Volumes of history: volume calculation from 3D sections at the Tell Leilan City Gates excavation.

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Introduction[1]

What is the degree of approximation that we can accept in a work related to volumetric data from an excavation? Answering this is not easy because, until laser scanners decrease in price, we will continue to have to interpolate data to obtain surface and volume measurements. As a result, we need to fix a standard for the digital survey of surfaces that will be processed in 3 D managing environments in order to help surveyors gather the data needed for IT operations and to encourage excavators to document their fieldwork with more precision. An Electronic Total Station survey allows enough precision, if we take care to fit our surveyed points grid to the different slopes of the stratigraphic units, increasing the number of points where the surface is discontinuous and decreasing it where the ground flattens. Using a surveyed point grid variable from 120 to 5 points/sqm. (i.e. from 1 point each 10 cm to 1 each 50 cm) according to the sloping of the soil, ensures that the final digital surfaces will be of a high quality. Recently I surveyed the entire excavation of the Garamantian site of Fehwet, Libya (ca. 100 sqm.) by total station using such a standard and am working on the digital reconstruction of the stratigraphic units with good results. But what if there is no chance to respect this standard? In this paper we will describe our experience in the rescue excavation of the City Gate complex in Tell Leilan, Syria where, due to logistical problems, (the distance of the city gates from the main focus of the project, the acropolis, and the inability of the surveyor to be in both places at once) we could not survey the surfaces of the stratigraphic units, but instead surveyed the sections enclosing the excavated area. (C.P.)

The archaeological context

Bulldozer damage from road construction in 2001 damaged the east side of the City Gate, and provided the opportunity to study a 24 meter span, north-south, through the Leilan City Wall. The phasing and stratigraphy at CG is defined by the excavation of a small slice of this central occupation area, 9 meters long, 1 meter wide (Figure 1).

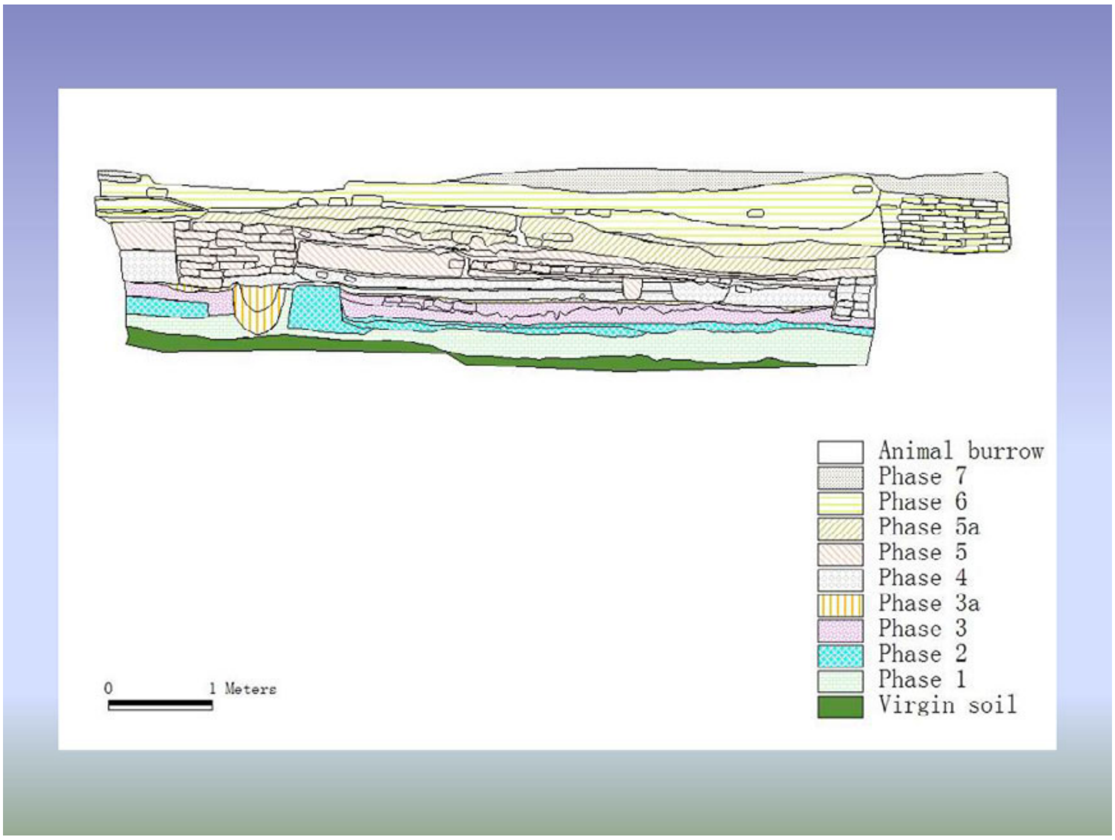


Figure 1. Tell Leilan City Gate excavation: Western section with different phases.

Prior to excavation, this area was divided into stratigraphic units, which were carefully floated and dry-sieved to recover botanical and small remains and sampled for soil micromorphological investigations. The current paper grew out of our need to provide accurate volumetric measurements to contextualize the archaeobotanical and soil-micromorphological data.

The initial stage of this fortification system (ca. 2600 BC) was characterized by a set of earthworks, into which a wall was cut, to form a 7m wide, 3 m tall northern wall. At 2200 BC, another 1 meter wide buttressed wall was built up against this area. 20 meters to the south, a similar type of construction can be observed, which probably reveals the southern limits of these fortifications.

Between these two massive walls lay the administrative quarter of the city gate complex. Excavation revealed 9 phases of this complex, dating from the mid-third to the early second millennium. Phase 1, founded on virgin soil, dates to the building of the wall complex, while phases 2-3 (Leilan IIId-IIa) see the conversion of this area into administrative spaces divided with pisé and mudbrick walls. In the next phase, 4, a large northern wall was constructed and a fine floor was laid, although the area's function remained administrative. Phase 5 witnessed the construction of an enormous, 4 meter wide fireplace in the north, and a baked-brick platform to the west and south, which may have formed the surface of the road entering the gate. Following Phase 5, this area fell into a short period of disuse. In Phases 6 and 7, at approximately 2300 BC the city gate area was rebuilt. A new northern defensive wall and a new southern dividing wall were constructed during phase 6, and three, successive plaster floors were laid in phase 7. The subsequent phase, 8, witnessed an approximately 300 year abandonment, when the area was allowed to fill in with a meter-thick dust deposit. Finally, phase 9 dates to the resettlement of Tell Leilan in the early second millenium B.C., when a final set of earthworks was built. (L.R.)

Volume calculation: from sections to volumetric data

In a previous paper written with Paolo Carafa and Sabatino Laurenza (Carafa, Laurenza and Putzolu 2002) we obtained volumetric data by creating pairs of TINs for each stratigraphic unit with *ESRI ArcView 3D Analyst* and calculating the *space* between them with the *Cut Fill* tool. In that case, the TINs were obtained by processing surface points surveyed by ETS, here we decided to create the TINs from the 3D polylines of the sections.

The idea was that, by assuming that the surfaces between the western and eastern sections (separated by just one meter) had a regular slope, the sections' upper and lower profile of each stratigraphic unit was enough for the interpolation of the final surfaces. Although this resulted in a lack of precision of the resulting TINs, this strategy allowed us to limit the presence of the surveyor to only a few hours.

After fixing a grid of control points, we took digital pictures of the sections, taking care that each image was positioned between four control points, the coordinates of which was surveyed by the ETS. These two steps (digital photographing of the sections and ETS surveying of the control points) were the only fieldwork done by the surveyor. As our approach was different from Pompeii 2000 we also had to rethink our surveying strategy and post-processing operations: Figure 2 shows the fieldwork steps for Pompeii and Tell Leilan, while Figure 3 shows slightly different IT operations adapted to the new situation.

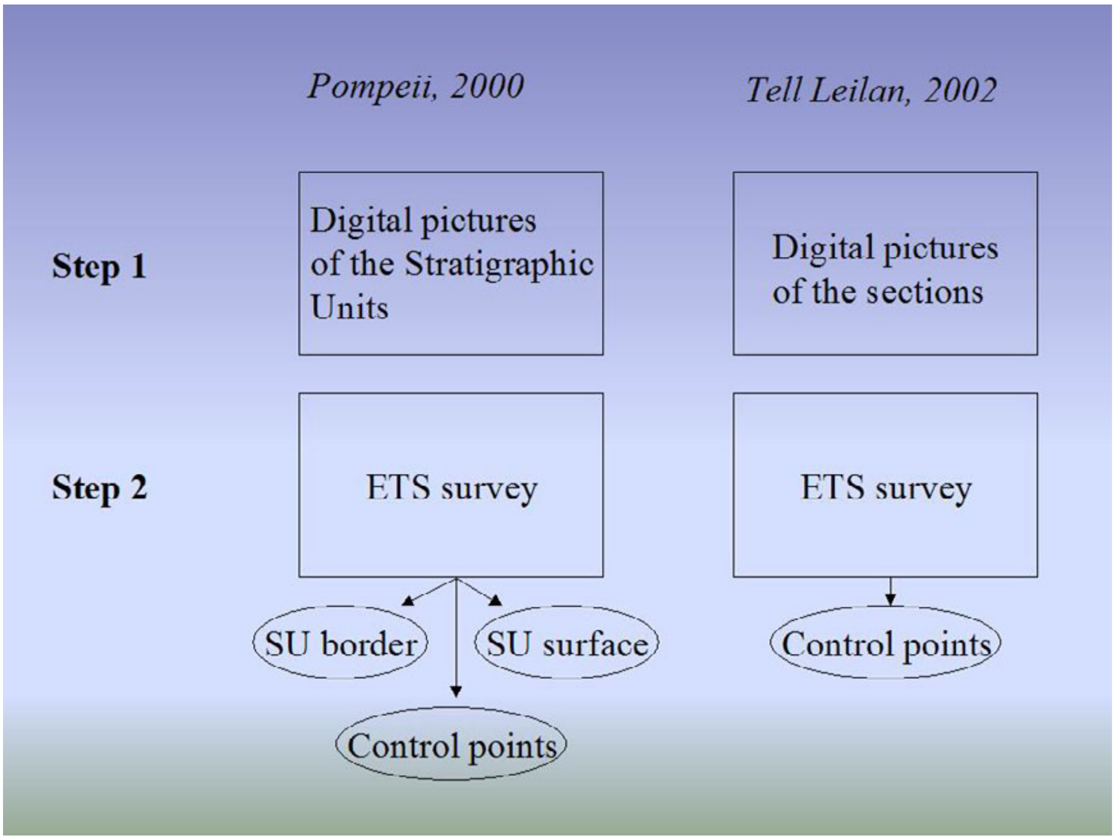


Figure 2. Fieldwork operations: Pompeii 2000 vs Tell Leilan 2002.

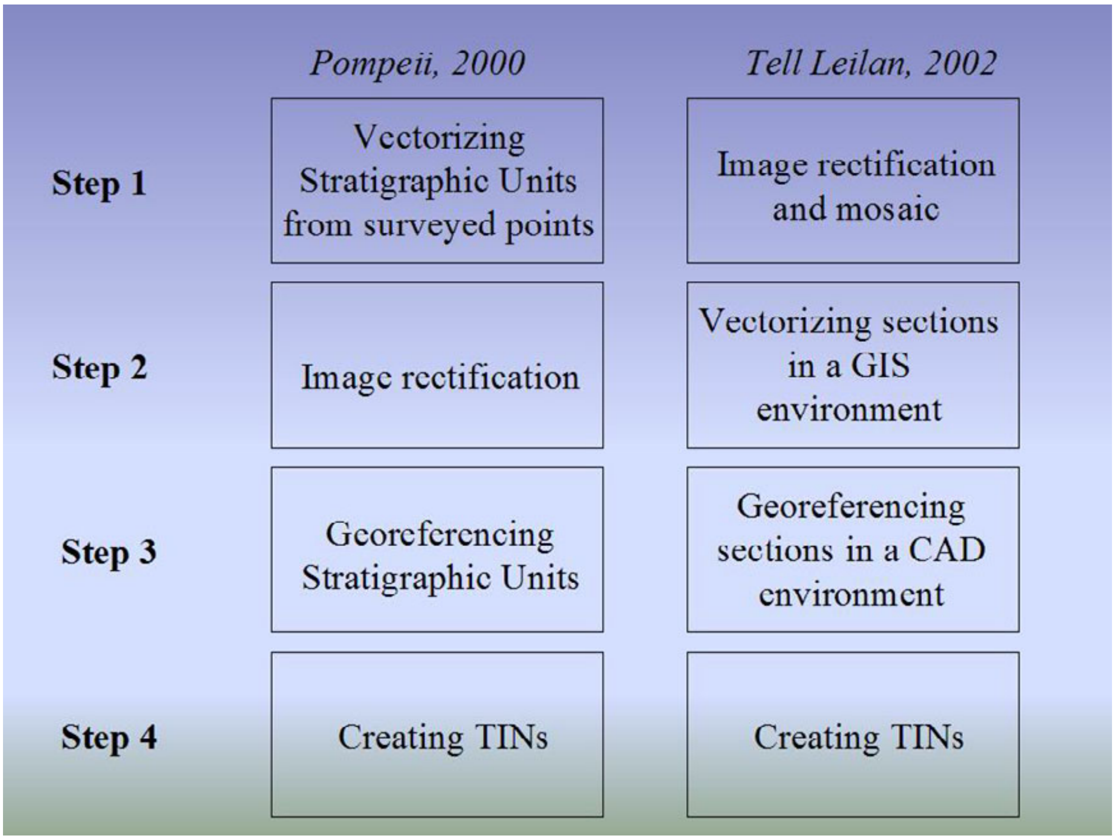


Figure 3. Post processing operations: Pompeii 2000 vs Tell Leilan 2002.

Image rectification and mosaic.

In order to correct the digital images and to merge them together we first processed them in Rolleimetric MSR. This software commonly used for photogrammetry can resample the pixels in raster images according to the coordinates of at least four control points and, when there are different images with common control points, process the input photographs into a single orthorectified mosaic. The final output of MSR was a set of five scaled and orthorectified pictures representing our five sections (figure 4).

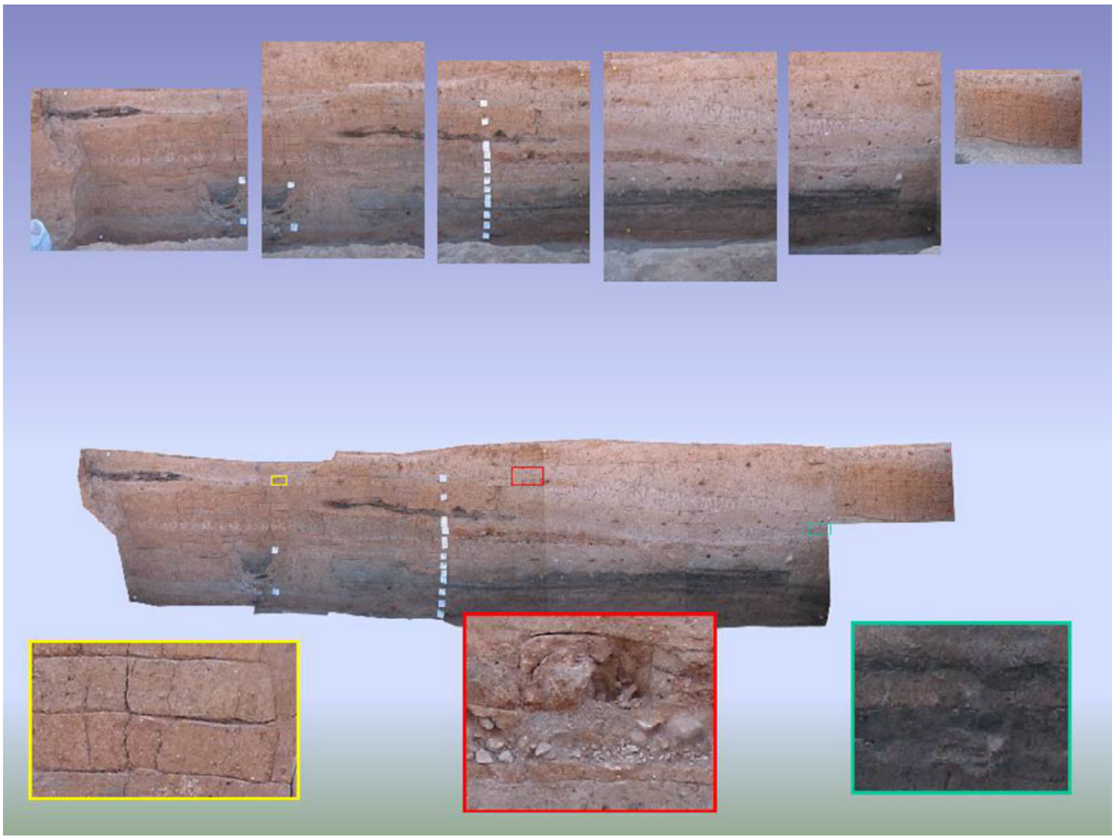


Figure 4. Orthorectified photomosaic of Western section.

Vectorizing sections in a GIS environment.

The MSR output images were then imported into ESRI ArcView 3.2a[2] and the different Stratigraphic Units (lots) were drawn.

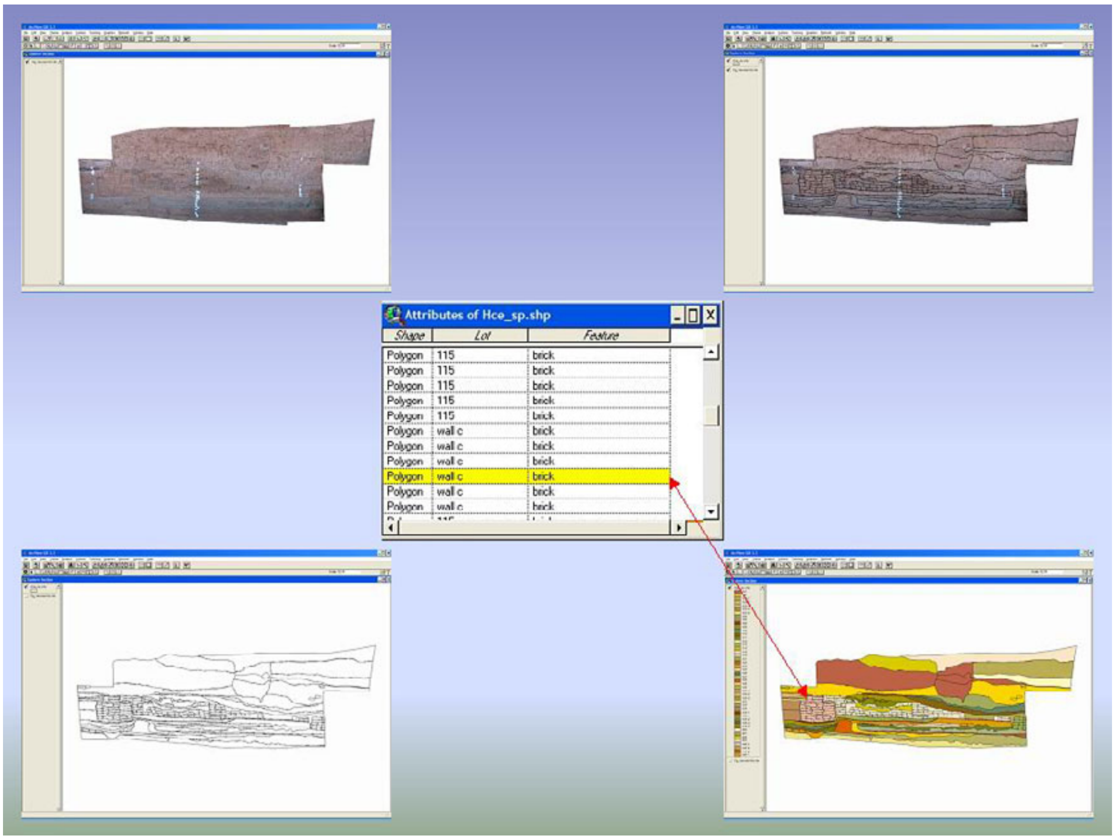


Figure 5. The MSR output raster becomes a vector file in ArcView.

Since the limits between lots were not always clear we processed the images in MSR at a very high resolution (1 pixel/1 mm) and checked the resulting printed image against the excavation. This enabled us to draw the profile of the different lots with a single graphic element in our GIS environment. Each lot and each feature within a lot (like a brick or stone) was drawn by a polyline and identified in the table of attributes by a Lot Id and/or a Feature Id (figure 5).

At the end of the process we obtained five ArcView Themes each of which grouped the graphic representation of one section and a linked table of attributes indicating the Lot Id of each polyline. The vectors were already scaled but they lacked georeferenciation and internal spatial relationships. The next step was locating our sections in "real world" space (figure 6).

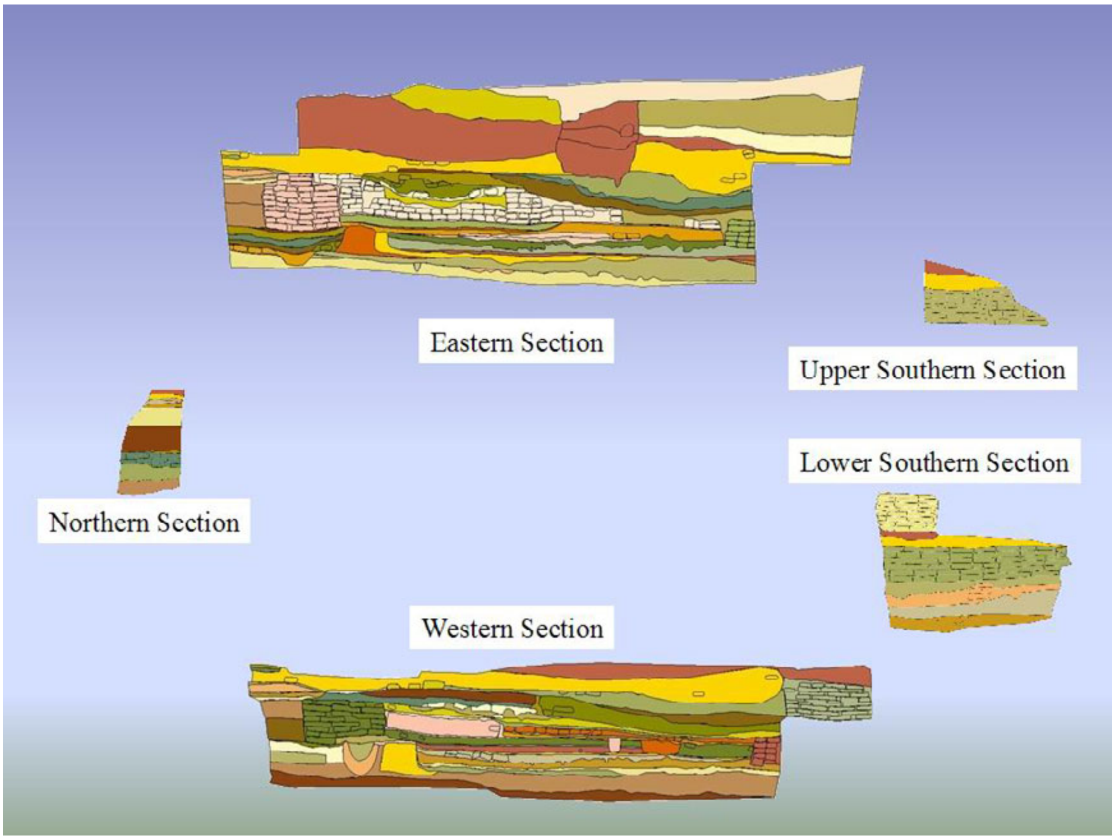


Figure 6. The five sections of City Gates excavation.

Georeferencing sections in a CAD environment.

We exported our vectors into Autodesk Autocad to give them a position in the 3D space that reflected their real world spatial relationships. For this purpose, we used the *3D align* tool, assigning the coordinates of just three control points to each section. As they were already scaled, this gave them the correct position in the Cartesian space (figure 7). We performed the georeferenciation in a local Cartesian space instead of a real world coordinate system because working with xx,xxx coordinates is definitely easier than working with xxx.xxx,xx ones!

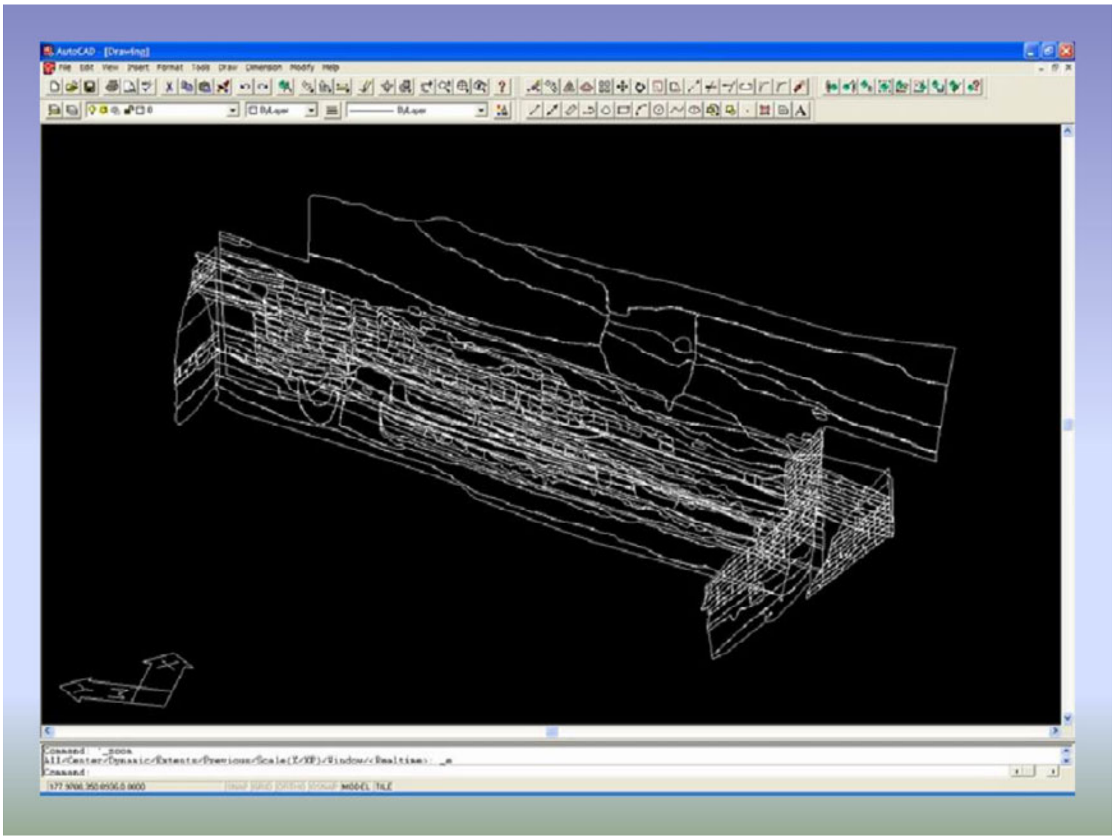


Figure 7. The five sections georeferenced in CAD environment.

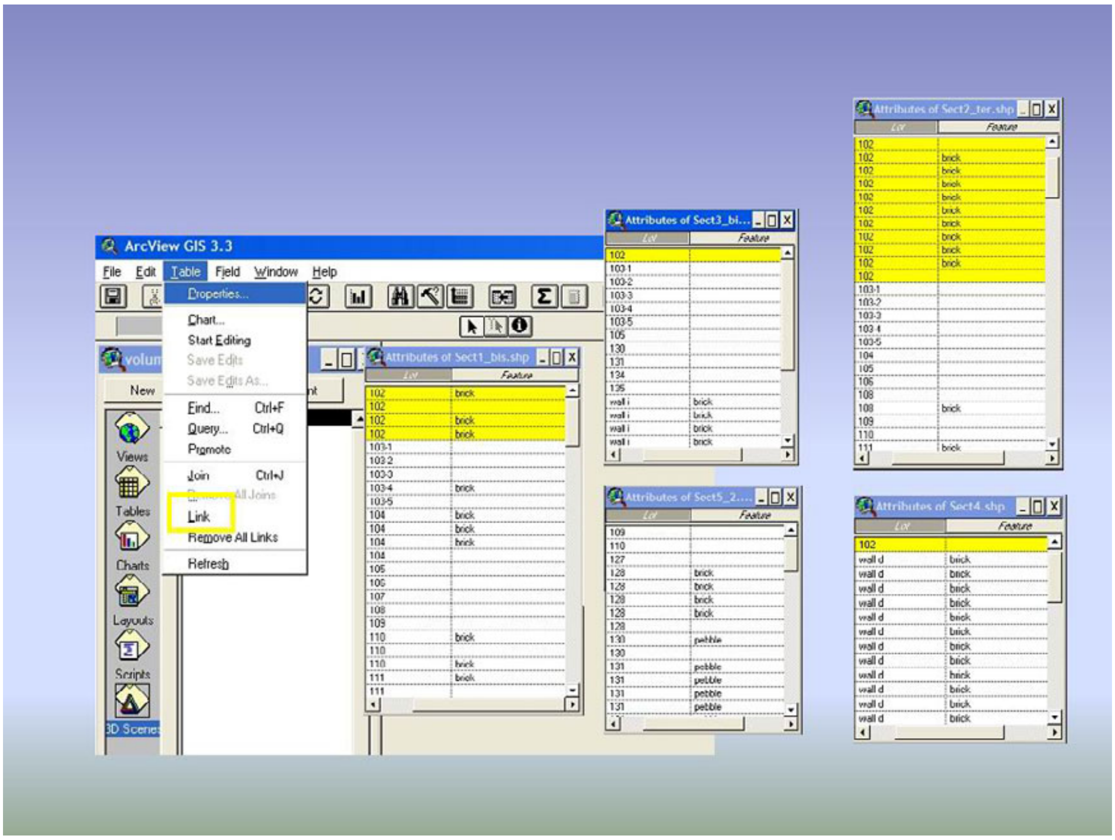


Figure 8. The link between the tables of attributes of the five sections.

Creating TINs.

Once reimported into ArcView, the sections were all visible in the same 3D Scene. In order to speed up the selection of each lot in the different sections we linked the five tables of attributes with a simple database (with Lot ID, phase and period).

The links between tables enabled us to isolate the 34 lots that were visible on both the N/S sections. A table with the 34 selected Lots was exported and linked with the five tables of attributes. In short we made a simple GIS where the representation of the lots in the five sections of the excavation was the only graphic element and an elementary relational database provided the alphanumeric data (figure 8).Once selected in the "Lot table" a stratigraphic unit was automatically selected in each section, allowing us to isolate it in separate shapefiles. These shapefiles, which could be considered the side faces of the lot solid (figure 9), were exported into Autocad to draw the top and bottom surface (upper and lower face of the Lot solid).

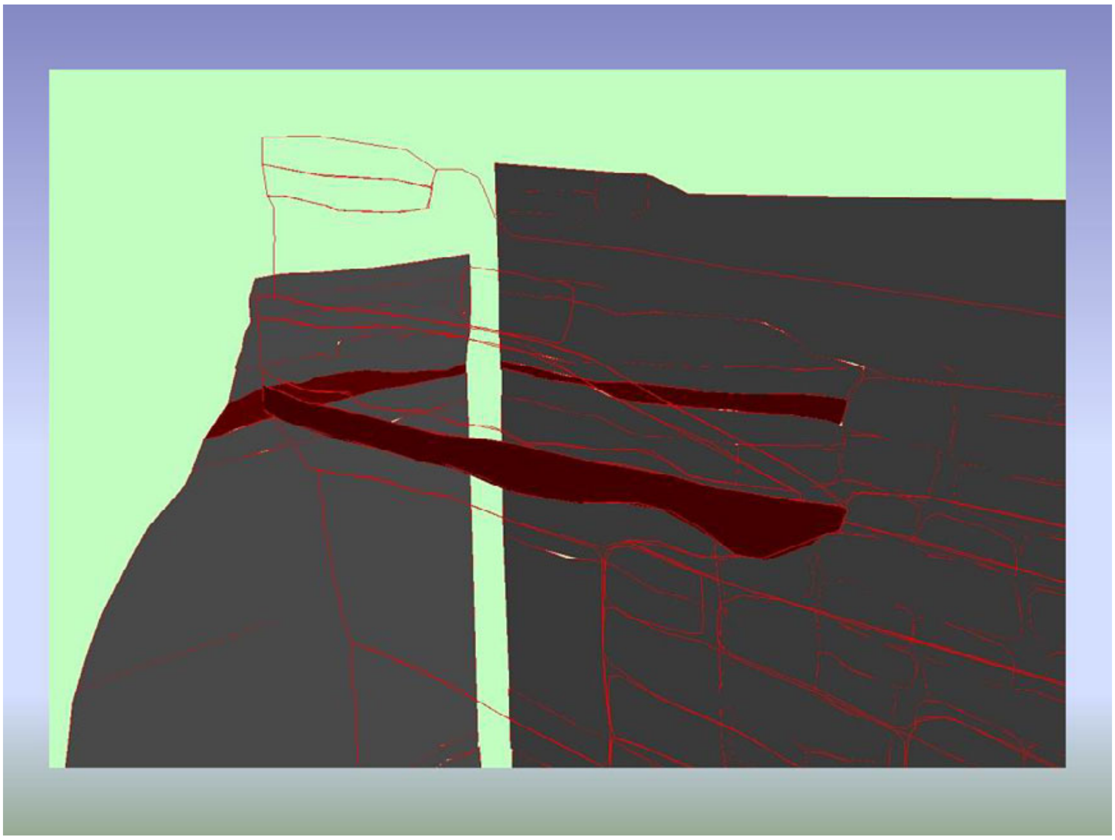


Figure 9. Lot 103.4 isolated in 3 sections.

The Autocad Object Snap Commands helped us create 3D polylines (one for the top and one for the bottom) which 3D Analyst needed to create TINs (Figure 10). Back in ArcView, the created TINs gave us two surfaces to use with 3D Analyst

Cut Fill tool (figure 11). This tool calculates the volume between a *before surface* and an *after surface.* In terms of archaeological fieldwork the before surface is the top of a Stratigraphic Unit, while the after surface is what we see after its removal (i.e. the top of the units under it): in between we have its volume. The Cut Fill tool generated a table with the values of area and volume, and, after performing these operations for all 34 Lots, we could summarize the results in one table with the area, volume and average width (volume/area) of each Lot (figure 12). (C.P.)

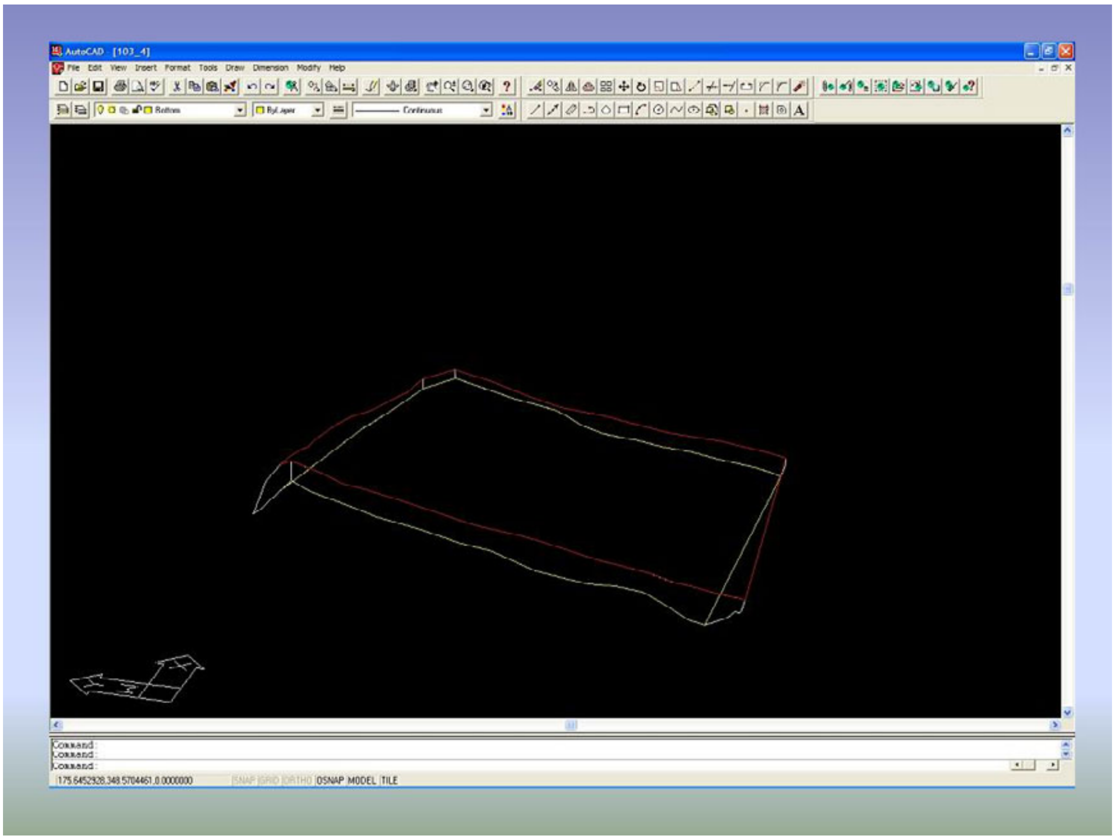


Figure 10. Drawing of top and bottom of Lot 103.4 in CAD environment.

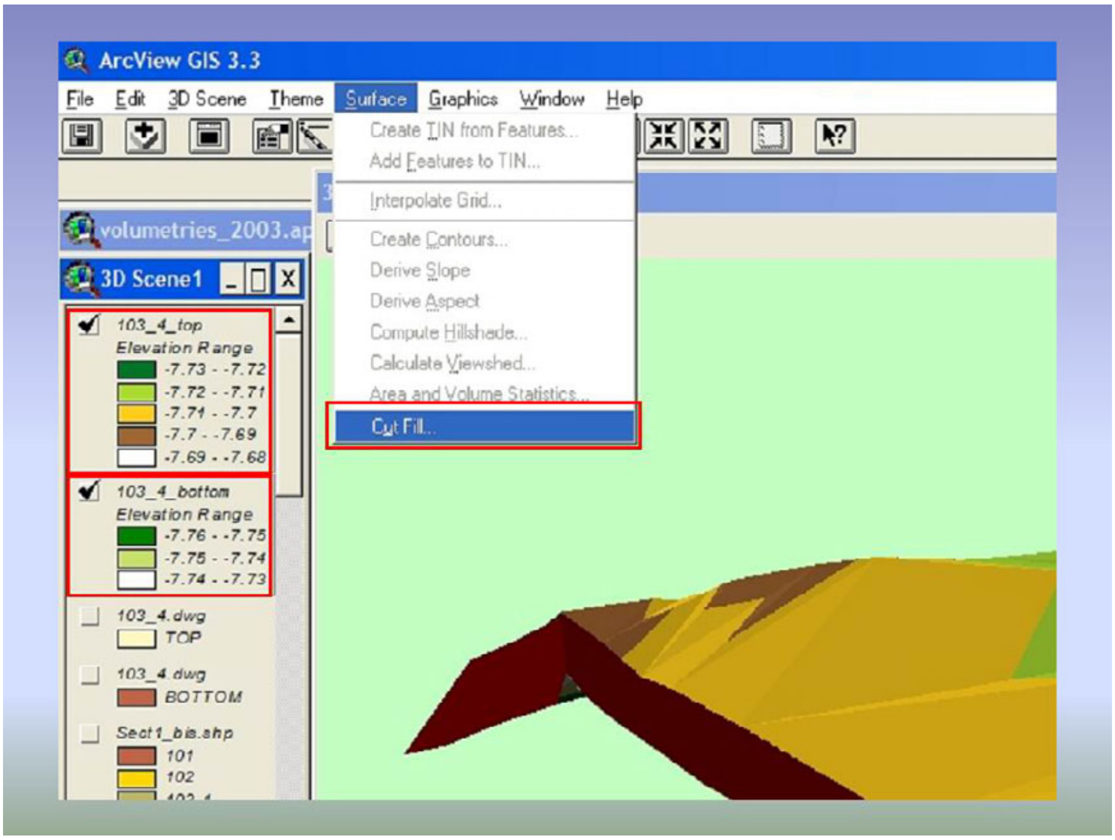
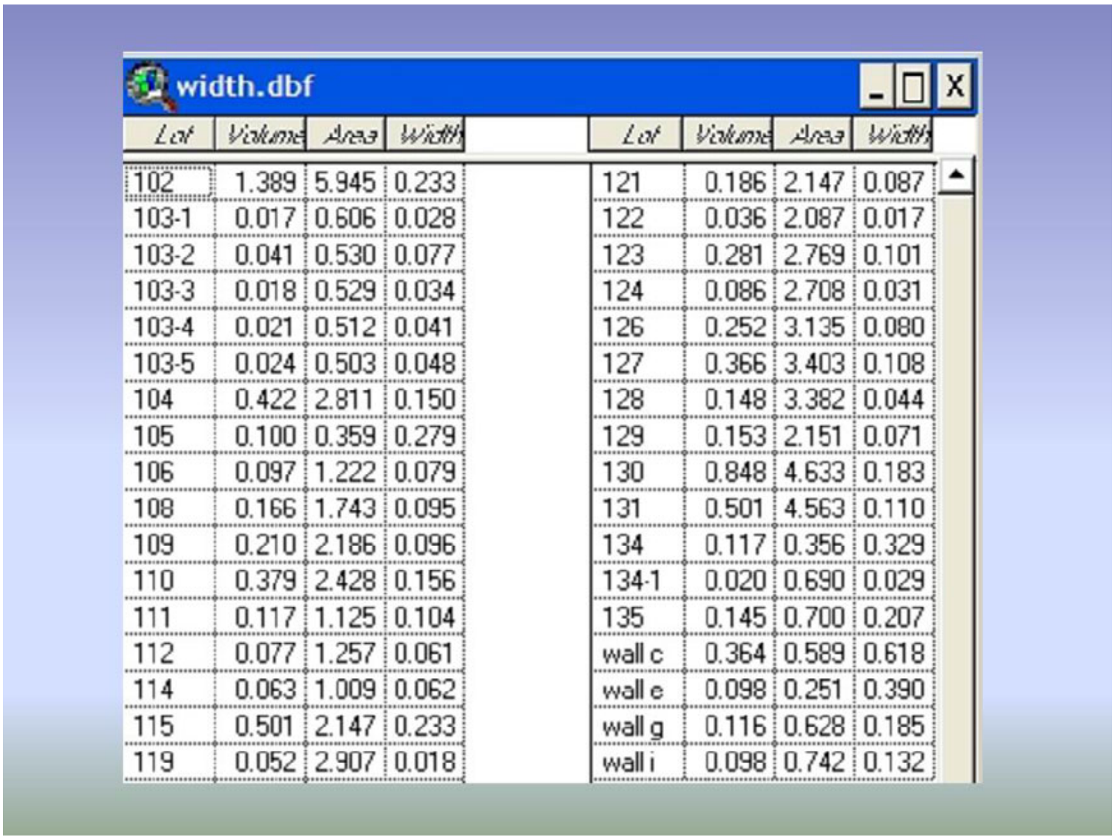


Figure 11. ArcView 3D Analyst Cut Fill tool.


width.dbf

Lot	Volume	Area	Width	Lot	Volume	Area	Width
102	1.389	5.945	0.233	121	0.186	2.147	0.087
103-1	0.017	0.606	0.028	122	0.036	2.087	0.017
103-2	0.041	0.530	0.077	123	0.281	2.769	0.101
103-3	0.018	0.529	0.034	124	0.086	2.708	0.031
103-4	0.021	0.512	0.041	126	0.252	3.135	0.080
103-5	0.024	0.503	0.048	127	0.366	3.403	0.108
104	0.422	2.811	0.150	128	0.148	3.382	0.044
105	0.100	0.359	0.279	129	0.153	2.151	0.071
106	0.097	1.222	0.079	130	0.848	4.633	0.183
108	0.166	1.743	0.095	131	0.501	4.563	0.110
109	0.210	2.186	0.096	134	0.117	0.356	0.329
110	0.379	2.428	0.156	134-1	0.020	0.690	0.029
111	0.117	1.125	0.104	135	0.145	0.700	0.207
112	0.077	1.257	0.061	wall c	0.364	0.589	0.618
114	0.063	1.009	0.062	wall e	0.098	0.251	0.390
115	0.501	2.147	0.233	wall g	0.116	0.628	0.185
119	0.052	2.907	0.018	wall i	0.098	0.742	0.132

Figure 12. Areas, Volumes and averaged Width of City Gates excavation Lots.

Site Formation Process Analysis: Diachronic Accumulation Rate

We plan to use the volumetric data to investigate site formation processes. The precise volume data recorded, alongside the impressive material culture and radiocarbon information retrieved from the excavation allow us a rare opportunity to explore the way in which a *tell* site forms, both in occupational and abandonment contexts, by contrasting the accumulation rate from the abandonment layer (phase 8) with the data from phases 1-5 for which we have multiple radiocarbon dates (figure 13).

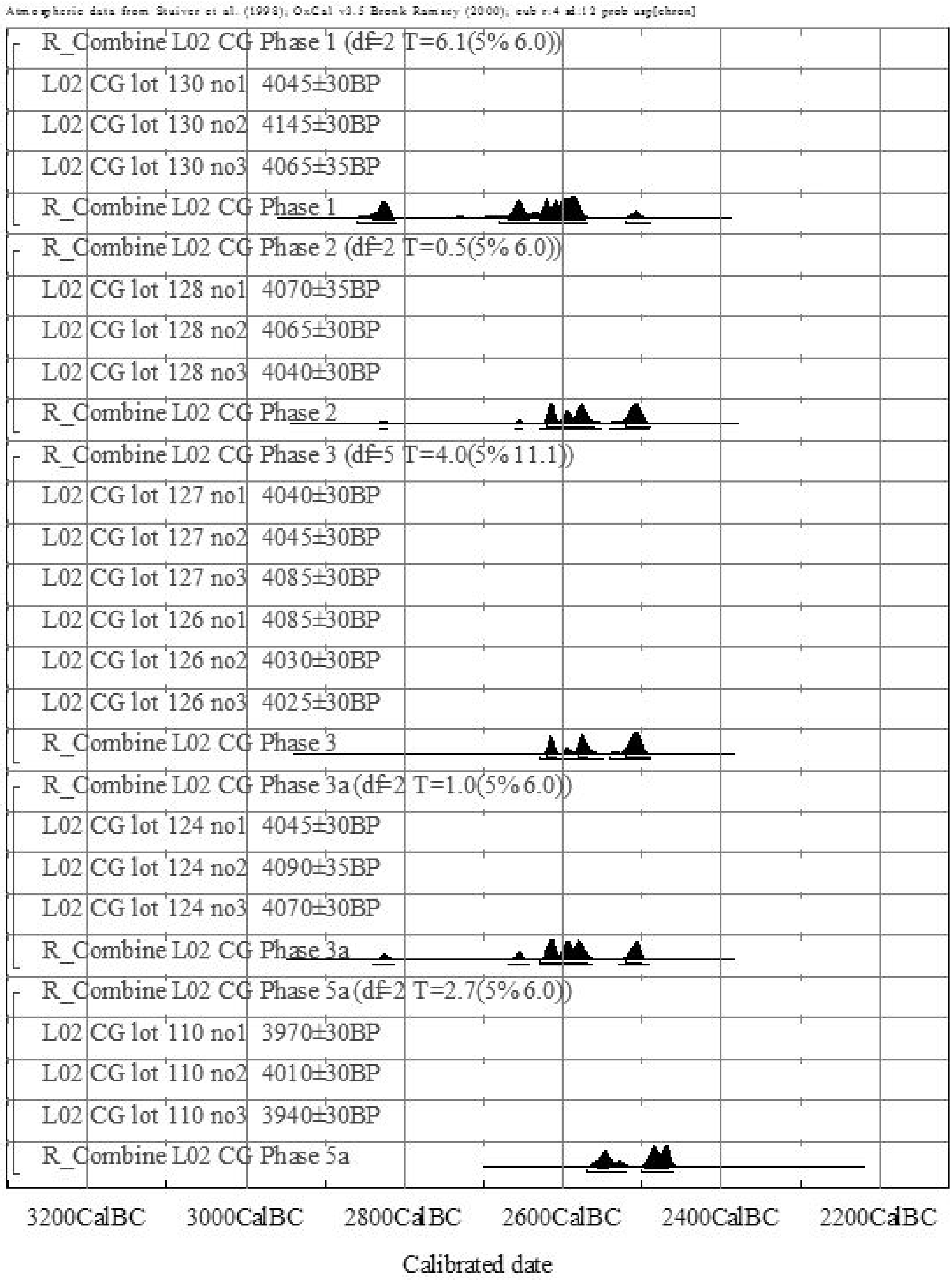


Figure 13. Calibrated radiocarbon dates.

This analysis would be virtually inconceivable without the data in electronic form. The algorithms that can be created will allow us to model how the *tell* formed. The explanation of the process (figure 14) is as follows:

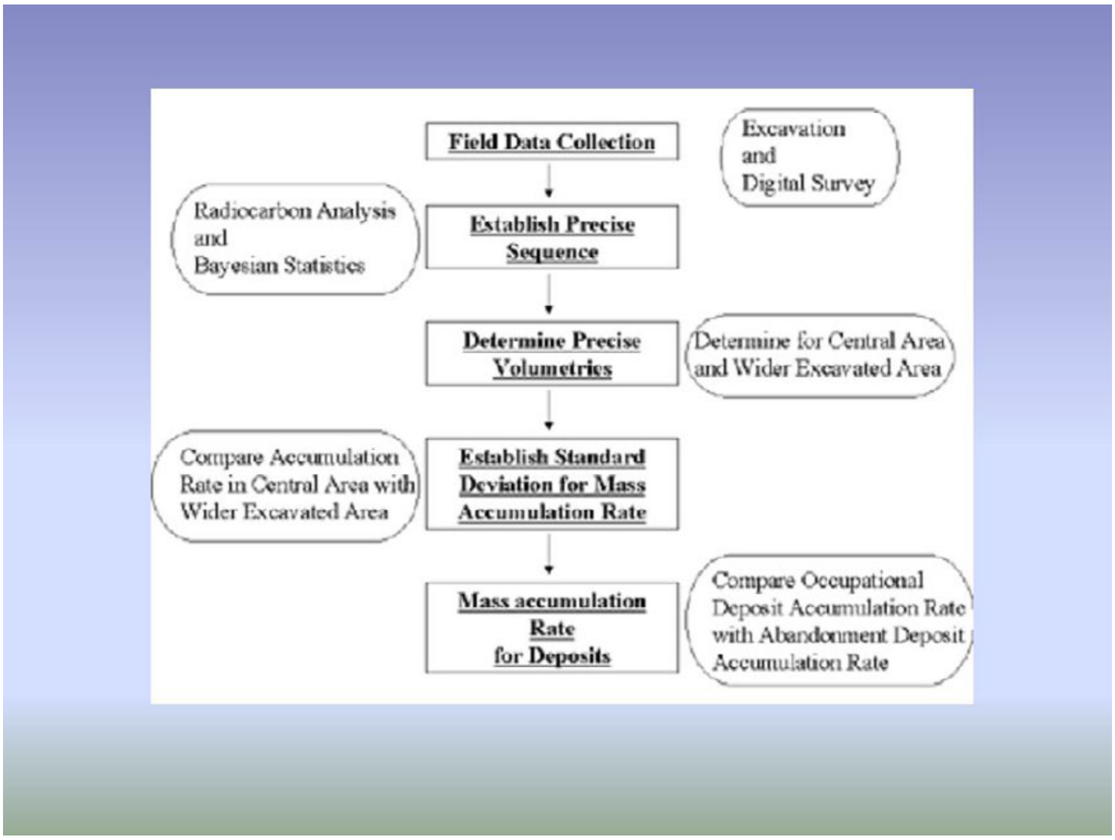


Figure 14. Site formation process analysys.

Field Data Collection: Excavation and Digital Survey. First, careful excavation of the site is digitally recorded to produce a 3D model of the central section. Essentially, this gives us a 'core sample,' similar to units used in paleoecology. This is necessary in order to interpolate the results to obtain a standard deviation for the Mass Accumulation Rate.

Establish Precise Sequence: Radiocarbon Analysis and Bayesian Statistics. Second, multiple radiocarbon samples must be taken from key stratigraphic units and precisely analysed in order to establish a tight dating sequence. This sequence can be further refined by the use of Bayesian statistics, which essentially omits radiocarbon ranges that are stratigraphically impossible.

Determine Precise Volumetrics: Determine for Central Area and Wider Excavated Area. The next step is to determine precise volumes for each of the stratigraphic layers in the central 'core' section, as well as for a sequence that is stratigraphically identical to the central section, but spatially separated. This aspect of our analysis is still underway.

Establish Standard Deviation for Mass Accumulation Rate: Compare Accumulation Rate in Central Area with Wider Excavated Area. Using the volumetrics and the dating sequence, we can establish a Standard Deviation for the Mass Accumulation Rate in the excavation area. This can be done by creating a statistical algorithm, which calculates a rate of accumulation for occupational deposits at Operation CG.

Mass Accumulation Rate for Deposits: Compare Occupational Deposit Accumulation Rate with Abandonment Deposit Accumulation Rate. Finally, at Tell Leilan and other sites in the region, there is evidence for large scale abandonment of settlements at around 2200 BC (Weiss et al. 1993, Weiss 2000). This is referred to as the Habur Hiatus and is probably linked to an abrupt climate change. Using abandonment volumetric data from the Hiatus Phase at Operation CG, and Hiatus data from other excavations at Tell Leilan, it may be possible to create a site-wide Mass Accumulation Rate for the Habur Hiatus. We therefore can juxtapose occupational mass accumulation rate to abandonment accumulation rate. This method of interpretation can be used as a model to study site formation processes in general, and can be compared/contrasted to other contemporary occupations and abandonments at other sites.

A study of the mass accumulation rate of Tell Leilan Operation CG would be an important attempt at modelling the rate of site formation. Very rarely are we afforded such precise dates and a corresponding precision of volumetrics. In this circumstance, therefore, we feel that it is valid to adopt what is essentially a paleoecological model of accumulation rate into our analysis of cultural deposits. Furthermore, the abandonment phase at the City Gate operation accumulated an equally impressive amount of debris through presumably non-cultural means. The study of the site formation process will be an invaluable interpretative device. In conclusion, the 3D recording and GIS analysis speaks volumes about the history of the City Gate complex at Tell Leilan, and the integration of this computer application and more traditional means of analysis may serve as a model for future excavations of Tell sites. (A.M.C.)

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[1] The authors would also like to thank Prof. Harvey Weiss (Yale University), the director of the Tell Leilan project for allowing us to excavate at Operation CG, The Syrian Directorate-General of Antiquities for aiding this project at every turn, Dr. Dominique de Moulins (University College London) for her work on the archaeobotany, Dr. Thomas Guilderson (Center for Accelerator Mass Spectometry, Lawrence Livermore National Laboratory) for his superb work on the radiocarbon dates, and our friends and colleagues from Tell Leilan, Tell Barham, and Qahtaniyeh for their outstanding excavation ability and invaluable assistance. Andrew McCarthy would like to thank colleagues at the University of Edinburgh, especially Dr. Mike Church, who has been very helpful in coming up with and discussing the practical details of the mass accumulation rate.

[2] The same could have been done in ArcGIS 8.2 (and now also in ArcGIS 8.3) but I was still using ArcView 3.2a at that time.

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