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Ghost centuriation of Roman Istria: new evidence from lidar survey

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ABSTRACT: This study presents new evidence of Roman centuriation in northern Istria (Croatia), a region previously considered devoid of such land division systems. While the centuriation grid of southern Istria—linked to the Roman colonies of *Pola* (Pula) and *Parentium* (Poreč)—have been documented since the 19th century, its northern extent remained unexplored until now. Using the Croatian national lidar data (2022–2023), we identified fossilized traces of Roman *limites* (cadastral boundaries) in the form of micro-reliefs (low embankments) and, primarily preserved in overgrown or forested areas. These features align with the 20 × 20 actus module (≈707 m) and NNE–SSW orientation characteristic of Istrian centuriation, confirming the grid’s extension across the 80 km of the western Istrian coast. This discovery shows that centuriation was not limited to Istrian administrative boundaries as previously thought. Instead, it suggests a unified survey campaign across the peninsula.

Unlike the south of the peninsula, where Roman boundaries still shape present-day field systems, traces in northern Istria are abandoned or "ghost" features, invisible without high-resolution topographic methods (lidar data and appropriate algorithms, in this case TPI and Toposhade). The study underscores the role of geology and taphonomy in preserving—or erasing—ancient landscapes, while demonstrating lidar’s potential to revisit "invisible" archaeological features. Future research may further revise Istria’s centuriation extent by targeting overgrown areas and subtle ploughsoil anomalies.

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Introduction

Centuriation was a method of land division in the Roman world, commonly used from at least the third century BCE onward. It involved the subdivision of territory into large, orthogonal blocks approximately 710 meters wide,

in order to allocate land to new settlers, organise agriculture, and establish infrastructure in newly conquered or colonized areas. In Istria (Croatia), such land division has been known since the nineteenth century; it was first identified by Pietro Kandler around the Roman colony of *Pola* (Pula) based on high-quality topographic maps of the

Austrian Empire (Kandler 1855, p. 179; Ramilli 1973, p. 22-24). Materialised in the landscape by a network of dry-stone walls and field paths which were mostly still in use at the time, traces of the Istrian centuriation constitute an excellent example of a colonised Roman agrarian landscape. The gridded layout displays a typical square module of 20 by 20 Roman *actus*, and is oriented NNE-SSW.

The centuriation of *Pola* was brought to wider attention through the aerial photographs published by John Bradford, who calculated its extent as some 16 by 24 km in the southern part of the peninsula (Bradford 1957). Following the same method, but on the basis of Yugoslav military aerial photographs, Mate Suić (1955) demonstrated the existence of a centuriated land division in the ager of *Parentium* (Poreč). The spatial continuity and identical orientation of the *Pola* and *Parentium* grids led to the proposal that the land division was laid out simultaneously for the two colonies (Suić 1955; Chevallier 1961). More recently Antonio Marchiori (2010), who also made use of satellite imagery and higher precision topographic maps, made a complete study of the *Parentium* area and produced a comprehensive map of the centuriation remains in the landscape. For a general overview of research on the Istrian Roman centuriation, see the meticulous historiographic analysis by Davor Bulić (2012).

Most of these studies share a desktop-based approach and thus rely on a limited set of methods, namely general mapping of the overall extent of centuriated grids, and only exceptionally precise measurements of land division layouts (e.g. Krizmanich 1981, who calculated the module size on topographical maps to be 706.39m, with a standard deviation of 49cm). However, the more recent use of lidar surveys, i.e. high precision topographic scans, seems to have finally inspired interest in archaeological fieldwork. Popović et al. (2021) undertook an archaeological survey and excavation of *limites* visible on lidar derived imagery in the southern part of the *Parentium* ager. In this karstic zone, the excavated features appear as the first levels of drystone walls, one of which is 1.6 m wide and may originally have stood about a metre high, according to the excavators. Similar approaches have also been implemented in the neighbouring regions of *Tergeste* (Trieste), to the north of Istria, and the Kvarner archipelago, to the south. Examina-

tion of lidar data led Dimitrij Mlekuž to propose a centuriated land division for the hinterland of *Tergeste* (Trieste), whose territory extended into northern Istria, encompassing at least Aegida (Mlekuž 2018). Here also excavation of the putative *limites* revealed drystone wall. Further south, lidar data analysis of the Kvarner archipelago south of Istria led to the discovery of several Roman period land divisions (Doneus et al. 2024). In this case, the use of OSL analysis (optically stimulated luminescence) permitted to ascertain the Roman date for a field system on the island of Cres by dating the sediment beneath the remains of drystone walls that in all likelihood served as *limites* (*ibid.*).



Figure 1. The extent of currently known Roman land divisions in Istria

Despite this long history of research, no traces of Roman land division had been identified in the northern part of the peninsula; the Mirna River was generally accepted as the boundary of both Parentium's territory and the Roman centuriation of Istria (Marchiori 2010; Bulić 2012).

Recently, however, Bernardini and Vinci (2020) have proposed otherwise, on the basis of only three fossilised linear features, identified in a lidar survey of the Oprtalj municipality. Unfortunately, the presence of two landscape lineaments aligned over 1 km, and separated from a third by about 1.15 km is far from sufficient to address the issue; it does not constitute evidence for the existence of Roman cadastral boundaries (*limites*).

As a caveat, the presence of a couple of active or fossilised field boundaries sharing the same orientation (so-called isocline field pattern) cannot be considered as sufficient to demonstrate the existence of a *limitatio* (a Roman surveyed land division). Such landscape boundaries should reflect the subdivisions of an agrarian layout that reproduces an ancient module, with intervals based on a defined number of *actus* in the Roman case (Dilke 1971). Therefore, this landscape pattern should be observable across a sufficiently wide geographical area in order to assess its precise orientation and periodicity, thereby demonstrating a planned land-division dimensioned according a historical metrological system (Favory 1997, p. 102; Chouquer 2008, pp. 868-869; Brigand 2010, p. 102). As we will see, the recent nationwide lidar survey of Croatia allows us to approach this issue adequately.

Lidar data processing

The Croatian national lidar survey was made between 2022 and 2023 (DGU 2022). Nominally, this topographic laser scan should contain a minimum of four points per metre square, but in reality the point cloud density in Istria does not fall below ten points per metre square. As we shall see further on, the quality of the dataset is more than sufficient for the detection of larger archaeological landscape features, such as land division traces, although it may become somewhat noisy at a finer scale.

For the purposes of the following analysis, lidar ground points (classified as such by the data provider) were interpolated into a 70 cm raster terrain model, itself visualised using the Toposhade algorithm of the Terrain Shading plugin for QGIS software (Čučković 2025). This approach is sensitive to both terrain aspect and relative height of surface features, expressed as shades of grey. Additionally, to reveal subtle relief anomalies, the terrain position index (TPI) was also calculated using the same tool.

Both methods calculate the relative altitude difference of each terrain element by comparing each pixel with its neighbourhood. The neighbourhood extent was set to 3 pixels (2.1 m radius) for the Toposhade approach, and to 20 pixels (14 m) for the TPI. The wider radius helps reveal very low and wide remnants of ploughed-out features.

Centuriation of the Northern Istria

As previously mentioned, northern Istria, north of the Mirna River, was presumed to be exempt from centuriated land division. However, the known extent of the Istrian centuriation appears to be contingent on advancements in survey technology: while aerial photography enabled to ascertain its existence in the territory of *Parentium*, the recent national lidar survey of Croatia finally provided evidence for the centuriated grid in northwestern Istria as well.

Our terrain models enabled us to detect and map traces of Roman landscape boundaries, which appear as low embankments in the relatively flat sector of the study area (Figure 2). Perhaps the best-preserved part of the centuriated grid is located at its northernmost edge, along the limestone ridge emerging from the sea near Savudrija, and extending eastward deep into the hinterland. The regular sequence of low embankments separated by an average of 706.5m (with a standard-deviation of 7.7m) is a typical module for Istrian Roman land division. The theoretical grid layout was then reconstructed based on linear topographic features revealed by our terrain models. We have decided to retain only those features that would correspond to main *limites*, i.e. to boundaries of *centuriae*. This leaves us with the skeleton of the layout, which would have been measured and marked in the field by surveyors. The internal subdivision of these blocks constitutes a separate issue, related to land use and property ownership, and is therefore left for future study.

A total of 47.7 km of linear features were identified from the lidar data, including 117 assignable to north-south-oriented *limites*, for a total length of 20.3 km, and 120 to east-west-oriented *limites*, for a total length of 27.4 km. These features account for only a small portion of the theoretical grid covering the study area. However, it is noteworthy that 43 of the 69 lines in this theoretical grid (62%)

are physically represented by at least one micro-relief lineament in the landscape. Moreover, although the linear features are not continuous, they can be aligned over very

long distances: several east–west *limites* can be reconstructed over more than 15 km (up to 20 km), while the longest north–south alignment extends over approximately 14 km.

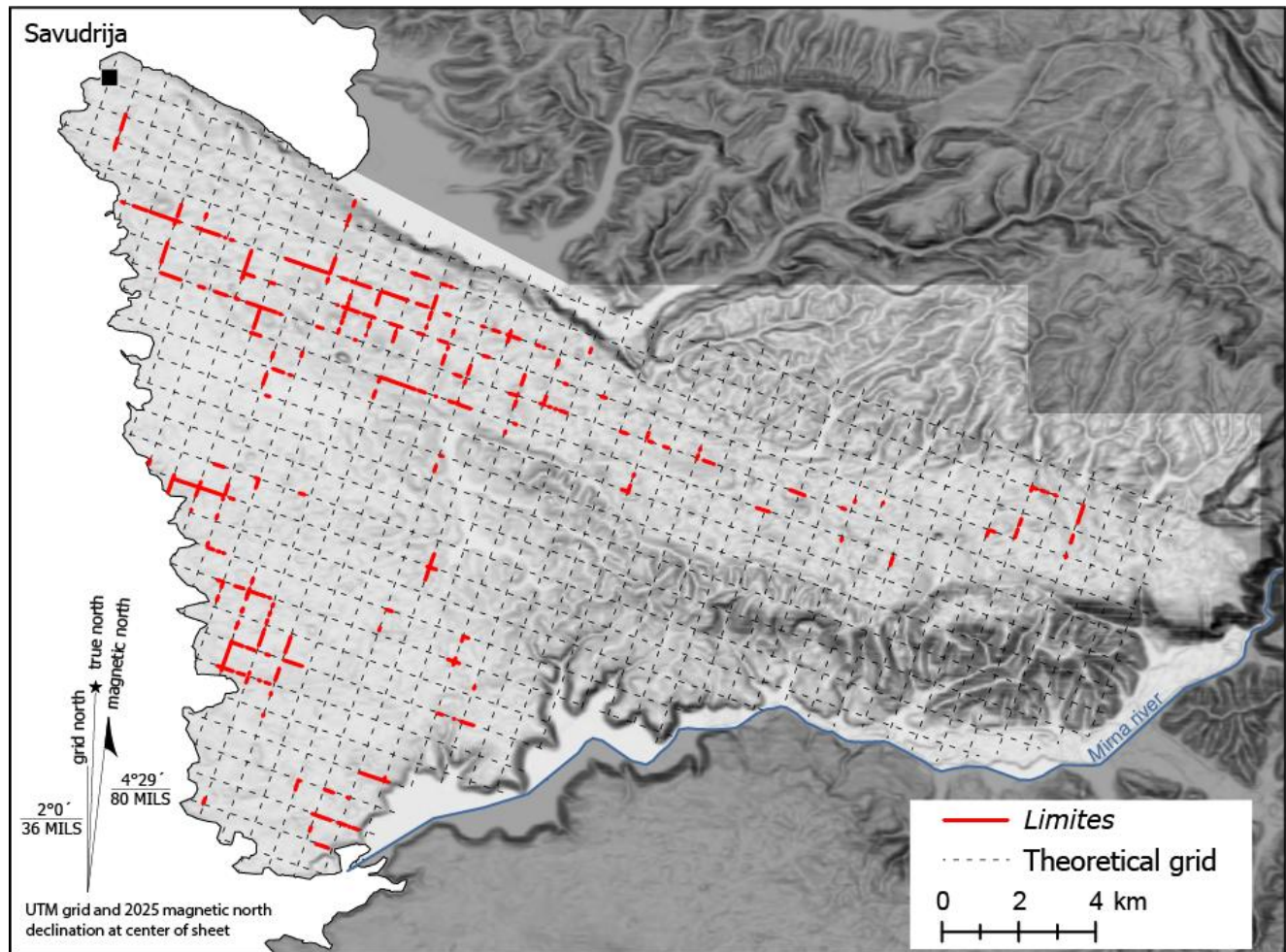


Figure 2. Traces of Roman centuriation in northern Istria (Croatia). Base map: Analytical hillshading (315° azimuth illumination, 45° sun elevation) transparently overlaid on a slope severity image. GLO-30©Copernicus DEM

The orientation and rhythm of the reconstituted square modules correspond to the centuriation grid layout covering the central and southern parts of Istria. Thus, the entire western Istria, from Pula to Savudrija, was covered by the same uniform centuriated grid. More specifically, in the national cartographic projection of Croatia (HTRS96 – EPSG:3765), the grid is oriented at 19°03' east¹. We may also remark that, the Istrian layout does not align with the

orientation proposed for the hinterland of *Tergeste* (Trieste), located some 30 km to the northeast (Mlekuž 2018). There, the putative layout orientation of 48° east seems to have been aligned with the local coastline and cannot be confused with the Istrian layout.

Curiously, very few centuriation *limites* are still in use as field boundaries or paths, in stark contrast to southern Istria, where the initial Roman land division continues to

¹ For this part of Istria, this corresponds to 17°1' east of true north.

shape the present-day countryside (Bulić 2012). The remains of the northern Istrian centuriation are either abandoned, fossilized features in overgrown areas or very faint, “ghost” anomalies in cultivated areas, invisible by most survey or remote sensing methods.

The best-preserved stretches of the centuriation in northern Istria appear as low embankments, typically some 20

cm high and 3 m wide, and locally up to 40 cm high and 6 m wide. These features are normally found in overgrown areas, spared from contemporary period agriculture (Figure 3). This clearly accounts for the survival of land division features, as well as for their patchy distribution.



Figure 3 Fossilized Roman centuriation limites in vegetation-covered areas. Above: Toposhade (2 m search radius), 0,7 m resolution lidar data © DGU. Below: Orthophotography © DGU



Figure 4. Rare and subtle traces of main ancient boundaries (limites) in ploughed areas. Above: TPI (14 m search radius), 0,7 m resolution lidar data © DGU. Below: Orthophotography © DGU

Much rarer traces can be found in cultivated areas where even lower and wider topographic anomalies were detected thanks to the TPI visualisation method (Figure 4). These linear elevations, only 10 to 15 cm high and 10 to 15 m wide, remain entirely invisible in the field. These elusive features are found on the ploughsoil and may be explained by the relatively recent conversion of forested areas to agriculture.

Discussion

The newly identified remains of ancient field boundaries north of the Mirna River follow the orientation, module, and periodicity known for the rest of Istria, demonstrating the existence of a single Roman *limitatio* that covered a vast area between Pula and Savudrija—some 80 km in length and 25 to 30 km in width. Given that *limitatio* is normally carried out before or shortly after the arrival of new settlers in colonised areas, the Istrian centuriation is commonly dated to the first century BCE. Its uniformity suggests it may have taken place in a single phase (Suić 1955; Bulić 2012).

By the end of the first century BCE, several administrative units covered this area, namely the Roman colonies of *Pola*, *Parentium*, and *Tergeste* north of the Mirna River (for the administrative status of northern Istria, see Zaccaria 1992; Starac 1999). Contrary to previous views that restricted that centuriation to the southern sectors administered by the colonies of *Pola* and *Parentium* (Suić 1955; Starac 1999; Marchiori 2010; Bulić 2012), we now see that Roman land division extended across most of the western Istrian coast. This invites us to reconsider what determines the extent of the system and, above all, our knowledge of it.

Until lidar coverage became available for this region, the known traces of Roman centuriation consisted mostly of features visible in the modern open landscape. In northern Istria, however, such traces were almost entirely erased by historical land use. Presently, the centuriation is clearly discernible only in forested areas. It is therefore likely that lidar, or perhaps other technologies, will further enrich the archaeological data, especially in overgrown areas, but also in cultivated areas, where “ghost” features have been detected. The extent of Istrian centuriation may thus be revised in future studies.

Traces of Roman centuriation are almost exclusively found on the limestone plateau that slopes gently down to the Adriatic Sea, forming the bulk of the peninsula (Figure 1). This area is mostly covered by a more or less thick layer of terra rossa soil and is prone to karstic phenomena (sinkholes, rocky outcrops). Outside this area lie marly soils on flysch—a soft, friable type of rock producing a dynamic relief of steep slopes and narrow ridges. Within the study area, the flysch zone between the Mirna River and the karstic plateau to the north bears no traces of the centuriation grid (Figure 2), which resumes its course on the southern side of the Mirna valley. This steep, erosion-prone terrain was almost completely reshaped by agricultural terracing which reached its maximum extent by the nineteenth century. It is thus possible that erosion and intensive terracing erased the physical traces of earlier land division systems.

That being said, the rugged terrain of the mountainous interior of the peninsula was likely not covered by the centuriated *limitatio* survey, as such land division was designed for agrarian colonisation and seems most reasonable over gentle terrain. This may also apply to the flysch area, which covers much of northern Istria. Steep slopes prone to erosion were historically cultivated there in an intricate web of terraces; a rigid orthogonal grid would fit poorly in such terrain.

Conclusion

The study of the Croatian national lidar survey revealed the existence of Roman centuriation boundaries in northern Istria. Their traces in the landscape are sporadic, but nevertheless numerous enough to establish the existence of a centuriation grid in northern Istria. These are fossil traces, materialised by micro-reliefs, which can mostly be found in areas that today lay overgrown and uncultivated, or as “ghosts” in the ploughsoil, invisible in the field. Geologically, these features are almost exclusively situated on limestone and terra rossa covered area. Unlike the south of the peninsula, the northern Istrian *limites* are no longer active in the landscape and have left no legacy in the modern field system, which explains why they have not been identified until now.

The evidence from northern Istria demonstrates that centuriation was not limited to the southern colonies of *Pola*

and *Parentium*, but extended along much of the western coastline, forming a largely uniform grid, possibly adapted to local geological conditions and seemingly defiant of presumed Roman administrative boundaries. Spanning over 80 km from Pula to Savudrija, the Istrian centuriation shares the same orientation, module and periodicity, suggesting a coordinated land survey conducted in one or several closely related campaigns. However, while there must

have been a link between the land division and Roman administration of Istria, the currently observable extent of Istrian centuriation may be less explained by ancient political or administrative limits than by long-term landscape formation processes—an outcome of landscape formation and transformation over centuries.

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Supplementary material

In the attachment to this paper (DOI: 10.5281/zenodo.18928451) can be found:

- Mapped traces of centuriation *limites* (Supplem_Limites_NorthIstria_v1.geojson)
- Metadata (Supplem_Metadata.pdf)

The GIS file is in GeoJSON format and projected in HTRS96 / Croatia TM (EPSG:3765) system.

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