Applying GIS tools to define prehistoric megalith transport route corridors: Olmec megalith transport routes: a case study

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Applying spatial data management and analytical tools is an accepted method for investigating potential settlement patterns. This study applied Geographic Information System (GIS) technology to the study of Preclassic Olmec megalith transport in Mesoamerica. The GIS slope gradient tool was used to identify potential transport corridors with gradients of less than 1:10, which defines the limit of human effort needed to control these stones as demonstrated in ethnographic and replication experiments by various researchers. These outcomes were also used to refine transportation methods and likely start points that would be used to cross lowlands near to the San Lorenzo centre of Olmec society.

Highlights:
- We model the terrain between Cerro Cintepec, and San Lorenzo using GIS.
- We identify potential land based transport pathways for megaliths, based on slope gradient analysis.
- Start points for crossing lowland terrain
- Megalith transportation methods are refined
- We highlight how GIS analyses can be applied to archaeological problems.

keywords: Olmec, megalith transport, GIS analysis, slope gradient

1 Introduction:

Stone use is enduring evidence of the industry, enterprise and resource of prehistoric cultures. Transporting large stones or megaliths was a pivotal part of this prehistoric industry. The methods and routes that were chosen for this undertaking continue to be the subject of debate and have given rise to considerable speculation. The sources for stones were often distant from their final position and the routes that were used to retrieve the stones traversed difficult terrain or open seas (Hazell, 2011). The sources and routes often bypassed, what to modern eyes, may seem to be suitable stones and more convenient sources; so adding significant logistical issues to the problem of stone retrieval.
A limited material and often fragmented, archaeological record, limits any endeavours to determine the methods and routes that were used to undertake these monumental activities. To overcome this, ethnographic examples are often cited (Ayres and Scheller, 2001, Dillon, 2004, Heyerdahl, 1958, Souden, 1997) and replication experiments (Atkinson, 1960, Ayres and Scheller, 2001, Richards and Whitby, 1997, Van Tilburg, 1995) are also used as a basis for research.

Experiments have limitations because the conditions under which they were conducted may differ substantially from those encountered by ancient cultures and are unlikely to replicate all aspects of this complex undertaking. In Mesoamerica transporting megaliths involved technological knowledge, logistical expertise (Diehl, 2007) and significant resources to overcome terrestrial features and - according to some - oceanographic hurdles (Coe, 2000, Stuart, 1993, Velson and Clark, 1975). While some aspects of replication experimentation are inappropriate it is still possible to use human physical capabilities, identified in replication experiments and corroborated by ethnographic observations. These sources have been adopted as part of Geographic Information System (GIS) analyses in order to identify viable and sustainable land route options and transportation methods, (Ayres and Scheller, 2001, Erasmus, 1965, Heyerdahl, 1958, Horvath and Finney, 1976, Irwin, et al., 1990, Richards and Whitby, 1997, Schiffer and Skibbo, 1987).

This Mesoamerican investigation of Preclassic (1800BC – 400BC±) Olmec society megalith transportation includes these and other challenges including limited field survey access to the large areas involved and securing sufficient funds to study such an extensive site; therefore another technique was required to study this geographically extensive transport problem. The focus of this study was on land transport of megaliths used in sculptures known as the Colossal Heads, ten of which were found at San Lorenz. Large numbers of stones, most weighing between 6 and 26 tonnes, were moved to this area and also to La Venta, which was another major and later Olmec complex. For this research a mean mass of twenty tonnes has been adopted.
This paper documents our use of GIS technology to determine whether viable land routes and methods, which comply with human power capability calculations and terrain conditions, can be established. The outcomes derived from this work were able to show that ancient Olmec could have transported stones by land in contrast to the more favoured open water and river routes. However, it went further by defining some transport methods because ground conditions also precluded the use log rollers, sleds and wheeled vehicles, even though the wheel was known to Olmec society, as evidence of wheeled toys demonstrate (Charnay, 1974).

The distances involved are considerable, and the terrain is challenging, with swamps, floodplains and rivers, many of which are seasonal. From their source near Cerro Cintepec in the Tuxtla Mountains to their final destination at the Preclassic centre of San Lorenzo is a straight line distance of around 80 kilometres across this difficult landscape (Coe, 2000 : 68). Importantly gradient analysis using the GIS software allowed us to establish a potential transport corridor from which the Olmec could begin to cross the lowlands. Transportation methods were also defined by gradient and related road structures needed to support this activity. For this reason, our GIS matrix included soil types and their distribution, as existing archaeological evidence shows significant earth structures associated with the San Lorenzo complex.

1.1 Preclassic Olmec:


The “Olmec heartland”, which is accepted as the Olmec sphere of social, political and economic influence, was an area of some 16,000 km². The Olmec traded in obsidian and jade, neither of which occur naturally around Olmec centres. Trade
pathways, while suitable for precious mineral trade, would not necessarily suit megalith transport; however trade in precious materials suggests that regularly used pathways may have existed during Olmec times.

Olmec society moved many large stones for stelae, altars or thrones and sculptures. Amongst the hundreds of stones that were used for different purposes, the largest known stone was La Venta 1, which weighed about 40 tonnes (Clewlow, et al., 1967, Clewlow Jnr, 1970). At San Lorenzo near Tenochtitlan extensive raised platforms, numerous mounds, stelae, altars and stone sculptures, known as Colossal Heads, have been found (Benson and de la Fuente, 1996, Clewlow, et al., 1967, Clewlow Jnr, 1970, Clewlow Jnr, 1974, Pohorilenko, 1996, Stuart, 1993).

1.2 Colossal Heads:

Most of the seventeen Colossal Heads weigh between 6 tonnes and 26 tonnes. They vary in height from between one and a half metres to nearly three metres; their circumference varies from just over three metres up to nearly six metres (Clewlow, et al., 1967) and each stone has a human face carved into it. The distinctively individual features of each stone’s carved face, arguably links each of the Colossal Heads to an Olmec ruler (Clewlow, et al., 1967, Stirling, 1965). The stones are generally accepted as being sourced near the foothills of the Tuxtla Mountains (Williams and Heizer, 1965). Ten of these stones have been found on or in gullies on the San Lorenzo Plateau. Some heads are believed to have been reused altar stones, perhaps pointing to their value and linked to difficulties in acquiring these stones (Cyphers, 2006, Porter, 1990).

Any direct land route would encounter swamps and perennial floodplains (INEGI, 1985, INEGI, 1986, INEGI, 1999). The existence of these natural obstacles endorsed argument for water transport of these megaliths (Cyphers and Ortiz, 2000, Cyphers and Zurita-Noguera, 2006h, Tamayo and West, 1964).

It is known that the Olmec used canoes for trade, whether these would be suitable for megalith transport is uncertain (Anawalt, 1992, Callaghan, 2003, Dillon, 1975, Edwards, 1978). Analyses of waterborne options highlighted serious limitations of the most likely watercraft known at the time these stones were moved. A study of
rafts and multi-hull dugout canoes (Hazell, 2003a), based on performance observations, structural integrity, and stability under significant loads, combined with human capability studies (Baumeister, 1967, Hazell, 2011, Henderson and Haggard, 1925, Horvath and Finney, 1976, Severin, 1988) of maximum human power and sustained effort, (Doran, 1978, Doran, 1971, Edwards, 1965, Kent, 1958, Ling, 1970, Muckle, 1975, Walton, 1906, West, 1961) has questioned whether water borne options for moving these megaliths would be viable or reliable. Even if the Olmec did use water transport for moving these stones from their source to final destination, establishing land based pathways from their source points in the foot hills of the Tuxtla Mountains to suitable water staging sites would still require analysis of large tracts of land.

With the considerable area involved and limited access, the use of GIS allowed a viable, cost effective research methodology for this aspect of the research.

1.3 Land Based Megalithic Transport:

The region between the source in the Tuxtla Mountains and final destination on the San Lorenzo Plateau is characterized by many rivers, seasonal swamps and floodplains which are subject to inundation during wet seasons or are permanently under water (Cyphers, 2008f, Cyphers and Ortiz, 2000). The use of land routes to avoid these constraints during drier months, or using strategies to overcome inundated areas, has already been suggested. (Cyphers, 2006). Besides these landform challenges, manpower needs must be considered for transportation methods.

Gradient is an important constraint when moving large stones. This constraint will limit the ability of humans to move the Colossal Heads across the landscape, irrespective of whether these megaliths are being hauled down hill, where there is a need to control their descent, or when they are being hauled uphill to isolated pockets of higher ground to avoid uncertain conditions. Gradient also plays an important part in the final stages when hauling them onto the San Lorenzo Plateau itself. Therefore slope gradient analyses were used to link pathways from the higher ground to potential routes across the low country.
2 GIS Analysis Strategy:

Although swamps, rivers and floodplains were recognised obstacles, the GIS analysis began by examining gradients from sources at Cerro Cintepec (Williams and Heizer, 1965) or nearby (Grove, et al., 1993) in the Tuxtla Mountain foothills. Controlling the stones, while descending these slopes, is difficult with the area characterised by many steep gullies. Conversely providing adequate motive power to drag the stones uphill also defines acceptable routes. To establish manpower parameters on routes, ethnographic (ArchaeoNews, 2004, Harmon, 2005, Mladjov and Mladjov, 1999), historical and experimentation examples of human power capabilities and sustained effort expectations (Richards and Whitby, 1997, Van Tilburg, 1995) were adopted. These analyses suggested a gradient of 1:10 defined the limit of human effort needed to control these stones so that the combined power of a work party can be effectively coordinated. This was also demonstrated in ethnographic and replication experiments (Heyerdahl, 1958, Richards and Whitby, 1997). Therefore potential routes identified by applying the GIS slope analysis, were based on gradients that did not exceed 1:10 at any point. Subsequent cross checking showed that the routes identified in the GIS study mirrored modern roads or tracks.

2.1 Establishing a Spatial Data Set for GIS Analysis:

GIS have been used for many spatial analyses (Longley, et al., 2005, Romero-Calcerrada, et al., 2008, Zhijun, et al., 2009). In this instance though, by using an appropriate spatial database, GIS can provide a valuable insight into different aspects of any prehistoric society, particularly when archaeological evidence is limited and terrestrial features are likely to have played a part in the activity. We used ArcView 3.2 GIS software, and its associated 3D Analyst extension, to create and digitise geographic themes.

The data set was primarily established from survey mapping at scales of both 1:250,000 (INEGI, 1984, INEGI, 1986, INEGI, 1997) and 1:50,000 (INEGI, 1984, INEGI, 1985, INEGI, 1987, INEGI, 1988, INEGI, 1990, INEGI, 1996, INEGI, 1999, INEGI, 2000, INEGI, 2003). These maps were scanned, georeferenced and used to create themes of contours, rivers, swamps, soil types and vegetation. Lowland
country, intersecting with possible routes and encompassing the region surrounding the San Lorenzo/Tenochtitlan plateau, was included. The GIS database also included La Venta, thus allowing future analysis of transport routes to that site.

The initial digitising procedure was undertaken using a HP 5100c flatbed scanner with a default scan speed for high quality scans. Resolution was set at 150 dots per inch (DPI). Even with the larger scale of the survey maps, each map required at least four and sometimes six A4 scanned sheets, which needed to be geolocated and joined in the GIS. This process became a potential source of accumulative errors.

All scans were enhanced using Adobe Photoshop 7 to improve legibility and associated accuracy during digitisation. Points on contour lines were digitised with changes in direction and intermediate points as frequently as possible to minimize error (Douglas and Peucker, 1973). Nevertheless this stage added another potential source of error. Our interpretation of specific features such as contour position and value imposed limitations on final accuracy of the spatial data set.

A Triangular Irregular Network (TIN) surface model of the landscape was generated from the contour data. Assembling this data as a surface model was a necessary precursor to applying a slope gradient analysis of the landscape to identify pathways of suitable gradient for land transport.

2.2 Results of the GIS Analysis

From the spatial analysis, based on slope analysis and circumnavigation of major obstacles in the flood plain, two possible overland routes for transport of the Colossal Heads were identified (Figure 1). To adopt other less direct routes would require crossing gullies and associated rivers with constant changes of direction while controlling the stones. Within the projected pathway corridor, the Olmec Llano del Jicaro workshop site described by Gillespie is situated (Gillespie, 1994).
2.3 Some Comments on Applying GIS Technology to Determine Possible Transport Routes

The management advantages of a GIS database are well known (Longley, et al., 2005) but its application for this research should be explained. The regional nature of the Olmec stone transport imposed more extensive use of preparatory scanning and data processing than might otherwise be the case for a less extensive project. In addition, the resolution or interpretation quality required to generate the terrain model of the Olmec heartland became a compromise between practicalities of managing file sizes and the need for reasonably accurate data. Larger files allowed clear image processing but required extensive handling to exchange and interpret the data.

The type of analysis that has been proposed in this paper could be undertaken empirically or by simply reading the contours on the map to trace likely routes that showed minimal grades; however this would have relied on visual assessment of the contour spacing or measuring and calculating the grade along a multitude of potential pathways. This is further complicated because the foothills near the stone source are
complex landforms, reflecting their volcanic origins and access permission from landholders is uncertain (Chase, 1981, Nelson, 1990, Williams and Heizer, 1965).

The surface model was developed using current topographical maps of the area. Without ground-truthing, our interpretation and digitising is subject to the tolerances and accuracy of the source survey maps. This potential source for error was recognised in this assemblage process and in subsequent analyses of the Digital Elevation Model (DEM) associated with the slope analysis tools (Hageman and Bennett, 2000).

2.4 Limitations associated with GIS application to this research:

A major limitation in this study was the process of data acquisition. Digitising such extensive landscapes is always a challenging undertaking. Without access to large scale remote sensing technologies, this study relied on the digitisation and interpretation of topographical land survey maps. Errors in interpretation of contour lines occur and may have influenced the gradient analysis; however the points of shallowest gradient in the landscape correspond to those parts of the digitised map, which are easiest to interpret accurately. To control a twenty tonne stone on steep downward slopes would have been impractical, as replication and historical observation have illustrated (Dillon, 2004, Heyerdahl, 1958, Richards and Whitby, 1997). Additionally there is strong correlation between corridors, identified by this study, and modern roads in the general area. Therefore the choice of potential transport paths, based on gradient analyses has some validity and could be used with confidence as part of ongoing investigation.

3 Conclusion:

The outcomes presented in this paper are not final solutions to the stone transport problem. While our use of GIS was able to highlight the value of using GIS software and using its extensions for studying prehistoric cultural activity, the corridor outcomes linked to gradient viability established other important results. Firstly this corridor could be linked to the known Olmec workshop at Llano Del Jicaro and secondly, the viable gradients indicated such gradients could only be traversed by
dragging stones in contact with the ground. In this regard the slope gradient tool has provided a useful insight into potential pathways and viable transport methods that may have been used by the ancient Olmec to move their Colossal Heads from their source at or near Cerro Cintepec to their final destination on the San Lorenzo Plateau.

We have noted limitations in its use and demonstrated how this technology contributed to this research by defining areas of interest, and establishing a starting point for investigating routes across the lowlands between San Lorenzo and the Tuxtla Mountains. A GIS matrix encompassing geographical features such as vegetation, swamps and floodplains are common themes a linked to settlement patterns for example. In our research though, these features were barriers and their complexity and their area, indicated a matrix was ideally suited for looking at transport routes. In this mode the tools could also be applied to investigating trade routes for example

3.1 Acknowledgements

LCH thanks La Trobe University library staff for access to resources and his wife Dianne for her continued patience, support and constructive comments.

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