boundaries have been observed in the cores. Coarse grained mica is extremely rare and no marine molluscs remains have been observed.

been carried out online by OxCal 4.3.2 (Bronk Ramsey, 2009), applying the IntCal13 (Reimer et al., 2013) calibration curve.

5. Results

5.1 Airborne laser topography and bathymetry

ALS data and aerial photography provided high-resolution topographic data for the geoarchaeological fieldwork and interpretation, showing even minute topographic structures (Figs. 1, 3, 4). Additionally, the use of a green laser for the measurement enabled the shallow sea floor to be documented in exceptional detail (Doneus et al., 2013). The penetration depth of the green laser into the water was around 10 meter. This was a result of the clearness of the water and the smooth water surface during acquisition time. The resulting digital terrain model (DTM) shows the shallowness of the Lošinj channel, southeast of Osor, with depths of hardly more than 4 m (Figs. 1, 6). To model the effect of the lower sea-level in Roman times, the combined DTM digital bathymetric model (DBM) as documented from the ALS scan was imported into a GIS and a lower sea-level was simulated. Figure 6a shows the area at present situation and Figure 6b the effect of lowering the sea-level by 1.5 m, which is a suggested value for the Roman period (e.g. Faber, 1980; Faivre et al., 2010). Due to the steeper sea-floor W of Osor, the coast line does not change very much, but because of the very gently sloping sea floor east of the city, the changes are much more pronounced. The narrowly excavated area in the Bay of Jaz, situated southeast of the city, is dry at the lower sea-level in Figure 6b. The simulation also shows that in ancient time the width and depth of the Lošinj channel must have been very narrow (some 200 m) and shallow (up to 2 m – based on today's sea floor).

The high-resolution topography data of the area northeast of Osor shown in Figure 3, and especially the topographic section between Uvala Bijar and Uvala Jaz in Figure 4a, indicate that this area is well above (modern) sea-level. As the elevated area comprises Cretaceous limestone (Fuček et al., 2014) with only a thin soil cover, any deposited material can be excluded and thus this area was above sea-level for much more than the Holocene.

5.2 Lithostratigraphy of the cores

Two sediment cores (D1 and D2) were taken in the low lying, flat area directly south-east of the ruined monastery at the coast (Figs. 1, 3-5, 7). The ground surface of both cores was ca. 0.23 m and 0.25 m asl, respectively. Lower parts of this depression were covered with water, that tasted salty, with a water level at ca. 0.10 m asl. Core D1 reached only 0.7 m and had to be abandoned because of a large stone that prevented further coring (Fig. 7a). This core showed a dark brown 10 cm thin soil layer and below brown silty clay with varying amounts of angular limestone clasts (Fig. 7a). The combination of silty clay and angular limestone clasts up to 4 cm size indicates very poor sorting of the sediment; it was not possible to decide between matrix- or clast-supported fabrics in the core. A few brick/ceramic fragments have been noticed throughout D1.

The second core (D2) reached 4.5 m depth and in total 9 samples were taken (Fig. 7b). Generally, the core can be divided into two parts, the upper 1.5 m comprises brownish to greyish colors characterized by bimodal sorted clay with angular limestone clasts < 45 mm and angular quartz clasts < ca. 5 mm. The core below 1.5 m depth is characterized by brownish-beige colors and striking red in the lowest one meter. The highly plastic clay contains fewer angular limestone clasts. Varying amounts of quartz grains were documented in all sieved samples. No sharp bed boundaries have been observed in the cores. Layers with angular limestone clasts occur, showing very poor sorting. Coarse-grained mica is extremely rare and not a single fragment of marine molluscs or of microorganisms has been observed (Fig. 7b).

D2 displays a dark brown silty, clayey soil, followed by silty clay with various amounts of angular limestone clasts. One small brick/ceramic fragment was noticed 21 cm below the surface (Fig. 7b). Layer 9 (0.99-1.6 m depth) and below mainly comprise well compacted, fine-grained plastic clay, which is drier than the layers above. Brown colors dominate the uppermost 2 m of the core; between ca. 2-3.5 m brownish yellow is common and the lowest 2 m show striking, intensive red color (Fig. 7b).

5.3 Analysis of sediment samples

Three of the samples have been sieved and the different grain size fractions have been inspected in the microscope. No fragments of any artifacts have been recognized. Of sample ED15/Osor/1, at 140-145 m depth (i.e. 117-125 cm below present-day sea-level,) the grain size fraction > 0.250 mm contains angular limestone clasts up to 45 mm in diameter. Angular quartz grains, the smaller of them sometimes rounded to well-rounded, are common and up to several millimeters in size. Conspicuous brown, glossy, almost spherical clasts, ca. 1 mm in diameter comprise concentric layering and possibly represent pedogenetic iron oxide concretions. There are angular, black, brittle, fragile fragments, in some cases with a wood-like cell structure that reach up to 5 mm size. Fresh fractures are glossy and they represent charcoal fragments (pers. comm. Otto Cichocki, 2016). Only one, well preserved, 2 mm long, terrestrial gastropod shell was found, at 1.40-1.45 m depth in core D2. If the shell is not intrusive from above, it indicates that shells have some preservation potential. The grain size fraction 0.125-0.250 mm comprises ca. 60% angular, clear and transparent quartz grains with some crystalline surfaces visible; well-rounded grains are very rare. The rest of the clasts are dominated by aggregates of very fine-grained calcite and Fe-oxides/hydroxide particles.

Virtually no mica is visible. Charcoal fragments constitute ca. 3 % of the grains. The 0.063-0.125 mm grain size fraction consist of ca. 80% angular quartz grains and charcoal fragments are less than ca. 1 %. ED15/Osor/4, taken at 2.45-2.50 m depth is very similar to ED15/Osor/1 in the 0.125-0.250 mm fraction, but contains less than 10 % quartz. ED15/Osor/9 from 4.40-4.45 m depth contains some rounded grains in the >0.250 mm fraction, 0.125-0.250 mm fraction contains ca. 20-30% quartz and the 0.063-0.125 mm fraction shows more than 60 % quartz grains.

The mineralogical composition of three samples (ED15/Osor 1, 4 and 9) was analyzed by XRD (Fig. 8). All three diffraction patterns are quite similar and the bulk samples mainly comprise illite, kaolinite, quartz, calcite and goethite. The abundance of quartz decreases slightly with depth Fig. 8). No indication of salt (halite, NaCl) was detected.

The clay fractions consist of vermiculite, illite and kaolinite with traces of smectite and chlorite (Fig. 9). Vermiculite is identified by a broad peak at 14 Å with Mg and Mg + glycerol saturation. This peak shifts to 10 Å in the K saturated sample and after heating to 550 °C. Illite is identified by the peaks at 10, 5 and 3.3 Å which do not change position during the treatments. Kaolinite peaks at 7 and 3.57 Å disappear after heating to 550 °C. Traces of chlorite are identified by small peaks at 14 Å in the K saturated sample and after heating to 550 °C. Traces of smectite are identified in the Mg and glycerol saturated samples by a small peak at 18 Å (Fig. 9).

5.4 Radiocarbon dating

Radiocarbon dating has been carried out on the only organic material that was found in the cores. The small charcoal fragments from D2 core at 140-145 core depth were found in the 125-250 and 250-500 µm wet-sieving fractions. Sample ED15/OSOR/1 (VERA laboratory number: VERA-6425) gave a radiocarbon age of 5250 ± 35 years BP. The calibration of this measurement by OxCal 4.3.2 (Bronk Ramsey, 2009), applying the IntCal13 (Reimer et al., 2013) calibration curve, gave a calendar age of 4229-3975 cal BCE (2σ) (Table 1).

6. Discussion

6.1 Ancient Osor and the sea

The strategic importance of Osor is due to its position at the junction of Kvarner (the sea area between the east coast of Istria, Cres and Lošinj) and Kvarnerić (the sea area between Krk, Cres, Rab and Pag). Comparable

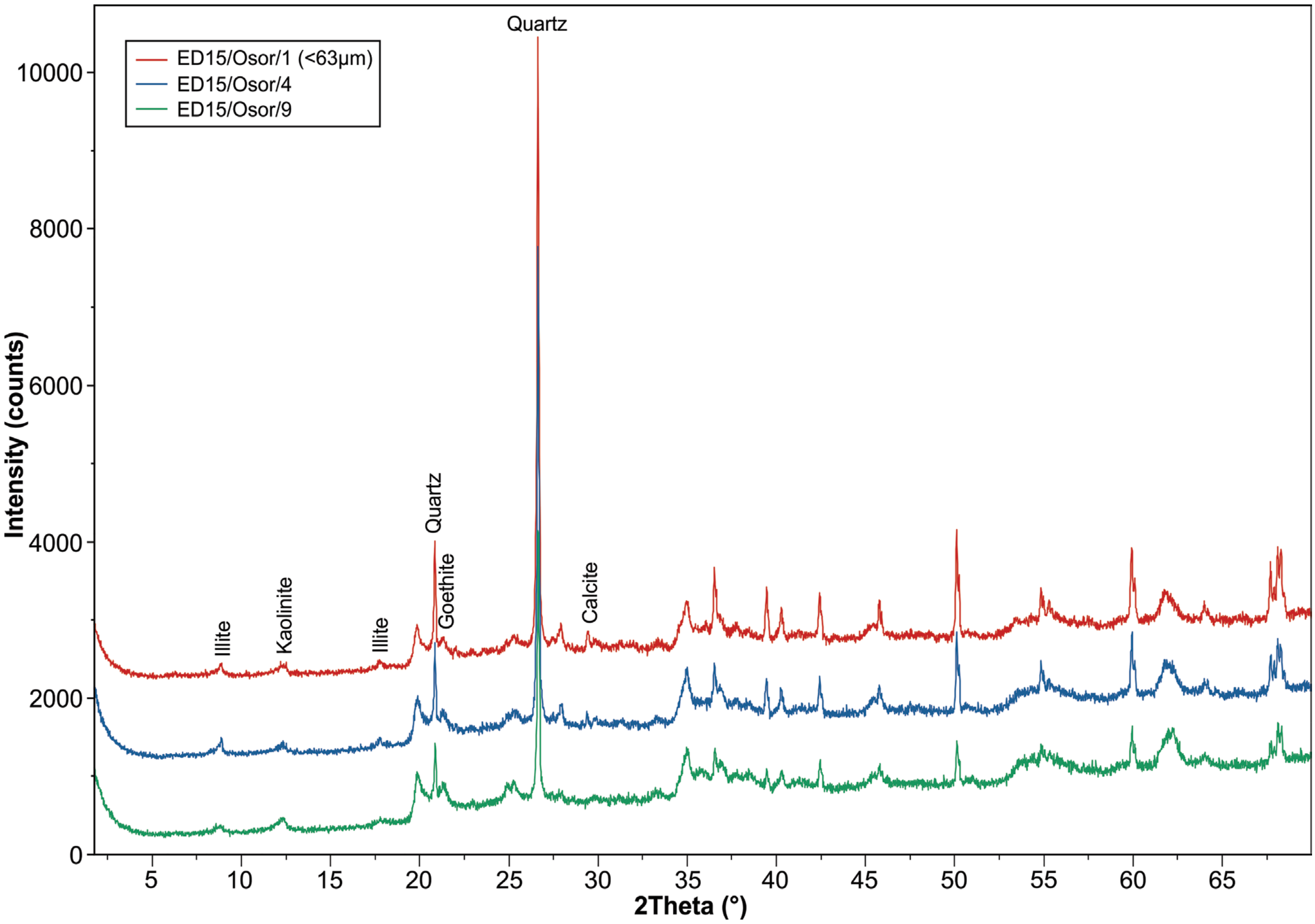

Figure 8: X-ray diffraction (XRD) patterns of sediment samples of core D2. For ED15/Osor/1 the fraction <0.063 mm was analysed, samples ED15/Osor/4 and ED15/Osor/9 represent whole rock samples. The diffraction patterns are quite similar and show illite, kaolinite, quartz, calcite and goethite. The abundance of quartz and calcite is slightly decreasing with depth. No salt (halite, NaCl) is indicated.

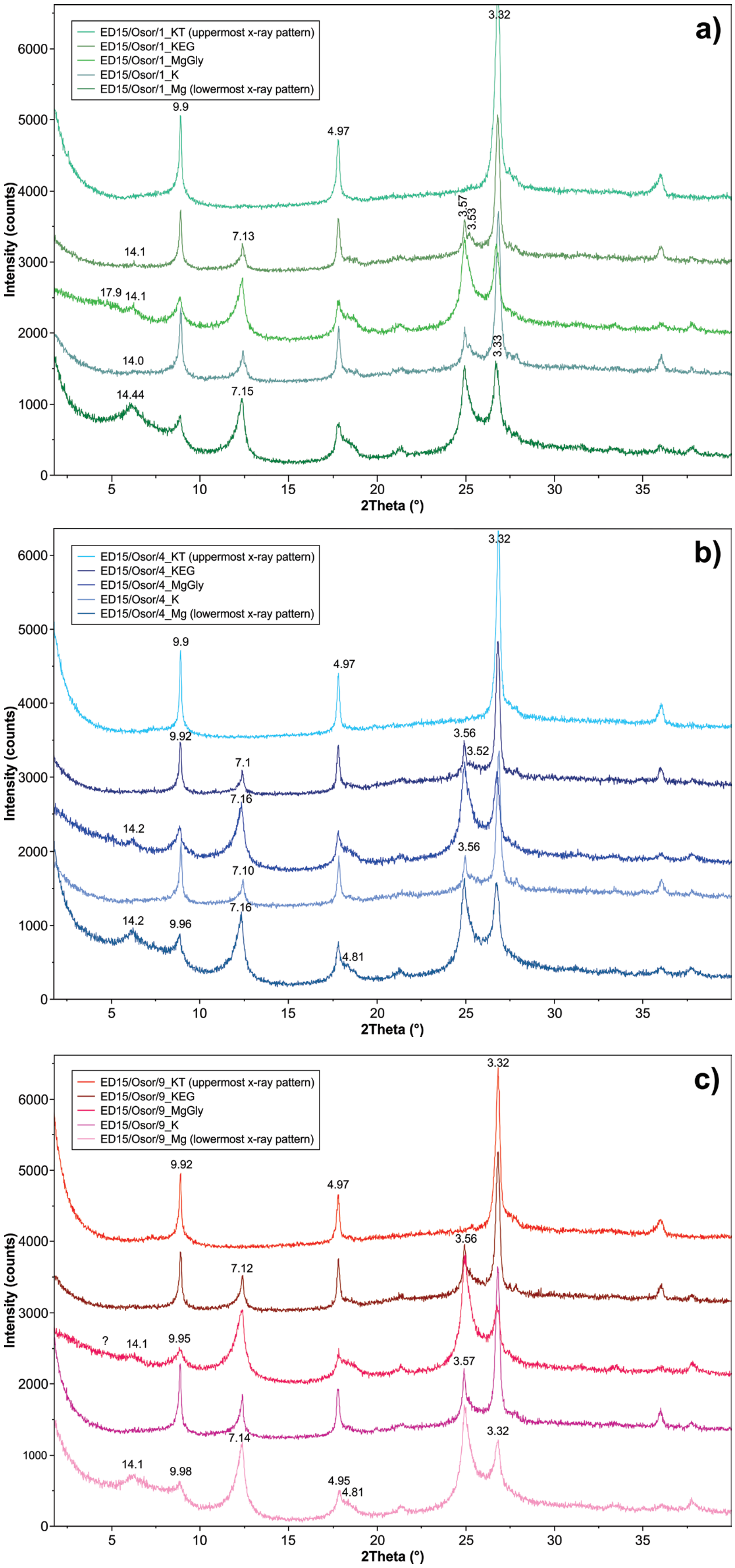

Figure 9: Clay fractions of samples a) ED15/Osor/1, b) ED15/Osor/4 and c) ED15/Osor/9. The clay fractions are saturated with Mg and K, Mg and glycerol (MgGly), K and ethylene glycol (KEG), and heated to 550 °C (KT); d-values are given in Å. The dominant clay minerals are vermiculite, illite and kaolinite with traces of smectite and chlorite.

Sample	Laboratory number[2]	d^{13}C[3] [‰]	^{14}C-age[3] [BP]	cal[4] [BC]
ED15/OSOR/1[1]	VERA-6425	-23.9 ± 1.7	5250 ± 35	4229-3975

[1] charcoal fragments (ca. 2 mg) handpicked from 125-500 µm sieve fractions

[2] VERA-Laboratories, University of Vienna, AMS measurement, [3] 1σ confidence interval

[4] OxCal 4.3.2 (Bronk Ramsey 2009), IntCal13 (Reimer et al. 2013), 2σ confidence interval

Table 1: Results of radiocarbon dating of charcoal fragments in sample ED15/Osor/1, deriving from core D2 at 140-145 cm depth, *i.e.* 117-125 cm below present-day sea-level (Figs. 4, 7b).

rich 12th century grave goods from Osor and the impressive Iron age city wall may indicate the early importance of this isthmus area (Blečić-Kavur, 2015). Kvarner Bay is known for its stormy winds (Marelić, 2016), especially northeast winds (Croatian: *bura*), which often prevail in winter and can reach more than 200 km/h in coastal areas. Stormy southeast winds (Croatian: *jugo*) are less common, but, like *bura*, they make sailing in Kvarner Bay very dangerous. During such weather conditions, it is advisable to anchor near the Istrian coast or the Cres and Lošinj until the wind has calmed down. On the way from Istria to Dalmatia, Osor therefore offers the first safe harbour for smaller ships after crossing Kvarner Bay. In addition to its sheltered location, the city canal (*Kavauda*) is assumed to have played an important role, as it made it possible to travel further south (Faber, 1980; Zaninović, 2005). In the Middle ages, however, malaria (e.g. Blečić Kavur, 2007) and the shifting of the sea route to the western side of Cres (Stražičić, 1995) determined the destiny of the city.

The circular shape of the city is closely linked to the relief (Doneus et al., 2017, fig. 18). The city is bordered by the sea in the north and northeast (Fig. 1); the bay of Bijar also lies in the northeast. In this bay, the sea floor deepens quite fast, and therefore it can be expected that the topography has changed little compared to Roman times with a lowered sea-level (Fig. 6). In Roman times, the bay offered, as it does today, protection for a small number of boats, including those with deep draughts. Roman ceramic material, scattered on the seabed of the bay (Ettinger Starčić, 2012), proves its use in antiquity. Finds of submerged boat moorings carved into stone (Faber, 1980) also bear witness to the use of the bay as a harbour in the past. Whether these, as suggested by Faber (1980), can actually date from pre-Roman times, cannot be judged from existing sources.

The Bay of Jaz in the southeast of the city (Figs. 1, 6) was suggested to have been a second city harbour (e.g. Faber 1982, map 1). Based on the new topographical data and a simulation of a 1.5 m lowered sea-level (Fig. 6b), the existence of any bay or harbour seems unlikely in Roman times. A probable Roman wall leads from the city wall to the Kampa peninsula and thus crosses the Bay of Jaz. This wall was destroyed in the bay area by human intervention, but its continuation can be seen on the Kampa peninsula. Its existence is a strong argument for terrestrial conditions there in Roman times, also supported by the modelling of the lower sea-level.

However, the coastline in this area has changed considerably since Roman times, caused by natural and anthropogenic processes. No archaeological finds are known from the L-shaped channel in the bay (Ettinger Starčić, 2012). The oldest historical sources date back to the time of the Venetian Republic, when area was already wetland, due to the rising sea-level. In historical maps (see e.g. Pavić, 2000, fig. 6), the Bay of Jaz is indicated, despite all the inaccuracies that such maps entail. The wetland contributed to the promotion of malaria, which led to its successive filling at the latest by the 19th century; Stražičić (1995, fig. 3) assumes that this took place after 1821. Subsequently dredged sediments from the Lošinj channel (Stražičić 1995) were deposited there and – as the last modern intervention – the creation of the L-shaped canal through the middle of the Jaz Bay. All these relief changes challenge the reconstruction of the Roman coastline in this area and further research would be necessary to pursue this topic.

6.2 Accessibility by sea of ancient Osor: geomorphology, bathymetry and sea-level change

The Kvarner Gulf comprises mainly carbonate sediments and is a prime example of karst and karst features. Karst is characterized by processes involving dissolution, at the surface as well as underground, and the formation of closed depressions (e.g. doline, uvala, polje) is very typical (Ford and Williams, 2007). Several closed depressions of variable sizes are visible at the southwestern coast of Cres in the Lošinj channel in the satellite and digital terrain models (DTM). At the ridge of Cres, these are about 50 m in diameter and directly at the coast they are up to 250 m across. The investigated closed depression is the northwestern most of more than 20 with a southeast-northwest alignment (Fig. 10), which is probably a result of thrust faults with this orientation in this area (Fuček et al., 2014). Some of them are slightly above sea-level, some of them have been completely flooded by the sea (Fig. 10); compare also with Brunović et al. (2017, fig. 12). Based on their size and shape, they can be classified as dolines (Ćalić, 2011; Sauro, 2012; Kranjc, 2013).

The global sea-level has been rising ca. 125 m in the last 19,000 years (Lambeck et al., 2014). According to Faivre et al. (2010) and Antonioli et al. (2007) the local sea-level rise since Roman time was about 1.0-1.5 m or 1.5 m, respectively. During sea-level rise, some of the dolines were completely flooded by the sea, some of them were partly inundated while others are still slightly above the present day sea-level (Brunović et al., 2019). According to our interpretations, the investigated doline northeast of Osor (Fig. 10) belongs to those that were not

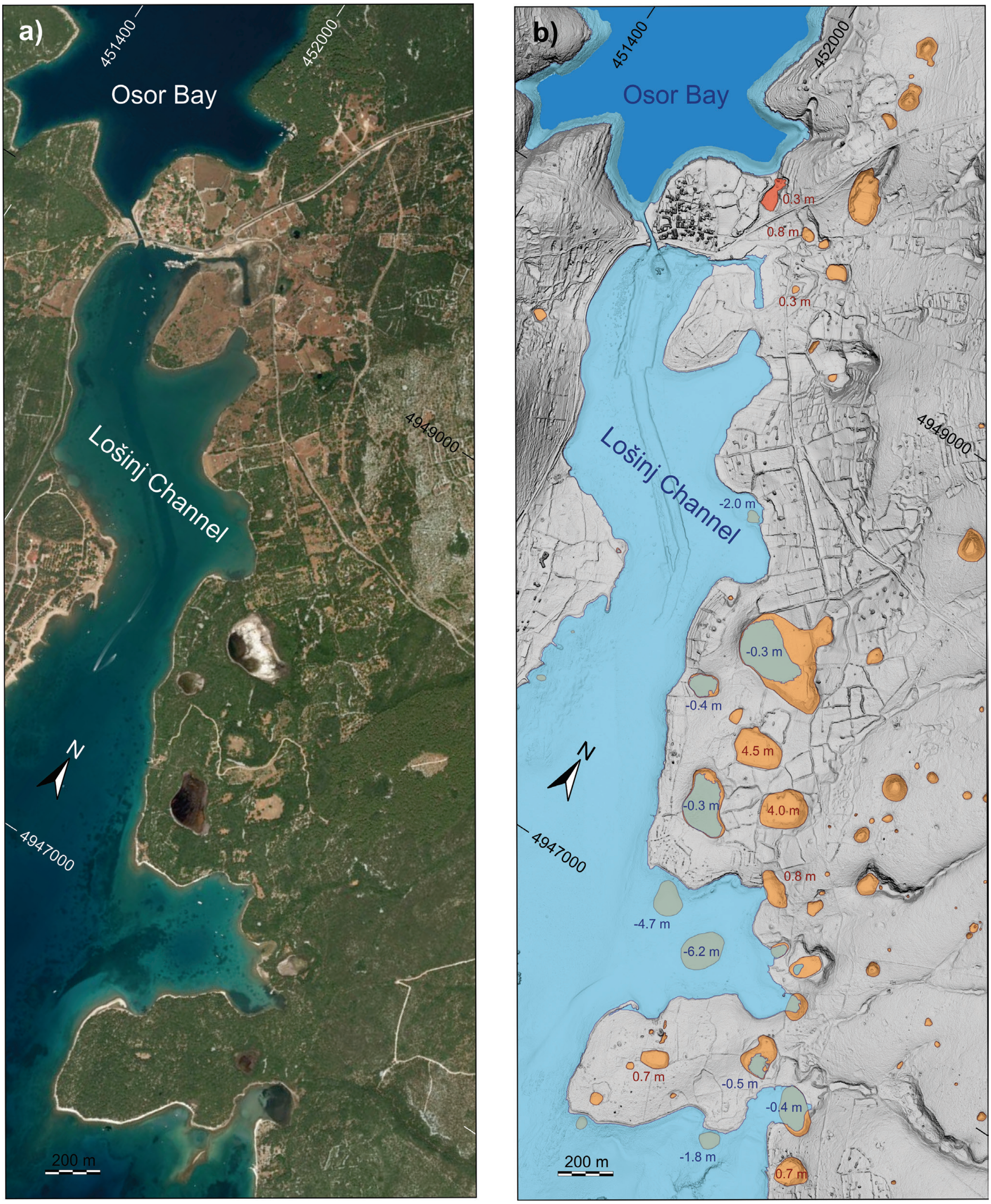

Figure 10: Overview of the isthmus at Osor and the Lošinj channel. a) Satellite imagery from ESRI ArcGIS world imagery basemap. b) Hillshade visualization combined with 50 % transparent slope visualization above of 0.5 x 0.5 m digital terrain and bathymetry data. Beige colors indicate closed depressions (dolines), with blue numbers indicating their depth below sea-level and red numbers their altitude above sea-level. Dark blue area west of Osor indicate water levels below -13 m, which is below the measurement capabilities of the applied laser scanner. Difference between ellipsoid- and geoid height was calculated at 43.2 m (see also Bašić and Bjelotomić 2014). Investigated doline directly northeast of Osor in red.

connected to the sea, especially in the Roman times, when the sea-level was ca. 1.5 m lower than today. Actually, based on core data the whole Lošinj channel is interpreted as a submerged palaeolake, when the sea-level was lower than -50 m (e.g. Brunović et al., 2017; Miko et al., 2017).

6.3 The swampy depression to the north of Osor: a possible ancient harbour?

Towards the north, an elongated depression, which runs parallel to the city wall, forms an extension of Bijar bay (Figs. 1, 3, 5). Close to the present day coastline, there is a 15th century monastery (Sekulić-Gvozdanović, 2007, 136) (Fig. 5). The depression was interpreted in older literature as a possible harbour or seaway between the bay of Bijar and Jaz (Mohorovičić, 1954; Faber, 1980). However, Stražičić (1981) noted that limestone bedrock was found in this area during the construction of water pipes in 1976, excluding the possibility of a sea connection between Bijar and Jaz Bays in the past.

The ALS/ALB-based DTM clearly shows that this depression (Figs. 5, 6) cannot have been a canal in Roman time. Based on today's topography, the low area would have been well above the Roman sea-level, which was 1-1.5 m below the present sea-level (Faivre et al., 2010). Although it is speculated that parts of the city wall were deposited in the area to dry up the depression (note that there is no written account of this), our core proves that this was at least not the case in the investigated area. In the following, the formation and evolution of the investigated depression is discussed.

A continuous connection between Bijar and Jaz bays, as suggested e.g. by Faber (1980, 298), is difficult to imagine at ca. 1.0-1.5 m lower sea-levels, as reconstructed for the Roman period in this area (Antonioli et al., 2007; Faivre et al., 2010) and based on high resolution topographic and bathymetric data (Doneus et al., 2017). Further, if the closed depression of the supposed harbour had been connected to the sea, at least some marine organism would be expected in the sediments. Due to the low calcite content of the sediment, dissolution of shells and microorganisms is possible, but unlikely, because of the compacted, highly plastic clay with very low permeability. The terrestrial gastropod shell at 1.40-1.45 m depth also indicates the preservation potential of shells in these sediments.

Both cores are characterized by (i) fine to very fine grain sizes (commonly even highly plastic clay), (ii) bimodal grain size distribution with variable sized angular limestone clasts, and fewer angular quartz clasts, in clay, (iii) lack of any observed marine shell or microfossil remains, (iv) lack of halite (NaCl) in XRD measurements, (v) striking intensive red colors in the lower part of D2, (vi) sample ED15/Osor/1 sample contained one terrestrial gastropod shell and (vii) no artifacts below 0.68 m depth (Fig. 7). All seven properties of the sediments may contribute for the reconstruction of the depositional environment.

The fine grain sizes of the investigated sediments generally indicate a quite low velocity of the transporting water, which seems incompatible with a connection of this depression with the sea, both towards the west and towards the east – as reconstructed by Faber (1980, fig. 4). Keeping in mind the currents at the present canal of Osor, related to tides and winds, which can reach more than 6 knots (c. 11 km/h) in both direction (HHI, 2003), and therefore coarser, better sorted and better rounded sediments would be expected.

Soil formation and properties are usually strongly controlled by the climate, underlying rock or sediment type and possible eolian input (Blume et al., 2016). The local geological situation of the study area is strongly dominated by Cretaceous limestone and dolomite (Fuček et al., 2014). Yaalon (1997) provides an overview of the properties and origin of Mediterranean soils. All three investigated samples of core D2 show vermiculite, illite and kaolinite presence, which is very common in terra rossa soils and related soils in the Kvarner Gulf (Benac and Durn, 1997; Durn et al., 1999). Based on this mineralogical composition as well as very fine grain size and color, the sediments, and possible also partly the angular limestone clasts, in the investigated depression probably originated from eroded soils from uphill areas and were transported by slope wash. If the interpretation of the brown, glossy, almost spherical clasts, ca. 0.5-1 mm diameter with concentric layering as pedogenetic iron oxide concretions is correct, their occurrence further shows the contribution of eroded soil for the deposits of the closed depression. The striking red plastic clay between 3.6 and 4.5 m of core D2 (Fig. 7b) may represent either autochthonous terra rossa soil or an early phase of soil erosion. Without entering the discussion of Mediterranean soil formation on limestone bedrock, either local origin from insoluble minerals in the limestone and/or eolian input (e.g. Benac and Durn, 1997; Yaalon, 1997; Durn, 2003), the most plausible origin for the abundant quartz in the silt and sand size fraction is eolian sediment, probably from a nearby source, because of the angular grain shape. Aeolian sediments, dating around 35 ka to 24 ka BP, are, for example, described from the nearby island of Susak (Wacha et al. 2018). The lack of halite (NaCl), the scarcity of calcite in the XRD analysis, the probable iron oxide concretions and the terrestrial gastropod fit better to colluvial sediments than to marine deposits. These observations are in strong contrast with the data from five sediment cores from water covered karst dolines from the eastern side of the Lošinj channel (Brunović et al., 2019, fig. 1c), all of which contained halite and all showed a (restricted) foraminiferal fauna, at least in their upper levels (Brunović et al., 2019). The difference can easily be explained by the fact that our two cores were located at a slightly higher altitude than those of Brunović et al. (2019). The most plausible interpretation for the lack of any artifacts discovered below 0.68 m depth is that most of the sediments in this closed depression were already deposited before Osor became a Bronze age settlement. These new results contradict the conclusions of Faber (1980, 298), who suspected a sea connection between the bays of Bijar and Jaz, based on a "sea shore" in the excavated layers along the city wall.

What could be the explanation of the common bimodal sorting of the sediment, comprising clay with angular limestone clasts up to 45 mm diameter? The above mentioned sediment properties argue for a slope wash origin of the doline filling. The colors of the fine-grained sediments and their mineralogical composition (Figs. 8, 9) point to a large contribution of upslope soil. Based on the very fine grain sizes a lacustrine environment similar to the water-filled doline 200 m east of the investigated depression is likely (Figs. 1, 5, 10). The lack of marine organisms, the lack of evidence of halite in the XRD-data, and especially the formerly much deeper sea-level (e.g. Faivre et al., 2010; Vacchi et al., 2016) point to a terrestrial depositional environment. The lowest parts with striking red (2.5YR 5/8) and extremely plastic clays with a few weathered limestone clasts could represent a relict soil ("terra rossa"). Nowadays, the depression is only some 0.25 m above sea-level and it is partly covered by a thin water layer, but 2,000 years ago, with sea-levels 1.0-1.5 m lower than today, it can be expected that also the ground water table was lower and this area drier. Even in the map of the Second Austrian Military Survey, mapped in 1821-1824 (http://mapire.eu/de/map/second-survey), this area is shown as dry land. This depression is the closest flat area near Osor and could have been used for agriculture at some point in the past. If this area was used for agriculture, the angular limestone and quartz clasts could have been mixed with clay by ploughing or trampling. Another possibility is that some of the clasts derive from landfill in order to reduce wetlands to fight against malaria. According to Stražičić (1995), the depression may have already been filled in the 15th century with the elements of the city wall. An even much earlier filling of the depression is indicated by the radiocarbon dating of charcoal from drill core D2 (Fig. 7b, Table 1). The most useful dating methods for the core sediments described above, are radiocarbon dating of organic material (Taylor and Bar-Yosef, 2014) and optical stimulation luminescence (OSL) of the quartz grains (Liritzidis et al., 2013). In our study, OSL applied to fine grained colluvial sediments is challenging because of possible re-setting issues. Additionally, the small diameter of the applied drilling method makes it difficult to retrieve samples unexposed to the sun. The discovery of charcoal fragments in core D2 in a depth of about 140-145 cm was very important. The calibrated age of 4,229-3,975 cal BCE that the depression was almost filled already during the Neolithic period.

6.4 The canal of Osor

The Kavauda, the city canal of Osor, borders the city in the south and connects the Bay of Osor (Kvarner) with the Lošinj channel (Kvarnerić) (Figs. 1, 2, 11). This canal allows shipping to pass between Cres and Lošinj, when travelling from Istria to Dalmatia. This route is still used today by small ships in times of strong winds or severe weather conditions. Stražičić (1995) noted that the shallow depth of the canal was probably a problem for large ships in ancient times. The new topographic data apparently support this conclusion. Today, the city canal, with its small dimensions is only passable for small boats. HHI (2003) describes the dimensions of the Osor canal as being 10.2-11.4 wide and 2.4 m deep (Figs. 6, 11). In contrast, our ALB measurements show that it is almost 3.5 m deep even in its shallowest parts (Fig. 11).

Written sources have been available on the subject since the 16th century (Stražičić, 1995). In an encyclopedia from 1747, the canal is described as being hardly more than 5 paces (ca. 4 m) wide with a draw bridge connecting Cres and Lošinj (NN, 1747, 1182). Schreiner (1835, 416) describes the Osor canal (*Cavanella di Ossero*) as ca. 45 m long and 7 m wide and very shallow at ebb tide. Schreiner (1835, 416) further mentioned that until the fall of Venice (captured by Napoleon in 1797) the Venetian Republic had kept the canal in good conditions, but since then it had fallen in disrepair. Biasoletto (1842, 30) mentioned that the canal was not passable for large ships during his visit in 1838. In 1906, the canal is described as only 6-8 m wide and 2.5-2.8 m deep with strong currents influenced by tides and winds reaching 2-4 nautical miles per hour (3.7-7.4 km/h) (HAKKK, 1906). Although the canal probably changed considerable over the time, it is very likely that some of the problems were the same in the past.

The width of the canal in Roman times or in the Middle ages is, however, not known. Even if the width has changed over time and could possibly be adapted to larger ships, this does not apply to its depth. Stražičić (1995) mentioned limestone bedrock at the bottom of the canal. In contras,t some deposits have been mentioned by Ettinger Starčić (personal communication, 2018), based on recent underwater observations. Accepting that the Roman sea-level was about 1-1.5 m lower than today, indicates that the canal was only about 2-2.5 m deep, based on the modern sea floor in the canal (Fig. 11). The size of Roman cargo ships has been reconstructed from ship wrecks (e.g. Boetto, 2010; Cuomo and Gassend, 1982), with lengths of 17-53 m, widths of 5.5-14 m and – especially important for the use of the canal – draughts of 1.9-7 m (Boetto, 2010). The width and depth of the canal at Osor, in the modern dimensions and especially at lower sea-levels must have made passage impossible except for the smallest ships, additionally complicated by the strong currents.

Stražičić (1995) mentioned that the ancient canal may have had a slightly different orientation than today, which could have allowed for a greater depth. He further suggested that the use of the tidal current, higher sea-level during high tide or the unloading of the ships before crossing the canal could have partially reduced the problem. However, at 1-1.5 m lower sea-levels, these suggestions may not have improved the situation considerably. More data about the sediments, sedimentation rates (e.g. Juračić et al., 1999) and ages of sediments in the Lošinj channel (e.g. Brunović et al., 2017; Miko et al., 2017) and especially the depth of the limestone bedrock in the Osor canal are desirable.

In addition to the difficult navigation for large ships through the city canal, there seem to be no installations to allow safe anchorages for a larger number of big ships. Towards the northwest, the Bay of Osor (Osorski zaljev, Kvarner), deepens very rapidly (Figs. 1, 10), reaching

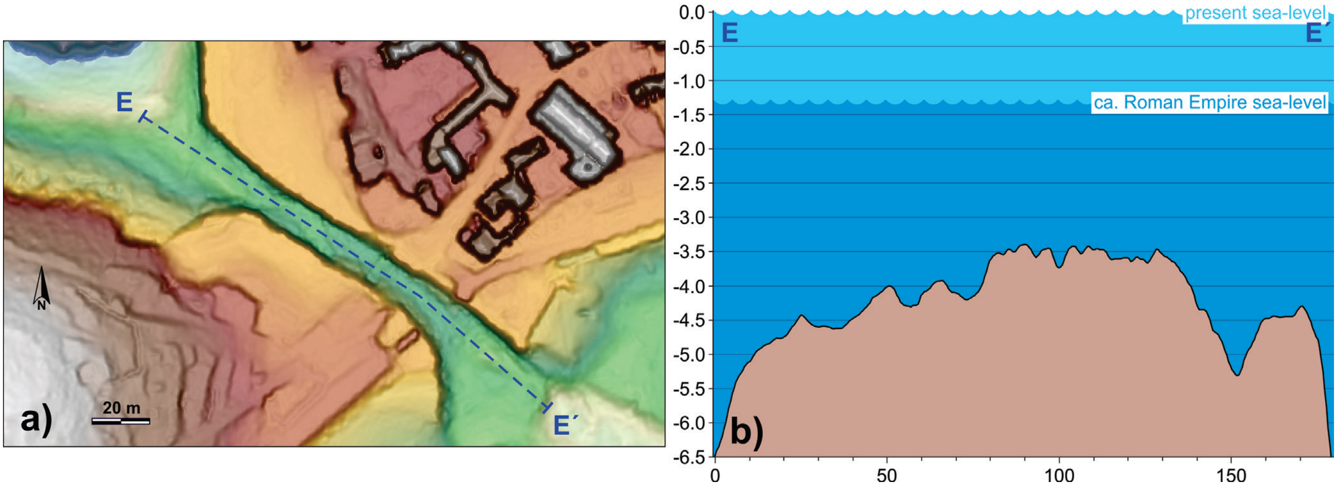

Figure 11: Detail of the Osor canal. a) High resolution (0.5 x 0.5 m) airborne laser bathymetry (ALB) and digital terrain model (DTM); visualization is a combination of color-coded altitude and hillshade. Location of the bathymetric section (Fig. 11b) is indicated. b) Bathymetric northwest-southeast section along the Osor canal, showing present day minimum depth at less than -3.5 m. Based on sea-level reconstructions, the Roman water depth would have been just around 2-2.5 m.

> -30 m depth in less than 100 m distance from the coast. A safe anchorage for a smaller number of ships is located in the Bay of Bijar (Fig. 1). In the southeast, the Lošinj channel (Kvarnerić), is relatively shallow and narrow. At present, the Lošinj channel reaches -4 m water depth ca. 1 km southeast of Osor (HHI 2007; Doneus et al., 2017, fig. 7). The Lošinj channel shows sedimentation processes, but no deposition rates have been published so far (Brunović et al., 2017), except for some karst dolines (Brunović et al., 2019). The natural deposition of sediments is still a problem for navigation and is being solved by repeatedly dragging of the Lošinj channel. Such traces are clearly visible in the ALB data (Figs. 6, 10) (Doneus et al., 2017, fig. 7). Therefore, the approach from the relatively shallow south, through the Lošinj channel, is considered challenging and risky with the 1-1.5 m lower sea-levels of the Roman period (e.g. Vacchi et al. 2016), especially for larger cargo ships with considerable draught as reconstructed by e.g. Boetto (2010). However, without further investigation, its original depth during Roman time is so far unknown and therefore speculative.Due to its inadequate wind protection, the Lošinj channel does not offer a safe anchorage close to Osor; although it is partially protected from the northeast wind (*bura*), it is not suitable for anchoring in strong southeastern wind (*jugo*).

These data and considerations challenge the traditional view of the importance of the Osor canal for long distance cargo ships. In addition, Apsorus's ability to offer a safe anchorage to many large ships appears to have been limited. The strong currents in the canal probably prevent the deposition of large amounts of sediment; even at its southern end there seems to be an elliptical scour in the sea floor (Figs. 6, 11). In modern times, the navigability of the shallow Lošinj channel was improved by dredging (Doneus et al., 2017, fig. 7).

7. Conclusions

The combination of high resolution ALS and ALB topographic data with geoarchaeological field and laboratory methods provides an extremely efficient toolbox for the understanding and reconstruction of past landscapes, especially in coastal settings. We expect that such a combination will become a state of the art approach for landscape archaeological investigations of (shallow) coastal areas.

Our study shows that Osor/Apsorus has never been surrounded by the sea in its northeast part; the conspicuous depression northeast of ancient Osor was almost completely filled with sediment ca. 6,000 years ago, in the Neolithic period, and consequently does not represent a harbour of ancient Osor, especially at the lower sea-levels of the past. The isthmus of Osor has been connecting Cres and Lošinj for much more than the Holocene and consequently Roman Apsorus was not located on an island.

The grain-sizes, mineralogical composition, color and age of the sedimentary fill of the doline northeast of Osor probably indicate the onset of increased erosion in this area already during the Neolithic period.

Our data and considerations challenge the traditional view of the importance of the Osor canal for long distance cargo ships in antiquity and in addition, Apsorus's ability to offer a safe anchorage to many large ships appears to have been limited.

This investigation at Osor clearly shows the importance of interdisciplinary cooperation between geology and archaeology, but even geoarchaeology is too limited without an innovative spirit. We conclude that additionally to geological and archaeological data and methods, it is important to understand as much as possible about the local environment, history, culture, practices and traditions and therefore an ethnogeoarchaeological (Tsartsidou, 2017) approach is most promising for this kind of interdisciplinary research.

Acknowledgements

The airborne laser scanning measurements were funded by RGZM Mainz in the project "Harbors and landing places on the Balkan coasts of Byzantine Empire (4th to

12th centuries)”. We thank Zrinka Ettinger Starčić, Lošinj Museum, for her support, which always accompanied us during the research on the Cres/Lošinj archipelago. Helpful reviews by Slobodan Miko and an anonymous reviewer are kindly acknowledged. Many thanks to Hugh Rice, who improved both, content and style.

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Received: 11 12 2018
Accepted: 26 03 2019

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