A Study in GPR Mapping and Concurrent Excavations at Gradina Rat, Brač, Croatia

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Abstract

A GPR program was conducted on a hilltop on the island of Brač, Croatia to assess whether this area was a fort, or a defensive structure, as had been suggested by people for many years. Its location, the sight-lines from the ridgetop, and the surface artifacts all supported this idea perhaps dating from the Bronze Age. The first goal of the project was to collect many profiles around the raised edge of a "basin" on the hilltop, which was hypothesized to have been walls of the fort. Instead, the GPR profiles showed resistant limestone bedrock, and no indication of constructed walls. This was supported with excavations. Inside the basin a burned floor had been uncovered the year before the GPR survey, and subsequent effort was focused to determine if it was part of some larger structure that was part of a defensive building. It was found that while there were some possible floors and walls on the hilltop, they were not substantial, and more likely ephemeral buildings with a non-defensive function.

Introduction

Ground-penetrating radar (GPR) data were collected at what was called the Gradina Rat Hill Fort on the island of Brač, Croatia (Figure 1) from May 30 through June 7, 2022. As our research later showed this was probably not a hill fort, I will just refer to it as Gradina Rat in the remainder of this article. In the literature it is still referred to as a hill fort, however. To confuse things even more the word "rat" in the Serbo-Croatian language has connotations of war or a battle, which retains the "hill fort" idea in its title. But I will keep "rat" in the name for now, until my Croatian friends tell me to take it out.

Figure 1: Location of the Gradina Rat site on the island of Brač, Croatia.

It is easy to see how this prominent location on the island seemed by many to have been a good location for a fort, or perhaps a defensive location (Figure 2). It is located on a very sharp ridgetop, with the ground sloping down precipitously on all sides. From the top there is a very good view to the southwest toward the Adriatic Sea, making it an excellent place to view potential belligerents coming to the island by sea.

Figure 2: Drone photo of Gradina Rat looking east, taken by Sara Popović. Grey limestone rubble from recent quarrying activity skirt the ridge in the foreground.

The area has long been known as an archaeological site based on a concentration of surface ceramics. While there may have been unreported excavations on the ridge top in the past, the first professional work was done here by Vedran Barbarić from the University of Split in 2022. His team's work uncovered ceramics that dated from the Bronze age, with other artifacts spanning the next 2,500 years or so. He also reported a buried burned floor.

There has been much use of this area over many millennia, with the most recent activity including terracing for the cultivation of olives, and perhaps stone quarrying for high-quality, white limestone, also often referred to as "Brač marble". Less valuable limestone was quarried nearby, from which most houses on the island were constructed. The waste stone from this activity was used in the construction of agricultural terraces (Figure 3), with the less-useful stone discarded as talus-like deposits, which are light grey in color near the site.

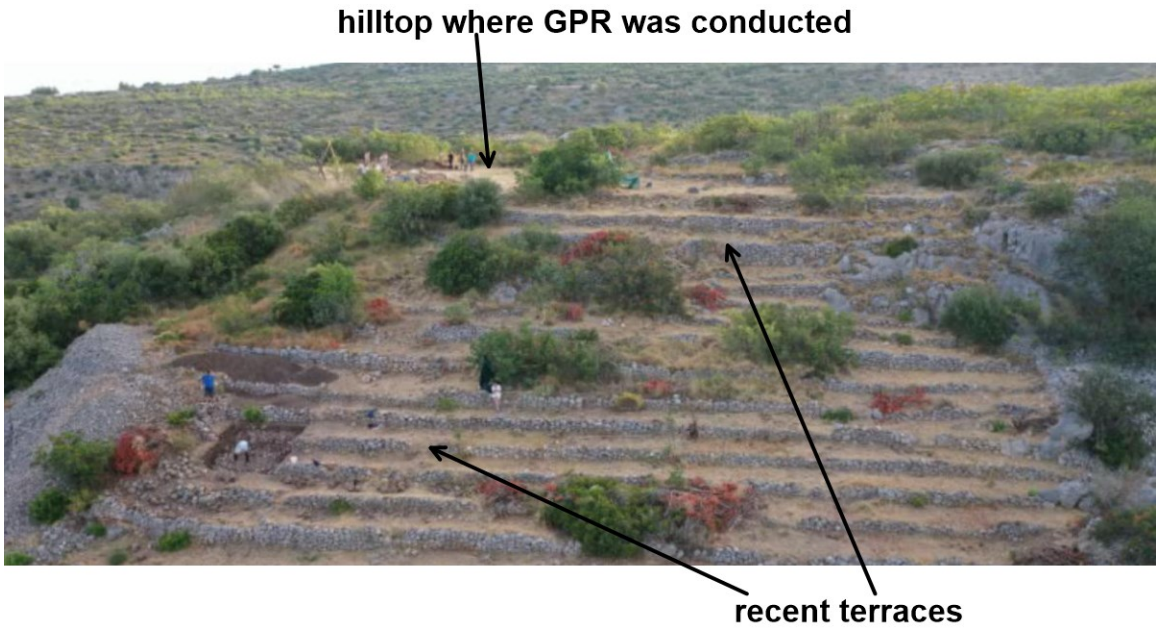

Figure 3: The hilltop looking north showing the recent terraces, and an area of limestone waste stone on the left. The GPR data were collected on the flat top of the ridge.

Background on the plan for GPR

With little to go on other than the burned floor and an abundance of pottery on the surface of the ridgetop, plans were made to test the idea that this was a hillfort, as had been suggested by many people over the years. There is a subtle “edge” along the perimeter of the mostly flat ridge summit, which was thought to perhaps be walls that bounded the subtle basin within. The first objective was therefore to search for buried walls or other defensive architecture along this perimeter, which would have been the natural location for them to be preserved.

As the project was fortunate to have many student workers to help with GPR data collection and concurrent excavations it was decided to collect data in the mornings, download and process it in the afternoon and evening every day. Meetings would then be held after dinner every evening, and plans formulated for the next data to include excavations to test GPR-based ideas and conduct further GPR data collection. Rarely have I had the luxury of being able to produce “immediate gratification” of GPR

results in the way, which made this project both very efficient and productive. Every evening GPR results that defined stratigraphy, cultural features and sometimes architecture were discussed among the team. In this manner hypotheses were continuously refined, with some discarded, and new ideas proposed, which then could be tested. The students were immeasurably helpful in this process.

A total of 279 two-dimensional radar reflection profiles were collected over the week of the project using a GSSI SIR-3000 system with 400 MHz antennas (Figure 4). Data were collected in grid regions, all contiguous at 1 meter or 50 cm profile spacing, depending on the definition needed to image the ground and the time allotted.

Figure 4: Radar collection equipment used at Gadina Rat site using the SIR-3000 system and 400 MHz antennas.

GPR data collection at Gradina Rat

At Gadina Rat the 400 MHz antennas were capable of transmitting radar waves about 2-3 meters into the ground before being attenuated. The returning waves were reflected from objects or features that were larger than about 10-150 cm in diameter, and those reflections were mapped using both 2-D profiles and combined within grids to produce 3-D amplitude maps (Conyers 2023). The subsurface resolution of the 400 MHz antenna is important as the resulting images effectively made any stones smaller than 10-15 cm in diameter "invisible". This is because the wavelength of 400 MHz in this ground, with a relative dielectric permittivity (RDP) of about 5, is 34 cm: therefore, a resolution of about ½ the wavelength of waves in the ground, being about 15 cm (Conyers 2023: 68). Radar waves therefore passed through or around stones smaller than this, and no reflections were generated.

Excavations revealed that this ground was composed of many small stones with sand and silt matrix, with many stones 15 cm in diameter or smaller. Most of these smaller stones were too small to have reflected waves, which proved to be a blessing as a plethora of reflections from each and every stone would likely have produced unusable images of mostly "clutter".

It became very important as the project proceeded to differentiate buried features that were natural and those of anthropogenic origin. By comparing excavation information to GPR images on a daily basis was this possible.

Bedrock in this area is primarily limestone and dolomite. Many cut or modified stones of this material are found on the surface and in the slopes surrounding the hill fort, which had been used until recent times for producing walls, terraces and all manner of architectural features. Terraces constructed with these stones were used to hold soil in place for olive orchards, with some walls used as livestock enclosures.

All grids were laid out using tape measures, and their corners later surveyed into space using differential GPS. There were many stones and vegetation that had to be cleared and moved prior to GPR collection, but some of the larger bedrock obstacles remained and had to be avoided in the placement of grids. The bumpy ground produced some antenna coupling problems (Conyers 2023), which was compensated for in data acquisition by performing real-time averaging of reflection traced along profiles, with the stacking of every three traces into one, in a running average. All GPR profiles saved 40 individual traces per linear meter along transects.

GPR data analysis and interpretation

The first idea to test was the hypothesis that this was a hillfort, and therefore there should be walls around it. We spent a day collecting reflection profiles over different areas of the "rim". All profiles were surveyed for elevation changes, and the reflection profiles corrected for topography (Figure 5). When this was done it was discovered that this rim, which was inferred to have been an enclosure for a fort, was actually intact bedrock. This was the case on all sides of this platform surface making up the top of the ridge. Bedrock could be easily seen in the 2-D reflection profiles as layered sediments of the limestone. In areas where the ground sloped dramatically from the top of the ridge, limestone clasts were also visible in these profiles as rubble deposits, which had slumped down from above.

What gave this new idea more support was that there was a bedrock layer, which could easily be "picked", and which was the "bowl rim" along the top of the ridge. Layers of sediment were mapped within this bowl, and all were horizontal, showing that these were deposits placed within the basin by active erosion and deposition over the centuries.

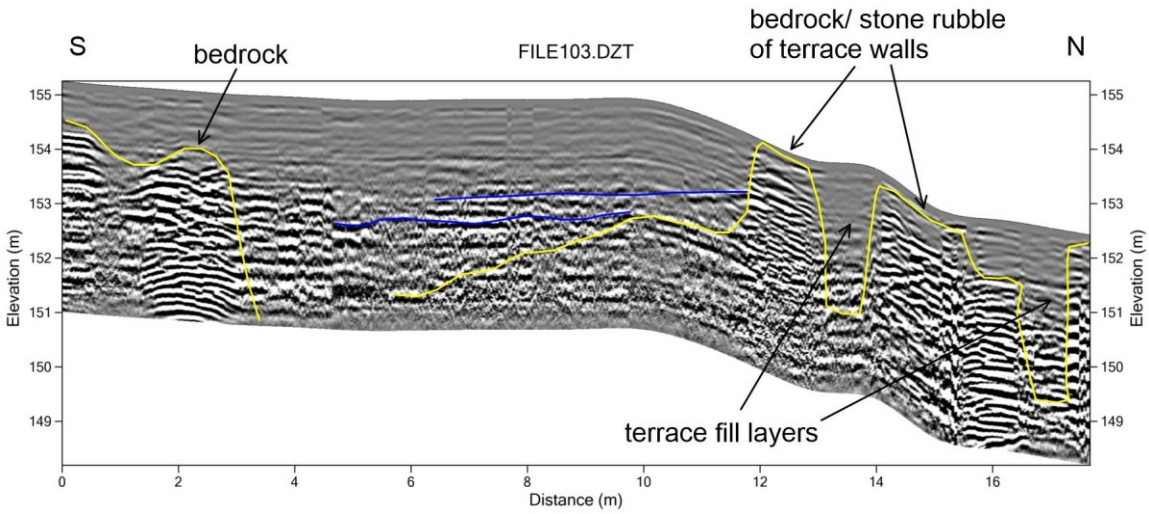

Figure 5: Topographically adjusted 2-D profile across the surface of the hilltop, showing the bedrock reflection and the layered sediments (in blue) within the bowl at the top of the hill.

Many tests of this sort were made along the rim of the flat surface on top of the ridge, and they all displayed variations of this same theme (Figure 6). These tests supported an alternative hypothesis to the "hill fort" idea that had been prevalent for many years. This subtle "bowl-shaped" area on the ridgetop instead was a natural depression, and while it provided an excellent view of the sea and the surrounding area, there were no constructed walls around its edge that may have been used for defense or other military purposes. The origin of the depression was not anthropogenic.

Instead this depression is likely a karstic limestone depression that formed by the solution removal of this limestone sediment, which then was filled slowly over time by minor sediment inflow during winter rains and the addition of small amount of windblown sand from the beaches below. As it retained water, soil also built up and the basin was slowly filled by pedogenic processes. Nowhere along this basin edge did we see any stacked stones with GPR that would have been evidence for a constructed wall around the edge of the upper terrace surface.

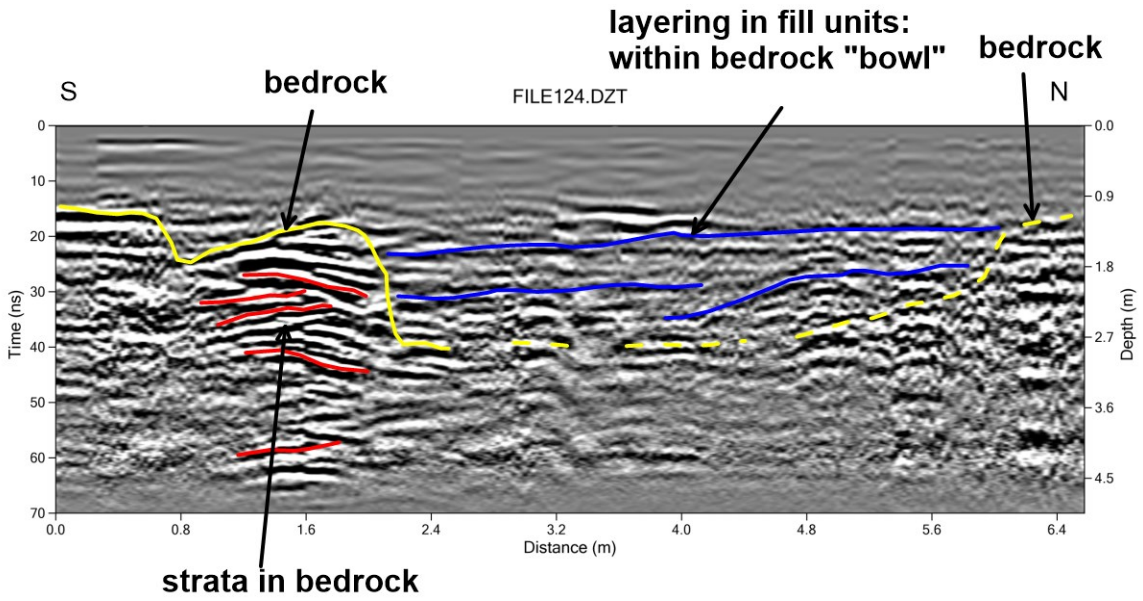

Figure 6: A test along the edge of the terrace showing a natural bedrock feature that provided a basin that filled with sediment and soil.

After a few days of work to test the "hillfort" hypothesis we proceeded to study what types of architectural features there may be within the recently re-interpreted "bowl" on top of the ridge. The abundance of pottery on the surface and the uncovering of a burned floor at about 1-meter depth in 2022 provided enough impetus for us to continue the search for cultural features.

Amplitude slice-maps were constructed for the complete grid on the ridgetop (Figure 7). This imaging method is always good as a "first-pass" to see what types of features might show up by using only image-recognition (Conyers 2023: 8). We were hoping that buildings with walls and floors might appear in these images, but they did not. Instead there was a prominent linear feature that crossed the basin from north to south in the 40 and 80 cm slice (Figure 7). A very quick excavation of this feature showed it to likely be a livestock-enclosure wall of recent origin. No other features of much interest appeared in these maps. Individual stones and bedrock that were within the slices displayed high amplitudes but they were mostly randomly placed.

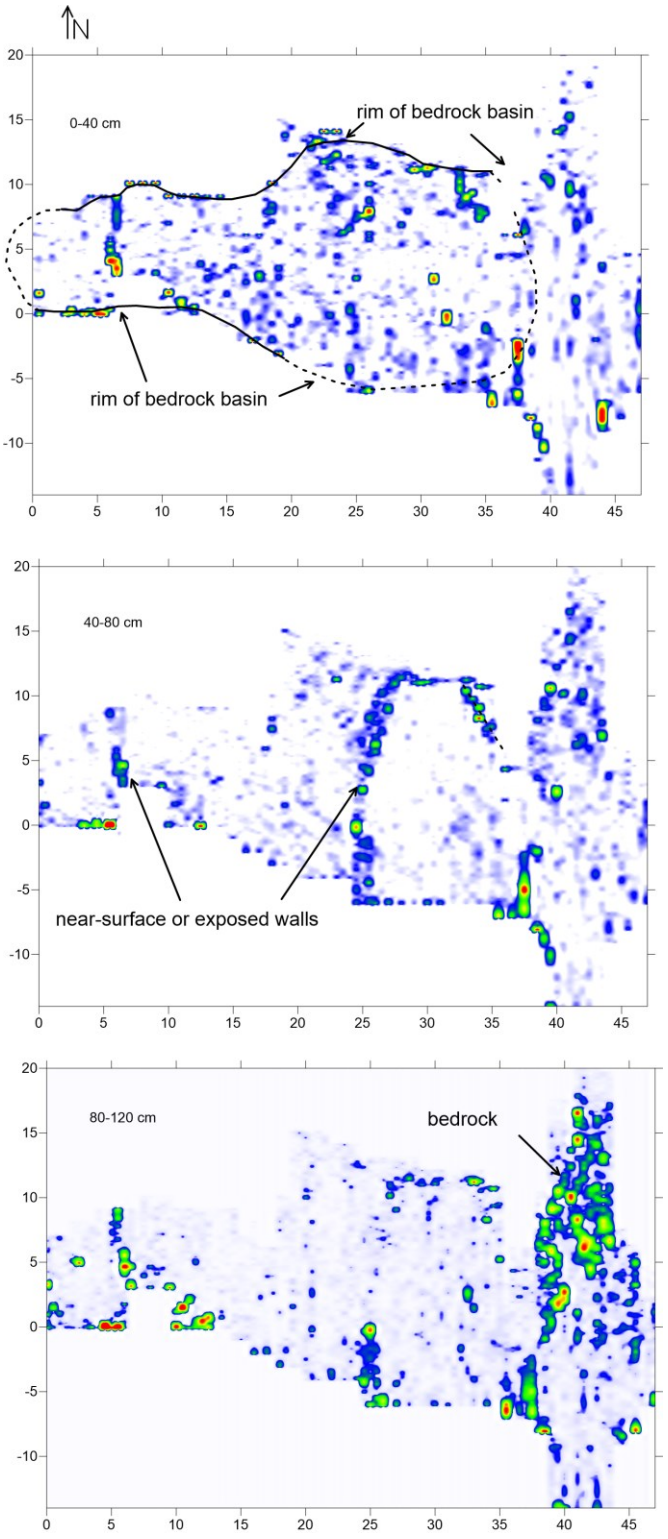

Figure 7: Amplitude slice-maps of the top of the ridge showing the outline of the bedrock basin in the shallow slice and a wall crossing the site in the 40-80 cm slice, which was determined to be part of a recent livestock-holding facility.

The project then focused on the identification and projection of the burned floor that had been uncovered in 2022. The GPR 2-D reflection profiles adjacent to that 2022 trench were directly compared to the excavation profile, and the burned layer was readily identified at the correct depth and location (Figure 8). A possible shallow floor, or perhaps a buried soil layer was also visible above it, which was not described in the archaeological excavation report. Its origin is unknown and was not of interest to the project. The top of the recent livestock-holding wall was also visible.

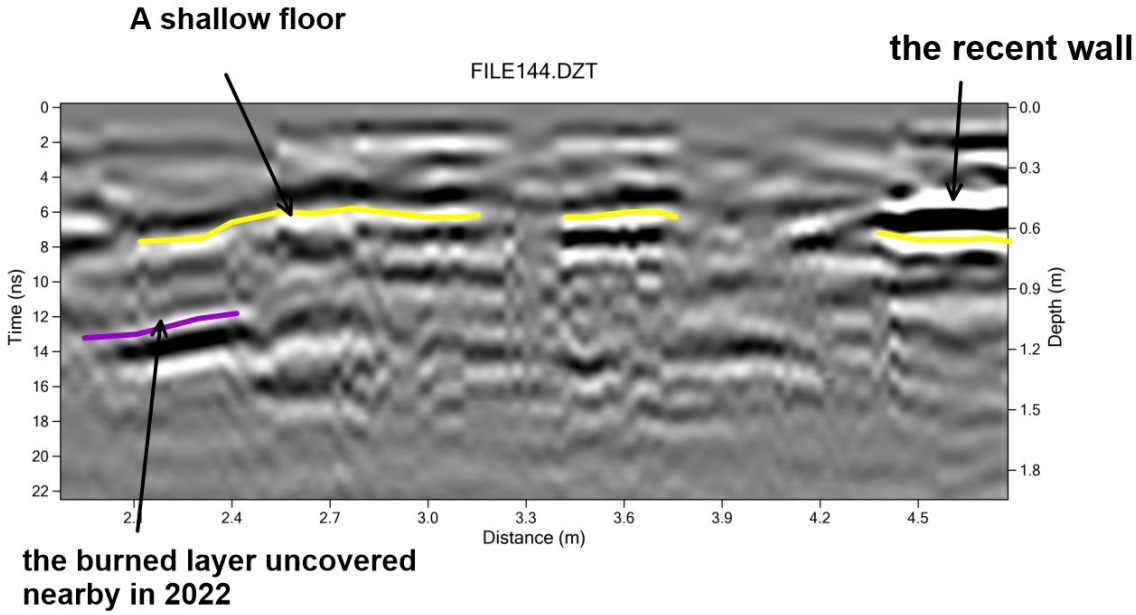

Figure 8: GPR reflection profile showing the burned floor in purple, the top of the recent livestock enclosure wall, and a possible shallower floor or buried soil horizon in yellow.

A good deal of time was spent analyzing all the reflection profiles collected in the grid and delineating reflections that were visible, and which might be of interest. Smaller very detailed grids of data were re-collected with a tighter line spacing and with more collected traces per meter, and no trace averaging. Those were then re-interpreted in 2-D and 3-D. That part of the project encompassed another 3 days of data collection and analysis. It was described in this article, published in Wired Magazine in 2022 (https://www.wired.com/story/scientists-have-an-audacious-plan-to-map-the-ancient-world-before-it-disappears/). Nothing of great archaeological interest was discovered other than some possible walls and floors.

Conclusions

My collaborators in this project were very gracious with me, but somewhat disappointed that the GPR results did not support the idea that this hilltop at Gradina

was a fort or other defensive location. Using GPR combined with follow-up excavations instead showed that there was a recent livestock enclosure wall, with some buried floors of buildings, one of which had been burned. The perimeter of the basin on top of the hill turned out to have been structurally supported by intact bedrock that was more resistant to weathering and erosion than the sediments within it. This important geological conclusion I think was disappointing to my friends and colleagues, as they were hoping for more formal and elaborate architecture consistent with some sort of warfare and perhaps martial function. I, however, considered this to be a great study that showed how an integrated GPR program with targeted excavations could test hypotheses in almost "real time", which allowed for the creation of almost immediate alternative hypotheses to test.

My friend and colleague, Sarah James of University of Colorado, Boulder, concluded that this project revealed a number of interesting finds suggesting possible activities at the site. "*One was the presence of Greek and Roman-style pan tiles, which could indicate the presence of a roofed structure during the Iron Age and Hellenistic period. Another was a large quantity of Bronze Age-Iron Age ceramic wares, suggesting permanent occupation of the site during that period. These and many other finds support the theory that there was at least a low level of activity at Gradina Rat from the Bronze Age onward and that the site remained continuously significant in the landscape of northwest Brač for millennia* (https://www.colorado.edu/classics/brac)".

I think these are important discoveries for the Classical Archaeology work that was done here, and we all should be proud of the results. I am particularly satisfied with the interactive way that GPR worked with standard excavations to produce these results. However, I have not been asked back to participate in subsequent field seasons. Perhaps the utility of GPR as reported here was satisfactorily completed for the project.

References Cited

Conyers, Lawrence B. 2012. *Interpretation of Ground-penetrating Radar for Archaeology*. Routledge, Taylor and Francis Group.

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