THE USE OF GROUND-PENETRATING RADAR FOR ARCHAEOLOGY: DETERMINING SITE FORMATION PROCESSES AND SUBSURFACE FEATURES ON TUTUILA ISLAND, AMERICAN SAMOA

A Senior Scholars Thesis

by

DANIEL RYAN WELCH

Submitted to the Office of Undergraduate Research
Texas A&M University
In partial fulfillment of the requirements for the designation as

UNDERGRADUATE RESEARCH SCHOLAR

April 2006

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ABSTRACT

The Use of Ground-Penetrating Radar for Archaeology: Determining Site Formation Processes and Subsurface Features on Tutuila Island, American Samoa (April 2006)

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The use of geophysical remote sensing techniques has been increasing for several decades. As this technology becomes increasingly affordable and accurate, more and more archaeologists are beginning to wonder how this emerging technology can complement traditional archaeological techniques. This thesis presents the results of a study using ground-penetrating radar in the mountain settings of American Samoa, a chain of volcanic islands in the South Pacific. Our results show that in American Samoa, ceremonial mound (i.e. star mound) construction details were easily seen in radar profiles. Ground penetrating radar has the potential to yield significant details about such mounds, with no physical impact to the site.

DEDICATION

To the people of ancestral Samoa for creating a culture of strength and beauty; and to the present-day people of Tutuila Island for their support, excitement and cooperation in our exploration of Samoan prehistory

ACKNOWLEDGMENTS

I must first thank all those who have helped me in my studies, travels, and fieldwork. I extend a special thanks to my research advisor, Dr. Frederic Pearl, who has time and again created new opportunities for student-conducted research. I would also like to thank my family for their interest and support in my research endeavors, and for creating an environment that fostered curiosity and exploration.

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CHAPTER I

INTRODUCTION: THE USE OF GROUND-PENETRATING RADAR FOR ARCHAEOLOGY

Ground-penetrating radar (GPR) is a geophysical remote sensing method that utilizes electromagnetic energy to determine subsurface variances due to chemical or physical changes. This is a non-destructive method of archaeological investigation, and is a valuable asset to the modern archaeological project. Excavation is often expensive and sometimes controversial. GPR offers a logical answer to this dilemma by delivering increasingly accurate data regarding site stratigraphy, the location and depths of covered anomalies, as well as geologic data about the site. Ground-penetrating radar equipment is not inexpensive; however the cost of this technology has decreased in recent years, prompting more and more archaeologists to take advantage of this growing technology.

Although GPR use and data interpretation is becoming more efficient and user-friendly, it is by no means self-explanatory. Data collection and interpretation remains a specialized field, with the rewards of this technology falling to those that gain an understanding of its potential through fieldwork, research of GPR principles and development of survey techniques.

This thesis follows the style of *American Antiquity.*

The remainder of this chapter will cover basic theory of GPR and provides information about the investigation of buried targets of archaeological interest through amplitude analysis, visualization of subsurface stratigraphy and the interpretation of commonly encountered buried objects.

Amplitude Analysis

The amplitude and speed of electromagnetic waves sent by the GPR unit increases or decreases as it passes through buried physical or chemical changes. As the waves encounter subsurface changes some of the energy is reflected back to the GPR unit and processed. The remaining energy continues through the ground until it attenuates and ceases propagation. This received energy creates a side-scrolling image of subsurface stratigraphy and buried areas of higher and lower amplitude. This data is then interpreted by the operator to determine the locations, depths, (and at times), materials that caused the reflection.

Data may be displayed in the form of a “trace”, which is a compilation of individual waveforms, or reflections. The amplitude of the individual waveform varies with the intensity of the reflection caused by buried targets. In analyzing traces, regions of lower amplitude typically signify homogenous soils or sediment, while high amplitude regions often indicate buried targets of archaeological interest. The amplitude intensity and spatial relationship of the waveforms within a trace may be analyzed in order to determine buried changes such as: soil horizons, changes in bulk density, chemical shifts, physical changes from buried objects etc. In the case of Star Mound

AS-21-89, amplitude analysis gave information regarding the number and locations of soil layers, as well as the spatial relationship of buried objects within the feature.

Visualizing Subsurface Stratigraphy

Clearly defined strata layers are not present at all archaeological sites. However, although stratigraphic changes may not be presented visibly, chemical or physical changes within the sediment are often present. Hypothetically, the sediments that became compacted as a result of a trade route may not display a visual change upon excavation, but GPR may show a change in amplitude in the region, due to the physical change (density) in relation to the surrounding earth.

As mentioned, waveforms often signify the boundaries of subsurface changes. Waveforms are made of "wavelets", which is a positive or negative shift in amplitude. These form as a result of the change in physical or chemical property of the targets that the signal encounters, and they often signify the top and bottom of buried items. When combined, the wavelets create a waveform, which is then compiled with the other waveforms from any given GPR sample to create a composite amplitude trace, or image of what lies beneath the GPR unit. Among many other uses, the analysis of these waveforms allows the researcher to understand subsurface stratigraphy of the survey region. The strata encountered may be layers of physical or chemical change, and although a change is evident in GPR profiles, the change may not be visible in the substrate. The use of this method, interpreting strata based on waveform analysis, gave valuable insight into the construction sequence of star mound AS-21-89.

Interpreting Subsurface Anomalies

The side-scrolling image created by the GPR unit reveals what seems to be a myriad of black and white lines, gray indiscriminate fuzz and random parabolas that criss-cross the display screen. The initial shock of interpreting the nonsense on the screen may seem overwhelming. However, with the knowledge of what to look for, data interpretation, while not easy, will in time become much less confusing.

Certain buried targets create unique GPR reflections. An understanding of why each type of signature appears as it does will allow the researcher to interpret many common subsurface anomalies while in the field. This will in turn cut down on post-acquisition processing time. Although there is some consistency in the identification of the major target types, there is rarely a way to identify exactly what material the target is made of. However, in respect to subsurface anomalies, the greater the amplitude of wave reflections through a medium, the greater the difference in physical and chemical characteristics of the buried material (Conyers 2004:149). The change in contrast on the GPR profile, either isolated regions of high or low contrast or amplitude may be analyzed to understand the possible material compositions of buried targets. Most of all, a prior knowledge of the types of buried targets, for example, covered middens or boulder alignments that may be present in the survey helps the investigator to interpret the findings as they appear on the display.

The following figures and text describe several of the major types of covered anomalies that are frequently encountered. These buried objects were discovered during the 2005 research season in American Samoa, and are from both mountain and coastal settings. Each section details a separate type of anomaly, and briefly describes the major the factors that contribute to its unique signature. It is important to note that the unique reflections created by covered features may change from site to site based on geological factors, soil saturation levels or complications attributed to ground coupling.

Metals

The GPR signals cannot penetrate metal objects. This phenomenon creates high-amplitude signals of repeating or "echoing" bands upon the screen. This results as the electromagnetic wave bounces back and forth from the highly reflective metal object to the GPR device over and over again. Very small metal objects may not appear on GPR profiles, especially with the use of low frequency antennas. However, metals are often visible in shallow settings with high frequency antennas. The reflected signature from metals is at most times unmistakable. However, other dense or reflective buried items are capable of creating echoes, such as ceramics or concrete. The most commonly encountered metallic objects are rebarring, metal piping, or covered metal scraps.

(Figure 1) shows a GPR profile taken from the village of Aganoa, American Samoa. This profile was taken behind a modern house, situated on a 2,500-year-old archaeological site. It shows the presence of metallic objects near the surface, denoted by repeating bands of high amplitude. The metal objects are probably from the modern-day house.

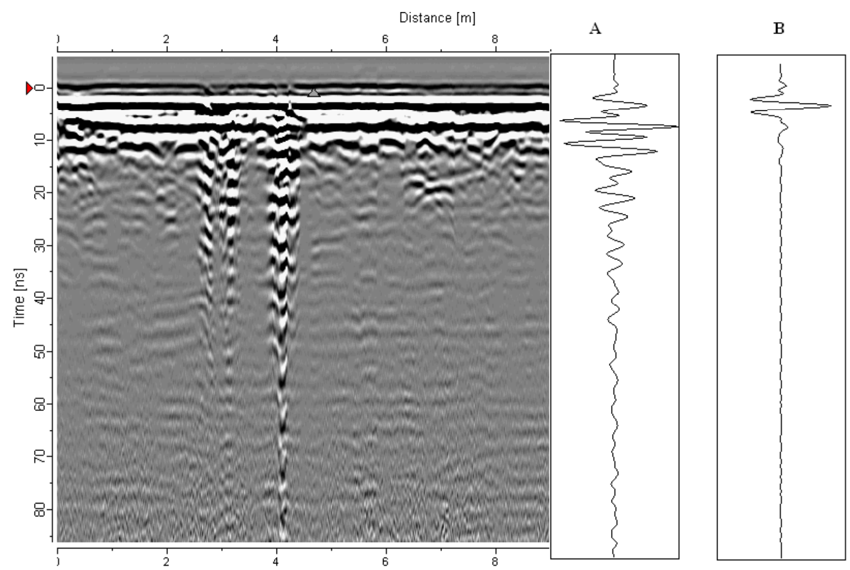

Figure 1. GPR profile showing echoing bands created by buried metal objects. Trace A shows the trace window as the GPR unit crossed the metal objects. Trace B shows the unimpeded signal as it travels through the ground next to trace A. Trace A exhibits higher amplitude, and a higher number of waveforms in relation to the trace B.

Point-Source Reflections

Point-source reflections (figure 2) are displayed as parabolas on GPR profiles. The object that creates the point-source reflection is located at the apex of the arc. The attributes of the parabola may be analyzed in order to gain an understanding of the material composition based on the contrast, size, extent or reach of the arms, and curvature of the parabola.

Point-source reflections are created as the GPR footprint move across rounded objects. Reflections of this type are distinct and relatively easiest to identify. Point-source reflections often denote covered boulders or pipes. A slight ringing or echo below the parabola may accompany concrete pipes. This often is created as a result of the reflectivity of the dense pipe. Other buried features are capable of creating parabolic signatures such as coffins, metals (accompanied by ringing) or covered bricks or ceramics. Figure 2 shows the presence of buried boulders beginning at a depth of 0.60 meters. Two of these anomalies (at the right) are indicated arrows.

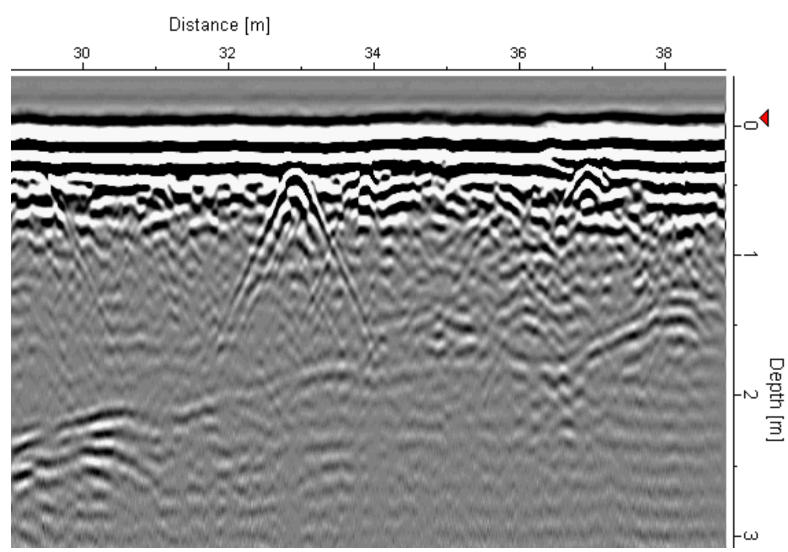

Figure 2. Point-source reflection at the village of Aganoa, American Samoa. The point-source is located near the upper portion of the GPR profile and is distinguished by parabolic arms reaching down from the apex of the anomaly.

Planar Reflections

Reflections from buried targets that do not appear as parabolas often take the form of planar reflections (figure 2). These appear as horizontal anomalies, and contain alternating light and dark bands that exhibit higher amplitude in relation to the surrounding matrix. These reflections are often the result of a stratigraphic horizon, or a physical discontinuity such as the water table, or a horizontal feature of archeological interest (Conyers 2004:55). Figure 3 shows the presence of a planar reflection (middle right) at the ancient coastal village of Aganoa, American Samoa. The upper layers are highly disturbed and contain multiple point-source reflections.

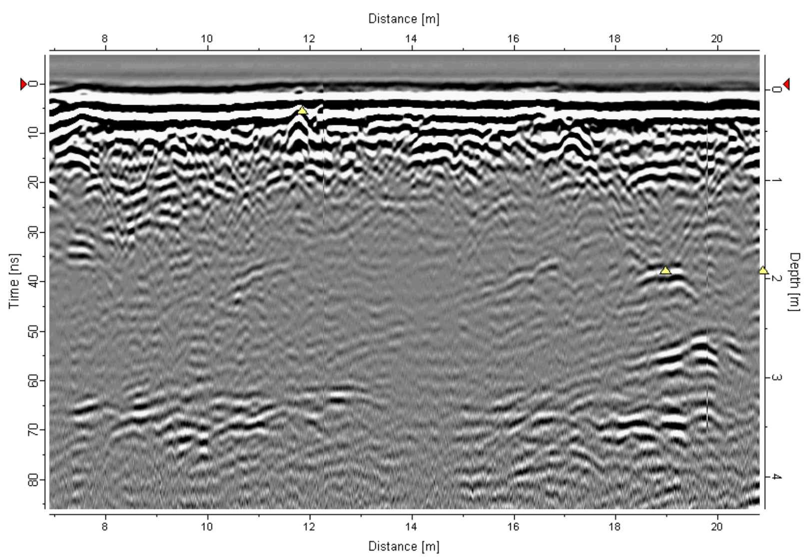

Figure 3. Planar reflections at the coastal village of Aganoa, American Samoa. One of these anomalies is visible at a lateral distance of 19 m, and a depth of 2 m.

Buried Trenches and Pits

Covered pits and V trenches (figure 4) are also easily identifiable features. The signatures indicating pit-like features and trenches are created as GPR energy becomes focused in the furrow of the pit or trench. This creates a high amplitude cup-shaped, or V-shaped signature on the display screen. A downward shift of the waveforms within the trace window may accompany a buried trench or pit. Pits and trenches are key indicators of cultural activity, and often contain valuable archaeological information regarding irrigation or agricultural techniques. Covered pits may also indicate the presence of graves or refuse pits. Figure 4 shows the presence of a covered trench, and a buried pit feature is visible in Figure 5. Feature A. exhibits a phenomenon called the "bow tie effect", and is the result of the intersection of the GPR waves that have reflected off of the sides of the trench. This intersection of GPR waves creates, what is at times misinterpreted as a buried object (center arrow below trench). The Buried pit is identified by its shape and isolation within the soil matrix, (Figure 5).

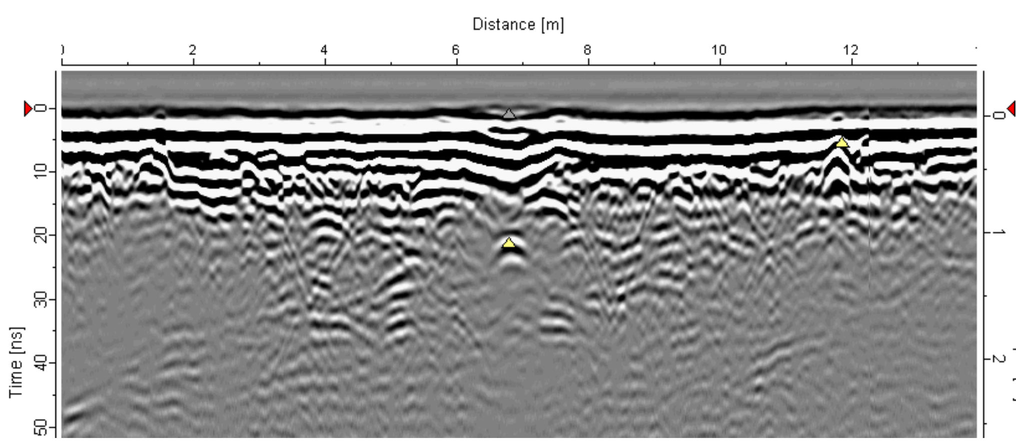

Figure 4. GPR profile showing the presence of a buried trench and "bowtie" effect.

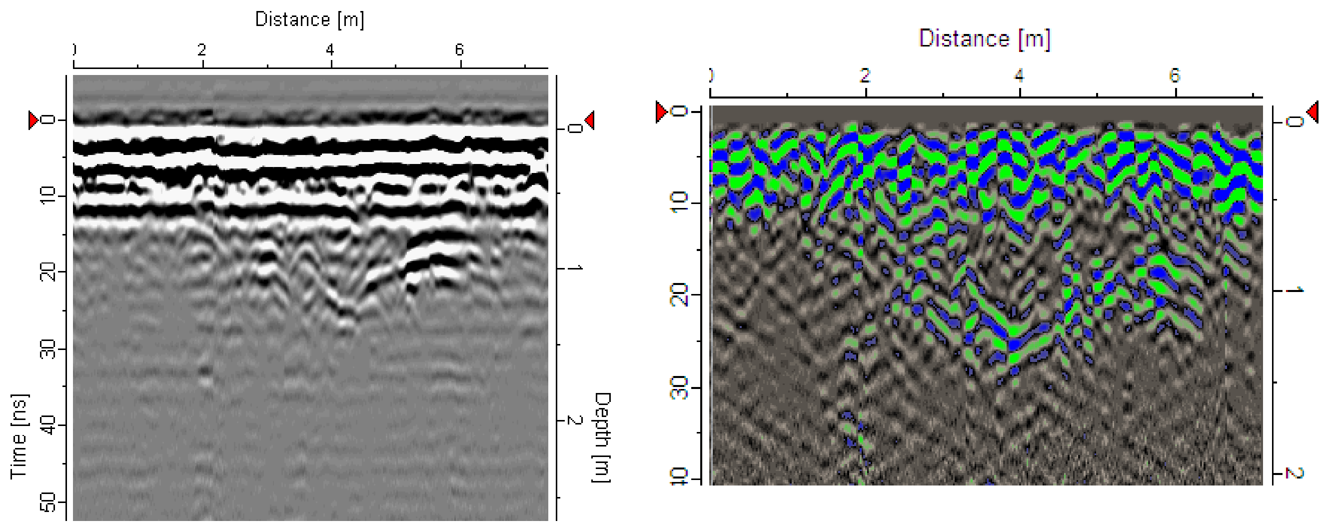

Figure 5. GPR Profiles showing the presence of a probable buried pit. The image at left has been interpolated and filtered to remove background noise. The probable pit is visible in both images as the high amplitude cup-shaped feature beneath the upper layer of increased amplitude.

Geologic Features

Prominent geologic features will be encountered during most surveys for buried objects of archaeological interest. These are features that have in no way been altered or created by humans, and are simply the result of the surrounding physical or chemical geology. These may be obvious features, such as the interface of bedrock, or extremely deep and large anomalies that are outside the depth ranges of archaeological potential.

The interpretation of some geologic features proves slightly harder to identify as non-archaeological targets. The definition of these anomalies may require further investigation, such as coring to analyze the cause of GPR reflections. The geology of archaeological sites often dictates the zones of habitation, trade routes, or areas of agriculture, and should not be overlooked simply because it does not offer up cultural materials. The ability for GPR to investigate the buried terrain at covered cultural sites offers new avenues of research that were previously very expensive and extremely time consuming due to the necessity of excavation.

The GPR profile in Figure 6 shows reflections taken as the GPR unit crossed a beach berm at the site of Aganoa, American Samoa. The large anomaly traveling diagonally across the profile was interpreted as an ancient beach berm that has since been covered. The ancient habitation surface is visible underneath the well-stratified layers. The interface of these layers is visible at a depth of 0.50 meters. A well-defined point source reflection is located near the center of the profile.

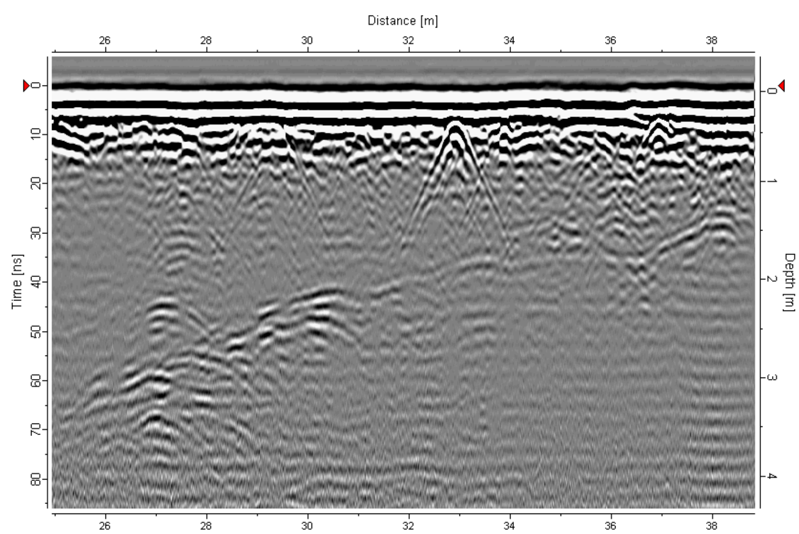

Figure 6. Geologic GPR reflections interpreted as a buried beach berm. This profile was taken at the coastal village of Aganoa, American Samoa. The probable buried beach berm begins at the lower left and extends upwards to the right of the profile.

CHAPTER II

GPR SURVEY OF STAR MOUND AS-21-89, AMERICAN SAMOA

Star mounds or *Tia 'ave* (rayed platform), are low cog-shaped earthen platforms created by prehistoric inhabitants of Tutuila Island, American Samoa. These features are located on mountain ridge tops and prominent mountain peaks, with only a few existing in the low-lying plain region of the island. Little is known about *tia 'ave* regarding their function, age, reasons for their ridge-top locations or construction techniques. During the summer of 2005, a field crew from Texas A&M University at Galveston conducted a ground penetrating radar survey on star mound AS-21-89 (Figure 7), located on Lefutu Ridge near on the eastern tip of Tutuila Island (Figure 8.)

The aim of this survey was to further the understanding of the stratigraphy, construction methods and buried objects within this feature. As a result of the survey, hypotheses regarding *tia 'ave* construction process, stratigraphy and methods for star mound erosion control are put forth. These conclusions are based on data collected through the use of ground penetrating radar, participant observation at a contemporary earthen mound construction site, and knowledge drawn from published works on excavated star mounds.

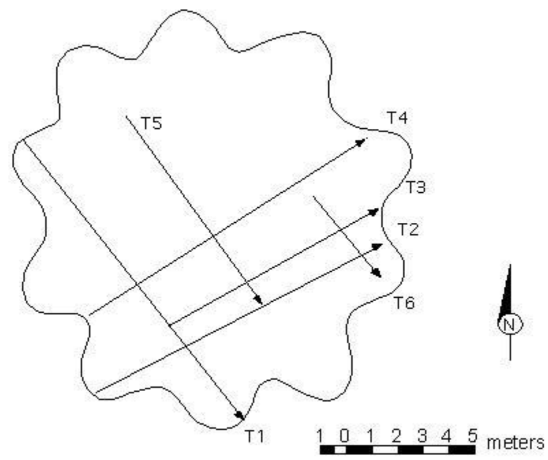

Figure 7. Plan view of Lefutu Star Mound (AS-21-89) showing GPR transects

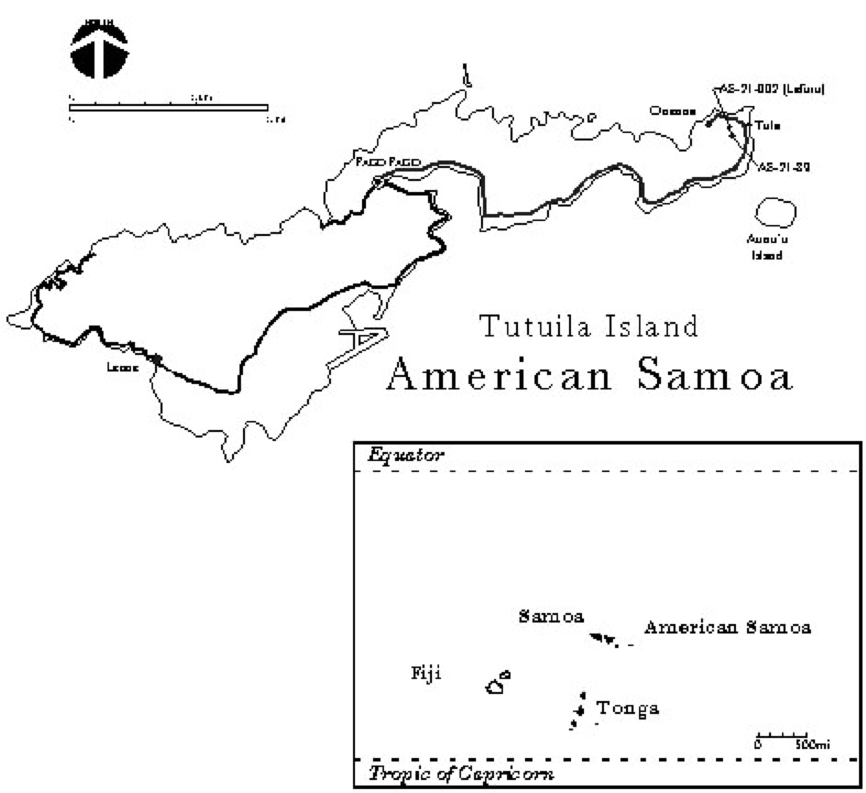

Figure 8. Map of Tutuila Island showing the location of Lefutu and Star Mound AS-21-89.

Samoan Star Mounds

The definitive function of star mounds in ancestral Samoa remains unknown. At times, the definition of a star mound itself is left up to debate. Defined by Herdrich and Clark, (Herdrich and Clark, 1993:52) star mounds are "any rock or earthen mound (*tia*) with one to 11 ray-like projections (*'ave*)". It should be mentioned that these authors created the term (*tia 'ave*), meaning rayed-platform or mound with projections, to describe star mounds in the Samoan language. The term *tia 'ave* is not an ethnic term. However it does serve to integrate these iconic rayed-platforms into the language.

The exact use of these mounds remains in debate. Nevertheless, many hypotheses exist, placing star mounds as burial mounds, residential structures, inland fortifications, territorial markers, pigeon catching platforms, and ritualistic sites.

The author conducted a brief personal interview while in the field with Mr. Wilson Fitiao, from the village of Matuu'u. Mr. Fitiao gave these mounds the designation of weather observation platforms. As told, a fire was made on the center of the platform and the smoke passed between small posts that encompassed the feature. Observers at the mound would know, based on the wind conditions, what avenues of trade were open to sail, or even which distant islands may set sail to attack as the breeze sent smoke between certain posts. These are merely hypotheses, none of which have been widely tested, or accepted as the ultimate function.

The use of star mounds as burial mounds or residential structures is shown to be unlikely, based on preliminary works (Peters 1969; Holmer 1976; Frost 1978; Hewitt 1980:41, 1980:32; and Best *et al.* 1989). At present, the case for *tia 'ave* as residential structures is poorly supported due to the fact that cultural materials indicating habitation have yet to be uncovered. The author and crew found no cultural remains that would indicate the use of star mounds as habitation sites during a surface search at AS-21-89.

Some star mounds are not completely barren of cultural remains. Basalt flakes were encountered during the excavation of a star mound on Tutuila Island by Best (Best *et al.* 1989). Best mentions a stone flake scatter just under the surface at a depth of 5-8 centimeters. Other tool fragments and flakes were found in the deeper layers that extended into an older platform on which activity had taken place, and on which the *tia 'ave* rested. Most of the flakes recovered from the *tia 'ave* itself were found lying on edge, suggesting that they did not originate on a star mound living surface, but were rather placed in the mound along with the soil fill (Best *et al.* 1989).

If it is the case that the star mound platform was mostly level during the final stages of soil build-up, Best suggests that the shallow flakes were simply thrown into the fill-dirt during the final stages of construction. This would create the appearance of an active habitation surface. Yet another hypothesis made by Best is that the 5-8 cm level may have been the original mound surface, and had been since been covered by soil wash as a result of runoff from the terrace above it. These hypotheses serve as possibilities to the function and construction methods of the star mound explored by Best, and are based on data collected during a single excavation project.

Although the common indicators of habitation sites, such as post holes or cooking features remain unseen at star mounds, there is little reason to rule out the eventual use of *tia 'ave* as locations for random activity such as impromptu stone tool manufacturing, small scale food preparation or meeting places. The level ground and open space of star mounds make a convenient location for small-scale cultural activity. Although the express function upon construction may not have been habitation, the later use of *tia'ave* for simple waste-producing activities, such as small-scale tool manufacture or cooking should not be overlooked. Cultural remains on or near the surface of star mounds may indeed be remnants from periods of secondary use. The apparent lack of cultural evidence, such as post-holes, stone pavement ('ili 'ili) or cooking features at star mounds fails to create a case for the creation of *tia 'ave* for habitation. It does indicate, however, that these sites were not created then abandoned, or used for one singular non waste-producing activity then forgotten.

The most widely accepted hypothesis concerning the use of star mounds is that they were used in pigeon catching games (Clark and Herdirch 1988; Clark 1989; Herdrich 1991). During a study of star mound SU-LU-53, in Western Samoa, Peters (Peters 1969) discovered a grinding bowl, supposedly used in the preparation of *kava*, (or ava). Pritchard (1866:162) states: "After a drink of ava all round" the decoy birds would then be released to attract the quarry. The discovery of grinding bowls for kava preparation at SU-LU-53 by Peters (Peters 1969) and the account given by Pritchard, linking kava to pigeon catching (Pritchard 1866:162) is one factor, among others, that helps the case for the use of star mounds as pigeon catching platforms, as argued by Herdrich and Clark (1988), and Clark (1989).

The hypothesis of star mounds as pigeon-catching platforms is well supported and widely accepted. The final answer, however, to the functional question of the *tia* *'ave* still remains a topic of debate. Additional surveys and excavations at star mound sites, as well as more research into the oral histories regarding *tia 'ave* may eventually provide the uncontested answer to the uses of these rayed platforms.

Statement of the Problem:

Understanding Site Formation Processes of Star Mounds

Although there may be no clear answer to the reason for the construction of star mounds, there are many important questions about these iconic sites that might be answered through archaeological investigation. Through archaeological study, answers regarding the general age of these rayed platforms, as well as the construction methods used in their creation are obtainable. Due to the possibility of hundreds of star mounds existing on Tutuila Island alone, a complete study of Samoan star mounds to determine age and construction details would prove extremely expensive and time consuming. Widespread excavation to determine the age of these features would also pose certain threats to the integrity the star mounds, as well as to the environment that surrounds them.

Over the last few decades advances in remote sensing technology has given researchers a new set of tools to assist them in archaeological investigation. Tools such as ground-penetrating radar (GPR), has become increasingly efficient, user friendly and accurate in recent years. This technology allows the user to remotely detect, locate and interpret buried objects that hold archaeological potential. This method allows for the collection of subsurface data without a physical impact to the site. GPR survey should not take the place of scientific excavation. However it is a valuable counterpart to excavation, and does have the capability to give accurate data relatively quickly. GPR has been especially helpful in situations where digging is not an option due to a lack of time, funding, crew or permission. The use of GPR for archaeology, in this case of this study geoarchaeology, has become a valuable addition to the investigation of star mounds, and the ways in which they came to be.

Research at the Lefutu Ridge star mound (AS-21-89) intended to answer the following questions about the site: 1) In what way was the earthen mound constructed, including the relative sequence and technique of its creation, and 2) were there any subsurface anomalies, such as possible cooking features, burials etc. that would indicate the use of the mound for activities other than the sport of pigeon catching, or any other use for that matter.

The use of excavation as a means to answer questions such as these necessitates serious funding and time. It was therefore suggested that, through the use of GPR it would be possible to gain a solid understanding of the methods used in construction, as well as the identification of covered features within the mound without causing physical impact. The inability to excavate at AS-21-89 was counterbalanced by the availability of GPR, and its potential to supply subsurface data. The use of GPR to cover a larger sample area in a shorter time, as opposed to a small and expensive excavation, does come with a trade off, this unfortunately being uncertainty. Without ground-truth tests at this site to confirm the result of the GPR data; the answers to the queries posed is the best interpretation regarding the site formation processes and covered features within star mound AS-21-89 at this time. The findings of this survey proved intriguing, providing answers to our initial questions, as well as opening new avenues for further research at star mound sites.

Observations of Earthen Mound Construction Processes

Data regarding star mounds were collected during the 2005 summer field season on Tutuila Island, American Samoa. During fieldwork at the village of Vatia, Tutuila Island, it was observed that when creating earthen structures, in this case an extension to a small church parking lot, the people of the village first constructed a loose foundation of basalt boulders and earth. These boulders were unearthed from an area nearby the construction site. Much of the soil and sediment that was excavated in order to uncover the basalt was used as fill.

Initially, the portion of the stone base closest to the source of fill-dirt was packed with earth. As the sides became filled with soil, workers created a small earthen ramp on the side of the platform nearest the fill-dirt origin. This gave those filling the structure access to the center of the feature. Earth and stones were added until the basal layer was covered. The size of the items used to create the matrix for the soil became progressively smaller as the structure grew taller and took shape. The resultant platform was finally smoothed and compacted. The surface of this platform was to be covered in cement to accommodate vehicles at a later date.

The cooperative efforts of those at Vatia helped to create a large earthen platform with large dense stone, concrete and metal scrap as a stabilizing matrix. This is an effective method for creating a strong, permanent earthen platform. The method used by those in Vatia to create a contemporary platform was simple and effective, and used locally available matierials. The basic materials used in mound construction, soil and stone, have not changed over time. The modern platform contains scrap metal. This however is a non-essential material for overall stability.

The addition of soil, sediment and stones in stages creates stratification across a feature. The use of different soils and sediment placed in random sequence within a feature creates discontinuities in the strata. A sidewall map of the Vatia platform would show randomly scattered large boulders and scrap near the base, and mixture of small stones and soil in the upper layers of the platform.

The simple and effective construction method for earthen features found on Tutuila Island gives little necessity for major changes over time. Furthermore, the similarities found in the materials used in contemporary platforms and ancestral star mound indicate that the resources and procedure used to create *tia 'ave* (AS-21-89) was similar to those used in the contemporary platform, witnessed in 2005 at the village of Vatia.

Subsurface Findings at Star Mound AS-21-89

GPR data suggests that the Lefutu star mound (AS-21-89) contains multiple changes in subsurface composition. These changes differ in density, extent, and material, as well as the number and size of buried objects contained in each region. The analysis of GPR profiles, as well as wavelength and amplitude reflections were successfully used as an archaeological tool for understanding the construction, general stratigraphy, and characteristics of buried objects within star mound AS-21-89.

Upper and Lower Layers

GPR data indicates that an interface of two layers within the *tia 'ave* is located at a depth ranging from 0.50 meters to 0.70 m below the surface. The depth range of this bedding plane is constant across the feature. The region above 0.75 m exhibits higher amplitude in relation to those below this stratigraphic boundary. This area of high amplitude indicates a difference in fill material, density, chemical variance or stone matrix composition in relation to the low amplitude fill below it. Although buried objects are present in both the upper and lower regions, the majority of buried objects in the upper layer are small items, possibly isolated regions of small stones. Given the close proximity of several large trees that surround the feature, some of these small point-source reflections may be tree roots.

Data also shows regions of increased amplitude in the upper portion of the feature. GPR profiles suggest that this upper region may display some form of faint stratification. Below this there exists a region of homogenous fill, poor stratification and a higher frequency of stone (Figure 9). The appearance of stratification on the GPR profiles does not specifically mean that the star mound exhibits clearly identifiable layers of different sediment and soil. The apparent stratification visible in some GPR profiles do indicate however, that the star mound may contains subsurface changes that are present in layers. The possibilities of these layers being differing fill material, chemical changes, density changes, and differences in water content or actual sediment or soil layers. A sediment core analysis across the star mound would show whether or not the star mound indeed has two distinct layers. This test might also indicate which factors are in fact creating the layers.

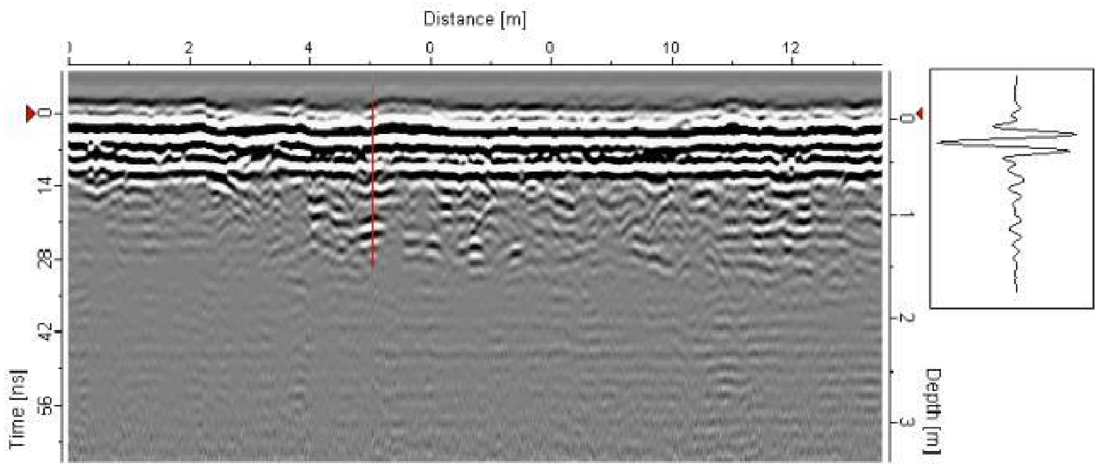

Figure 9. GPR profile and trace from AS-21-89 indicating the presence of two layers within the feature.

GPR data indicates that at one point there was a break in construction. GPR profiles also indicate the possibility of a change in the composition of the fill material, creating an upper and lower layer. However, at this point, there is no way of telling the extent of time between the stages of construction. Additionally, solid physical evidence provided through core samples or excavation does not exist at this site to prove the presence of multiple fill-types. The shift in composition at this depth may also be the result of geological factors, such as leaching of materials from the surface into the upper portion of the feature, or clay translocation, both of which could possibly create a higher amplitude signal. Without excavation at this site there may be room for interpretation regarding the differences in strata.

It does stand to reason, however, that due to the high ratio of boulders in the lower layer, and the lack of boulders in the upper region, that the base was created first, and then after some period of time the upper layer was finished with a thick layer of sediments to "top-off" the feature.

Buried Boulders

GPR data collected at the site indicates that the lower region of the feature contains buried boulders (Figure 10). These boulders are located below the shift in amplitude and most likely extend to the bottom of the feature, or the original ridge-top surface. These objects are indicated by high-contrast/amplitude point-source reflections. This type of reflection signature is common of dense rounded objects such as large cobbles, boulders or pipes. This region is located on an uninhabited ridge-top knoll, and therefore the presence of buried piping has been ruled out completely.

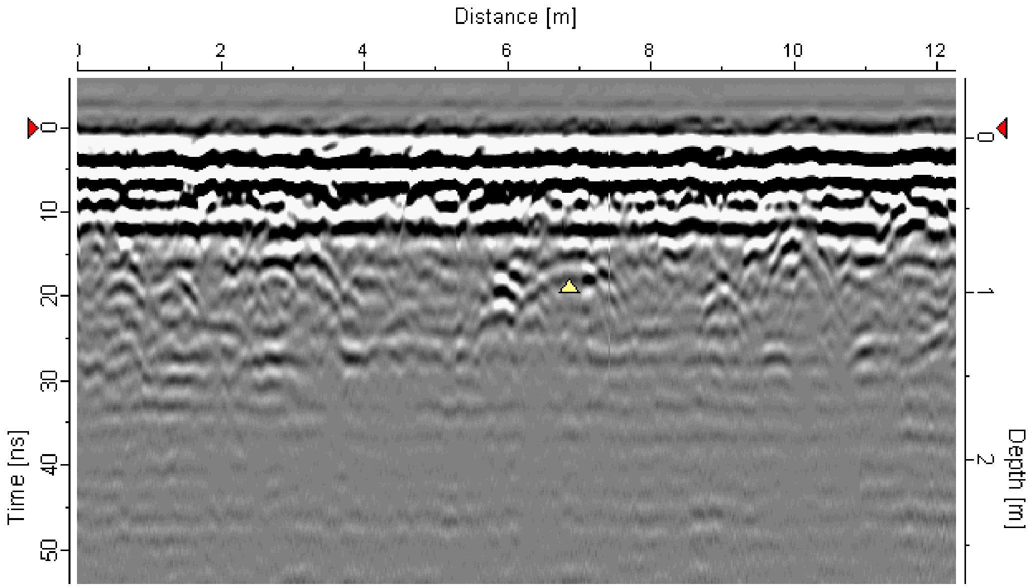

Figure 10. Profile of AS-21-89 detailing buried boulders in the lower layer.

Buried boulders were also shown to exist in the lower layers of the star mound (SU-LU-53), which was excavated by Peters (Peters 1969). The star mound excavated by Peters shows other commonalities to the Lefutu star mound (AS-21-89). As with AS-21-89, the upper region of the mound is largely void of large stones, while the lower regions contain loose aggregations of boulders throughout. Buried boulders are also largely present in the rays that project from the mound platform at SU-LU-53. The boulders range from the lower levels to just below the surface of the ray.

The buried boulders indicated in GPR profiles of star mound AS-21-89 would serve as a stabilizing matrix for the lower portion of the feature. The buried boulders may help to hold the sediments of the basal fill together, and combat erosion and shifting or slumping of the fill material. The presence of more boulders in the rays themselves, as opposed to the platform portion of SU-LU-53 might be attributed to the fact that the rays of earthen star mounds are the weakest portions. If so, the sloped arms of the mounds were given extra strength to counterbalance the higher risk of erosion by runoff or damage from human activity at the site.

The existence of boulders in the basal regions shown in GPR profiles of AS-21-89, as well as boulders in lower levels and in the arms of SU-LU-53 indicates that the final shape and number of rays at these features was pre-determined. The presence of boulders buried during the initial phases of construction, within both the platform and the rays also points towards the use of boulders as rough template, to which the fill of sediments and additional boulders were added.

The use of boulders as a stabilizing matrix for star mounds provided a lasting feature that became in all senses, monumental. The intent was, therefore, for these rayed platforms to be prevalent and permanent features within Samoan society. It may also be held of star mounds, that the shape and number of rays was preconceived. The use of boulders to give stability to the *tia 'ave* shows that these were constructed as lasting and sturdy monuments, capable of standing up to the slow destruction of use, time, and weather.

The study of excavated star mounds, (Peters 1969; Holmer 1976; Hewitt 1980; Best et al. 1989), shows that there is no formula for the construction methods of star mounds. There are very few constants to the internal stratigraphy of star mounds, making the construction processes of these features unique and site-specific. The presence of boulders within a few star mound sites does not mean that every star mound should then have buried boulders. Boulders within star mounds are not uncommon, and therefore the indications given by GPR profiles indicating the presence of buried boulders at AS-21-89 are quite plausible.

Buried pit and Stratigraphic Truncation

Ground-penetrating radar data taken at AS-21-89 also shows the possibility of a buried pit and a stratigraphic truncation (Figure 11). Stratigraphic truncation is caused by the addition of a homogenized soil to previously stratified region (Conyers 2004: 160). Reflection trace analysis of sediment truncations reveals that the traces within the truncation itself exhibit lower amplitude in relation to the traces on either side of the anomaly (Figure 12). The two covered features share a similar depth within the mound of roughly 0.60m to 0.70 meters beneath the surface. This depth, in-coincidentally, marks the beginning of the shift in amplitude that may distinguish the two major layers of the star mound. Pits and sediment truncations would of course require human activity; aside from the construction of the mound, as well as a hiatus in construction. Their existence below what appears to be a stratigraphic horizon further strengthens the idea of a dual phase construction process.

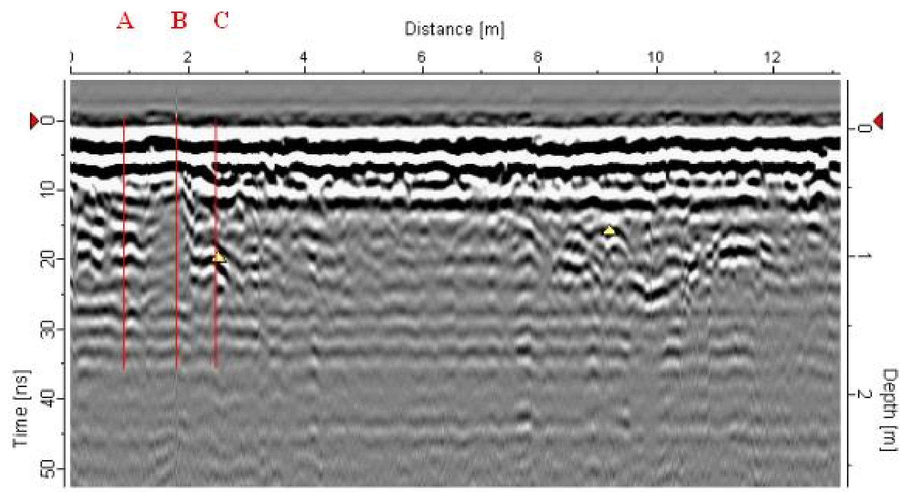

Figure 11. GPR profile indicating the existence of a buried stratigraphic truncation and probable pit feature. Letters A, B and C correspond with Figure 12.

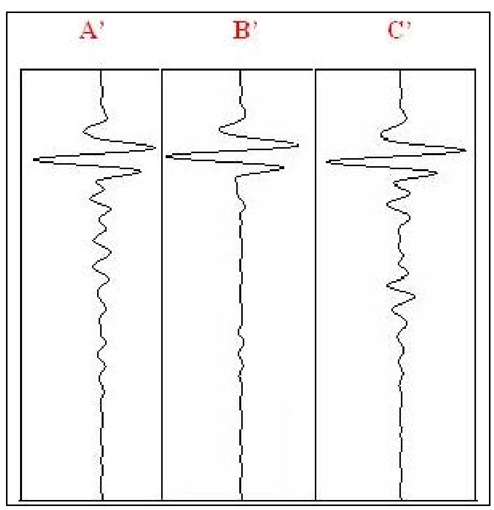

Figure 12. Reflection trace analysis of the stratigraphic truncation present within AS-21-89. Letters A', B' and C' correspond to the red lines (A, B, C) in Figure 11.

The presence of a probable buried pit, as well as the truncation lying buried within the star mound offers key information to this archaeological investigation. That is, at one point in time an activity took place on the primary level of the mound, before the final layer was added that created, what can best be interpreted as a pit. GPR profiles show that the pit feature measures approximately 3m across and 0.50 cm deep. This pit may be the remains of a charcoal lens left from a fire ring, or from a pit used in food storage, water casement, or although unsupported by any excavation (and viewed as highly unlikely by the author), a burial site. These finding give little direction as the ultimate use of this mound. However, it does indicate that: 1) The mound was not formed during a single event, 2) that activities took place on this mound that changed the original contour of the primary level, and 3) that the remains of this activity was later covered to create a taller, more prominent star mound.

The covered pit and truncation of course have the possibility of being geologic anomalies created during the fill process by means of clay translocation, or some other geologic factor that might create a pit-like contour on GPR profiles. Other factors may affect the interpretation of GPR profiles, such as background scatter or echoing lines on the profile. These may be erroneously interpreted as strata levels or buried objects of archeological interest, when in fact there are none present. To combat this dilemma of false data, background filters and time-gain filters are used to create more truthful GPR images. In the case of the profiles that indicate a pit and truncation, once filtered for background noise and given a time-gain adjustment, the probable pit and stratigraphic shear created by the truncation are still visible, and lie below a layer of increased amplitude (figure 13).

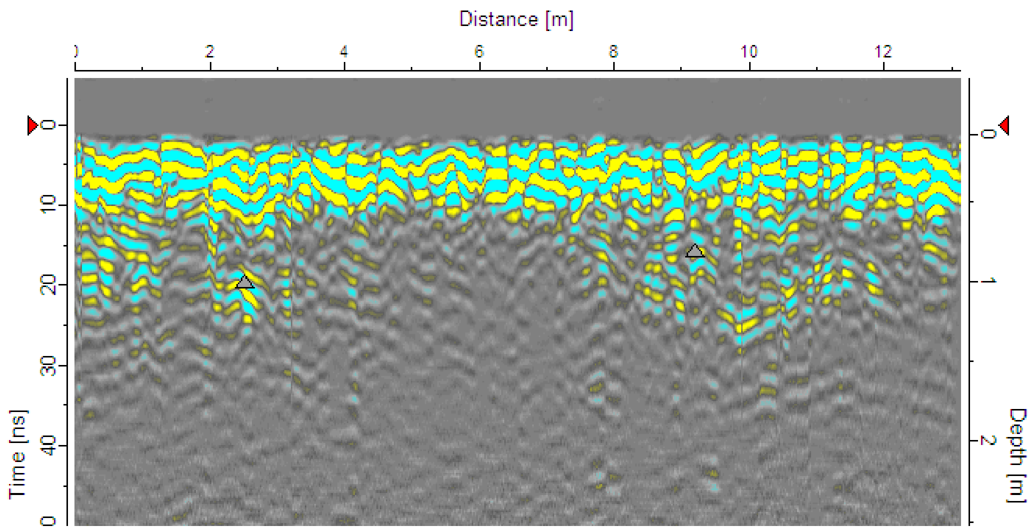

Figure 13. GPR image filtered for background scatter and echoes to diffuse false data. A time-gain filter was also applied, and shows the two probable features (pit and truncation) located under the layer of high amplitude. Note the break in amplitude that denotes the truncation (left) and the bowl shape of the pit (right).

The following passage is from the report made by Peters (Peters 1969), after excavations at star mound SU-LU-53. This offers a final note regarding the presence of a buried pit, as opposed to a geologic feature at star mound AS-21-89:

"*While in the interior of the mound were discovered, in the east section of rectangle A-2, two fire pits cut into each other at a depth of 63 cm. The diameter, which is only approximate because they were not fully excavated, was 130 cm, with a depth of .25 cm.*"(Peters 1969).

The Use of Border Stones at Star Mound Sites

A survey of star mounds on Eastern Tutuila by David Herdrich and Jeffery Clark (Clark and Herdrich 1988; Clark 1989) shows that not every star mound displays a retaining structure. However, the majority of *tia 'ave* are bordered by basalt cobbles, coral chunks, or a combination of both. Of the 62 star mounds described by Clark (1989) 57 star mounds display a prevalent or partial border of stone, coral, or both about the periphery. Five of the 62 star mounds show signs of little or no stone facing. The *tia 'ave* that display little or no stone border are also among the lowest and most poorly defined star mounds encountered by Clark (1989).

Those star mounds that display the best definition, such as AS-21-9 and AS-21-89 among others, exhibit a well-defined retaining structure of basalt boulders and/or coral chunks. Edging at star mounds ranges from a single broken ring of stones, up to a series of stacked stones several courses tall. The best example of a well-defined, un-weathered *tia 'ave* in the survey conducted by Clark is AS-21-9. It exhibits a large number of contiguous peripheral stones in relation to the other star mounds in the study. There is therefore an apparent relationship between low (eroded), poorly defined star mounds and the lack of well-constructed stone borders about the perimeter.

Beginning at the surface of the ridge top itself, ten earthen rays and the ten coves separating the arms of AS-21-89 slant gradually upwards. At approximately 1.5 m in elevation they level out and meet the platform surface. Slanted earthen walls are especially susceptible to erosion in regions with abundant rainfall, such as Tutuila Island. The use of border stones about the periphery of earthen features, graves, prehistoric house foundations and monumental structures is a common practice on Tutuila Island. The contiguous basalt cobbles present about the foot of the tia ’ave would have protected against the loss of definition at the mound due to weathering.

CHAPTER III

SUMMARY AND CONCLUSIONS: LEFUTU STAR MOUND (AS-21-89)

Based on GPR data gathered in the summer of 2005, and the limited publications of star mound excavations, it can be said that *tia 'ave* are rayed earthen features, located predominantly on ridge tops and mountain peaks, and were most likely created within the last 600 years (Davidson 1974; Holmer 1976; Frost 1978). The mounds in mountain regions consist of earthen and stone fill, while the few located in the plains were constructed of stone only. Star mounds are constructed with fill from the surrounding area. As seen in Peters (1969) and Clark (1989), large trenches and depressions often found surrounding these features provide a logical explanation for the origin of the fill material.

The vast majority of star mounds exhibit a full or partial border of basalt stones, coral chunks or a combination of both. Some star mounds, such as AS-21-89 and the star mound investigated by Peters (1969) also contain buried boulders within the mound. These boulders are most prevalent in the lower regions of the features, as well as within the rays (Peters 1969). The *tia 'ave* that display the best definition are those that have a well-made contiguous stone border about the periphery.

In comparing star mound excavations of Best (1989), and Peters (1969), it can be seen that there is no strict formula for star mound construction. The star mound investigated by Peters shows a concentration of larger stones in the lower levels of the feature, as also seen in the GPR survey of star mound AS-21-89. While the star mound investigation by Best makes no mention of large stones at all. An excavation of star mound SU MU-165 conducted by Holmer (1976) showed that it was comprised predominantly of basalt chunks with only a finishing layer of soil resting on top of the boulders. The availability of materials, therefore, appears to largely dictate the construction materials used to create star mounds (Clark 1989; Holmer 1976).

Regarding human activity at star mounds, Best does mention the presence of basaltic flakes near the surface of the star mound in his study. As a result, Best supports the idea that this may have been the original surface, and was eventually covered by sediment as a result of runoff from a terrace above it. This may indicate that the site explored by Best (1989) was used at one time for an activity other than the sport of pigeon snaring, possibly as a secondary use after the initial use(s) curtailed. Best also concludes that the presence of stone flakes near the surface may simply be the result of flakes thrown onto the mound fill as it neared completion.

Other possible explanations regarding the origin of stone artifacts at the star mound explored by Best (1989) exist. The lithics found within the star mound may have been deposited along with sediment and soils during the suggested runoff from the terrace above it. No cultural remains were found on the surface during a surface search at star mound AS-21-89. This does not eliminate the possibility that stone tool fragments or flakes may exist within the mound, however none were visible on the surface.

SU-LU-53 shows a layer of humus resting on the top of the mound with sediment layers below it that is relatively void of large stones. The large stones are present in loose collections near the base of the star mound and are also prevalent within rays. The construction schedule of AS-21-89 shares many similarities with that of SU-MU-53. Both exhibit a relatively homogenous upper region, with discontinuous soil and boulders in the lower region.

Ground-penetrating radar information collected at AS-21-89 shows that the site may contains subsurface anomalies such as a stratigraphic truncation, a buried pit and isolated regions of increased amplitude. Other subsurface changes that create GPR reflections are contained within the mound. These may include: density differences, changes in soil chemistry, fill material, electric or magnetic properties of the buried stones or different saturation levels within the mound.

The stratigraphic truncation may be the result of an intentionally refilled shaft. The possibility that the truncation simply resulted during the mound construction process also exists. The discovery of buried fire pits during excavation at SU-LU-53 by Peters (1969) lends additional support to GPR data taken in 2005, which points towards a buried pit feature at AS-21-89. If it is the case that a covered fire pit exists within AS-21-89, the surviving charcoal may be responsible for the high amplitude pit-shaped reflection due to its change in chemistry and density. Besides what appears to be two buried stones used for fill, there is no apparent object resting within the probable pit. This result gives no further credit to the idea of star mounds as burial mounds.

The possibility of two distinct layers within the mound, as well as a probable buried pit and truncation below the interface of these layers tells us that the mound may have been created in a dual phase process. If so, the mound was initially created with a fill of stone and earth. Upon this level an activity took place that caused the creation of a pit and stratigraphic truncation. This layer was later "topped off" with additional soil that, for the most part, lacked large stones. The period between fill phases remains unknown. However, this may be of lesser importance in comparison to the knowledge that human activity did in fact take place between phases.

Depressions found on the surface of star mounds may be somewhat rare, yet they do exist. Clark and Herdrich (1988) detail multiple star mounds that exhibit circular depressions or enclosures (e.g. AS-21-12, AS-21-13 and AS-21-14), which are often lined with stone. The presence of depressions on the surface of some star mound sites surveyed by Clark and Herdrich, and the indication of a two-layer construction at the Lefutu Ridge Mound (AS-21-89), gives further credit to the hypothesis of a buried pit or depression at AS-21-89.

Based on the existence of boulders in the lower layer of AS-21-89 it has been put forth that the stabilizing matrix of stones also served as a rough template for the construction process. This being said, the final shape of the star mound (AS-21-89) was pre-conceived by those that constructed it, using the boulders placed during the early stages as a partial constraint for the outline. Additional fill was then added until the feature attained the desired (primary) height.

Without excavation at AS-21-89 to search for the remains of shallow postholes, as well as research into oral histories and ethnographic works, it is impossible to determine the validity of the use of star mounds for weather observation platforms as presented in the interview with Mr. Wilson Fitiao of Matuu'u. It is an intriguing and physically feasible use of star mounds, even if as a secondary function. Further investigation and testing is required of this hypothesis to determine the validity of the claim.

Further investigation of additional star mound sites, sediment core analysis and excavations in order to ground-truth GPR data would give a wider base of information to draw upon in considering the varied array of construction methods and possible functions of star mounds. The conclusions and hypotheses created regarding *tia 'ave* construction methods and techniques are based on the most precise information presently available. As further investigation takes place at star mounds our ideas about them may change. It may be found that the function of star mound was multi-faceted, hence the difficulty in attributing them to a single use. It may be that *tia 'ave* served a purpose completely unknown to researchers, and since forgotten in oral history by the inhabitants of the Samoan Islands. As for now, we must continue the pursuit of an answer regarding the ultimate function of these prehistoric star-shaped mounds through continued survey, a deeper understanding of the oral histories, and new excavation projects.

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