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PAPERS OF THE DEPARTMENT
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Recenzija / Review

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Domagoj PERKIĆ & Miroslav VUKOVIĆ

DOCUMENTING AN ARCHAEOLOGICAL LANDSCAPE AND ITS FEATURES USING A LOW COST UAV – CASE STUDY: MRAVINCA IN DUBROVAČKO PRIMORJE

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The primary goal of case study Mravinca was to document the current state of the prehistoric necropolis near Mravinca in Dubrovačko primorje. Using a low cost UAV system equipped with a compact camera proved to be more than enough to document individual stone mounds as well as the whole area. A number of high and low altitude photograph sets were used to create 11 image based models of the mounds, and one model of the entire area (DTM). Besides documentary value, this way of recording data provided us with new sets of information which could be used to better understand the underlying archaeological data. The chosen area is geologically enclosed and the idea was to try to understand the basic spatial and volumetric relations between the mounds. Considering the wider area, and the fact that there are more than 600 stone mounds in the county of Dubrovačko primorje alone, this type of case study could be a basis for further research.

Keywords: UAV, DTM, archeological landscape, stone mound, Dubrovnik, photogrammetry, photoscan, DJI phantom

INTRODUCTION

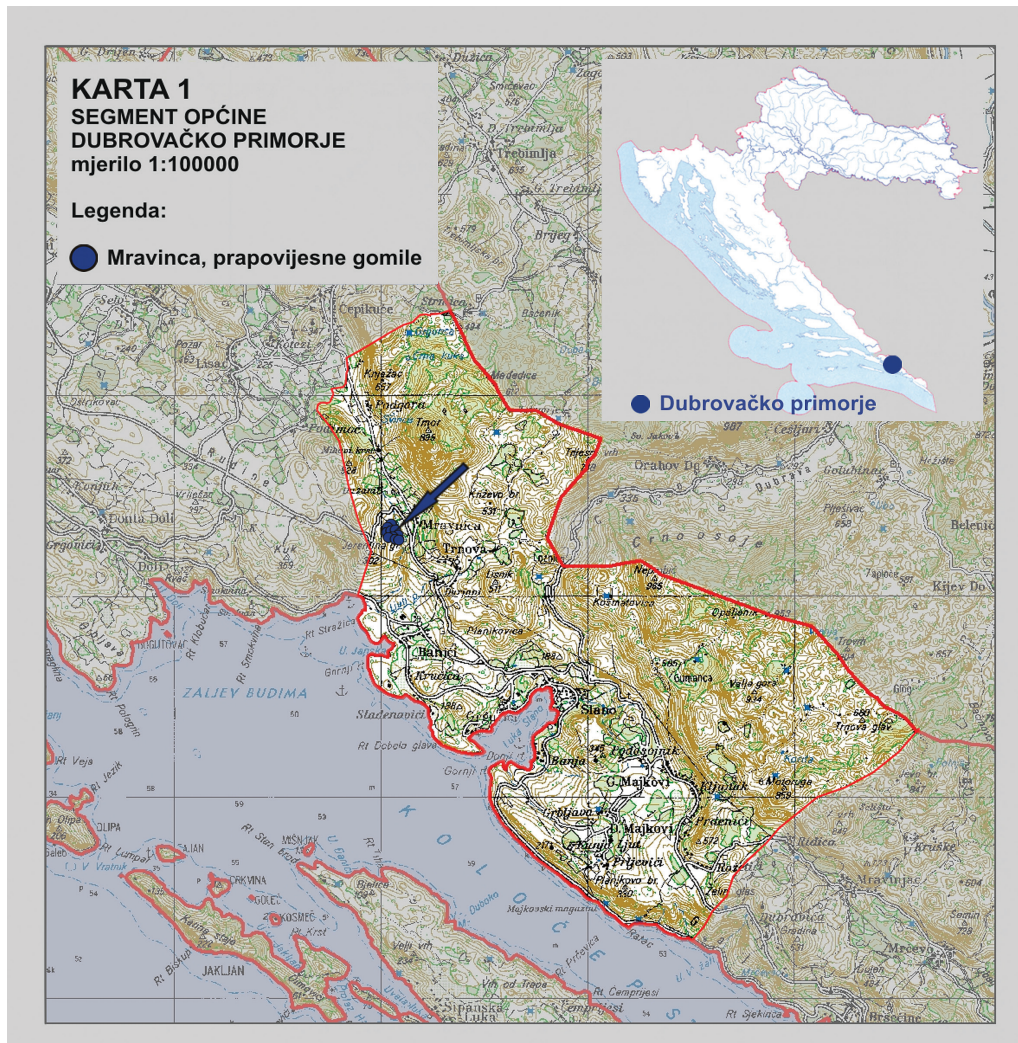
The initial goal of the paper was to present a new, fast and effective way for the documentation of a small scale archaeological landscape and its main features. In recent years we have seen a steady rise of UAV use in archaeology. Although initially used as platform for low altitude aerial photography, which is extremely useful in the process of documenting a site, the full potential of UAV uses was realized with the rise of advanced SFM software solutions which enabled the creation of 3D models (Remondino *et al.* 2011). When compared to older methods of documentation, which involved a great number of GCPs (ground control points) taken with a total station, using photogrammetric 3D models has greatly increased the speed and the detail with which we acquire the data in the field. (De Reu *et al.* 2012) Although the models can be created using other low altitude platforms such as balloons, kites and poles, the maneuverability of a UAV allows for detailed documentation using low

altitude images (resolution: 2 – 9mm/pix), as well as landscape scale documentation using images from higher altitudes (resolution: 5 – 10cm/pix).

The three dimensional dataset recorded on the site provided us with the opportunity to further analyze the spatial relations in the target area, as well as the volumetric data for each individual archaeological feature. During the second higher altitude UAV flight a new potential archaeological feature was detected and recorded, and is clearly visible on the extrapolated DTM of the target area. This demonstrated the versatility of the low-cost UAV platform in documentational, as well as in the small scale remote sensing area.

COUNTY DUBROVAČKO PRIMORJE, VILLAGE MRAVINCA

The Dubrovačko Primorje County is spatially defined by the City of Dubrovnik on the south–east and by the border with Bosnia and Hercegovina near the city of Neum to the north–west. The north east boundary of the county is on the actual border with Bosnia and Hercegovina extending to the south, and the boundary on the south–west is defined by the coastline and the Adriatic sea (Koločep channel, Malostonski bay and bay Bistrina). The county spreads from the northwest to the south-east following the coastline for about 40 km, and its width varies between 5 to 15 km (Karlić–Mujo 2010: 110). The village of Mravince is situated 4 km northwest from the town of Slano which is the center of the county (Map 1). The village of Mravince itself is referred to under different names, including: Mravinca and Mravnica, but the local dialect prefers the title Mravince.



Map 1: County Dubrovačko primorje with the stone mounds marked in blue, author: D. Perkić

The Dubrovačko Primorje County is composed out of two distinct topographic and geological areas: the coastline and the hinterland. Both areas have a Mediterranean climate and vegetation. The terrain is comprised out of limestone and dolomite rocks which are characteristic for the karst region. This type of terrain is extremely complex in relief, and is comprised out of many depressions, sinkholes, fields, canyons, caves, and underground water systems (Roglić 1974: 11). The wider area of Dubrovačko primorje is a part of a geotectonic transition area between the geostructures of Dinaric and the Adriatic (Šundov 2004: 23, 61). This area experienced severe changes during the Late Pliocen – Holocen era due to a sea level change of around 100 m which defined today's coastline (Karlič–Mujo 2010: 111–112).

This type of terrain usually hosts a large number of stone mounds. Unfortunately it is currently impossible to define the original purpose of the mound construction, without actually dismantling the mound and conducting excavations (Perkić 2010: 45). The mounds could be burial places, cenotaphs, or they could be parts of old fortifications systems. Some of the mounds have been created by field clearing, and some theories maintain that most of them were created this way. The burial context in this case would be the result of secondary use of the existing mound (Chapman & Shiel 1988: 11). While logical this theory doesn't take into account the fact that a big number of these stone mounds are situated on strategically important areas, near settlements and hillforts, near communications and on top of hills, so they are obviously not a consequence of field clearing. They are also found near the fields, and they could have served as a sort of ancestral protection, or a cultural–territorial marker (Čače 1981: 35–40). The ritual of burial is closely associated with agriculture so the placement of stone mounds near fields could be a consequence of that connection.

More than 600 stone mounds have been identified in the Dubrovačko Primorje County, and the funerary ones were formed during the Late Eneolithic and the Iron Age. Each stone mound's size, condition, type, and location (GPS) was documented, and they were also photographed and placed on a map in scale 1: 25 000.

Since the so called large scale documentation was completed in the form of mapping the stone mounds, it was time to move forward and choose a smaller area for further study. Our target area was a plateau on the hill called Jeremina glava bordered by a canyon creek Oberdove stine to the east and steep hills to the west. The southern part of the plateau also has a steep drop in elevation, and a few

kilometers further is the bay of Slano, and the way towards open sea. The northern part of the plateau is really the only easily accessible side, and the way north from there leads across the pass Miholj krst towards a natural communication route to what is today Bosnia and Herzegovina, in the direction of Stolac (Map 1). The plateau itself has 11 loosely grouped stone mounds which form a prehistoric necropolis mostly undisturbed for thousands of years. A detailed analysis could yield interesting data regarding the spatial and dimensional relationships between individual mounds, or mound groups. Besides being archaeologically interesting the area of Mravinca is also strategically set on a defensible and prominent position, as well as being set on the crossroads of natural and probably prehistoric communications. For precisely these reasons this area was chosen for further study, and it will certainly yield lots of information about prehistoric communities which inhabited this area of Slano hinterlands. The documentation carried out was envisioned as a detailed analysis of the area and the mounds, which could serve as a basis for future archaeological exploration. The study was organized by the Archaeological Museum of Dubrovnik Museums, and the work was carried out by the company Luperca M.T. j.d.o.o. from Zagreb in November 2014.

HARDWARE AND SOFTWARE

Recent advances in UAV technology transformed simple rotor based systems to powerful and precise tools which can be effectively used in archaeology. The key factor was the development of advanced stabilization software and hardware, which used in combination with precise GPS data enables smooth and steady in-flight performance (Sauerbier & Eisenbeiss, 2010: 526–531) As a result of increasing demand the UAVs became more affordable, and as time went on, more powerful and stable



Figure 1: *Dji Phantom2 mounted with a RicohGR compact digital camera, author: M. Vuković; Lower right corner - UAV mid-flight, author: M. Doneus*

as each new model came out. In this study we used a quadcopter DJI Phantom2 in combination with a RicohGR compact camera. Securing a platform for acquiring aerial photographs of the area was just a part of our case study.

Using the low altitude aerial photographs we created image based models of individual stone mounds in the area. Higher altitude photographs taken from the same platform were used to create a digital terrain model (DTM) of the area. The models were created using Agisoft Photoscan (AgiSoft LLC 2011).

After gathering the data and creating 3D models, detailed plans of stone structures were made using AutoCAD. Besides the plans, the individual stone structure models and the DTM of the whole area were used to gather spatial information.

AREA (DTM)

During four working days we documented a 252 961 m² area. The first part was studying the area/plateau itself. For this task we used existing maps, high altitude aerial photographs, and satellite data. After

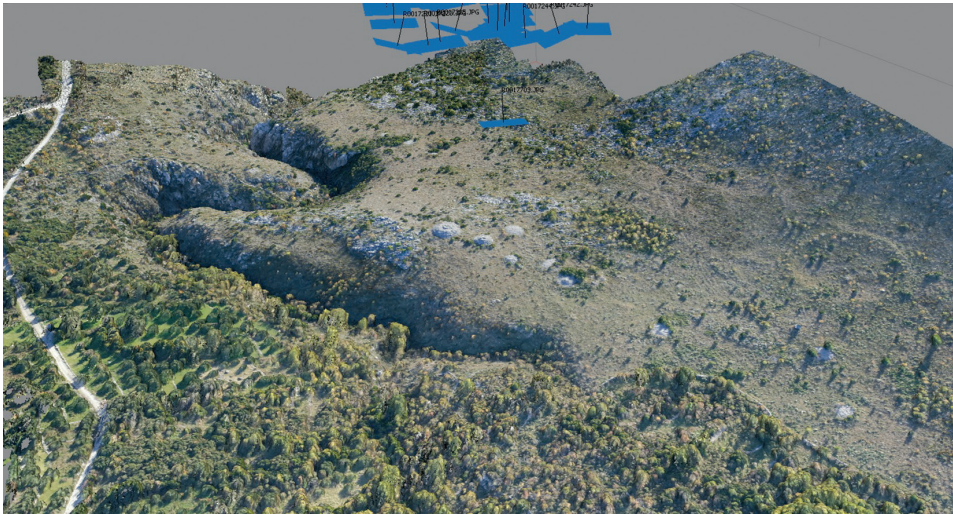


Figure 2: Dense point cloud of the plateau with stone mounds visible in the middle and a circular enclosure like shape to the right of the image, author: M. Vuković

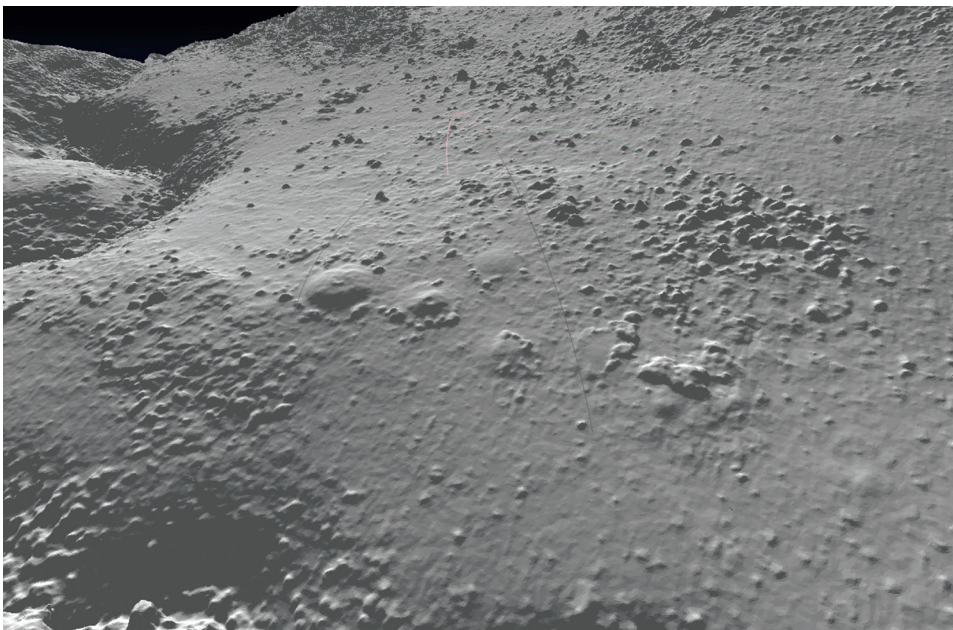


Figure 3: A DTM of the plateau, shaded by two-sided directional light in Meshlab, author: M. Vuković

determining the exact target area three ground control points were set for georeferencing the DTM.

The first two days of flying gave us higher altitude photographs which we used to create an image based model of the terrain. The flight altitude was between 150–200 m above ground, the camera was set to interval shooting of 2 seconds. After sorting out the photographs, 148 aerial shots were selected for the creation of the digital terrain model. The end result was a dense point cloud with 30 440 971 points, and the model itself had 6 132 300 polygons. The resolution of the DTM was 5cm/pix.

After creating the model in Photoscan, it was exported to .obj format and imported to another software, Meshlab. In this case we chose Meshlab because it gave us an easy way to point a directional light at the DTM and give us a good render of the shaded terrain model. Individual stone mounds are easily visible on such a model (Figure 3). An interesting terrain feature to the west of the plateau appeared on photographs and on the DTM. The feature is a ring like elevation in the terrain only 50 cm higher than the surrounding terrain with a diameter of 82 m. It is situated on the slope of a hill which defines the plateau's western geological border (Figure

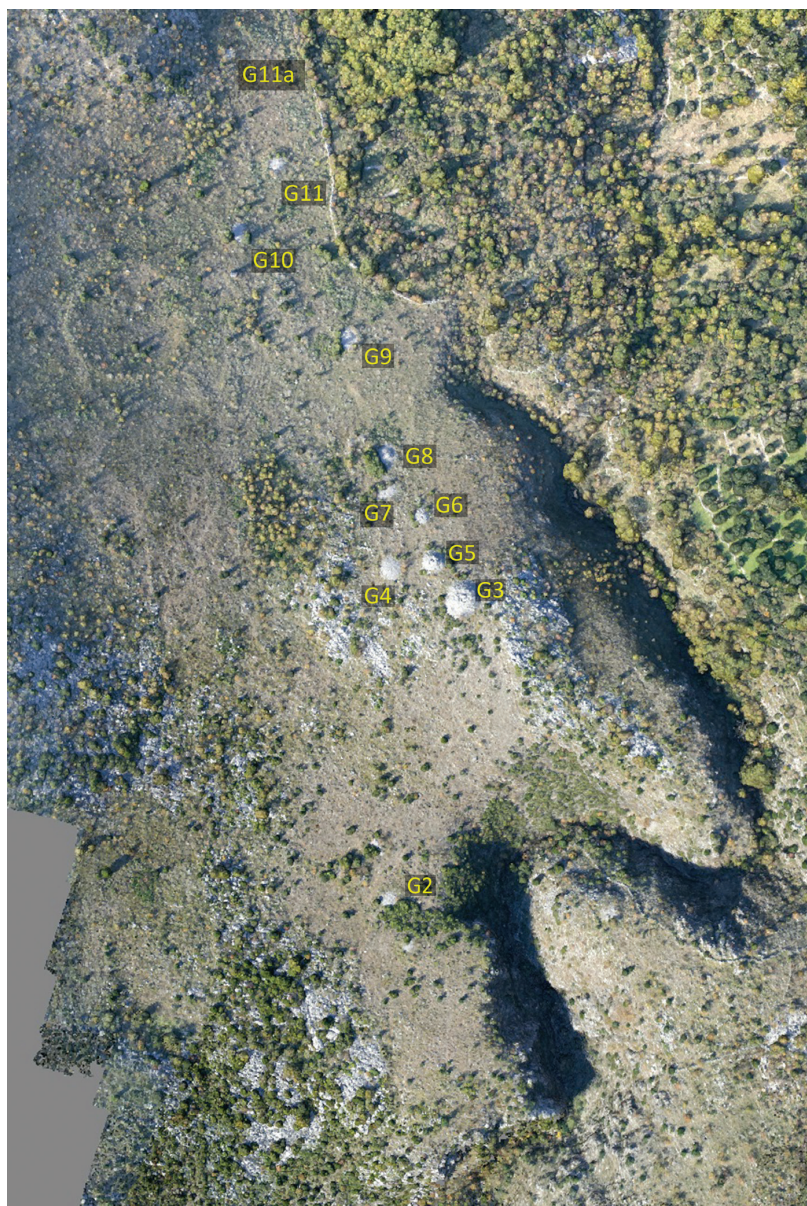


Figure 4: Rectified ortophoto mosaic of the entire area with marked stone mounds (G2 – G11a), author: M. Vuković

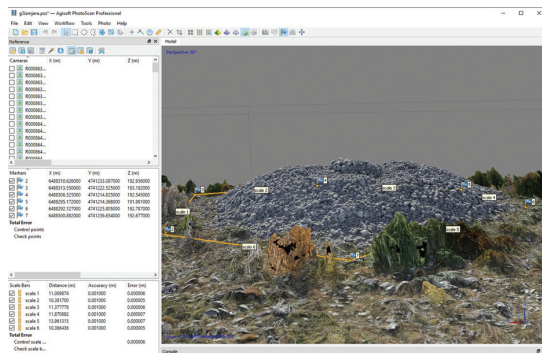


Figure 5: Image-based model of the stone mound G3, created in Agisoft Photoscan, author: M. Vuković

2). Its shape and proximity to the necropolis suggest it to be an archeological feature reminiscent of pre-historic enclosures.

STONE MOUNDS

The stone mounds themselves required a different approach. One of our goals was to document the current state of these archaeological structures. After extensive field surveying, conducted by Domagoj Perkić on behalf of the Dubrovnik Museums, potential targets were marked on a satellite image and were given numbered and lettered designations; G2 – G11a (Figure 4).

Since the resolution of 5cm/pix used for the DTM wasn't good enough we used low altitude aerial photographs taken from 10 m – 25 m above ground over each mound. Before conducting the flights



Figure 6: Aerial photograph of a part of the mound G5; "A" indicates a layer of smaller stones visible beneath the large ones, and "B" indicates the circular rock formation with vegetation, author: M. Vuković

a set of ground control points was placed around each mound, the points were measured with a total station and later on used to georeference each model. The number of photographs for each mound changed depending on the size and the elevation of the stone mounds, smaller ones averaged around 40 photographs and bigger ones around 100. The position of the camera remained perpendicular to the ground during all flights, and the total flight time was 2 hours. The result were 11 image based models of the stone mounds with a resolution of 5mm/pix, and detailed orthophotos extrapolated for the creation of plans.

Stone mound G2 with the surface area of just 66.57 m² was our first target. It is the southernmost mound in a bad state of preservation. The stones are almost level with the surrounding landscape and it had no distinct structural features. Some 150 m to the north was mound G3, with a prominent position and impressive size (382.59 m²) it is the biggest mound on the plateau. (Figure 5) It stands almost 4 m above the surrounding terrain, and it's probably safe to assume that it is in a good state of preservation, although no clear signs of the original structure are visible.

Only a few meters away we can find mounds G4 and G5. While almost identical in surface area (G4 = 121.41 m²; G5 = 128.69 m²), these two mounds are in a very different state of preservation. G4 is on the same level with the surrounding terrain and its stones are almost uniform in size. G5 on the other hand rises to 2 m above the surrounding terrain, and on its northern part a layer of smaller stones is visible beneath the uniform larger stones on the surface.

Next to these smaller stones there is a circular stone formation from which vegetation grows. On top of the mound there is a round stone formation similar



Figure 7: Aerial photograph of the stone mound G8, author: M. Vuković



Figure 8: Aerial photograph of a part of the mound G9; "A" indicates the only possible trace of the mounds original structure, and "B" indicates the circular rock formation with vegetation

to the one found on top of G3, but it is probably a modern modification of the existing mound. G6, G7 and G8 are situated to the west close to the before mentioned G4 and G6. While G6 and G7 are smaller in size (around 80 m²), G8 with the surface area of 128.79 m² is in the same size range as G4 and G5. Over half of the mound is covered in smaller stones, which could be an indication of a lower construction layer, visible also on mounds G5 and G6. Some of the larger stones could be a part of a former circular structure in the middle of the mound (Figure 7). Mound G8 is also the last one of the closely grouped mounds (G3 – G8).

Mound G9 is located 60 m to the west from the closely grouped mounds on the eastern part of the plateau. It is slightly smaller in size (99.46 m²) than the group G4, G5 and G8, but it is the only one with what appears to be a part of the original stone architecture of the mound itself. It also has a circular formation with vegetation in the middle as seen on G5 and G7 already. Some 70 m away to the northwest lies mound G10. It has two intermixing layers of smaller and bigger stones, and its surface (73.64 m²) reminds us of mounds G6 and G7. The last two mounds are G11 and G11a, located on the northwestern part of the plateau where the terrain starts to climb sharply towards the western hill. They are characterized by the presence of extremely large stones on their edges, and mound G11a is the smallest in the area with a surface of 26 m².

DISCUSSION

Some subtle differences in stone sizes became visible during the process of drawing the plans. It seems that a layer of smaller stones (G5, G6, G8) precedes and is beneath the layer of larger stones which is dominant on most of the mounds. Only mounds G11 and G11a show signs of large stone usage which seem to stand out from the construction practice in other mounds. Mounds G3, G5 and G8 have smaller stone circular formations in their centers, but it would be a far reach to label them as parts of the original mound structure. The only likely trace of the original structure of the mounds was found on the mound G9. At its northern part a clearly defined edge is visible with at least two rows of stones neatly stacked one upon the other.

This section ends with the aforementioned circular formation on the stone mound with vegetation in the middle (Figure 8). This type of circular formation with vegetation in the middle has been documented on mound G5 and G7 as well, but it is questionable if these formations are in any relation with the structure of the mounds themselves. The

Mound	Surface/Area	Volume
G11a	26.66 m ²	-
G2	66.57 m ²	4.88 m ³
G7	80.69 m ²	6.22 m ³
G11	63.99 m ²	7.26 m ³
G9	99.46 m ²	10.61 m ³
G10	73.64 m ²	19.59 m ³
G6	74.23 m ²	20.19 m ³
G8	128.79 m ²	23.12 m ³
G4	121.41 m ²	33.30 m ³
G5	128.69 m ²	68.84 m ³
G3	382.59 m ²	326.39 m ³

Table 1: Stone mounds sorted by total volume, from smallest to biggest, author: M. Vuković

stones on all the other mounds are either spread out or have tumbled down and there are no traces of structure or a clearly defined edge. Creating photogrammetric models of all the mounds gave us the opportunity to analyze measurable data and compare the values of all the mounds. Two sets of data were calculated, one was the total surface of each



Figure 9: Aerial photograph of a group of mounds: G3, G4, G5, G6, G7 and G8, author: M. Vuković.

mound, and the other the total volume. The results are probably flawed due to vegetation obstructing visible parts of mounds, and due to the nature of the total volume calculation. Total volume is calculated by using the surrounding terrain as a starting point, so basically only the above ground part of the mound is calculated, and since we don't know how deep the mound goes underground, the calculation is flawed from the start. All the same, the number of mounds is big enough to conduct some basic comparison (Table 1).

Considering all the data, stone mound G9 has the most archaeological potential, and its volume and surface area makes it also one of the most cost-effective targets to consider for further exploration. Other interesting targets for exploration would be stone mounds G5 and G3. Stone mound G5 rises 2 m above the surrounding terrain, with a total volume of 68.84 m³ which makes it the second largest one on the plateau after G3, which has the impressive volume of 326.39 m³. By analyzing the spatial data acquired from the DTM of the area some basic conclusions were drawn. Stone mound G2 is completely isolated from the rest of the mounds, it stands at the distance of 150 m from the biggest group of stone mounds. It is also situated on the lower part of the plateau at the altitude of 170 m above sea level.

Mounds G3, G4, G5, G6, G7 and G8 compose a group of mounds situated on the northern ridge of

the plateau (Image 9). The altitude of this ridge is 191–192 m above sea level and the distance between each next stone mound is never more than 15 m. It is a compact group of mounds among which G3 stands out as the biggest. G4, G5 and G8 form a second subgroup with a similar surface area of around 120 m², while G6 and G7 are distinctly smaller in size, around 80 m². Mounds G9, G10, G11 and G11a are spread out in the northwest direction from the big group. The distance between each mound varies from 30–60 m, and the terrain starts to rise from 191 m at G9, to 205 m above sea level at the last mound G11a.

CONCLUSION

Four days of work with a total station and low cost UAV platform gave us enough data to create 11 image based 3D models of stone mounds and one digital terrain model (DTM). This data was further used to make 11 technical plans of the stone mounds, and to analyze the spatial data in this geologically enclosed and archaeologically interesting area. Although the three dimensional data gives us an unprecedented level of detail we are still restricted by the traditional documental practices which are limited to two dimensions standard in technical plan drawings. Calculations of surface area and approximate volume of each mound gives us a new set of data which can be used when taking into account the cost of the possible future excavation. This data set could also be used as a basis for a more detailed study of the mounds in the wider area. Provided that enough data is gathered this type of database could give us the opportunity to categorize different types of mounds based on their volume, surface and condition. Image based models created for this study are a faithful representation of the situation in the field, but besides their documental value they can be a source of new datasets which could be used for reinterpretation in the future. The work done provided us with a comprehensive study of the prehistoric necropolis in Mravinca, which can now be used as a base reference for further exploration of this area or the stone mounds themselves.

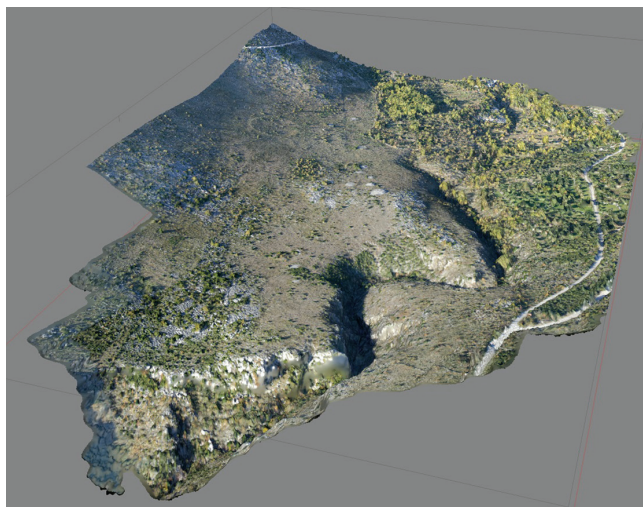


Figure 10: DTM of the whole area created in Agisoft Photoscan, view from the south, author: M. Vuković.

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