Chapter 6

ESTABLISHING MEGALITH TRANSPORT ROUTES USING GEOGRAPHICAL INFORMATION SYSTEM

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Limited evidence has led to considerable debate about land routes and methods to move megaliths chosen for sculpture by prehistoric societies. The current research is investigating the question using Geographic Information System (GIS) to determine likely land pathways to transport megaliths over 100 kilometres in Mesoamerica by Preclassic Olmec society. Access was restricted and the terrain included floodplains, seasonal rivers and extensive swamps. Analyses were derived from digitised survey maps using slope gradient tools initially from ARCVIEW 3.2 and finally ARC10. Although compatibility issues arose with this combination as we describe, tools of both versions provided a starting point between stones' source from which to then define a pathway across the challenging terrain.

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INTRODUCTION

The study by archaeologists of large stone or megalith transportation by prehistoric societies is often restricted by limited physical evidence. The known evidence will frequently show the stones were retrieved over long distances, across difficult and variable terrain. These considerations influence the transportation methods that could have been employed, the routes used and the time needed to complete these tasks. Most transportation efforts are affected by seasonal restrictions and manpower availability.

These considerations impose the need to manage, collate and analyse extensive spatial data sets to establish starting points for the archaeological investigation. Further analysis may then be possible using other methodologies and information sources. These analyses would include replication experiments, ethnographic observations and environmental data linked by mathematical models. All megalith transportation efforts are constrained by slope gradient limitations, which define viable movement of stones. Analysis of environmental factors using Geographic Information Systems (GIS), incorporating human physiology capability and slope gradient analysis as a constraint allows viable transportation routes to be identified. This paper describes how we established a database, applied the GIS analysis, while identifying its limitations and compatibility concerns between early analysis and those that followed.

The study of megalith transport in ancient societies provides an insight into various elements of these societies such as the necessary economies to support this activity and the relationship between the sculpture and political or hierarchical status of individuals within the society.

Replication experiments are often limited to specific examples (Cyphers, 2006, Richards and Whitby, 1997) and so require a methodology that can be used to synthesize relevant factors. Establishing how the transportation was done and where, is often the subject of considerable debate hence the use of slope gradient analysis to define both method and routes is important.

In theory massive weights can be moved by manpower alone; however in reality these loads are limited by the hauling teams' ability to co-ordinate their power. Richards' experiment (Richards & Whitby, 1997) suggested in theory 200 persons were needed for a 40 tonne stone to be moved uphill on a gradient of 1 in 20. In practice 130 people were used, while only 60 were needed for downhill hauling or control (Richards and Whitby, 1997).

The experiment described by Richards & Whitby, (1997) concluded that progress of approximately 1 km per day on level ground can be expected.

These data, together with ethnographic sources (ArchaeoNews, 2004, Harmon, 2005, Mladjov and Mladjov, 1999, Van Tilburg, 1995) and other sources (Royal Engineers, 1960, Royal Engineers, 1952) were used in conjunction with GIS slope analysis during this study. The following section describes the GIS research methodology associated with the megalith transport research. Analyses are detailed and conclusions outline its application to Olmec megalith transport and issues arising from this approach using GIS.

OLMEC COLOSSAL HEADS AND THEIR MEGALITH TRANSPORT

The Olmec are often referred to as the "Mother Culture" a title that is debated. This society held a sphere of influence some 200 kilometres long and 80 kilometres wide (125 x 50 miles) known as the "heartland", At its centre during a period between 1200-900BC known as the Preclassic was the San Lorenzo (SL) Plateau, the political hub of the period. Situated some 60 kilometres (38 miles) from the Gulf of Mexico, the SL Plateau is a partly man made ridge around 1200 metres long and rising some 45 metres above the extensive floodplains and swamplands, characteristic of the Rio Coatzacoalcos Basin. Its position and elevation make the plateau a dominant feature over this area, underwritten by the agriculturally productive floodplains that supported the general population and its hierarchy comprising artisans and rulers.

Photo Leslie C. Hazell.

San Lorenzo Head 1; Xalapa Museum of Anthropology.

Of the eighteen known Colossal Heads attributed to the Olmec, ten heads were found on the San Lorenzo Plateau and these weigh between six tonnes and 25 tonnes. They vary in height 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). Their source is accepted as being from or near Cerro Cintepec in the foothills of the Tuxtla Mountains (Williams and Heizer, 1965). The straight line distance is around 80 kilometres or 50 miles with swamps, flood plains and many rivers that must be crossed.

At least one head is believed to have been a reused altar stone (Porter, 1989). The heads are noteworthy for their broad noses, short faced styles and having a flat backed form. The latter observation may be a clue to the method of transport as striations are visible, and such marks could be caused by direct contact with the ground, conversely these may be created by sculptors (Clewlow, et al., 1967).

A study using and testing various parameters essential for viable transport concluded that water routes would not be viable due to environmental, watercraft and crew capability limitations (Hazell, 2013, Hazell, 2011). These uncertainties indicate the difficulties of conflicting evidence and the need for robust data analysis of transport routes and methods. Many other smaller stones were moved and used in other sculptures, but the size and mass of the Heads makes their retrieval over such a distance and challenging terrain logistically complex. The GIS analyses, as shown in the various figures, indicated viable corridors that would avoid most river crossings, swamps and adverse gradients. Further analysis suggested that land transport was viable by using a direct contact dragging process as soil bearing capacity of dominant soils was adequate even in the vicinity of floodplains (Hazell, 2011). The known technology of the Olmec indicated their willingness and capacity to construct causeways to overcome problems associated with the floodplains (Cyphers, 1997).

MEGALITHIC TRANSPORT BY LAND

While slope analyses formed an important part of the investigation, identifying viable land routes had to include the avoidance of wide or fast flowing rivers, flood plains and swamps. Gradient is a major constraint when hauling megaliths uphill or while maintaining control during descents, as ethnographic records and replication experiments clearly describe (Dillon, 2004, Heyerdahl, 1958, Richards and Whitby, 1997). Arguably, significant

labour sources influence transport pathways, so the location and size of villages may have also contributed to route choice. Some routes *appear* possible but seasonal variations change their viability.

Floodplains, swamps and river positions could all change over millennia. Using GIS, allowed us to establish a viable database of terrain features that included signs of a feature's past position, as in the example of ox bow lakes or lagoons. So it is possible to interpret past landscape features and take these into account during the analysis process.

This investigation was a theoretical exercise using GIS technology as an analytical and management research tool. It was limited as later comments will highlight.

In modern times, hauling large stones over long distances would be a mechanised process. Therefore our expectations of what was possible, in terms of capability, time frames and commitment, could be vastly different from those of prehistoric societies. With a limited archaeological record, our database and GIS software, allows interpretative analyses and comparative testing of potential scenarios to provide testable outcomes on the question of land transport routes.

ESTABLISHING THE DATABASE

1:250000 and 1:50000 survey maps were sourced to establish the database comprising themes of contours, rivers, swamps, soil types and vegetation (Figure 1). This data was combined with historical observations and contemporary archaeological surveys of land features where possible. Nevertheless these sources would not portray or indicate prehistoric terrain conditions, while hydrology dynamics would change the position of swamps and oxbow lakes on the floodplains. Such positional changes could not be expected to materially affect analytical outcomes, as pathways would shift marginally within the same area to suit these changes.

The management advantages of GIS database are well known (Longley et al. 2001) but its application to the Olmec research should be explained. The regional nature of the stone transport in Mesoamerica posed particular elements for which GIS tools were well suited. Nevertheless considerable scanning of hard copy maps and data processing was needed to form a comprehensive geo-database. In the early stages of this process it was evident that the resolution would determine interpretation quality required to generate a usable terrain model. This necessity became a compromise between

practicalities of managing file sizes and the need for reasonably accurate data. Larger files allowed clear image processing, however file handling was limited by available hardware (Figure 2).

Our study began by developing a geographical surface model of the region using ArcView 3.2 software and its accompanying 3-D Analyst tool (Figure 3). This model allowed us to geo-spatially analyse slopes in an extensive landscape and identify potential transport corridors without the need for extensive individual pathway calculations. 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. Error when using a Digital Elevation Model (DEM) and the associated slope tools in the GIS was expected during this assemblage process (Hageman and Bennett, 2000). The digitising process itself was understood to be another potential source for errors, which arise from interpretation. This was a problem that was noted by others as are strategies to minimize the problem (Bolstad, et al., 1990, Morad, et al., 1996).
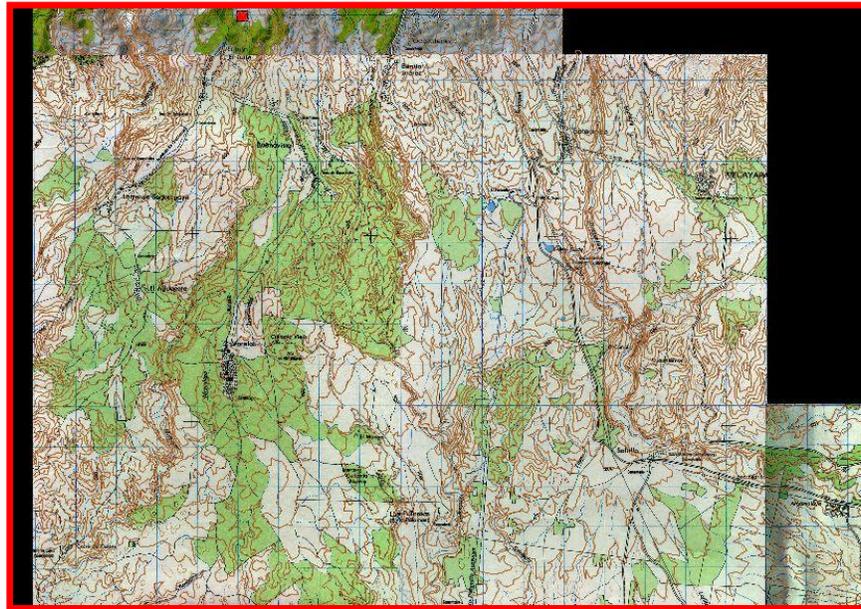

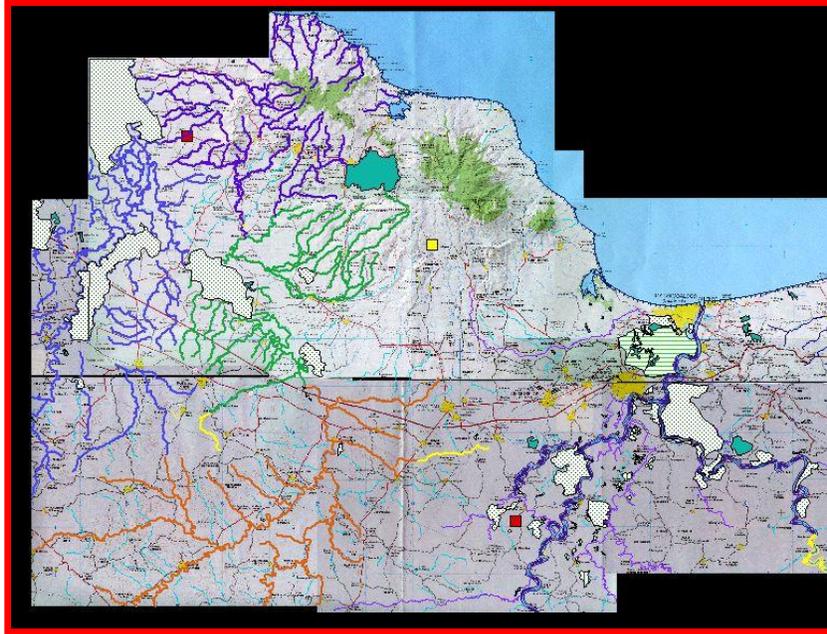Figure 1. Preliminary digitising using INEGI survey map 1:50000 (L. C. Hazell).

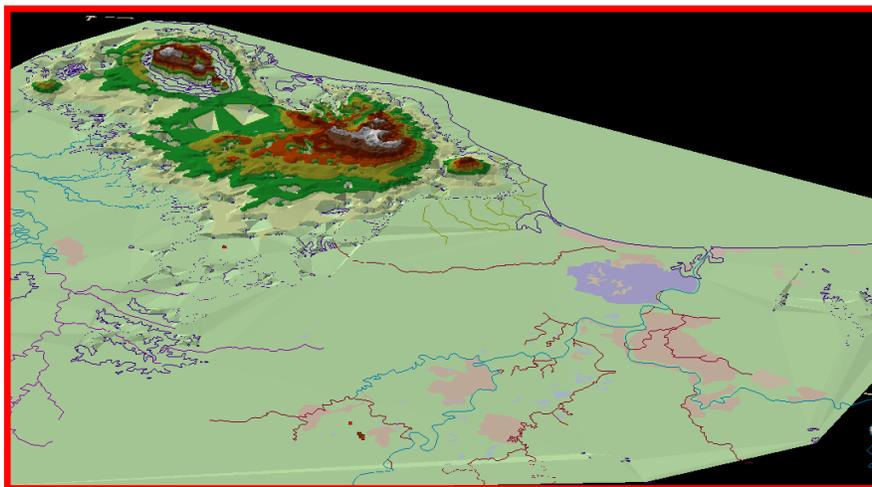Figure 2. GIS matrixof the region after INEGI survey map 1:250000 (L.C. Hazell).

Figure 3. 3D terrain scene using ARC10 Scene (L.C. Hazell).

In the background the Tuxtla Mountains can be seen whilethe San Lorenzo Plateau is in the centre foreground.

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 a 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 that needed to be geo-located and joined in the GIS software. This also became a potential source of accumulative errors.

In an attempt to overcome these potential errors, digital photography was used on the original survey maps. The camera used in this process was a Digital SLR Nikon D1X with a 28-70mm 2.8 lens. The picture quality setting for this process was the RAW format with a resolution of 300dpi. The photographs were taken outside in a shaded area with natural light and a distance of 1 to 1.5m between the map and the camera. Generally, shutter speed was 100th of a second, but the aperture was varied between f18 and f11 with a focal length between 42 and 31 mm, which when translated into 35 mm film equivalents, was between 63 mm and 46 mm. The advantage of speed and efficiency that was anticipated by this procedure was negated by a lack of map clarity and consequent limitations on interpretation of the final photographic images. This was in spite of enhancement using Adobe Photoshop 7 filters and image adjustments to the image sharpness, brightness and contrast.

With these disappointing results we returned to the initial process of joining A4 scanned images, see also (Hazell and Brodie, 2012).

To keep within a practical research time frame we adopted a multi-layered approach by capturing thematic layers from scanned 1:250,000 survey maps. In later analysis, maps with a scale of 1:50,000 were used to provide greater detail in specific areas of interest. All maps were scanned and enhanced using Adobe Photoshop 7 to improve legibility and associated accuracy during final digitisation. Nevertheless our interpretation of specific features such as contour position and value imposed limitations on final accuracy. Points on contour lines were inserted at changes in direction and intermediate points were included as frequently as possible to minimize error (Douglas and Peucker, 1973). The individual maps were joined into a matrix, as shown in Figure 3, from which an initial analysis could be undertaken. The contour data was then used to create a surface model of the landscape as a Triangular Irregular Network (TIN) that was formed from our digitised contour data (Figure 4).
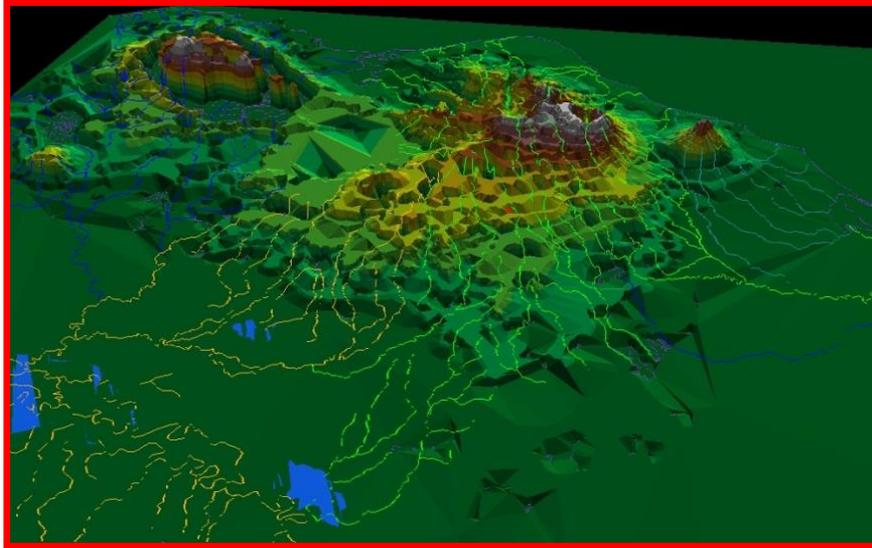
Figure 4. 3D scene of same area using Arcview 3.2 (L.C. Hazell).

In the background errors noted in the text due to contour crossovers in digitising can be seen. These did not affect analyses.

The slope gradient and 3D model tools produced analyses and representations with visible errors formed through contour crossing or incorrect digitising. This occurred with the earlier version of Arcview 3.2; however, when digitising contours using ARCMap 10, it was necessary to zoom in or deactivate the Snapping tool to avoid crossing contours or incorrect joining of different elevation contours. The same technique applies when editing vertices. This problem occurred only when contours were close to together.

In spite of this problem, only a small percentage of the final map area was affected and usually these contour crossings only occurred when contours were very close together indicating a steep gradient. This would automatically exclude these parts of the resulting terrain surface from consideration as a transport route because of the excessive gradients involved. Attempting to control a twenty tonne stone on steep downward slopes would have been impractical as replication and historical observation illustrated (Dillon, 2004, Heyerdahl, 1958, Richards and Whitby, 1997). In any case the analyses identified safer, more practical options that were nearby (Figure 5).
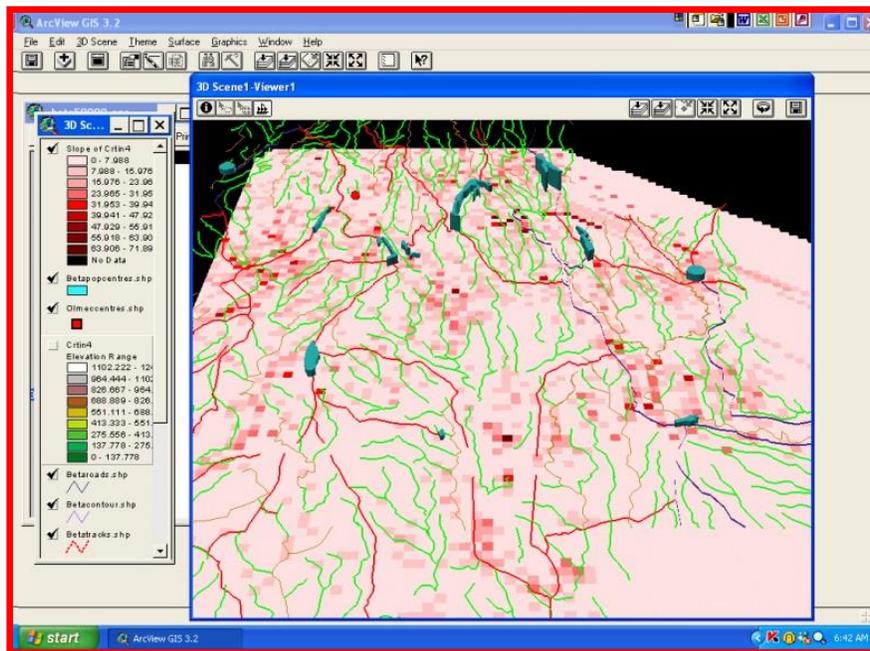
Figure 5. Detail of Slope Gradient analysis using Arcview 3.2 (L.C. Hazell).

The darker pixels indicated the steeper gradients and generally these are gradients which modern roads or tracks follow.

The analysis could have been undertaken empirically by simply reading the contours on the map or trace likely routes that showed minimal grades and then marking these on photocopied survey maps. But this would have necessitated either assessing contour spacing visually or measuring and calculating the grade along a multitude of potential pathways. The study area exhibits complex landforms, reflecting their volcanic origins. Using the slope gradient tool in ArcView ensured consistent analyses. This is particularly valuable when working with large areas and small-scale maps. Slope is defined by pixel size. Adobe Photoshop pixel counts and grid value tools determined the ground area that each pixel represented on our maps. Therefore a linear distance of: ±40 m on 1:250000 scale maps; ±16 m at 1:50000 and ±4 m for 1:16000 per pixel applied in our maps.

To manually sample slope grades at these scales would require analysis of each change of contour value across a potential pathway. The total fall from the source to the floodplain is some 400m in vertical height with contour

intervals between 10 m and 20 m. Analysis of this area and gradient range would require between 50 and 260 individual measurements for each potential path even if this was confined to a width of only 500 metres. Therefore, the slope gradient tool is more efficient in research hours and provides acceptable accuracy for route options that can be used with other data such as soil types, vegetation and hydrology to corroborate likely pathways (Figure 6).
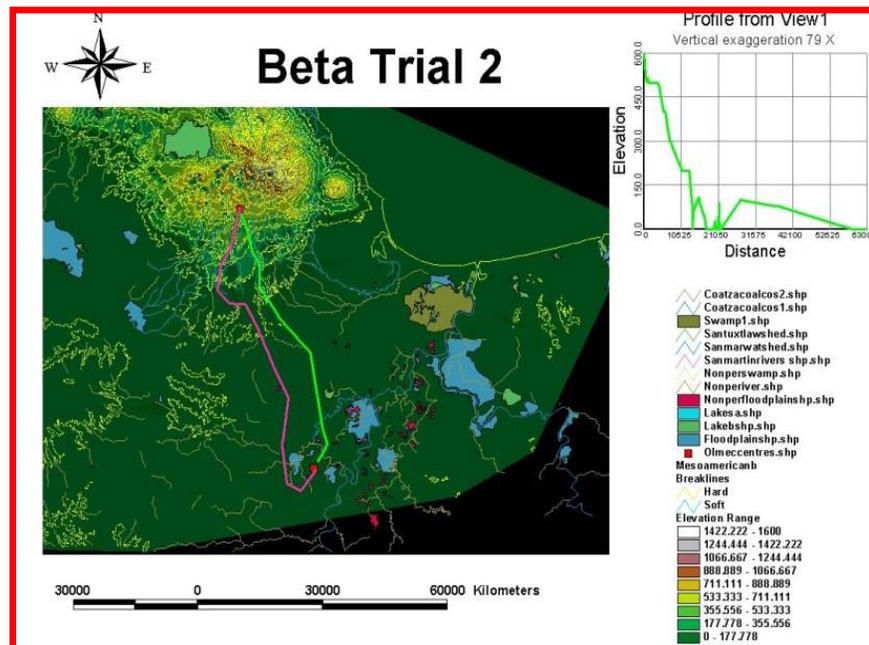

Figure 6. Route corridor options using Arcview 3.2 (L.C. Hazell).

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 do 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. Additionally, correlation between the route corridors identified by this method, show similar pathways to modern roads in the general area. Therefore the choice of potential transport paths, based on gradient analyses has validity. The benefits of GIS slope gradient and thematic database analyses are emphasised when linked to other research methodologies including: soil bearing capacity; friction coefficient studies; and other technology such as High Resolution Satellite image analysis. However we also noted some limitations while using GIS with this research:

- Care must be taken when using data from ARCView3.2 files and its coordinate systems with in ArcScene 10. The need to ground truth data is highlighted by this problem.
- ArcView 3.2 Slope gradient tool outcomes were easier to interpret than those derived from ArcView 10.

CONCLUSION

The pathways identified in these analyses are not final solutions to the megalith transport problem; however a research project of this type and scale required a manageable protocol from which further research, including field surveys, could be established. The purpose of this paper was to highlight the value and options of using GIS software for doing this. We have noted some limitations in its use but we have also demonstrated how this technology contributed to this research. It is proposed further studies of Olmec land transport be undertaken on the basis of this work. Research is also proposed that will include megalith transport in Neolithic Britain, to retrieve the Bluestones used in Stonehenge and standing stones on the Orkney Islands. Utilising other GIS attributes, research will be extended to human energetic aspects of megalith use. This focus will include constructing various funerary enclosures at Nan Modal on Pohnpei and Palauan terraces in the Oceania region.

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