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Understanding the Role of Production and Craft Specialization in Ancient
Socio-Economic Systems: Toward the Integration of Spatial analysis, 3D
Modeling and Virtual Reality in Archaeology

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

in

Anthropology

by

Kyle Andrew Knabb

Committee in charge:

>   Professor Thomas E. Levy, Chair
>   Professor Guillermo Algaze
>   Professor Paul S. Godlstein

2008

The Thesis of Kyle Andrew Knabb is approved and it is acceptable in
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Chair

University of California, San Diego

2008

Dedication

For my Dad, Mom, Brother and Tammy

For Jesse, my Bunny

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ABSTRACT OF THE THESIS

Understanding the Role of Production and Craft Specialization in Ancient
Socio-Economic Systems: Toward the Integration of Spatial analysis, 3D
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by

Kyle Andrew Knabb

Master of Arts in Anthropology

University of California, San Diego, 2008

Professor Thomas E. Levy, Chair

Over the past several decades, technology has proven to be a key

variable for measuring social change in the archaeological record. This

thesis examines some of the models anthropologists use to parse out the

organization of craft specialization in an effort link the dynamics of craft

production with human behavior. After exploring some useful approaches to

this problem, such as the *chaîne opératoire* (Leroi-Gourhan 1993) and

'behavior chains' (Schiffer 1976), a case study in craft specialization is presented for the Iron Age (ca. 1200 – 900 BCE) metal production site of Khirbat en-Nahas in southern Jordan. To identify the *chaîne opératoire* a series of traditional and innovative methods of spatial analysis will be carried out.

1) Introduction

This paper is an anthropological archaeological investigation of dynamic socio-economic systems. I investigate some of the anthropological frameworks commonly used in analyzing the role of production and craft specialization in ancient socio-economies. The craft production models proposed by van der Leeuw (1977) and Costin (1991, 2001) are valuable tools for characterizing the organization of craft production and specialization as lens for examining social change. This thesis examines how anthropological archaeology can use these models to link the dynamics of craft production with human behavior.

Behavior chains (Schiffer 1976) and *chaînes opératoires* (Leroi-Gourhan 1993; Dobres 1999, 2000) are powerful tools for explaining the organization of production, for finding material correlates in the archaeological record and the behavior related to them. These are two similar approaches: the former developed out of the scientific foundation of the New Archaeology of American academia while the latter was initially influenced by French structuralism and later peppered with practice theory, habitus, and agency theory.

Spatial analyses of artifact distributions can pinpoint patterns in the deposition of metallurgical tools, installations and waste. By using these analyses I aim to characterize the *chaîne opératoire* of metal production at Khirbat en-Nahas and measure fluctuations in the industrial scale mining and metal production processes. Additionally, I have generated a 3D model of the site and its major structures. With the help of faculty and use of the facilities at the California Institute of Telecommunications and Information

Technology (CALIT2) at UCSD I have been able to render these models in immersive

virtual reality, a tool that literally puts the researcher inside the site and displays life-size

representations of the researchers interpretations. This is a cutting-edge tool for testing

and evaluating the interpretation of archaeological data.

2) Craft Specialization as a Lens for Examining Social Change

Changes in the organization of craft production systems provide a valuable lens for detecting fluctuations in the structure of ancient cultures. Craft production and crafted goods intersect with all cultural domains: economic, social, political and ritual, because everything made and used by craft specialists and their consumers is the result of crafting and thus through these products we can see the formation and expression of individual, group and cultural identity (Costin 1998:3). Studies of craft production enable us to make rich inferences about a number of important issues, such as technology, material culture, ecology, economic organization, political relationships, political economy, and social reproduction. Generally, archaeologists have examined the link between sociopolitical organization and craft production in one of three ways (Costin 2001:273). The first is the investigation of the role of specialization in the formation and maintenance of hierarchical societies. Whether it is viewed as a cause or a marker of social complexity craft specialization informs us on key issues of labor specialization and intensification and processes in social evolution. Craft specialists have an important role in creating symbols of power and legitimacy pertinent to the maintenance of elite authority. A second perspective examines the social and political implications of the organization of production systems for social structure and process. Craft production is nearly always connected with some form of social relationships created by obtaining raw materials and the process of distributing objects from maker to consumer. The relationship can be among equals or may structure a relationship of inequality. Thus, craft production is a social activity in that participation in craft production influences

participation in society and access to goods and services, creates personal relationships and reflects inequalities in status and power. The third way that craft production has been linked to sociopolitical structure is through the study of the function and social meaning of craft items. Craft production and craft specialists infuse objects with meaning; that is, objects are imbued with value, power and meaning through productive processes and by the artisans who produce them. Craft objects are ideology manifested in physical form; construct social relationships, differentiate status, affiliation and power; and legitimize authority. There is great explanatory power in studying the organization of craft production and specialization. A number of scholars have developed anthropological models for doing just this; a selection of these models is outlined below.

The first is a model of the organization of production of pottery making posited by van der Leeuw (1977). His results are largely based on multiple sources of ethnographic data from different parts of the world. Based on these data, van der Leeuw argues that craft specialization comprises a set of relations between the crafter, the raw materials, the crafters knowledge and his or her customers, as seen from an economic perspective rather than a technological one (van der Leeuw 1977:72). The system of production is divided into six categories that focus on differences in the scale and intensity of production (Table 1). These categories are based on a number of factors including the technological knowledge of the potter, the number of people involved in the production system, the intended use of the crafted object, the type and amount of raw materials required and the distance required to gather them. This model also emphasizes the importance of understanding the relationship between the natural environment and the crafters. As van der Leeuw notes, "The nature of the raw materials required is co-

determined by the nature of the potting technique he uses to make his pottery: the more

sophisticated his technique, the larger usually his output (unless he devotes the gain in

time to embellishment), but the more selective the requirements for raw materials," (van

der Leeuw 1977:71). One might expect there to be a concentration in production centers

when selectivity is high and raw materials are less readily available. This may mean that

the number of potters is small relative to the total population, and that they are full-time

producers, whereas if the techniques employed in production are relatively simple there

may be a higher tolerance for variation in the types of raw materials. As a result, raw

materials are more readily available and the skill and knowledge of crafting are easier to

learn. In this case one might assume local production based on need, and therefore part-

time production with low output (van der Leeuw 1977:71-72).

Costin (1991), drawing from Earle's (1981) distinction between independent and

attached specialists and Sinopoli's (1988) categories of independent, centralized and

administered specialists, has suggested four parameters that characterize the organization

of production (Table 2): the degree of elite sponsorship and control, the relative regional

concentration of production centers, the scale of the production units, and the intensity of

production, or the degree to which production is carried out on a part-time or full-time

basis (Costin 1991:8-9). She has also produced an eight-part typology for the

organization of specialist production (Table 3) based on social, economic, political and

environmental variables that affect the above parameter values (Costin 1991:8-9).

The context of production describes the nature and control over production and

distribution. Attached production is sponsored and managed by elite or governmental

officials or institutions, while independent specialists produce for a general market and

are governed by general principles of supply and demand. Attached and independent specialists generally produce different types of goods. For example, crafts produced by independent specialists tend to be utilitarian in nature; obtained and used by most households. These types of crafts include food preparation and cooking tools, serving vessels, clothing, and utilitarian tools. These objects are used on a daily (or nearly daily) basis and have no restrictions placed on their distribution. By making goods for those who want them, independent specialists promote and broaden consumption. In this type of production system both producer and consumer will benefit from minimizing production and transaction costs (Costin 1991:11). Attached specialists produce goods that are important within the context of political economy and the status, power, and structure of control of the society, e.g. luxury and wealth items, weaponry, and wealth-generating goods. The distribution of these goods is limited to a small minority of the population, most likely the group of elite or governmental officials sponsoring the production (Costin 1991:11-12). Independent and attached specialization evolves under different conditions (Costin 2001:297). The development of independent specialization is the primary result of economic conditions, whereas attached specialization most likely develops as a result of social and political factors. Attached specialization is an important indicator of an elite class and social inequality, and is a means for elites and governments to supply themselves with high-value, exotic, luxury items to finance their activities, and to control the ideology and technology of power (Costin 1991:12-13).

Concentration describes the geographic distribution and organization of production specialists across the landscape, their relationship to each other and their consumers (Costin 2001:295). At one end of the spectrum specialists are evenly

distributed throughout the population and each community will be served by specialists, depending on the size of the community and the demand for crafted items. At the other end of the spectrum craft specialists are unevenly distributed across the region in nucleated workshops in a small number of communities in the region. The aggregation of specialists means that the products they produce must be exchanged on a regional or interregional basis (Costin 1991:13). A variety of factors affect the distribution of production centers. These may include social and environmental factors such as environmental diversity, territoriality, the location of raw materials, transportation costs associated with distributing products, the location of marketplaces, and informal cooperation among specialists (sharing of tools, facilities and laborers). For example, the degree of nucleation among attached specialists varies with the need to control raw materials, technology, final products and distribution. Attached specialists are also nucleated because they will produce near their patrons, who need to control and monitor the acquisition of raw materials and finished goods being produced by artisans. Thus, having craft specialists centrally located and in direct association with their patrons is an effective means to manage the input and output of raw materials and crafted items (Costin 1991:14-15).

Scale relates to the composition of the production unit (Costin 1991:15-16). The size of the production unit reflects the number of people involved in the crafting process. Principles of recruitment reflect the way in which craftspeople are brought into the system. This can take the form of, at one extreme, small kin-based production units or, at the other extreme, large labor forces and factories where recruitment depends on skill and availability. Among independent specialists the primary factor determining scale is

efficiency, which is a function of the technology used and the level of workshop output. Attached specialists, on the other hand, vary in scale depending on the need for supervision and the required output. The workshops of attached specialists tend to be larger than those of independent specialists, in part because it is easier to supervise a large work group confined to a single workshop, and control for quality, theft and unnecessary waste, or inefficiency, than many smaller workshops scattered in several locations.

Intensity is the amount of time producers spend on their craft (Costin 1991:17-18). This can be part-time or full-time production. Three economic factors influence the intensity of production among independent specialists: efficiency, risk and scheduling. Full-time production might be more efficient if it can be routinized, such as mass production. Technologically expensive industries, that is, processes of production in which the capital investment in technology are high, will require more full-time specialization to cover overhead. Producers with more skill and knowledge also make this process more efficient. Risk determines the intensity of production among independent specialists. Independent specialists are risk minimizers who combine economic strategies to remain generalized. For example, independent specialists might combine craft production with agricultural production to minimize the risks inherent in relying on markets for subsistence. Scheduling is the third factor that affects production intensity among independent specialists. Independent specialists need to maintain a balance between part-time craft production and other necessities of life, such as agricultural production. Other factors that influence scheduling could be pressure to expand craft production to supplement household income or an increase in agricultural

productivity that frees up time to focus on craft production. There is a greater tendency for attached specialists to work full-time and independent specialists to work part-time. This is, in part, because attached specialists make their living from revenues generated by their patrons and are not as at risk to the ebb and flow of food market supplies. Since the production of many of the items crafted by specialists requires a great deal of skill, it is more efficient to employ a small number of skilled, full-time laborers that it is to train and supervise many part time producers. Lastly, patrons might employ artisans full-time in order to monopolize their services and prevent others from undercutting their resources and power.

Craft production is always linked to distribution and use, and these actions create both social identities of those involved in the process, and define social relationships among them. Craft production is a socially integrating mechanism; it creates social networks at a number of scales, from supra-household to intra-regional (Costin 1998:10). Costin asserts that the interplay between the various components of production systems must be addressed in addition to describing them (Costin 2001:277).

In addition to archaeological models of craft production, it is also possible to conduct ethnoarchaeological and ethnographic research to see if modern human behavior can be linked to past human behavior (David and Kramer 2001). This approach has been successfully applied by Levy and Levy (2008) to gain a better understanding of how lost-wax method was used by Chalcolithic metallurgists and to construct a *chaîne opératoire* of metal production in the Chalcolithic period of the southern Levant.

3) Technological Approaches to the Investigation of Social Change

The anthropological study of technology is, in one respect, a systematic framework for studying the material correlates of ancient technological processes, for explaining the organization of production and interpreting the behavior related to the production that they reflect. It is an analytic method that employs techniques such as use-wear analysis, seriation studies, GIS, and so forth, is particularly useful for identifying and describing in empirical detail the physical sequences of technical stages through which artifacts were manufactured, used and repaired (Dobres 2000:165; Schiffer 1992). But the study of material culture and technology should not be limited to describing the *chaîne opératoire* of ancient production systems. This is, of course, an incredibly powerful descriptive tool for making empirical observations, but it has also been demonstrated that the study of *chaînes opératoires,* technological processes and agency in technological systems can inform us of social and symbolic processes and social agency in ancient material remains (Dobres 2000, 2001; Dobres and Hoffman 1994; Schiffer 1992, 2001b, 2005).

Human behavior is inferred from the material remains left behind by ancient people (Schiffer 1992:3). Activity is a basic component of human behavior - a patterned interaction between humans and material elements, such as technology. As such, activities leave behind artifacts for us to study. These artifacts are not of much use in-and-of-themselves but, as Schiffer argues, "Activities – the empirical manifestation of a society's organization – bind the behavioral and material, the social and biological, and the ideological and technological," (Schiffer 1992:4). Thus, by focusing our attention on

activities we begin to recognize the inseparability of human behavior and places and things.

Archaeologists study changes in human behavior, across time and space, through the study of artifact variability (Schiffer 1992:7). Technological activities are assembled at various scales of organization, temporality, and scale (Schiffer 2001a:2). Thus, an understanding of how and why artifacts vary across time, space and within different kinds of social organizations, it is important to be able to characterize, describe and explain artifact variability. There are a number of ways that we observe variability amongst artifacts: empirical observations about physical qualities, spatial relationships between activity areas, relative frequency, relationships to other co-occurring artifacts, life histories or cycles (i.e. the process of procurement, manufacture, use, maintenance, reuse, and eventually deposition), function and style. As individuals or social groups go through stages of social development their activities change, as do, the types of artifacts they leave behind (Schiffer 1992:7-12). Understanding how and why an artifact was made and why it ended up the way it did, for example Skibo and Schiffer's (2001) theory of and for design, not only relates people and artifacts, but is a framework for understanding behavioral change through artifact variability and change.

Assumptions about knowledge in technology underlie explanations of technological change (Schiffer 1992:45), so uninformed assumptions can lead to poorly supported conclusions. Technological knowledge, according to Schiffer (1992:46-48), has three components: recipes for action, teaching frameworks, and technoscience. Recipes for action are the rules that determining the process of turning raw materials into finished products and govern artifact use. This appears to be markedly similar to his

behavioral chain approach (Schiffer 1976) and the *chaîne opératoire* approach put fourth by a handful of scholars (Dobres 1999, 2000; Dobres and Hoffman 1994). A teaching framework describes how knowledge and skill are past on from artisan to student, or from generation to generation. Technosciences are the principles that underlie a technologies operation, and understanding these principles are crucial for explaining technological variability and change.

Sources of technological change often come from the technological, social, and ideological functions that an artifact performs in society (Schiffer 1992:49). As a society's activities change the functions that artifacts perform in society will respond to meet those changes. Another source of change is feedback from the context of repeated use or experimenting. A third source of change, which is especially important in the context of craft specialists, be they attached or independent, is producer pressure: the drive to constantly make better, to innovate, invent and beat out the competition (Schiffer 1992:49-50, 2005).

Processes of technological change result from a sequence of behaviors that result from specific technical choices (Schiffer 1992:52). Technological choices affect the formal properties, or attributes of artifacts, which in turn affect the performance characteristics of artifacts. Much has been written on the process of choice, as well as its relation to social agency (Dobres and Hoffman 1994; Dobres 2000, 2001, Keller 2001, Schiffer 1992, 2005). While this growing body of literature on social agency offers many new ways to examine technological change, it is beyond the scope of this paper to do so.

Leroi-Gourhan's (1993) introduction of the *chaîne opératoire* into archaeological research was an important step toward an interest in the 'life histories' of artifacts.

Technologies are acts of social and material transformation and enable the expression and mediation of social relations and world-views. Dobres (1999:128) views the *chaîne opératoire* as a way to infuse the archaeological study of technology with a more 'human face'. *Chaîne opératoire* is a powerful analytic research methodology that provides detailed and quantifiable data on artifact 'life histories', on sequential technical operations of the acquisition and transformation of raw materials, by-products, the relationship between design, raw material and final product, and problem solving aspects of artifact production, use, maintenance, and repair. This approach to doing research allows us to explore the "social underpinnings" of artifact typologies, functions, and styles (Dobres 2000:167-168). However, analyses employing the *chaîne opératoire* approach always start with empirical data before moving on to more intangible aspects of society.

4) Case Study: Khirbat en-Nahas - An Iron Age Copper Factory in Southern Jordan

Khirbat en-Nahas is situated in the region of Edom in southern Jordan, bounded roughly by Wadi al-Hasa in the north to the Wadi Hisma and Jabal Ram in the south, the Wadi Arabah on the west and the Transjordanian desert plateau to the east (Bartlett 1992a; Bartlett 1992b; Glueck 1940). Physiographically, Edom has two important key attributes: it holds one of the richest copper ore deposits in the southern Levant (Hauptmann 2000, 2007) and there is great geographical and environmental diversity between the 'lowlands' and highlands'. For example, the highlands are characterized by elevations of over 1500 masl, a semi-arid landscape and, in some areas, Mediterranean rainfall zones with over 600 mm of average annual rainfall (Centre 2001). Conversely, the lowlands of Edom have elevations reaching below -80 masl and are typical of a hyper-arid desert environment with less than 70 mm of average annual rainfall. Thus, rain-fed agriculture has been possible in the highlands while limited agriculture, made possible by irrigation and making use of local springs, has been practiced in the lowlands. Furthermore, this difference has had a profound effect on the need for pastoralism, which has characterized human settlement in the area since the Early Bronze Age (*c*. 3600 – 2000 BCE) (Levy *et al.* 2002). Therefore, it is essential that we take into account these geographical and environmental dichotomies if we are to fully understand human settlement and the history of Edom.

Prior to the end of the 1990s, most major excavations in tool place in the Edomite highlands (Bennett 1966, 1977; Bennett and Bienkowski 1995; Bienkowski 1990; Bienkowski and Adams 1999; Bienkowski and Bennett 2003). The lack of systematic

archaeological investigation on the lowlands resulted in a misrepresentation of Iron Age

human settlement in Edom and a poor understanding of the role that copper production

played in the social evolution of Iron Age society (however, *cf.* Levy and Najjar 2007).

Nevertheless, the work of Levy and others (Hauptmann and Weisgerber 1992;

Hauptmann 2000; Levy *et al.* 2003, 2004, 2005b, 2007; Levy and Najjar 2006a, 2007) in

the Faynan district of the Edom lowlands have begun to fill the gap in Iron Age research

due to what Levy *et al.* (2005b:131) refer to as the 'highland bias'.

During the Early Bronze Age (*c*. 3600 – 2000 BCE) the Faynan district was a

center of copper production that lasted until approximately 1950 BCE, after which

Cyprus was the primary source of copper through the Middle and Late Bronze Ages (*c*.

2000 – 1200 BCE) (Levy *et al.* 2002). At the end of the Late Bronze Age there was a

collapse and breakdown of many complex societies in the Mediterranean basin, which

may have disrupted the production, distribution and long distance exchange of Cypriot

metals (Muhly *et al.* 1982) and promoted a renewed interest in the southern Levantine

copper ore deposits amongst local polities (Knauf and Lenzen 1987).

Based on the excavations by Bennett (1966) at Umm el Biyara in the Edomite

highlands it was assumed that the formation of the Edomite kingdom occurred in the 8th

through 6th centuries BCE and that the rise of the Edomite state was linked to Assyrian

core dominance (Bienkowski 1990). This view developed in part because of the

'highland bias' – that is, limited excavations in the region confined to the highland

plateau. Additional problems stem from chronological issues – the pottery sequence

developed from excavations on the highland plateau is a 'floating chronology' anchored

to the 7th and 6th centuries BCE by a single clay bulla found at Umm el-Biyara

(Bienkowski 1990). This pottery sequence is not tied to a stratified archaeological sequence, a series of radiocarbon dates or a sequence of datable epigraphic artifacts (Levy *et al.* 2004).

Nelson Glueck's (1939, 1940) surveys were the first systematic investigation of the network of Iron Age metal production sites in Edom and recognized the central importance of Khirbat en-Nahas. Other scholars had visited the site since the beginning of the 20th century, but only in a cursory manner (for summary of other early explorations see Levy *et al.* 2004:867-868, 2005b:134). Glueck (1940:60-61) believed that the primary periods of copper production were during and after the reign of King Solomon *ca.* Iron Age II (10th century BCE). Later scholars ignored this date and the presence of the fortress in considering the history of Edom. MacDonald's Southern Ghors and Northeast 'Arabah archaeological survey (SGNAS) identified Khirbat en-Nahas as an Iron Age Site and collected ceramics that dated to the Iron Age I and II period (MacDonald 1992:73-77, 209). In the early 1990s a team of researchers from the German Mining Museum conducted archaeometallurgical investigations in the Faynan district (Hauptmann 2000). They conducted a handful of cursory surveys and a excavated a number of slag mounds at Khirbat en-Nahas to study slag and other debris in an effort to reconstruct the smelting process and to analyze the chemical composition of copper from Faynan for further provenance studies. In 2002 and 2006 the Edom Lowlands Regional Archaeology Project carried out large-scale excavations at specific areas within the site (Levy *et al* 2004, 2007, N.D.). With the aid of high precision radiocarbon dating and Bayesian statistical modeling it is clear that there were two major phases of production at Khirbat en-Nahas in the 12-11th centuries BCE and 10-9th

centuries BCE (Higham *et al.* 2005; Levy *et al.* 2005b; Levy and Najjar 2006b). These

dates are further bolstered by architectural styles and imports (Levy *et al.* 2005b:158),

and bring the Iron Age archaeology of Edom back to Glueck's (1940) original assertions.

These new data show that complex societies existed in Edom that were heavily involved

in the extraction of copper ore and production of copper metal long before the influence

of the Assyrian empire from the 8-6th centuries BCE. They also revealed that future

research needs to reexamine local processes of social evolution and take on historical

issues, perhaps by taking into account biblical records. Edom is mentioned no less than

99 times in the Hebrew Bible (Levy *et al*. 2005b), and Levy *et al.* argue that this fact

alone should justify a reexamination of historical issues in relation to the recent

excavations that took place in the Edom lowlands. However, this study does not attempt

to solve historical problems, but instead uses anthropological archaeological approaches

to craft production to document and describe the *chaîne opératoire* as well as form an

index of social complexity, with the hope that future research projects can be compared

and contrasted with the data presented here.

Khirbat en-Nahas was a huge (ca. 10 hectares) copper-smelting center in the

southern Levant during the Iron Age. Its surface is spotted with dozens of black slag

heaps with an estimated tonnage of 50,000 to 60,000 tons (Hauptmann 2007:127). In

light of new excavations and a deep section of one of the slag mounds this estimate

should probably be revised. Nevertheless, the sheer amount of slag and debris left behind

by the Edomite copper producers is evidence of a large-scale, intensive and specialized

metal industry.

The copper mines that supplied Khirbat en-Nahas were within the immediate surroundings of the site, probably no more than a few kilometers away. These were no doubt exploited to a high degree during the Iron Age. Based on the surveys by Levy *et al.* in 2002 (Levy *et al.* 2003) and myself in 2007 (Unpublished) of the Wadi Jariya, 47 Iron Age copper mines were recorded in this wadi alone. This figure nearly quadruples the number of mines recorded in the prior exploitation of Wadi Jariya during the Early Bronze Age. A number of other sites related to mining and metallurgy were recorded during the course of these surveys (Figure 1). These data suggest an explosion of metallurgical production during the Iron Age.

Levy *et al.* carried out excavations in at Khirbat en-Nahas in 2002 and 2006. Their team recorded over 100 building complexes and opened up six excavation areas: Area A – the fortress gatehouse, Area F – a building and part of the fortification wall inside the fortress, Area T – a monumental four room tower-building with dimensions of approximately 11 x 10 m, Area R – an even larger monumental building with a large courtyard in the center of the site, Area M – a slag mound that revealed industrial scale smelting activity down to approximately six meters, and Area S – a four room building related to metal production (Levy *et al.* 2004, Levy and Najjar 2006b). The metallurgical assemblage is characterized by debris typical of Iron Age copper processing (Hauptmann 2007; Levy *et al. 2004*; Lupu and Rothenberg 1970; Rothenberg 1990): Tap and furnace slag from smelting copper ore, crushed slag deposits that imply the mechanical reprocessing of slag to extract metal prills, ceramic furnace fragments and tuyere pipes, copper slag and partially processed copper, hammerstones, dimpled hammerstones, pestles, mortars, anvils and groundstone basin for crushing slag, and grinding and

polishing stones for finishing final products. The co-occurrence of these artifacts

suggests that all aspects of the smelting process were carried out at Khirbat en-Nahas.

While the excavations at Khirbat en-Nahas have generated a large corpus of data,

much is still a mystery. For example, little to no direct evidence for the systematic

casting of ingots or copper objects has been found. In Area A one fragment of a copper

pin was discovered (Levy *et al.* 2004) but little else remains to inform us on final

production. The nature of the distribution of copper is uncertain as well. With little

evidence regarding the types of final products it is difficult to say who got it and how

much. Were prestige objects the foci of production? Or copper ingots to be traded with

other local polities? The Wadi Fidan 40 cemetery may lend some circumstantial

evidence regarding these questions. The remains of hundreds of a nomadic Iron Age

population were excavated in 2004. These excavations yielded a few copper earrings and

bracelets in a small number of cyst graves. Even if these copper ornaments were

manufactured at Khirbat en-Nahas we still cannot account for the huge amounts of

copper that were produced at the site. Contacts with foreign polities is evidenced by the

presence of Medianite pottery (though it has been shown that this was locally

manufactured, not imported) and two scarabs from the 12th/10th centuries BCE and point

to possible contacts with Egypt (Hauptmann 2007:303). Nevertheless, the current data

are quite insufficient to make any strong claims about the Edomites' trading partners.

5) Spatial Analysis in Archaeology

The *chaîne opératoire*, as an analytical method, employs such techniques as GIS and exploratory data analysis (Dobres 2001:166). Because *chaînes opératoires* describe sequential technical operations and relationships between objects and objects and objects and people, spatial analysis – which identifies, describes and quantifies spatial relatedness – is an especially fitting technique for parsing out these technological relationships.

Systematic methods for studying the spatial distribution of archaeological data began to develop in the 1970s. The distribution map was then, and still is, an important analytical tool for interpreting archaeological finds. Some of the most important aspects of archaeological investigation are plotted on distribution maps, such as trade, diffusion and culture (Hodder and Orton 1976:1). The method of research prior to the use of spatial statistics was largely a visual assessment of distribution maps in which patterns and structure were "eye-balled" by the archaeologist. This map-based approach was often insufficient because it was inherently subjective and uncritical and unable to handle large datasets collected by archaeologists (Hodder and Orton 1976:2). During the 1970s archaeology was part of an interdisciplinary movement drawn toward the application of quantitative methods for data recording and analysis. The use of mathematics and statistics to represent patterns in map data are important because "it has been shown that the ability of the map-user to discriminate and evaluate the information contained in the map is not free from subjective elements and that the more the information contained in a map the more ambiguity and uncertainty there is likely to be as regards the interpretation

put upon it," (Harvey 1969:377). Furthermore, archaeologists now recognize that there is important information to gain from the spatial relationship between objects as well is in the objects themselves and an objective method to describe the characteristics of these relationships is necessary (Clarke 1977:5). The value of employing spatial analyses lies in the ability to process large data sets with more objectivity than traditional methods of "eye-balling."

Spatial analysis provides us with a way of describing some of the general patterns in point distributions. "These descriptions are constructed with some reference to some hypothesized mathematical process. The question thus arises whether the hypothesized *mathematical* process can be interpreted in terms of some *geographical* [or archaeological] process," (Harvey 1969: 383). The mathematical process involved in spatial analysis is often the Poisson distribution, or random distribution. An approach often used to model the spatial pattern of archaeological data is a random or stochastic one. Its use for examining spatial patterns is explained by Hodder and Orton (1976:9) as follows:

> We expect non-random spatial patterns because we know that individual behavior is not random but is constrained and determined by, for example, kinship factors in the exchange of goods and physical factors in the location of sites. However, it will be found that non-random behavior is often not apparent in the spatial patterns. Many of the observed archaeological patterns have a form that is similar to patterns produced by a random process. If the form of the pattern is similar to the end result of a random process, this does not necessarily mean that the process that produced the observed pattern was random. It is possible, however, that, given a 'satellite view', aggregate human behavior is often best simulated by a random process, or by very simple models incorporating a strong random element.

Thus in the analysis of spatial data we often treat human behavior as if it was the result of random processes. This theoretical random process can be used as a norm against which a particular pattern may be measured (Harvey 1969:381). A number of the models used in spatial analysis employ this principle.

Many of the methods we use in spatial analyses originated in other disciplines, such as geography and ecology. In all these fields the investigation of spatial patterns is based on the assumption of randomness. The spatial pattern of objects is determined by the departure from a random distribution (Clark and Evans 1954:446). Three types of distributions are shown in Figure 2. Most maps will exhibit patterns that fall somewhere within these three extremes.

Techniques for identifying non-random patterns are commonly used in archaeology. For example, the distribution of artifacts across a site may be used to distinguish activity centers. Though it is possible to distinguish non-random patterns of artifacts it is not always clear that the identification of clustering actually aids the interpretation of an archaeological site. Spatial analysis involves firstly testing for spatial patterning and then describing the cultural processes that resulted in those patterns. Formal methods of spatial analysis can only be applied to the first of these and the relationship between the two is often complex because patterns of clustering could be the result of many cultural or natural factors, such as localization of activities or discard, the cleansing and reorganization of a site, or wind and water erosion. (Hodder and Orton 1976:31-32, 239-240). The spatial pattern alone cannot wholly explain the process behind the end result.

A major drawback with formal quantitative methods is their inability to incorporate contextual, or symbolic information into the analysis. By this I mean the relationship between a point pattern and a variable or variables that describe the environment of the pattern. These are often non-numeric variables, for example soil type or vegetation type. It is important to acknowledge that a quantitative approach can only incorporate a small sub-set of the total amount of archaeological data. If we accept that the spatial structure of archaeological data reflects some cultural or behavioral process, then to use only a sub-set of that data could result in an inaccurate interpretation (Hodder and Orton 1976:224, Lock and Harris 1992:84-85). The importance of contextual information can be incorporated into quantitative methods by applying a test of association (Hodder and Orton 1976:224). By doing so it is possible to comment on the relationship between a point and some of the qualitative variables that accompany it.

A powerful critique of the quantitative approach to spatial analysis appears in the article by Kintigh and Ammerman (1982). To them, methods of traditional spatial analysis are limited by the fact that they operate in a way that is independent of the context data of the archaeological data. They suggest an alternative approach of "heuristic spatial analysis" that attempts to "combine the intellectual sophistication of intuitive approaches with the information processing capacity and systematic benefits of quantitative treatments," (Kintigh and Ammerman 1982:33). However, the quantitative methods they develop are disappointing because they are only heuristic "in the sense that the methodology is iterative so that new assumptions can be incorporated during each iteration," (Lock and Harris 1992:85). Furthermore, the problem of incorporating contextual information is never resolved and only addressed in a future "area for

development" at the end of the paper. Another criticism of quantitative methods is outlined by Whallon (1984), who asserts that the main problem centers on inconsistencies between the statistical techniques and the archaeological data and the questions asked of the data.

Methods of point pattern analysis can be divided into two categories: quadrat methods and distance methods (e.g. nearest neighbor). The research presented here deals only with distance methods so only those will be discussed (for a summary and explanation of quadrat methods cf. Hodder and Orton 1976). Tests based on distance measures are more sensitive and more appropriate for the analysis of most archaeological data. The basic data consists of the distances from each point to the point nearest to it. The distribution of distances to the 1st. 2nd, 3rd… nearest neighbor is calculated. Actual distance measures to the nearest neighbors are then compared to the random expectation (Harvey 1969:382). A classic development of this test by Clarke and Evans (1954) is useful to the archaeologist, in which a scale was constructed starting at zero (clustered distribution) through one (random distribution) to 2.1491 (regular distribution). Nearest neighbor tests provide a simple objective tool for analyzing spatial patterns.

The objectives of the quantitative approach in archaeology are grounded in formulating hypotheses and then testing them against the data. A set of points is tested to identify the relationships between the points, if any. The result of these tests is usually in the form of a summary statistic often with an associated measure of significance (Lock and Harris 1992:86). Carr (1984) has exposed some of the limitations of these objectives for archaeology. He classifies them according to which of these three questions they might be applied (Carr 1984:134): 1) are the points randomly scattered, 2) what are the

spatial limits of clusters, and 3) do the clusters overlap? It should be noted that many of the quantitative methods used by archaeologists employ a graphical representation of the results to visualize the data. Lock and Harris (1992:87) note the wider interdisciplinary trend toward retaining a strong visual analysis in spatial analysis and an attempt to move away from reductionist approaches of some statistical methods.

Both map-based and quantitative approaches to analyzing spatial data have their own embedded limitations and strengths. Integration of the two approaches was not possible for quite some time because of the inability to integrate the different spatial primitives within the same analytical environment: the computer (Lock and Harris 1992:87). This is made possible today by the use of Geographic Information Systems (GIS). Clarke (1972) recognized the strengths of an integrated approach in his model of the Iron Age settlement system at Glastonbury. This revolutionary work embodies some of the major strengths of map-based methods and reflects Clarke's strong quantitative approach. His approach enabled the combination of various data types such as artifacts, structures, features and environmental variables, in an effort to create as complete a picture as possible. The data were subjected to a "developing lattice" of analyses that combined vertical spatial relationships, horizontal spatial relationships, structural relationships and artifact relationships. His intent was to incorporate as much relevant data into the analysis so that a broader range of questions could be asked, improving the final interpretations. The ability to integrate all types of spatial data is what makes GIS such a flexible and powerful tool.

Geographic Information Systems are a relatively new technology but their importance as a storage and analytical tool has penetrated into a variety of disciplines.

Though GIS offer a wide range of practical applications they share a set of common features. GIS are computer-based systems designed to input, store, manipulate, analyze and present information about geographic space. They are like a "spatial toolbox" that comprises a set of several different software technologies. The power of GIS lies in their ability to store locational and attribute data for spatial objects and the topographical relationships between them (Lock and Harris 1992:90).

Marble (1990) notes that GIS comprise four major subsystems: 1) the data entry subsystem handles the tasks involved in translating raw or partially processed spatial data into an input stream of known and controlled characteristics, 2) the spatial database is responsible for storing spatial, topological and attribute information, 3) the manipulation and analysis subsystem transforms and carries out spatial analyses and modeling functions, and 4) the visualization and reporting subsystem returns the results of queries and analyses in the form of maps, graphics or texts. Wheatley and Gillings (2002:11) add another subsystem, the user interface. The user interface is an important part of modern GIS because it is through this that the user interacts with the GIS and receives feedback on the progress of commands. Figure 3 shows the organization of these subsystems together with the flow of data and the flow of control.

Data entry tools take the information collected by the archaeologist and place them in the GIS. This data commonly comes from digitized records (e.g. scanned maps or paper lists of coordinates) and survey instruments like total stations and GPS units. The spatial database organizes data into layers, each of which represents a different theme. This is similar to a collection of maps, with each map showing some different characteristics of the study area (Wheatley and Gillings 2002:12). The manipulation and

analysis subsystem includes a number of functions for transforming data or performing

analyses. This subsystem is a defining characteristic of GIS. According to Wheatley and

Gillings (2002:13), "data manipulation refers to the ability of a GIS to generate new

layers from existing ones. This leads to a distinction between *primary* layers, such as the

location of roads, rivers or archaeological sites and *secondary* layers, which are derived

from these." Thus, a primary feature of GIS is the ability to select, integrate, and analyze

features from a combination of sources and to construct new composite variables or maps

from the original map layers. The ability to overlay map layers in this way enables areas

of intersection or union between data layers to be examined and to be used as a stepping

point for further analysis. GIS also possess operations that enable the buffering of point,

line or polygon features or creating separate map overlays. A buffer around a particular

feature of interest would generate a digital study area that could be analyzed or

manipulated. The use of this for neighborhood analysis or other spatial statistics along

with buffering of environmental or other contextual variables enables the examination of

hypothesized relationships. GIS offer flexibility of output formats that can take the form

of two- or three-dimensional surface maps, statistical and tabular information. Digital

Terrain Models can be produced from elevation data and natural or cultural attribute data

draped onto the graphical surface to portray the spatial information in the context of

landscape form. Finally, GIS provide a sophisticated modeling environment for

predicting, or interpolating, beyond available data or for displaying the current

interpretation of available data (Lock and Harris 1992:90-91). The ability to visualize the

results of an excavation and impose ones interpretations on the landscape makes GIS a

powerful analytical tool.

6) Hypotheses to be Tested

1. The social context of craft specialization can be characterized as large-scale, attached specialization with a high degree of elite sponsorship.

2. Local sources of copper ore were exploited by the workers at Khirbat en-Nahas, similar to the strategy of the Early Bronze Age copper producers, and in contrast to Chalcolithic strategies of ore exploitation (Levy 2006).

3. Khirbat en-Nahas possessed a monopoly on production in the northeastern region of the Faynan district and maintained control over the nucleated specialists working the mines in Wadi Jariya and producing copper at Khirbat en-Nahas.

4. The production force at Khirbat en-Nahas was relatively large, but the nature of labor recruitment rest on the following distinction:

    a. The social organization of the labor force at Khirbat en-Nahas was primarily composed of nomadic or semi-nomadic pastoralists and, thus, labor recruitment was kin-based.

    b. The social organization of the labor force at Khirbat en-Nahas was composed of sedentary, agropastoralists and, thus, labor recruitment was based more on skill and demand for labor (Costin 1991:15).

5. The economic strategy in practice at Khirbat en-Nahas was a *maximizing* strategy focused on output, not efficiency.

6. The copper producers at Khirbat en-Nahas were full-time specialists, who made their livelihood from revenues obtained from elite sponsors, which allowed them to focus on full-time production.

7) A New Approach to Spatial Analysis on Archaeological Sites: 3D Modeling and Virtual Reality at Khirbat en-Nahas

The integration of Virtual Reality and GIS is exciting for a number of reasons: First, the system database is a traditional GIS; ratcheted up with a third-dimension (this is important for archaeologists because most GIS programs are still centered around map-based representation, and thus have limited functionality when it comes to z-coordinates, or elevation. Elevation is, in many cases, a function of time) that is more suitable for performing analytical functions and manipulating information within the GIS. Second, the Virtual Reality environment is used to augment the cartographic and topographic capabilities of GIS. VRML (Virtual Reality Markup Language) is becoming an 'industry standard', which makes publishing VR models on the web seamless. Thus, scholars who are interested and comfortable in communicating their findings to the public *vis-à-vis* the Internet can do so quite easily. This is not to say that combined Virtual Reality and Geographic Information Systems exist in a perfect state, it is still in a state of infancy. Nonetheless, every advance in this integration will have a profound analytical and hermeneutic impact on the scholarly and public spheres.

Models and the process of modeling are fundamental to interpreting archaeological data. Clarke (1972:2) saw models as idealized representations of observations. Working through models is often the best way to explain and experiment with the meaning of data. In a general sense a model is a simplification, which we can easily understand and manipulate, of some part of reality, which is more difficult to comprehend. Thus, if we can understand the process and end result of a model we can attempt to apply that understanding to the situation in reality we are trying to figure out

(Lock 2003:147). Computer modeling involves the visualization and reconstruction of archaeological data. Three-dimensional modeling and virtual reality are dynamic models in which the user can interact with the modeled environment. In addition to the representation of archaeological remains, the spatial relationships between data are crucial to archaeologists (Losier et al. 2007:272-273). 3D modeling and virtual reality (VR) are tools that have become available to archaeologists in the last decade or so as hardware and software have become less expensive, while at the same time, user-friendlier.

Surface modelers and solid modelers refer to different methods of storing information about three-dimensional objects in the computer (Wood and Chapman 1992:123). Surface modeling is the simplest way of displaying a model on the computer. It consists of objects represented by points and lines to create a wire-frame or mesh model. The only data that needs to be stored in the computer is the x, y, and z coordinates of the vertices and which of these vertices should be connected. Surface models do not produce solid objects, but as the name suggests, models only the surface of the object. A surface model represents objects as one or more polygons consisting of points, lines and surfaces. Joining a series of polygons can create complex surfaces. By increasing the number of polygons and decreasing the size of those polygons one may achieve higher resolution of the surface. A surface can be given texture or color, or have a digital image draped on to it. A surface model can also be rendered to achieve realistic lighting conditions.

Solid modelers create real three-dimensional representations that define enclosed space. This includes the complete physical representation of an object, rather than its

shell (i.e. surface modeling), so that properties such as mass, volume and center of gravity can be calculated. Solid modelers use shapes instead of surfaces, which causes them to require intense computational power. User-friendly solid modelers have not developed to the same extent as surface modelers. As a result of these two factors solid modelers have had limited use in archaeology (Lock 2003:152). Nevertheless, there are a number of projects in which solid modeling techniques have been applied to three-dimensional reconstruction. A discussion of these techniques and examples of solid modeling in archaeology is given by Reilly (1992).

Lock (2003:152-153) describes some of the basic terms of modeling and virtual reality:

Once a model is constructed it needs to be rendered to add visible surfaces based on lighting and shade. Polygon rendering reduces objects to a series of polygons that are smoothed and rendered. This is the most common method of rendering and the least computational power. This method tends to produce a blocky appearance unless high-resolution surfaces are used.

Animation is a sequence of slightly different images shown in rapid succession to suggest movement. An example of this is a walk-through or fly-through of an archaeological site that gives the appearance of one walking or flying through the model. Real-time rendering is computationally expensive but allows the user to go anywhere within the model and the changing views are rendered as necessary. Conversely, pre-rendered animations can be stored as a sequence so that the walk-through is along predetermined routes within the model.

Virtual reality applications can be either immersive or non-immersive depending on the delivery technology and user experience. Non-immersive technology is through a computer monitor or other visual display. The boundaries between non-immersive and immersive simulations are becoming blurred as readily available software enables models to be entered and traveled through using a mouse or keyboard for controlling direction, speed and view. Immersive virtual reality requires high-end computing power to generate complex real-time moving models within the computer into an experience that can seem as real as life for the participant. It is the quality of experience that gives meaning to immersive virtual reality more than most other modeling technologies. The media in which immersive virtual reality is displayed vary. A Head Mounted Display (HMD) replaces the participants' visual field with an equivalently positioned view of the virtual world. Virtual Environment Theaters (VETs) and CAVE Automatic Virtual Environments (CAVEs) are small rooms with a number of projection screens that surround the user to create an immersive environment.

The popularity of computer modeling has increase in a number of ways since the 1980s, mainly due to the constantly improving power of hardware and software, its affordability, and an increasing awareness that the technology has a lot to offer archaeology (Lock 2003:154). Another boost to the application of modeling was the introduction of VRML (Virtual Reality Markup Language). VRML is a language that describes three-dimensional objects and allows the user to move from texts into three-dimensional spaces and then back again. It is a way of visualizing information in three-dimensional space through hypermedia links, allowing objects to be moved and observed from any angle. Collaborations between archaeologists and computer graphic specialists

is still commonplace and the results of these types of collaborations is presented by Forte and Siliotti (1997) in a collection of high-profile archaeological sites that have been reconstructed by computer modeling.

Virtual reality and computer modeling offer two great benefits to archaeologists. First, they allow the researcher to illustrate reconstructed sites. This is especially helpful to the public, who has little or no experience in reading archaeological maps. Modeling assists the researcher in articulating and communicating his or her interpretation of the archaeological data. Second, the model can allow the archaeologist to test new theories, ideas and reconstructions and see the effect of those new interpretations on the archaeological site. It is these strengths that make virtual modeling such a valuable tool, but it is not without its drawbacks.

Computer modeling has received some criticism from the academic community. For some the technology is too successful, too convincing, it is too believable. Many researchers would want to emphasize the uncertainty of knowing the past and the various interpretations used to understand it. Few computer models attempt to represent alternative explanations; most offer a single interpretation. For example, Boland and Johnson (1996) state that the virtual reconstruction of the palace at Dudley Castle is a "best guess" rather than a concrete reconstruction incorporating the vast amounts of data from excavations and the various interpretations surrounding them.

Computer modeling is a powerful medium with which to communicate archaeological data to the public. Nevertheless, any image accompanied by the perceived sense of authority of an expert or scientist is likely to convey a single certain interpretation that is divorced from any background information or the archaeological

debate surrounding the uncertainties inherent within the interpretation. It is important that representations not stand alone, but instead are presented with an explanation of the information they are based upon and other aspects that affect their interpretation (Lock 2003:155).

The merging of GIS with virtual reality is a research area with a great deal of potential. There have been attempts to overcome the two-dimensional limitations of standard GIS, along with the development of three-dimensional GIS software that has a continuous z-axis. Having a continuous z-axis makes it possible to perform spatial analysis based on three-dimensional topology. In archaeology time is an important dimension that is not often represented in GIS software. A continuous z-axis has the potential to allow continuous time rather than treating it as a snapshot of the past (Lock 2003:182). As technology develops the boundaries between software categories are blurring such that GIS, modeling and virtual reality are becoming integrated tools for interpreting and visualizing archaeological sites.

8) Methodologies – Digital Field Recording, Spatial Analyses, 3D Modeling and Visualization

Tracing shifts in the scale and organization of metal production at Khirbat en-Nahas is enabled by a GIS-based recording system (Figure 4). This system as changed over the years and has been described in more detail in previous articles (Levy et al. 2001 and Levy and Smith 2007). Data are recorded in the field digitally and stored in a Geographic Information System. A GIS may be defined as "computer systems whose main purpose is to store, manipulate, analyze and present information about geographic space," (Wheatly and Gillings 2002:9). GIS is not a single entity, though, and is better thought of as a multitude of available software programs. For the purposes of this paper, the primary software technology used in the analysis of the Khirbat en-Nahas artifact assemblage is the proprietary package by Environmental Systems Research Institute (ESRI), ArcView. ArcView has several important features, most notably the map-based interface ArcMap and a database catalog similar to Windows Explorer, ArcCatalog in which the majority of data processing is done.

Field data are recorded using a Total Station in three formats: points, polylines and polygons. A point consists of a single x, y, and z coordinate. A polyline is a series of connected points that form a line. A polygon is a plane figure comprised of at least three points, or vertices. These spatial data are tied to the international UTM (Universal Transversal Mercator) system based on the WGS1984 datum. All artifacts, features and elevation points are recorded using the total station and are stored in the GIS as shapefiles. Once recorded, these data can be easily and quickly accessed for analysis and manipulation.

ArcView offers a suite of analysis tools for analyzing spatial distributions, patterns, and spatial relatedness in ArcToolbox. ArcToolbox computes complex statistical equations such as nearest neighbor, spatial autocorrelation and interpolation from data stored in the GIS. Traditional spatial analyses extend the archaeologists ability to interpret spatial data – they go beyond what the human mind is capable of processing (Wheatley and Gillings 2002:125). For example, when presented with a plot of random points one might have the tendency to suggest a pattern even if one does not exits. Spatial analyses are a form of quantification that summarize spatial data and can be used to identify statistical significance, structure and patterning in archaeological data. As GIS software, handling spatial data is one of ArcView's strengths.

The first step in analyzing spatial data is creating spatial distribution maps of artifacts and other features (Figure 5). These maps are visual tools for conceptualizing spatial patterns. Artifacts displayed as point data can be given symbols that represent different typological categories. The next step is selecting which sets of data to analyze in the attribute table so that statistical analyses may be performed. The results are displayed graphically in a pop-up dialogue box. For example, when performing a nearest neighbor test, the degree of clustering, regularity, or randomness is given according to Clark and Evans (1954) scale from zero to 2.1491. An output of zero represents a perfectly clustered distribution. An output of one represents a perfectly random distribution and an output of 2.1491 represents an ordered or regular distribution. The results are generally somewhere in between these three extremes. An additional statistic is the degree of significance of the clustering that is based on a chi-square test. This gives likelihood of the calculated pattern being the result of chance. This type of spatial

analysis is useful to archaeologists because it can be used to locate centers of specialized

activity. Further interpretations about the process that produced a pattern, be they

random or clustered, may begin after identifying structure in artifact distributions.

In order to perform 3D modeling, I had to choose a software program that was

adequate to our needs and adapted to the spatial and descriptive nature of our data. The

3D modeling program also needed to be able to read files exported from ArcView. Poor

compatibility across programs may distort data or render a file unreadable. The 3D

modeling of site terrain and structures was carried out using an open source 3D modeling

program called Blender. Blender is a sophisticated (and free!) program for modeling,

animating, rendering and shading 3D graphics. The Blender reference system is

composed of three orthogonal axes, x, y and z, that are needed to edit, display and

manage spatial objects. The objects created in Blender are surface models, and thus are

composed of a wire-frame mesh during design. Once a model is complete it can be

viewed in the StarCAVE at the Immersive Virtual Reality laboratory at Calit2. The

StarCAVE (Figure 6) consists of five walls each with three screens. Two digital

projectors generate a stereo image for each screen. To interact with the virtual

environment we use a wireless optical head and hand tracking system that consists of four

cameras and a 3D joystick.

To construct 3D models with Blender I used the following procedure:

Terrain model creation: the first step of the modeling process was creating a valid surface

upon which the reconstructed buildings would sit. My hope was to reflect the actual

contours of the site as accurately as possible. In order to do so I needed to create a

Digital Terrain Model (DTM) that represented variations in elevation by displaying

different shades of grey (Figure 7). The DTM was created by interpolating contours from

elevation points taken in a grid form across the site. The interpolate contours tool can be

found in the Spatial Analyst extension of ArcGIS and does not come with the ArcView

package. Thus, I used the GIS machines available in the UCSD GIS laboratory of Geisel

Library. The resultant DTM was exported to a TIFF format so that it could be imported

into Blender. Additionally it was my goal to drape a satellite image over the 3D surface.

Google Earth offers some of the most high-resolution color satellite photographs of the

research area free of charge. I exported a high quality image of the site (Google Earth

only allows one to export images in JPEG format), imported it into ArcView,

georeferenced the image and projected it to the proper WGS1984 UTM Zone 36N

coordinate system. To ensure that the satellite image was the same size as the 3D surface

model I cropped the satellite image with the Digital Terrain Model in ArcGIS using the

mask tool in the Spatial Analyst extension. The georeferenced, cropped satellite image

was exported to TIFF format so it could be easily imported into Blender.

The Blender user-interface starts with a simple cube. All three-dimensional

objects start from here. To create a "blank slate" for the surface I scaled the cube to

seven units by seven units by one unit (Figure 8). A cube only has six surfaces or

polygons, one for each three-dimensional face. To accurately reflect terrain contours

more polygons were needed. Creating more polygons is a simple process of subdividing

the object until the desired number of polygons is achieved (Figure 9). However, as more

polygons make up the three-dimensional model the more computer power is required. In

my experience a total of six subdivides was enough to reflect surface contours without

slowing the computer.

The next step was to create contours on the three-dimensional surface. To do so the DTM was imported into the Blender Texture Editor. The "noise" button may be used to distort the 3D surface based on the qualities of the texture. Blender essentially assigns a higher height to the vertices corresponding to a brighter color than the ones corresponding to a darker one (Figure 10). The new surface reflects the contours defined by the Digital Terrain Model. To improve the appearance of the 3D surface I used the smooth button and the Smooth Set operation, which give the model a less boxy appearance and make it more life-like.

The final step in creating a three-dimensional terrain model was draping the color satellite photo over the surface. This was a simple process in which I changed the texture in the texture editor from the Digital Terrain Model to the satellite image. When rendered the model displays the image draped over the newly created 3D surface (Figure 11). To view the model in the CAVE it must to be exported to VRML format. However, the standard VRML exporter in Blender does not include image textures when exporting. Among the many free plug-ins available for Blender is an exporter called BS Exporter, which specifically exports Blender documents to VRML with an option to include image textures.

Creating three-dimensional structures: Creating a building like object in Blender is fairly easy, but doing so in a way that preserves the scale of the site is more complicated. The coordinate system of our data is WGS1984 UTM Zone 36 with units expressed in meters. This coordinate system covers much of the southern Levant. This makes the coordinate numbers in the research area very large. Blender has finite room in its model space, so if objects are imported directly from ArcView they will be placed tens

or hundreds of thousands of meters from the origin, where the terrain model happens to be. This also causes the program to run very slow because it cannot handle objects placed so far from the origin. To get around this problem some modifications of the data needed to be done in ArcView, namely downsizing the value of the objects coordinates. To do this a point on the map was arbitrarily selected to become the new origin. However, the original coordinates must be preserved if further analyses are to be carries out in ArcView. By modifying the False Easting and False Northing in the Data Frame Properties dialogue the data can be exported with smaller coordinates but retain their original coordinates in ArcView. The x and y values of the new origin was subtracted from the original values in the False Easting and False Northing properties. This basically shifts our data coordinates to the new origin while maintaining the inherent coordinates of the data.

The next step is exporting GIS data to CAD. GIS data in ArcView is stored as shapefiles, but Blender needs a DXF file. This process is complicated because CAD files have a very particular means of storing attribute data. This is especially important in regards to storing elevation data. Preparing for export to DXF was done as follows: 1) New CAD fields must be added to the shapefiles table. A set of Entity Attributes was added using the Add CAD Fields tool in ArcToolbox. To add elevation data to the new CAD field I used calculate values and set the value for the Elevation attribute equal to the value of the Contour field. The data was then ready to export to DXF and be imported into Blender.

When first imported into Blender the shapes of the structures are essentially flat. To create three-dimensional reconstructions of architecture I used the Extrude tool, which

adds height to the objects. The height of the structures can reflect the actual height of the

walls as observed in the field or a hypothetical reconstruction of what they might have

looked like during antiquity (Figure 12). Once a satisfactory model of the site has been

created it is exported to VRML format and viewed in the CAVE.

9) Results

Based on the spatial analysis of the material assemblage, preliminary experiments with implementing my 3D model in the cave and other sources on mining and metallurgy in the southern Levant discussed above I have developed a preliminary model of the *chaîne opératoire* of metal production during the Iron Age at Khirbat en-Nahas (Figure 3) and some of the archaeological correlates of these activities (Table 4). Craft specialists played an important role in the ancient socio-economic system. The resources required for copper production were available within a few kilometers of Khirbat en-Nahas. Incredible amounts of ore were smelted into various forms of copper, indicating trade relationships with local polities. These results suggest that copper production was an elite sponsored activity.

Future work will continue the process of creating and visualizing sites in the CAVE. The next step will be to go beyond simply visualizing sites and incorporate GIS and spatial analyses into the picture. The ultimate goal of this project is to create an analytical tool that merges virtual reality with Geographic Information Systems.

10) Conclusion

This thesis is an investigation of the role that production and craft specialization systems play in ancient socio-economies. Drawing from anthropological, archaeological and ethnoarchaeological models of craft production and specialization I attempted to parse out the organization of craft production and its underlying parameters. In addition, by using the 'behavior chain' and *chaîne opératoire* approaches to describing production systems, I hope I have identified the relationship between the archaeological record and the behavior and technological processes that it represents. Based on the data collected during the 2002 and 2006 excavations at Khirbat en-Nahas, the following parameters of production may be preliminarily defined:

Parameters of Production

Social context (degree of elite sponsorship)

- Workshops, courtyards and other activity centers are found in association with monumental, elite structures that controlled or maintained copper production. Metalworking most likely occurred in public buildings supervised by an elite presence.

Concentration (how specialists are distributed across the landscape)

- Metalworking and mining occurred very close together
- Khirbat en-Nahas dominated the extraction and production of copper ore and copper objects in the northeastern region of the Faynan district, and probably the rest of Faynan given the scale and intensity of metal production (see below).

Scale (number of individuals in the productive force and principles governing labor recruitment)

- If producers are full-time specialists: a large number of skilled craftspeople are employed and not often replaced or training new artisans. Recruitment is based on need and skill.

- If producers are part-time specialists: a large number of skilled craftspeople are employed but balance craft with pastoralism or mixed agropastoralism. Recruitment is partly based on need and skill, partly based on kinship or tribal affiliations.

Intensity (amount of time producers spend on their craft)

- The large quantities of slag and dramatic increase in mining activity, coupled with the paucity of evidence for agriculture suggest that producers were either full-time specialists or practiced some form of mixed crafting and pastoralism.

Another aim of this project was to evaluate the potential of using spatial analyses, three-dimensional modeling and virtual reality in examining, interpreting, and visualizing archaeological sites. This to, is in a preliminary phase, but seems to be a promising and exciting new technology. There are several advantages of using these techniques. For an archaeologist to be able to visualize the results of excavations, which inherently destroy the context of a site would be a tremendous aid to get a realistic representation of the site through the various stages of excavation. In a way one is able to revisit the site again and again without ever going back to the field. It is possible to investigate each excavation unit or area and the data collected from these units in three-dimensions, instead of the typical two-dimensional representation of artifact data on distribution maps. In this manner one is able to see the topological relationship between artifacts and surrounding features. 3D modeling and virtual reality can be used as a tool to help archaeologists explore the excavation from a new perspective. I aim to use this cutting-edge technology to acquire new information by exploring alternative perspectives and interpretations. By modeling in 3D one can observe more quickly and from a number of fields of view the

relationship between excavation units, artifact distributions, feature locations, and other qualitative information without consulting multiple field records. Blender offers the possibility to render three-dimensional models in image format. These images can be used as visual aids in publications. Blender also offers the possibility to do 3D walk-throughs of a site with Virtual Reality Modeling Language (VRML), which can be put on a web page.

Perhaps the most powerful potential of 3D modeling is the potential to integrate virtual reality with GIS so that spatial analyses can be done in three dimensions. This integration, along with the spatial analysis of the complete Khirbat en-Nahas assemblage and other regional data, the parameters of production I defined above and the *chaîne opératoire* model I developed in this paper, are still a work-in-progress. These models can help us get a clearer picture of the social organization of production and the processes of social evolution that took place in Iron Age Edom.

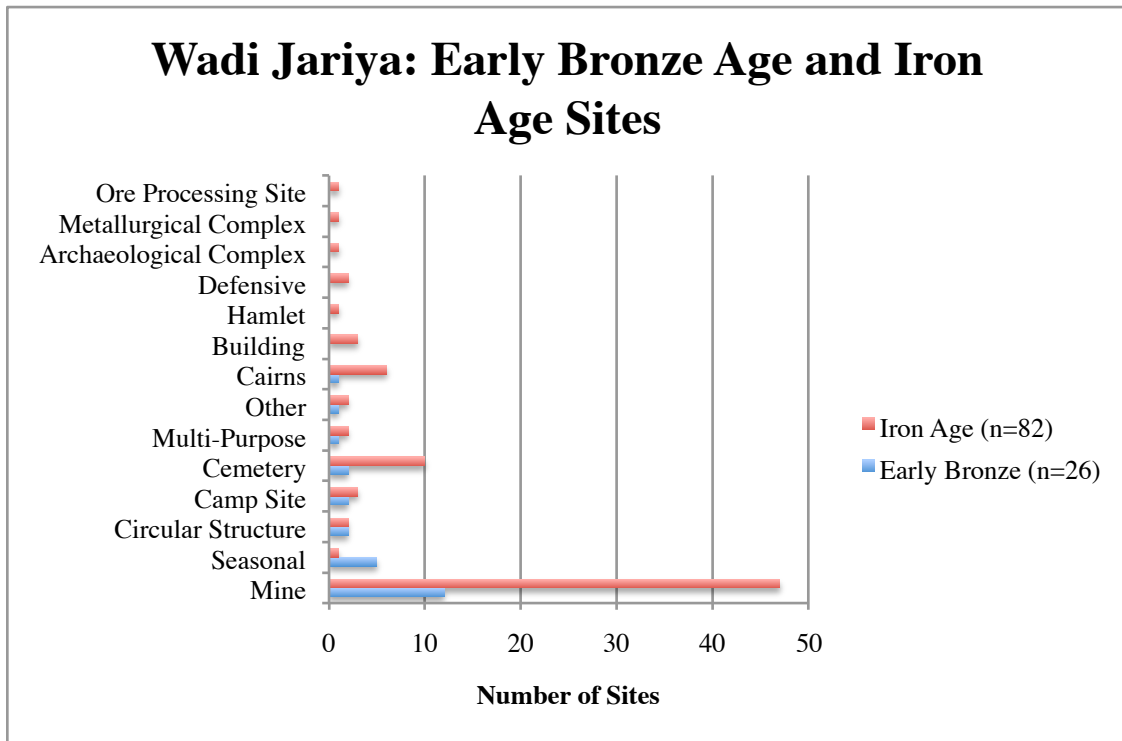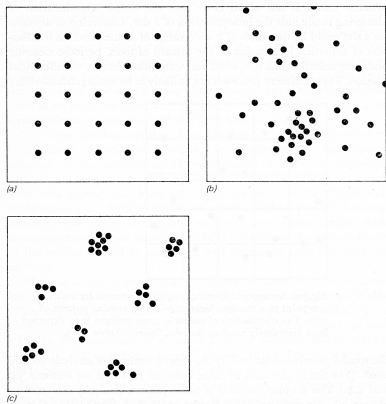**Figure 1: Number of EBA and IA sites by type recorded in Wadi Jariya**
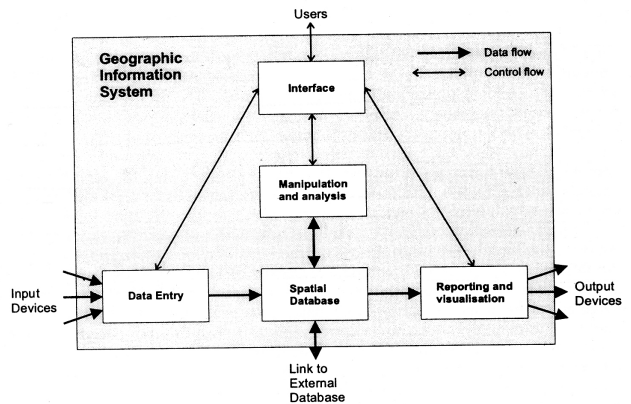

Figure 2: Types of Point Distributions

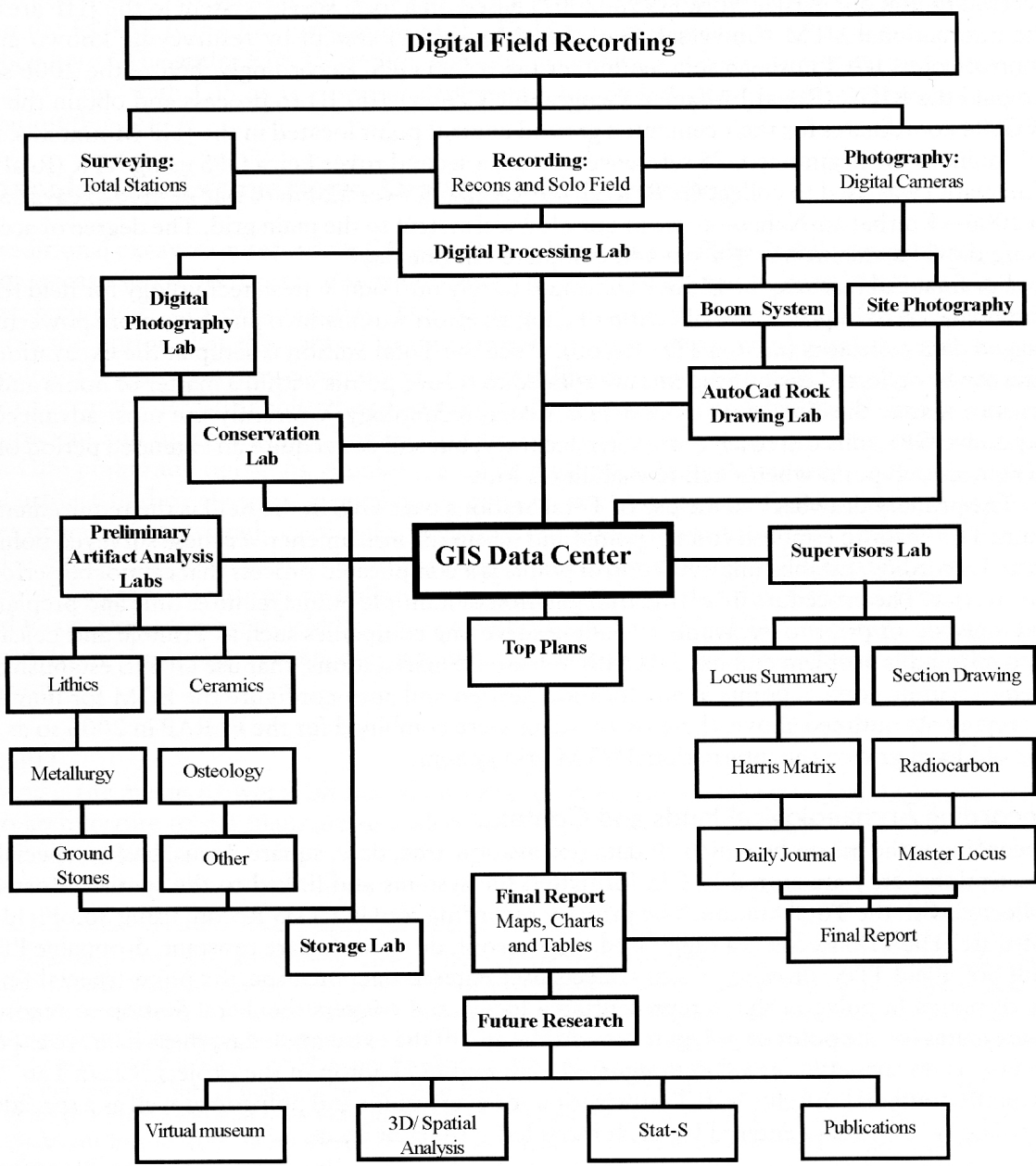**Figure 3: Subsystems of GIS**

The Digital Archaeology System

Digital Field Recording

Surveying: Total Stations

Recording: Recons and Solo Field

Photography: Digital Cameras

Digital Processing Lab

Digital Photography Lab

Boom System

Site Photography

AutoCad Rock Drawing Lab

Conservation Lab

Preliminary Artifact Analysis Labs

GIS Data Center

Supervisors Lab

Lithics

Ceramics

Top Plans

Locus Summary

Section Drawing

Metallurgy

Osteology

Harris Matrix

Radiocarbon

Ground Stones

Other

Daily Journal

Master Locus

Storage Lab

Final Report Maps, Charts and Tables

Final Report

Future Research

Virtual museum

3D/ Spatial Analysis

Stat-S

Publications

Figure 4: GIS –based recording system
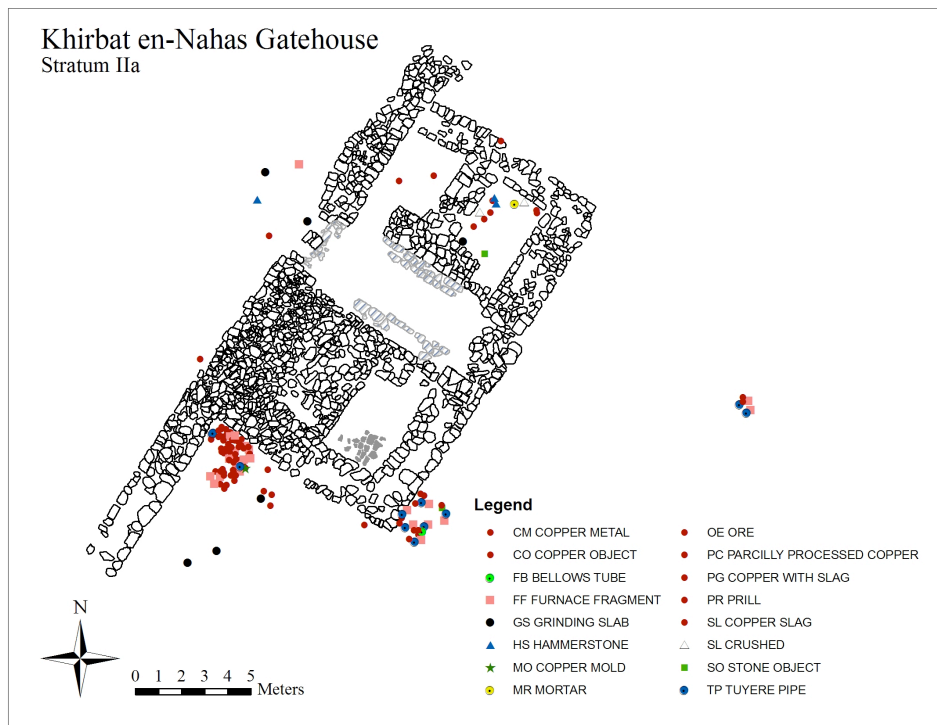
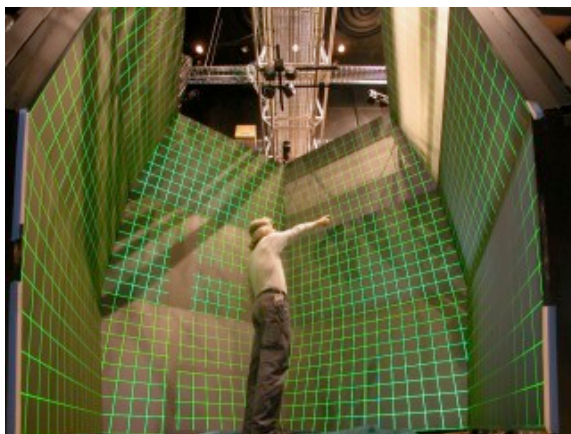**Figure 5: Archaeological Distribution Map**
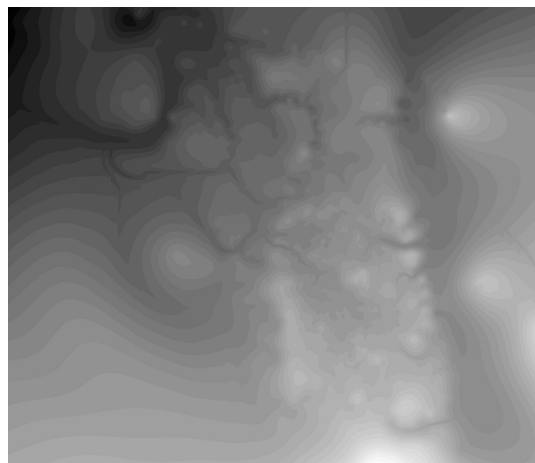

Figure 6: StarCAVE at Calit2

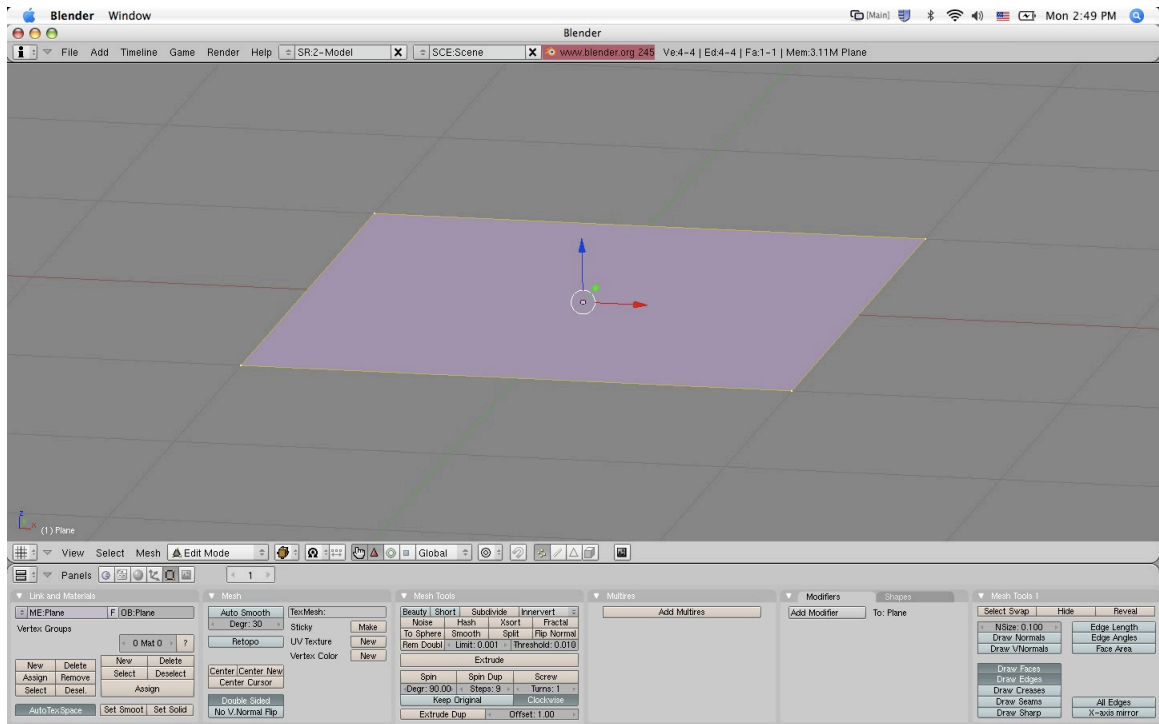**Figure 7: Digital Terrain Model**

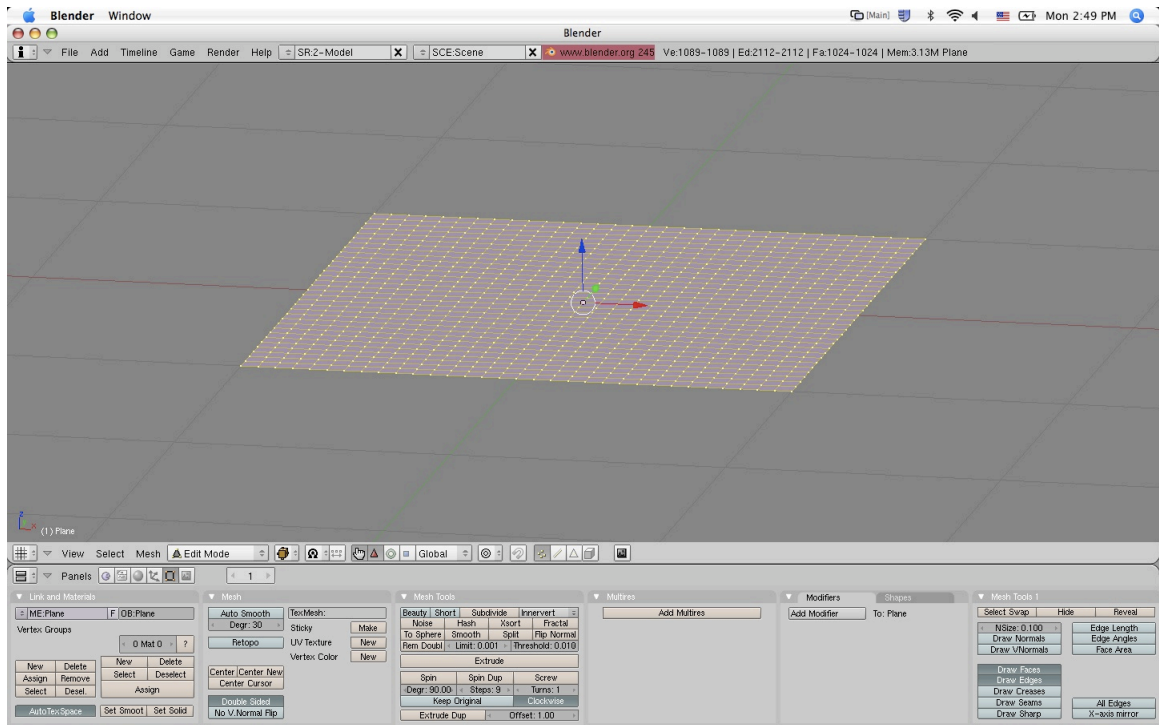**Figure 8: 3D "blank slate" used to create terrain model**

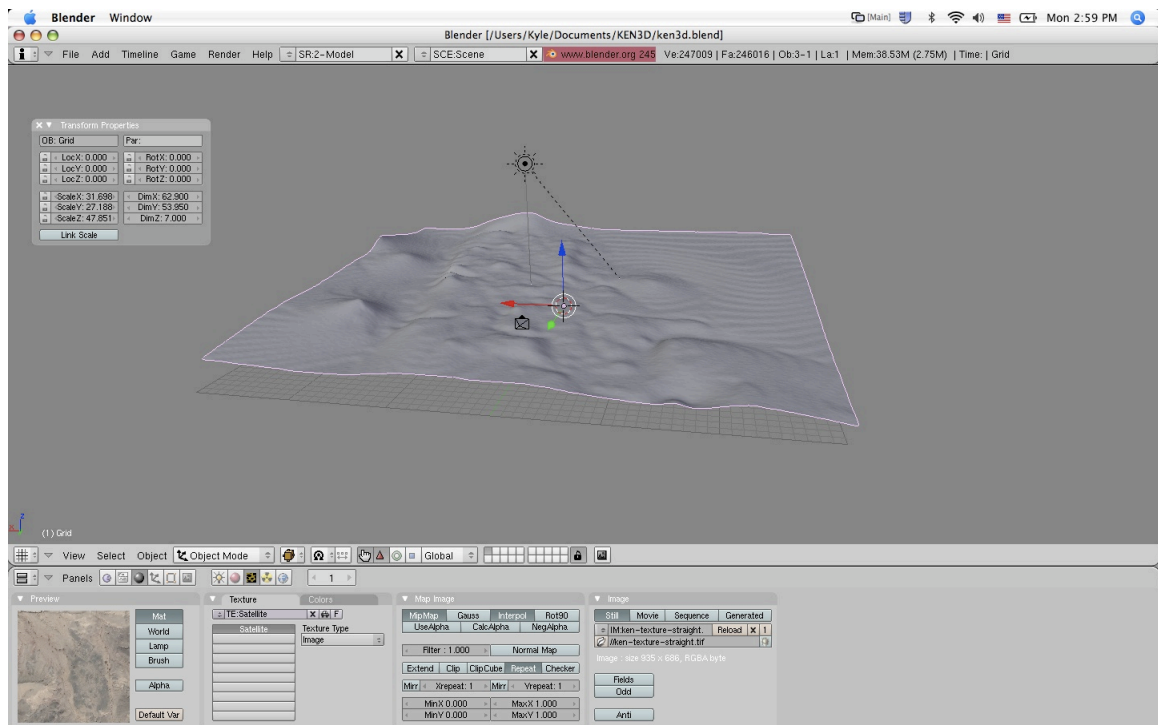**Figure 9: 3D "blank slate" with subdivided polygons**

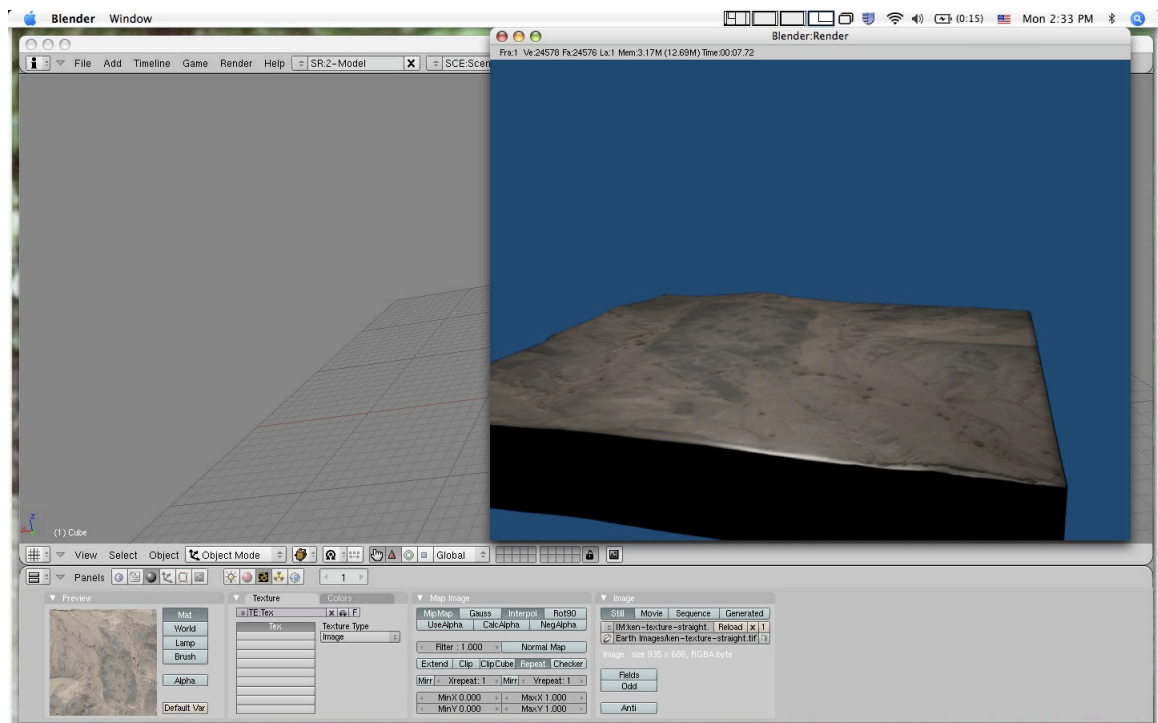**Figure 10: 3D terrain model after creating noise**

Figure 11: 3D terrain model rendered with satellite image
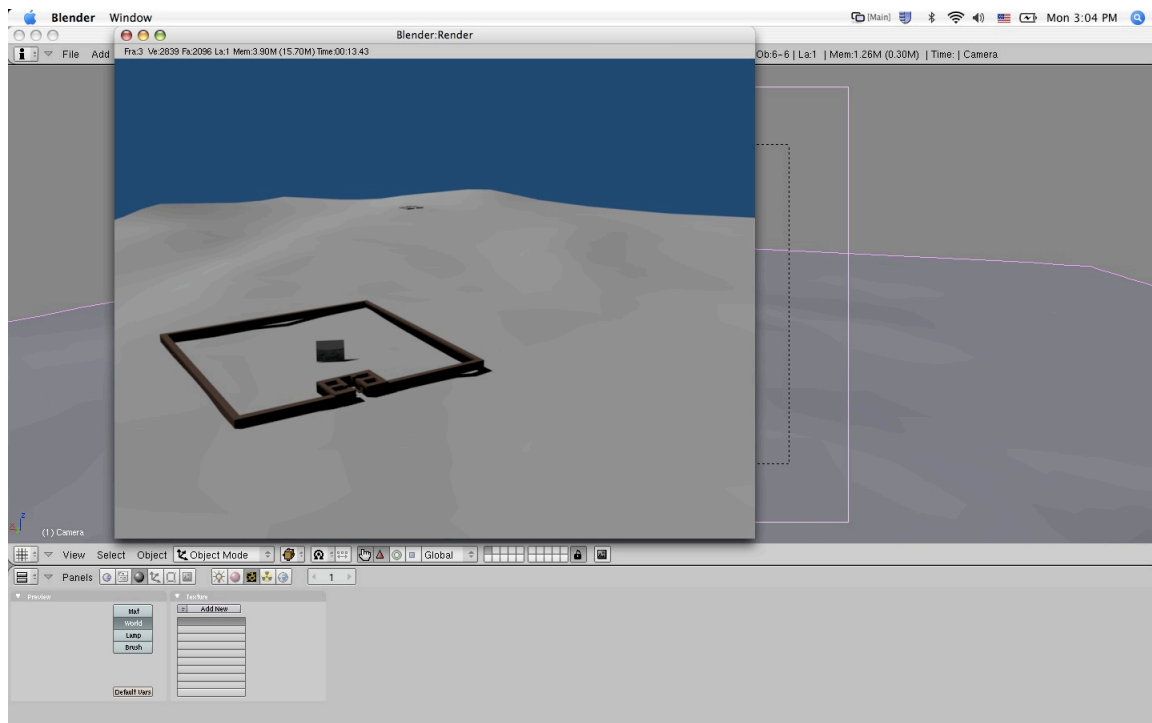
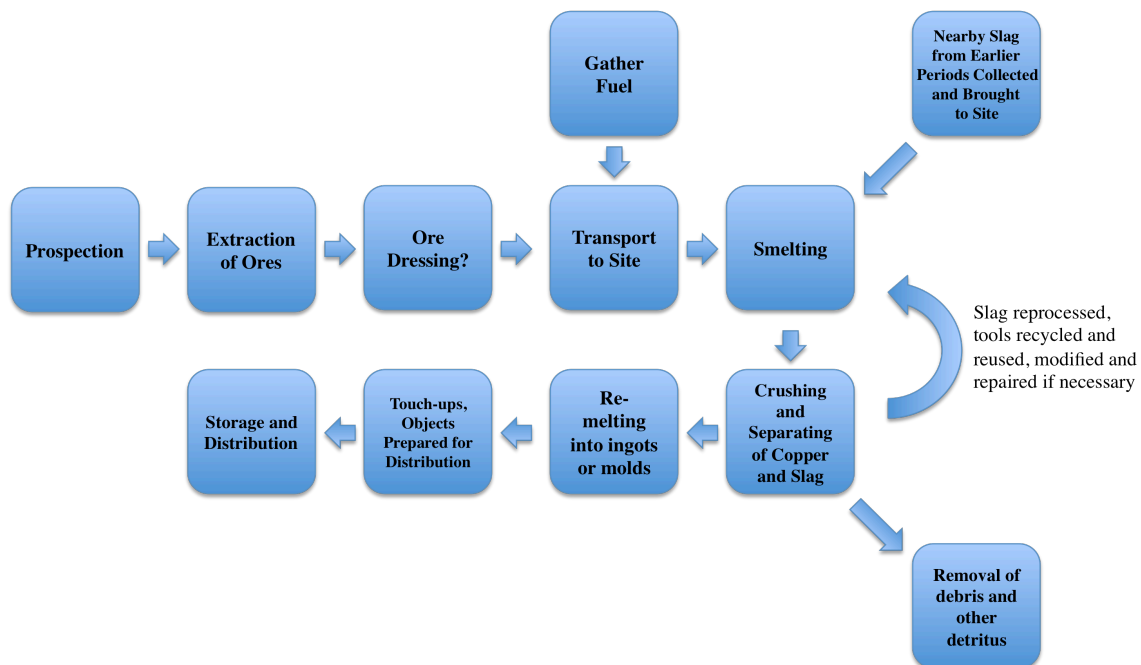**Figure 12: KEN Gatehouse Preliminary Reconstruction**

Figure 13: Chain of operation during the Iron Age at Khirbat en-Nahas

Table 1: Typology and characteristics of production organization drawn from ethnographic observations of ceramic production, modified after van der Leeuw (1977) and David & Kramer (2001)

	Variables	Household Production	Household Industry	Individual Industry	Workshop Industry	Village Industry	Large-Scale Industry
				------- Scale and Intensity -------		+	
Economy	*time involved*	occasional	part-time	full-time	full-time	part-time/full-time	full-time
	persons involved	one	several	one	several	several	many
	gender	women	women	men	men	men, women	men, women
	organization	none	none	none	Guild	certain	certain
	locality	sedentary or itinerant	sedentary or itinerant	itinerant	sedentary	sedentary	sedentary
	hired hands	none	none	none	some	some	labor force
	market	own use	group use	regional	village/town	region (wide)	regional and export
	raw materials						
	clay	local	local	local	neighborhood	neighborhood	neighborhood/distant
	temper	local	local	local	neighborhood	neighborhood	neighborhood/distant
	water	local	local	local	local	local	local
	fuel	local	local	local	neighborhood	neighborhood	neighborhood/distant
	investments	none	none	few	some	some	capital
	seasonality	production as needed	season without other work	all year except winter	all year/good weather	all year/good weather	all year
	labor division	none	none	none	some - considerable	some - considerable	detailed
	time per pot	high	high	medium	medium - low	medium - low	low
	status	amateur	semispecialist	specialist (many techniques)	specialist	specialist	specialist (few techniques)

Table 1: Continued

Technology	hand/small tools	hand/small tools	hand/small tools	mold/wheel	mold/wheel	wheel/cast/press
manufacturing techniques						
tools/facilities						
sed. basin	none	none	none	when needed	when needed	needed
wheel	none	none; rotary support	turntable	various kinds	various kinds	kickwheel or similar
drying shed	none	none	none	needed	needed	needed
firing/kiln	open firing	open firing/impermanent	impermanent	(semi)-permanent	(semi)-permanent	permanent
raw materials						
clay	wide range	wide range	wide range	narrower range	narrower range	narrow range
temper	wide range	wide range	wide range	narrower range	narrower range	narrow range
water	any	any	any	any	any	any
fuel	wide range	wide range	wide range	narrower range	narrower range	narrow range
range of pottery	narrow	narrow	wide	narrow or wide	narrow or wide	narrow or wide
range of functions per pot	wide	wide	wide	narrower	narrower	narrower
Ethnographic data	Kabyles (N. Africa)	Cameroon Tanzania	Tibet	Farnham (UK)	Tzintzuntzan (Mexico)	Wedgwood (UK)

Table 3: Multidimensional typology of specialized production based on the four parameters of the organization of production, modified after Costin (1991)

	Context (attached vs. independent)	Concentration (nucleated vs. dispersed)	Scale (composition) (labor vs. kin-based)	Intensity (part-time vs. full-time)
Individual	independent	dispersed	kin-based	part- or full-time
Dispersed Workshop	independent	dispersed	labor	full-time
Community	independent	nucleated	kin-based	part- or full-time
Nucleated Workshop	independent	nucleated	labor	full-time
Dispersed Corvee	attached	dispersed	labor or kin-based	part-time
Individual Retainer	attached	nucleated	kin-based	full-time
Nucleated Corvee	attached	nucleated	labor	part-time
Retainer Workshop	attached	nucleated	labor	full-time

Table 4: Archaeological Correlates of Metallurgical Activities

Mining	Ore Dressing	Smelting	Crushing and Separation	Re-melting	Final Product Prep.	Storage and Distribution
mine shafts	tailings	furnaces/ furnace fragements	crushed slag	furnaces/ furnace fragements	groundstone	copper ingots/ pins
ventallation shafts	hammerstones	tuyere pipes	copper/ copper prills	tuyere pipes	polishing/ grinding stones	storage areas
tailings		bellows tubes	groundstone implements	bellows tubes	molds/ ingot molds	imported items (scarabs, imported pottery, trade goods)
mining hammers		fuel/ charred wood	mortars/ basins	fuel/ charred wood	copper ingots/ pins	
water storage vessles		hammerstones/ pounding implements		hammerstones/ pounding implements		
mine prospects		groundstones/ basins		groundstones/ basins		
		slag		slag		
		partially processed copper/ copper prills		copper		
		crucibles		crucibles		
				molds/ ingot molds		

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