USING SPATIAL ANALYSIS TO DETERMINE THE MNI OF MASS GRAVES

by

Carmen Dianne Spruill

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Approved by:

Gwendolyn M. Robbins Schug, Ph.D, Thesis Director

Ellen A. Cowan, Ph.D, First Reader

Susan M. Lappan, Ph.D, Second Reader

Ted Zerucha, Ph.D, Interim Director, The Honors College

Abstract: *The commingled state of individuals interred in mass graves present a complex issue when it comes to identifying individuals. Many common methods for establishing the number of individuals represented by a skeletal assemblage decontextualize the elements by not considering the position of the element within the burial site. Here I argue that based on the position of skeletal elements within space, they can be inferred to belong to the same individual (or not). The ability to reassociate elements can provide more accurate estimates of the number of individuals present. This requires conscientious collection of* in situ *data. Geophysical site surveying is useful not only for detecting mass graves, but also for providing a "map" of the grave site showing the distribution of anomalies. The position of the elements within the grave is affected by a variety of geotaphonomic forces which must be considered before assaying spatial analysis. Mass graves which represent a primary inhumation site, in which the remains are articulated or were disarticulated through natural taphonomic processes, in which carnivore scavenging is minimal, in which the geological context is favorable for preservation, and in which fluvial transport is low-energy or not present are the best candidates for effective analysis of the spatial distribution of remains. This thesis will discuss current methods for detecting and mapping mass graves, geotaphonomic factors which affect spatial distribution of bones relative to each other, and the potential application of technologies for spatial analysis to the establishment of the number of individuals represented by an assemblage.*

1.0 Introduction

There are cases where determining the number of individuals represented by a skeletal assemblage is a straightforward process; for example, if only one individual is buried in a grave, or the skeletal remains are articulated. In these cases, some researchers focus on ascertaining the identity of the individual, using estimates of sex, age, stature, and in some cases, ethnicity or population membership. In many cases, however, individuals are not preserved in discrete units (Karch, 2008). Biological anthropologists frequently investigate sites containing disarticulated and commingled remains of multiple individuals. In these cases, the first task is to establish the number of individuals represented by the assemblage (Burns, 2012, Badgley, 1986a). This thesis will discuss current methods for detecting and mapping mass graves, geotaphonomic factors which affect spatial distribution of bones relative to each other, and the potential application of spatial analysis to the establishment of the number of individuals represented at a given site.

It may be possible to develop more precise methods that ascertain the number of individuals in the original assemblage based on the differentiation of individuals represented in an assemblage. Some currently existing methods include osteometric sorting based on size of element, age, and sex (Byrd, 2008). I argue that estimates of the number of individuals represented by an assemblagecan be refined based on the spatial distribution of skeletal elements within the grave site. Although this may lead to overestimation of the MNI, it is a more conservative approach to the problem because it avoids errors inherent to methods which decontextualize the assemblage.

The ways that remains are distributed in space can indicate that they are not associated with each other and therefore must represent more than one individual. If, for example, at hypothetical site X, excavators dug Trench 1, which is 20ft long. One left femoral fragment was excavated from stratum 1, one right femoral fragment was excavated directly below in stratum 2, and one left calcaneus was excavated from stratum 2, 10ft uphill of the other remains. Based on the paired elements alone, the minimum number of individuals presentis 1. But, given that the two femora were discovered in separate strata, they were deposited at different times and therefore could not belong to the same individual. Given that the calcaneus is uphill from the right femoral fragment, it is unlikely to have been transported by wind or water (Andrews, 1995, Badgley, 1986a, Badgley, 1986b, Boaz & Behrensmeyer, 1976). Let's say there is no evidence of carnivore activity that could have transported the remains (Moraitis & Spiliopoulou, 2010). Therefore, the calcaneus must also belong to a separate individual. Based on this analysis of the remains' spatial distribution, the MNI of hypothetical site X is actually 3.

Naturally, the process of recognizing remains as belonging to separate individuals using spatial information becomes increasingly difficult as sites yield larger and more commingled assemblages (Horton, 1984), and cannot be used at sites at which random sorting and transportation of remains has occurred (Ubelaker, 2008 & Skinner, Alempijevic, & Djuric-Srejic, 2003). Determining whether remains could have become disarticulated and transported away from each other requires intimate knowledge of geologic and taphonomic processes. It cannot be assumed that remains over an arbitrary distance away from each other do not belong to the same individual. Rather, the probability of their association must be determined based on consideration of the element and its siding, sex and age when possible, geotaphonomy, and cultural disturbance when necessary (Charles & Buikstra, 2008). Taking these factors into account and applying them to hundreds or even thousands of elements in an assemblage would be impractical to do by hand. I propose therefore, to explore applications of GIS technologies that may provide an automated method to refine MNI through spatial interpretation.

2.0 Geophysical Methods for the Detection of Mass Graves

Using spatial analysis to characterize assemblage population would be most useful in cases where multiple individuals have been interred within a single grave. While these complex sites present a challenge in terms of site interpretation, it is in these circumstances that refined estimates of MNI are most important. The reconstruction of site formation processes must begin with the effective detection of mass graves sites, preferably through non-invasive techniques.

There is no universally agreed upon definition of what constitutes a “mass grave,” particularly as it applies across disciplines (Haglund, 2001). While some researchers suggest that a least a given number of individuals be interred for a site to constitute a mass grave (Skinner, 1987), others argue that because of the variety of contexts in which sites containing multiple individuals may form, the term “mass grave” should remain a relative definition not constrained by arbitrary boundaries (Haglund, 2001 & Kalacska et al., 2009). For the purposes of this paper, a mass grave is considered any site containing more than one individual interred in a single burial.

2.1 Detection of Mass Graves

The circumstances under which mass graves are discovered vary depending on the age of the mass grave. In the aftermath of mass fatality events, testimony by individuals who either witnessed others burying the remains or buried the remains themselves is often used to locate the mass graves (Egaña et al., 2008 & Kalacska et al., 2009). However, it is often the responsibility of investigators to manually search a large area after being pointed to the general vicinity of the grave, using techniques such soil probing to detect properties indicative of recent disturbance. The time-consuming and, considering the unstable political conditions of areas in which these investigations take place, often dangerous nature of this method raises concerns regarding the security of personnel (Kalacska et al., 2009). Because of this, researchers such as Kalacksa and colleagues (2009) are researching methods for detecting mass graves using remote sensing technology.

Remote sensing technology, especially satellite-based imagery, has been used to discover archaeological sites since the 1970s. This technological advancement has led to a boom in the number of archaeological sites discovered and excavated (Giardino, 2011 & Pollard, 1999). Other studies have used this technology to draw correlations between site distribution and geomorphological features (Rajani & Rajawat, 2011 & Pollard, 1999). Some of the most groundbreaking geophysical techniques in site detection include the application of ground penetrating radar, magnetometry, and electrical resistivity (Seramur, 2017).

2.2 Using Ground Penetrating Radar, Magnetometry, and Electrical Resistivity

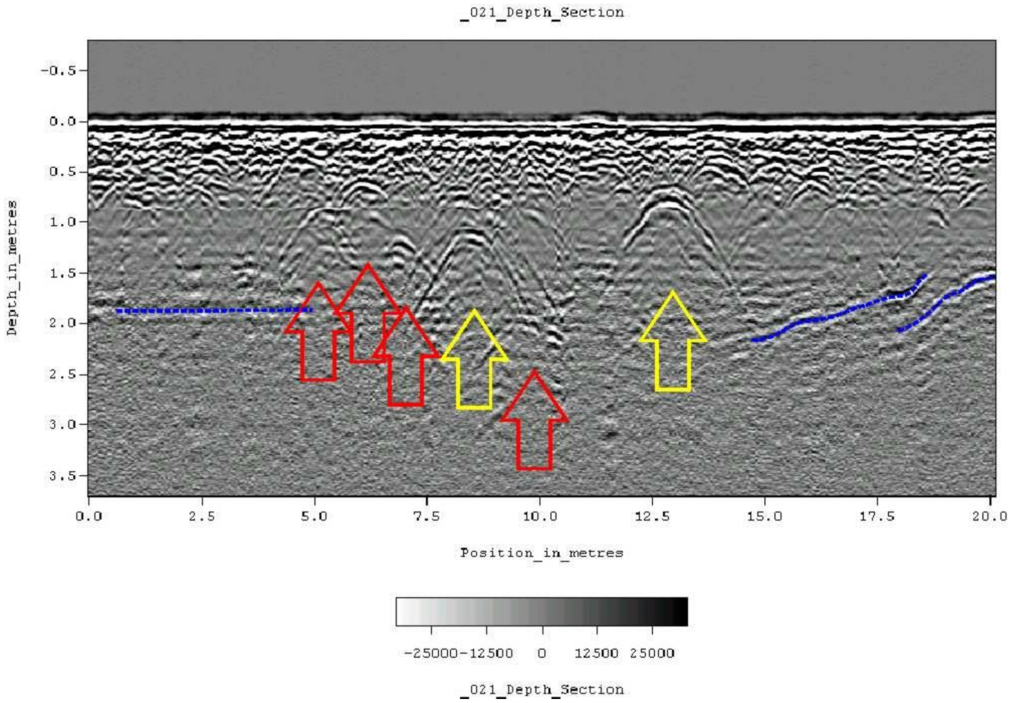
Ground Penetrating Radar, or GPR, is a general term for a geophysical technique that uses high-frequency radio signals to detect anomalies underground by measuring the travel time of waves reflected from objects or discontinuities in the ground. These technologies use this data to create a numerical model that appears as a “map” or profile of a site (Goldberg & MacPhail, 2011). GPR machines have a source antenna, which generates electromagnetic waves that then reflect off underground objects, and a receiving antenna, which receives the reflected EM waves. Data is collected as the instrument is pushed on a cart along a transect (Fig. 1). It is important to consider the wavelength of the antenna used. Available GPR antenna range from 25 to 2000 MHz, with wavelengths of 100-500 MHz being the most commonly employed (Ruffell et al., 2009). Shorter wavelengths have a lower resolution but have greater depth penetration. Likewise, longer wavelengths have a higher resolution but lower depth penetration (Schultz, Collins, & Falsetti, 2006). The antenna frequency depends on the preferences of the researcher, expected burial depth, and type of objects one is attempting to detect (Goldberg & MacPhail, 2011).

(Fig. 1) Man using GPR displayed on a push cart. Image by The Charles Machine Works (2010), (Public domain, Accessed via Wikimedia Commons)

One of GPR's attributes is that as a non-destructive, non-invasive surveying technique, it allows scientists to collect data without compromising a site or crime scene (Novo et al., 2011). GPR surveying is a quick, relatively inexpensive technique that usually can be completed in as little as single field day (Doolittle & Bellantoni, 2010 & Nuzzo et al., 2002).

One issue frequently encountered with GPR, however, is the degree to which local geological conditions limit penetration of the GPR signal. Because GPR operates via electromagnetic (EM) waves, highly conductive subsoils will disperse and absorb signals, thus muddling the data (Doolittle & Bellantoni, 2010 & Nuzzo et al., 2002). Highly conductive soils include those which are clay-rich and/or highly water-saturated. The effectiveness of GPR surveying is therefore site specific (Fiedler et al., 2009). A criticism of GPR is the complexity of the data it produces and subsequent difficulty in interpretation. In response to this issue, researchers have developed software that can simplify processing (Giannopoulos, 2005).

GPR specifically records the reflective characteristics of materials when exposed to short pulses of electromagnetic waves (Fiedler, Illich, Berger, & Graw, 2009). The reflective characteristics are recorded in a graph in either “depth slices” or “time slices” (see Fig. 2).



(Fig. 2) Example of a depth slice radargram recorded by GPR. This radargram was taken at a historic cemetery in Alabama, USA. The yellow arrows indicate distinct reflections, probably associated with human burials. Such distinct hyperbolas are usually associated with discrete objects. The red arrows indicate less distinct hyperbolas. The blue lines are horizontal reflectors, most likely bedrock. (Public domain, Accessed via Wikimedia Commons)

The horizontal axis of the radargram measures the distance on the transect over which the GPR antenna was moved. In a “time slice” radargram, the vertical axis measures the travel time of the reflected wave (Fiedler, Illich, Berger, & Graw, 2009). In a “depth slice” radargram, the vertical axis represents the depth at which a wave was reflected, calculated based on the travel time of the wave (Giannopoulos, 2005).

GPR radargrams are not a map showing the shape of buried objects. Instead, they record anomalies which, based on their appearance, are then interpreted as being “of interest” or “doubtful” (Doolittle & Bellantoni, 2010). Of most interest are distinct, hyperbolic anomalies, which could represent burials (Damiata et al., 2013). Blurry, horizontal, and/or sloping features usually represent other anomalies, such as bedrock.

GPR technologies have become increasingly refined over the years. One popular advancement is the use of 3D visualization of GPR radargrams. In this technique, transects are aligned to create a 3D block showing anomalies (Nuzzo et al., 2002 & Novo et al., 2011).

Although it is known that GPR cannot directly detect skeletal material, the degree to which various burial conditions, such as the use of burial shrouds, affect GPR’s ability to detect grave sites is not well understood. Much of this uncertainty stems from the lack of controlled experiments truly reflective of archaeological or forensic burials in which a single variable (soil composition, antenna frequency, depth of burial, type of burial, etc.) can be manipulated. The age of the burial is crucial, as more recent burials have a higher dielectric constant (Semanur, 2017). Other factors to be considered for the purposes of controlled study include the survey area, grid divisions, model and make of GPR used, type of antenna used, time window, transect spacing, filtering of background “noise” data, post-processing software used, migrating of data, number of burials present, number of burials excavated, and vegetation of survey area (Goldberg & MacPhail, 2011).

Although GPR is a useful technique, geophysical surveys should always consist of multiple survey types compared side by side. Data from multiple technologies can be examined for locations which consistently produce a signature, and are therefore more likely to represent an anomaly of interest (Seramur, 2017). Magnetometry techniques measure the magnetic field over the surface of a suspected site, detecting irregularities possibly associated with buried archaeological or skeletal remains (Seramur, 2017 & Goldberg & MacPhail, 2011). The most commonly used magnetometer is the fluxgate magnetometer, a handheld instrument with two sensors. Anomalies which enhance magnetic susceptibility will give a strong reading. Data measured by thousands of points can be displayed in numerous ways including XY plots, producing a “map” highlighting irregular readings (Goldberg & MacPhail, 2011).

Electrical resistivity is a useful geophysical technique which involves placing two electrodes in the ground, generating an electrical current between them and measuring the time required for the current to pass through the soil and buried objects, which indicates the resistance of the substrate (Seramur, 2017 & Goldberg & MacPhail, 2011). Because soil conductivity is enhanced by moisture and salt content, electrical resistivity should be measured during wetter seasons (Goldberg & Macphail, 2011). Anomalies with a high resistance include stone walls and coffins, while anomalies with a low resistance include graves and backfill (Seramur, 2017 & Goldberg & MacPhail, 2011). Like GPR, detection of graves using electrical resistivity relies on strong contrast in the readings from the grave and the surrounding soil (Seramur, 2017). GPR, magnetometry, and electrical resistivity can be used in any combination as appropriate for the site, but it is essential that at least two techniques are applied for data comparison.

2.3 Mass Grave Surveying

There is little literature concerning the use of geophysical surveying specifically for the detection of mass graves, despite many studies and case reports regarding its application for detection of clandestine burials and historical grave sites. While the detection of mass graves shares some qualities with the detection of other burials, the taphonomic forces at work in mass graves merit their separate consideration as a subject of geophysical survey.

Although mass graves cover a large geographical area, like graveyards, the data collected within this area is very dense and therefore difficult to sift through (Ruffell et al., 2009). Individuals in mass graves are commingled, so rather than a graveyard survey in which separate clusters of hyperbolas indicate distinct interments, a GPR radargram of a mass grave may not present distinct anomalies because hyperbolas occur in response to a strong contrasting target such as a coffin or boulder. It is therefore important to apply a combination of geophysical techniques when assessing site boundaries (Seramur, 2017).

Another, more practical concern reported in one study is that due to local public concern associated with the discovery of a mass grave, site assessment is often rushed (Ruffell et al., 2009). This compromises the ability to use multiple surveying techniques. Mass graves may also be associated with public health concerns over latent disease and water contamination, and so there is often political pressures to quickly glean certain types of data.

OneA mass grave of victims of the Irish Great Potato Famine (c. 1845-1851) in northwest Ireland, first located using a combination of aerial photography and historic records (Ruffell et al. 2009), provides an interesting case study. Prior to excavation, the site was assessed using GPR to locate burials not associated with surface depressions, to locate possible multiple inhumations, and to assess the geology of the site regarding concerns over leachate contamination. Because of the multipurpose nature of this GPR survey, multiple transects were collected first at 100 MHz, then at 200 MHz, and finally at 400 MHz. The study demonstrated that GPR can be used to provide a preliminary estimate of the maximum number of burials that could be expected.

Geophysical techniques have great potential applications to spatial analysis because they record the position of anomalies within the site prior to excavation. Even in cases where site documentation was perhaps otherwise neglected, GPR radargram data could give some insight into the original spatial arrangement of bodies within the site. This information could then be compared with known consistencies between site formation processes that affect spatial distribution.

3.0 The Geoarchaeology of Mass Graves

It is unsurprising that much surveying technology was developed for geophysical studies before being applied to archaeology (Dick et al., 2015). Geoarchaeology is an inter-disciplinary field that applies geological theory and techniques to the study of archaeology (Goldberg & MacPhail, 2011). Geoarchaeology's integrated approach to understanding archaeological sites allows an informed perspective on site interpretation (Pollard, 1999). Because of progress in geoarchaeology, we now have a deeper understanding of how geologic forces affect the distribution, quality, and characteristics of sites.

3.1 Following Proper Excavation Techniques, Site Recording, and Site Mapping

Proper archaeological field techniques not only maximize recovery of skeletal elements, but are essential for proper geoarchaeological assessment (Goldberg & MacPhail, 2011). Nonetheless, on-site surveying may not always be conducted following established guidelines. In cases where the mass grave is of forensic interest, researchers are often put under pressure to process the site as quickly as possible, and thus may be forced to sacrifice thoroughness in site documentation (Ruffell et al., 2009 & Burns, 2012). While it would be irresponsible for excavators to ignore pressures from outside bodies and the requirements of their employer, the omission of crucial data will later prove regrettable.

The first step to avoiding such a mistake is the designation of a site photographer(s), whose duty is to photograph the site before and after every step of the excavation process as well as all artifacts/evidence while *in situ*. All photographs should be time stamped and include a ruler for scale. Assigning an individual the responsibility of keeping a detailed log of all activities at the site is crucial for spotting instances of information loss or material contamination later in the analysis (Burns, 2012).

Excavation should begin with the identification of site parameters, initially with non-invasive techniques (when possible) and later with soil probing and test pit excavation. Measurements of the mass grave should be taken and a perimeter of excavation should be established (Burns, 2012). Aerial photography is useful for visualizing the entire site area and creating accurate maps. It is useful to have an archaeologist on staff who is intimately familiar with traditional methods of site logistics, surveying, mapping, and excavation (Skinner, Alempijevic, & Djuric-Srejic, 2003).

After establishing the site perimeter, the site should be separated into grid squares (Stewart, 2002). Grid units should be excavated in unison to prevent collapse (Tuller & Đurić, 2006). During the removal of remains, there are two commonly employed methods: the pedestal method and the stratigraphic method. In the pedestal method, the soil around the skeleton is removed, creating a trench surrounding the remains. While this method is argued to provide more data because it allows a 360° view of the skeleton, it requires the destruction of some or all of the grave walls and may result in the loss of smaller elements that are mixed with the soil. In mass graves, this method may not be possible because there are not discrete units of remains. In the stratigraphic method, however, the grave walls are retained during excavation while bodies are removed in reversed order of deposition. This method maximizes understanding of grave formation processes and *in situ* grave content placement (Tuller & Đurić, 2006). For the analysis of spatial distribution in mass graves, the stratigraphic method is preferred.

Complete records should be kept on site, including photographs, a written log, mapping, and results of surveying technologies that may be needed for later GIS analysis. There is no substitute for good record keeping; once the remains are removed, there are no more chances at retrieving *in situ* data, and spatial analysis cannot be applied (Steward, 2002 & Burns, 2012).

3.2 Steno's Laws of Stratigraphy

Geoarchaeological assessment must be placed in the framework of Steno's Laws of Stratigraphy. In the 17th century, Danish scientist Nicolaus Steno made five observations, ingenious in their simplicity, that are still used to sequence geological and archaeological events. They are as follows:

1. Principle of Superposition: Stratigraphic layers must be deposited on a surface. Therefore, lower layers are older than the layers above them.

2. <u>Principle of Original Horizontality:</u> Stratigraphic layers are originally deposited flat. Therefore, tilting of layers can only have occurred after deposition.
3. <u>Principle of Lateral Continuity:</u> Sediment is deposited in an even layer over a horizontally infinite area unless otherwise disrupted.
4. <u>Principle of Cross-Cutting Relationships:</u> Any solid body or breakage cannot cut across a stratum unless there is a stratum to be cut across. Therefore, the stratum must be older than any intrusion or break.
5. <u>Principle of Inclusions:</u> Foreign rock fragments cannot spontaneously form within another solid rock. Therefore, foreign rock fragments must be older than the rock which contains them.

While these principles are usually considered as they apply to relative dating techniques, they can also be used to establish the sequence of events in site formation. For example, a disruption in stratigraphic ordering following a burial is a commonly identified feature when attempting to locate burial sites. Graves often result in the admixture of soil horizons. When rock fragments are included, the Principle of Inclusions informs researchers that the surrounding soil matrix is more recent and may have been disturbed.

When digging a mass grave, people tend to keep poor track of backfill. Once soil is broken, it becomes less compact, creating a backfill pile much larger than the hole itself (Burns, 2012). But because the soil is loosened, it often scatters during reburial. The amount of soil that is used to refill a grave is always less than the amount of soil that originally occupied that space (Schuldenrein et al., 2017 & Burns, 2012). During the process of decomposition, bloated and eventual collapse of the body cavity will further disturb soil within the grave (Burns, 2012 & Duday, 2006). The creation of a grave therefore always interrupts original surface topography, and these anomalies can be detected using Steno's Laws.

3.3 Case Study on the Forensic Geoarchaeology of a Mass Grave from the Iraqi War (2003-2011)

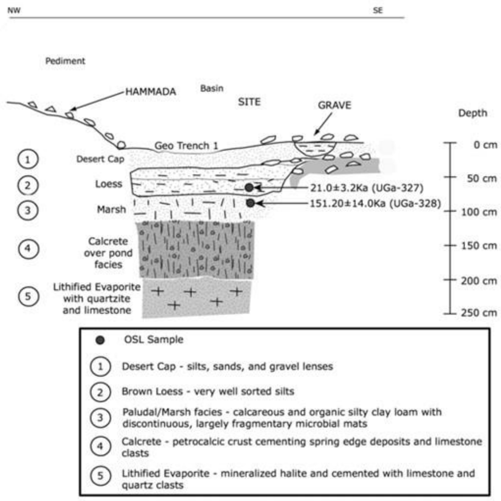
A recent study illustrates how landscape reconstruction based on surface topography can be used to identify anomalies associated with mass burials (Schuldenrein et al., 2017). The excavation of Muthanna, one of many mass graves created in Iraq to bury victims of the Kurdish genocide in the late 1980s/early 1990s, illustrates how landscape reconstruction based on based on surface topography can be used to identify anomalies associated with mass burials (Schuldenrein et al. 2017). During the mid-2000s, the U.S. Regime Crimes Liaison Organization (RCLO) deployed a team of forensic investigators to the site for the purposes of confirming its status as a mass grave and collecting evidence for the prosecution of the Hussein regime. Crime perpetrators often select sites they consider to be remote and have minimal possibility of exposure by degradational/erosional processes (Schuldrein et al., 2017). It is therefore logical for a geoarchaeologist to be part of any coordinated effort to reconstruct grave site histories.

At Muthanna, the necessity of geoarchaeological expertise was apparent by the seemingly chaotic distribution of empty trenches less than half a meter deep. The site itself was located in a lenticular basin hidden behind a hill and surrounded by 8m high ridges. In addition to the trenches, the landscape was dotted with spoil mounds constructed by large earth-moving equipment. The landscape surrounded the grave complex consisted of the ridges bound by pediment and overlain with hamada composed of wind-blasted limestone, flint rocks, and small boulders. These structures are dominantly Pleistocene in age. Lithic assemblages found on the surface have been dated to the Middle and Late Paleolithic and are associated with sites of ancient springs and loess deposits. The topography of the region was heavily characterized by the spoil mounds.

The site was initially located by local witness testimony. Subsequent test pit excavations confirmed the presence of human remains in a mass grave context. GPR was then used to locate areas of interest and delineate site margins. Geoarchaeological fieldwork began with the excavation of exploratory trench GT-1, which was used to document the site stratigraphy. The stratigraphy of the site was well-defined into discrete lithostrata, each containing a variable amount of calcium carbonate which later proved to be a valuable index for determining soil disturbance. Each stratum was subjected to a suite of geochemical tests which identified anthropogenic introduction of compounds into the soil.

Trench GT-1 revealed five distinct strata (Fig. 3). Lithostratum 1, the Desert Cap (0-0.7 m), consists of massive sandy silt loams with laminar interdigitations. Lithostratum 2, the Loess (0.7-1.1 m), consists of massive loamy silt sprinkled with autochthonous $CaCO_3$ nodules. Lithostratum 3, the Paludal/Marsh facies (1.1-1.35 m), is a calcareous and organic silty clay loam with discontinuous, fragmentary microbial mats. This stratum is quite thin, and has sub angular blocky structures which are perhaps paleo-vertisols. Lithostratum 4, the Calcrete (1.35-2.05 m), is a white siliceous crust cementing spring edge deposits and limestone clasts. This layer is discontinuous and interdigitates with the Paludal/Marsh facies. Lithostratum 5 (>2.05 m) is a lithified evaporite consisting of purple to reddish halite crystals cemented with limestone, quartz, and dolomite clasts.

Geoarchaeology, Forensics, and the Prosecution of Saddam Hussein: A Case Study from the Iraq War (2003–2011)



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(Fig. 3) Stratigraphic cross-section of Trench GT-1, Muthanna. (Schuldenrein et al., 2017).

Loss of ignition (LOI) was performed on all layers to measure soil organic carbon and calcium carbonate content. It was found that organic concentration decreased through lithostratum 4 and 5, but between 0.6 and 1.2 m (lower desert cap through mid-paludal/marsh) there was a progressive increase in organic concentration. This is consistent with the known depth of the mass grave.

Almost two decades had passed between the time of the mass grave formation and excavation, and during this interval variable sedimentation and erosion affected the site's topography. In some cases, this resulted in accretion of depositional pocks atop burial mounds and empty pits. Geochemical analysis of several trenches produced clustered readings within similar ranges, a pattern consistent with rapid excavation and infilling of the trench. Other trenches show evidence of fluviatile deposition and sheet flow.

Covering up a genocide requires long-term planning and careful site selection for the internment of victims. In this case, the victims were forced to march a long distance to the site before being forced into the grave and executed. While the perpetrators likely selected the site for its remote location, they erred in assuming the subsurface topography would reflect the surface topography.

Several geoarchaeological features were used to locate the grave sites. One was the substrate within the graves. It is only in very few locations at Muthanna that all five lithostrata are present. The presence of numerous shallow, refilled trenches was indicative of several attempts to dig graves before being thwarted by the shallow lithified evaporate stratum.

Soils disturbed by the perpetrators had a high level of K_2O, or potash. There has been some speculation as to how anthropogenic activity introduced the potash, including the possibility that it was used for its effect of speeding up body decomposition by promoting bacterial growth. It is also possible that it was introduced from local soils, as high concentrations of potassium feldspar ($KAlSi_3O_8$) and mica minerals (especially muscovite) are common in desert soils. Statistical tests confirmed the strong association between high potash concentration and anthropogenic influence on soil composition. Finally, the creation of soil depressions that are then infilled with new sediment resulted in topographic and sedimentological differences between the trench cap and the surrounded undisturbed surfaces.

This study is an excellent demonstration of how traditional methods of landscape reconstruction can be used to estimate the natural geologic setting of an area and, by comparison between what is expected and what is observed, determine the likelihood of site disturbance by anthropogenic forces. This study also calls attention to the geoarchaeological foundation that should characterize site assessment. This is best carried out, as it was here, through a multi-disciplinary team of experts assigned to each site.

4.0 Taphonomic Movement of Human Remains in Mass Grave Formation

Archaeothanatology studies the myriad of factors that determine the spatial distribution of remains in a mass grave site begin immediately upon death of an individual and continue up until the moment of excavation. This involves the extrapolation of a body's position during deposition based on the distribution of remains, which during decomposition move in a predictable fashion in accordance with the law of gravity (Duday, 2006 & Duday, 2011). Archaeothanatology can answer several questions regarding the mortuary context of remains. Was the individual dismembered? Was the individual exhumed and relocated to secondary or even tertiary burial site? Was the individual buried deeply enough to deter carnivore scavenging? Has flowing water moved material at the site? Is burial in a mass grave the standard manner of burial within a given cultural context? These are just a few of the questions that must be addressed before spatial analysis of a site can be deemed appropriate.

4.1 Mortuary Contexts of Mass Graves

Just as there is no universally agreed-upon definition of what constitutes a mass grave, there is no universally employed terminology used to concisely describe mass graves. Most of the available literature is from the field of forensic anthropology, and therefore is somewhat exclusive of mass grave sites formed in non-medico-legal contexts (Jesse &

Skinner, 2005 & Skinner et al., 2003). This is unfortunate, as bioarchaeological analyses using a biocultural paradigm could lead to a wealth of information on how culturally distinct mortuary traditions and agency of participants affect the formation of mass graves as cultural products (Armelagos, 2003, Binford, 1971, & Charles & Buikstra, 2008).

Jessee & Skinner (2005) identified six main types of mass graves sites that are of concern to forensic anthropologists. In their study, mass graves were defined as "any location containing two or more associated bodies, indiscriminately or deliberately placed, of victims who have died as a result of extrajudicial, summary, or arbitrary executions, not including those individuals who have died as a result of armed confrontations or known major catastrophes (p. 56)."

The first two types of mass graves of concern are *execution sites (ES),* or sites at which the execution took place. *Grave execution sites (GES)* are sites at which individuals are execution within the grave that they are then buried (Jessee & Skinner, 2005). At these sites, commingling is reduced. *Surface execution sites (SES)* are ES' at which the individuals were executed outside of a grave; they may or may not be buried after the execution. The degree of commingling of remains at these sites depends on the time elapsed between death and burial. Remains that are allowed to decompose outside the grave will disarticulate and will therefore become highly commingled upon burial.

The other four types of mass graves are inhumations, in which the victims of an unspecified mass fatality event are buried. Individuals may be removed from an initial grave site and relocated to another. A *primary inhumation site (PIS)* is the site at which remains are first buried. PIS' will have comparatively lower rates of commingling. *Secondary inhumation sites (SIS)* are sites containing remains which were exhumed from another grave and redeposited. During the process of relocating the remains, they are often severely commingled, disarticulated, and smaller fragments and skeletal elements are lost. Some sites may contain both primary and secondary exhumations, and are referred to as a *multiple deposit interment site (MDIS)*. MDIS' are often severely commingled due to the disturbance of the original grave site. Finally, a *Looted Inhumation Site (LIS)* is a site from which individuals have unearthed and removed remains before re-burying them at an SIS. During the process of exhumation, remains at LIS' are often commingled (Jesse & Skinner, 2005).

Mass burials created during natural disasters such as tsunamis and earthquakes are very high energy events which result in the extreme commingling and disarticulation of remains (Mundorff, 2008). Spatial analysis cannot be applied in these events. Finally, it is important to note that different types of mass graves are not mutually exclusive. For example, a primary inhumation site could be the result of a ground execution, or a secondary inhumation site could contain the remains of victims of a natural disaster which were later unearthed and reburied by family members (Jesse & Skinner, 2005). Archaeothanatological analysis of the position of remains can accurately assess the type of mass grave based on the positioning of the remains *in situ* (Duday, 2011).

4.2 The Processes of Decomposition

While forensic investigators are often concerned with taphonomy as it pertains to the assessment of post-mortem interval (PMI), here we are concerned with how taphonomic forces affect the spatial distribution of remains in mass burials. There is no set timeline of decomposition each body takes after death. A body's decomposition depends upon its environmental circumstances as well as the mass and composition of the body itself (Burns, 2012 & Dent, Forbes, & Stuart, 2004). Large bodies take longer to decompose than smaller bodies. Hot, humid climates speed up decomposition. Buried remains will take longer to fully decompose, especially in deep burials (Burns, 2012). Soil pH also affects decomposition, with bodies decomposing faster in acidic soils and slower in neutral or slightly alkaline soils (Dent, Forbes, & Stuart, 2004).

Decomposition begins with the process of autolysis, or self-digestion, in which cells produce self-destructive enzymes. By this process, the microstructure of soft tissue is disintegrated. The destruction of cellular membranes in the digestive system releases the gut flora into the bodily cavity in a process called putrefaction (Dent, Forbes, & Stuart, 2004). Metabolic processes by the gut flora release gasses and cause the body to bloat. Fluid building up beneath the skin's epidermis causes it to separate and peel, a process called skin slippage. As red blood cells break down, the skin turns green and finally black (Burns, 2012). In cool, wet conditions (such as those found underground), hydrolysis of adipose tissues causes the formation of adipocere, or grave wax, a substance which when unable to drain from the body can slow down decomposition (Dent, Forbes, & Stuart, 2004 & Ruffell et al., 2009). As fluids drain from the body, it deflates, causing the skin to drape over the skeleton. Ligaments, cartilage, and mummified epidermis are the last soft tissues to survive (Burns, 2012 & Lyman, 1994).

When bones are first exposed, they are yellow and greasy, especially if poor drainage has allowed them to soak in adipocere. Bones whiten as oils slowly drain from them, and will bleach whiter if exposed to sunlight (Shipman, 1981). In time, the outer cortical bone will crack, flake, and exfoliate, thus exposing the comparatively fragile cancellous bone (Burns, 2012). If buried in an acidic soil H^+ will bond with the hydroxide endmember of the bone's hydroxyapatite matrix, decalcifying and destroying the bone (Dent, Forbes, & Stuart 2004).

The time scale of these processes is environmentally dependent. In warm, moist environments, remains are usually fully skeletonized by 2-12 months after deposition. In extreme cases, such as a typical summer day in the southeastern United States, where daytime temperatures average in the 90s (°F) and relative humidity is between 80-100%, and if animals have access to the body, adult human remains can skeletonize in as little as two days (Burns, 2012). Even when environmental conditions are accounted for, decomposition rates can vary tremendously. For example, in one case study of a Portuguese cemetery, 25 individuals with the same post-mortem interval (PMI) were exhumed. After being buried in a coffin for 5 years without embalming fluid, the head of 4 individuals still retained soft tissues (16%), 19 were completely skeletonized (76%), and 2 were saponified (8%) (Ferreira & Cunha, 2013).

During the process of decomposition, the body disarticulates and thus lends itself to selective movement by various animals, affecting the bones' spatial distribution. Small birds and insects do not usually cause extensive damage or relocation of bone (Lyman, 1994). Rodents gnaw on bone after it is fully skeletonized, and tend to carry off smaller elements. Large mammals, such as canids and wild pigs, tend to fully disarticulate and consume corpses as well as carry larger elements to different locations (Burns, 2012). Predation on remains can result in both the dispersal of the original assemblage and in the accumulation of a new assemblage by scavengers that "collect" their food in a certain location (Andrews, 1995). In a series of case studies in Greece, researchers found that carnivores were able to scatter the remains of two homicide victims in a radius as large as 15 meters (Moraitis &

Spiliopoulou, 2010). Due to their round shape, crania can be moved over long distances by rolling by predators or by gravitational movement down a sloped surface (Robbins-Schug, G. M., personal communication).

4.3 Decomposition in Mass Graves

Decomposition in a mass grave context presents different issues than those present in single burials. As the remains of multiple individuals disarticulate in mass graves, they become commingled. In cases where remains are deposited in deep piles, the commingling can make the reassociation of discrete individuals extremely arduous (Adams & Konigsberg, 2008 & Herrmann & Bennett Devlin, 2008). Skeletons in mass graves often form an interlocking, intertwining web that can seem impossible to untangle, much less sort into single individuals (Tuller & Đurić, 2006).

Mass graves produce a greater volume of decomposition fluids than do single burials. Drainage in mass graves is poorer, as fluid is trapped between and around bodies. Bodies in mass graves soak in the voluminous fluids of each other, many of which have properties which slow decomposition. In cool, wet conditions, bodies in mass graves often produce large amounts of adipocere which then acts as a preservative for the bodies within (Fiedler & Graw, 2003).

Unfortunately, very little research on the taphonomy of mass graves has been undertaken. Most research into the taphonomy of mass graves of animals concerns zooarchaeological or paleontological sites, and thus offers little insight into earlier processes of decomposition (Shipman, 1981 & Badgley, 1986b). But overall, bodies in mass graves will take longer to skeletonize and will become commingled.

4.4 Fluvial Transport of Remains

Spatial assessment of mass grave sites strongly modified by fluvial transport cannot produce any meaningful assessment of MNI. Fluvial transport refers to the movement of materials by running water. Transport of remains can be unraveled in cases where only some remains have been transported and/or the distance of transport is minimal. Fluvial transport can be inferred geologically based on associated bodies of water, by the degree of sorting of the associated sediment, and by hydraulic equivalence between the material deposited and the associated sediment (Badgley, 1986a).

In the 1980s, Catherine Badgley carried out extensive research on the effects of fluvial transport on preservation of the paleofauna at the Siwalik Hills, Pakistan.. This site is Miocene in age, and geologic evidence suggests that at the time the area was floodplain characterized by braided streams (Badgley & Behrensmeyer, 1980). The low energy stream motion and low energy of floodplain deposition makes this site ideal for spatial analysis of commingled assemblages that experienced minimal transport.

While the site is most well-known for the *Sivapithecus* fossils it produces, these hominid fossils are quite rare. Most of the fossils found at the site are bovids and equids, followed by suids, elephants, rhinoceroses, tragulids, and giraffe. Less common fossils include sivapithecids, anthracotheres, and chalicotheres. The fossils at the site are highly fragmentary. Site representation is biased towards the preservation of animals smaller than 200 kg; larger animals tend to be represented only by teeth and long bone fragments (Badgley & Behrensmeyer, 1980).

Badgley conducted their taphonomic analysis on 21 localities deposited in four facies. The circumstances of deposition in Facies I was by major stream channels, in Facies II by flood deposits such as crevasse splays, in Facies III by channel margins such as swales and ponds, and Facies IV on floodplain lands surfaces and in paleosols. Gnaw marks on bones indicated significant carnivore activity at all localities. Bones collected from Facies I were predictably diverse in their spatial and temporal sources, whereas bones from Facies III and Facies IV were much less scattered but still notably fragmented and biased towards the preservation of smaller mammals (Badgley 1986b).

Determining the original population size represented by these assemblages was confounded by the lack of articulated material, degree of hydraulic sorting, preservation bias against juvenile remains, and bone damage. Remains were not articulated at sites affected by fluvial transport, but depending on the velocity of transport some specimens were spatially clustered. Fluvial transport of bones was assessed by measuring the hydraulic equivalence of the bones and surrounding sediment; while hydraulic equivalence between the bones and sediment does not prove that they were transported together, lack of hydraulic equivalence proves that they could not have been transported together. The sorting of the surrounding sediment further confirmed transportation (Badgley, 1986a).

Badgley concluded that the features of Facies III and Facies IV assemblages suggest a high probably of the association of remains based on clustering patterns. In these assemblages, she suggests that pair-based estimation of the least possible number of individuals represented is an appropriate method for counting individuals (Badgley, 1986a). I extrapolate that in mass grave assemblages affected by low-energy flood activity or transported as a unit, the likelihood of association indicates that spatial analysis may be possible.

When present, fluvial transport tends to preferentially affect certain skeletal elements. An experimental study on human bones indicated that crania, sacra, vertebrae, and certain tarsals are transported at much higher rates than other skeletal elements. This pattern correlates most strongly with element density (Boaz & Behrensmeyer, 1976). Other factors known to affect transport potential are the size and shape of the bone, with smaller and/or irregularly shaped bones being easier to transport (Pante & Blumenschine, 2010). As demonstrated by experimental studies on domestic sheep, pigtail macaque, and domestic dog remains, remains that are disarticulated are much more likely to be transported than those that are articulated (Coard & Dennell, 1995 & Coard, 1999). Thus, when determining how fluvial transport may have affected spatial distribution of elements within a mass grave, it is important to consider when the transport occurred (i.e. a flooding event immediately after burial vs. after remains have skeletonized). Finally, fluvial transport can affect sedimentological dating techniques because even if a sediment has been transported, bones can accumulate during times of erosion or non-deposition (Behrensmeyer, 1982). This also means that fluvial transport should be determined primarily from sedimentological evidence assessment of the assemblage for element bias and spatial distribution patterns consistent with fluvial transport.

5.0 Methods for Counting Individuals:

MNI is a quantitative measure of the fewest number of individuals it would have taken to a form an assemblage. It therefore consistently underestimates the actual number of individuals represented by skeletal remains or fossil assemblages (Casteel, 1977, Grayson, 1973, & Horton, 1984). Many new approaches have been developed to address this problem. This section describes the methods for estimating MNI, the challenges of these different approaches, and current research to address some of the challenges.

The simplest method for estimating a minimum number of individuals represented by a skeletal assemblage is to count the paired elements present (Casteel, 1977). Because humans have bilateral symmetry, pairs from a certain element and side must belong to a different individual (i.e., nobody has two left humeri, or three right fibulas, etc.). The most commonly occurring element in an assemblage is taken as the fewest number of individuals that assemblage could possibly contain; for example, in a fictional assemblage containing 78 right temporal bones, 23 left clavicles, 18 right cuboids, and 89 left parietal bones, the MNI is 89 based on the number of left parietal bones.

However, an MNI based on paired elements only gives the most conservative estimate of the sample size. It is not just possible, but probable, that some of the other bones in the assemblage do not belong to any of the 89 individuals represented by the left parietal bones. In these cases, the collection of secondary data, such as the age and sex of individuals, is used to refine MNI estimates. However, biological parameters of individual identity are not always useful because only certain skeletal elements can provide reasonable estimates of age and sex (İşcan, & Steyn, 2013). Furthermore, neither of these techniques account for the common circumstance that additional skeletal material was initially present at a site but was lost (Horton, 1984).

For these reasons, many authors have argued that although the MNI is useful in contexts where other estimations of assemblage sample size are impossible, other methods should be explored (Adams & Konigsberg, 2004, Badgley, 1986a, Casteel, 1977, Grayson, 1973, & Horton, 1984). Researchers have argued that there is no universally "correct" method for estimating the size of these assemblages and that methods used for quantification should be selected on a case-by-case basis, taking into consideration the taphonomic processes that led to the formation of each site (Badgley, 1986a). MNI is appropriate for assemblages where recovery rate is high and/or conditions of the remains render other estimations unfeasible (Adams & Konigsberg, 2004).

Sample population at other sites may apply mathematical approaches to quantifying assemblages. Chaplin (1971) developed a formula known as the Grand Minimum Total. The GMT is the number of paired elements added to the number of unpaired elements, sometimes expressed as:

$$\text{GMT} = C^t/2 + D^t$$

Where C^t is the total of paired left and right elements and D^t is the total number of unpaired left and right elements (Chaplin, 1971 & Horton, 1984). For example, let's say a fictional assemblage contains 33 left radii, 24 right radii, 27 left ulnae, and 18 right ulnae. In this assemblage,

$$\text{GMT} = (24_{\text{radii w/ pair}} + 18_{\text{ulnae w/ pair}}) / 2 + [(33_{\text{side w/ most radii}} - 24_{\text{side w/ least radii}}) + (27_{\text{side w/ most ulnae}} - 18_{\text{side w/ least ulnae}})]$$

$$\text{GMT} = 42_{\text{bones w/ pair}} / 2 + (9_{\text{radii w/o pair}} + 9_{\text{ulnae w/o pair}})$$

$$\text{GMT} = 21 + 18_{\text{bones w/o pair}}$$

$$\text{GMT} = 39$$

In this example, the MNI is 33, whereas the GMT is 39. The GMT method increases the estimated sample size, but the method is flawed in that elements which are not true pairs can be mistakenly identified as such (Adams & Konigsberg, 2004).

Some researchers have opted to use techniques from zooarchaeology that estimate the original population represented by skeletal assemblages. The most popular of these is the Lincoln Index, or LI. The LI is commonly used in capture-recapture population studies of living animals. In these studies, a group of n_1 animals is captured, tagged, and released. After a period of time, another group of n_2 animals is captured. The animals in this group recaptured from the initial group is counted as m. The estimated population size ($\check{N}$) is then calculated as

$$\check{N}=n_1n_2/m$$

In studies of skeletal assemblages, the Lincoln Index is calculated using pair-matching. This means that left and right elements are compared to determine if they are from a single individual. Here, the number of left elements (L) is equivalent to n_1, the number of right elements (R) is equivalent to n_2, and the number of elements that can be matched as pairs (P) is equivalent to m. Therefore, the original death assemblage (LI) is estimated as

$$LI = LR/P$$

Seber (1973) proposed a new formula derived from the Lincoln Index that could eliminate some sampling bias. It was later that Adams and Konigsberg (2004) demonstrated that this formula represented the maximum likelihood estimate, and dubbed it the Most Likely Number of Individuals (MLNI). It is calculated as follows:

$$\mathrm{MLNI} = [[(\mathrm{L} + 1)(\mathrm{R}+1)] / (\mathrm{P} + 1)] - 1$$

Adams and Konigsberg (2008) later argued that this formula was preferable not only because it provided less conservative estimates than both the MNI and GMT methods, but also because confidence intervals can be applied to this formula.

Estimations of LI and MLNI can be grossly miscalculated due to errors in pair-matching (Adams & Konigsberg, 2004). There are some situations where pair matching of elements is impossible, most notably in highly fragmentary samples (Adams & Konigsberg, 2008). Calculation of LI and MLNI may be impossible due to the destruction of identifiable morphological features (Adams & Konigsberg, 2004).

6.0 The Application, Effectiveness, and Future Potential of GIS Technologies in Refining MNI

Given the above geotaphonomic factors and their complex relationships with each other, is may be possible to predict the probability of association based on spatial distribution of remains at a given site. Geographic Information Systems (GIS) could be used for this purpose (Wheatley & Gillings, 2002).

It is important to remember that GIS is not a single, monolithic technology. GIS are a group of technologies that specialize in the collection, processing, and interpretation of spatial data. A GIS technology could be a paper map, but here only computer programs are considered (Wheatley & Gillings, 2002). The definition I found most useful is that a GIS is "a powerful set of tools for collecting, storing, retrieving at will, transforming, and displaying spatial data from the real world for a particular set of purposes (Burrough, 1986)." Wheatley & Gillings (2002) describe four key subsystems that constitute a GIS:

1. The *Data Entry* subsystem, which translates raw or only partially processed spatial data into a stream of input of known characteristics.
2. The *Spatial Database* subsystem, which stores all of the spatial, topological, and attribute information while communicating with the Data Entry subsystem.
3. The *Manipulation and Analysis* subsystem allows transformations of data and application of spatial analysis and data modelling functions.
4. The *Visualization and Reporting* subsystem generates maps, other graphics, and texts in response to commands by the user through the *Manipulation and Analysis* subsystem.

The input of site information into a GIS technology begins with the proper excavation and documentation of the position of remains within the mass grave. Using a GIS during excavation, the biological anthropologist should carefully record data within the Data Entry subsystem.

6.2 Current Related Technologies and Case Studies

After remains have been logged and excavated, data can be entered in a GIS software tool and translated into an easy to visualize tool for quick queries of site data (Wheatley & Gillings, 2002). While no known GIS has been applied for the specific purpose of calculating MNI based on the spatial distribution of remains, software with similar purposes have been used, and more generalized GIS technologies have been applied to anthropological research of grave sites.

One such case occurred in a bioarchaeological investigation of the Río Talgua caves in northeast Honduras, reported by Herrmann (2002). Two ossuaries in this site were radiocarbon dated to between 3110 BP and 2510 BP. It was determined that the remains were either disarticulated or allowed to decompose elsewhere before being placed within an undetermined type of container and deposited within the caves. Grave offerings were found at one of the ossuaries, and included ceramic vessels, jade pendants, and beads. The demographic profile is somewhat biased towards infants and young children.

Many of the skeletons were fragmented and commingled. Excavation and analysis was complicated by the requests of the Honduran government that all the remains should stay *in situ*, and all analysis should be conducted within the cave. Many of the remains were encrusted and cemented in place with calcite, and thus could not be removed for measurement or examination of pathological lesions. Elements which were deposited above the old waterline had disintegrated, due to either grave looting or taphonomic factors. This case demonstrates that spatial analysis could be useful in situations where remains can only be analyzed *in situ* for either cultural or geological reasons.

The highly fragmentary nature of the remains made MNI a poor indicator of assemblage population. The author therefore suggested application of the Lincoln Index, but cautioned that fragmentation of the remains would limit pair matching and so this parameter may not necessarily be accurate either. It was at one ossuary, in the cave called Arañas (so named for its abundant spider population), that GIS was applied to examine elemental, taphonomic, and demographic patterns in the scattered bone assemblage.

During the 1996 field season, the site was extensively documented via digital imagery, which provided preliminary maps for later excavators. More digital photographs were taken, and entered into the program ArcView to produce a line drawing. In addition, skeletal material that appeared to be articulated was mapped by hand onto graph paper and tied to a specific datum on the site map. A 3D plan of the cave and the individual burial lot data were entered into ArcView. The burial lots were then converted into polygons and assigned a Specimen Number. The generated maps were then ready to be visually examined by the researchers, who were able to determine distinct bone clusters and arrive at an MNI estimate of 22.

Another study by Tuller, Hofmeister, and Daley (2008) focused on the use of spatial analysis in the reassociation of commingled remains within mass graves. This study was carried out a mass grave excavated in Belgrade, Serbia, and contained both primary and secondary internments. There was evidence of a failed cremation event that resulted in minimal impact on bone preservation.

Surveyors efficiently generated a map of the site with a total station. Total stations are devices which record position points in a 3-dimensional scale, rendering data that can be input into GIS software to generate a map. For each body within the grave, points on body parts were recorded to create a stick figure reconstruction, providing a visualization of the body’s position in the grave.

The authors used an analysis program created using Microsoft Access to calculate the distance between bodies and produce a list of potential matches in order from nearest to furthest on a 3-dimensional scale. This program assumes that the element nearest to the body is most likely to be the missing element. Accuracy of reassociation was assessed afterwards using DNA analysis; both methods were used to eventually reassociate 41 out of 594 disarticulated elements with the rest of their original body. Although that is only 7%, it is promising considering that this program did not use formulas inclusive of taphonomic factors that produce commingling.

Herrmann and Devlin (2008) describe a customized ArcView extension, *BoneEntryGIS*, which uses an element specific GIS to calculate the minimum number of elements (MNE) of an assemblage. MNE is a quantification used in fragmentary assemblages which estimates the number of whole elements that would have been needed to be originally present to contribute to the number of fragments preserved (Casteel, 1977). This system uses a visual inventory through which MNE can be efficiently quantified.

BoneEntryGIS was used in the analysis of the Walker-Noe site, a Middle Woodland period burial mound in the south-central Bluegrass Region of Kentucky. This highly fragmented assemblage has clearly been cremated, and a site plan revealed concentration of skeletal elements around an identified hearth. For the purposes of this study, the authors focused on craniofacial elements. BoneEntryGIS was then used to place the fragments on an outline of an idealized cranium, thus making overlapping regions apparent. The resulting image contained 26 overlapping regions on the cranium, and so the MNE was estimated to be 26. The authors speculate that this same program could be used to estimate MNI. (Herrmann & Devlin, 2008).

6.3 Potential Application to the Case of Homo naledi

Homo naledi is an extinct hominid unusual among paleoanthropological finds; not only is the anatomy of the extinct hominid unique, but the size of the assemblage found is greater than that of any other (Berger et al., 2015). In 2013, three spelunkers happened across the *Homo naledi* remains in the Dinaledi chamber of the Rising Star cave system, South Africa. The inaccessibility of the Dinaledi chamber makes the fact that *Homo naledi* was discovered at all remarkable; besides being deep within the cave system, part of the passage leading to the only access point into the chamber involves a 15-meter-long vertical drop through a tunnel barely large enough for a slender adult human to pass through (Throckmorton, 2016 & Dirks et al., 2015).

The Dinaledi Chamber is an ideal location for preservation of remains. Its seclusion has resulted in it being nearly untouched since the site formation; even non-hominid mammalian remains are comparatively uncommon. Although water has been present in the limestone cave, deposits of massive, mud clasts breccia in a brown mud matrix with occasional patches of carbonate cement indicate minimal transport by groundwater. The Dinaledi chamber contains abundant flowstone deposits which have encrusted many of the *Homo naledi* remains and cemented them *in situ* (Dirks et al., 2015).

The manner of deposition of the *Homo naledi* is most similar to that of a mass grave mortuary context. To date, over 1550 specimens representing an MNI of 15 individuals have been recovered from the site, and these come from a single excavation pit. The remains appear to have been placed down there in a manner consistent with a mortuary rite (Berger et al., 2015). Attempts at dating the site have so far been unsuccessful, but research is still ongoing as to the age and potential culture of *Homo naledi* (Dirks et al., 2015 & Berger et al., 2015).

The Dinaledi Chamber site of *Homo naledi* is an example of a site at which spatial analysis could be applied to estimate MNI. Although the remains are fragmentary, they have been transported little, if at all, since deposition. Calcite cementation of remains at this site would not inhibit spatial analysis. Carnivore activity at the site was minimal. Commingling during the process of disarticulation and during some movement during periods in which the chamber was flooded does pose complications, but it is those contexts in which better methods for determining MNI are needed most.

7.0 Conclusion and Future Directions

Although the necessary GIS technologies are available, the problem presented here is the lack of application to determining the MNI of mass graves. Past studies have demonstrated repeatedly the importance of understanding space and other in-context data. Thorough site documentation is not a matter of formality, but perhaps one of the richest sources of information available to biological anthropologists. One factor limiting application of a GIS software for determining MNI in mass graves is the lack of research into the taphonomy of mass graves. It is known how bodies decompose in single burial contexts, but what happens when a mass of bodies soak in each other's fluids for years or even decades? Can degree of intermingling and scattering be calculated based on a hypothetical formula accounting for fluvial transport, intermingling, primary vs. secondary grave context, and other discussed factors that affect space? It is a bold suggestion, but one worth investigating.

MNI will remain as it's always been: a measurement of the least possible number of individuals it would take to constitute an assemblage. What spatial analysis can do is refine that estimate to make a more accurate assessment of the population of the assemblage. The complex, intermingling factors of that contribute to site formation coupled with limited available technology make spatial analysis currently impractical for the same standard usage MNI estimates have enjoyed. But in geotaphonomic contexts that limit commingling and scattering, for the purposes of paleodemographic research, and for the purposes of forensic investigations of mass graves, I argue that spatial analysis has the potential to become an indispensable tool.

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