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ARCHAEOLOGICAL TOPOGRAPHY

FROM MĂGURA CĂLANULUI TO THE ORĂȘTIE MOUNTAINS: PREDICTING LIMESTONE TRANSPORTATION ROUTES WITH LEAST-COST PATH ANALYSIS

Abstract: The aim of this study was to predict using least-cost path analysis potential ancient routes between the limestone quarry from Măgura Călanului and the Dacian fortresses from Costești-Cetățuie, Costești-Blidaru, Piatra Roșie and Dealul Grădiștii. Multiple optimal routes were computed by calculating the minimum level of energy consumption theoretically necessary for travelling between the respective locations, while taking into account the slope variations. Two types of models were obtained. Some simulate walking, others simulate travelling via wheeled transport. The models that represent wheeled transport routes are less direct, but seem naturally more accessible, and more accurately replicate the ancient roads near the fortresses. The respective models may offer an explanation for the formation of those roads, and indicate by what transportation means those might have been accessible. The optimal routes generally suggest that the quarried limestone might have been transported to the fortresses probably along the natural ways of entry into the Orăștie Mountains, through the Luncani and Grădiște Valleys.

Keywords: *Orăștie Mountains, Dacian fortresses, limestone quarry, ancient roads, optimal routes, least-cost path analysis*

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INTRODUCTION

In the Orăștie Mountains, at Sarmizegetusa Regia (Dealul Grădiștii), was the political and religious center of the Dacian kingdom in the pre-Roman period. The respective region was dominated by a number of fortresses, which presumably formed together a system subordinated to a single authority.¹ This system, which gradually took shape during the existence of the Dacian kingdom, would have included in the final stage all Dacian fortresses from the area, Costești-Cetățuie, Costești-Blidaru and Piatra Roșie, and probably other distant fortresses too, such as Dealul Cetății-Bănița and Dealul Cetății-Căpâlna. This theory is supported by the various architectural elements of Hellenistic inspiration present at Sarmizegetusa and the respective fortresses.² Limestone, as construction material, was a notable component in

¹ H. Daicoviciu proposed this theory (DAICOVICIU 1978, 4–8). K. Lockyear questioned this hypothesis and proposed an alternative theory on the creation of the fortresses and the links between them (LOCKYEAR 2004, 51, 70). G. Florea contested the latter's hypothesis (FLOREA 2011, 159).

² GLODARIU 1983, 36, 92, 123–126.

both civilian and military architecture, but most extensively it was used for carrying out defensive works.

It is I. Glodariu who first attempted to calculate the limestone volume within the walls of the fortresses and their adjacent sacred constructions. Only for Costești-Cetățuie, Costești-Blidaru, Piatra Roșie, Dealul Grădiștii and Dealul Cetății-Căpâlna, in total, it is estimated that no less than 16.000 m³ of limestone would have been included in the composition of the enclosures, bastions, dwelling-towers and the retaining walls of various terraces. With the construction material from all the other types of monumental buildings, the total volume would have reached approximately 20.000 m³. These estimations refer only to the total quantity of processed material, the total quantity of extracted limestone must have been much greater.³ To all of the fortresses, the limestone was more or less certainly transported from Măgura Călanului,⁴ because local stone from the Orăștie Mountains, the mica schist, was unsuitable for use as construction material for building monumental structures.⁵

The limestone quarry from Măgura Călanului was systematically exploited in the I century B.C., the period in which architectural elements made of processed limestone first appeared at these fortresses. The quarry continued to be used in the next centuries, including in the Roman period, extensive exploitation marks being still visible in the field today. Limestone extraction fronts appeared on almost the entire surface of the hill, but the highest concentration of these are located in the eastern, middle and western parts of the hill, and most notably in the western extremity. Closely linked to past quarrying activities are the agglomerations of limestone pieces left in the field in various processing stages, mounds of limestone fragments, access roads and some terraces. It is impossible to ascertain how extensive the quarry was in the pre-Roman period. One can only assume that quarrying took place at that time where the largest and most numerous extraction fronts are visibly concentrated today.⁶

OBJECTIVES

Supplying the construction sites with the necessary limestone undoubtedly must have represented in antiquity a greater challenge than the exploitation and the processing of the respective material. Most roads were rough at that time, and difficult to use in bad weather conditions. Because the fortresses are located at variable distances from the quarry, the remoteness of the destination probably would have necessitated adapting the dimensions of the limestone pieces destined for transportation.⁷ Nevertheless, for

example some stone elements from the area of Dealul Grădiștii weigh 300–400 kg, and even more in some cases.⁸ The stone quarrying and transportation system, organised and supervised by a single authority, played an important part in the emergence of the fortress complex in the Orăștie Mountains. The resulting constructions, mostly built in times of peace, had more than defensive functionality. The fortresses were simultaneously a manifestation of the local elites' ideology, being symbols of power and prestige in antiquity. Related to this phenomenon is the opening of the quarry and the organisation of the logistical system.⁹

At Măgura Călanului some old road tracks are visible today, but it is impossible to ascertain their date of origin. In the Orăștie Mountains, some road segments from the proximity of the Dacian fortresses most likely date from antiquity. One must ask how suitable these roads were in reality for limestone transportation, whether their use truly was for this purpose. The general question is what routes the conveyors took in order to deliver limestone to the Orăștie Mountains. The distance between the quarry and the fortresses is relatively long, and the routes used in antiquity are completely unknown to us. The aim of this study is to predict using least-cost path analysis potential ancient routes between Măgura Călanului and the Dacian fortresses from Costești-Cetățuie, Costești-Blidaru, Piatra Roșie and Dealul Grădiștii.

METHODOLOGY

Using least-cost path analysis¹⁰ it is possible to obtain a digital cartographic model by calculating the optimal route between two pairs of spatial coordinates, one representing the origin, the other the destination. In order to achieve this, it is essential to start from spatial data that expresses and quantifies a range of terrain factors (slope, water, vegetation, etc.) that can potentially influence the speed or energy consumption of travelers while traversing the landscape for a particular reason. By cumulating all available data, the optimal route is determined based on the idea that minimising time or energy expenditure is the most efficient way to reach a destination. The cost of movement, measured in time or energy spent, is calculated with an isotropic or anisotropic cost function that models a particular type of movement (by walking or by travelling via wheeled transport) under simulated conditions. Anisotropic cost functions are dependent on the direction of movement when traversing a slope, so an optimal route recalculated in reverse direction may sometimes differ for this reason.¹¹ However, all cost functions model imperfectly and simplistically the true relationship between slope and the cost associated with its traversal. That is why the cost functions, together

³ I. Glodariu based his estimations on the assumption that the fortress walls were 5 m tall, and the wall-faces 0.4 m thick. For the whole discussion on this topic see GLODARIU 1985–86, 92, 102.

⁴ For the origin of the processed limestone see GLODARIU 1985–86, 100; MĂRZA 1995, 199–202 and MATEESCU *et alii* 2021, 38–40.

⁵ GLODARIU *et alii* 1996, 11.

⁶ For an overall presentation of the quarry see MATEESCU *et alii* 2021, 38–45, 48 and PEȚAN 2022, 120–133.

⁷ It was noted that at Costești-Cetățuie the limestone blocks are generally bigger than anywhere else in the Orăștie Mountains. At Costești-Blidaru, Piatra Roșie, Dealul Grădiștii and Dealul Cetății-Căpâlna the blocks are inversely proportional in size with the distance between these fortresses

and Măgura Călanului (GLODARIU 1985–86, 95, 101).

⁸ MATEESCU *et alii* 2021, 45.

⁹ PUPEZĂ 2012, 82–84.

¹⁰ For a general overview on least-cost path analysis in archaeology see CHAPMAN 2006, 107–111; CONOLLY/LAKE 2006, 214–224, 252–256; ANDERSON 2012, 239–252; HERZOG 2013a, 179–211.

¹¹ For a general description of the main cost functions available for least-cost path analysis, and the various ways in which they calculate optimal routes, see HERZOG 2013b, 375–382.

with the resulting models, represent hypotheses first and foremost. If the models closely follow old road tracks for example, then the cost function used in the analysis, and the hypothesis it implicitly represents, can probably explain how the road was formed. Because old roads are rarely ever fully preserved, the models may also provide suggestions by potentially reconstructing the road segments that are no longer traceable.¹²

Concerning past human movement in the Orăștie Mountains, there are two case-studies which already dealt with least-cost path analysis. The first one examines the link between Roman marching camps from the area and the Dacian fortresses that would have represented strategic objectives during the wars of conquest. With their least-cost path models, the authors suggest potential routes the Roman army might have taken, assuming that visibility and topography were the key factors influencing the movement patterns. I. Oltean and J. Fonte hypothesize that the Romans avoided the mountain valleys, the seemingly most accessible ways of entry, preferring to advance instead on the ridges.¹³ The routes suggested by the authors generally do follow the mountain ridges, which presumably have been used by travelers throughout the ages,¹⁴ but limestone in antiquity may have been transported along different ways.

The second case-study focuses on trade relations. Its author, C. Dima, relies on least-cost path analysis in order to obtain models suggesting potential trade routes between the Dacian fortresses or settlements from the Orăștie Mountains, but also between the Măgura Călanului quarry and Costești-Cetățuie.¹⁵ The optimal route between the quarry and the respective fortress is rather direct, in some places featuring uphill or downhill movement across gradients over 10° (17.6%), according to the digital elevation model used by the author. Regarding limestone transportation to Dealul Grădiștii, the author presumes that the construction material would have reached the foothill of the Costești fortresses ‘one way or another’, from where it would have moved uphill, and continued on the mountain ridges towards the destination. Although some of the optimal routes computed between the fortresses go on ridges, the models sometimes feature uphill movement across gradients over 20–25° (36.4–46.6%), according to the digital elevation model from the case-study. The author validated some of the optimal routes by taking measurements with a non-differential Global Positioning System, and suggested that it may have been possible to travel on the mountain ridges

in antiquity with heavy loads.¹⁶ The ancient travellers likely would have used the ridgeways, but probably for other reasons. Climbing uphill to the ridges must have been quite a challenge with heavy loads such as limestone, even under good weather conditions, so the potential existence of easier alternative routes should be further explored.

At least one important terrain factor would have influenced the decision making of the conveyors when choosing the most suitable route for transporting the limestone, namely the slope variation. Other factors may have just as likely influenced the decision making process, such as forest land cover and density, but it cannot be ascertained to what extent. The paleoenvironment of the Orăștie Mountains cannot be reconstructed in detail at the moment due to lack of information. At least in some situations, besides the environmentally deterministic factors, the human factor may have also played a role. By clearing the forest, or by turning naturally steep slopes into gentler gradients,¹⁷ in certain places it would have been possible to prepare the routes in advance. However, this may have not been practical or desirable in some cases, for reasons inconceivable to us. The human factor is usually difficult to grasp and quantify, so route predictions mostly have to rely on environmental factors for exploring past human movement.

In the present study, the optimal routes were obtained starting from slope variations. Spatial data that expresses and quantifies this particular terrain factor was extracted from the ~30 m resolution digital elevation model derived from the Shuttle Radar Topography Mission, a dataset that can be accessed through the U.S. Geological Survey portal.¹⁸ The respective data can be alternatively extracted from the 1 m resolution Land Administration Knowledge Improvement II digital elevation model, a dataset obtained with Light Detection and Ranging technology that can be accessed through the ANCP (Cadastru and Land Registration Office) portal.¹⁹ Both digital elevation models reflect the current landscape of the Orăștie Mountains, but the lower resolution dataset is more appropriate for least-cost path analysis. Although the generalization of the landscape is more evident in this digital elevation model, many modern man-made features (tarmac roads, bridges, hydroelectric stations, etc.), that can counterintuitively influence the least-cost path calculations, are smoothed out in this dataset.²⁰ The optimal routes were determined by cumulating all available data, the main consideration in this case being the minimization of energy consumption. In the context of limestone transportation, in order to effectively reach the destination, likely more important it would have been to minimize energy consumption

¹² LEWIS 2024, 855–857.

¹³ The modeling is based on spatial data extracted from two digital elevation models. The data was partly extracted from a 0.5 m resolution digital elevation model obtained with Light Detection and Ranging technology. The remaining data was extracted from the ~30 m resolution digital elevation model derived from the Shuttle Radar Topography Mission. The cost of movement, measured in levels of energy spent, was calculated with Llobera & Sluckin’s anisotropic cost function, which simulates pedestrian movement (OLTEAN/FONTE 2021, 4–9).

¹⁴ DAICOVICIU/GLODARIU/FERENCZI 1989, 18–19, 86–119.

¹⁵ The modeling is based in this case on spatial data extracted from the ~25 m resolution Digital Elevation Model Over Europe. The cost of movement, measured in levels of energy spent, was calculated with Tobler’s anisotropic cost function available in the ArcGIS software, which simulates pedestrian movement (DIMA 2021, 195–205).

¹⁶ DIMA 2021, 209–213, 222.

¹⁷ At Piatra Roșie (DAICOVICIU/FERENCZI 1951, 59) and Dealul Pustăiosu (DAICOVICIU *et alii* 1957, 269) it was noted that certain segments of the access road had been manually excavated in the bedrock, most likely in antiquity.

¹⁸ USGS 2025.

¹⁹ ANCP 2025.

²⁰ Many archaeological studies dealing with least-cost path analysis reported this technical problem, so the extraction of spatial data from a lower resolution digital elevation model is recommended for this reason (HERZOG 2021, 133–134).

rather than time. The cost of movement was separately calculated with three different anisotropic cost functions, in all cases relying on a four-cell neighbourhood search pattern. The three tested cost functions were Tobler's, Llobera & Sluckin's and Wheeled Transport, all of them being available in the Leastcostpath²¹ module of the R²² software. The first two cost functions, which also have been used in the previous two case-studies, model movement in pedestrian form under simulated conditions. The models resulting from these functions may for example reflect hypothetical situations in which the construction material

was transported with pack animals, which could move in difficult terrain more easily than their walkers, so the humans would have adjusted the path according to their own needs.²³ However, given their limited carrying capacity, pack animals (donkeys or mules) probably fulfilled auxiliary rather than primary roles in the logistical system, limestone being transported more likely with wheeled vehicles pulled by draft animals (oxen most likely). The third anisotropic cost function reflects this hypothetical situation, because it models movement using a wheeled vehicle, which must normally transition to switchbacks in order to effectively

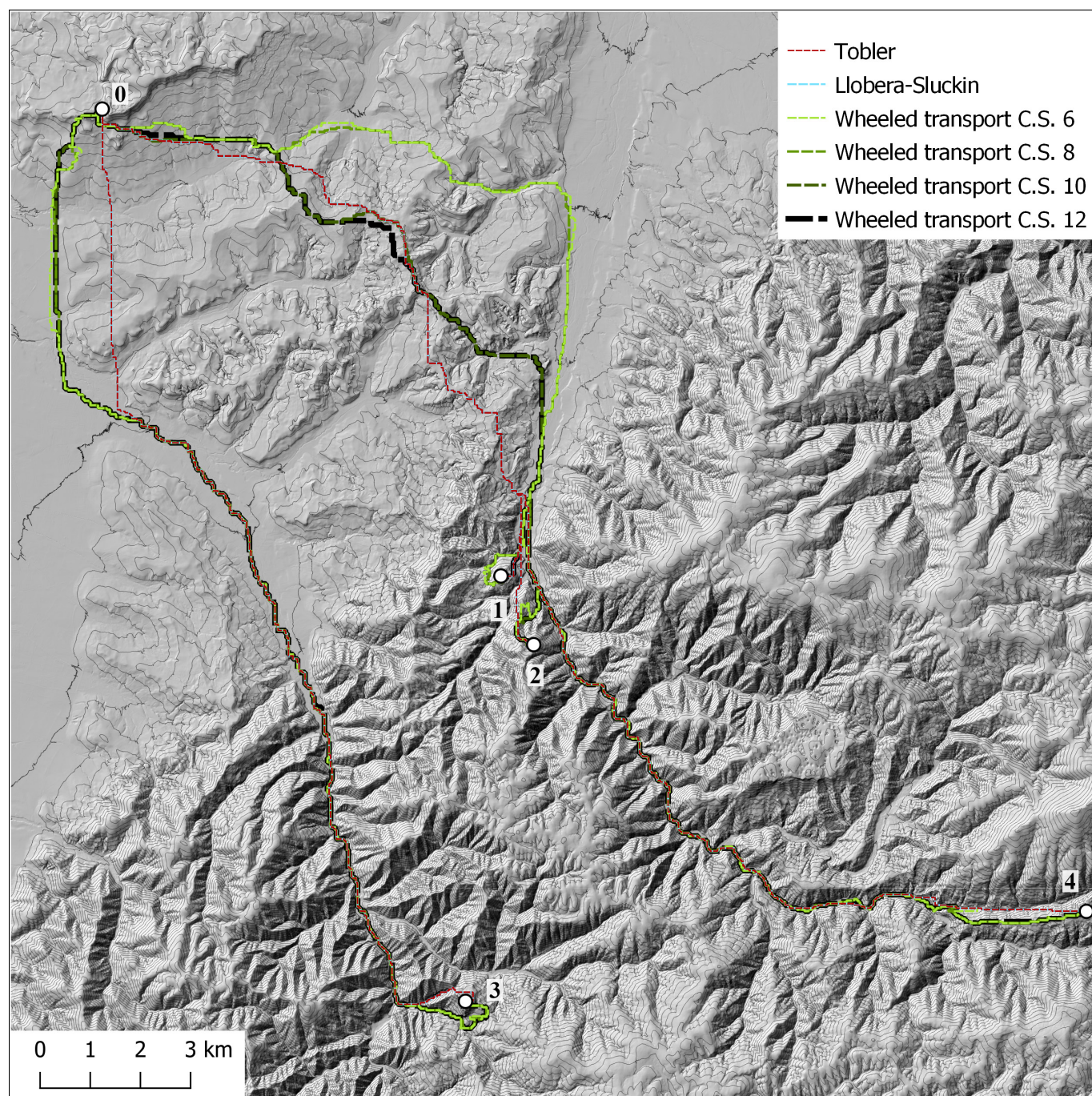


Fig. 1. Optimal routes obtained between Măgura Călanului (0 – The first origin point) and the Dacian fortresses (1 – Costești-Cețățuie; 2 – Costești-Blidaru; 3 – Piatra Roșie; 4 – Dealul Grădiștii) with various cost functions.

²¹ LCP 2025.

²² R 2025.

²³ HERZOG 2013a, 183–184.

ascend or descend steep gradients, the transition threshold being defined in this case by a critical slope parameter. The optimal routes were computed separately with all three cost functions in order to compare between them the resulting models. Particularly relevant are the models that were able to replicate most accurately the ancient roads near the Dacian fortresses. These models can probably suggest most accurately what routes the conveyors might have taken in order to transport limestone from the quarry all the way to the Orăștie Mountains. These may also provide theoretical explanations for the formation of those roads, and indicate by what transportation means those might have been accessible.

RESULTS

Because the limestone quarry is rather extensive, with extraction fronts scattered across a large surface, six locations were chosen for the least-cost path analysis, each representing a potential origin point, the destination being in each case the Dacian fortresses. The models suggest that the easiest way of transporting limestone to Piatra Roșie might have been through the Lunca Valley. For transporting limestone to the Costești-Cetățuie, Costești-Blidaru and Dealul Grădiștii fortresses, the suggested optimal routes mostly run through the Grădiște Valley. More challenging to establish is the particular area where the descent from Măgura Călanului into these two valleys would have occurred, because the

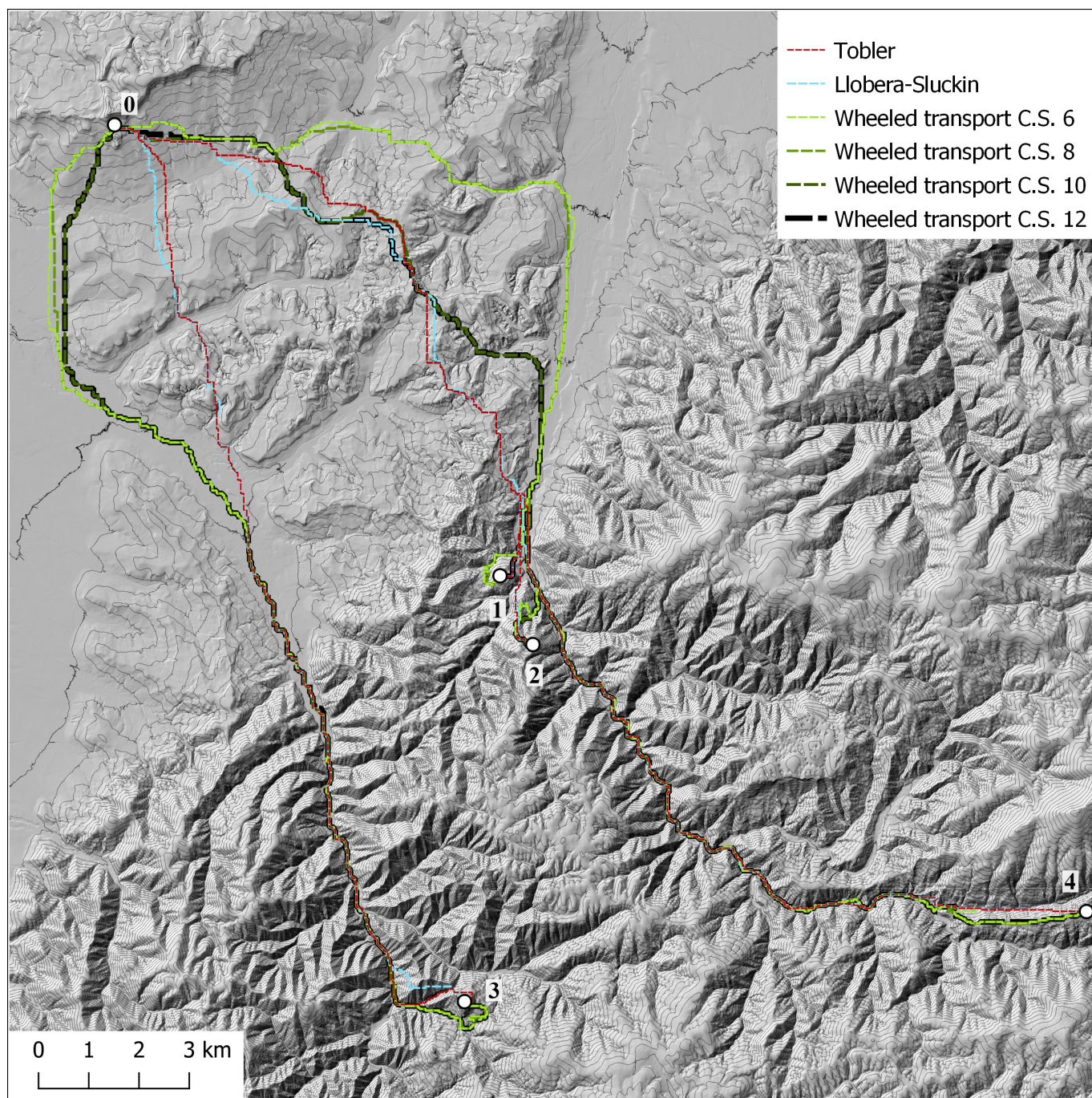


Fig. 2. Optimal routes obtained between Măgura Călanului (0 – The second origin point) and the Dacian fortresses (1 – Costești-Cetățuie; 2 – Costești-Blidaru; 3 – Piatra Roșie; 4 – Dealul Grădiștii) with various cost functions.

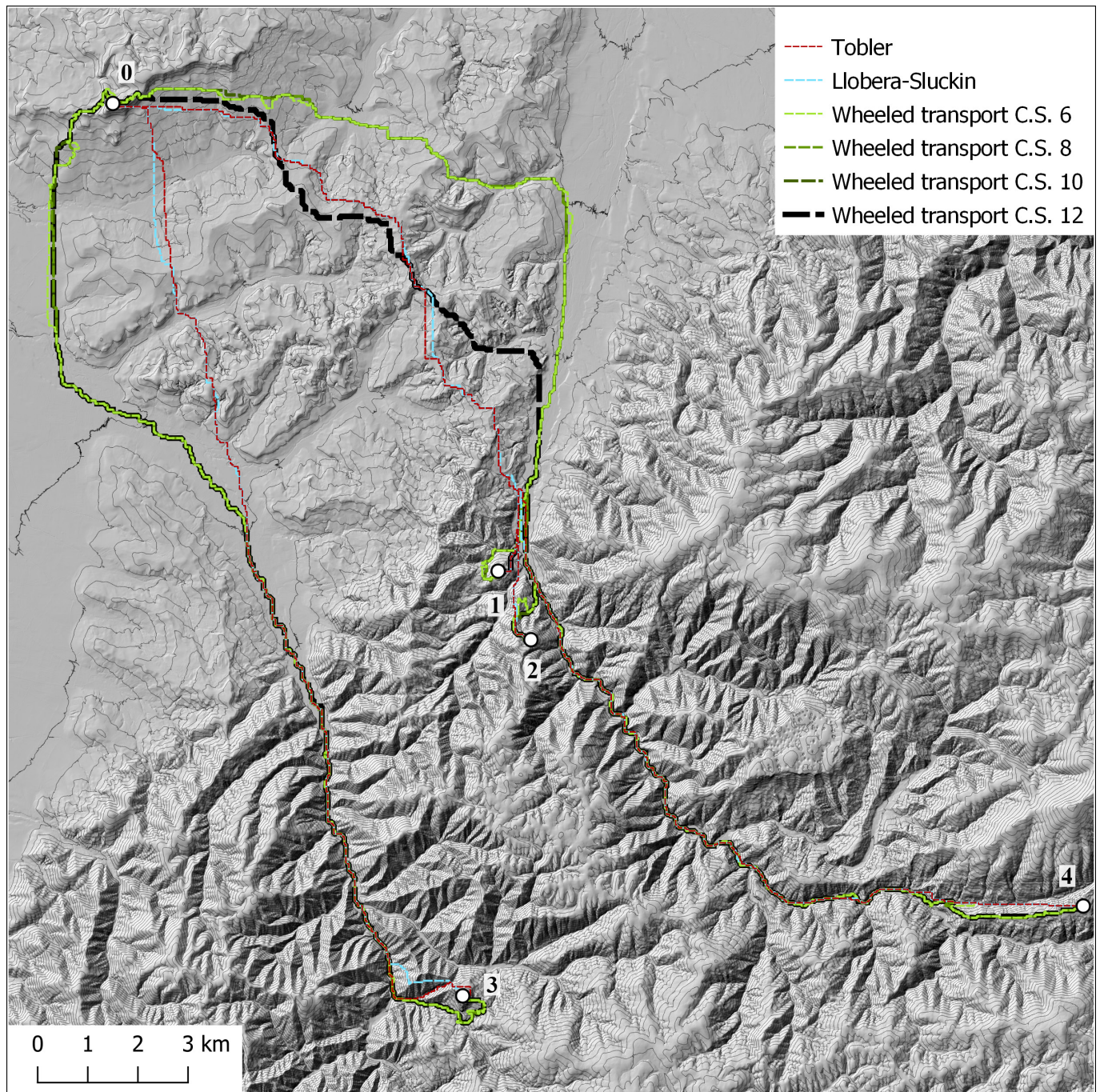


Fig. 3. Optimal routes obtained between Măgura Călanului (0 – The third origin point) and the Dacian fortresses (1 – Costești-Cetățuie; 2 – Costești-Blidaru; 3 – Piatra Roșie; 4 – Dealul Grădiștii) with various cost functions.

models suggest multiple possibilities (Fig. 1–6). The ascent from these valleys to the fortress hilltops also differs in the case of some models (Fig. 7).

When the cost of movement was calculated with Tobler's or Llobera & Sluckin's cost functions the results were generally similar. Regarding limestone transportation to Costești-Cetățuie or Dealul Grădiștii especially, the optimal routes computed with Tobler's cost function differ from the models obtained by Dima with the very same function²⁴. The routes from the present study are better adapted to the terrain, because they mostly follow either ridgeways or valleys, more frequently avoiding consecutive uphill and downhill

movements. This may be related to the digital elevation model and the software used in this study for performing the analysis, which differ from the ones used by Dima, but it may be due to differing preconceptions too. Dima obtained his models starting from the hypothesis that not only slope variation would have influenced the decision making of the conveyors when choosing the most suitable route for transporting limestone, but also watercourses. I believe that mainly slope variation would have been the deciding terrain factor, because preliminary human action could have mitigated the cost of movement for crossing rivers or creeks by building bridges. Given how costly it must have been to transport large quantities of limestone over long distances, setting up an adequate logistical infrastructure in advance

²⁴ DIMA 2021, 210–211 (see Fig. 36), 217–222 (see Fig. 49 and 50).

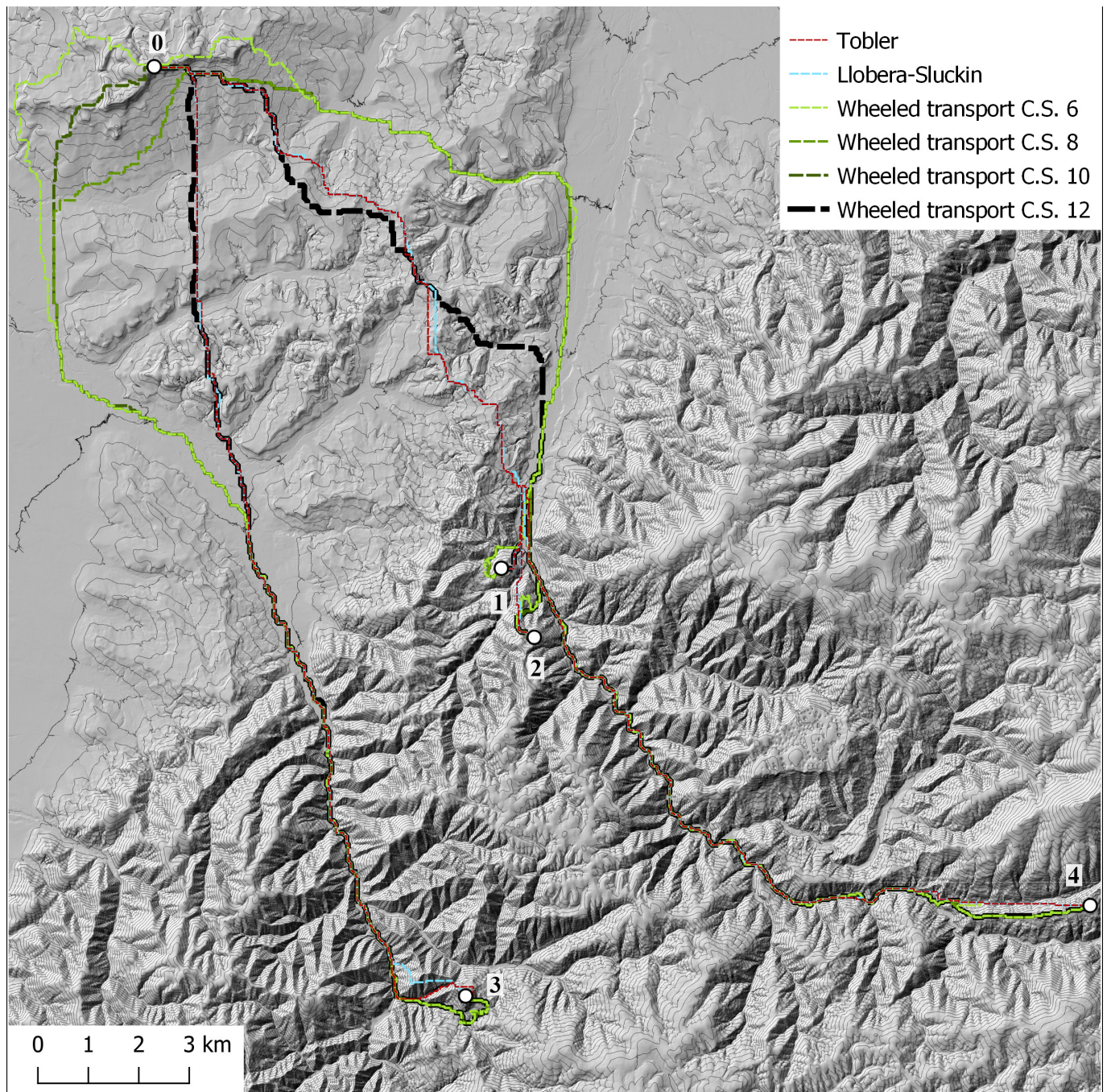


Fig. 4. Optimal routes obtained between Măgura Călanului (0 – The fourth origin point) and the Dacian fortresses (1 – Costești-Cetățuie; 2 – Costești-Blidaru; 3 – Piatra Roșie; 4 – Dealul Grădiștii) with various cost functions.

must have been worthwhile. Moreover, watercourses in the Orăștie Mountains are relatively modest. The Grădiște River appears on old maps from the XVIII century²⁵ as having multiple crossing points. The Austrian topographic survey map from the XIX century represents the Grădiște Valley as being entirely accessible.²⁶ At the foothill of Costești-Blidaru fortress, road tracks of presumably ancient origin²⁷ are distinguishable in a particular place on the left bank of the Grădiște Valley, indicating that the valley was accessible to travelers in antiquity, at least partially if not entirely.

²⁵ FTS 2025.

²⁶ STS 2025.

²⁷ DAICOVICIU/FERENCZI 1951, 27; DAICOVICIU/GLODARIU/FERENCZI 1989, 89–90.

Because valleys are the most obvious ways of entry into mountain areas, watercourses likely would not have been major obstacles forcing limestone conveyors to necessarily travel on the ridges. On the contrary, the main consideration of the conveyors must have been the avoidance of uphill movement as much as possible. As a result, routes were obtained in this study which do not avoid mountain valleys deliberately, strictly starting from slope variations as an influential terrain factor for determining optimal movement. Moreover, the respective models were generally able to replicate the ancient roads near the fortresses. The models that most successfully achieved this were the ones computed with the Wheeled Transport cost function.

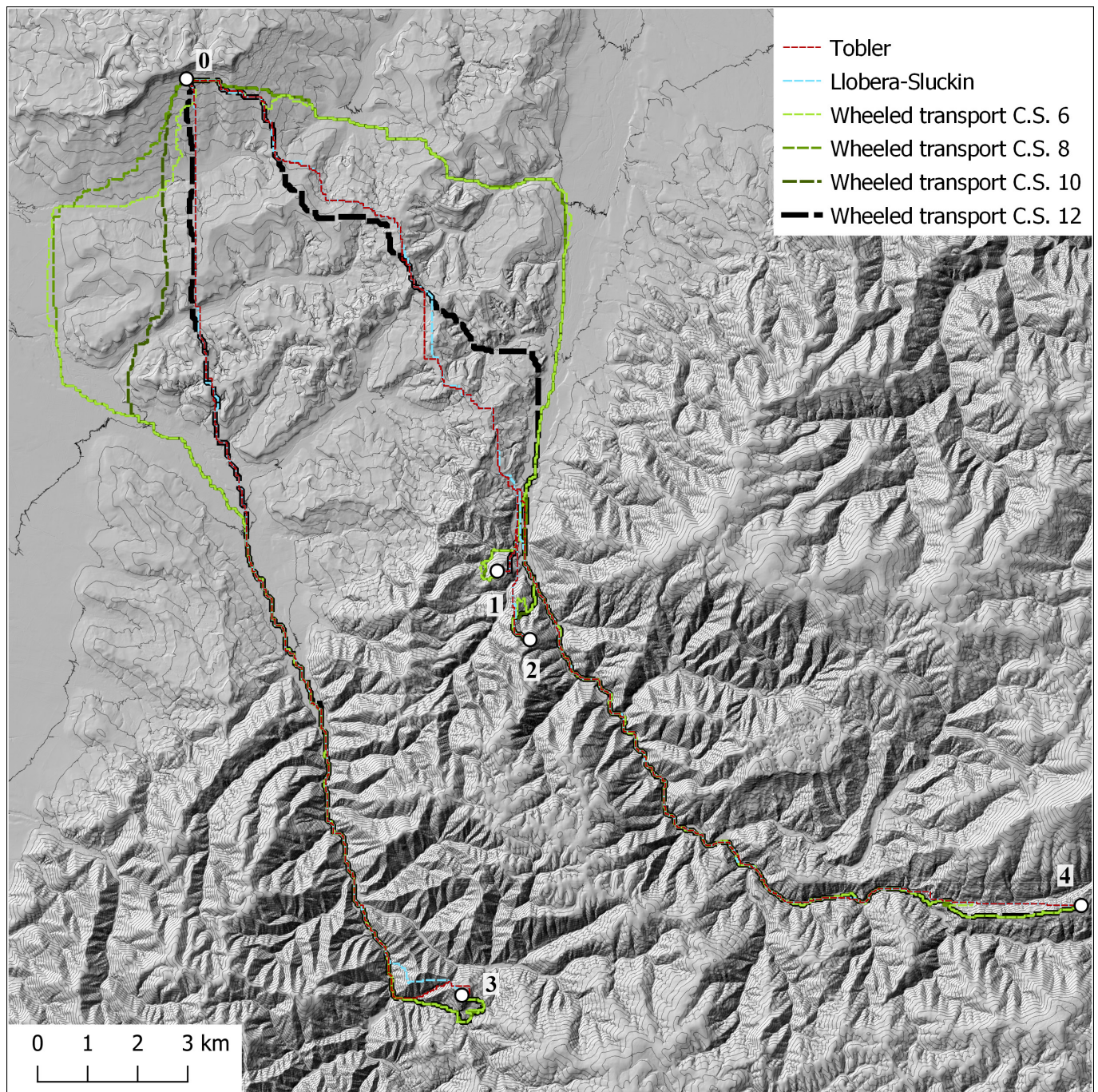


Fig. 5. Optimal routes obtained between Măgura Călanului (0 – The fifth origin point) and the Dacian fortresses (1 – Costești-Cetățuie; 2 – Costești-Blidaru; 3 – Piatra Roșie; 4 – Dealul Grădiștii) with various cost functions.

With the Wheeled Transport cost function, the cost of movement was calculated by considering for the critical slope, which more exactly is the least slope requiring switchbacks for effectively ascending or descending a gradient, a value of 6, 8, 10 or 12%. The models obtained with this cost function generally differ from the ones obtained with Tobler's or Llobera & Sluckin's. These optimal routes are less direct, but seem naturally more accessible, and easier to take. These characteristics are more evident at the 6 or 8% critical slope models, and less so at the 10 or 12% critical slope ones. The models obtained with a value of 6 or 8% for the critical slope parameter can generally replicate the ancient roads near the fortresses. The ancient road from Costești-Cetățuie is

an exception though, and only the models obtained with a value of 10 or 12% for the critical slope parameter were able to somewhat replicate it.

The Costești-Cetățuie road starts off at the left bank of the Grădiște River, and it forks after approximately 300 m. One branch road goes around the fortress from north and west, before ascending to the fortress towards north-east, this being the modern access road actually. From the above-mentioned fork, the other branch road continues towards south and south-west, and reaches the fortress on the southern side, where the respective road goes through a ditch that resulted from the construction of an earth rampart. For this reason, it is believed that this road was

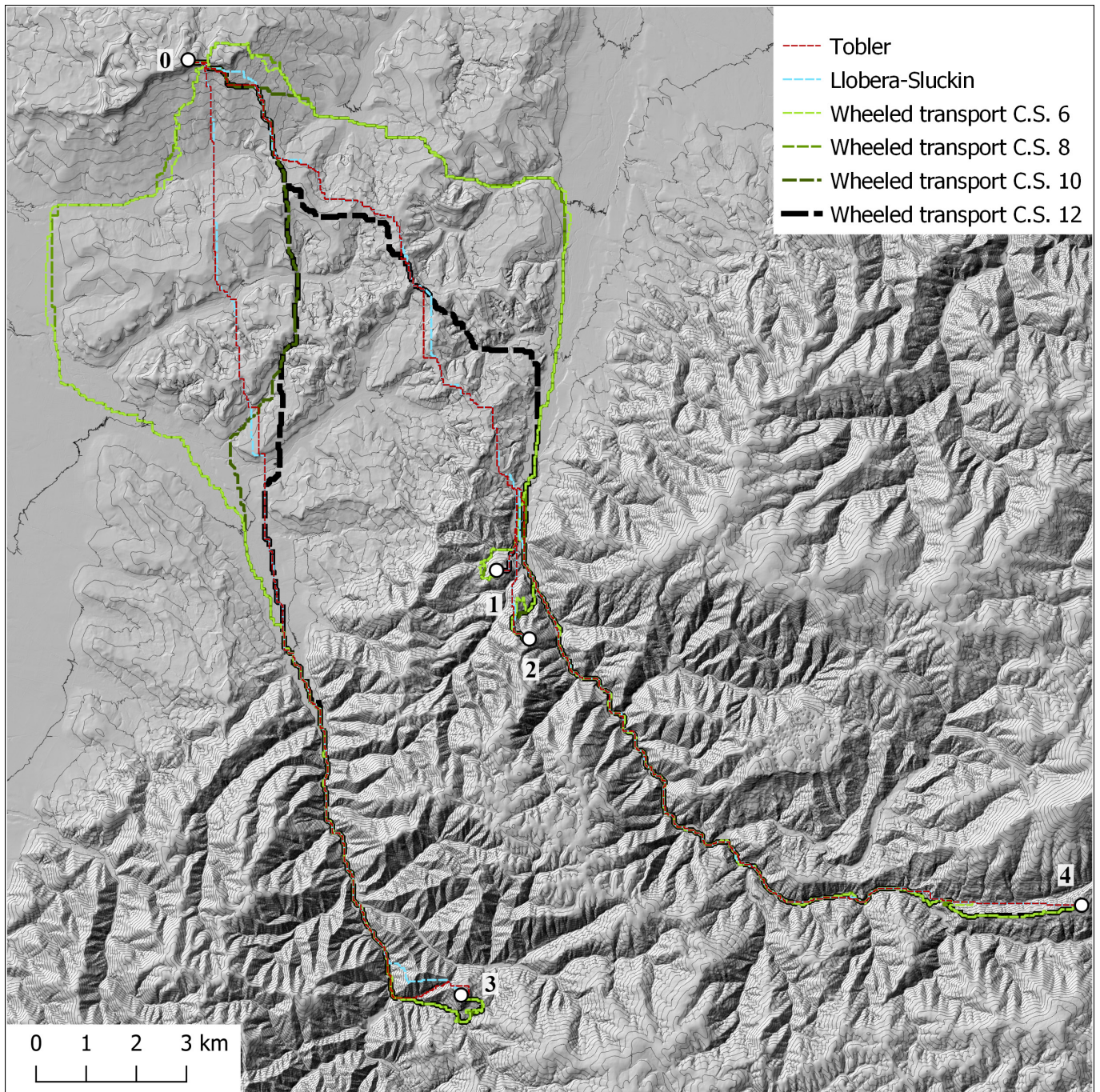


Fig. 6. Optimal routes obtained between Măgura Călanului (0 – The sixth origin point) and the Dacian fortresses (1 – Costești-Cetățuie; 2 – Costești-Blidaru; 3 – Piatra Roșie; 4 – Dealul Grădiștii) with various cost functions.

used in ancient times.²⁸ The road from Costești-Cetățuie (Fig. 8) ascends rather sharply to where the fork is (segment A – 11.6%), then it gets more difficult to take (segment B – approx. 21%). In the latter part, it continues towards the fortress on gentler gradients (segment C – 7.5%), traversing a large terrace (segment D – approx. 11%), and then goes almost even (segment E – approx. 1%).

At Costești-Blidaru, from north starts off the current access path to the fortress, near the confluence of the Grădiște River and the Faeragul Creek, and it ascends to the destination by traversing the eastern slopes of the Faeragul

Hill, beneath the plateau with the same name. Another track, of presumably ancient origin, starts off near the confluence of the Grădiște River and the Chișetoara Creek, ascends the slopes of the Chișetoara Valley, and joins the above-mentioned access path.²⁹ By comparing the two tracks from Costești-Blidaru (Fig. 9), it can be said that the first one, the current access path, has alternating gradients (ranging from 2.5% – segment A4 to 30.5% – segment A2), and it is slightly steeper overall. The second track, the presumably ancient road, is slightly shorter, has a rather constant gradient, and is more accessible on the most difficult portion (segment B3

²⁸ DAICOVICIU/FERENCZI 1951, 9; GLODARIU *et alii* 1996, 52.

²⁹ DAICOVICIU/FERENCZI 1951, 21; DAICOVICIU/GLODARIU/FERENCZI 1989, 184–185.

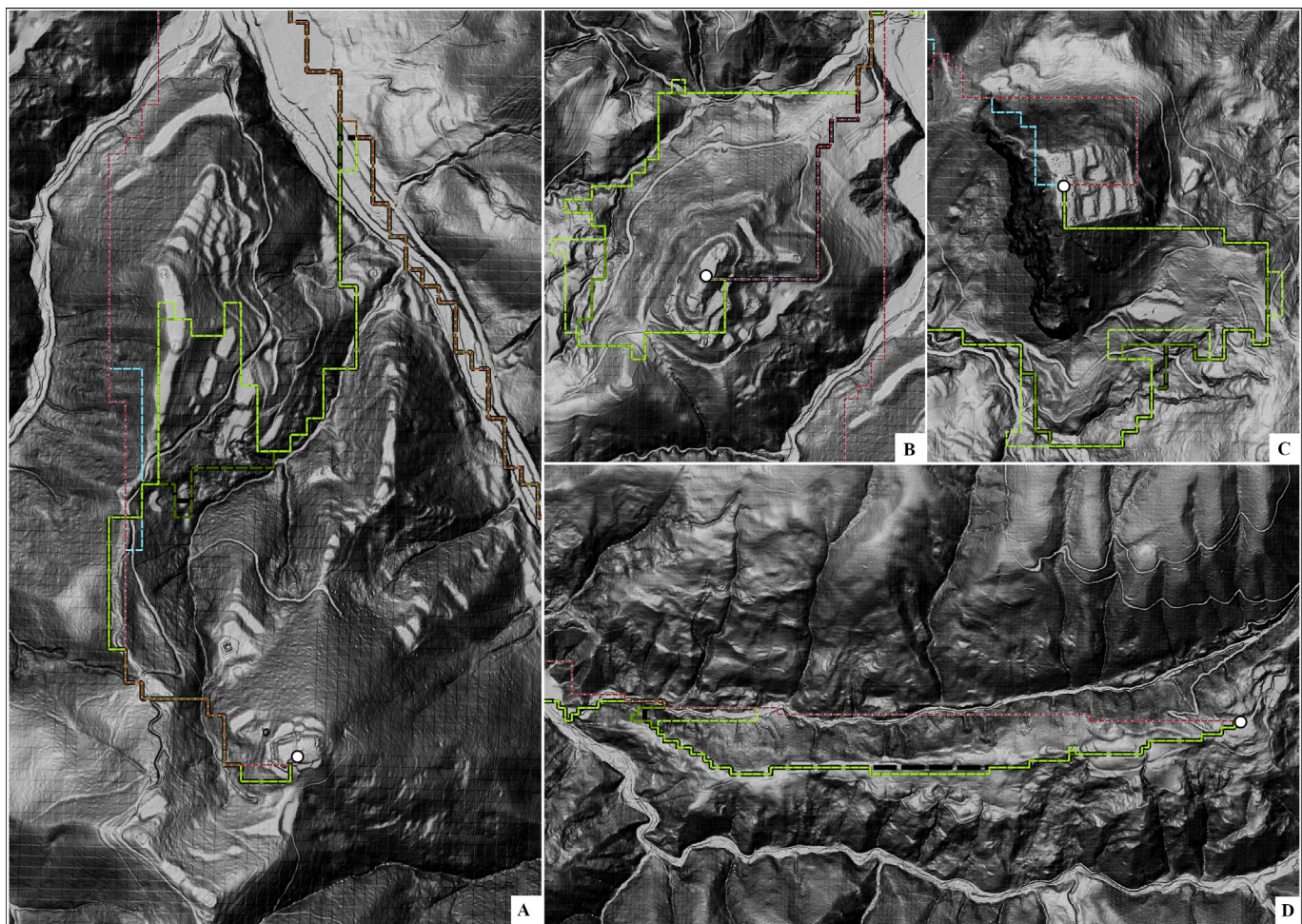


Fig. 7. Optimal routes ascending to the Dacian fortresses (A – Costești-Blidaru; B – Costești-Cetățuie; C – Piatra Roșie; D – Dealul Grădiștii).

– 27%). From where the two tracks merge as one, almost all the way to the fortress, the road has alternating gradients once again (ranging from 10.5% – segment C to 27% – segment G), but it gets almost even towards the destination (segment I – approx. 1%).

At Piatra Roșie, because the fortress stands on a very steep hill, the only way to reach the destination is by climbing the most accessible side, the eastern slopes. The current access path follows very closely the ancient road. In old times, the track led to the outer enclosure of the fortress in simple form, from where it continued to the inner enclosure’s gateway as a road paved with limestone slabs. On the preserved portions, the ancient road measured 3 m in width, and consisted of platforms that alternated with short sections of stairs.³⁰ The road to Piatra Roșie (Fig. 10) ascends rather sharply at first (segment A – approx. 10.5%), and it gets more difficult to take in the latter part (segment B – 27.7%). However, the ascent is constant, not only outside the outer enclosure, but also inside the fortress.

Dealul Grădiștii can be reached today by travelling through Valea Albă, starting from the confluence where the waters of this valley meet the Godeanul River, and form together the Grădiște River. Probably the Valea Albă was inaccessible in antiquity, as it is a narrow and steep valley, and old maps

from the XVIII–XIX centuries³¹ indicate no road running through it. In the 50s, travelling through the valley was still being mentioned as difficult,³² until the modern access road was created. In antiquity, the road started off probably from the above-mentioned confluence, at the western extremity of Grădiște Hill. In the interwar period, two road tracks were mentioned in that area, which went up on either side of the steep ridge, ascended with switchbacks, and merged as one.³³ In the early 50s, a single road was mentioned in that area.³⁴ Heading east towards the fortress, the road traverses the southern slopes of the hill, mostly right beneath the ridgeline, first passing through a strait called *La Porți*, then bypassing a reservoir named *Tău*.³⁵ At the western gate of the fortress, both outside and inside the enclosure, the ancient road was paved with local stone, and measured approximately 3 m in width.³⁶ The respective road traversed the fortress, heading to the sacred area, and the portion towards that area was paved with limestone slabs, and it was 4–5 m wide.³⁷ The road leading to the fortress has alternating gradients (Fig. 11).

³¹ FTS 2025; STS 2025.

³² DAICOVICIU *et alii* 1951, 97.

³³ TEODORESCU 1932, 49.

³⁴ DAICOVICIU *et alii* 1951, 97.

³⁵ TEODORESCU 1932, 49; DAICOVICIU *et alii* 1954, 151; DAICOVICIU *et alii* 1955, 195–196, 201; DAICOVICIU *et alii* 1957, 256; DAICOVICIU *et alii* 1959, 397.

³⁶ DAICOVICIU *et alii* 1951, 121; DAICOVICIU *et alii* 1953, 173–176.

³⁷ DAICOVICIU *et alii* 1951, 104–105, 108; GLODARIU *et alii* 1996, 86.

³⁰ DAICOVICIU/FERENCZI 1951, 54, 59; GLODARIU 1983, 35, 101–102.

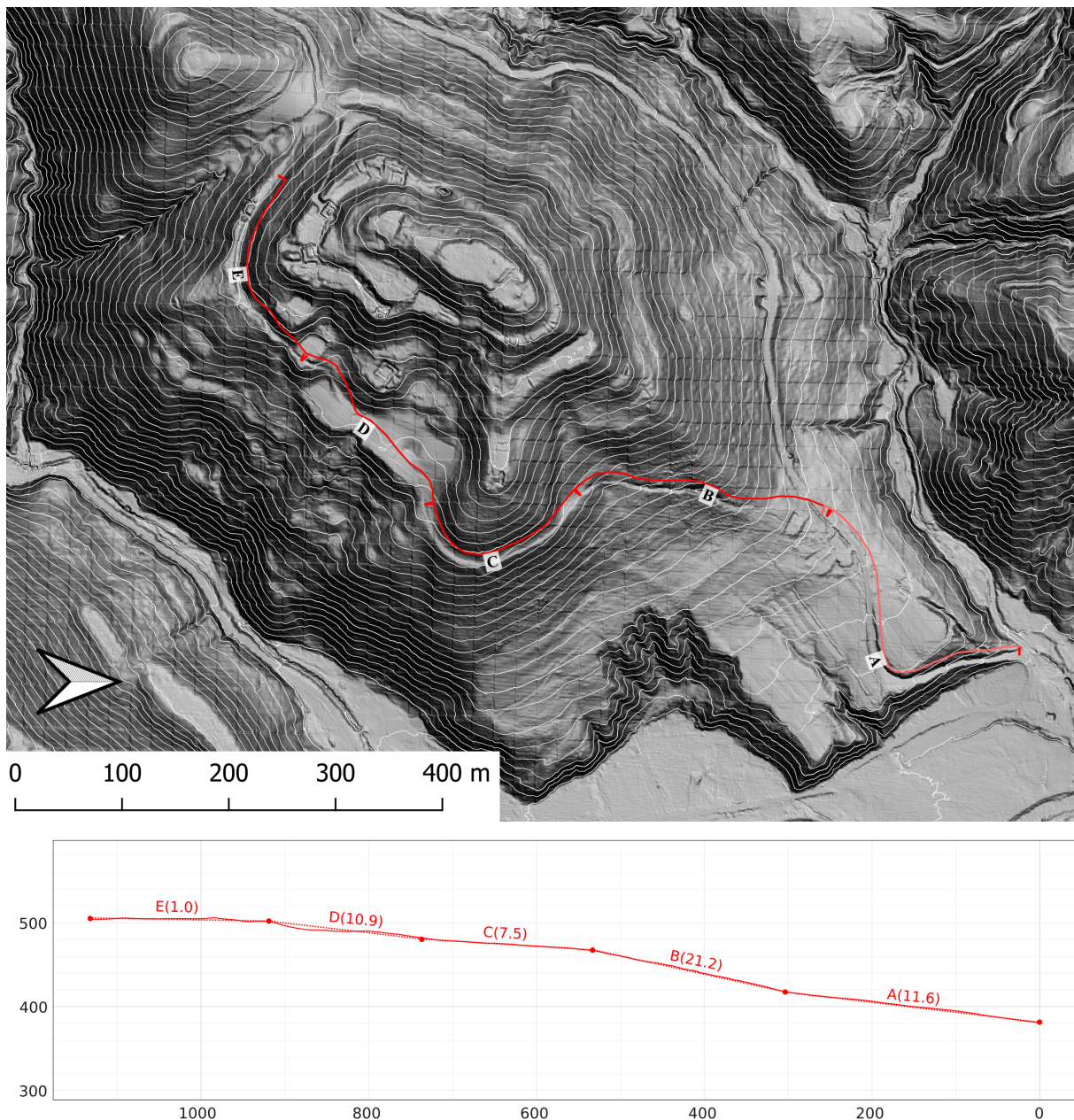


Fig. 8. The road near Costești-Cetățuie fortress (gradients in the road profile section are expressed in percent and distances or elevation in meters).

At the western extremity of the hill, the track ascending head-on is rather steep (segment A1 – approx. 29%), but it gets more accessible (segments A2 and A3 – approx. 9 and 15% respectively) as the slope falls. The other track has more constant gradient, and is more accessible on the most difficult portion (segment B1 – approx. 22%), but this road in its current form could be modern, as it could be linked to logging activities undertaken in the area in past decades. From where the two tracks merge as one, the road continues with alternating gradients, as it ascends rather steep slopes on some portions (segments C, E, H – 10, 11 and 12.4% respectively), then gentler slopes (segments D, F, G, I – approx. 1, 3 and 7% respectively). However, the ancient road is now discontinued in certain places (between segments E–F, F–G and H–I) due to landslides and erosion.

The optimal routes obtained with the Wheeled Transport cost function, by considering for the critical slope a value of 6, 8, 10 or 12%, generally traverse areas that are naturally most accessible. Because ancient roads were formed largely based on the same principle, there is a fair level of similarity between the theoretical models and the actual roads. The optimal routes transition to switchbacks in order to effectively ascend or descend steep gradients (higher than 12% for example), so they avoid going up or down on excessively steep slopes head-on. The ancient roads also feature hairpin turns in some difficult areas, but their gradient seems quite steep on some portions (up to almost 30%). The discrepancy exists because the optimal route calculations were based on slope variations derived from a ~30 m resolution digital elevation model, which portrays the landscape rather simplistically. The gradient

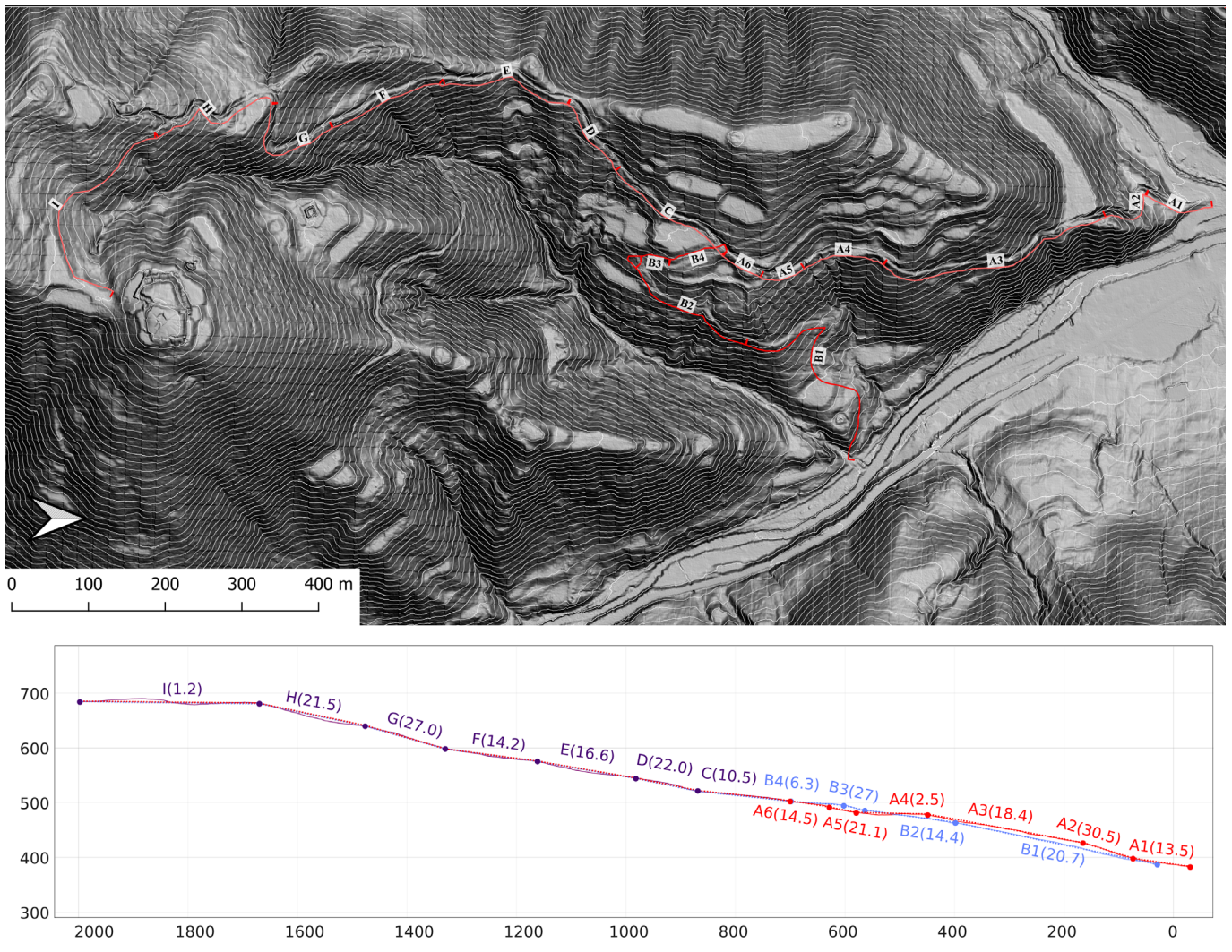


Fig. 9. The roads near Costești-Blidaru fortress (gradients in the road profile section are expressed in percent and distances or elevation in meters).

of the ancient roads comes closer to reality, because it is derived from the 1 m resolution Land Administration Knowledge Improvement II digital elevation model. For technical reasons, the wheeled transport models replicate imperfectly the ancient roads, but more accurately do so than the models deriving from the other two cost functions. If the wheeled transport models mirror the ancient roads, one must ask whether those roads truly would have been accessible by such transportation means. Artefacts from Dacian environment representing cart or wagon parts have been discovered in the Orăștie Mountains.³⁸ At Costești-Blidaru, on the ancient road near *Poiana Popii*, wheel track marks are still visible on the surface-level mica schist bedrock.³⁹ In the respective area, the gradient of the ancient road varies between 14–27% (see Fig. 9 – segments F, G, H), which seems rather steep. In the Roman world for example, roads rarely took slopes over 8%, and over 15% in exceptional cases only.⁴⁰ The resolution of the digital elevation model used for deriving

the gradient of the ancient roads near the fortresses (as it is today), as well as the landscape changes that occurred over time, undoubtedly influence these measurements and the resulting perception. At the same time, the probability of transporting the limestone in antiquity by wheeled vehicle only on the gentler portions of the road should not be ruled out.⁴¹ In places like *Piatra Roșie*, where the ancient road consisted of alternating platforms and stairs, the existent infrastructure would have necessitated adapting the transportation techniques.

CONCLUSION

The limestone quarried from Măgura Călanului was transported to the fortresses probably along the natural ways of entry into the Orăștie Mountains, through the Luncani and Grădiște Valleys. Two types of models were obtained with least-cost path analysis, and both generally suggest this. The first type of model simulates walking,

³⁸ For ancient cart or wagon metallic pieces originating from the Orăștie Mountains see DIMA 2021, 64–67.

³⁹ PESCARU *et alii* 2014, 6 (see Fig. 5).

⁴⁰ VERHAGEN/JENESON 2012, 125.

⁴¹ C. Daicovicu suggested the possibility that the Dacians may have transported the stone blocks along roads only up to a certain point, from where they would have lifted them to the upper terraces of the settlements using pulleys. (DAICOVICIU *et alii* 1951, 97).

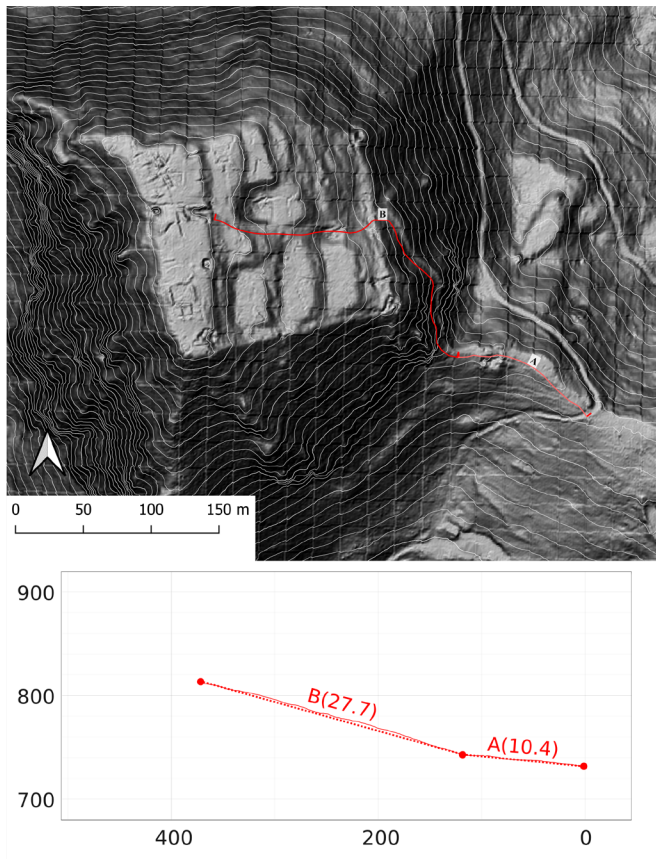


Fig. 10. The road near Piatra Roșie fortress (gradients in the road profile section are expressed in percent and distances or elevation in meters).

based on the hypothesis that pack animals transported the construction material, and could move in difficult terrain more easily than their walkers, so the humans would have adjusted the path according to their own needs. The second type simulates travelling via wheeled vehicle, based on the hypothesis that limestone was transported this way by directly avoiding excessively steep slopes, instead preferring to use switchbacks when having to ascend or descend such gradients. The models were obtained strictly starting from slope variations as an influential terrain factor for determining optimal movement in the landscape. The models that represent wheeled transport routes are less direct, but seem naturally more accessible, and more accurately replicate the ancient roads near the fortresses. The respective models may offer an explanation for the formation of those roads, and indicate by what transportation means those might have been accessible.

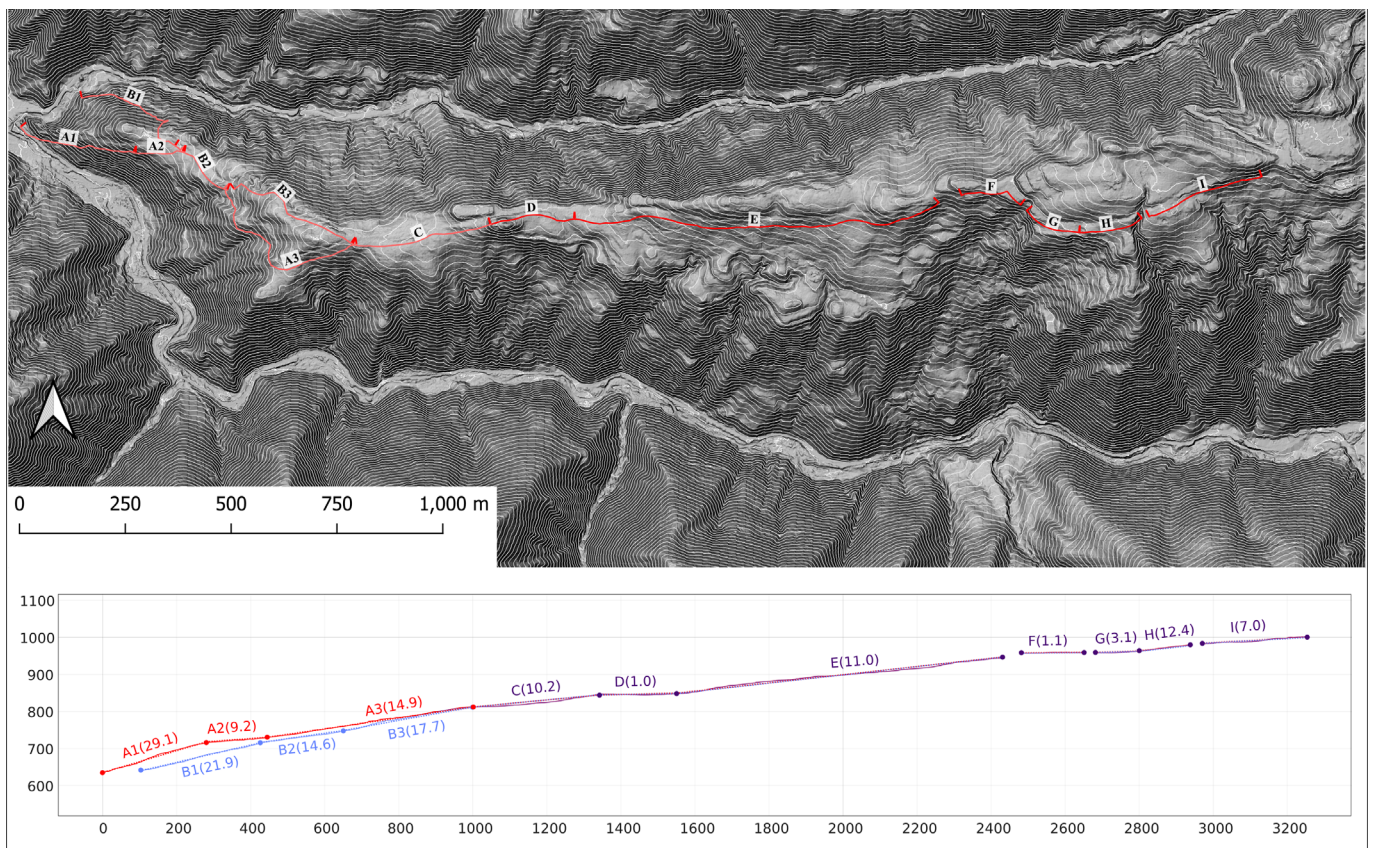


Fig. 11. The roads near Dealul Grădiștii fortress (gradients in the road profile section are expressed in percent and distances or elevation in meters).

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