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The morphological variability of Maltese 'cart ruts' and its implications

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ABSTRACT

Hundreds of 'cart ruts' – pairs of incised parallel grooves in the bedrock – are found across the Maltese Archipelago in the central Mediterranean. The age, functional association, formation processes, and taphonomic alteration of these ruts, which occur here with a globally unrivalled frequency, has been much debated. Generally seen as being created by erosion from vehicles such as wheeled carts, or alternatively being cut into the rock to facilitate movement of such vehicles, specific models range from the use of carts to move soil in the Neolithic to them reflecting classical era stone quarrying, and many other possibilities. One interesting aspect concerns the morphological variability of the cart ruts, such as the notion that they have a standard gauge (width between ruts), and that this gauge is very similar to that of modern railway tracks. Evaluating the morphological variability of the cart ruts contributes to an understanding of the phenomenon, as, for instance, we might expect that if they date to different periods, with different functions, and/or were extensively modified by geomorphological processes this will be reflected in the character of their morphological variability. The analysis suggests that cart ruts are fairly standardised in terms of basic measurements such as widths and depth, perhaps suggesting that they are of a consistent age and function. This study identified a need for definitional clarity as the commonly cited gauge measurements are not taken in the same way as gauge is defined for railway tracks. There are hints of rut shape changes reflecting extensive use and or processes such as limestone dissolution, which give insights into their formation histories.

1. Introduction

1.1. Background and context

The 'cart ruts' of the Maltese islands – pairs of parallel linear grooves incised into bedrock (Figs. 1, 2) – have fascinated generations of archaeologists, geographers, and the general public (e.g. Abela, 1647; Houël, 1782; Adams, 1870; Fenton, 1918; Murray 1928; Zammit, 1928; Evans, 1934; Gracie, 1954; Evans, 1971; Parker and Rubenstein, 1984; Bonanno, 1990; 1993; 1994; 2017; Ventura and Tanti, 1994; Trump, 1998; 2002; 2004; Hughes, 1999; Sagona, 2004; 2015; Magro Conti and Saliba, 2007a; Cardona, 2008; Mottershead et al., 2008, 2019; Trump and Cilia, 2008; Weston 2010). Cart ruts have been reported from several parts of the world (Magro Conti and Saliba 2007b), but never with the profusion in which they occur in Malta. In other parts of the world cart ruts are often associated with either urban settings or relate to quarrying. Ruts occur across the length and breadth of the Maltese islands, from close to the highest point to below current sea level. While mostly focussed on the Coralline limestone formations, they also occur on the Globigerina Formation (Pedley et al., 2002).

Diverse views have been expressed on how and when the cart ruts formed, with implications for elucidating the archaeology and geomorphology of the Maltese islands. While there have been occasional suggestions that some ruts may be natural geological features (e.g. Dawkins, 1918; Sagona, 2004, p. 46), the overwhelming view has been that cart ruts are the result of anthropogenic activity. The estimated age range for the ruts has included Neolithic (e.g. Zammit, 1928; Sagona, 2015; McLaughlin et al., 2018), Bronze Age (Trump, 2002; French et al., 2020), Punic/Phoenician to Roman (Parker and Rubenstein, 1984; Bonanno, 2007, 2017), and Medieval to Early Modern (e.g. Abela, 1647; Adams, 1870). As several authors have pointed out, cart ruts may have been used in different periods, possibly for distinct activities (Bugeja 2001; Magro Conti and Saliba 2007c; Stoddart et al., 2020).

In general, the ruts have been seen as being created by vehicles, be it wheeled carts (e.g. Fenton 1918; Weston, 2010) or other forms such as 'slide cars' (e.g. Gracie, 1954; Evans, 1971). Functional interpretations have ranged from moving soil uphill to create terraced fields (e.g. Zammit, 1928; Parker and Rubenstein, 1984), the transport of quarried

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stone (e.g. Abela, 1647; Bonanno, 1994, 2007, 2017), and the movement of general agricultural produce (e.g. Trump, 2002). Less common views include those suggested by Sagona (2004, 2015), who argued that the ruts were not produced by vehicles at all, but were deliberately made as 'field furrows' and sometimes as water channels. Finally, Arnaiz-Villeina et al. (2018) suggest some ruts may have had an "astronomical/religious purpose" and were deliberately aligned as a calendar to mark things like solstices. The dominant narrative, however, sees the cart ruts as being created by, and perhaps for, vehicular transport.

No actual remains of ancient carts are known from Malta, so suggestions that cart ruts were produced by carts flow from circumstantial factors and by triangulating evidence from surrounding regions. Wheeled vehicles extend back to least the 4th millennium BC in SW Asia (e.g. Piggott, 1983), but it is unclear when they began to be used in Malta. The extent to which wheel technology had a single origin or was repeated re-invented is also unclear (e.g. Köpp-Junk, 2016). It is interesting to note that in the more recent past, carts were widely used in Malta. Extending back to at least the 18th century CE, *calesse* carts were widely used, and were precursors to the more recent *karozzin* (e.g. Chetcuti, 2018). Unlike the more elaborate and four-wheeled *karozzin*, the *calesse* carts were simple two-wheeled affairs. Likewise, the British Army used what they called 'Maltese carts' in the 19th and early 20th centuries (Smith, 2008). Could carts similar to these recent two-wheeled forms have been used in ancient Malta, and be related to the cart phenomenon? It is quite possible, and is an idea which needs to be further evaluated. Limited information is available on the gauge of traditional carts in Malta, but certainly visually they appear to be similar to the gauge of cart ruts.

There has been considerable disagreement on the character by which ruts were first formed, and subsequently modified by both anthropogenic and natural processes (Fig. 3). There has been disagreement on whether cart ruts were initially deliberately cut into the limestone bedrock (e.g. Zammit, 1928; Trump, 2004; Magro Conti and Saliba 2007c; Sagona, 2015) or not (e.g. Fenton, 1918; Gracie, 1954; Hughes, 1999; Mottershead et al., 2008; Weston, 2010). Subsequent change, such as deepening, can be attributed to both repeated vehicular use causing erosion (e.g. Mottershead et al., 2008) and natural geomorphological processes of erosion and limestone disolution (e.g. Magro Conti and Saliba 2007d; Pedley, 2007). These natural processes are typically regarded as being rather minor, with Trump (1998, p. 36), for instance, suggesting that limestone dissolution may have removed "a millimetre or two, but not more" of the base of the ruts. Pedley (2007, p 68) suggested that limestone dissolution may have lowered the bottom of some ruts by "about 1.5 cm". Weston (2010) argues that these natural processes were much more extensive, and in fact that ruts as visible today are primarily natural, with initial vehicular use creating an indent in overlying soil, in which water accumulated, triggering a process of dissolution.

1.2. Previous work on cart-rut morphology

Two significant morphological aspects of cart ruts have been repeatedly discussed. Firstly, there is the possible distinction between more V-shaped and more flat-bottomed forms, with some suggesting that the former are typically older (Zammit, 1928; Sagona, 2004; Cardona, 2008; Weston, 2010), but others contest this (Magro Conti and Saliba 2007c). Secondly, there has been discussion of the dimensions of the cart ruts, and particularly the notion of them having a standardized gauge. The gauge has been described as being around 140 cm (Hughes, 1999; Magro Conti and Saliba 2007e; Mottershead et al., 2008), 141 cm (Trump, 2002; 2004; Trump and Cilia, 2008), or 142 cm (Evans, 1971; Cardona, 2008).

The notion of standardised gauge, with little variation, close to modern standard train gauge has been repeatedly mentioned (e.g. Evans, 1971, Hughes, 1999, Trump, 2002; Trump and Cilia, 2008). Sagona (2004, p. 128) agrees that the ruts have a "uniform distance" between them, but suggests that this reflects reach by people using hand tools. A more common intuition is that the apparent consistency of rut gauge suggests that they were "formed by a standardised device" in terms of a vehicle (Weston, 2010, p. 117).

Gracie (1954) took multiple measurements of cart rut mid-point to mid-point width, suggesting that they ranged from 130 cm to 145 cm. He also published multiple measurements along a single pair of ruts, showing that it varied from 131 cm to 141 cm. An important paper was that of Ventura and Tanti (1994) for proposing a standardized set of measurement definitions, and providing detailed data on ruts at a single locality, at Naxxar. Magro Conti and Saliba (2007a) used the measurement system of Ventura and Tanti. They provide an extensive catalogue of measurements in their monograph on Maltese cart ruts, and summarise the kind of ranges and averages involved.

While there are numerous suggestions that Maltese cart ruts have very standardised gauges, data on ruts in other parts of the world seem to present a different picture, with highly diverse gauges (e.g. Schneider, 2001). Magro Conti and Saliba (2007c, p. 171), discuss ruts from sites in

Fig. 1. Examples of cart ruts. A: Misraħ Għar il-Kbir, B: Xemxija. Human scale: 107 cm. (Colour Image).

Italy, some having mid-point to mid-point width of 80 cm, others 90 cm, others 110 cm, and others 140 cm. Other ruts discussed by Magro Conti and Saliba (2007c) are from Egypt, and have large mid-point to mid-point widths of 230 cm, 274 cm, and 325 cm. This diversity seems striking. Ogata et al. (2006) provide an example of the suggestion that the modern railway gauge is somehow related to ancient cart width, citing mid-point to mid-point ruts from the Mediterranean and across Asia of between 130 and 180 cm.

As well as the gauge, there has been some discussion of the dimensions of the individual ruts. For instance, Fenton (1918) suggested that on average they were about 21 cm wide at the top and 7.5 cm wide at the bottom, while Zammit (1928) suggested 25–50 cm and 10 cm respectively.

While, with current data, the age, formation, and modification of cart ruts are challenging to understand, elucidating the morphological and metric variability of these features can advance the debate. After this brief introduction, the aim of this paper is to explore variation in cart rut morphology using basic descriptive statistics.

2. Methods

To evaluate the morphological variability of the Maltese cart ruts, firstly a literature review was conducted (summarised in the previous section). Secondly, field surveys were conducted at multiple localities in Malta where abundant cart ruts are found. The major localities visited were ruts at the main Misraħ Għar il-Kbir site (35.852314 N, 14.397223 E), Misraħ Għar il-Kbir east (35.853092 N, 14,400694 E), San Pawl tat-Tarġa / It-Telgħa t'Alla u Ommu (35.925764 N, 14.437817 E), Binġemma (35.902601 N, 14.378890 E), and Xemxija (35.952020 N, 14.382988 E). The aim of these field visits was primarily to evaluate the general characteristics of the ruts, bringing context to the quantitative aspects described below. A particular point was a consideration of variability within particular ruts, i.e. do they display consistent characteristics along their length, and to evaluate indications of potential aspects of landscape context and geomorphological modifications of the ruts, such as Weston's (2010) emphasis on limestone dissolution as an explanatory mechanism.

The major aim of this paper is to compile quantitative data on cart ruts – published by Ventura and Tanti (1994) and, particularly, Magro Conti and Saliba (2007a), and to use basic descriptive statistics to evaluate these data. Ventura and Tanti (1994) provide data for the Naxxar ruts; and Magro Conti and Saliba (2007a) provide data on many sites across Malta and Gozo. These measurements, and measurements which can be calculated from the original data, are summarised visually in Fig. 4. Not all measurements are available for each rut, so the sample size for different measures varies. The only additional note is that as cart ruts consist of a pair of ruts, and is it is interesting to compare the features of each individual rut, 'right' and 'left' ruts were recorded simply in the order shown on the diagrams in Magro Conti and Saliba (2007a). There is no general meaning to this division, as it depends on the direction that the ruts were recorded in. To explore rut shape, an index of rut convergence was calculated, which is simply the width at the top of rut divided by the width at the bottom. A higher value for this indicates a more V-shaped rut.

Descriptive statistics such as averages and ranges of the measurements shown in Fig. 4 and provided in full in the supplementary table were calculated, and graphical depictions (such as histograms) used to summarise and visualise the data. The software 'PAST' was used for all visualisations and analyses. For histograms, the number of bins was kept constant at one quarter of the total sample size for each variable. These data and graphs are then discussed, to highlight the major trends. Given the limitations of the data – i.e. a few linear measurements to capture the structure of relatively complicated three-dimensional features, the aim is not to conduct formal comparisons between variables. As a simple exploratory exercise, measures of rut width were compared to the rut shape index and rut depth. Regression lines and R^2 values are shown. This was repeated with outliers removed to explore the impact they had on the correlations. The aim of this is to evaluate whether the shape of the ruts changed in relation to overall aspects of morphology, which might elucidate cart rut formation processes.

3. Results

3.1. General remarks

While much has previously been written on the general characteristics of the Maltese cart ruts, a few observations can be mentioned here. Firstly, there is clearly considerable variability in the basic shape of ruts, from the wide, deep and flat-bottomed forms, to deep V-shaped, to shallow sets of parallel ruts (Figs. 1, 3, 4). It is currently not clear to what extent a gradient links these forms, and the evaluation of this is complicated by many ruts having sediment or vegetation at their base. Often different ruts at a single locality will have rather different shapes. Ruts are found in diverse topographic settings, and some points can be noted here which contribute to supporting a vehicular origin of the ruts. At some points an individual set of ruts are found either side of, and extending over, a high point in the landscape, such as at 35.851916 N, 14.397066 E at Misraħ Għar il-Kbir. This makes the notion that they were for something like water capture unlikely. In some settings, such as below Naxxar on the aptly named It-Telgħa t'Alla u Ommu (Hill of God and His Mother), ruts are found on fairly steep ground. This perhaps makes it unlikely that ruts were 'field furrows' (contra Sagona, 2004; 2015), as such sites would have no need for drainage improvement, and their location on steep ground would seemingly have ensured rapid soil loss. Conversely, aspects of the topographic context of ruts do make sense in terms of vehicle movement. Key here again are the Naxxar ruts. These curve up-hill, following the gentlest available slope, at the locality known as the Naxxar Gap. This offers a transit point through an east–west escarpment created by the 'Great Fault', which was fortified by both the Knights of Saint John and the British as the 'Victoria Lines'. The crucial nature of the route followed by the ruts here is reflected in a 20th century pillbox being located just above them (Fig. 2A), as well as late Medieval fortifications built by the Knights of Saint John. An essential caveat here is that it is easy to visit a particular cart-rut site and discuss its characteristics and their apparent implications. This, however, says little about the overall nature of the cart rut phenomenon, such as whether all ruts reflect the same function, and have the same chronology. While providing support for a vehicular interpretation, it is

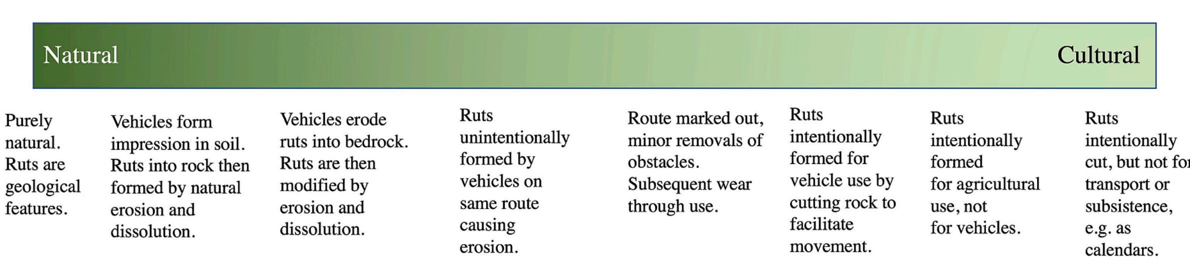

Fig. 2. The spectrum of explanations for 'cart-rut' formation. (Colour Image).

Fig. 3. Further examples of cart ruts showing additional aspects of morphology and landscape context. A: ruts on a relatively steep slope at San Pawl tat-Tarġa, Naxxar. Note right track repeatedly goes into solution hollows. B: junction of two deep, flat-bottomed ruts at Misraħ Għar il-Kbir (Fig. 1A is taken from the other direction a few metres along the right-hand ruts), C: shallow parallel ruts on flatter ground at Misraħ Għar il-Kbir. (Colour Image).

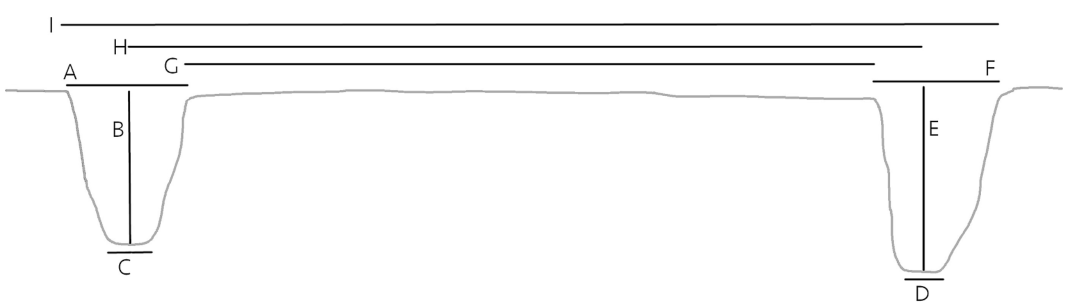

Fig. 4. Summary of measurements used in study (all in cm). A: left rut top width, B: left rut depth, C: left rut base width, D: right rut base width, E: right rut depth, F: right rut top width, G: inner edge of rut to inner edge of rut, 'central gap width', H: rut mid-point to rut mid-point, I: outer edge of rut to outer edge of rut, 'total width'. See text for description.

emphasised here that caution is needed with generalising impressions from a site in terms of factors such as vehicle types, material transported, and age.

While a vehicular origin of the ruts does therefore seem most likely, many uncertain aspects remain. At sites including It-Telgħa t'Alla u Ommu ruts rise and fall in and out of dissolution features (Fig. 2A). As widely discussed in the literature, this seems rather unlikely if there was not a soil fill when the ruts were in use. Yet the extent of this soil cover, and whether we can imagine fairly steep sloped hillsides being covered in soil is currently not clear. In some localities it is tempting to suggest that there is a relationship between rut morphology and slope. Ruts on flatter land often seen shallower (Fig. 2C) while those on slopes are deeper. Yet the form this takes varies, with some of the deepest ruts at Misraħ Għar il-Kbir which are on sloping land being flat-bottomed (Fig. 1A, 2B), while those at Naxxar are often more V-shaped (Fig. 5). Within single pairs of ruts, where a step-like area of rock exists on a slope, ruts are often deep at this point, and shallower either side. The meaning of these points in terms of formation processes is opaque, with it difficult to distinguish between some of the formation options summarised in Fig. 3. While it seems *a priori* difficult to imagine carts navigating ruts which are places over 60 cm deep, the morphological variability of ruts likewise problematises notions such as Weston's (2010) suggestion that ruts were formed by sub-soil limestone dissolution, with the only anthropogenic aspect being ruts creating slight depressions in overlying soil. That said, the bases of many ruts do clearly demonstrate limestone dissolution. And in many cases the Coralline Limestone around the ruts is highly karstic and weathered. In many places, circular hollows in the base of ruts clearly show the impact of limestone dissolution. Today some ruts see water flowing in them after rainfall (e.g. Fig. 5), as well as the movement of associated gravel clasts. It is therefore quite possible that geomorphological processes such as limestone dissolution have played a role in shaping the ruts, but arguably not as an exclusive mechanism for their formation. Evaluating these factors requires both detailed on-site studies, and three-dimensional analyses of cart ruts in their landscape settings. For now, the present paper will focus on basic descriptive statistics, set against the backdrop of these aspects of uncertainty and complexity, which should be kept in mind.

Fig. 5. Ruts at San Pawl tat-Tarġa/ It-Telgħa t'Alla u Ommu, just north of Naxxar. Note two generations of overlying ruts, and deep V-shape. Photos taken a day after heavy rain, note water in ruts, and gravel clasts on left. (Colour Image).

3.2. Basic aspects of morphological variability

Basic aspects of cart rut morphological variability are summarised in Table 1 and Figs. 6–9. Before exploring some of the aspects of variation in terms of distributions and so on, a key point is that there has been some ambiguity in the literature on the meaning of different terms, particularly the gauge of, or distance between, ruts. In the setting of railways, gauge refers to the distance from the inner side of one track to the inner side of the other track. It is in this measurement, i.e. G on Fig. 4, that modern standard railway gauge measures 143.5 cm, as defined by George Stephenson in the 19th century. However, in the case of Maltese cart ruts 'gauge' has actually often been measured as mid-point to mid-point of the ruts. As discussed in the introduction, some studies are explicit on using mid-point to mid-point width as a measurement of gauge (e.g. Gracie, 1954), while others implicitly suggest this given the figures they cite. In global terms, Ogata et al. (2006) also refer to gauge as mid-point to mid-point width, and therefore mistakenly suggest that various cart measurements around the world are very close to modern railway gauge.

At this point, it is of course germane to consider the basic difference between the Maltese cart ruts and railway tracks to which they are often compared in terms of gauge. Where railway trains move along fixed tracks, the general idea is that the carts (or slide cars) which made cart ruts both had considerable axle flexibility and over time caused erosion by movement within the rut. Given this, it may therefore be the case that mid-point to mid-point width is a more useful measurement in terms of calculating the dimensions of the vehicles which produced the ruts; but that measurement is not the same as that which is used to define modern railway gauge. The latter measurement (G on Fig. 4) has a mean of 111 cm and median of 113 cm (Table 1). Variation is relatively low, with 50% falling between 109 and 119 cm. This can seen visually in Fig. 6. The distribution can be seen as having a relatively narrow dominant focus; but with a few outliers, including one at just 33 cm. Mid-point to mid-point width has a mean of 139 cm and median of 140 cm; close to, or slightly smaller, than the typically mentioned measurements for cart rut 'gauge' in Malta (see introduction). The range of variability is again quite narrow; with 50% between 134 and 145 cm, and a lower standard deviation than for inner edge to inner edge distance. The final measure of width, outside edge to outside (I on Fig. 4) has a mean of mean of 165 cm and median of 161 cm. As shown by having the lower standard deviation, and visually indicated in Fig. 6, the mid-point to mid-point width is the least variable of the width measurements. This can also be seen in Fig. 7, where mid-point to mid-point width (which actually is very close to modern standard railway gauge) has less skewed distributions than the other width measurements.

For the width measurements of individual ruts, the top width has a

Table 1
Basic Descriptive statistics of cart ruts.

	Rut width top (cm)	Rut width base (cm)	Central gap width (cm)	Maximum depth (cm)	Width between rut midpoints (cm)	Combined total width (cm)	Right width convergence	Left width convergence
N	159	83	64	75	82	64	41	42
Min	8.00	5.00	33.00	4.00	85.00	137.00	1.14	1.21
Max	79.00	48.00	130.00	60.00	170.00	230.00	5.00	7.90
Mean	26.28	12.72	110.78	20.43	138.93	165.47	2.43	2.52
Stand. dev	12.01	8.02	15.58	10.07	10.61	18.07	0.89	1.22
Median	23.00	10.00	112.50	19.00	140.00	161.00	2.18	2.23
25 %	19.00	7.00	109.00	13.00	133.88	154.00	1.75	1.64
75 %	30.00	15.00	118.75	27.00	145.13	173.75	3.16	3.04

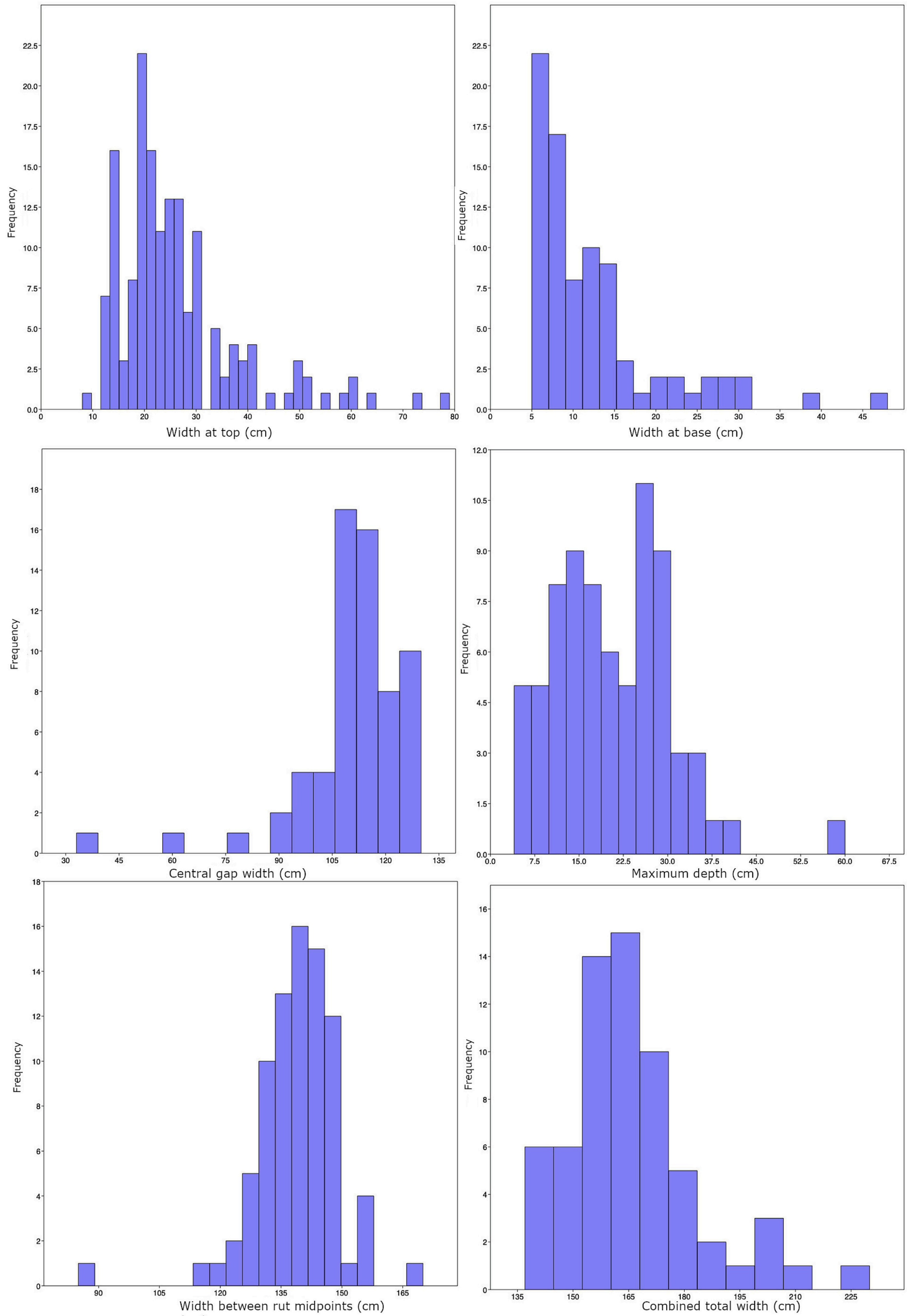

Fig. 6. Histograms of measurements on cart ruts (see methods for definitions of values). (Colour Image).

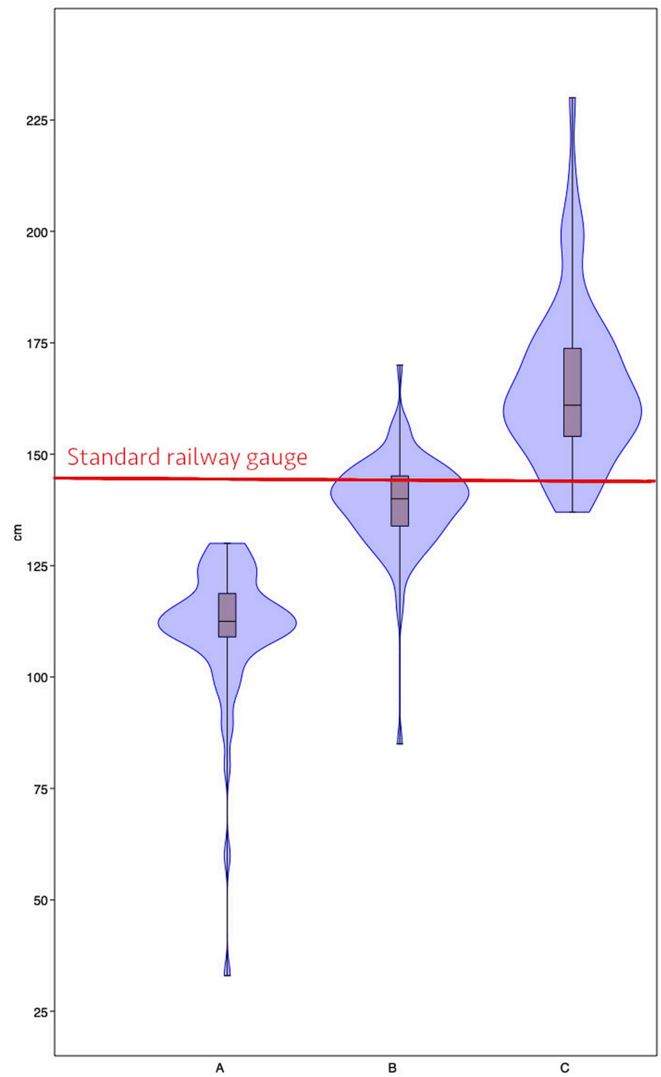

Fig. 7. Violin and box plots of different measures of cart rut gauge, and standard railway gauge (143.5 cm). A: inner-edge to inner-edge width ('central gap width'), B: mid-point to mid-point, C: outer-edge to outer-edge. (Colour Image).

mean of 26 cm and median of 23 cm and the bottom width a mean of 13 cm and median of 10 cm. While most ruts fall within a failure narrow range for these widths – 10 to 30 cm for top width, and 5 to 15 cm for bottom width – both values are right skewed with a trail of outliers extending up to 79 cm and 48 cm respectively. The depth is seemingly somewhat more varied than other measurements, with a mean of 20 cm and median of 19 cm. With depth there is a hint of bimodality about the distribution (Fig. 6), but it is unclear whether this is statistically meaningful. When it comes to the index of rut convergence (i.e. how V-shaped), the mean is 2.5 – i.e. the top is on average 2.5 times wider than the base – and the median is 2.2 (Table 1).

The preceding paragraphs relate to summaries of the overall cart rut dataset for the Maltese Islands. Another useful perspective is to consider variability within rut pairs, along the length. Fig. 8 summarizes such data for multiple cart rut pairs in the San Pawl tat-Tarġa (Naxxar group, data from Ventura and Tanti (1994)). As mentioned above, the mean and median mid-point to mid-point width for the whole dataset is 139 and 140 cm, respectively. As can be seen, most of the Naxxar ruts are somewhat wider than this, in both mean and minimum/maximum measurements along their length. The mean of the means for this group is 143 cm. An important point with these data is that in most cases there is seemingly little variation between the minimum and maximum width measurements taken along a pair of ruts, with a mean average of 6 cm difference. There are perhaps two key take home points here; firstly, there is seemingly fairly high standardisation within rut pairs, but, secondly, there is some variation between these pairs; the widest ruts at Naxxar having a width of 151 cm (mean) and the narrowest 132 cm (mean).

3.3. Relationships between morphological features

As discussed above, the aim of this paper is to outline basic descriptive statistics, not to conduct detailed comparisons and tests for significance. However, in the light of the previous descriptive statistics it was judged to be useful to visually compare the relationship between certain variables as an exploratory evaluation. Fig. 9 plots the rut width convergence index and maximum depth against two measures of the width between ruts, mid-point to mid-point and the 'central gap' width, and shows the regression slopes and R^2 values. This was then repeated with a few outliers removed to see how these impacted correlations.

In all cases there is a correlation between the variables, although in all cases most of the data is clustered in one area of the graph, and the correlation is not strong. For central gap width, as this gets larger ruts get shallower and less V-shaped. This is less strongly expressed with outliers removed, but the basic pattern stays the same. With midpoint-to-midpoint width, the direction of the correlation is reversed, and ruts get deeper and more convergent as width increases. In these cases, the correlation is stronger where the outliers are removed (although R^2 values are still low).

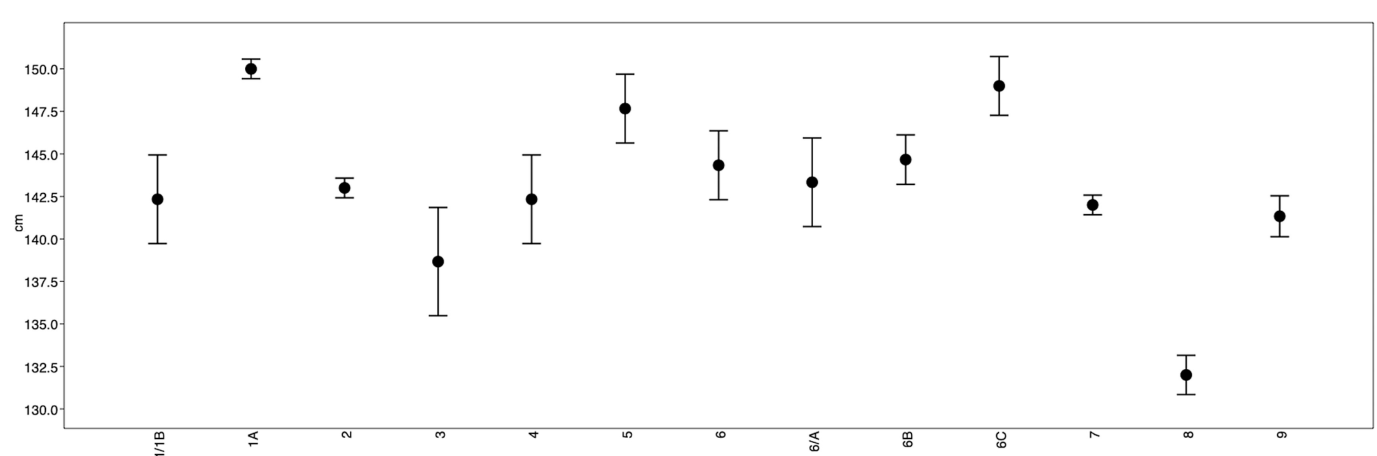

Fig. 8. Range of mid-point to mid-point measurements for a set of ruts at San Pawl tat-Tarġa (Naxxar), showing mean, minimum, and maximum measurements. Data from Ventura and Tanti (1994).

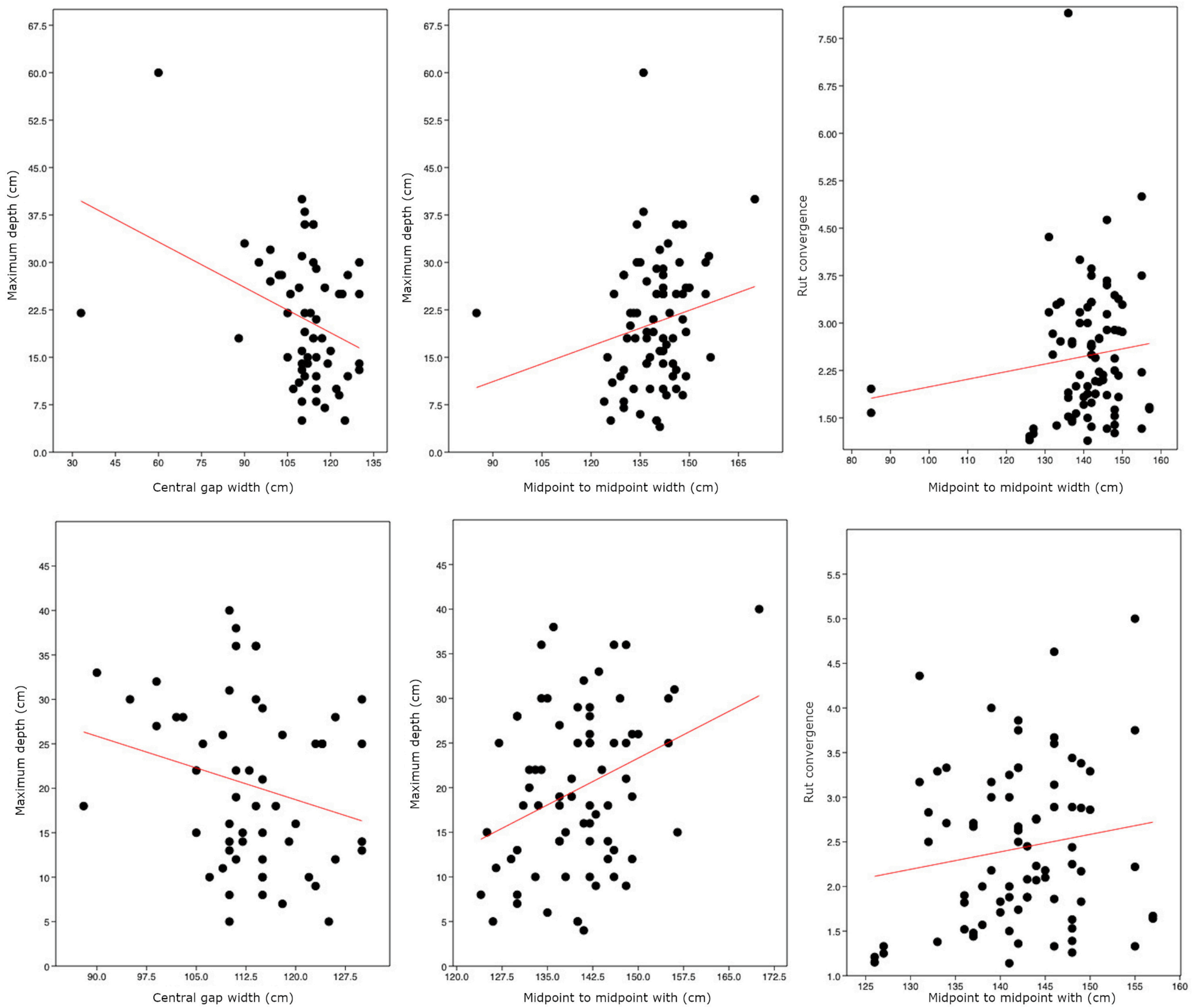

Fig. 9. Comparisons of width convergence index and depth with rut width. Top row, left to right: $R^2 = 0.1238$, $R^2 = 0.0380$, $R^2 = 0.01590$. Bottom row with outliers removed: $R^2 = 0.0561$, $R^2 = 0.1145$, $R^2 = 0.0237$.

If we hypothesise that changes in rut depth and convergence relate to rut modification over time, then decreasing central gap width may reflect factors such as movement of vehicles within ruts causing lateral erosion. In this is the case, then it suggests that over time the ruts become deeper and more convergent. With midpoint-to-midpoint width, the meaning is perhaps less clear. Even if there is widening of ruts over time, the rut mid-points should still stay more or less the same. Some suggestions on this pattern can be made. It might be the case that ruts which are wider to begin with are deeper and more convergent because of factors to do with their original form, with wider and deeper ruts relating to the movement of heavier materials. Alternatively, the pattern may reflect differential widening of the ruts due to factors such as the slope of the land, so that widening of the ruts is somewhat misleadingly indicated in midpoint-to-midpoint width. It is clear that it is currently challenging to separate such possibilities. This exploratory exercise identifies grounds for future analyses, with more nuanced analysis of three-dimensional data more likely to illuminate the topic than two dimensional summaries.

4. Discussion

The typical morphology of Maltese cart ruts can be described as around 15–30 cm wide at the top, narrowing to 5–15 cm at the base, between 10 and 35 cm deep, and with a distance of typically 100–130 cm between inside rut edges and 125–150 cm between rut mid-points. While there is a lack of clarity on what 'standardisation' means in such a setting, it is arguably the case that the data do suggest that ruts are fairly standardised. There are, however, exceptions to these dominant trends, with some ruts being very wide at the top at nearly 80 cm and some having a depth of over 60 cm, for instance. In general, the relatively clustered and narrow distributions of morphological variables suggest a consistency to the cart rut phenomenon, although it is not self-evident what this means in terms of the age, function, formation, and taphonomy of cart ruts. Given the diversity of cart forms in the ancient world (e.g. Köpp-Junk, 2016), and of cart ruts in various parts of the world, as discussed in the introduction, the relative standardisation of Maltese cart ruts is an important point to emphasise in these debates.

An important aspect that emerges from this is that care is needed to ensure the same definitions of terms are being used. This is most evident in terms of gauge. The common point about similarity with modern standard railway gauge is problematised as the latter is measured in a different way to the common way that cart ruts are measured. When the internal edge of ruts is measured, ruts emerge as considerably smaller than standard railway tracks. However, given the likely way in which ruts formed, mid-point to mid-point measurement is perhaps a more informative measure. And it is notable that this is the least varied of the width measurements measured. The implications is that ruts were formed by vehicles with a mid-point to mid-point width of about 140 cm. From there, horizontal and vertical wear, limestone dissolution, and abrasion of clasts against bedrock, modified the ruts. As suggested in Fig. 9, there are hints of shape changes relating to changes in the width between ruts, which may indicate changes associated with use and/or geomorphological processes, but the nature of these changes is currently opaque.

This paper provides a summary of available morphological data on cart ruts. Future work should look at more continuous and three-dimensional shape variability. This, along with the detailed analysis of the ruts themselves and their landscape setting, can help clarify the age, function, and modification of the cart ruts can be achieved.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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References

Adams, A.L., 1870. Notes of a Naturalist in the Nile Valley and Malta. Edinburgh, Edmonston and Douglas.

G. Abela Della Descrittione di Malta Isola nel Mare Siciliano: con le sue Antichità (1647). Libr. Quattro, Malta.

Arnaiz-Villeina, A., Medina, M., Palacio-Gruber, J., Lopez-Nares, A., Ruiz-de-Valle, V., 2018. Malta and Lanzarote (Canary Islands, Spain) Cart-ruts and Rock Prehistoric Calendar at Zomzamas, Lanzarote – "Quesera"/Cheeseboard. Int. J. Mod. Anthropol. 2, 214–231.

Bonanno, A. (1990). The Archaeology of Goo: From Prehistory to Arab Times. In: Cini, C. (ed). *Gozo, the Roots of an Island*. Malta, Said International. Pp 11-45.

Bonanno, A. (1994). Archaeology. In: H. Frendo and O. Friggierei (eds.), *Malta. Culture and Identity.* Ministry of Youth and the Arts, Marsa. Pp. 81-104.

Bonanno, A. (2007). Foreword. In: J. Magro Conti and P.C. Saliba (eds.), *The Significance of Cart-Ruts in Ancient Landscapes*. Malta, Midsea. Pp. vi-ix.

Bonanno, A., 2017. *The Archaeology of Malta and Gozo: 5000 BC-AD 1091*. Heritage Malta, Malta.

Bugeja, A., 2001. Methods of date assignment for cart-ruts in the Maltese Islands: Discussing relationships with Bronze Age fortified settlements on promontories. The Oracle 2, 23–35.

Cardona, D. (2008). Beyond the Temples: An Assessment of Archaeological Remains around Ta' Ħaġrat and Skorba. (45-71). In: M. Zammit, J. Mallia (eds.), TA' ĦAĠRAT AND SKORBA. Ancient Monuments in a Modern World. Midsea, Malta.

Chetcuti, E., 2018. The maltese calesse: visitors' impressions in nineteenth century travel narratives. J. Malt. Hist. 5, 98–125.

Dawkins, B., 1918. The Maltese cart-ruts. Antiquity 8, 339–342.

Evans, E.M.P., 1934. Maltese cart-ruts. Antiquity 7, 339–342.

Evans, J.D., 1971. The Prehistoric Antiquities of the Maltese Islands. University of London, Athlone Press.

Fenton, E.G., 1918. The Maltese cart ruts. *Man* 18, 67–72.

French, C., Hunt, C.O., Farrell, M., Fenech, K., McLaughlin, R., Grima, R., Vella, N.C., Schembri, P.J., Stoddart, S., Malone, C. (2020). In: French, C., Hunt, C.O., Grima, R., McLaughlin, R., Stoddart, S., Malone, C (eds.), *Temple Landscapes: Fragility, change and resilience of Holocene environments in the Maltese Islands*. McDonald Institute for Archaeological Research, Cambridge, pp. 303-324.

Gracie, H.S., 1954. The ancient cart-tracks of Malta. Antiquity 28 (110), 91–98.

Houël J.P.L.L. (1782). *Voyage Pittoresque des Isles de Sicile: De Malte et de Lipari, où l'on Traite des Antiquités qui s'y Trouvent Encore; Des Principaux Phénomènes que la Nature y Offre; Du Costume des Habitants and de Quelques Usages.* Paris, Imprimeri de Monsieur.

Hughes, K.J., 1999. Persistent features from a palaeo-landscape: the ancient tracks of the Maltese Islands. Geogr. J. 165 (1), 62. https://doi.org/10.2307/3060511.

Magro Conti, J., Saliba, P.C. (eds.) (2007a). *The Significance of Cart-Ruts in Ancient Landscapes*. Malta, Midsea.

Magro Conti, J., Saliba, P.C. (2007b). Cart ruts in other parts of the world. In: J. Magro Conti and P.C. Saliba (eds.), *The Significance of Cart-Ruts in Ancient Landscapes*. Malta, Midsea. Pp. 169-176.

Magro Conti, J., Saliba, P.C. (2007c). Dating. In: J. Magro Conti and P.C. Saliba (eds.), *The Significance of Cart-Ruts in Ancient Landscapes*. Malta, Midsea. Pp. 73-107.

Magro Conti, J., Saliba, P.C. (2007d). Vehicles and purpose. In: J. Magro Conti and P.C. Saliba (eds.), *The Significance of Cart-Ruts in Ancient Landscapes*. Malta, Midsea. Pp. 109-120.

Magro Conti, J., Saliba, P.C. (2007e). Description, history and archaeology of cart ruts. In: J. Magro Conti and P.C. Saliba (eds.), *The Significance of Cart-Ruts in Ancient Landscapes*. Malta, Midsea. Pp. 35-51.

Köpp-Junk, H., 2016. Wagons and carts and their significance in Ancient Egypt. Journal of Ancient Egyptian Interconnections 9, 14–58.

McLaughlin, T.R., Stoddart, S., Malone, C., 2018. Island risks and the resilience of a prehistoric civilization. World Archaeol. 50 (4), 570–600.

Mottershead, D., Pearson, A., Schaefer, M., 2008. The cart ruts of Malta: an applied geomorphology approach. Antiquity 82 (318), 1065–1079.

Mottershead, D., Pearson, A., Farres, P., Schaefer, M. (2019), Humans as agents of geomorphological change: The case of the Maltese cart-ruts at Misraħ Għar Il-Kbir, San Ġwann, San Pawl Tat-Tarġa and Imtaħleb. In: R. Gauci, J.A., Schembri (eds.) *Landscapes and Landforms of the Maltese Islands*. Springer: Cham. Pp. 103-116.

Murray, M.A., 1928. The cart-ruts of Malta. *Man* 28, 21–22.

Ogata, M., Tsutsumi, I., Shimotsuma, Y., Shiotsu, N. (2006). Origin of the world's standard gauge railway is in the interval of wheel ruts of ancient carriages. The International Conference on Business and Technology Transfer 2006, 3: 98-103 (available online at https://www.jstage.jst.go.jp/article/jsmeicbtt/2006.3/0/2006.3_98/_article).

Parker, R., Rubenstein, M., 1984. The cart-ruts on Malta and Gozo. Gozo Press, Malta.

Pedley, M. (2007). Sedimentological study of karstic landforms and associated cart ruts at Misraħ Għar il-Kbir, T'Alla w Ommu, and Dwejra sites. In: J. Magro Conti and P.C. Saliba (eds.), *The Significance of Cart-Ruts in Ancient Landscapes*. Malta, Midsea. Pp. 53-72.

Pedley, M., Clarke, M.H., Galea, P., 2002. Limestone Islands in a Crystal Sea. Publishers Enterprise Group, Malta.

Piggott, S., 1983. The Earliest Wheeled Transport. From the Atlantic Coast to the Caspian Sea, Thames and Hudson, London.

Sagona, C., 2004. Land use in prehistoric Malta: A re-examination of the Maltese 'cart ruts'. Oxford J. Archaeol. 23 (1), 45–60.

Sagona, C., 2015. The Archaeology of Malta: from the Neolithic through the Roman period. Cambridge University Press, Cambridge.

Schneider, G., 2001. Investigating historical traffic routes and cart-ruts in Switzerland, Elsass (France) and Aosta Valley (Italy). The Oracle 2, 12–22.

Smith, D.J., 2008. Discovering Horse-Drawn Transport of the British Army. Shire Publications, Princes Risborough.

Stoddart, S., Pace, A., Cutajar, N., Vella, N.C., McLaughlin, R., Malone, C., Meneely, J., Trump, D. (2020). Cultural landscapes from 2000 BC onwards. In: French, C., Hunt, C.O., Grima, R., McLaughlin, R., Stoddart, S., Malone, C (eds.) (2020). *Temple Landscapes: Fragility, change and resilience of Holocene environments in the Maltese Islands*. McDonald Institute for Archaeological Research, Cambridge, pp. 241-252.

Trump, D., 1998. The cart ruts of Malta. Treasures of Malta 4, 33–37.

Trump, D., 2002. Malta: Prehistory and Temples. Midsea Books, Santa Venera.

Trump, D. (2004). The enigma of cart ruts. In: D. Cilia (ed.), *Malta Before History*. Malta, Miranda, Pp. 379-398.

Trump, D.H., Cilia, D., 2008. Cart-ruts and their impact on the Maltese landscape. Heritage Books, Santa Venera, Malta.

Ventura, F., Tanti, T., 1994. The cart tracks at San Pawl tat-Tarġa, Naxxar. Melita Historica 11, 219–240.

Weston, G.E., 2010. The Maltese cart-ruts: Unravelling and Enigma. Progress Press, Valetta.

Zammit, T., 1928. Prehistoric cart-tracks in Malta. Antiquity 2 (5), 18–25.