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Case Report

Earth Resistance Tomography for Detecting Previous Excavation Trenches in Cave and Rock Shelter Sites in the Lim Channel, Croatia

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A B S T R A C T

Earth Resistance Tomography (ERT) is a geophysical prospecting technique that has the capacity to model subsurface sediments. This technique is applied at the Cave near Rovinjsko Selo 1 site which is in the Lim Channel, Croatia. ERT is used as a means for positively identifying a previous excavation trench location within site which, in turn, informs the excavation planning process. The potential benefits of this technique are discussed for future excavation planning efforts at Romuald's Cave, another cave site location in the Lim Channel. While beneficial in this study, the technique's utility will vary in other locations according to site conditions, amount of previous excavation activities, and age of earlier excavation activities which affects both the geophysical survey design and applicability of ERT to the specific site environment.

Key words: *Earth Resistance Tomography, Archaeological Prospection, Subsurface Modeling, Cave Sites, Rock Shelters*

Introduction

Identifying the location of previously excavated sediments within cave sites benefits researchers who are revisiting these locations many years after the initial work has been completed. While locating disturbed sediments from previous investigations through surface observations can often be accomplished with ease and a high degree of confidence, on those sites where time has returned the excavated sediments to a state very similar to the surrounding unexcavated matrix it can be difficult to discern previous trench locations without causing ground disturbance. Earth resistance tomography is a noninvasive geophysical prospecting technique that can be used to model subsurface geology. However, it is also capable of identifying areas of ground disturbance including an estimate of the depth of disturbance which makes it a useful technique for locating previously excavated trenches.

In this study, a GeoScan RM85 is used to conduct an earth resistance tomography (ERT) survey which positively identified a 2007 excavation trench at the Cave near Rovinjsko Selo 1 site (Rovinjsko Selo 1) on the south side of the Lim Channel in the Istria region of Croatia. The remote sensing survey design for the overarching Archaeological Investigations into the Late Pleistocene and Early Holocene of the Lim Channel, Istria (ARCHAEOLIM) Project, which includes four cave and rock shelter locations within the fjord, focuses on creating 2D depth profiles to model site sediments as a means to estimate sediment depth to bedrock. Through the process of conducting the ERT testing at the Rovinjsko Selo 1 site, there was also the opportunity for ERT to contribute information about previously excavated sediments which can be used to inform excavation efforts at another site included in the ARCHAEOLIM Project, namely the Romuald's Cave site. Mirko Malez (1987) conducted excavations at Romuald's Cave in the early 1960s.and 1970s. While two of Malez's excavation trenches have since been reopened, others remain undisturbed and unidentified with only their general location known from field notes and maps[1]. Using the

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Rovinjsko Selo 1 results to design a dedicated ERT survey for positively identifying Malez's excavation trenches saves the project time, money, and resources in planning future excavations at Romuald's Cave.

The ARCHAEOLIM Project

The ARCHAEOLIM Project is a three-year endeavor that delves into questions related to the period of the Middle and Upper Palaeolithic and Mesolithic in the Lim Channel area of Istria, Croatia. This research effort focuses on biological and cultural continuity/discontinuity, adaptation to environmental factors, contact with neighboring regions, and other issues affecting the region in prehistory[2]. The archaeological investigations conducted as part of the ARCHAEOLIM Project are funded by the Croatian Science Foundation and the project lead is Ivor Janković of the Institute for Anthropological Research Zagreb. During the initial year of the project from July 3rd to 28th of 2014, the Romuald's Cave and Abri Kontija 02 site investigations were initiated. The second year of the project, from June 29th to August 8th of 2015, saw the inclusion of the Rovinjsko Selo and Lim 001 sites with continued excavations at both Romuald's Cave and Abri Kontija 02. In the third year, from July 11th to August 20th of 2016, investigations at all four sites continued with the work at Rovinjsko Selo 1 and Lim 001 being concluded at the close of the 2016 field season. Also conducted as part of the Lim Channel Project was an underwater field survey of submerged caves in the area of the channel. This scuba diving work was completed during the 2015 field season with the expertise of Krunoslav Zubčić, Ivor Karavanić and Ivor Janković. Though the three years originally planned for the project have all been completed, the initial results from the project have been positive, especially the excavation efforts at Romuald's Cave and Abri Kontija 02, and so continued work at these locations are planned for the upcoming field seasons[2].

Cave near Rovinjsko Selo 1

The Cave near Rovinjsko Selo 1 (Pećina kod Rovinjskog sela 1) site is the largest in a series of four caves and rock shelters located immediately beneath Kamenjača Peak on the south side of the Lim Channel rim. Rovinjsko Selo 1 is a large cave, facing northwest (320°). It consists of two areas – the entrance, formed by a spacious rock shelter, from the south part of which a passage opens into the interior. The opening of the rock shelter has a height of four meters and measures 25 meters across, with the rock shelter itself having a depth of 7.5 meters. The surface is formed for the most part of the bedrock, with sediment preserved only in the western part of the rock shelter. The entrance to the interior of the cave is 1.3 meters high, with a width of 4.5 meters and is partially closed with a drystone wall. The interior space is entirely covered with sediment, with breccia on the edges. It is home to a large colony of bats. A recent fire pit has also been identified, as has one possible trench – excavated either by one of the previous investigators of the site or by an inquisitive unknown person. A small prehistoric potsherd was found in the interior area and several fragments of bone at the entrance area. The position and size of the cave, and a number of archaeological and paleontological finds, indicate the possible human use of the cave in the prehistoric period. A test pit was opened in the period from the 21st to 23rd of May 2007 with the objective of assessing this hypothesis[1].

A 1.5 by 1.5 meter trench (total area 2.25 meters) was excavated just in front of the entrance to the cave with its west profile 60 centimeters east of the cave's west wall. The total achieved depth was 130 centimeters. Four layers and two features were identified that can be assigned to three horizons – A, B and C. Horizon A includes the surface layer 1 and feature 1F1 (small pits) (Figure 1). Finds of pottery, seashells (mussel/Mytilus), the remains of animal and fish bones and recent glass were collected. Based on the collected finds and the stratigraphic position Horizon A can be roughly dated to the prehistoric period, within an undetermined time ranging from the Neolithic to the Iron Age, without any possibility of a more precise chronological determination.

Horizon B includes layers 2 and 3 and feature 3F1. Feature 3F1 is a fire pit that enters into the north profile, with investigated dimensions of 70 by 60 centimeters and a maximum thickness of 10 centimeters. A total of 52 flint artefacts were collected, of which nine are tools and two are cores. The most frequent tools are those used for hunting such as backed blades and backed points. Also collected were faunal remains and the shells of marine mollusks. Based on the collected finds and the stratigraphic position Horizon B can be roughly dated to the Late Upper Palaeolithic or the Mesolithic.

Horizon C is comprised of layer 4. The bedrock appears at the lower extent of the excavated area. Only a few very small bone fragments were collected from this layer. Based on the collected finds and the stratigraphic position Horizon C can be roughly dated to the Pleistocene.

The preliminary analysis of the collected archaeological, paleontological and malacological finds from the 2007

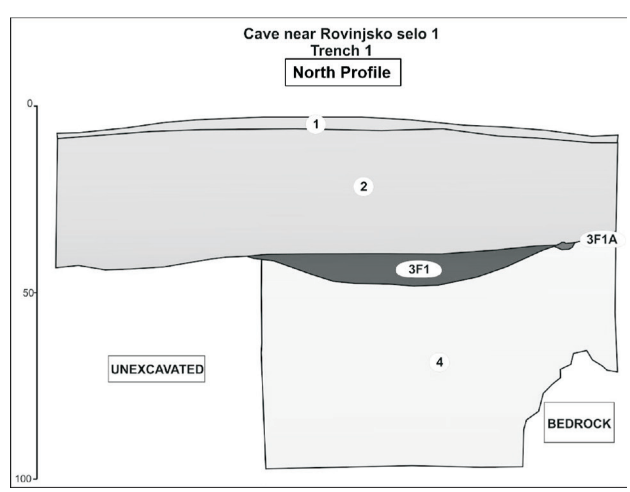

Fig. 1. Profile of the 2007 excavation trench 1 at the Cave near Rovinjsko Selo 1.

excavation efforts in addition to the documented sedimentological and stratigraphic data indicate that this cave was used by hunter-gatherers in the course of the Late Upper Palaeolithic or Mesolithic period. The planned absolute dating of radioactive carbon should help in establishing a more precise determination of the period during which this cave was in use. Since the previous work at the Rovinjsko Selo 1 site showed promise for providing information related to the research design of the ARCHAEOLIM Project, its inclusion in the project makes good sense. However, the site's potential to inform on the geophysical testing portion of the project proved essential given its potential for establishing long ERT profiles and the ability to collect high quality resistance data from the sediments.

Methods

Earth resistance imaging using the tomography method, or earth resistivity tomography (ERT), is a multi-probe geophysical technique that creates depth profiles or pseudosections similar to those produced by Ground Penetrating Radar (GPR). Earth resistance surveys are commonly employed at archaeological sites and have been since at least the late 1940s[3-5]. A mainstay of remote sensing in archaeology, earth resistance has been touted at the most widely applicable geophysical technique for archaeological sites due to its capacity for identifying relevant archaeological information in a wide range of configurations[6]. Earth resistance can be used for both broad area, fixed depth surveys and also for creating 2D and 3D depth profiles even with the same instrumentation through altering the configuration of the survey design[7].

Though the most common probe arrays for conducting resistivity tomography surveys are the inline arrangements such as Wenner and Schlumberger (and their variants) [5,8,9], the pole-pole probe array is selected as the preferred array for use at the Cave near Rovinjsko Selo 1 following Bevan's[6] design[10]. A total of thirty-two resistance profiles were established at the site in areas where sediment is present both outside the mouth of the cave and also inside the cave. Four of these profiles intersected the location of the 2007 Excavation Trench (Trench 1). Electrodes along each profile were set at 0.5 m intervals and a maximum mobile probe spacing of 3 m was used.

The data was collected by the GeoScan RM85 along each profile line proceeded in the forward direction by placing the current probe at the starting position or 0.0 m on the line and connecting the potential probe to the first electrode at the 0.5 m position. Once the first reading was collected in the line, the potential probe was moved to the 1.0 m spacing while the current probe remained in the same position. This process results in an increase of 0.5 m spacing between mobile probes for each reading in a line and was repeated until the maximum spacing of three meters was reached. The second line of data for the same profile line was collected starting with the current probe at the 0.5 m position and the potential probe located at 1.0 m. The same process of a 0.5 m spacing increase for each reading was repeated until the potential probe reached the 3.5 m position which represents a maximum probe spacing for this line of 3 m as well. For profile lines that did not exceed 3 m in length, a maximum probe spacing of 3.0 m was not reached though all readings between 0.5 m and the maximum available spacing in the line were, of course, collected. The above sequence was repeated for each line until the last reading in the profile was recorded. The decrease in maximum probe spacing by one station (or 0.5m) for each line near the end of the profile is why the results of ERT surveys have a trapezoidal shape to their data. This shape would occur regardless of which probe array type is used since greater depth readings with resistance tomography are achieved by increasing the distance between the mobile probes in all instances. As such, a 3 m profile with a maximum probe spacing of 3 m will have a single data point at its deepest position. Alternatively, a 5 m long profile with a maximum probe spacing of 3 m would have five readings at the maximum depth because there are five stations along the profile where a probe separation of 3 m can be achieved. Since the ERT profiles established at Rovinjsko Selo 1 are of various lengths, the total number of data points for each 2D profile according to the total length of the profile thought the maximum depth of each profile (approximately 3 m) remains constant.

The RM85 is primarily designed for fixed depth, broad area resistance surveys using a twin probe array and so the data collected for ERT surveys with this instrument must be converted to resistivity separately once extracted from the instrument. Conversion of resistance (ohms) to resistivity (ohm-m) is accomplished using the formula for the given the array geometry as provided by Loke[11]. For all pole-pole arrays data collected at Rovinjsko Selo 1 and presented here, the conversions to resistivity is $x*(2a)$ where x is the resistance reading and a is the mobile probe spacing in meters when x was acquired. Once converted, inversion modeling of data is handled by the Res2DInv software from Geotomo Software. The data presented here were all processed using the finite-difference method and the inversion routine utilized is the smoothness-constrained least-squares method[11].

Results

Four of the thirty-two ERT profiles established at the Rovinjsko Selo 1 site during the 2015 field season intersect the location for the 2007 excavation trench. These four profiles are identified as Profiles 12, 13, 14, & 15 here. Each profile runs east/west according to the geophysics grid layout and are parallel to one another paced 0.5 m apart. The geophysical survey grid was established along a straight line from the longest axis available at the site which extended from the back of the cave, out the mouth of the cave, to the furthest extent of the sediment filled area in the western portion of the rock shelter. Since the geophysical grid was established along a line different from that of the archaeological grid, the ERT profiles intersect a portion of the 2007 excavation trench in a way that is neither parallel nor perpendicular to the trench walls. As such, the trench locations identified in the ERT profiles were not expected to measure the actual 1.5 meter length and width of the trench and, indeed, they do not (Figure 2a-d). In any case, the 0.5 m probe spacing used in the survey is far too coarse to have identified the trench wall in fine detail though it is worth noting here that the ERT profile lines are askew from the archaeological grid both intentionally and by design.

The interpretation of 2D ERT profiles for near surface sediments has a reputation for being quite ambiguous[12]. Changes in the sediment strata can be subtle and unidentifiable in the data. However, a rapid change in resistivity either horizontally or vertically within the profile is indicative of a rapid change in soil moisture or compaction of the sediments thereby indicating a dramatic change in density[13-15]. This could be caused by disturbed sediments (a looser sediment) or by bedrock and calcium carbonate layers which are far more dense than most sediments. A horizontal earth resistance survey used commonly on archaeological sites relies on this property of disturbed soils and sediments to identify subsurface features such as filled-in pits, trenches, and foundation walls[16-19]. The same principle applies to ERT surveys and so the 2007 excavation trench stands out from the surrounding sediment matrix in Profiles 12, 14, and 15 (Figure 2a, c, d). In each of these 2D depth profiles, the western wall of the excavation trench is prominent in the geophysical data and the floor of the excavation is fairly well defined at the approximate depth indicated in the 2007 excavation notes[1].

The lack of definition in profile 13 is of particular interest (Figure 2b). In this instance, it is likely that the large rock (visible on the surface and in the 2D profile) between the 0.0 m and 0.5 m readings is generating high resistance readings which are affecting the modeling of this profile. However, and interestingly, omitting the first set of readings (all those collected with a current probe location of 0.0 m) and processing the rest of the data separately does not much change the modeling of this data. The visual representation of the inversion model remains much the same

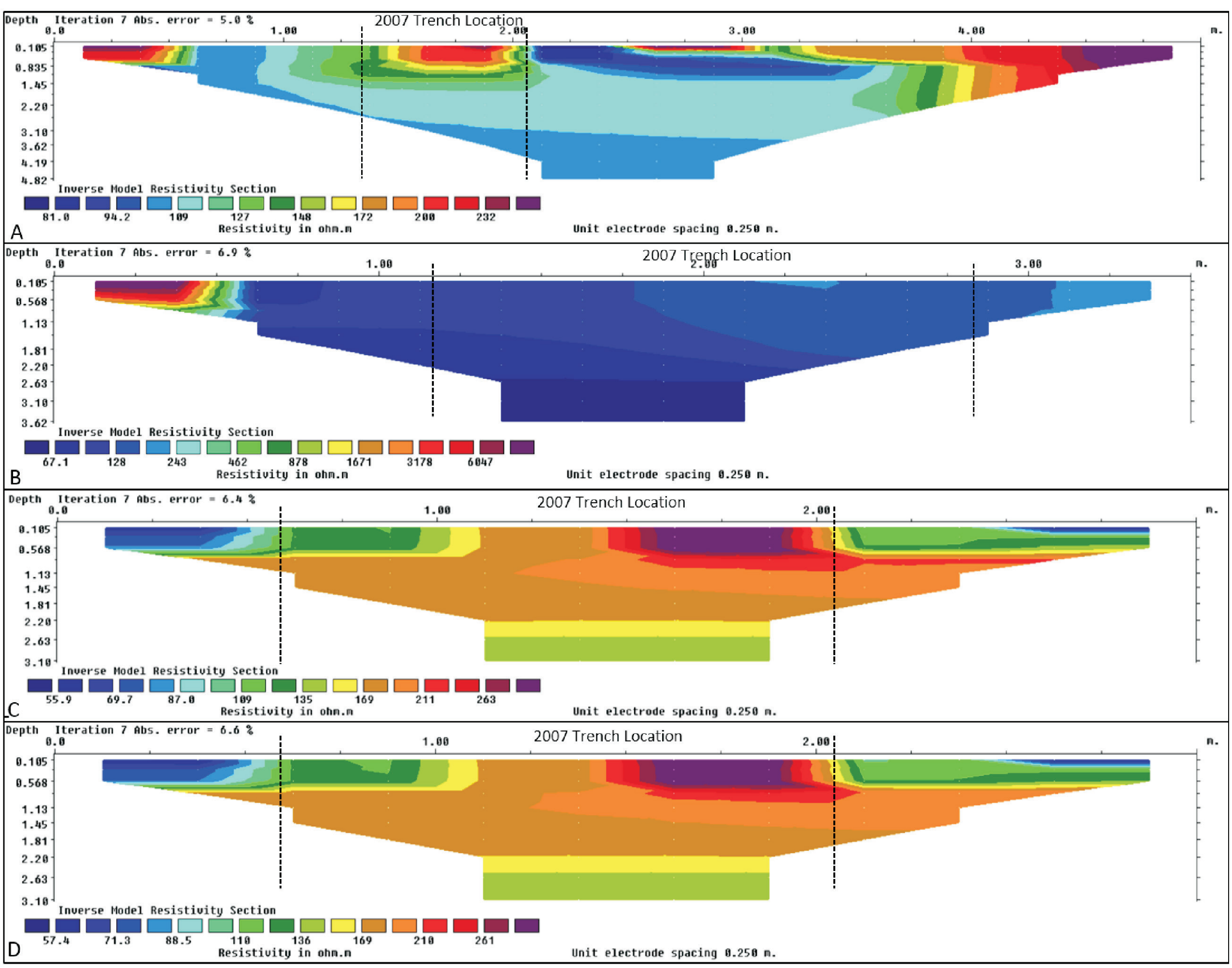

Fig. 2. ERT Results from profiles that intersect Trench 1 at Rovinjsko Selo 1. Note the different lengths of the profiles and different starting locations (east/west) as compared to Trench 1 due to the presence of bedrock in some areas east of the trench. a) Profile 12, b) Profile 13, c) Profile 14, d) Profile 15.

and the 2007 excavation trench cannot be identified though the ERT profile is confirmed to intersect the trench through both measurements from the site datum and photographic evidence. The variation in this profile as compared to the clear evidence for the trench in profiles 12, 14, and 15 emphasizes a principle of best practice common to all archaeological prospection surveys; use multiple and overlapping data sets whenever possible. A GPR survey of the same area may provide a line of evidence to inform why this ERT profile varies significantly from the others and, given the opportunity in future field seasons, this additional survey with a different technique may be possible[3,20].

Three of the four ERT profiles that intersect the 2007 excavation trench show the trench location to a reasonable degree both in the horizontal and vertical dimensions. Though the reason for the lack of evidence of the excavation trench in the other profile is not currently known (even when the high resistance readings from 0.0 m to 0.5 m are removed), it presents an opportunity to further explore this question in future field sessions and with other survey techniques. Profile 1, which is located 0.5 m north of Profile 12, and Profile 16, which is located 0.5 m south of Profile 15, do not intersect the 2007 trench and show no evidence of ground disturbance similar to the ERT profiles that do transect the previous excavation. Additionally, the slight rise in topography created by the back dirt pile to the north of the trench (away from the mouth of the cave) that was noted during the collection of elevation data along Profile 1 corresponds well to a shallow anomaly in the ERT data. Though perhaps of minor significance, it is worth noting that even with a coarse data density of 0.5 m probe spacing, the back dirt pile for the 2007 excavation trench could be identified in the geophysical data which is confirmed through surface observation and as indicated onsite by Darko Komšo during the 2016 field season.

Discussion

Though the 2015 ERT survey of the Rovinjsko Selo 1 site is primarily concerned with producing 2D depth profiles as a means to estimate sediment depth to bedrock, the data collected also proved useful for identifying the 2007 excavation trench location. This allows the Rovinjsko Selo 1 results to be translated to other sites included in the ARCHAEOLIM Project such as Romuald's Cave and Lim 001. Unfortunately, the 2015 earth resistance testing at the south facing Lim 001 rock shelter site demonstrated that the sediments were too dry to collect reliable data. At least, this is true for the summer of 2015 which had record high heat during the fieldwork window available which was in late July. Collecting earth resistance data at this location in other years and/or seasons with higher moisture levels may prove more productive. Continued geophysical testing at the site was discontinued due to the small size of the rock shelter, the difficulty in collecting quality data, and a greater need for ERT results from other sites included in the ARCHAEOLIM Project. In contrast to Lim 001, the initial testing at Romuald's Cave proved favorable for earth resistance data collection and the site also has several unidentified excavation trenches dug under the direction of Mirko Malez in the 1960s and 70s. This presents a situation where the Rovinjsko Selo 1 results and ERT technique for modeling 2D depth profiles can be put to good use informing future excavation efforts at the cave site.

Romuald's cave

Romuald's Cave is located on the southern slope of the Lim Channel. It has, since the end of the nineteenth century, been studied by a number of researchers[1,21-23]. The investigations conducted by academician and Croatian Academy of Sciences and Arts member Mirko Malez are significant as he registered various lithic tools at the site which dated to the Upper Palaeolithic period[24]. A small-scale re-excavation of Malez's investigation was conducted in 2007 and 2008 under the leadership of Darko Komšo with the objective of collecting samples for various analyses and absolute dating[1].

In 2008, Komšo directed the re-excavation of Trench 2 inside the main hall of the cave with the intend of reviewing Malez's earlier stratigraphic observations. Traces of prehistoric pottery, bones and several lithic artefacts were found in the trench. The re-excavation of the Malez trench proved to be of great interest and demonstrated a need for further systematic investigation of the site. In 2014 as part of the Lim Channel Project, further investigation of Trench 2 at Romuald's Cave was conducted. The walls of Trench 2, which was originally excavated by Malez in 1961 and re-excavated by D. Komšo in 2008, were cleaned in support of the stratigraphy correlation effort initiated by Komšo and it was determined that the stratigraphic descent in Trench 2 was not uniform. Some undisturbed sediment remained remained along the edges of the trench, especially in the lower stratigraphic units (Layers 9 through 14 according to Komšo's stratigraphic division). Animal bones and stone tools were found in these undisturbed sediments. The bones are highly fragmented, with a Pleistocene age indicated by the taxonomical attribution, i.e. the presence of animals such as the cave bear (*Ursus spelaeus*), the horse (*Equus ferus*) and the Alpine ibex (*Capra ibex*). Remains from a red deer (Cervus elaphus) and a medium sized canid, likely a wolf (*Canis lupus*), although this may be a dhole (Asiatic wild dog) (Cuon alpinus), were recovered. Additionally, bird remains (*Aves sp.*) were recovered from the trench though these currently remain unidentified as to a specific species[2,25].

The lithic material recovered in the undisturbed sediments from the lower layers of Trench 2 can be typologically attributed to the Middle Palaeolithic period, i.e. the Mousterian culture. Finds were set aside in the course of the investigation for the radiocarbon dating of layers, with the results obtained for the Middle Palaeolithic sequence being an age of over 48,000 years. These are for now the only reliable results of radiocarbon dating for the Middle Palaeolithic in Istria and, in general, the oldest indicators of human presence in the area with the exception of possible tools from the Lower Palaeolithic from the Šandalja I site, for which there are no absolute dating results. On

Fig. 3. Interior of the main hall in Romuald's Cave showing Trench 2 (in the foreground right) and Trench 3 (in the background left).

the basis of typological characteristics and the results of absolute dating, it is hypothesized that the accumulation of archaeological material in layers 11 through 13 in Trench 2 at Romuald's Cave are of Neandertal provenance[2,25].

Along with the cleaning of the existing trench in 2014, a new trench (Trench 3) was established and excavations initiated in the southwest part of the cave's entrance hall (Figure 3). In the course of the investigations of 2014, stratigraphic layers 1 through 5 were investigated in this trench, which is, based on archaeological finds (pottery) and faunal finds, attributable to the Holocene. The finds of pottery in Trench 3 can be approximately dated to the final period of the Middle Bronze Age in Istria, to the Late Bronze Age and the early Old Iron Age. Without clearer corroborated substantiation in terms of the stratigraphy and absolute chronology, however, we cannot offer a final assessment of the time frame of the cave's use. Some of the indicative forms, for example, such as flat-top handles or horseshoe-shaped plastic ribs, have been present in Istria and the broader region since the Early Bronze Age, while some elements are related to later phases of the Old Iron Age. Among the decoration techniques we see grooving (concentric circles on the walls of vessels), incision (discontinuous vertical lines, short incisions along edges), fluting, punctation, finger impression decoration (usually along the edges of pots and on relief bands on the walls of vessels) and plastic applications (in the form of horseshoes, zigzag lines or knobs) and pseudo-strap ornaments. Faunal finds from Trench 3 are largely from the following species: badger (*Meles meles*), hare and/or rabbit (*Lepus europeus* / *Oryctolagus cunilicus*), fox (*Vulpes vulpes*) and the domesticated sheep (*Ovis aries*). The presence of domesticated sheep indicates a period not earlier than the Neolithic. The majority of finds do not show traces of human activity and modification, and the remains are relatively homogenous throughout the entire sequence. This is most likely a natural accumulation of sediment, with traces of badger activity[2,25].

Human skeletal remains were also found in the trench. On the basis of the few remains of skeletal material (teeth, cranial and postcranial remains) we can ascertain the presence of at least two individuals, one adult (likely above the age of 35, perhaps a male) and a child (likely under the age of 5). Based on the stratigraphic position of the human skeletal remains, the presence of skeletal elements and the state of preservation, we can likely attribute the cited finds to the same period. A small fragment of the distal tibia bone was sent for radiometric dating using the AMS method, yielding a result of 3150 +/- 46 years before the present [2,25].

Conclusion

The potential to recover cultural materials dating from the Middle Palaeolithic though the early Holocene at Romuald's Cave is well established. Given that these time periods are of particular interest to the research questions posed for the Lim Channel Project, continuing the excavations at this site remains a priority. Additionally, the 2008 re-excavation efforts of Trench 2 by Komšo and the 2014 wall cleaning of the same trench demonstrate that the identification and re-excavation of the rest of Malez's trenches from the 1961 and 1962 field seasons may provide valuable data (Figure 4). As such, a method for positively identifying Malez's trenches after more than 50 years of natural sedimentation and disturbance from tourist activities on the surface of the cave is needed.

The use of earth resistance to locate areas of ground disturbance, either through depth profiles from tomography data or from fixed-depth surveys, is not new in archaeology. It is well known that the technique is capable of identifying previous excavations from earlier archaeological investigations. However, the positive results of the

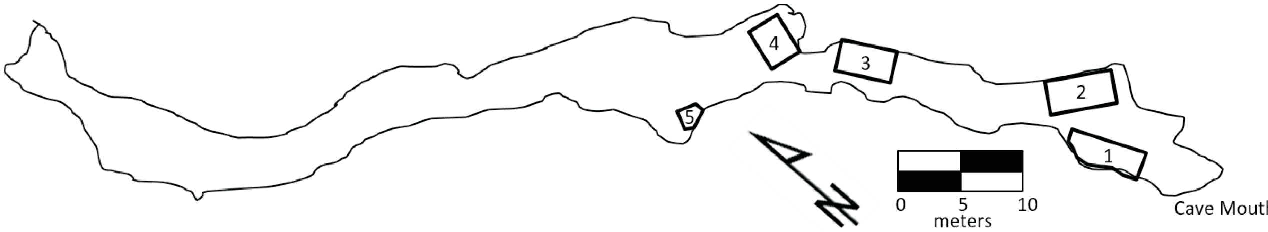

Fig. 4. Sketch Map showing general locations for Malez's trenches at Romuald's Cave. Image adapted from Malez 1987[24].

2015 ERT survey of Rovinjsko Selo 1 provide a clear means to proceed with an ERT survey and planning for the re-excavation of Malez's other trenches from the early 1960s at Romuald's Cave which is located just a few kilometers to the east and also on the south slope of the Lim Channel. The re-excavation of these trenches has a high potential to yield new data and information related to the time periods from the Middle Palaeolithic to Early Holocene in the Istria region of Croatia. Use of ERT, and other geophysical prospection techniques as available, to efficiently identify the earlier trenches through noninvasive means facilitates the excavation efforts by maximizing funding resources and fieldwork time.

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TOMOGRAFIJA OTPORNOSTI ZEMLJE ZA OTKRIVANJE PRETHODNIH ISKOPINSKIH ROVOVA U PEĆINSKIM I KAMENIM ZAKLONJENIM LOKALITETIMA U LIMSKOM KANALU, HRVATSKA

SAŽETAK

Tomografija otpora Zemlje (ERT) je geofizička tehnika pretraživanja koja ima sposobnost modeliranja podzemnih sedimenata. Ova se tehnika primjenjuje u špilji kod lokaliteta Rovinjsko Selo 1, koji se nalazi u Limskom kanalu, Hrvatska. ERT se koristi kao sredstvo za pozitivno prepoznavanje prethodne lokacije iskopavanja rovova na mjestu koje, zauzvrat, obavještava proces planiranja iskopa. Potencijalne prednosti ove tehnike raspravljane su zbog budućig napora za planiranje iskopa u Romualdovoj špilji, drugoj lokaciji špilje u Limskom kanalu. Iako je korisno u ovoj studiji, korisnost tehnike će varirati na drugim lokacijama prema uvjetima lokacije, količini prethodnih aktivnosti iskopa i starosti ranijih iskopavanja koje utječu i na dizajn geofizičkog pregleda i primjenjivost ERT-a u specifičnu lokaciju lokacije.