Modeling Site Formation Processes with Low-altitude Aerial Photography, Structure from Motion, and GIS

A thesis submitted in partial satisfaction of the requirements for the degree of Master of Arts

in

Anthropology

by

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2014
The Thesis of Matthew David Howland is approved and it is acceptable in quality and form for publication on microfilm and electronically:

Chair

University of California, San Diego

2014
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ACKNOWLEDGEMENTS

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ABSTRACT OF THE THESIS

Modeling Site Formation Processes with Low-altitude Aerial Photography, Structure from Motion, and GIS

by

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Master of Arts in Anthropology

University of California, San Diego, 2014

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A workflow featuring combined methods of low-altitude aerial photography (LAAP), digital photogrammetry and Structure from Motion (SfM), Geographic Information Systems (GIS) analyses, and ethnographic analogy is proposed as a viable survey method for investigation of site formation processes. LAAP and photogrammetry are techniques with long histories of application to archaeology, although technological developments have improved their efficiency and usefulness to the field archaeologist. Structure from Motion and GIS are relatively new technologies, and their use allows for new applications of traditional
techniques. By consulting ethnographic studies and operationalizing them within a GIS framework using data acquired through LAAP and SfM, this paper aims to outline a method of modeling site formation processes, including artifact deposition and natural transformations of archaeological context.
1. Introduction

The development of digital technologies has revolutionized the world of archaeological documentation, recording, and interpretation. It can be seen that nearly all aspects of archaeological research have benefitted in some way – whether slight or significant – from the evolution of digital techniques over the last 30 years. While some methods, such as low-altitude aerial photography, have improved slightly in efficiency, others, such as spatial recording, have been truly transformed. The combination of traditional techniques, such as aerial photography and photogrammetry, with cutting-edge technologies, such as Structure from Motion and GIS, have the potential to revolutionize intra-site archaeological survey methodology through unique combined applications. These combined methods form a workflow with unprecedented efficiency, accuracy, and precision. Furthermore, they serve as a baseline from which more complex theoretical studies can be made. This paper aims to demonstrate the utility of traditional, updated, and modern techniques combined with anthropological ethnography to investigate cultural and natural site formation processes at the Middle Islamic period site of Khirbat Nuqayb al-Asaymir (KNA), located in southern Jordan.

This work was done as part of the University of California, San Diego’s Edom Lowlands Regional Archaeology Project (ELRAP) 2012 field season.

2. Low-altitude Aerial Photography Background

Aerial photography is a technique that has a long history of application in archaeology, and can be divided into two categories: low-altitude aerial photography (LAAP) and high-altitude aerial photography (HAAP). LAAP can be defined as imaging from a camera platform suspended ca. 800m or less above the earth, with HAAP occurring at greater elevations. LAAP dates back to at least 1887, when Major Elsdale of the British army
experimented with photography from large balloons and also invented a system with an automatically-triggered camera suspended from a small balloon as part of a survey of India. Elsdale’s system was proposed to take photographs of archaeological sites near Agra, India, which would have been the first aerial photographs of an archaeological site. As this plan encountered difficulties (Crawford 1924: 580), images taken of Stonehenge from a war balloon in 1906 by Lieutenant P.H. Sharpe are the first archaeological images from the air (Capper 1907). Henry S. Wellcome soon after established the usefulness of kite photography with his work in Sudan (Deuel 1973: 33). Despite early and successful uses of low-altitude platforms, aerial photography did not take off until the outbreak of the First World War. As taking pictures from the sky became increasingly viable with developments in both cameras and planes, militaries latched onto the developing technologies in order to improve their knowledge of the landscape and aim their guns for accurate indirect bombardment (Guy 1932: 148). Pioneers such as O.G.S. Crawford, P.L.O. Guy, and Colonel G.A. Beazeley were able to make use of these improvements to photograph archaeological sites from the air themselves or to capitalize on the sudden availability of aerial images and even reconnaissance flights to gain a new perspective on their sites (Guy 1932: 148; Crawford 1924; RCHME 1960; Beazeley 1919; 1920). These experiments were some of the first applications of HAAP to archaeology. Military development and applications of new techniques of aerial imagery crossing over into archaeology has remained a theme since, with archaeologists making use of declassified satellite reconnaissance imagery, which represents by far the majority of HAAP applications in archaeology today, and the military development of unmanned aerial vehicles (UAVs), which are only recently being applied to archaeological imaging. Techniques of image interpretation developed for military purposes also crossed over to archaeologists examining aerial photographs (Reeves 1936: 104). Beazeley in particular was able to make
use of the higher vantage point provided by military flights to map archaeological sites in Mesopotamia and discover ancient irrigation systems invisible from the ground, despite being shot down and bombarded by his Turkish enemies (Beazeley 1919; 1920). Archaeologists soon came to the realization that shadows, soil discolorations, and differences in crop growth made it easy to locate certain sites and features that would be nearly imperceptible from the ground (Reeves 1936: 105), as seen in Beazeley’s early work. The technique of archaeological prospecting using high-altitude aerial photographs has been continuously used up to the present day, often with satellite imagery in recent times (Sadr and Rodier 2012; Savage et al 2013). Despite the initial usefulness of military research and development, once early adopters recognized the usefulness of vertical and comprehensive photographs, they searched for a way to acquire aerial images at reasonable cost without depending on military projects. These initial projects, along with Wellcome’s work in Sudan, were the first true applications of low-altitude aerial photography to archaeology, and demonstrated the utility and practicality of the endeavor. P.L.O. Guy, director of the University of Chicago’s Oriental Institute’s Megiddo Expedition in the late 1920s in Palestine, was one of the pioneers of custom LAAP systems for archaeological purposes. Guy acquired a 12-ft diameter balloon, inflated it with hydrogen, and attached a camera. His team used the system to acquire images of the site of Megiddo, and create photomosaics at a 1:250 scale. These stitched-together images proved to be useful for discerning the stratum to which walls should be assigned and to compare architecture across the site (Guy 1932). For archaeologists seeking to interpret sites, the inclusion of even the most minor visual details in aerial photography was seen as an enormous advantage recommending its use (Reeves 1936: 104). Using vertical photographs to trace features and details was quickly recognized as a helpful and efficient way to map sites (Reeves 1936: 106), as seen by Beazeley’s work during the war. Despite the early recognition
of the advantages of LAAP and advances in its use, the technique lost momentum and popularity during the mid-20\textsuperscript{th} century. The outbreak of World War II limited opportunities for archaeologists to travel widely and use their own systems of LAAP. Furthermore, this restriction coincided with the further development of planes allowing for increased military reconnaissance through HAAP, which was adapted for archaeological purposes post-war (RCHME 1960; Bewley 2003). Obtaining imagery from plane-based photography was seen as a more efficient method of gaining perspective on archaeological sites and landscapes, resulting in a relative abandonment of archaeological applications of LAAP during much of the mid-20\textsuperscript{th} century.

Today, low-altitude aerial photography is widely applied as a tool to obtain new perspectives on sites or to map them as archaeologists have again realized the need for cheap, efficient, and versatile methods of obtaining aerial perspective. Perhaps the most significant and substantive effort made with this technique was the creation of \textit{The Aerial Atlas of Ancient Crete} by J. Wilson Myers and Eleanor Emlen Myers. The \textit{Atlas} represents a comprehensive documentation of 44 archaeological sites on Crete with low-altitude aerial photography, taken from a 33-foot-long balloon. This work primarily represents the aesthetic and perspectival advantages of vertical photography, with the images produced proving to be of use for checking top plans and spatial relationships at the site and also providing excellent overviews of the sites (Myers and Myers 1992). While not all current uses of LAAP are quite as ambitious in scope and scale as that of the Myers, they still reap the same advantages. These advantages are applicable at a number of scales and angles. Oblique images provide excellent overviews of sites, and are aesthetically pleasing photographic records that are well-suited to publication (Renfrew and Bahn 2000: 82-3). When considering localized features, vertical photography proves to be very useful for making measurements, acquiring publication-quality
detailed shots for displaying relationships between archaeological contexts (loci) and, perhaps more importantly, for serving as the basis for drawing a top plan (Renfrew and Bahn 2000: 83). Vertical images, once georeferenced, are suitable for tracing or digitizing loci or architectural features, subject to interpretation by an archaeologist (Sterud and Pratt 1975). The use of these images can drastically reduce the time needed to create top plans with traditional methods of drawing, which can take several weeks to produce and potentially months to digitize (Schlitz 2004; Levy and Smith 2007). Digitizing directly from georeferenced images can also improve the simplicity of the process of creating top plans while retaining or improving accuracy and comprehensiveness of the plans (Quartermaine et al 2013; Levy and Smith 2007). Making top plans from quality aerial images may thus be the optimal solution in terms of efficiency and accuracy of their creation and the quality of the final result.

The type of system used to elevate cameras for cost-efficient low-altitude aerial photography have – for the most part – not substantially changed over the past hundred years. Kites and small balloons, originally used for archaeology by Wellcome and Guy, respectively, are still widely used as relatively cheap and practical ways of acquiring vertical photographs. The use of UAVs has also become increasingly common in recent years. Kites are a viable platform for high-quality aerial imagery, as demonstrated by Wellcome in the early 20th century, and remain a practical form of acquiring aerial images today. Various types of kites specifically designed for aerial photography under different wind conditions exist, along with several systems for controlling the kite and recalling it once the necessary photography is performed (Anderson 2001). However, the use of kites does depend on appropriate wind conditions, ideally 15-40 km/h (Aber and Aber 2002; Aber 2004). Lack of wind rules out kite
aerial photography as an option, and inconsistent wind can result in an unstable platform and the potential for a costly crash.

Balloons, lifted by helium in most cases, have also remained a popular option for low-cost aerial photography. These balloons also come in varying shapes and sizes depending on use, from small weather balloons to large blimps (Aber 2004). Balloons can be flown and taken down with relative ease, and can operate in the absence of wind. These systems also have the additional advantage of a level of fine manipulation not possible with kites. Balloons have no minimum elevation at which they can be flown (Myers and Myers 1992), meaning that the resolution of the imagery they can acquire is not limited by the system, but rather by the camera attached to the system, as the camera can be lowered to within inches of the ground. Balloon photography has become more viable since the efforts of Guy in the 1930s (Myers and Myers 1992), and has only become more practical with the development of digital photography and lightweight equipment. Today’s memory cards can potentially store thousands of high-definition images, and digital photography means that images can be taken without regard to the cost of film. Furthermore, balloons can also remain in the air, taking photographs, for a period of up to several days (Aber 2004), a substantial advantage that means that any given flight session is only limited by the size of a memory card. These advantages of balloon photography give it a versatility and practicality that is unmatched by other forms of LAAP. However, balloon photography suffers from limitations imposed by the cost and availability of helium, which may eliminate helium balloons as a viable option (Aber 2004). As a result, one must consider the logistical challenge of acquiring a supply of helium before selecting a balloon-based system.

UAVs have also become a popular option for LAAP since their development to the point of affordability and practicality. This boom has largely come as the result of military
development of unmanned vehicles (Bendea et al. 2007). Today, many UAVs allow for automated flight in preplanned patterns, meaning that acquiring images at precisely the needed elevations and locations is a simple process, a significant advantage for LAAP. Tightly-regulated flight patterns also facilitate the acquiring of images suitable for photogrammetric purposes (Eisenbeiss et al. 2005). However, UAVs also suffer from a number of limitations. UAVs, relying on battery or gas fueling, have a maximum flight time of one hour, at the most (Everaerts 2008). More often, they cannot fly for longer than 30 minutes without a battery change or recharge (Sauerbier and Eisenbeiss 2010). Furthermore, most affordable UAVs have very limited payloads, usually not more than 100-200 grams, restricting the size of camera that can be flown (Everaerts 2008). This disadvantage is mitigated to some extent by the increasing availability of small yet high-resolution cameras, although true digital single-lens reflex cameras are still impractical to mount on most UAVs. Additionally, UAVs often raise dust during take-off, landing, or flying at low altitudes, which may introduce unwanted dust into the attached camera. This issue requires specific countermeasures to avoid and may restrict LAAP at the lowest levels of flight over a site (Eisenbeiss 2005). Finally, and perhaps most significantly, using UAVs involves a substantial risk of complete failure. UAVs are somewhat prone to crashing, especially at low altitudes (Everaerts 2008; Eisenbeiss 2005). These crashes can potentially damage or destroy the camera attached to the system, and may be extremely costly, both financially and in terms of opportunity in the field.

3. LAAP Methods

After a comprehensive consideration of the above advantages and disadvantages of the various LAAP systems, the ELRAP team selected a balloon-based platform as the most practical method for acquiring high-quality images in the varying wind conditions and desert environment of Southern Jordan’s Faynan Region. The ELRAP team chose a Kingfisher
Aerostat balloon, capable of supporting an attached camera platform. The balloon was also outfitted with a wind sail, ensuring that the entire system would remain oriented to the same direction as the wind, allowing for maximum camera stability. The balloon was inflated with helium and staked down in a tent overnight at the site, allowing the balloon to remain inflated overnight, allowing for the conservation of helium gas. The ELRAP team also designed a dual-camera LAAP platform suitable for capturing high-resolution images of excavation units on a daily basis, as well as sitewide images when necessary (Keller and Tuttle 2010: 536). This platform consisted of a custom-built aluminum triangular frame with two attached digital single-lens reflex (DSLR) Canon EOS 50D cameras. The platform was also equipped with two intervalometers, programmed to trigger the cameras at a preset interval, usually of 10-15 seconds. This allowed the collection of hundreds of images per balloon flight, increasing the likelihood of capturing images with quality focus and targeting.

The ELRAP balloon photography system was applied at a number of sites, including the sites of Khirbat Faynan (Bronze Age, Iron Age, and Byzantine Period) (Glueck 1934: 8-9; Levy et al, in press; Hauptmann 2007: 97), Wadi Fidan 61 (Neolithic Period and Iron Age) (Raikes 1980: 50-52; Levy et al 2001: 175), Petra (Nabatean and Roman Periods) (Levy et al 2013), and the Middle Islamic-period site Khirbat Nuqayb al-Asaymir (KNA) (Glueck 1935: 30-32; Hauptmann 2007: 126-7; Jones et al 2012). Site photography was primarily performed as part of one of two endeavors: semidaily photography of excavation units or overall site photography. Imaging of excavation units serves a dual-purpose – documentation of the conditions of excavation and providing a background for mapping of sites through digitization of archaeological features. Overall site photography allows for the generation of publication-quality images as well as creating a spatial record of the entire site. Naturally, each of these types of documentation required different photographic approaches. Excavation unit
photography was performed with the balloon system flown at a height of between 10-25 meters, in transects across the unit separated by approximately one meter to ensure appropriate coverage. Site photography required a higher flight pattern of roughly 75-150 meters elevation, with transect width varying depending on wind conditions and site size. The vast majority of ELRAP balloon photography was performed with the goal of collecting images suitable for photogrammetric Structure from Motion processing.

4. Photogrammetry

Photogrammetry is a technique with a history in archaeology nearly as long as aerial photography, dating back to the beginning of the 20th century at least (Baudouin 1902). Photogrammetry, essentially, is a technique involving the use of multiple images of the same subject taken from different angles in order to correct or reduce distortion caused by the angle of photography. This process allows for increased accuracy when mapping from aerial images (Kucukkaya 2004). Naturally, given the previously-outlined advantages of aerial imagery for mapping, photogrammetry provides substantial added benefit to a LAAP program. Traditionally, photogrammetry has been performed through manual comparison of photographs or by viewing images together as stereo pairs. Photogrammetric techniques have been used in recent times to produce orthophotographs, top-down images corrected for lens and elevation distortion, and digital elevation models (DEMs) (Lo 1974; Karras et al 1999; Bewley 2003; Skarlatos et al 2003; Matsumoto and Ono 2009). However, traditional methods of photogrammetry are expensive, time-consuming, and produce less-than-ideal results. Even updated techniques of traditional photogrammetry are difficult to perform with low-cost imaging platforms such as those discussed above (Skarlatos et al 2003). Fortunately, technological developments have resulted in the development of a digital photogrammetric approach known as Structure from Motion (SfM), which allows for the processing of
potentially hundreds of images into accurate and precise 3D models. Combining LAAP and SfM for use in archaeology has been the subject of much recent work with the increasing practicality of Structure from Motion approaches, as well as the availability of both open-source and commercial software packages performing these processes (Verhoeven et al 2012; Olson et al 2013). SfM is an efficient and cost-effective method of producing 3D results that rival the accuracy and precision of more expensive techniques such as terrestrial LiDAR survey (Verhoeven et al 2012). Yet even more important from an archaeological perspective is the possibility of creating high-quality georeferenced outputs such as orthophotos and DEMs, which can be created within SfM software packages. These accurate, precise, and efficiently-collected GIS outputs are one of the main benefits of performing SfM-based spatial recording in the field, and can be critical to archaeological investigation (Verhoeven et al 2012), especially at sites without an extensive history of research or mapping. DEMs are essential for cell-based analyses (i.e. spatial analyses performed using raster data) (Chapman 2009) and can also serve as the basis for other raster-based datasets that can be derived from a DEM (Conolly and Lake 2006: 103). DEMs also provide a basemap for sites and can be used to create contour lines within ArcGIS or other GIS software (Price 2006). Orthophotos are also important to the archaeological process, as they are one of the most accurate foundations for digitization of archaeological features. Digitization is an important process as it allows for a transformation of data from raster format, in which data consists of discrete cells with individual values ascribed to each square cell to data in vector format, which takes the form of representative points, lines, and polygons (Kvamme 1989). Orthophotos are also free of the lens- and elevation-based error inherent to other vertical images and allow for a reduction in human error from methods of traditional drafting (Verhoeven et al 2012; Olson et al 2013). Digitizing directly on orthophotos eliminates hand measurements, manual sketching, and
calculation errors, all sources of error when practicing traditional methods of drafting top plans. Instead, the user can carefully outline selected features on an accurate vertical photograph with millimeter precision.

5. Khirbat Nuqayb al-Asaymir

Khirbat Nuqayb al-Asaymir (Arabic for “Ruin of the Small Black Pass”) (Figure 1) has been investigated by ELRAP since 2002 (Jones et al 2012). The site is located between the Wadi Ghuwayb al-‘Atshana and the Wadi Nuqayb al-Asaymir, and consists of a cluster of 15 structures and several slag mounds dating to the Middle Islamic Ayyubid-Mamluk era (Hauptmann 2007: 126-27; Jones et al 2012). Originally visited by Alois Musil (1907: 298-99) and later Nelson Glueck (1935: 30-32), the site was recognized as a copper production site of some importance from the start, although it was not intensively mapped or investigated until the beginning of an ELRAP survey project spanning 2002-2007 (Jones et al 2012). This project consisted of total station mapping of extant architecture at the site and intensive pedestrian survey recovering 1,300 sherds, primarily relating to the Middle Islamic period (Jones et al 2012). The most significant habitation at the site apparently occurred in the Middle Islamic IIa. (Jones et al 2012). Aside from chronological corroboration and constriction, the ELRAP survey also proved critical to a reevaluation of the significance of Middle Islamic copper production from a regional perspective. Jones and colleagues explain the resurgence in copper production in Faynan during this period as relating to a substantial sugar industry in the Jordan Valley, for which copper cauldrons would be a key tool (Jones et al 2012). Further investigation, including excavation, into KNA as an important piece of the economic puzzle of the Middle Islamic period are ongoing under the ELRAP banner. Therefore, additional approaches, including LAAP, photogrammetry, and GIS-based spatial
analyses, are warranted in order to form a more complete picture of the site’s significance and habitation.

6. Photogrammetric Methods

The ELRAP team selected the commercially-available Agisoft Photoscan program as the most efficient software package for developing DEMs and orthophotos from images taken from the balloon-based LAAP system. Agisoft Photoscan is a user-friendly program providing a complete Structure from Motion workflow, developing unsorted photographs into a photorealistic and geometrically-accurate 3D model. One main advantage that recommended the use of this program to the team is its ability to georeferences models within the program, allowing for spatially-referenced GIS outputs to be simply exported once a model is completely processed. The process of generating these spatial datasets through this program’s workflow breaks down into four main steps. After photos of a site such as KNA are uploaded, the first stage of processing relates to the development of a sparse point cloud, with each point representing a point of similarity between images taken at different angles. Users have the opportunity to set the number of points in the cloud, depending on hardware limitations and needed specifications. Point clouds developed by the ELRAP team usually consisted of 200,000 to 2,000,000 points, depending on available processing power, size of the target area, and required resolution. Point clouds in Agisoft Photoscan can be edited according to its accuracy or to eliminate unwanted areas from the model to improve processing time of subsequent stages. The locations from which the photos were taken relative to the site are also calculated at this step. At the next stage of processing, the points in the cloud are interpolated to form a solid geometrical model, which can also be trimmed as needed. The number of polygons in the model (a proxy for its resolution) can be customized and increased for more precise elevation data later down the line. At the final stage of model
building, the images used to create the model are mosaicked or have their pixel values averaged and are layered onto the model to create a photorealistic representation of the site. This model can then be georeferenced through control points, taken with a total station or GPS unit. The ELRAP team, over the course of excavation, established a number of stable – yet temporary – markers spread around both excavation areas and sites, highly-visible both from the ground and from the higher ranges of low-altitude photography. Each area targeted for photogrammetric modeling was given approximately 6-8 markers, spread evenly. The ELRAP team recorded the exact coordinates of these control points with a total station, and manually georeferenced each model within the SfM software. Once the model is spatially referenced, Agisoft Photoscan is able to export DEMs and orthophotos for immediate use within GIS. These outputs can be created within ca. 10 hours at resolutions that compare favorably with products created only after days or weeks in the field using traditional methods. Despite the considerable advantages of SfM processing for the creation of photorealistic 3D records as well as accurate and precise GIS outputs, certain limitations may limit or prohibit its use. Most significantly, SfM is a computationally-intensive procedure that requires the use of hardware with substantial processing power for practical use of the technique. As a result, applying SfM may be impractical given costs for such workstations or in field conditions where their use is not possible. The time required for processing photographs into 3D models is also a drawback of this technique. On the ELRAP project, models with the quality required for appropriately-high-resolution GIS outputs took ca. 4-8 hours to process on average. Agisoft Photoscan also carries a cost of $549 for an educational license, amplifying the cost barrier to its implementation (although open source SfM software packages are available). Despite these downsides to applying SfM to archaeological projects, the ELRAP team calculated that Agisoft Photoscan’s efficiency in capturing a photorealistic record of the
project’s sites while also producing high-quality GIS outputs with an efficiency, accuracy, and precision unmatched by other methods was worth the temporal and financial costs of its application. At KNA, the ELRAP team developed a 5cm resolution DEM (Figure 2) and a 2cm resolution orthophoto (Figure 3) with submeter spatial accuracy with approximately 1.5 hours of time in the field and ca. 8 hours of lab processing with Agisoft Photoscan. These GIS outputs provide both a supplement for ongoing work at KNA and an excellent basis for further research at the site, especially GIS-based spatial studies. As discussed above, a high-quality DEM is necessary for cell-based analyses and can serve as a springboard for the creation of numerous other types of data. Meanwhile, an accurate orthophoto like that made of KNA can allow for digitization or features and additional detailed study facilitated by the new perspective on the site provided by the vertical image. As a result, the ELRAP team judged that these spatial datasets – developed through combined application of LAAP and SfM – were an ideal point of departure for a more theoretically-involved study of site formation processes at KNA.

7. Site Formation Processes

To create a model of site formation processes, two main cornerstones are required: an understanding of the types of processes that occur and data from which to base the project. Fortunately, the intensive LAAP survey program on the ELRAP project has provided a foundational dataset suitable for this kind of study. Now, it is important to turn to site formation processes in order to gain an understanding of how they affect and create the archaeological sites as they exist today. In order to do so, it will be necessary to review the different theoretical approaches to conceptualizing how sites develop and turn to ethnoarchaeological studies for concrete evidence and to provide analogies for these processes.
The question of how artifacts make their way into the archaeological record is critical within the field of archaeology, and one that has occupied scholars since the 1970s. In a sense, it is the most important question, as archaeology is essentially the study of material remnants of past societies in order to interpret and reconstruct their lives. Knowing how materials are incorporated into the archaeological record is necessary for making conclusions about the processes that put them there. Thus, how one views the depositional processes that form the archaeological record conditions the way in which one interprets the evidence at hand. Interestingly, these “site formation processes” have been considered in different ways over the course of history of archaeology. For much of this period, processes of artifact deposition and their importance were only implicit within the work of the archaeologist, with these issues not seriously considered or explicitly discussed until the rise of Processualism and, later, the Post-Processualist critique. The addressing of site formation processes and their effect on the validity of archaeological interpretation necessitated their explicit consideration and justification by archaeologists, regardless of their theoretical orientation.

Lewis Binford was one of the first archaeologists to justify his method of interpreting past societies from their archaeological remains through an explicit theoretical model explaining how past actions leave material evidence (Binford 1964). Binford’s characterization of this process was later criticized as overly simplistic, although his work in this area was a pioneering venture, catalytic for further development by other thinkers. Binford (1964) argued that activities performed by people have a “structured set of spatial-formal relationships” with where these tasks are performed and what tools are used to do so. In other words, Binford held that objects and locations can be associated with specific activities performed by people, given that specific tasks always take place in specific areas using specific objects. Furthermore, in Binford’s view, these relationships exist in the
archaeological record, as “the loss, breakage, and abandonment of implements and facilities at different locations, where groups of variable structure performed different tasks, leaves a “fossil” record of the actual operation of artifacts” (Binford 1964). Therefore, according to Binford’s approach, it is possible to discover evidence for the performance of activities in specific locations through the recovery of spatially coherent artifacts relating to that activity. Binford takes this line of reasoning even further by arguing that the entire cultural system of a past people can be recovered using this framework, as social and ideological aspects of society fossilize in a similar way (Binford 1962; 1964). Moreover, he held that our understanding of the past is not limited by the archaeological record, but instead by limitations in methodological approaches to studying the past (Binford 1968). Binford’s ideas built on the criticisms levelled at the archaeological establishment of the 1940s by Walter Taylor, who argued that American archaeology of that period was essentially un-anthropological and was overly concerned with history and comparative typology to the detriment of broader understanding of culture and the quotidian (Taylor 1948). On the other hand, Binford’s archaeological method was essentially anthropological, as evidenced by the attempts to uncover activities of past people, their social structure, and their ideology through a scientific method. Binford’s goal of developing an analytical archaeology that aimed to recover past activities through their spatially-coherent remnants gained a good deal of popularity, as a number of researchers were attracted to this newly-theorized way of interpreting the archaeological record (Clarke 1968; Longacre 1970; Parsons 1972: 133; Dunnell and Dancey 1983: 267). Binford’s approach to archaeology achieved further importance beyond its own not insignificant merits because of the subsequent debate it inspired.

Despite the popularity of Binford’s paradigm, the “New Archaeology,” the idea that cultural activities would fossilize into the archaeological record as they were performed was
called into question by scholars who disputed Binford’s understanding. Michael B. Schiffer took particular issue with Binford’s characterization of the ways in which activities transform themselves into archaeological evidence. Schiffer advocated a new paradigm called “Behavioral Archaeology” focused on the processes that formed the archaeological record as it exists (Schiffer 1972; 1976). More specifically, Schiffer argues for the need for a more rigorously-demonstrated connection between cultural activities and depositional processes. This he expands on by differentiating between the conditions of “elements” – materials in a cultural system—as existing in “systemic context,” in active use in a behavioral system, or “archaeological context,” referring to the condition of having passed out of use and into the archaeological record (Schiffer 1972). The strict separation of these two groups has been disputed by some, given the complexity of deposition processes and people’s interaction with refuse (Siegel and Roe 1986). However, the distinction between elements in use and those that have passed out of use remains important. According to Schiffer, elements pass through five processes during their life: procurement, manufacture, use, maintenance, and discard, although different elements can undergo different processes. The first four of these represent the element’s existence in systemic context, while discard represents its transition into archaeological context. Each of these processes contains one or more stages, which represent cultural activities (Schiffer 1972). Schiffer’s scheme differs from Binford’s in two important ways. First, – and perhaps most importantly – Schiffer clearly differentiates systemic context from archaeological context, while Binford’s scheme conflates the two, holding that archaeological context is created by the fossilization of cultural activities. Secondly, Schiffer perceives the deposition of artifacts into archaeological contexts as an individual cultural process, unique for each element in the cultural system. Schiffer’s scheme, therefore, necessitates explicit consideration of artifacts’ life processes and how they move into the
archaeological record before one can make conclusions based on the artifact’s context. In the simplest possible terms, an artifact’s find-location is not necessarily its use-location.

Binford (1981), in response to Schiffer’s (1972) behavioral archaeology and critique, elaborated his view to deny his use of the so-called “Pompeii premise,” in which the archaeological record is assumed to consist of a snapshot of a past society as if activity had ceased and become fossilized in the ground (Binford 1981). He criticizes Schiffer for his characterization of cultural formation processes as causing distortion, arguing that pre-depositional events affecting the archaeological record are not distortive, but rather reflect different kinds of past activity. Binford cites the disposal of elements in a system as an activity that is part of a cultural, and their final location in a dump of some sort is a fossilization of the activity of cleaning and disposal (Binford 1981). Binford also criticizes Schiffer’s understanding of formation processes and his ability to understand complex inhabitation patterns (Binford 1981). Interestingly, Schiffer (1985) responded to Binford’s criticisms with not only a refutation of his assertion that behavioral archaeology depends on Pompeii-like sites, but also a reaffirmation of the accusation that many practitioners of the New Archaeology indiscriminately assume Pompeii-like conditions without due consideration of site formation processes. This is implicitly predicated on “equivalence transformations,” in which systemic contexts are assumed to be closely related to archaeological contexts in key ways (Schiffer 1985). Schiffer’s arguments can be understood as attempts to expand on Binford’s model of how systemic context transforms into archaeological context. Schiffer argues that this relationship is considerably more complex than initially stated by Binford and therefore requires explicit justification in archaeological interpretation.

Perhaps the most important takeaway of this debate is the importance of considering site formation processes and explicitly including and justifying them in archaeological
analyses. Credit must be given to both Binford and Schiffer; Binford (1964) for initially relating a scheme for interpreting archaeological remains in terms of their deposition processes, and Schiffer (1972; 1976; 2010) for pushing the debate forward and developing an archaeology fundamentally focused on site formation processes. It seems clear that the way in which Schiffer’s systemic context transforms itself into archaeological context is an important aspect of study and consideration for all archaeologists, given that the interpretation of this process directly affects how one would reconstruct a society from archaeological remains. As a result, it seems prudent to elaborate on the cultural and natural formation processes in question that affect the deposition and distortion of the archaeological record.

Cultural formation processes (also known as “c-transforms”) are processes that take place prior to deposition and during deposition itself. This category contains a number of types of element use that can affect their deposition. These include pre-depositional processes such as artifact reuse. Possible forms of reuse include “lateral cycling,” recycling, and secondary use. In each of these forms, an element is reused, although lateral cycling implies use by a different owner, recycling refers to the element’s return to the manufacturing process, and secondary use brings a new purpose to the same artifact (Schiffer 1987). Each of these processes is potentially discernible in the archaeological record and bears keeping in mind. Perhaps most important among c-transforms to archaeologists are discard processes, which result in the transformation of systemic context to archaeological context. Importantly, different types of artifacts undergo different types of deposition and have use-lives of widely-varying lengths (Hayden and Cannon 1983). Deposition practices can be generally divided into three categories: primary refuse, secondary refuse, and de facto refuse (Schiffer 1972). According to Schiffer’s (1972: 160-1) schema, primary refuse consists of elements discarded in their use-area. This category of artifact bears the simplest connection between the
archaeological record and Binford’s (1964) fossilization of activities, as one can reconstruct activities (such as stone tool production, to use a classic example) from the discards (e.g. stone flakes) associated with them. It is important to note that during habitation and performance of activities, regularly-used areas are frequently cleaned (Schiffer 1987). This results in the movement of refuse to another location, at which point it becomes secondary refuse. Secondary refuse can be created through processes as simple as sweeping of debris in household spaces through the entryway to the exterior or as complex as collecting debris over a longer period of time for later disposal at a dump or pit (Hayden and Cannon 1983). The third type of deposition is the creation of de facto refuse, which relates to abandonment. This results in the entire evacuated area transforming into archaeological context (Schiffer 1987). However, it is important to note that different rates of abandonment result in varying quantities of element deposition (Ascher 1961). One can consider what remnants would be left at a site where the inhabitants chose to move somewhere else, taking their valuables with them in opposition to what might be left in the archaeological context at a site suffering a sudden, unexpected destruction. Schiffer (1987: 89-90), appropriately enough given his prior debate with Binford, cites Pompeii as an example of a site with a rapid abandonment pattern resulting in high quantities of de facto refuse. Reclamation processes make up a final type of C-transform that affects the archaeological record and are actually post-depositional. These refer to recovery or salvage of elements from the archaeological record, as well as reoccupation of structures and sites. Reclamation processes also include the salvaging and scavenging of sites for useful elements, and can result in relocated refuse (Schiffer 1987), complicating interpretation of the archaeological record. It is this second category of post-depositional c-transforms of the archaeological record that has resulted in the creation of large tells, characteristic of Near Eastern archaeology.
Environmental formation processes (also known as “n-transforms”) are the second critical category of site formation processes that affect the archaeological record. These processes are post-depositional, for the most part, and in many cases result in distortion of the archaeological record. Schiffer (1987: 143, 199) divides his schema of n-transforms into two broad categories: those that affect artifacts and those that affect sites. Processes affecting artifacts can be further broken down by their causes: chemical agents, physical agents, and biological agents (Schiffer 1987). Chemical processes include corrosion, and acidic and saline effects on artifacts resulting in their deterioration or destruction. Water is the primary physical factor to affect artifacts in the archaeological record, as it has a high potential to erode, move, and destroy artifacts. Wind-blasted sand can also have a significant effect on artifacts’ conditions. Biological agents have perhaps the greatest effect on the archaeological record, as microorganisms obliterate organic matter over time, and animals and roots can destroy or move artifacts (Schiffer 1987). Given that these n-transforms have the potential to eliminate certain lines of data from the archaeological record, they are important for archaeologists to consider. For example, an archaeologist excavating a site with many stone tools might miss the importance of tools made of wood or other organic material, given their lack of preservation in the archaeological record.

Environmental formation processes affecting sites at a broader scale are equally insidious to the archaeological process, given that these have the chance to move cultural deposits and mix them. Processes of “pedoturbation,” or soil mixing, can have potentially great effects on the archaeological record. Nine main processes of pedoturbation exist (Hole 1961), and are important to consider. Faunalturbation (sometimes colloquially referred to as “bioturbation”) is soil disturbance caused by animals. This type of soil mixing can take place at the hands or paws of various types of animals, including burrowing animals, insects, and
earthworms. Burrowing animals tunneling through topsoil can cause a great deal of soil mixing and turnover, as well as movement of artifacts by tunnel through meters of soil, destroying their original context (Wood and Johnson 1978). Insects and earthworms can also blur and mix soil strata to the point where they are indistinguishable (Wood and Johnson 1978). Floralturbation refers to the effects of plants on soil. The actions of tree roots under the earth’s surface and tree collapse and decay are responsible for the largest-scale processes of this type of soil disturbance (Wood and Johnson 1978). Graviturbation refers to the movement of soil downslope under the effects of gravity and without air or water. This category of processes, consisting of soil creep, soilfluction, subsidence, and earthflows, is very important to archaeology, as it can result in large movements of soil and sediment out of their original contexts (Wood and Johnson 1978). Graviturbation, along with wind and water driven erosion, are probably the most important soil disturbance processes affecting archaeological sites on slopes. The erosion of sediment and artifacts downslope has been recognized as a significant problem, “blurring” our understanding of archaeological sites and spatial context (Wainwright 1994). Cryoturbation, soil disturbance by freeze-thaw processes, crystalurbation, the effects of growing and shrinking soil crystals, and seismoturbation, soil disturbance by earthquakes, also may have important effects in certain parts of the world (Wood and Johnson 1978). Argilliturbation refers to soil disturbance caused by the expansion and contraction of clay in soil and can also have noticeable effects depending on site soil type (Wood and Johnson 1978). Soil mixing in all of these forms can have important effects on the archaeological record.

With an understanding of the importance of site formation processes and their effect on the archaeological record, the archaeologist is left with the problem of how to consider these principles, and make use of them when reconstructing systemic context from
archaeological context. Much of this is situationally dependent – for example, one does not need to understand the effects of cryoturbation working in a climate that never dips below freezing temperature. Schiffer’s work with behavioral archaeology provides an excellent framework for identifying different environmental formation processes from their telltale signs in the archaeological record when the need to do so arises. When dealing with cultural formation processes, it is critical to understand the ways in which artifacts were deposited in the past. One way to do so is by use of ethnoarchaeology, or the application of the ethnographic analogy to archaeology. By studying the behavior of people today, it is possible to derive models of how people may have acted and interacted with their environment in the past. The value of ethnography or ethnoarchaeology to the archaeologist is well-documented (Schiffer 1975; Binford 1967; Wylie 1985), despite cautions (Ascher 1961) and criticisms (Gould and Watson 1982). Thus, we arrive at a potential solution to the question of how to obtain valid hypotheses for how people in the past discarded and disposed of elements of their material culture. By studying ethnography and contemporary accounts of the passage of elements from systemic context to archaeological context, we can generate ideas and hypotheses for how this same process occurred in the past. Naturally, it is critically important to bear in mind the limits of ethnographic analogy and consider the validity of the analogy before applying it. Furthermore, conceiving of the ethnoarchaeological approach as a method of generating testable hypotheses, rather than proof of similarity, is important. With this approach, one can apply strategies of evaluation – developed as a reaction to the proliferation of flawed analogies used in the past (Wylie 1985) — to demonstrate the utility of ones’ analogy and weed out faulty comparisons if necessary.

Fortunately, there exists a body of work of ethnoarchaeological and ethnographic study of artifact deposition patterns. Generally speaking, Schiffer’s differentiation between
primary and secondary refuse applies, although it bears some elaboration as to how elements are actually discarded. Interestingly, ethnoarchaeological studies indicate that in nearly all cases, central activity and habitation areas within structures in sedentary settlements are kept relatively clear of refuse (Murray 1980). These areas of active and frequent use are often swept to clear refuse (Simms 1988), and the primary deposition (i.e. in their activity area) of elements in areas that are well-maintained is rare (LaMotta and Schiffer 1999). As such, they have very little pottery, with the exception of small, unnoticed sherds and those that sink into the floor (Longacre 1981). This ethnographic evidence casts doubt on Binford’s idea of the “fossilization of activities” into the archaeological record, at least a simplistic understanding of that line of thinking. Furthermore, the continuous cleaning of floors would imply that the majority of objects associated with floors may actually relate to stages of abandonment, rather than active use (LaMotta and Schiffer 1999).

Processes of secondary discard are perhaps more important than those of primary discard to understand through ethnographic analogy. Secondary discard is more complex than primary deposition, due to the fact that artifacts resulting from secondary disposal cannot be understood to be in the location of their activity use. Thus ethnoarchaeological study into secondary deposition practices can facilitate understanding of how these processes contribute to the formation of the archaeological record. Deal’s (1985) study of types of discard based on ethnographic study of Tzeltal households in Mexico provides a useful schema of types of secondary refuse disposal. Deal laid out four types of discard: provisional discard, disposal resulting from household maintenance, dumping, and loss (1985). Provisional discard stands out as a particularly important category. This classification refers to the stashing of broken elements so that they may be used later or collected for secondary disposal (Deal 1985: 253-9). This is a critical category for understanding disposal patterns in sedentary communities
since, “almost all implements in sedentary communities are curated and represent some significant investment of time, labor, or money,” and are not easily parted with (Hayden and Cannon 1983). Items are very often reused whenever possible (Kamp 2000). Provisional discard occurs in communities around the world, including Mayan households, Syrian villages, and semi-nomadic Bedouin camps in Jordan (Hayden and Cannon 1983; Kamp 2000; Simms 1988). Provisional discard usually occurs in areas within or near living quarters, out of the way but readily accessible. These areas are along interior walls, in corners, and also along exterior walls and fences (Hayden and Cannon 1983; Deal 1985). Once elements are provisionally discarded in this way, they are subject to the possibility of further damage from factors such as trampling, weathering, children’s play, animal activities, and additional use and breakage (Hayden and Cannon 1983). The second type of secondary element deposition is that resulting from household maintenance. This is the process that results in the relative cleanliness of activity areas, and the increased rate of secondary deposition as opposed to primary discard. Various ethnographic sources evidence the processes of household cleaning (Simms 1988; Binford 1978; Longacre 1981; Hayden and Cannon 1983; Deal 1985). Interestingly, some sources indicate an extremely casual attitude toward disposal of ordinary household trash. This type of refuse can be swept or thrown out an entrance (Simms 1988; Hayden and Cannon 1983). Little effort is spent to dispose of animal bones or other organic refuse, other than to make sure it is disposed of in a downhill direction when an inhabitance is on a slope (Hayden and Cannon 1983). Dumping is Deal’s third form of secondary refuse disposal and it is responsible for the highest quantity of elements in the archaeological record (Deal 1985). This type of deposition refers to elements that are intentionally discarded in a specific area. These areas need not be specific dumps, but can also be discard areas within household compounds or elsewhere (Deal 1985). How to interpret high-density deposits such
as pits has been an important matter of consideration (Wilson 1994), although the study of such deposits depends on their discovery. Generally, ethnoarchaeological evidence suggests that the vast majority of refuse is actually deposited within household compounds, or within concentrations of population (Murray 1980; Hayden and Cannon 1983). As Kamp (2000: 91) succinctly puts it, “few usable items reach the garbage dump.” Thus, between provisional discard, household maintenance disposal, and certain dumping processes, it seems that areas immediately inside (i.e. along walls) and nearby outside residences are some of the most critical for understanding sites during their period of active use. The spatial boundaries of the area of highest disposal density are somewhat flexible, given that household compound areas of varying sizes are the key loci of discard. However, based on certain ethnographic studies, it appears that a radius of approximately five meters around households and key structures and activity areas is a common disposal pattern across various societies (Hayden and Cannon 1983; Simms 1988). Thus it seems that the highest density loci of secondary refuse disposal are often within five meters of residential or locations at which activities are performed.

8. How to Operationalize Theory and Ethnography?

As we have seen, there exists a great deal of literature that deals with site formation processes and how systemic context results in the development of archaeological context. This body of work contains both theoretical approaches to bridging the gap between these stages in artifact lives and empirical studies of contemporary societies that actually document this process. The primary challenge to archaeologists is operationalizing these theories and the empirical evidence into a general strategy that allows them to reconstruct past lifeways from their excavation and/or survey results. Schiffer’s (1995; 2010) program of Behavioral Archaeology is a comprehensive and exemplary system representing one approach archaeologists can take to apply wisdom received from scholars interested in formation
processes and their effects on the archaeological record. The questions raised by each of Schiffer’s (2010: 6-8) four strategies of Behavioral Archaeology show that his modus operandi is, generally speaking, intended to link material culture to past human behavior. Thus Behavioral Archaeology – as a practice and as a concept – can be considered to be middle-range theory, given that it takes us “from contemporary facts to statements about the past” (Binford 1977). With an appropriately-comprehensive middle-range theoretical approach to material evidence in place, we can turn to what can be termed “low-range theory,” referring to ways of understanding specific evidence in terms of formation processes at a site – in particular, environmental transformation processes. As the above discussion makes clear, archaeologists would be well-advised to have an understanding of n-transforms and how they can affect sites. However, a methodological approach to applying “low-range” theory to understanding how environmental transformation processes can affect a site in advance of actual archaeological investigation (akin to the way in which one might plan survey or investigation based on the received wisdom of Behavioral Archaeology”) is presently not common in archaeological research. Rather, n-transforms are discussed and considered after they are specifically evidenced. However, it seems apparent that postulating potential pre- and post-depositional processes of material culture prior to archaeological investigation can serve as a useful guide to planning this research, as well as providing a hypothesis to be falsified or potentially confirmed with the acquisition of empirical evidence.

9. Hypothesis

We propose here that a consideration of site formation processes (including both c- and n-transforms) can be an important survey tool when approaching archaeological sites. We suggest that ethnoarchaeology can be a useful tool for generating hypotheses of processes and patterns of artifact deposition, which can be translated into GIS to simulate these c-transforms.
Furthermore, we submit that the combined workflow of low-altitude aerial photography and Structure from Motion allows for the creation of spatially-referenced data suitable to serve as the basis for GIS-based patterns of certain environmental formation processes, erosion in particular. In summary, we intend to develop a model for considering site formation processes, applying LAAP, SfM, and ethnoarchaeology to acquire data allowing for the modeling of the ways in which sites have developed over time. Considering these factors can potentially pay great benefits for researchers approaching a site. To demonstrate the utility and practicality of this type of analysis, formation processes affecting the site of Khirbat Nuqayb al-Asaymir (KNA), will be modeled using the previously-alluded to data.

10. GIS Investigation of Site Formation Processes

As a first step to this modelling, the SfM-produced orthophoto of KNA was used as the basis to digitize extant structures and slag mounds at the site into a polygon shapefile in order to create a record of the highest-density areas of inhabitation and usage (Figure 4). These polygons represent, variously, areas of copper production, habitation, administration, work, and refuse (especially slag) disposal (Jones et al 2012). With the site’s use and inhabitation spatially schemed, we can begin to apply some of the principles gleaned from ethnoarchaeological research into deposition patterns and model these at KNA. Naturally, the interiors of structures are the first matter of consideration. While ethnographic study tells us that areas of high and active use within buildings are often kept relatively clean, we also see that processes of abandonment result in deposition on floors (LaMotta and Schiffer 1999). Furthermore, provisional discard is an important factor to consider, and results in the deposition of artifacts along the edges of structures, both interior and exterior (Deal 1985). Based on these processes, we can (perhaps self-evidently) consider the interiors of buildings as important areas of artifact deposition. Our shapefiles corresponding to buildings and their
interiors serve as a good proxy for these areas. A more difficult challenge is to model secondary deposition on the exterior of buildings, given that they are not quite as conveniently spatially bounded by walls and also not yet investigated by ongoing excavations at the site. Yet two principles derived from ethnography seem helpful here. First, the area of highest density of secondary disposal occurs within approximately five meters of a structure (Hayden and Cannon 1983; Simms 1988). Second, disposal does not often occur uphill, given the likelihood of refuse rolling back downhill (Hayden and Cannon 1983). By creating a shapefile consisting of a five meter buffer around the digitized structures and eliminating uphill areas, it is possible to model the most proximal types of secondary deposition (Figure 5). This area would also include provisional discards immediately outside of structures. Other forms of secondary discard, or even primary discard outside of buildings, are harder to model without specific evidence in for their existence and location. For example, it is not practical to represent the existence of disposal in pits without actual discovery of such a locus. The shapefiles described and created here are not intended to serve as a final and definitive scheme of c-transforms at KNA, but rather as a preliminary technique to guide further investigation, with the potential to be updated and corrected with further research.

Modeling n-transforms at archaeological sites is equally – if not more – important to the endeavor of connecting the archaeological context of today to the systemic context of the past. At a site such as KNA, located in a valley with fairly steep slopes on which some structures were located, it is hypothesized that the primary natural formation process at work is erosion downhill through the work of wind and water. Naturally, the validity of this assumption depends on the potential discovery of other n-transforms in play, such as those discussed above. However, erosion of artifacts down the slope is a process that we know to occur, and one that affects the archaeological record in a significant way. Thus, modeling
processes of erosion in order to gain a greater understanding of site formation processes at KNA is a worthwhile endeavor. The problem of erosion of archaeological sites is a significant one that has not been widely addressed (Wainwright 1994). As such, it bears consideration through an attempt to model its effects on the archaeological record.

11. Erosion Estimation

The importance of considering erosion and its consequences for the archaeological record has been noted before (Padgett 1994). However, modeling of erosion-related disturbances and their effects on specific sites is also relatively difficult, perhaps resulting in a lack of attention in the archaeological record (Padgett 1994), with a few notable exceptions (Wood and Johnson 1978; Ayala and French 2005; Wainwright 1994). The ELRAP team, needing to evaluate the significance of erosion-caused disturbances at KNA, decided to apply the Revised Universal Soil Loss Equation (RUSLE), an equation developed by the United States Department of Agriculture (originally as USLE, later revised) (Wischmeier and Smith 1965) to calculate levels of rainfall-caused erosion based on several environmental factors. The equation has been widely-tested and refined (Goldman et al 1986: 5.2), and as such, was selected as appropriate for application to KNA in order to empirically determine the erosion-based risks and effects on the site. One point of difficulty to applying this formula to KNA, in remote southern Jordan, is the lack of appropriately-recorded and detailed data regarding the area in question. This issue has been previously addressed in RUSLE-based studies of erosion in more-heavily populated and farmed northern Jordan, where approximation and calculation of certain factors was necessary (Eltaif et al 2010). Nevertheless, RUSLE has been successfully applied to model erosion in Jordan, in each case demonstrating the severity of the problem of erosion in the country (Essa 2004; Farhan et al 2013). As such, RUSLE was selected as a viable tool, even despite issues of data availability.
RUSLE requires six variables in order to accurately calculate soil erosion. These are the *rainfall erosion index* (R), the *soil erodability factor* (K), the *slope length and steepness factor* (LS), the *vegetative cover factor* (C), and the *erosion control practice factor* (P) (Goldman et al 1986: 5.6). The R variable, representing the degree to which rain precipitation causes erosion, was the most difficult to acquire, given a lack of highly-detailed precipitation data for the study area. In RUSLE, R is usually calculated by multiplying the total energy produced by storm events in a region by the maximum intensity of rainfall over a 30-minute period (Goldman et al 1986: 5.7). However, these data were not available for the KNA area. Thus it was necessary to approximate the R-factor using Renard and Freimund’s (1994) equation \( R = 0.0483P^{1.610} \), where \( P \) = annual precipitation total less than 850 mm) for low-precipitation areas using available climatic data for the study area (Hijmans et al 2005). The unitless calculated R-factor for KNA was 46.182. For KNA, the K-factor – representing the erodability of the soil in question – required substantial estimation as well, also due to a lack of sufficiently detailed data. No soil survey of sufficient quality from KNA itself was available, and as such, a soil profile (Casler 2006) from land approximately 5.5 km to the south was used instead to approximate the variables involved in calculating the K-factor of soil at KNA. Ideally, detailed data on all soil at KNA would be available, allowing for precise and accurate calculation of the various K-factors of the site. This not being the case, we expect that the substituted soil profile will provide similar values given its similar consistency. A further level of estimation was also required due to a lack of specification of soil texture ratios (percentages of clay, silt, and sand) in the soil survey, beyond classification of the soil as a silty clay loam. In order to perform the RUSLE calculations, it was necessary to estimate soil composition percentages based on averages for silty clay loams. The K-factor was calculated using a nomograph provided by Goldman et al (1986: 5.6). This resulted in a
unitless $K$ of 0.520. The next factor required in order to perform the RUSLE is the Length-Slope Factor (LS), which accounts for the degree to which slope gradient and length affect amount of erosion, and can be calculated using an equation with these variables and constant based on slope (Goldman et al 1986: 5.19-20). It is possible to derive the data needed to calculate the LS factor from a DEM using functions within ArcGIS. To calculate the slope gradient across KNA, we applied the Slope tool in the Spatial Analyst toolbox (ESRI 2013) to create a raster dataset with slope data at the site. It was also necessary to calculate slope length, for which we applied the Flow Length tool, also in the Spatial Analyst toolbox, which calculates the distance downhill each cell at the site is from the local maximum in elevation (ESRI 2013). In other words, the length of the slope leading to each point is calculated, providing a comprehensive calculation of slope length across the entire site. The last variable required to calculate the LS is known as the “m-factor,” which consists of fixed values for ranges of slope. This we operationalized in GIS through reclassification (ESRI 2013) of the slope raster. With each of the key variables for working out the LS-factor in raster format in GIS, we were able to apply the raster calculator to this data using the formula provided by Goldman et al (1986: 5.20) and create a raster dataset showing the LS-factor over the entire site of KNA. By multiplying this raster by each of the other variables in the RUSLE equation, we calculated soil loss per hectare per year over the site at KNA within the GIS (Figure 6).

12. Modeling Pathways of Erosion

Given the importance of spatial context in archaeology, understanding the way artifacts have moved due to n-transforms is important for both factoring in distortion of the archaeological record and reconstructing original spatial and systemic context. Here we intend to simulate artifact erosion through use of the LAAP- and SfM-produced DEM and hydrological flow modeling as a proxy for movement of artifacts, given the complexity of
modeling the movement of actual artifacts of varying and unknown shapes, sizes, and densities. Rather, by estimating the paths on which artifacts would have been carried downslope by water and soil erosion, we can approximate the ways in which they would have been moved and deposited by erosion. This estimation can be performed within a GIS-framework through use of the “cost-path analysis” functionality.

Cost path analysis is GIS-based method that modifies space to reflect the difficulty of moving through terrain based on a set of input factors. Each cell in a raster grid is assigned a value representing the difficulty of traveling over that cell, and it is possible to calculate the easiest route through the landscape by determining which route has the lowest accumulated cost based on the cost values of the raster cells (Mitchell 1999: 144; Hart et al 1968). By applying cost path analysis to a digital elevation model, it is possible to model the way in which water flows over the surface (Metz et al 2011). This is accomplished by analyzing each cell in a chosen starting area of a DEM and considering the 8 adjacent DEM cells. Whichever of these cells has the least cost of movement into it (in the case of water flow, steepest downhill slope) is selected for the next movement, at which point the process is repeated for that cell (O’Callaghan and Mark 1984). The extension of this process to the extent of the DEM results in a raster-based path (potentially multiple paths) showing path of least-accumulated cost down the slope of the DEM. This path represents the downward route of water originating at a preselected starting point. However, prior to applying cost-path analysis, it is necessary to adjust the DEM to ensure a more realistic flow pattern. Computer-generated DEMs face the problem of “noise,” which refers to small inconsistencies in an even surface, which can result in the creation of “sinks.” Sinks are relative low points on a DEM where drainage paths and cost routes can potentially terminate because of small number of cells surrounded by cells of higher elevation values (DeVantier and Feldman 1993). To
eliminate this kind of disruptive noise, it is necessary to apply “hydrological conditioning,” or “sink removal,” to a DEM before applying flow tools. This process fills small sinks and is a necessary prerequisite to hydrological analyses (Danner et al 2007).

Prior to our cost path analysis, we realized the necessity of filling small sinks, although also the importance of differentiating between sinks with significance to flow across the landscape and those resulting from DEM noise (Danner et al 2007). Using the ArcGIS Sink tool within the Spatial Analysis toolbox (Merwade et al 2004), we identified all of the sinks within the KNA DEM. 1025 sinks were identified, although, none of the sinks exceeded 0.34 sq. m in size (Figure 7). Therefore, it was decided that none of these sinks were actually significant hydrological features when dealing with the flow of water and it was decided to fill them with the Fill tool, also of the Spatial Analyst toolbox within ArcGIS. This resulted in the creation of a sinkless DEM, suitable for cost path analysis. From this DEM, it was necessary to create a derived raster showing the direction of flow for each cell of the raster, in one of the eight directions possible using the Flow Direction tool of the Spatial Analyst kit. With the DEM base map, the Flow Direction raster, and the shapefiles representing artifact distribution patterns, we were able to simulate downhill flow from the predicted area of highest-density primary and secondary discard and create a raster showing the flow paths of water down the slope from the area of each structure or slag mound. These are hypothesized as the direct paths artifacts under the effects of erosion would take down the slope of the site. In order to apply additional analyses to these paths, it was decided to apply the Raster to Polyline tool in the Conversion toolbox (ESRI 2013) to convert these paths into a vector-based polyline shapefile, given that vector datasets are more suitable for certain spatial analyses than raster formats. Each of these polylines was then individually buffered by five meters to allow for a more disperse simulation of erosion of artifacts down the slope, as we suspect that erosion
patterns are somewhat more variable than strictly following the optimal flow path. These buffered shapefiles were then associated with original deposition areas, with mixed areas (i.e. areas in which erosion from multiple deposition areas overlapped) were removed into a separate shapefile. The final model represents the areas in which our simulation suggests that artifacts may have eroded into over time from each of the deposition areas (Figure 8).

13. Discussion

Pedestrian survey at KNA recovered thousands of sherds, very few of which were closely and concretely associated with structures or depositional areas. Furthermore, the number of surface sherds collected has thus far vastly exceeded the numbers recovered in excavation (Jones et al 2012; Ian Jones, personal communication, 2013). It seems apparent that without being able to assign an original provenience to these survey sherds, they are limited in their potential value, given that they must then be relegated to relating to the general history of the site. However, by analyzing the findspots of sherds located through a sitewide survey and comparing this data to our simulated deposition and erosion patterns, it may be possible to actually reopen the closed case of the systemic context of these isolated sherds. This simulation is not intended to suggest that all artifacts found in simulated erosion areas should be reassociated with concrete contexts of excavated structures. However, it seems acceptable to accord at least some sherds that have apparently eroded from a building the same level of significance as surface pottery would otherwise be given – not archaeologically secure but still somewhat important. In the view of this author, efforts to restore meaning to artifacts collected but more or less ignored are worthwhile.

14. Conclusion
This simulation of site formation processes using LAAP, SfM, ethnoarchaeological analogy, and GIS aims to recreate some of the processes that result in the development of the archaeological record through the passage of time. Expecting activities to permanently fossilize in the exact locations where they were performed is a view that appears too simplistic, given the complex ways in which people and the environment interact with their waste. This paper has attempted to present a framework through which archaeologists can operationalize formation process theory, and make use of it in their work in an efficient way with limited cost. These methods are also proposed as an effective survey tool, allowing researchers to gain new, nuanced perspectives on their sites within as little as a day of approaching a new site. A consideration of ways that the environment of a site would affect the ways in which systemic context transforms into archaeological context is always fruitful, and perhaps most so when other tactics of investigation have not yet shed light on these issues.
Table 1: Processes of Pedoturbation (soil mixing) and their causes and effects. (Modified from Wood and Johnson 1978).

<table>
<thead>
<tr>
<th>Process</th>
<th>Cause</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faunalturbation</td>
<td>Animals</td>
<td>Soil mixing and turnover, tunnels</td>
</tr>
<tr>
<td>Floralturbation</td>
<td>Plants, especially roots and tree collapse</td>
<td>Creation of depressions, mounds, root-disturbance</td>
</tr>
<tr>
<td>Graviturbation</td>
<td>Gravity</td>
<td>Soil movement downslope</td>
</tr>
<tr>
<td>Cryoturbation</td>
<td>Freeze-thaw processes</td>
<td>Can prevent soil-profile formation, upheaving</td>
</tr>
<tr>
<td>Argilliturbation</td>
<td>Expanding, contracting clays</td>
<td>Soil cracking, movement of artifacts upward</td>
</tr>
<tr>
<td>Aeroturbation</td>
<td>Soil gas and wind</td>
<td>Lowering of materials, blurring of site context</td>
</tr>
<tr>
<td>Aquaturbation</td>
<td>Artesian action</td>
<td>Soil mixing, formation of soil structures</td>
</tr>
</tbody>
</table>
Figure 1: Map of the Southern Levant, showing Khirbat Nuqayb al-Asaymir.
Figure 2: SfM-produced 5cm resolution DEM of Khirbat Nuqayb al-Asaymir
Figure 3: SfM-produced 2cm resolution Orthophoto of Khirbat Nuqayb al-Asaymir
Figure 4: Map showing digitized structures and slag mounds at KNA.
Figure 5: Simulated Secondary deposition at KNA from extant structures and slag mounds. This includes a 5m radius around these areas without considering areas directly uphill.
Figure 6: Soil Loss per Hectare per Year at Khirbat Nuqayb al-Asaymir calculated with the RUSLE equation.
Figure 7: Hydrological Sinks at KNA. Each of the red polygons represents a small sink, or a depression in which water flow would terminate. These sinks were removed with a smoothing technique.
Figure 8: Map showing simulated deposition and erosion areas. Green polygons represent areas in which artifacts are simulated to have eroded into.
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