Modeling Roman Trade with GIS: A Study of 1st Century *Terra Sigillata* Transportation Routes in Southern Gaul

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I. Abstract

Ceramic remains are the most abundant evidence of Roman economic activity in the archaeological record. The manufacture, consumption, and transportation of pottery across the Roman world can therefore serve as a useful foundation for understanding the Roman economy as a whole. *Terra sigillata*, a high-quality tableware manufactured across the western provinces of the Roman Empire, was a popular and widely exported commodity in the 1st and 2nd centuries AD. However, the exact routes and methods used to transport *terra sigillata* from production centers to markets and consumers are not always clearly understood and have remained largely unexplored in geospatial analyses. Although the method of least cost analysis has been employed to examine the relationship between mobility and geography in numerous archaeological contexts, its use in the context of Roman trade is relatively unexplored. The objective of this study is to investigate the potential transportation routes between a *terra sigillata* production and distribution center, using the major kiln complex at La Graufesenque, and the nearby port of Narbonne, in southwestern Gaul, as a case study. This is accomplished through a least cost analysis based on the topographic and hydrological conditions of southwestern France and the Roman road network. The resulting least cost paths represent the likely routes available to 1st and 2nd century *terra sigillata* manufacturers and can contextualize the decisions made when negotiating their landscapes to interact with the wider economy and bring their goods to consumers.

II. Background

Introduction

Ceramic remains are the most abundant evidence of Roman economic activity in the archaeological record (Peacock, 1982; Peña, 2007). The manufacture, consumption, and movement of pottery across the Roman world can therefore serve as a useful foundation for understanding the Roman economy as a whole (Peacock, 1982). *Terra sigillata*, a style of pottery first developed in Italy at the end of the 1st century BC, was immensely popular throughout the 1st and 2nd centuries AD and is found in plentiful quantities throughout the Roman world (Willis, 2011; Mirti, Appolonia & Casoli, 1999; Oyen, 2015). Therefore, *terra sigillata* is particularly well-positioned to be considered a representative commodity or indicator of the scale and complexity of the 1st century Roman economy (Willis, 2011; Fulford, 2013; Oyen, 2015).

This study will utilize GIS and geospatial analysis to explore the possible transportation routes between La Graufesenque, an important center of 1st century *terra sigillata* production in southern Gaul, and Narbonne, a close regional port and likely distribution center (Middleton, 1980; Fulford, 2013). Modeling these routes can contextualize the decisions that Roman era manufacturers made when negotiating their landscapes to interact with the wider economy and bring their goods to consumers. Furthermore, the techniques and methods developed in this study can also be used to comprehend the potential transportation routes between centers of production, distribution, and consumption associated with other styles of Roman pottery, or with other contemporary trade goods.

Terra Sigillata: An Introduction

Terra sigillata is a style of Roman pottery characterized by a glossy surface and red coloration (Willis, 2011; Mirti, Appolonia & Casoli, 1999; Oyen, 2015). It was part of a broader category of pottery termed *fineware*, which consisted of the types of ceramics used in everyday dining, such as plates, bowls, and cups (Mirti, Appolonia & Casoli, 1999; Oyen, 2015). Consumers across the Roman world widely recognized *terra sigillata* as being of remarkably high quality, even above other styles of *fineware*, and it perhaps attained some role in provincial social display as a marker of status and taste (Mees, 2018; Willis, 2011). This reputation for quality, however, was reflected in its cost, and *terra sigillata* could command high prices in the marketplace (Willis, 2011).

Despite its cost, *terra sigillata* was exceptionally popular for nearly two centuries, achieving a wide circulation amongst the various social and cultural classes that comprised the population of the western Roman Empire (Willis, 2011). Due to its former popularity, fragments of *terra sigillata* ceramics are found in abundant quantities across much of western Europe, particularly Britain and France (Willis, 2011; Mees, 2018). Archaeologists have therefore had an ample opportunity to extensively study *terra sigillata*, compiling a significant scholarly record of its typological characteristics and various production centers, leading to its becoming of one the most comprehensively studied styles of Roman pottery (Willis, 2011; Fulford, 2013; Oyen, 2015).

The production of terra sigillata originated in central Italy around 30 BC, in the city of Arezzo (Mees, 2018; Mirti, Appolonia & Casoli, 1999; Oyen, 2015). Throughout the 1st and 2nd centuries

AD, the production of the style gradually spread across the western half of the Roman world (Willis, 2011). As production extended into new regions, numerous regional styles of *terra sigillata* developed (Willis, 2011). This was especially true of Gaul, where numerous regional production centers emerged (Willis, 2011).

***Terra Sigillata* Production in La Graufesenque**

In the beginning of the 1st century AD, southern Gaul emerged as a center of *terra sigillata* production, and pottery manufacture there would flourish until the middle of the 2nd century (Mees, 2018; Oyen, 2015). Although numerous kiln complexes were active in southern Gaul during this period, by far the most important was La Graufesenque, on the outskirts of the minor Roman settlement of *Condatomagus*, or modern-day Millau, France (Middleton, 1980; Fulford, 2013). Archaeologists have studied the site for nearly a century, with the first excavations occurring in the 1920s, and numerous subsequent studies seeking to understand the output, structure, and distribution of individual pottery makers at the complex (Middleton, 1980; Allen, 2013).

La Graufesenque has long been recognized as an important site of archaeological interest (Middleton, 1980). The *terra sigillata* created there achieved a staggeringly wide distribution across the western provinces of the Roman Empire (Middleton, 1980; Allen, 2013). In this respect, La Graufesenque is somewhat unique among other centers of *terra sigillata* production, or other centers of Roman pottery manufacturing as a whole (Lewit, 2013). Ceramics from other sites were typically traded on a more limited regional or provincial scale and did not reach the level of prominence attained by La Graufesenque (Lewit, 2013). However, despite the prominence of the site, the exact reasons why La Graufesenque developed such dominance over other production centers are not precisely known, and remain subject to speculation (Lewit, 2013).

The geography of the region surrounding La Graufesenque does not contain any particular advantages to trade, and instead restricted the possible forms of transportation and accessible markets available to the *terra sigillata* manufacturers located there (Lewit, 2013). As previously stated, La Graufesenque was located near a minor Roman settlement, and was additionally on the banks of the Tarn River (Middleton, 1980; Oyen, 2015). The Tarn, a tributary of the Garonne River, could have allowed access to the port of Bordeaux, and thus, other Atlantic markets, but the water levels of the Tarn may have been too low for navigable shipping during Roman times (Middleton, 1980). Furthermore, La Graufesenque also lies within a steep valley at the northern edge of the Causse du Larzac plateau, which similarly constrained overland approaches to the site (Oyen, 2015).

The Distribution of Pottery from La Graufesenque

Regardless of the difficulty of the terrain around La Graufesenque, the *terra sigillata* manufactured there needed to arrive at a distribution center to reach consumers in the various military installations and urban centers of the Roman Empire (Oyen, 2015). Narbonne, an important seaport in the 1st and 2nd centuries AD, and one of the closest major ports to La Graufesenque, was the most likely distribution center for La Graufesenque *terra sigillata* (Middleton, 1980; Fulford, 2013; Oyen, 2015). By shipping their pottery to Narbonne, the manufacturers of La Graufesenque could tap into the complex trade networks and highly developed urban markets of the Mediterranean world (Middleton, 1980; Fulford, 2013; Oyen, 2015). From Narbonne, *terra sigillata* from La Graufesenque would have been sent across the Roman world (Oyen, 2015

The exact routes that the *terra sigillata* manufacturers of La Graufesenque used to transport their goods to Narbonne are not conclusively known, and therefore, much of the scholarship on the matter is primarily speculative (Dannell & Mees, 2013). Middleton (1980) conducted one of the most thorough and widely-recognized investigations into these routes and identified a generalized overland route between La Graufesenque and Narbonne, and the means of transportation used to undertake this journey. First, mules carried pottery out of the valley in which La Graufesenque lies (Middleton, 1980). Then, after being loaded onto carts, the pottery was shipped southwards, across Causse du Larzac plateau, to the port of Narbonne, utilizing the available road systems (Middleton, 1980). Middleton (1980) additionally identifies the sites of Ceilhes and Salèlles as potential intermediary distribution centers, due to the quantity of La Graufesenque *terra sigillata* uncovered at these sites, and their locations at the head of valleys at the edge of the Causse du Larzac plateau. However, Middleton did not identify the details of its course, or provide a visualization of his route, and therefore, this route not been explored through GIS or through the methods of geospatial analysis.

The Role of GIS in Archaeology

The use of Geographic Information Systems (GIS) has become an accepted and commonplace part of the practice of archaeology. The technology has provided archaeologists with new ways of performing routine tasks such as data management, data visualization, and spatial and geostatistical analysis (McCoy & Ladefoged, 2009). However, despite the pervasiveness of GIS, a prevailing theme among recent evaluations of its position within archaeology is an emphasis on the need for critically examining its role within the discipline (Burg, 2017; Howey & Burg, 2017; Lock & Pouncett, 2017). It has been argued that there has been a tendency among archaeologists to view GIS as merely an analytical or representational tool, rather than as a comprehensive methodological approach with its own intricacies and limitations (Burg, 2017; Howey & Burg, 2017; Lock & Pouncett, 2017). Archaeological criticisms of GIS have focused on its perceived inability to capture the complexities of humanist or experiential understandings of geographic space (Lock & Pouncett, 2017). Therefore, proponents of GIS in archaeology have maintained that its use should not be divorced from archaeological theory and should instead more fully engage with it in geospatial analysis (Burg, 2017; Lock & Pouncett, 2017; McCoy & Ladefoged, 2009).

Despite these theoretical concerns about the utilization (or misuse) of GIS in archaeology, some believe that GIS has the potential to free archaeologists from the conceptual limitations that have long characterized the discipline, allowing archaeologists to ask and investigate new types of questions about the human past (Howey & Burg, 2017; Whitley, 2017). For example, GIS may enable archaeologists to move beyond the confines of the concept of the archaeological site and understand a landscape in its totality, perhaps closer to how past individuals and societies may have perceived it (Howey & Burg, 2017; Whitley, 2017). GIS is particularly appropriate for the analysis of entire landscapes, and perhaps for this reason, analyses of mobility and visibility within past landscapes have tended to predominate in archaeological GIS (Howey & Burg, 2017).

Least Cost Analysis in Archaeology

Investigations of mobility, particularly the manner in which past people interacted and negotiated with the landscapes they inhabited, have long been of interest of archaeologists, but the emergence of specialized and complex toolsets within GIS has given archaeologists the means to more thoroughly explore these issues (Lock, Kormann & Pouncett, 2014; Llobera, Fabrega-Alvarez & Parcero-Oubiña, 2011; Llobera, 2000). Least cost analysis is a commonplace method employed by archaeologists to analyze or model the potentialities of movement or the possible routes across past landscapes in GIS (Llobera, Fabrega-Alvarez & Parcero-Oubiña, 2011; Herzog, 2014). Although other methods have been proposed, least cost analysis remains the predominant technique utilized in archaeological studies regarding mobility, and the proposed alternatives largely build upon its well-established framework (Howey, 2011; White & Barber, 2012).

In the earlier days of archaeological GIS, slope was typically the only potential impediment to mobility incorporated into least cost analyses (Bell & Lock, 2000; Bell, Wilson & Wickham, 2002). However, the importance of cultural and anthropogeographic landscape features, and their influences on mobility, are increasingly incorporated, or at least acknowledged, in archaeological least cost analyses (Howey, 2007; Fabrega-Alvarez & Parcero-Oubiña, 2007; Gustas & Supernant, 2017). The emergence of multi-criteria least cost analysis has also allowed archaeologists to incorporate specific variables unique to a particular study area into their analyses, although this technique is not always plausible, especially when information on past environments is missing or unreliable (Howey, 2007; Gustas & Supernant, 2017; Taliaferro, Schriever & Shackley, 2010). Archaeologists have also continually pushed to further adapt least cost analysis to better capture the realities of movement within past landscapes, and have encouraged more complete understandings and integrations of various archaeological conceptions of movement and space into their investigations (Bell & Lock, 2000; Herzog, 2014; Llobera, Fabrega-Alvarez & Parcero-Oubiña, 2011).

Archaeologists utilize least cost analysis to answer a wide-ranging number of questions concerning the different aspects of mobility within past landscapes. However, it is the modeling of potential trade routes, exchange networks, and the transportation of commodities that I am most concerned with here, and several archaeological studies centered on least cost analysis have investigated the relationship between trade and mobility (Taliaferro, Schriever & Shackley, 2010; McCoy et al., 2011; Leidwanger, 2013). Other archaeological studies, while not focused solely on trade or exchange, have nonetheless examined these associations with least cost analyses as well, linking trade with other areas of archaeological interest, including political development and expansion, settlement location choice, megalithic construction, and the degree of interconnectivity between societies (Batten, 2007; Sherman et al., 2010).

The Methodology of Least Cost Analysis

Least cost analysis is a common geospatial methodology that "models the cost of moving from a specified origin to one or more destinations;" in archaeology, this type of analysis generally assesses how easily navigable a landscape is, and determines the most likely or the most plausible routes for traversing that landscape (Conolly & Lake, 2006). In this form of analysis, the "cost" most frequently refers to either the time or energy expenditure associated with traveling across a landscape (Conolly & Lake, 2006; Wheatley and Gillings, 2002). Least cost analysis is nearly always conducted on raster datasets, in which a continuous surface composed of equally sized, usually square, cells represents geographic space (Conolly & Lake, 2006; Lock & Pouncett, 2017). In least cost analyses, each cell corresponds to a section of landscape, and has a cost associated with either the amount of time required to move through it, or the amount of energy expended while traversing it (Conolly & Lake, 2006; Wheatley & Gillings, 2002). These costs are calculated by using a cost function which simulates the time or energy expenditure of travel (Conolly & Lake, 2006). The choice of cost function is generally dependent on the available modes of transportation or a particular perception of mobility, although in archaeological analyses, cost functions simulating pedestrian travel tend to predominate, and archaeologists have utilized a number of different cost functions for this purpose (Herzog, 2010).

Least cost analysis is a multi-step process which can roughly be broken down into three steps: the creation of a cost-of-passage map, the creation of an accumulated cost surface, and the creation of a least cost path (Atkinson et al., 2005). First, a cost-of-passage map, also known as a friction surface, "models the cost of traversing each individual map cell" as based on the specified cost variable (as previously mentioned, usually time or energy expenditure) (Conolly & Lake, 2006). If multiple variables are identified, then "a friction surface is created for each criterion," and then "weighted and combined to create a cost-of passage surface" (Atkinson et al., 2005). The next step is to produce an accumulated cost surface, which "is calculated by applying a spreading function to a cost-of-passage map" (Conolly & Lake, 2006). Lastly, the line of cells with the least accumulated cost "is traced down the accumulated-cost-surface from a departure point to a destination," thereby creating the least cost path (Atkinson et al., 2005).

Cost surfaces can be considered either isotropic or anisotropic; these two forms of cost surfaces rely on different conceptions of mobility or differing interpretations of how landscape features affect movement (Conolly & Lake, 2006; Wheatley & Gillings, 2002). Isotropic cost surfaces, the simpler of the two conceptions, are those in which the cost of traversing a cell is "the same irrespective of the direction in which one is traveling" (Conolly & Lake, 2006). Alternatively, an anisotropic cost surface is one in which "costs are dependent on both the direction of travel and the attributes of individual map cells;" for example, walking on flat ground is faster or less exhausting than walking uphill, but walking at an incline of 1˚ is far less strenuous than walking at an incline of 30˚ (Conolly & Lake, 2006).

Although a vast number of factors that might potentially influence mobility are present throughout any given landscape, slope is generally recognized as being the most important (Herzog, 2014). For this reason, slope is usually what cost functions that simulate traveling speed or energy expenditure are based around (Herzog, 2014; Wheatley & Gillings, 2002; Conolly & Lake, 2006). However, the influence that other landscape features might have on movement can also be incorporated into least cost analyses. Rather than focusing on a single criterion, such as slope, these analyses focus on multiple criteria (Atkinson et al., 2005). Landscape features such as water bodies, roads, land cover, soil types, or significant cultural features can be designated as either impediments or attractors to movement (Herzog, 2014; Wheatley & Gillings, 2002; Conolly & Lake, 2006). For example, navigable waterways like rivers may be treated as being conducive to mobility, and the resulting least cost path might then make use of rivers as corridors of movement (Herzog, 2014; Wheatley & Gillings, 2002). Conversely, important social or cultural forces affect how people conceptualize their world, and some areas may be seen by the traveler as being dangerous or polluting, and therefore the resulting least cost path may avoid these regions, even if the path is less optimal as a result (Herzog, 2014). Incorporating multiple criteria into least cost analysis can, in theory, allow archaeologists to more completely replicate and comprehend past movements and landscapes, though, in practice, this can be difficult to effectively implement (Herzog, 2014).

Despite its utility, least cost analyses have a number of methodological limitations. First, some amount of error is unavoidable, since the number of directions least cost path algorithms can progress across an accumulated cost surface in is limited by the number of cell adjacencies allowed by the raster format (Conolly & Lake, 2006; Wheatley & Gillings, 2002; Herzog, 2014). This error can, however, at least be mitigated by allowing the least cost path algorithm to move in more mathematically complex ways across the surfaces (Herzog, 2014; Wheatley & Gillings, 2002). Additionally, in slope-based analyses, the accuracy of the cost surface or least cost path is highly dependent on the quality of the DEM used to derive the slope from (Wheatley & Gillings, 2002; Herzog, 2014). If the DEM is of an insufficient resolution for suitable analysis, then the cost surfaces and paths will be unsatisfactory (Wheatley & Gillings, 2002; Herzog, 2014). Least cost analyses are also generally limited to modeling routes between a single origin and destination point, and the technique is not well-suited to concurrently modeling routes between multiple origins and destinations (Conolly & Lake, 2006). Lastly, identifying and recreating all of the factors relevant to mobility within a given context, as well as the magnitude of these factors upon movement, can be exceptionally difficult, if not impossible in some cases (Herzog, 2014). Often, our current understandings of past environments are too incomplete or uncertain to fully replicate landscapes as past people would have understood them (Herzog, 2014).

A Review of Similar Studies

Archaeological least cost studies on trade and landscape mobility share some methodological and analytical commonalities. Perhaps most importantly, slope remains the primary variable upon which these analyses are structured, although there is a growing recognition of the anisotropic nature of slope in certain contexts (Taliaferro, Schriever & Shackley, 2010; McCoy et al., 2011; Batten, 2007). Additionally, current studies have principally applied least cost analysis in investigating the potentialities of pedestrian travel across a landscape, and modeling routes based on vehicular or mounted travel is rare (Taliaferro, Schriever & Shackley, 2010; McCoy et al., 2011; Batten, 2007; Sherman et al., 2010). Lastly, relatively few studies incorporate marine environments or maritime forms of transportation into their analyses, despite the obvious importance of maritime travel and trade to numerous prehistoric and early historic societies (Leidwanger, 2013). Unlike with terrestrial trade routes and exchange networks, the application of least cost analysis to modeling maritime trade networks has so far been relatively unexplored (Leidwanger, 2013).

Similarly, a somewhat limited nature in the geographic and historic contexts of these studies is also evident. The study areas explored in recent analyses are typically confined to the southwestern United States or Mesoamerica, although some exceptions exist (Batten, 2007; Sherman et al., 2010; Taliaferro, Schriever & Shackley, 2010). For example, McCoy et al. (2011) use the main island of Hawaii as a study area, and Leidwanger (2013) examines trade within the southeastern Aegean. Likewise, the selection of historical contexts is also somewhat limited, and previous studies have more closely focused on analyzing prehistoric exchange networks than historic trade routes (Taliaferro, Schriever & Shackley, 2010; McCoy et al., 2011; Sherman et al., 2010; Batten, 2007). Additionally, prior studies concentrating on modeling or tracking the exchange routes of a specific trade good tend to be predominantly concerned with the distribution of lithic resources, which are common within the archaeological record and often traceable back to a particular source (Taliaferro, Schriever & Shackley, 2010; McCoy et al., 2011).

Goals and Objectives

This study has two central objectives:

1. To model a route, though the use of least cost analysis in GIS, between La Graufesenque, a major center for *terra sigillata* production in the 1st century, and Narbonne, the closest and most likely transshipment port in the region. It is important to note that the modeled route does not necessarily constitute the actual route that was historically used, and it should perhaps be best understood as one of the many potential routes, albeit a likely one, that the *terra sigillata* manufacturers of La Graufesenque took advantage of to transport their goods abroad.
2. To evaluate and visualize the route between La Graufesenque and Narbonne proposed by Middleton (1980), which runs south from La Graufesenque, across the plateau of the Causse du Larzac, to Narbonne, potentially by way of the intermediary centers of Ceilhes and Salèlles, located at the southern edge of the plateau.

Lastly, a minor, third objective of this study is to demonstrate the utility of least cost analysis in modeling the trade routes that spanned the Roman Empire, particularly the movements between production centers, their primary distribution points, and largest centers of consumption. Although this study is limited in scope, future applications of this methodology to the context of Roman trade can potentially reveal new insights into the organization, scale, and complexity of the Roman economy, and the economic relations between different parts of the Roman world.

III. Methodology

Study Area

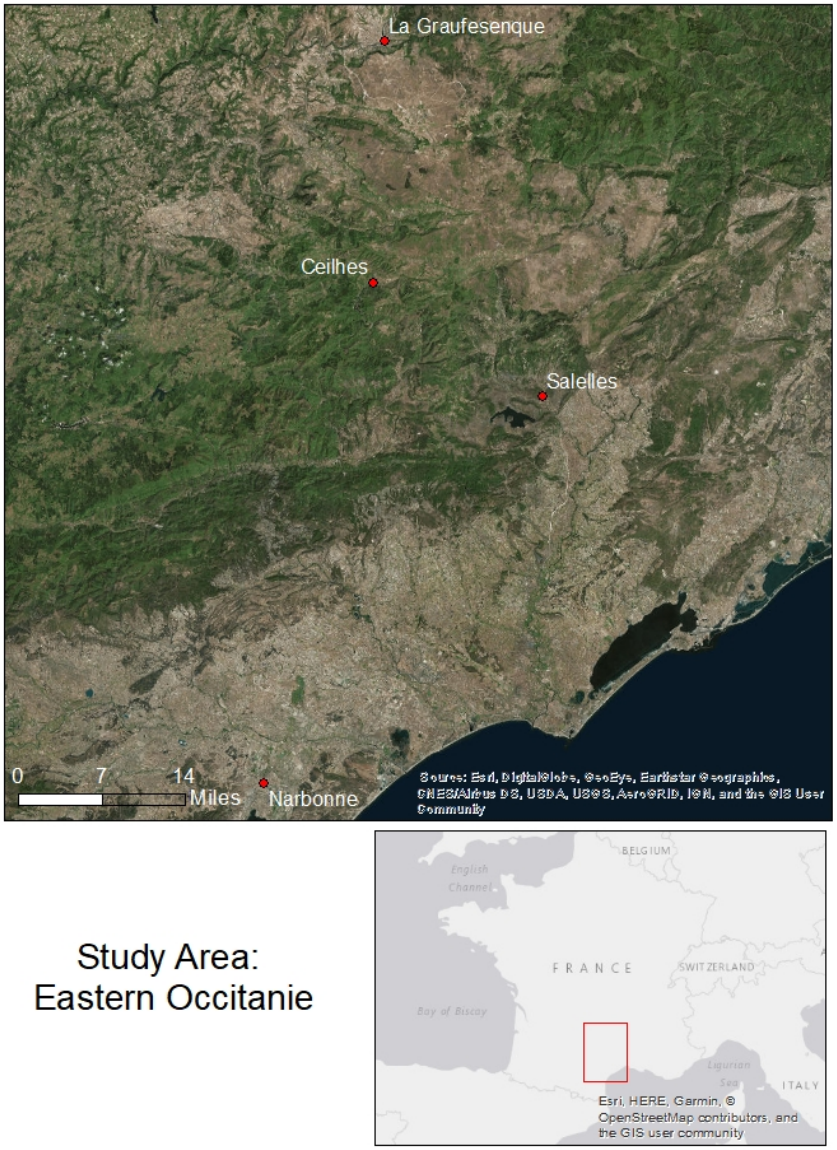


Figure 1. A map of the study area in the eastern section of the French region of Occitanie, located in the southwest of the country, depicting the locations of the sites relevant to this analysis.

This study is primarily concerned with a section of southwestern France, within the region of Occitanie (specifically, sections of the departments of Averyon, Hérault, Aude and Tarn), comprising of the landscape immediately surrounding and between the sites of La Graufesenque (in the department of Aveyron) and Narbonne (in the department of Aude). These sites are located within relative proximity to each other, only separated by about 63 miles. The surrounding region is dominated by the Massif Central, a highland region that extends across much of south-central France. La Graufesenque, on the southern banks of the Tarn River, lies at the northern edge of the Causse du Larzac, a karst limestone plateau that forms part of the southern Massif Central, and reaches an elevation of approximately 3000 ft. The towns of Ceilhes and Salèlles (both within the department of Hérault) are located at the southern edge of this plateau, on the shores of the Orb and Lergue Rivers, respectively. As the landscape extends south towards the Mediterranean, the rugged terrain of the Massif Central gives way to coastal plains. The city of Narbonne lies in these coastal lowlands, near the Mediterranean coast.

The Roman Republic first established a permanent presence in what is now southern France in the late 120s BC, as the result of a series of campaigns defending the Greek city-state of Massalia (Marseilles), a Roman ally, from the native Celtic inhabitants of the region (Drinkwater, 1983). In the years following this victory, Rome strengthened their position in the region by founding a colony at Narbo Martius (Narbonne), and by constructing a great road, the Via Domitia, through this newly acquired territory (Drinkwater, 1983). The Via Domitia established an overland route from Rome's Italian heartland to Spanish provinces, and therefore southern Gaul (Gallia Transalpina, though usually simply referred to as "The Province") came to hold a special strategic significance for the Roman state (Drinkwater, 1983).

The remainder of Gaul north of "The Province", comprising of a vast territory from the Atlantic in the west to the Rhine River in the east, had decidedly less previous contact with the Mediterranean world, and was only brought under Roman control through the rather well-documented campaigns of Julius Caesar in the 50s BC (Drinkwater, 1983). After Caesar's assassination in 44 BC, Rome was embroiled in civil war; however, this did not prevent Caesar's heir, Octavian (the future Emperor Augustus) from promoting development in the region, which fell under his control (Drinkwater, 1983). Following his ultimate victory in these civil wars, the newly-crowned Augustus, in 27 BC, reorganized the administrative divisions within Gaul, separating it into four provinces (Drinkwater, 1983; King, 1990). The older Roman possession of "The Province," in southern Gaul, was reconstituted as Gallia Narbonensis, with its capital at Narbonne, whereas the more territories more recently acquired by Caesar were partitioned into the provinces of Aquitania, in southwest and central Gaul, Gallia Lugdunensis, primarily in northern Gaul, and Gallia Belgica, in the northeast (Drinkwater, 1983; King, 1990; Sitwell, 1981).

In 39 BC, Octavian assigned his friend Marcus Vipsanius Agrippa the governorship of Gaul, still a single province, and during his tenure as governor, Agrippa did much to development the transportation network of the region (Drinkwater, 1983; King, 1990). Agrippa began the construction of a road network, linking the most important urban and administrative centers in the region; the city of Lugdunum (Lyon), capital of Gallia Lugdunensis, was selected to act as the central hub in this network (Drinkwater, 1983; King, 1990). However, it was not until the reign of the Emperor Claudius in the mid-1st century AD that the road network begun by Agrippa was brought to completion (Drinkwater, 1983).

Data and Materials

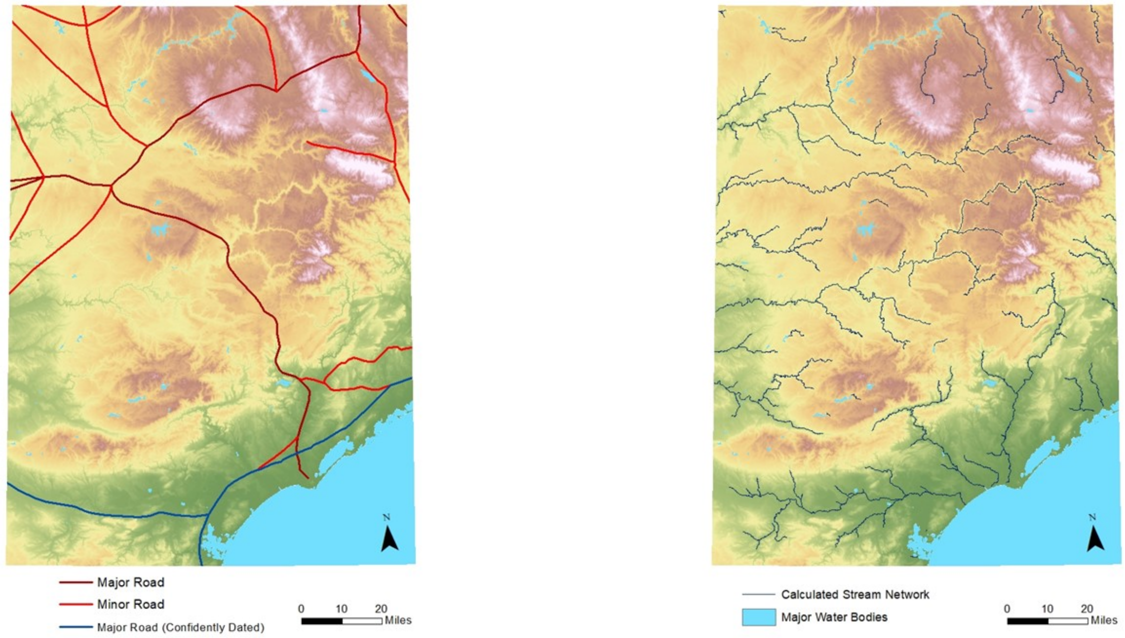


Figure 2. A map showing the Roman road shapefile developed by McCormick et al. (2008) within the area of interest (Left); and a map displaying the results of the accumulation analysis with the SRTM Water Bodies Dataset (Right).

To represent the locations of La Graufesenque, Ceilhes, Salèlles, and Narbonne, four point shapefiles, one for each location, were created in ArcGIS 10.6. The placement of these shapefiles was derived from the geographic coordinate information provided in the Getty Thesaurus of Geographic Names, a free online gazetteer maintained by the J. Paul Getty Trust (J. Paul Getty Trust, 2017). The Getty Thesaurus of Geographic Names includes both historical and modern names for the same locations (J. Paul Getty Trust, 2017).

There are three datasets, representing different analytical criteria, from which the friction surface representative of overland travel in 1st century southern Gaul, and ultimately the least cost paths between La Graufesenque, Ceilhes, Salèlles, and Narbonne will be derived. These datasets consist of:

1. An elevation dataset, SRTM 1-Arc Second Digital Elevation Models (DEMs), covering a portion of southwestern France. These rasters, with a cell size of 1 arc second, or about 30m, were produced as part of the Shuttle Radar Topography Mission (SRTM) and were acquired through the United State Geological Survey (USGS) online data repository, EarthExplorer (USGS, 2015). The slope of the landscape of southern France will be derived from this dataset.
2. A water body dataset, SRTM Water Body Data, which consists of polygon shapefiles of large water bodies within the same geographic extent as the elevation data outlined above. This dataset, also produced as part of the Shuttle Radar Topography Mission, can also be found at the USGS online data repository EarthExplorer (USGS, 2015).

3. A dataset depicting the Roman road system, constituted by a shapefile developed in 2008 by McCormick et al., compiled from the information contained in *The Barrington Atlas of the Greek and Roman World* (Talbert, 2000). This dataset can be acquired from the Digital Atlas of Roman and Medieval Civilizations (DARMC), an online data repository developed by Harvard (DARMC, 2018). These roads were originally mapped at a scale of either 500,000 or 1,000,000, and therefore, only the general course of known roads across the Roman world are depicted (Talbert, 2000). Additionally, there is no indication of when, or for how long, such roads were in use, or when these roads were constructed.

Methods and Analysis

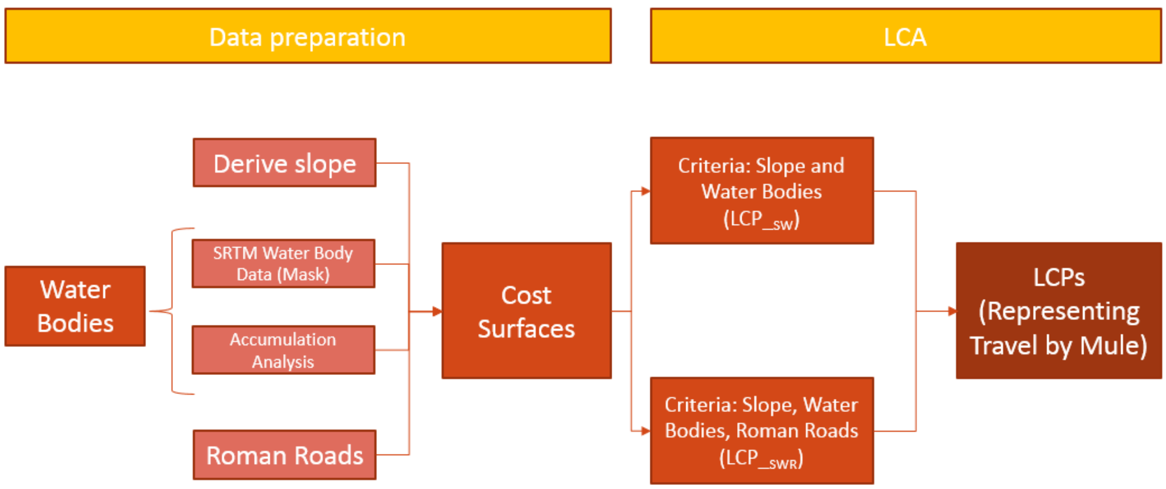


Figure 3. A workflow representing an overview of the methodological process employed in this study.

Two friction surfaces, representing two different scenarios that those transporting La Graufesenque pottery may have encountered, were created in ArcGIS 10.6 to simulate the conditions of overland travel in landscape of 1st century Gaul. These friction surfaces were based on three analytical criteria, representing different geographic features that might influence overland travel:

1. Percent slope, which was derived from the mosaicked SRTM DEMs, and reclassified according to the scale devised by Pozzi and Robinson (2008). However, since Pozzi and Robinson's scale runs from 100 (signifying 100% of a maximum potential speed) to 10 (denoting 10% of this maximum speed), it was necessary to reorient the scale so that higher values represent higher costs, and lower values lower costs (2008). This was achieved by dividing 100, the base value, by the percent of maximum speed for each range of slope values. Therefore, for example, travelling at 10% of maximum potential speed for slopes of more than 32% is assigned the value of 1000 (100/0.1 = 1000; for instance, if it takes one hour to traverse one mile, travelling at only 10% of this speed would render the journey ten times longer, or ten hours).

Slope (%)	New Reclassified Value
0-2	100
2-5	125
5-8	167
8-12	200
12-16	250
16-32	500
32+	1000

Table 1. The percent slope cost values reoriented, based on the scale formulated by Pozzi and Robinson (2008), so that higher values denote higher costs, and lower values lower costs.

2. Water bodies, which were divided into two categories: those large enough to be included within the SRTM Water Body Dataset, and a network of major streams and rivers, the result of an accumulation analysis. Within this particularly study area, the former category consists of lakes, the Mediterranean Sea, and those sections of major rivers where the riverbed covers a relatively wide area. These larger water bodies were excluded from the analytical workspace by applying a mask; obviously the presence of standing water precludes the possibility of overland travel. An accumulation analysis was conducted to estimate the locations of prominent streams and rivers throughout the study area. A few river segments appear disconnected from the stream network; these sections are flowing into river surfaces deemed large enough for inclusion in the SRTM Water Body dataset. The results of this analysis were converted into polyline shapefiles to capture individual stream beds, and then converted back to the raster format and assigned the relatively high value of 1000. This was to disincentivize the least cost paths from directly following stream beds, and to represent the cost associated with fording a smaller water body.
3. Roman roads, specifically those that can confidently be assumed to have existed during La Graufesenque's years of operation in the 1st century. The road shapefiles developed by McCormick et al. (2008) were compared to their sources in the *Barrington Atlas*, and edited if any discrepancies appeared. Although informal networks of paths or trails were likely present at the time, probably predating the Roman conquest, they are difficult to identify, although some were perhaps used as the foundation for later Roman additions to the road network (Drinkwater, 1983; Sitwell, 1981). However, the Via Domitia, constructed at the end of the 2nd century BC, and a road extending west from Narbonne towards Toulouse, an Augustan era construction, were certainly contemporaneous with La Graufesenque's period of prominence (Drinkwater, 1983; Sitwell, 1981). These roads were assigned the value of 10, whereas any land off-road was given the value of 100. These values were decided at after repeated testing; higher values for both on-and-off road travel resulted in least cost paths that cut across the landscape to the nearest point in the road network with little regard for topography, although the ratio between on-and-off road travel was kept at 1:10 in all tests. In effect, this lowers the significance of roads relative to the other criteria. However, it can reasonably be assumed that one would not follow a direct bearing to the closest point on a road, and would instead likely decide a course in accordance with local topographic conditions until the road within proximity.

These criteria were reclassified to the specified weights, and combined to produce the two friction surfaces. The first friction surface simulated overland travel in 1st century Gaul based on the criteria of percent slope and the calculated stream network; for the second surface, the Via Domitia and the road extending from Narbonne to Toulouse (outside of the study area) were added. For both surfaces, five least cost paths (LCP) were calculated, representing routes from: (1) La Graufesenque directly to Narbonne, (2) La Graufesenque to the intermediary market town of Ceilhes, (3) La Graufesenque to another intermediary market town, Salèlles, (4) Ceilhes to Narbonne, and (5) Salèlles to Narbonne. Finally, the LCPs were grouped based on destination, and overlaid to detect any commonalities between the two methodologies, and to produce a generalized description of the routes.

For the purposes of display, and in the discussion that follows below, routes between La Graufesenque and an intermediary market town, and thence from the market town to Narbonne, shall be considered as one unit. Therefore, the three types of paths shall hereafter be referred to as La Graufesenque-Narbonne, La Graufesenque-Ceilhes-Narbonne, and La Graufesenque-Salèlles-Narbonne. Likewise, for the remainder of this study LCP based on slope and water bodies will be referred to as LCP_{SW} (where S = slope and W = water bodies) and LCP based on slope, water bodies, and Roman roads as LCP_{SWR} (where S = slope, W = water bodies, and R = Roman roads).

IV. Results and Discussion

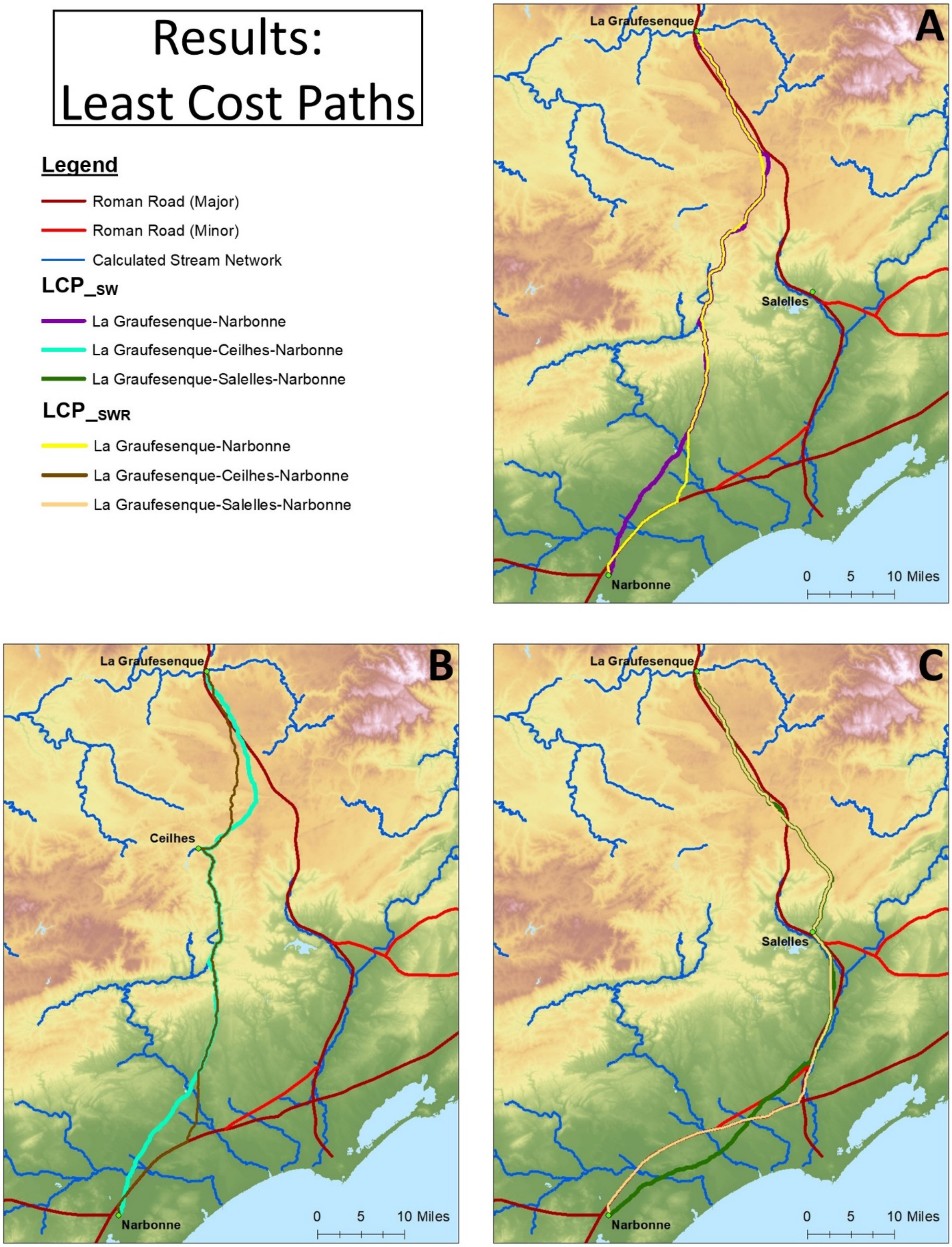
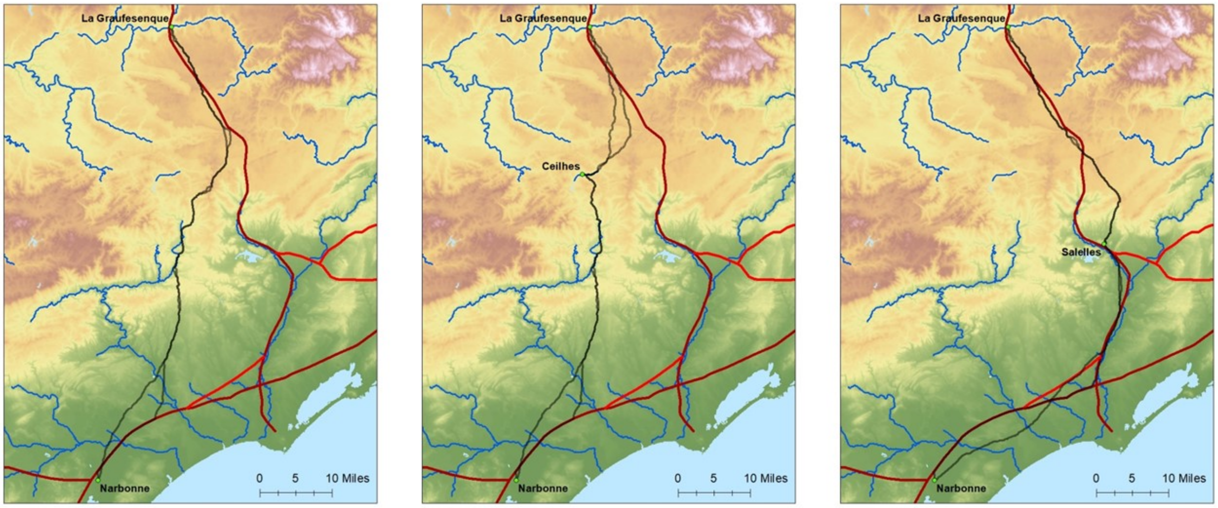


Figure 4. The results of the least cost analysis. The LCPs running directly from La Graufesenque to Narbonne are depicted in Map A (upper right; LCP_$_{SW}$ in purple, LCP_$_{SWR}$ in yellow), La

Graufesenque-Ceilhes-Narbonne LCPs are displayed in Map B (lower left; LCP_$_{SW}$ in cyan, LCP_$_{SWR}$ in brown), and La Graufesenque-Salèlles-Narbonne LCPs are shown in Map C (lower right; LCP_$_{SW}$ in green, LCP_$_{SWR}$ in peach).



1. Southeast across the Causse du Larzac, southwest towards the Orb River, then south, and lastly southwest across the coastal plains towards Narbonne

2. Southeast across the Causse du Larzac, southwest to Ceilhes, south, roughly following the Orb River, and continuing south to Narbonne

3. Southeast across the length of the Causse du Larzac, southwest to Salèlles, roughly following the Lergue and L'Hérault Rivers, and then west towards Narbonne

Figure 5. A visualization and description of the three general routes between La Graufesenque and Narbonne.

Three general routes between La Graufesenque and Narbonne were identified (Figure 5):

1. From La Graufesenque directly to Narbonne. This route first extends southeast across the plateau of the Causse du Larzac. It then turns southwest and runs towards the Orb River. It briefly follows the general course of the river south, staying near its shores, and then lastly extends southwest across the coastal plains to Narbonne.
2. From La Graufesenque to Ceilhes, and then to Narbonne. This route runs briefly southwest across the Causse du Larzac, and then turns southwest, reaching the market town of Ceilhes on the shores of the Orb River. It then generally follows the Orb River south, remaining close to its banks, and then continues south across the coastal lowlands to Narbonne.
3. From La Graufesenque to Salèlles, then to Narbonne. This route runs southeast across the length of the Causse du Larzac, and then runs briefly southwest to Salèlles, a market town on the banks of the Lergue River. It then roughly follows the shores of first the Lergue, and then the L'Hérault, Rivers. It then runs west across the coastal plains, reaching Narbonne.

The average distance of the six LCP between La Graufesenque and Narbonne is about 82 miles, roughly 19 miles (or 30%) longer than the Euclidean distance between the two locations. The shortest LCP, La Graufesenque-Narbonne LCP_$_{SWR}$, is approximately 77 miles long. The longest, La Graufesenque-Salèlles-Narbonne LCP_SWR, is about 12 miles longer, at roughly 89 miles.

Path	LCP_SW (Where S = Slope, W = Water Bodies)	LCP_SWR (Where S = Slope, W = Water Bodies, R = Roman Roads)	Average Distance
La Graufesenque-Narbonne	78	77	**77.5**
La Graufesenque-Ceilhes-Narbonne	80	78	**79**
La Graufesenque-Salèlles-Narbonne	88	89	**88.5**
Average Distance	**82**	**81.3**	***81.67***

Table 2. Summary of total distances between La Graufesenque and Narbonne based on the least cost path analyses (miles).

Distances were shortest for La Graufesenque-Narbonne LCP (mean = 77.5 miles) and longest for La Graufesenque-Salèlles-Narbonne LCP (mean = 88.5 miles), Table 2. This is perhaps to be expected; a path running directly from La Graufesenque to Narbonne, bypassing either intermediary town, will deviate the least from the straight line representing the Euclidian distance between the two sites.

Similarly, the shorter average distance of the La Graufesenque-Ceilhes-Narbonne LCP, as compared to the La Graufesenque-Salèlles-Narbonne LCP, is also unsurprising. Ceilhes lies at about 2.5 miles east from the theoretical straight line connecting La Graufesenque and Narbonne, while Salèlles lies roughly 18 miles east of this line. However, paths to and from Salèlles have a different advantage: they remain on the Causse du Larzac, and thus at altitude, for a shorter percentage of their distances.

When distances were compared between the two methods (LCP_SW and LCP_SWR), a variation of 1-2 miles was found (Table 2). The choice of criteria appears to have relatively little influence on the distance of the journey, with those paths calculated from purely natural features (slope and water bodies) being only marginally longer than those paths calculated with the addition of roads. However, it should be taken into account that travelling on roads is often faster than travelling off-road, and therefore, this similarity in distance may not entirely correlate to travel time.

Rivers are important natural corridors of transportation. Even if river transportation is prohibited or implausible (for example, a river may be unnavigable, or only seasonably navigable), the land immediately adjacent to a river, its shores or banks, may still provide a useful corridor for overland transportation, since rivers tend to occupy the lowest points in a given landscape. This is of particular significance when considering rivers cutting across rough terrain. In this case, a river, and the neighboring land comprising the nadir of the river valley, can often considerably be lower in elevation and more level than the rest of the surrounding area. Additionally, the presence of rivers may bring other benefits to overland shippers, such as the presence of fresh water, a necessity, especially when utilizing the labor of draft animals.

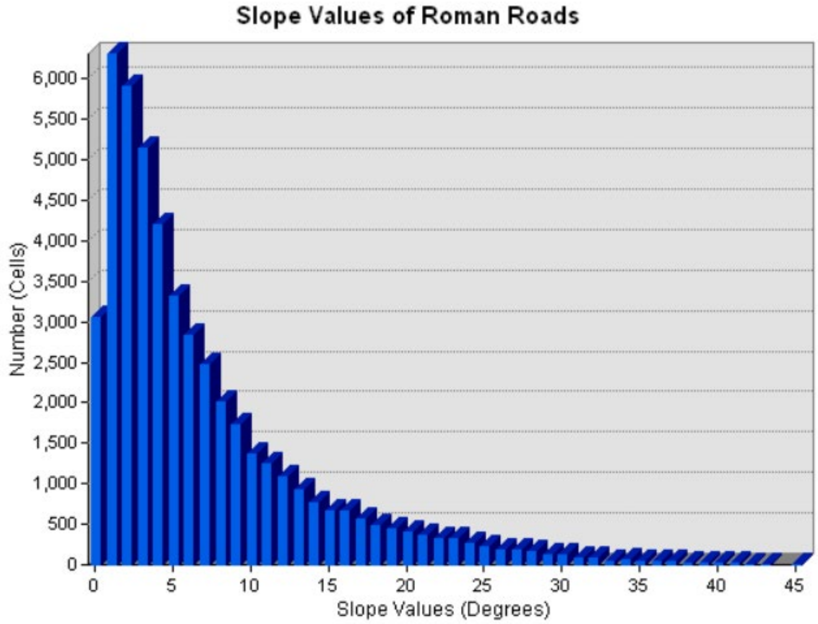


Figure 6. A graph showing the slope values (in degrees, x-axis) of Roman road segments (as represented by raster cells; y axis) within the study area.

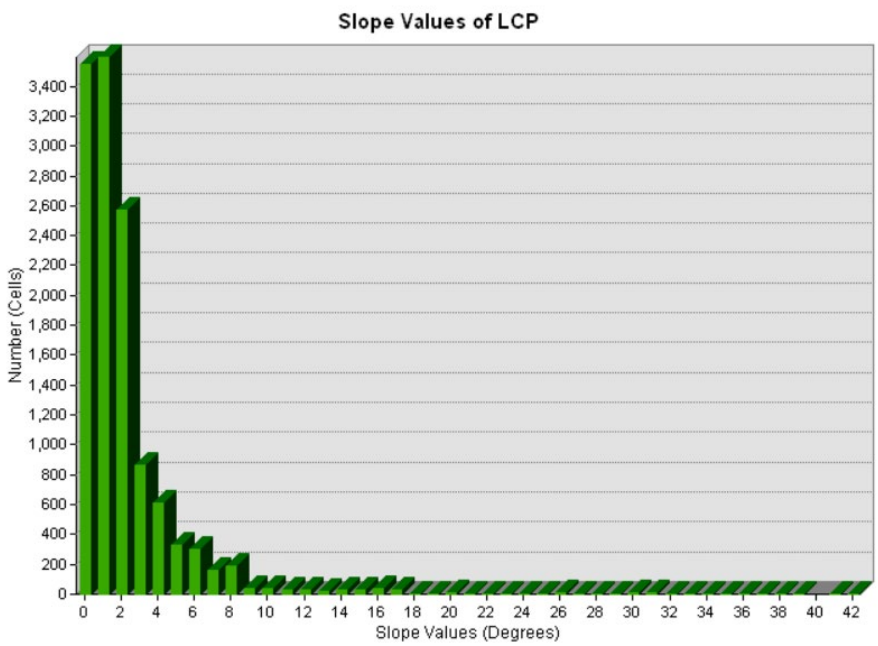


Figure 7. A graph showing the slope values (in degrees, x-axis) of the LCPs (as represented by raster cells; y axis).

Although rugged or difficult terrain did not deter Roman roadbuilders, their preference was for even terrain with nearby sources of fresh water (Staccioli, 2003; Chevallier, 1976). In highland areas, gently sloping routes were preferred to more direct (and therefore more energy-intensive) routes, with slopes rarely exceeding 20%, or about 11˚ (Staccioli, 2003). Low-lying, even terrain near rivers could provide these sought-after conditions, and therefore, it was fairly common for

Roman roads to follow the general course of a river; indeed, the oldest known Roman road, the Via Salaria, was built along the very river that ran through Rome itself, the Tiber (Sitwell, 1981). Further examples of this phenomenon can be seen across the enormity and diversity of the Roman Empire, roughly following the Tagus, Rhone, Rhine, Danube, Nile, and Euphrates Rivers, among numerous others (Sitwell, 1981).

Graphing the relationship between known Roman road segments in the study area, as represented by raster cells, and the slopes on which they are situated corroborates the Roman preference for roadbuilding in level terrain (Figure 5). At approximately 82%, the vast majority of road segments within the study area are found on slopes of between 0 and 11˚; just over half are situated on slopes of only 0-4˚. This relationship is even more pronounced when considering the LCPs (Figure 6). The known Roman roads and the LCPs both occupy similar terrain, and therefore some similarities between their locations are perhaps inevitable, although it is important to remember that many of the known Roman roads within the study area were likely not present in the 1st century AD, and therefore not available for use by mule drivers.

Percent of LCP within 1 mile of a Roman Road			
Path	**LCP_SW**	**LCP_SWR**	**Average**
La Graufesenque-Narbonne	30.8%	41.6%	**36.2%**
La Graufesenque-Ceilhes-Narbonne	22.5%	29.5%	**26%**
La Graufesenque-Salèlles-Narbonne	61.4%	80.9%	**71.2%**
Average	**38.2%**	**50.7%**	***44.5%***

Table 3. The percentage of LCPs within 1 mile of a Roman road.

Some degree of overlap is evident when comparing the LCP with the Roman roads within the study area. About 44.5% of the LCP lengths were found to be within 1 mile of a Roman road; this includes instances in which an LCP is directly following a road (namely, in the three LCP_SWR, the Via Domitia in the south of the study area). The two La Graufesenque-Ceilhes-Narbonne LCP demonstrate the least amount of proximity to a road (mean = 26%), whereas the two La Graufesenque-Salèlles-Narbonne LCP show the most (mean = 71.2%). This can be attributed to the closeness of Salèlles to a major road, and its crossroads with the Via Domitia, and the distance of Ceilhes from any known Roman road.

There are two discernable stretches where a high degree of overlap between the LCPs and the Roman roads:

1. In the two La Graufesenque-Narbonne LCP, for approximately 20 miles, starting from La Graufesenque and extending across the plateau of the Causse du Larzac; and
2. In the two La Graufesenque-Salèlles-Narbonne LCP, for a similar distance, first south, and then southwest, running roughly near the courses of the Lergue and L'Hérault Rivers.

Due to the small scale at which the roads are depicted in the *Barrington Atlas*, these examples may serve to highlight some of the nuances concerning the precise courses of the roads in question.

Furthermore, numerous Roman roads were constructed based on earlier transportation networks, especially in Gaul (Sitwell, 1981; Hitchner, 2012). That the LCPs show some level of conformity with known Roman roads may suggest precedents in older networks. If this is the case, then mule drivers travelling to and from La Graufesenque may have been utilizing routes that had already been established before the production of *terra sigillata* in southern Gaul, or even before the Roman occupation of the region. Later in the Roman period, the significance of these routes must have attracted the attention of Roman roadbuilders.

Percent of LCP within 1 mile of a River			
Path	**LCP_SW**	**LCP_SWR**	**Average**
La Graufesenque-Narbonne	23.1%	23.4%	**23.3%**
La Graufesenque-Ceilhes-Narbonne	32.5%	32.1%	**32.3%**
La Graufesenque-Salèlles-Narbonne	35.2%	37.1%	**36.2%**
Average	**30.4%**	**30.9%**	***30.7%***

Table 4. The percentage of LCPs within 1 mile of a river.

Similarly, a relationship between the LCPs and the courses of rivers within the study area can be demonstrated. Such a relationship is not unusual in Archaeological LCA studies; connections between waterways and LCPs are present in Howey (2007) and Sherman et al. (2010). However, with only 30.7% of the LCP lengths within 1 mile of a river, this relationship appears to be less pronounced than the relationship between the LCPs and Roman roads. There seems to be relatively little difference in proximity to a river between the two methodologies (LCP_SW and LCP_SWR), although more variation is displayed when considering the itinerary of each LCP. Ceilhes and Salèlles lie on the Orb and Lergue Rivers, respectively, and therefore, a path running directly between La Graufesenque and Narbonne, avoiding these locations, also avoids the waterways on which they are located; this may explain the low level of proximity to local rivers displayed by the two La Graufesenque-Narbonne LCPs (mean = 23.3%), compared to the relatively similar levels shown by the other four LCPs.

Although about 30% of the LCP lengths are within 1 mile of a river, this figure includes instances in which an LCP merely crosses a river. From sections that more closely follow the banks of a river, three waterways can be identified as potentially significant in the transportation of pottery from La Graufesenque to Narbonne: the Orb, the Lergue, and the L'Hérault Rivers (although the Lergue is a tributary of the L'Hérault). Sections of both the La Graufesenque-Narbonne and La Graufesenque-Ceilhes-Narbonne LCP run roughly along the shores of the Orb River. Similarly, a section of the La Graufesenque-Salèlles-Narbonne LCP maintains a closeness to the banks of the Lergue and L'Herault Rivers. This second example is also an instance in which the LCPs correlate to the location of Roman roads, suggesting that both topographic and hydrological factors were significant in the establishment of an overland route, and eventually a Roman road, in the area.

The findings in this study support Middleton's proposal for an overland route south across the Causse du Larzac between the kiln complex of La Graufesenque and the port of Narbonne (1980).

Moreover, his identification of potential intermediary waypoints or markets at Ceilhes and Salèlles is also supported, especially when considering that these sites occupy advantageous locations that at the heads of waterways that offer natural transportation corridors descending the Causse du Larzac. Lastly, unlike Bordeaux, once assumed to be the principal transshipment center in the La Graufesenque pottery trade, Narbonne appears well-situated to supply significant contemporary markets (Middleton, 1980). Through its proximity to the Mediterranean coast and the Rhone river, Narbonne could easily supply important military markets on the Rhine-Danube frontier; through river routes along the Aude and Garonne Rivers, the transportation of pottery to Bordeaux was similarly feasible (Middleton, 1980; Sitwell, 1981).

The primary limitations of this study are based on its methodological approach. Due to the difficulty of identifying or recreating the land cover or climatic conditions of southern Gaul in the 1st century, the analytical criteria this study will be based on are somewhat limited. Furthermore, datasets for historic hydrological or topographic conditions are also difficult to obtain, and therefore, modern datasets for these features will be used, even though these conditions may have considerably changed since the 1st century. This degree of uncertainty is simply part of working with the archaeological record, but nonetheless presents a limitation to this study (Howey & Burg, 2017).

V. Conclusion

This study has introduced three potential overland routes across the plateau of the Causse du Larzac and the adjacent Mediterranean coastal plains connecting the significant 1st century *terra sigillata* manufacturing center of La Graufesenque and the port of Narbonne. However, the economic viability of these routes, as well as the volume of traffic that may have utilized them, remain unknown. Perhaps analyzing the profitability of these routes within the context of the economic conditions of 1st century Gaul, and the wider western Mediterranean world, can shed some light on these matters. Furthermore, alternative routes or even modes of transportation should be given some consideration; if the Orb, Lergue, or L'Hérault Rivers are navigable, if only temporarily throughout the year, the possibility that Ceilhes and Salèlles were transshipment centers in a river trade should be investigated.

Finally, the applicability of least cost analysis in analyzing the Roman pottery trade has been demonstrated. A multitude of other kiln complexes, transshipment centers, and potential trade routes, not merely within Gaul, but across the entirety of the Roman world and beyond, are left to be analyzed. It is my hope that in the future, the methods of geospatial analysis can be utilized to provide a richer, more detailed, and more nuanced understanding of the Roman pottery trade, and of the Roman economy as a whole.

VI. References

Allen, J. R. (2013). Some Potters of Samian Ware at La Graufesenque: Notes toward the Shape of the Industry. In M. Fulford & E. Durham (Eds.), *Seeing red: new economic and social perspectives on terra sigillata* (pp. 49-65). London: Institute of Classical Studies, University of London.

Atkinson, D. M., Deadman, P., Dudycha, D., & Traynor, S. (2005). Multi-criteria evaluation and least cost path analysis for an arctic all-weather road. *Applied Geography, 25*(4), 287-307. doi:10.1016/j.apgeog.2005.08.001.

Batten, D. C., Clark, J. T., & Hagemeister, E. M. (2007, April). Least-Cost Pathways, Exchange Routes, and Settlement Patterns in Late Prehistoric East-Central New Mexico. In *Digital Discovery Exploring New Frontiers in Human Heritage, CAA 2006 Computer Applications and Quantitative Methods in Archaeology,* Proceedings of the 34th Conference, Fargo, United States.

Bell T., & Lock, G. (2000). Topographic and cultural influences on walking the Ridgeway in later prehistoric times. In G. Lock (Ed.), *Beyond the Map: Archaeology and Spatial Technologies* (pp. 85-100). Amsterdam: IOS Press.

Bell, T., Wilson, A., & Wickham, A. (2002). Tracking the Samnites: Landscape and Communications Routes in the Sangro Valley, Italy. *American Journal of Archaeology, 106*(2), 169-186. doi:10.2307/4126242.

Burg, M. B. (2017). It must be right, GIS told me so! Questioning the infallibility of GIS as a methodological tool. *Journal of Archaeological Science, 84*, 115-120. doi:10.1016/j.jas.2017.05.010.

Chevallier, R. (1976). *Roman Roads*. Berkeley: University of California Press.

Conolly, J., & Lake, M. (2006). *Geographical information systems in archaeology*. Cambridge: Cambridge University Press.

Dannell, G., & Mees, A. (2013). The Mainz internet database of names on *terra sigillata.* In M. Fulford & E. Durham (Eds.), *Seeing red: new economic and social perspectives on terra sigillata* (pp. 28-35). London: Institute of Classical Studies, University of London.

Digital Atlas of Roman and Medieval Civilizations. (2018). *Data Availability*. Retrieved August 1, 2018 from https://darmc.harvard.edu/data-availability.

Drinkwater, J.F. (1983). *Roman Gaul: The Three Provinces, 58 BC-AD 260*. Ithaca: Cornell University Press.

Fábrega Álvarez, P., & Parcero Oubiña, C. (2007). Proposals for an archaeological analysis of pathways and movement. *Archeologia e Calcolatori,* (18), 121-140. Retrieved July 31, 2018 from http://www.archcalc.cnr.it/indice/PDF18/7_Fabrega.pdf.

Fulford, M. (2013) Gallo-Roman sigillata: fresh approaches, fresh challenges, fresh questions. In M. Fulford & E. Durham (Eds.), *Seeing red: new economic and social perspectives on terra sigillata* (pp. 1-17). London: Institute of Classical Studies, University of London.

Güimil-Fariña, A., & Parcero-Oubiña, C. (2015). "Dotting the joins": A non-reconstructive use of Least Cost Paths to approach ancient roads. The case of the Roman roads in the NW Iberian Peninsula. *Journal of Archaeological Science, 54*, 31-44. doi:10.1016/j.jas.2014.11.030.

Gustas, R., & Supernant, K. (2017). Least cost path analysis of early maritime movement on the Pacific Northwest Coast. *Journal of Archaeological Science, 78*, 40-56. doi:10.1016/j.jas.2016.11.006.

Herzog, I. (2010, April). Theory and practice of cost functions. In *CAA* (pp. 431-34).

Herzog, I. (2014). Least-cost Paths – Some Methodological Issues. *Internet Archaeology,* (36). doi:10.11141/ia.36.5.

Hitchner, R. B. (2012). Roads, Integration, Connectivity, and Economic Performance in the Roman Empire. In Susan E. Alcock et al. (Eds.), *Highways, Byways, and Road Systems in the Pre-Modern World* (pp. 228-234). John Wiley & Sons.

Howey, M. C. (2007). Using multi-criteria cost surface analysis to explore past regional landscapes: A case study of ritual activity and social interaction in Michigan, AD 1200–1600. *Journal of Archaeological Science, 34*(11), 1830-1846. doi:10.1016/j.jas.2007.01.002.

Howey, M. C. (2011). Multiple pathways across past landscapes: Circuit theory as a complementary geospatial method to least cost path for modeling past movement. *Journal of Archaeological Science, 38*(10), 2523-2535. doi:10.1016/j.jas.2011.03.024.

Howey, M. C., & Burg, M. B. (2017). Assessing the state of archaeological GIS research: Unbinding analyses of past landscapes. *Journal of Archaeological Science, 84*, 1-9. doi:10.1016/j.jas.2017.05.002.

J. Paul Getty Trust. (2017). *About the TGN*, Retrieved August 1, 2018 from http://www.getty.edu/research/tools/vocabularies/tgn/about.html.

King, Anthony. (1990). *Roman Gaul and Germany*. University of California Press.

Leidwanger, J. (2013). Modeling distance with time in ancient Mediterranean seafaring: A GIS application for the interpretation of maritime connectivity. *Journal of Archaeological Science*, 40(8), 3302-3308. doi:10.1016/j.jas.2013.03.016.

Lewit, T. (2013). The mysterious case of La Graufesenque? Stimuli to large-scale fine pottery production and trade in the Roman empire In M. Fulford & E. Durham (Eds.), *Seeing red: new economic and social perspectives on terra sigillata* (pp. 111-120). London: Institute of Classical Studies, University of London.

Llobera, M. (2000). Understanding movement: A pilot model towards the sociology of movement. In G. Lock (Ed.), *Beyond the Map: Archaeology and Spatial Technologies* (pp. 65-84). Amsterdam: IOS Press.

Llobera, M., Fábrega-Álvarez, P., & Parcero-Oubiña, C. (2011). Order in movement: A GIS approach to accessibility. *Journal of Archaeological Science, 38*(4), 843-851. doi:10.1016/j.jas.2010.11.006.

Lock, G., & Pouncett, J. (2017). Spatial thinking in archaeology: Is GIS the answer? *Journal of Archaeological Science, 84*, 129-135. doi:10.1016/j.jas.2017.06.002.

Lock, G., Kormann, M., & Pouncett, J. (2014). Visibility and movement: towards a GIS-based integrated approach. In S. Polla & P. Verhagen (Eds.), *Computational approaches to the study of movement in archaeology: theory, practice and interpretation of factors and effects of long term landscape formation and transformation* (pp. 23-42). Berlin: De Gruyter.

McCoy, M. D., & Ladefoged, T. N. (2009). New Developments in the Use of Spatial Technology in Archaeology. *Journal of Archaeological Research, 17*(3), 263-295. doi:10.1007/s10814-009-9030-1.

McCoy, M. D., Mills, P. R., Lundblad, S., Rieth, T., Kahn, J. G., & Gard, R. (2011). A cost surface model of volcanic glass quarrying and exchange in Hawaiʻi. *Journal of Archaeological Science*, 38(10), 2547-2560. doi:10.1016/j.jas.2011.04.017.

Mees, A. (2018). Was there a Difference between Roman Civil and Military Samian (terra sigillata) Market Supply? Finding answers with statistical distribution analysis methods. *Internet Archaeology,* (50). doi:10.11141/ia.50.16.

Middleton, P. (1980). La graufesenque: A question of marketing. *Athenaeum, 58*, 186-191. Retrieved July 31, 2018 from http://ezaccess.libraries.psu.edu/login?url=https://search-proquest-com.ezaccess.libraries.psu.edu/docview/1300394334?accountid=13158.

Mirti, P., Appolonia, L., & Casoli, A. (1999). Technological Features of Roman Terra Sigillata from Gallic and Italian Centres of Production. *Journal of Archaeological Science*, 26(12), 1427-1435. doi:10.1006/jasc.1999.0435.

Oyen, A. V. (2015). The Roman City as Articulated through Terra Sigillata. *Oxford Journal of Archaeology, 34*(3), 279-299. doi:10.1111/ojoa.12059.

Peacock, D. P. (1982). *Pottery in the Roman world: an ethnoarchaeological approach*. New York: Longman Publishing Group.

Peña, J. T. (2007). *Roman pottery in the archaeological record*. New York: Cambridge University Press.

Pozzi, Francesca, & Robinson, Tim. (2008). Accessibility mapping in the Horn of Africa: Applications for livestock policy. IGAD.

Sherman, R. J., Balkansky, A. K., Spencer, C. S., & Nicholls, B. D. (2010). Expansionary dynamics of the nascent Monte Albán state. *Journal of Anthropological Archaeology*, 29(3), 278-301. doi:10.1016/j.jaa.2010.04.001.

Sitwell, N. H. H. (1981). *Roman Roads of Europe*. London: Cassel.

Staccioli, R. A. (2003). *The Roads of the Romans*. Los Angeles: Getty Publications.

Talbert, Richard J. A. (Ed.). (2000). *Barrington Atlas of the Greek and Roman World*. Princeton University Press.

Taliaferro, M. S., Schriever, B. A., & Shackley, M. S. (2010). Obsidian procurement, least cost path analysis, and social interaction in the Mimbres area of southwestern New Mexico. *Journal of Archaeological Science*, 37(3), 536-548. doi:10.1016/j.jas.2009.10.018.

United States Geological Service. (2018). *EarthExplorer*. Retrieved August 1, 2018 from https://earthexplorer.usgs.gov/.

United States Geological Service. (2015). *Shuttle Radar Topography Mission (SRTM)*. Retrieved August 1, 2018 from https://lta.cr.usgs.gov/SRTM.

United States Geological Service. (2015). *SRTM Water Body Dataset*. Retrieved August 1, 2018 from https://lta.cr.usgs.gov/srtm_water_body_dataset.

Wheatley, D., & Gillings, M. (2002). *Spatial technology and archaeology: The archaeological applications of GIS*. London: Taylor & Francis.

White, D. A., & Barber, S. B. (2012). Geospatial modeling of pedestrian transportation networks: A case study from precolumbian Oaxaca, Mexico. *Journal of Archaeological Science, 39*(8), 2684-2696. doi:10.1016/j.jas.2012.04.017.

Whitley, T. G. (2017). Geospatial analysis as experimental archaeology. *Journal of Archaeological Science, 84*, 103-114. doi:10.1016/j.jas.2017.05.008.

Willis, S. (2011). Samian Ware and Society in Roman Britain and Beyond. *Britannia*, 42, 167-242. Retrieved July 31, 2018 from http://www.jstor.org.ezaccess.libraries.psu.edu/stable/41725118.