INTERROGATING DATA-INTEGRITY FROM ARCHAEOLOGICAL SURFACE SURVEYS USING SPATIAL STATISTICS AND GEOSPATIAL ANALYSIS: A CASE STUDY FROM STELIDA, NAXOS

By

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Abstract:

The implementation and application of Geographic Information Systems (GIS) and spatial analyses have become standard practice in many archaeological projects. In this study, we demonstrate how GIS can play a crucial role in the study of taphonomy, i.e., understanding the processes that underpinned the creation of archaeological deposits, in this case the distribution of artifacts across an archeological site. The *Stelida Naxos Archeological Project* (SNAP) is focused on the exploration of a Paleolithic-Mesolithic stone tool quarry site located on the island of Naxos, Greece. An extensive pedestrian survey was conducted during the 2013 and 2014 archeological field seasons. An abundance of lithic material was collected across the surface, with some diagnostic pieces dating to more than 250 Kya. Spatial statistical analysis (Empirical Bayesian Kriging) was conducted on the survey data to generate predictive distribution maps for the site. This study then determined the contextual integrity of the surface artifact distributions through a study of geomorphic processes. A digital surface model (DSM) of the site was produced using Unmanned Aerial Vehicle (UAV) aerial photography and Structure from Motion (SfM) terrain modeling. The DSM employed to develop a Revised Universal Soil Loss Equation (RUSLE) model and hydrological flow models. The model results provide important insights into the site geomorphological processes and allow categorization of the diagnostic surface material locations based on their contextual integrity. The GIS analysis demonstrates that the surface artifact distribution has been significantly altered by post-depositional geomorphic processes, resulting in an overall low contextual integrity of surface artifacts. Conversely, the study identified a few areas with high contextual integrity, loci that represent prime locations for excavation. The results from this study will not only be used to inform and guide further development of the archeological project (as well as representing significant new data in its own right), but also contributes to current debates in survey archaeology, and in mapping and prospection more generally. This project demonstrates the benefit of using spatial analysis as a tool for planning of pedestrian surveys and for predictive mapping of artifact distributions prior to archaeological excavations.

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Table of Contents

Lists of Figures and Tables:

Chapter 1: Introduction

Chapter 2: SPATIAL ANALYSIS AS A TOOL FOR INTERROGATING AND INTERPRETING SURFACE PEDESTRIAN SURVEY RESULTS AT STELIDA (LOWER PALEOLITHIC-MESOLITHIC) SITE, NAXOS GREECE.

Chapter 3: EVALUATING GEOMORPHIC CONTROLS ON SITE FORMATION PROCESSES AND SURFACE ARTIFACT DISTRIBUTION USING DRONE-BASED AERIAL PHOTOGRAMMETRY: A CASE STUDY FROM THE STELIDA PREHISTORIC QUARRY (NAXOS, GREECE).

Preface:

McMaster University copyright regulations require a report of writings submitted for thesis completion that will also be used in professional publications. This section outlines the author's and co-authors contribution to various papers.

Chapter 2: SPATIAL ANALYSIS AS A TOOL FOR INTERROGATING AND INTERPRETING SURFACE PEDESTRIAN SURVEY RESULTS AT STELIDA (LOWER PALEOLITHIC-MESOLITHIC) SITE, NAXOS GREECE.

In this paper, spatial analysis was applied to mapping of the distribution patterns of surface artifacts with the aim of identifying significant clusters of archaeological materials. Due to the large number of lithic artifacts on the modern surface, spatial statistical methods were implemented to identify statistically-significant assemblages and to determine the spatial pattern of artifact 'hot-spots'. The pedestrian survey was conducted by members of SNAP in 2013-2014 and comprised the primary data source for this project. Y. Pitt assembled the artifact database and conducted all spatial analysis and interpretation of data under the supervision of Drs. Carter and Boyce. After a final round of edits this paper will be submitted to the *Journal of Archaeological Sciences*.

Chapter 3: EVALUATING GEOMORPHIC CONTROLS ON SITE FORMATION PROCESSES AND SURFACE ARTIFACT DISTRIBUTION USING DRONE-BASED AERIAL PHOTOGRAMMETRY: A CASE STUDY FROM THE STELIDA PREHISTORIC QUARRY (NAXOS, GREECE).

This paper evaluates the geomorphic controls on the surface distribution of lithic artifacts at Stelida using digital terrain and soil erosion modelling (RUSLE) to quantify slope erosion and sediment source areas. Y. Pitt acquired the drone photogrammetric survey in collaboration with a Greek survey UAV contractor and was responsible for processing and analysis of all SfM workflows, RUSLE and hydrological modelling. Supervisors Carter and Boyce and SNAP colleagues assisted with study design and data collection and contributed to the interpretation of results. Following a final round of edits this paper will be submitted to the *Journal of Field Archaeology*.

CHAPTER 1 INTRODUCTION

1.1 RATIONAL AND OBJECTIVES

This research project aims to evaluate the spatial integrity of artifact distribution from site-specific archaeological surveys, focusing on the results of the *Stelida Naxos Archaeological Project* (SNAP) (Cyclades, Greece). A GIS-based approach was employed to spatially analyze surface artifact distribution with the objective of quantifying 'hot-' and 'cold-spots' in the context of various geomorphic processes and other factors that have influenced artifact distribution. The analysis draws upon quantified/qualified (dated) and standardized archaeological pedestrian survey data that was overlain a micro-topographic model digital terrain model generated from Unmanned Aerial Vehicle (UAV) photography using Structure from Motion (SfM) methods. Site characteristics, such as topography, will impact the geomorphic evolution of the area and therefore will have altered the surface distribution of cultural material.

A long-established component of archaeological fieldwork globally is the pedestrian survey, which is the non-invasive, systematic collection and mapping of surface artifacts across a site (Cherry et al., 1988; French and Whitelaw, 1999; Rick, 1976; Terrenato, 2004; Whitelaw, 2007). Nearly all archaeological data has a spatial component and therefore may be mapped and analyzed spatially (Hill et al., 2009; Kvamme, 2012; Maschner, 1996). Understanding the spatial distributions of artifacts, as well as identifying primary versus secondary deposits, provides valuable insight into the activity that occurred within the area (Conolly and Lake 2006; Kvamme 2012). Many different processes can influence cultural materials; thus, it is imperative that an effort is made to identify what environmental processes have occurred so that the cultural activity can be more clearly understood (Conolly and Lake 2006; Kvamme 2012; Maschner 1996). One of the key requirements of survey archaeology is to critically reflect on the environmental and cultural factors that determine the distribution of artifacts across landscapes rather than taking this data at face value. Environmental factors include geomorphic processes such as fluvial and aeolian erosion. Cultural factors may include agricultural practices (e.g., terracing) and landscape modification (terracing, bulldozing, quarrying). The effects of these processes, both environmental and cultural, are difficult to separate and understanding the spatial distribution of materials requires drawing upon a range of geo-archaeological data types and analytical skills. There is a range of environmental and cultural factors that could shape/distort/hide the archaeological record, with the underlying question being: Does what you find on surface reflect what is directly under the ground, or has the material been transported from somewhere else?

Conventional distribution analysis within archaeology has been based largely on qualitative observations of artifact distribution. Few studies have employed spatial statistical methodologies to quantify the distribution patterns. This project aims to build on the emerging trend within archaeology to statistically derive and evaluate distribution patterns (Rick, 1976, Maschner, 1996). Microtopographic modelling using UAV image capture and SfM methodology is still in its early phases in archaeological studies (Hill, 2013; Kvamme, 2012; Roosevelt, 2014). With archaeologists' increasing access to hardware and software, the implementation of these processes is expected to become common practice.

This thesis builds upon the Doyle's (2018) preliminary analysis of cultural material deposition and assemblage integrity at Stelida. In his study, increased artifact edge rounding was used as an indicator of the degree of taphonomic alteration by post-depositional transport. Ultimately, it was concluded that larger, heavier artifacts were associated with a greater down slope transport from their source locations. Doyle's (2018) research focused only on a small sub-sample of the site but demonstrated that a larger-scale taphonomic analysis of the site and artifact distribution would be of benefit to SNAP.

This research project employs innovative spatial statistical methods in conjunction with high resolution UAV-derived topographic models to evaluate the influence of geomorphic processes on the distribution of artifacts at Stelida. The spatial datasets and predictive mapping produced in this investigation will be added to the extensive SNAP database to aid in further exploration and future research at Stelida. Furthermore, the thesis highlights the importance of utilizing spatial statistics to analyze archaeological artifact distribution, as a method of determining areas of cultural relevance at a site as well as to guide further archaeological surveys. This research study adds to the growing number of projects to implement similar techniques to aid with the furtherment of technology, archeological project design, and the study of taphonomy.

1.2 STUDY AREA

1.2.1 Physical and Geological Setting

The Stelida study site is located on the west coast of Naxos in the southern Aegean, about 175 km southeast of Athens (Fig. 1.1). Naxos is the largest of the Cycladic Islands (430 km^2) with a population of ~20,000 (Fig. 1.1). The island has a high relief topography defined by a central mountain range that extends from north to the southernmost tip of the island. Stelida is the westernmost point on Naxos (Fig. 1.1) and is characterized by a steep double-peaked hill with maximum elevation of 151 m.a.s.l (Fig. 1.3).

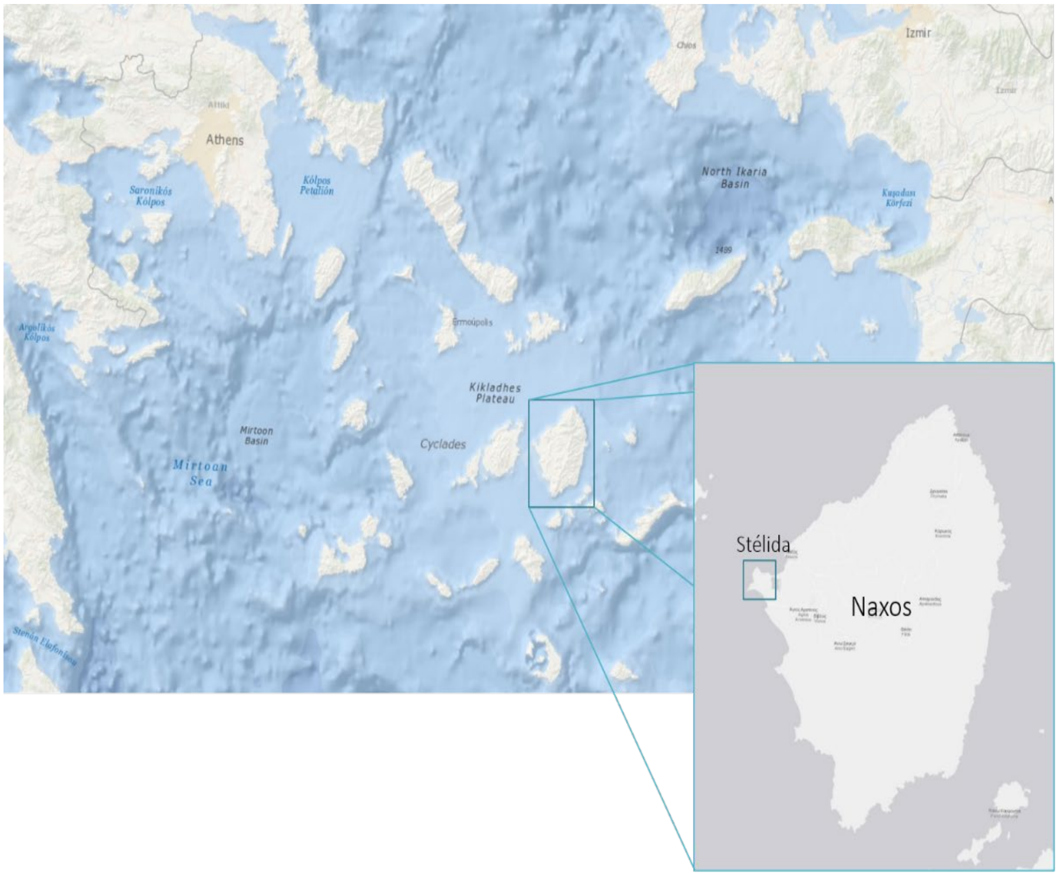

Figure 1.1: Map showing location of Naxos in the southern Aegean and the Stelida study area (inset) (Map source ESRI).

Naxos forms part of the Attico-Cycladic collisional belt of the Hellenides formed during Eocene (ca. 50 Ma) Alpine subduction and subsequent Cenozoic continental extension (Piper et al., 1997; Vanderhaeghe et al., 2017)(Fig. 1.2). The island is a well preserved example of a metamorphic core complex (MCC), comprising a central migmatite dome surrounded by high-grade Permo-Carboniferous to latest Cretaceous metamorphic rocks (the Cycladic Blueschist Unit; CBU). The CBU metasediments consist of marble, schists, and metapelites with minor meta-volcanic and amphibolite units (Evelpidou et al., 2012; Skarpelis et al., 2017). In the western part of the island, the CBU is intruded by Miocene (ca. 13-14 Ma) granodiorites (Piper et al., 1997).

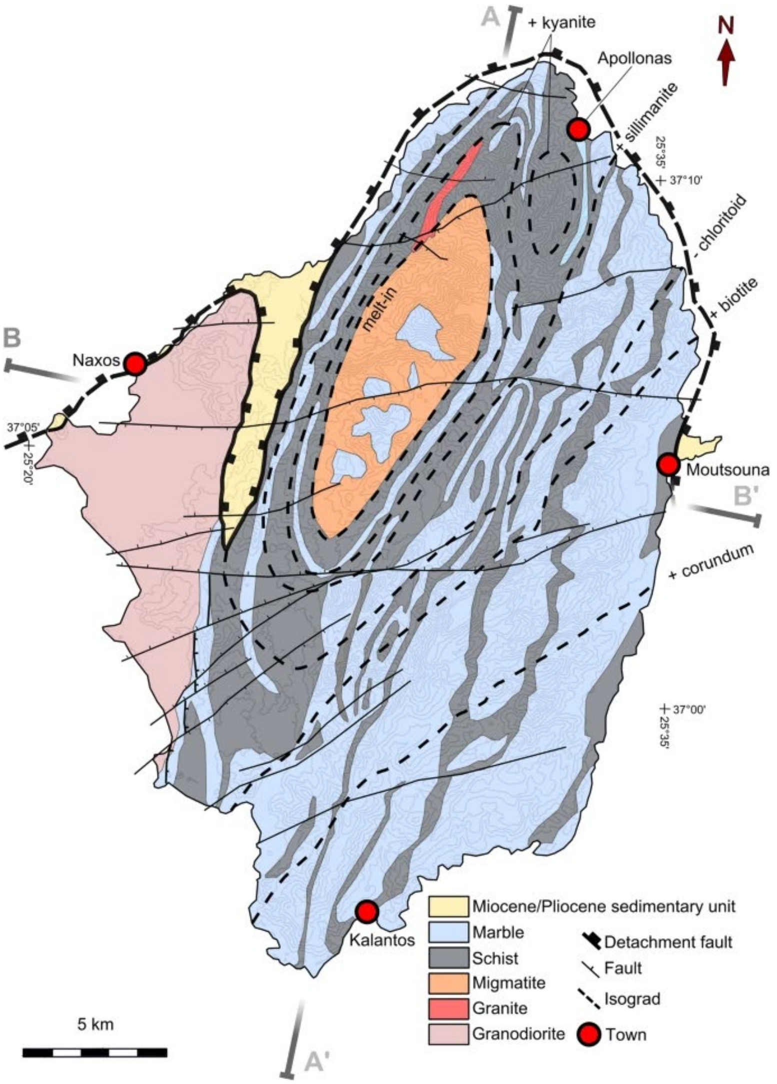

Figure 1.2: Geological map of Naxos (Linnros et al., 2019). The Stelida study site straddles the Moutsounas detachment fault which juxtaposes Miocene granodiorites and Miocene-Pliocene sedimentary rocks. The Stelida chert deposits likely formed as a result of hydrothermal alteration and silicification of clastic sediments following the intrusion of the granodiorite.

Figure 1.3: Westward view of Stelida peninsula, Naxos. The southern peak (left) consisting of Oligocene-Miocene clastic sedimentary rocks has a maximum altitude of 151 m.a.s.l. Rocks in the foreground are Miocene granodiorites.

At Stelida, the bedrock comprises a sequence of Upper Oligocene to Middle Miocene clastic sedimentary rocks which are juxtaposed against Miocene granodiorite along a west-east detachment fault (Fig. 1.2). The southern half of Stelida is underlain by granodiorite bedrock, while the northern half has a sedimentary rock base. Shales, sandstone and conglomerate rocks underly the northern section that formed from detrital marine, lacustrine and fluvial deposits of Miocene age (Skarpelis et al., 2017). The detachment fault, that separates the granodiorite and sedimentary, is part of the Moutsouna extensional fault system (Skarpelis et al., 2017). The hanging wall of the fault contains the sedimentary rocks.

Located at the hill's peaks are large exposures of underlying chert units. It is these outcrops of raw material that are believed to be the focus of archeological activity across the site (Fig. 1.3). Chert is a siliceous microcrystalline sedimentary rock that results from the silicification of sedimentary precursors (Skarpelis et al., 2017). The chert formation has been attributed to the movement of hydrothermal fluids along the W-E detachment fault that separates the Mesozoic protolith units. from the granodiorite intrusion. A silica-rich hydrothermal solution moved along the detachment fault fed by the thermal energy and circulating water as the intrusion cooled (Evelpidou et al., 2012; Piper et al., 1997; Skarpelis et al., 2017). The silica-rich fluid penetrated into the sedimentary protolith forming the chert. The characteristics of the Stelida chert are not uniform and change from one side of the hill due to changes in the lithology of the chert protolith. The chert deposits vary in multiple characteristics including: colour which can range from white, to shades of grey and light-yellow hues; luster from earthy to vitreous; and sedimentary structures which include irregular, sub parallel, wavy bedding and laminations. The chert is cross-cut at several locations by quartz veins that are believed to have formed at later stages in the alteration process (Skarpelis et al., 2017).

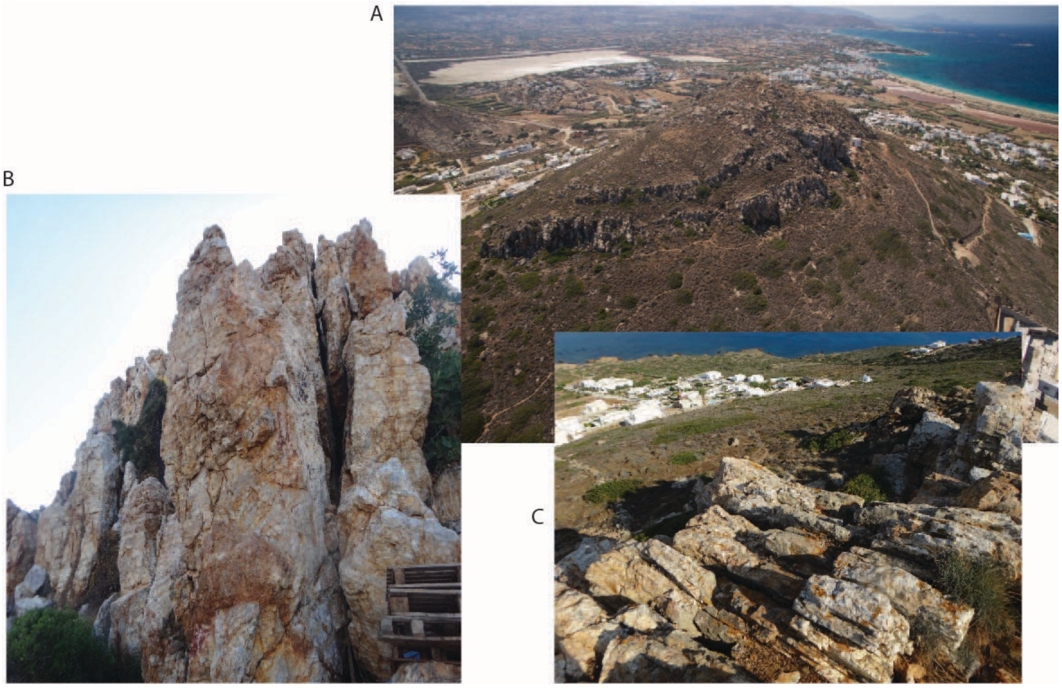

Figure 1.4: A) Southeastern view of the southern peak of Stelida showing chert outcrops, B) 10 m high chert outcrop exposure on western side south peak. C) Northward-dipping chert beds cropping out on the western slope.

The slopes of Stelida and the surrounding lowlands are covered by a variable thickness of unconsolidated Quaternary deposits, which include colluvium (debris, sheetflood deposits), alluvium and aeolian deposits (Carter et al., 2019; Evelpidou et al., 2010). An excavation trench on the western slope of Stelida revealed 3.8 m of stratified colluvial deposits and capped by a thin (< 20 cm) poorly-sorted silt-loam soil (Fig. 1.4) (Carter et al., 2019). The soils at Stelida are alkaline (pH 7.4 to 8.6), which results in a poor preservation of buried organic material (Carter et al., 2019). The lithostratigraphy of artifact-bearing Quarternary units have been examined in a number of outcrop sections and trenches and dated by infrared stimulated luminescence (IRSL) dating. Dating of surficial debris flow deposits have yielded ages of 13.8 to 12.2 Kya and paleosols at 2.7 m depth have ages of 189.3-219.9 to Kya (Carter et al., 2019).

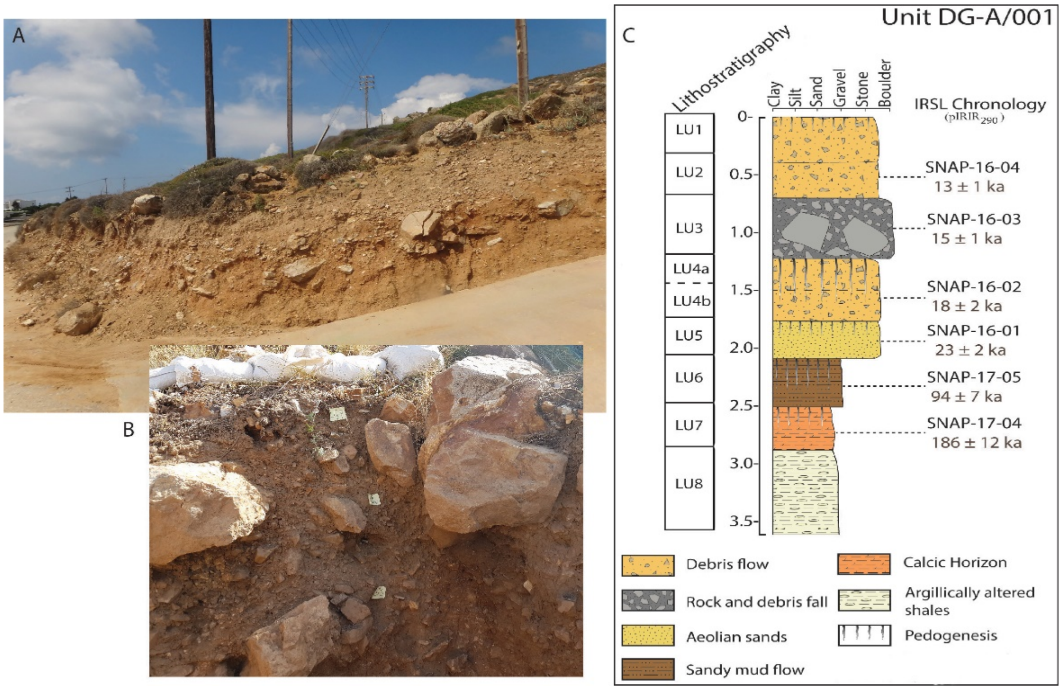

Figure 1.5: A) 1.5 m outcrop on the eastern slope of Stelida exposing Quaternary colluvial deposits, including debris flows and sheetwash units. B) Upper 0.3 m of an excavation trench on the western slope of the Stelida showing poorly sorted debris flow units with a silty sand matrix with abundant angular pebble- to boulder-sized clasts. C) Stratigraphic profile, geoarchaeological interpretation, and geochronology of unit DG-A/001 with dates expressed as 68% confidence intervals. Modified from figure by J. Holcomb. and P.Karkanas (Carter et al., 2019).

1.2.2 Archaeology of Stelida

A focused geological study was conducted at Stelida in the 1960s (Roesler 1969), however the presents of archaeological material was only formally recognized in the early 1980’s during an island-wide archaeological survey by the *École Française D’Athènes* (Treuil, 1983). This survey’s initial report of the site afforded a brief description of the artifacts recovered (Séfériadès, 1983). During that time, the perceived wisdom was that the Cyclades had not been colonized until ~7000kya during the Late Neolithic (Cherry 1981). The Stelida artifacts had little resemblance to the later Neolithic or Bronze Age material, thus it was concluded that the site must be of earlier date, and tentatively assigned to the

Early Neolithic, or Epi-Palaeolithic (Séfériadès, 1983). In the early 2000's, the Greek Ministry of Culture conducted a small-scale salvage excavation ahead of land development projects (Carter, 2017). Since the 1980's the land at Stelida has become increasingly valuable for residential and commercial use, and in 2000 the site was given formal Ministry protection (Carter, 2017). Publications from these Ministry rescue excavations claimed that not only might the site be pre-Neolithic, as first suggested by Séfériadès (1983), but also that it had a greater antiquity, with artifacts as far back as the Lower Palaeolithic based on the techno-typological characteristics (Skarpelis et al., 2017; Legaki, 2012, 2014). SNAP was initiated in 2013 with the aim of characterizing the archaeology of Stelida, and remains ongoing at the time of writing (www.stelida.org). The importance of this site lies in the insight that it can provide into the pre-Neolithic activity on Naxos and within the Cyclades (Carter et al., 2017).

The study of the migration and dispersion of early hominins out of Africa and into Europe during the Pleistocene (2.59ma – 11.7ka) has been a primary area of research in anthropology, archaeology, and geology for decades (Holcomb, 2020; Darwins, 1859; Grayson, 1983). There are still remaining areas pertaining to the nature and timing of the dispersion of various Homo species into Europe that are the subject of study today (Kintigh et al., 2014; Forman and Stinchcomb, 2015, Harvati et al., 2009; Tourloukis, 2010). Historically, the accepted theory is that several species of early hominins migrated out of Africa utilizing predominately terrestrial routes into southwest Asia and Europe (Templeton, 2002; Anton and Swisher, 2004; Carbonell et al., 2008; Abbate & Sagri, 2011; Bar-Yosef & Belfer-Cohen, 2001, 2013; Roebroeks, 2006; Rolland, 2013; Groucutt et al., 2015). However, recent studies have begun to argue that this traditional migration model is overly simplistic and does not account for alternate routes that utilized open water crossing or the likelihood of back-and-forth migration (Villa, 2001; Bednarik, 2003; Rolland, 2013; Runnels, 2014; Simmons, 2014; Groucutt et al., 2015). Based on these modern theories, Greece and the

Aegean Sea basin have become an increasingly important area of interest due to its geographic location between southwestern Asia and Europe (Tourloukis, 2010; Harvati et al., 2009). Current research is looking for evidence to support the theory that hominin species migrated from Anatolia through the Greek Island and/or an Aegean Basin land bridge and into Europe, utilizing a combination of terrestrial land bridges and open-water crossing (Harvati et al., 2009; Tourloukis, 2010; Tourloukis and Karkanas, 2012; Runnels, 2014; Runnels et al., 2014b; Carter et al., 2019; contra Leppard, 2014).

There has been relatively recent development in Paleolithic Archeology in Greece, with emerging research on sites dating from the Upper Paleolithic to Pleistocene (Gowlett, 1999; Bailey et al., 1999; Runnels, 2001; Harvati et al. 2009; Tourloukis, 2010;Tourloukis and Harvati, 2018). Recent paleogeographic reconstructions suggest that the Greek islands alternated between isolated islands and land bridge connected land masses several times during the Pleistocene as the result of sea-level oscillations during the glacial and interglacial periods (Lambeck 1996; Lykousis 2009). During the last glacial maximum Naxos is believe to have been part of a mega-island (Cycladia) (Carter et al., 2019; Lambeck, 1996; Runnels, 2014). Excavations at Stelida by SNAP examined ~4m of artifact rich stratified sediments that date ~200kya, resulting in some of the first evidence of early hominin activity in the Aegean Basin, and extending the prehistory of the island by 180,000 years (Carter et al., 2019). These findings indicate that early hominins were able to access the raw chert material on Stelida, tens of millennia earlier than previously believed (Carter et al., 2019). This research at Stelida, supports the development of new migration theories that there was early hominin exploration or colonization through terrestrial or seafaring migration paths through the Aegean basin (Carter et al., 2019).

1.3 STRUCTURE FROM MOTION

Structure from Motion (SfM) is photogrammetric technique for construction of 3-D digital surface models from a set of overlapping 2-D photo images. The method determines the spatial and geometric relationships between objects on a 3-D surface (e.g., surface topography) using the displacement vectors determined from a moving camera platform. Images are captured from various locations around the subject of study and the object shape and 3-D structure is determined from a set of co-incident pixels on overlapping photo images (Howland et al., 2014; Micheletti et al., 2015; Snavely et al., 2008). A major benefit of SfM is that it does not require prior knowledge of the surface geometry or the camera locations or orientation. SfM can utilize images from multiple collections of photos and fundamentally lowers the skill level required for users to produce SfM models (Aber et al., 2019; Bi et al., 2017; Chandler et al., 2015; Letortu et al., 2018; Micheletti et al., 2015; Tonkin et al., 2014; Westoby et al., 2012). Collection of overlapping images is an important requirement for SfM methods. Typically, images are acquired with at least a 75% overlap. Shadows and changes in light should be minimized to maximize the surface textural contrast to provide key points for pixel matching within SfM algorithms (Letortu et al., 2018; Micheletti et al., 2015; Westoby et al., 2012).

The SfM workflow can be implemented using a number of available software platforms, including VisualSfM and Meshlab freeware and commercial software packages such as Agisoft Metashape or Pix4D. Regardless of which software is used, the methodology requires the use of at least three or more photos, that were taken at different distances and with minimal shadows and changes in light (Aber et al., 2019; Howland et al., 2018; Letortu et al., 2018; Micheletti et al., 2015; Westoby et al., 2012). This methodology has undergone much refinement in the last decade through implementation in a number of applications across a variety of disciplines such as geoarchaeology, glaciology, sedimentology, hydrology and civil engineering (Bi et al., 2017; Eltner et al., 2018; Gouma et al., 2011; Letortu et al., 2018; Micheletti et al., 2015; Oczipka et al., 2009; Smith et al., 2014; Stumpf et al., 2015; Tonkin et al., 2014).

1.3.1 Unmanned Aerial Vehicle (UAVs) Photography

Over the past decade there have been major advances in Unmanned Aerial Vehicle (UAV) and high-resolution camera sensors technology, which has broadened the adoption of SfM techniques for topographic relief modelling in a broad range of disciplines (Bi et al., 2017; Clark, 2017; Hill, 2019; Hugenholtz et al., 2016). Aerial drone mapping has been adopted for surface topographic modelling in archaeology, cultural resource management, architecture and geoscience research. The growing adoption of UAV mapping has also been accelerated by improvements in camera sensor resolution, UAV maneuverability, increased flight time, and easy to use controls and interfaces (Bi et al., 2017; Clark, 2017; Tonkin et al., 2014). Currently available UAV systems have the ability to follow and capture images along a pre-defined flight paths, allowing rapid swath mapping of large areas at high image resolution (Bi et al., 2017; Clark, 2017; Eltner et al., 2018). UAVs and SfM methods are being employed increasingly in archaeological studies to create high-resolution digital terrain and microtopographic models.

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CHAPTER 2 SPATIAL ANALYSIS AS A TOOL FOR INTERROGATING AND INTERPRETING SURFACE PEDESTRIAN SURVEY RESULTS AT STELIDA (LOWER PALEOLITHIC-MESOLITHIC) SITE, NAXOS GREECE

ABSTRACT

In 2013 and 2014 the *Stelida Naxos Archeology Project* (SNAP) conducted an intensive pedestrian survey of a chert source and prehistoric stone-tool production site on the Cycladic island of Naxos, Greece. Over 30,000 archaeological artifacts were collected systematically, of which ~7000 were chronologically diagnostic, indicating intermittent exploitation of the source material from the Lower Paleolithic to Mesolithic (≥250,000 – 9000 kya) by *Homo sapiens*, *Neanderthals* and potentially earlier *hominins*. Preliminary interpretation of the survey results indicated the existence of a number of artifact 'hot-spots' with elevated concentrations of lithic materials but failed to (a) contextually quantify the pattern of hot-spots or (b) critically reflect on their significance as records of prehistoric activity and the site formation (taphonomic) processes that led to their creation. This study addresses these issues by spatial statistical analysis of the SNAP survey data to generate predictive maps of the distribution of lithic materials across the site. The lithic distribution was mapped using Empirical Bayesian Kriging (EBK) and the patterns for four different archaeological periods were compared to understand the site occupation history and exploitation of chert sources. Predictive mapping demonstrates that Lower Paleolithic period hot-spots were concentrated around the northern peak and on the northeastern slope of the southern peak. Middle Paleolithic period artifacts were concentrated in the mid-northeastern and mid-western slope of the southern peak and Upper Paleolithic and Mesolithic periods materials were found on the southern slopes of the southern peak closer to summit of chert source outcrops. The results indicate that spatial distribution of lithic materials is non-random and has been influenced both by human agency and by hillslope sediment transport processes. This project demonstrates the benefit of using spatial analysis as a tool for resource management and planning as an archeological study progresses. This approach uses statistics to quantifiably define what concentration of surface material is considered a hot-spot, by determining the numerical threshold value that a concentration needs to exceed in ordered to be considered statistically significant. The distribution analysis of this project then delineated the spatial extent and position of these significant areas located predominately on the western and eastern mid-slopes of the southern peak.

KEYWORDS: Spatial analysis, pedestrian surveys, lithics, predictive mapping, Empirical Bayesian Kriging,

2.1 INTRODUCTION

The purpose of archeological fieldwork is to generate various forms of materially based evidence with which to help further understand past cultural activities not only at that location, but also the human condition and practices more generally (Renfrew & Bahn, 2010a; Thomas & Kelly, 2007). Central to this endeavor is the recovery of ‘artifacts’, i.e., objects that were anthropogenically created, used and discarded, whose study can inform us as to past activities, cultural traditions, environment *inter alia* (Hodges, 1964). While stratigraphic excavation is arguably the best-known means of investigating the physical remains of past human activity, there has been a significant turn since the 1970’s to the use of pedestrian survey (hereafter ‘survey’) to locate, map and investigate archaeological sites (Banning, 2002; Peregrine, 2001). Surveys thus involve the prospection for, and documentation of artifacts that lay on a modern land surface, with all recording and collection following a systematic method that ideally allows for comparison between sites/projects on a regional and supra-regional scale (Alcock and Cherry 2016; Cherry et al., 1988; French & Whitelaw, 1999; Schiffer et al 1978; Terrenato, 2004; Whitelaw, 2007).

Archeological surveys can vary in scale from regional investigations of many square kilometers, to site-specific studies of a few hundred square meters (Cavanagh et al., 2005; Peregrine, 2001; Renfrew & Bahn, 2010b; Terrenato, 2004), with the projects involving the production, storage and interrogation of large datasets (Bevan, 2012; Bevan & Conolly, 2006, 2012). By extent, the spatial variability in artifact distribution is a critical attribute to site definition and the interpretation of the activities that took place there, it follows that there has been an increase in the implementation of geographic information systems (GIS) as a tool for organization and analysis of these survey datasets (Bevan & Conolly, 2004; Conolly & Lake, 2006; Kvamme, 2012; Maschner, 1996).

This paper is concerned with the use of GIS in the context of site-specific survey data, with a case study on the island of Naxos in the southern Aegean, Greece (Fig. 2.1). Survey archaeology has a very rich history in continental and insular Greece (Tartaron 2008), including the development and implementation of projects dedicated to the study of single sites, as for example with the work of Whitelaw (1991, 2006) at Kephala and Paoura on Kea, and Markiani on Amorgos, Cavanagh et al. (2005) on the Laconia Rural Site Project, and Runnels et al. (2003), at Spilaion in Epirus. While projects now involve the collection of both cultural and environmental variables, these vast datasets often remain analytically dormant (Bevan & Conolly, 2009). Surveying techniques are becoming more technologically enabled, with remotely sensed and geophysical survey data included in the collection process (Peregrine, 2001; Renfrew & Bahn, 2010b). Though the collection and implementation of GIS datasets is increasingly common utilization of spatial statistical analyses to further interrogate the data has not been adopted as rapidly (Bevan & Conolly, 2009; Kvamme, 2012).

One key issue facing survey archaeologists is the locational integrity of their surface material. Simply stated, do the artifacts we find on the ground reflect past activities that took place *in that spot*, the material having been unearthed by some form of disturbance (e.g., ploughing, development), or have they come to rest in this locus, having been displaced from their original place of deposition by processes such as downslope soil erosion, bulldozing, or even the introduction of soil from somewhere completely different (landfilling, road levelling etc.)? Understanding how the artifacts came to be upon the modern surface, and where they came from, is fundamental to the interpretative process. If an archaeologist wants to investigate a particular aspect of human behavior though a scientific excavation, they will first need to find a site that appears to fulfil those characteristics. Survey data is often the point of departure for such ventures, yet it is imperative to know whether surface artifact location can be used directly to guide our excavation strategy (‘X-marks-the-spot’), or provides no such straightforward insight to the location of past cultural practices. The main underlying issue is that of taphonomy, i.e., the study that seeks to make sense of the cultural and environmental processes that shape the archaeological record (what happens to an artifact post-deposition), including the heterogeneous spatial distribution of surface material (Bevan & Conolly, 2009; French and Whitelaw, 1999; Schiffer, 1983). In short, one of the key requirements of survey archaeology is to *critically reflect on the natural (environmental) and cultural processes that underpin the distribution of artifacts across a site or landscape*. The categories of environmental processes include gravity-driven hillslope processes (e.g., sediment gravity flows), fluvial and aeolian processes, climate and the influence of vegetation and animals (environment). Cultural factors include anthropogenic activities such as agricultural practices and landscape modification (terracing, bulldozing, quarrying).

An important tool available to archeologists to tackle these questions and better understand their data is the implementation of GIS-based spatial statistical analyses (Conolly & Lake, 2006; Kvamme, 2012; Maschner, 1996; Peregrine, 2001; Renfrew & Bahn, 2010a). Some examples of the use of modern spatial statistical methods in archaeology can be found in the work on the Greek islands of Kythera and Antikythera (Bevan & Conolly, 2004, 2009) as well as the work in Junin, Perú (Rick, 1976). This project builds on this emerging trend of statistical analysis integration within archaeological investigations, in order to evaluate the spatial distribution patterns of artifacts at Stelida, Naxos. The results of this study support the use of this methodology for predictive mapping of artifact distribution and data interrogation to aid in the interpretation of archeological data. This study forms a part of the larger *Stelida Naxos Archaeological Project* (SNAP) research framework and employs data from their 2013-14 survey (Carter et al., 2014, 2016).

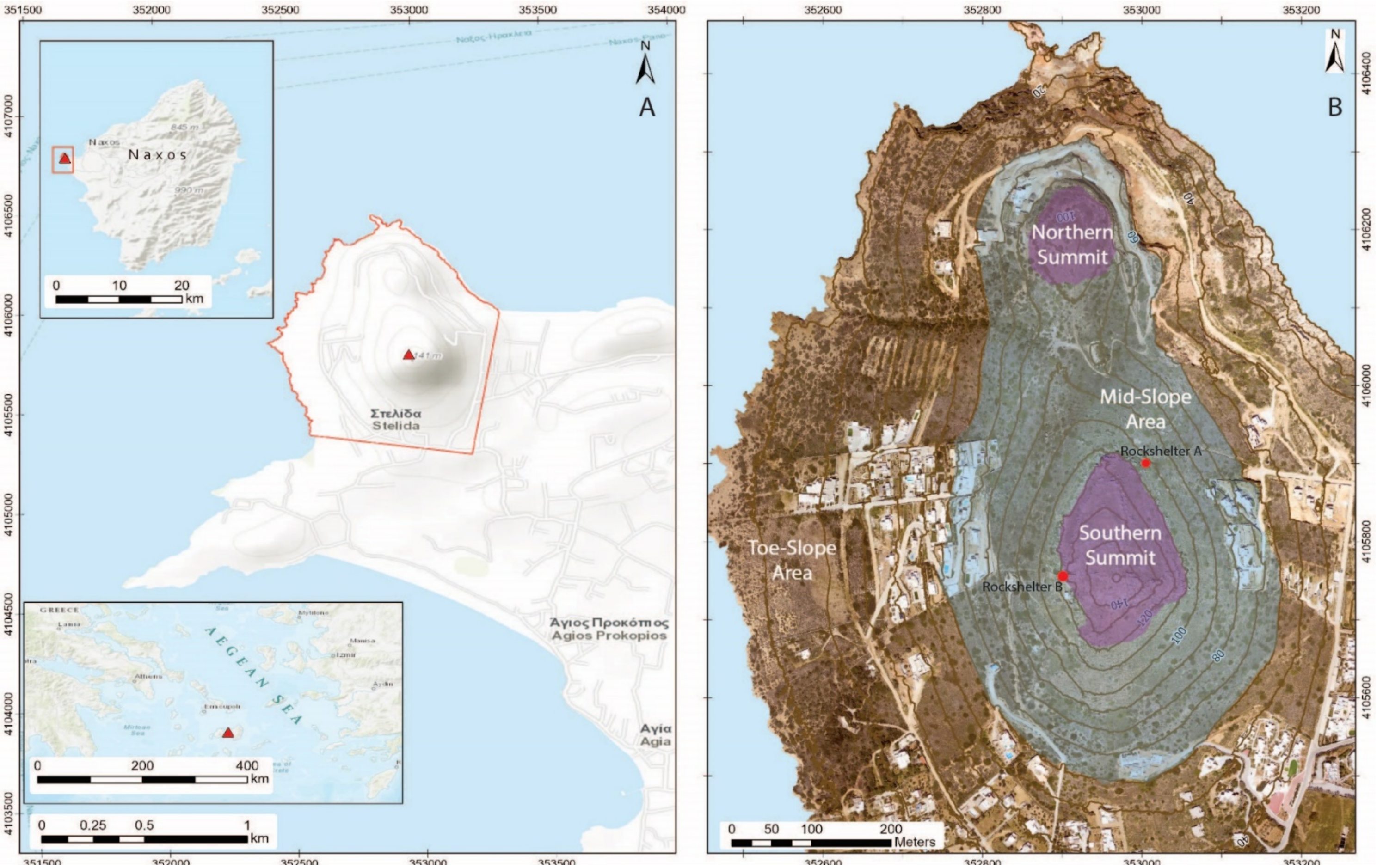

Figure 2.1: A) Location of Stelida in western Naxos. B) Orthomosaic of Stelida showing SNAP survey zones (North and South Summit, Mid-Slope and Toe-Slope areas) and interpreted rock shelters (A and B).

2.2 CASE STUDY: STELIDA, NAXOS

2.2.1 Physical Setting and Geology

The Stelida study site is located on the west coast of Naxos, in the southern Cyclades, approximately 175 km southwest of Athens (Fig. 2.1A). The geology on Naxos consists of a central migmatite dome surrounded by a complex of schists, gneiss and marbles of decreasing metamorphic grade (Evelpidou et al., 2018; Rye et al., 1976).

The western most point of the island is Stelida (Fig. 2.1A). Stelida is comprised primarily of a steep dual peaked hill, with its highest southern peak reaching 151 m.a.s.l. The hill has a gradient of 30% with steeper sections on the shoulder and back slope and a shallower slope on the foot and toe slope. The coastline is characterized by sections of cliffs and steep land slumps that meet the sea. Encircling the peaks of the hill are abrupt outcrops of ’chert’, a general term given to highly siliceous microcrystalline sedimentary rocks (Luedtke, 1992). Chert is an important sedimentary rock as its composition allows it to be knapped, chipped and fractured in a controlled manner so that it can be used to make tools with sharp, durable edges (Luedtke, 1992;). Stelida comprises the largest accessible source of chert in the southern Aegean. These the raw materials have been exploited for the manufacture of stone tools by prehistoric populations from the Middle Pleistocene to Early Holocene (Carter et al. 2017, 2019). The chert at Stelida originated from hydrothermal fluids from a detachment fault causing the silicification of the upper sedimentary sequence, as part of a larger fault system that was active ~13 to 9 mya (Skarpelis et al., 2017). The two dominant types of chert present at Stelida are bedded cherts and silcretes with colours that vary from mostly light grey to white to deep blues and purples (Skarpelis et al., 2017).

Like the other Cycladic islands, Naxos has a warm, temperate climate with more precipitation during the winter months (Evelpidou, Polykreti, et al., 2018). At present, the average annual rainfall for the island is about 400 mm/year, however the island is subjected to very intense rainfall events which often result in flash flooding (Evelpidouet al., 2018).

The vegetation across the hill was categorized into barren, dense vegetation and shrublands (Fig. 2.4A). The dense vegetation is comprised of woody evergreen shrubs (maquis or garrigue) that are short in stature with sclerophyllous leaves (Shoshany, 2000). The shrubland is comprised of knee-high evergreen and deciduous woody shrubs (phrygana) (Shoshany, 2000).

In some areas the outcrops are less than a meter in height, while the outcrops above the western slope are taller (up to 10 meters high). Thick Quaternary deposits blanket the surrounding slopes of the hill. The geology of the southern portion of the hill is different to the northern portion, a thinner Quaternary deposits rest upon granodiorite. The boundary between these two areas defines the west-east Naxos-Paros detachment fault that cuts across Stelida extends to the Molos peninsula on the neighboring island of Paros (Skarpelis et al., 2017).

2.2.2 Previous Work

The geology of Stelida was first mapped in the late 1960's and the prehistoric tool-making sites were discovered in 1981 during an island-wide archaeological inventory by the École Française D'Athènes (Treuil, 1983). The initial report on the site afforded a brief description of the artifacts recovered, but included no distribution map, or quantification of the data (Sériadès, 1983). At the time of the site's discovery the perceived wisdom was that the Cyclades had not been colonized until the Late Neolithic (Cherry 1981), some 7000 kya, with the incoming populations henceforth making their tools primarily from obsidian (Evans and Renfrew 1968). With the Stelida artifacts bearing little resemblance to the later Neolithic or Bronze Age material it was concluded that the site must be of earlier date, and tentatively assigned to the Early Neolithic, or Epi-Palaeolithic (Séfériadès, 1983).

No further archaeological fieldwork occurred at the site until the early 2000's when the Greek Ministry of Culture conducted small-scale salvage excavations ahead of land development projects (Carter, 2017). Since the 1980's the land at Stelida has become increasingly valuable for residential and commercial construction; with the need to stem the destruction of the archaeological record the site was accorded formal Ministry protection in 2000, with the upper portion of the hill being classified as 'Alpha Zone' (development prohibited), and the lower flanks 'Beta Zone' (development only permitted after archaeological investigations) (Carter, 2017). The publications of these Ministry rescue excavations claimed that not only might the site be pre-Neolithic, as first suggested by Séfériadès (1983), but also that it had a greater antiquity, with artifacts not only of Mesolithic date, but also Upper and Middle Palaeolithic (Legaki, 2012, 2014). SNAP was initiated in 2013 with the aim of characterizing the archaeology of Stelida in the larger context of claimed Middle and Lower Palaeolithic activity in the Aegean islands – allegedly the product of Neanderthals and earlier hominins - discoveries that potentially had implications for our understanding of pre-*sapiens'* capabilities should this have involved seafaring (Runnels et al., 2014; Leppard and Runnels 2017). The project was directed by T. Carter of McMaster University, and conducted under the auspices of the Canadian Institute in Greece, with permission from the Greek Ministry of Culture. The initial iteration of SNAP was a pedestrian survey and geological mapping project during the summers of 2013-14 (Carter et al. 2014, 2016; Skarpelis et al 2017). In 2015 SNAP shifted from survey to excavation, and became an official collaboration with the Cycladic Ephorate of Antiquities, now co-directed by T. Carter and D. Athanasoulis (Carter 2017, Carter et al. 2017); the project remains ongoing at the time of writing (www.stelida.org). The importance of this site lies in the insight that it can provide into the pre-Neolithic activity on Naxos and the surrounding area (Carter et al., 2017). In addition, providing a more comprehensive understanding and description of the raw material at the site will aid in potential tracking of this material's use throughout the prehistoric Aegean..

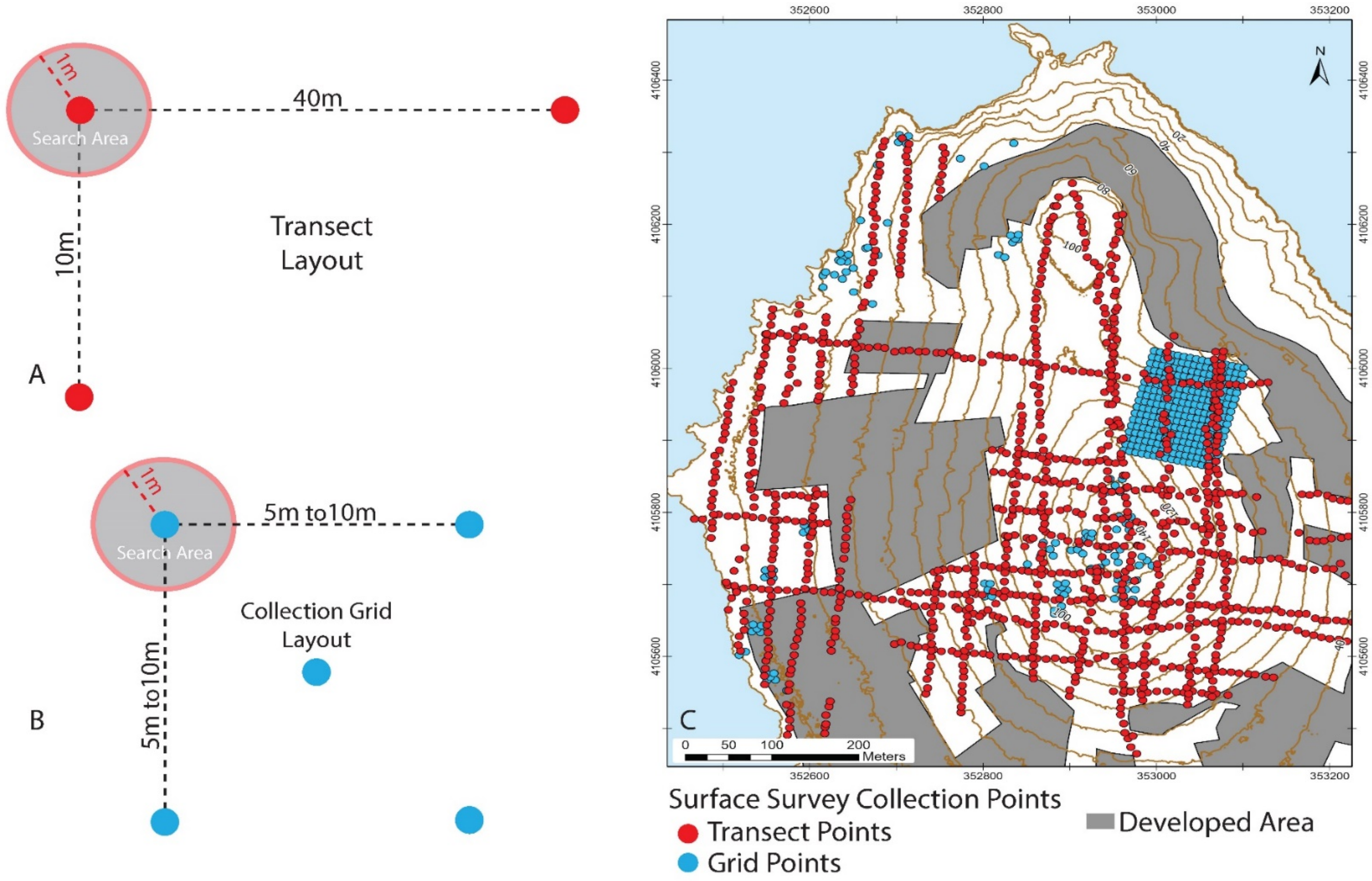

Figure 2.2: A) Layout of the survey collection transects. B) Layout of the survey collection grids. C) 2013-2014 pedestrian survey showing location of transects and grid survey points. Grey-shaded areas indicate residential areas and private property where survey work was limited by infrastructure or restricted property access.

2.3 METHODS

2.3.1 Pedestrian Survey

A pedestrian survey was conducted at Stelida over seven weeks in 2013 and 2014 with the objective of mapping and dating the distribution of surface artifacts. The surveys were conducted using a combination of collections transects and grids, drawing on methods implemented previously on other sites in the Aegean and beyond (Bevan & Conolly, 2004; Cavanagh et al., 2005; Rick, 1978; Whitelaw et al. 2006; Whitelaw, 2007). The work commenced with four pairs of archaeologists walking linear transects oriented to the cardinal directions and established in relationship to the site grid which was centred on the Greek army trigonometrical station on Stelida's southern and highest peak. These North-South and East-West transects were established with tape and compass, and covered as much of Stelida as possible, with limitations caused by development and land access permissions. The transects were set 40 meters apart with collection points established along the transect every 10 meters using a recreation-grade GPS unit (Fig. 2.2A); all artifacts within a 1-meter radius were collected and labeled at these points. Each collection point was photographed and the percentage of vegetation cover and the apparent slope were also recorded as these were variables, we believed would help us critically reflect on the artifacts' locational integrity.

As well as transect walking the team used a targeted collection procedure focusing on those areas deemed to be of interest based on the density and/or character of the lithic material found there (as determined by transect results, or field observations). These study units mainly ranged between $1m^2 – 15m^2$, plus one much larger 70 × 80m grid on the eastern flanks in front of Rockshelter A (Fig. 2.1B). The grids involved a systematic collection procedure, with the recovery of all surface material culture from at least one $1m^2$ unit. Where grids comprised a simple $1m^2$ unit these acted a stand-alone collection points, while in the case of larger sampling units, for example a 5 × 5m square, all artifacts from 1m² collection units located in the four corners, and centre-point were collected, thus providing a 20% sample of the total area (Fig. 2.2B). The survey involved 29 transects and 61 grids (Fig. 2.2C), a total of 1656 collection points, with approximately 30,000 artifacts collected, the vast majority being chert tools and their associated manufacturing debris.

The study of the survey finds involved a two-level recording process. Level 1 involved simple quantification, i.e., the number and weight of the chert artifacts by collection unit. These data were employed to produce an initial, broad-stroke characterization of artifact density across the site, and by extent an initial view of potential intra-site distinctions, and the existence of artifact-rich ‘hot-spots’ that might be worthy of further attention through grid sampling (Carter et al., 2016). Level 2 analysis of the material recorded a range of data on an artifact-by-artifact basis, including their raw material (with distinct types of Stelida chert being recognized), plus a variety of other attributes employed by stone tool specialists to describe their material (a mix of globally-employed nomenclature, and region-specific terms).

2.3.2 Spatial Analysis Methods

Following the initial analysis of the survey data we were left with rudimentary collection location maps that illustrated there was a substantial amount of material across the entire site. Further analysis was conducted to refine and filter the data, which then was used to determine if there was an underlying distribution pattern of the artifacts. Previous, operational documentation and external publications from SNAP refer to “hot-spots”, i.e., areas perceived to have a lot of material that were worthy of further exploration (Carter et al., 2016, 2017). These classification of these areas as “hot-spots” was based upon *unquantified* on-site observations. The principal question being asked in this paper is then; what concentration of material is significant enough to warrant the classification as a ‘hot-spot’? The primary aim of this study was to use spatial statistics to determine areas of significant groupings of artifacts from the four major chronological periods: Lower, Middle and Upper Paleolithic, plus Mesolithic (Table 2.1). For each of these periods, a threshold value was calculated which indicated the number of artifact pieces required within an assemblage of material for that “hot spot” to be considered statistically significant.

The first step in the analysis will be to address some of the spatial and collection biases that are present in the survey data. Physical limitations (e.g., cliffs but primarily areas of modern development) during the collection process resulted in some under-representation or lack of coverage of some areas of the site. Areas of dense vegetation obscured sections of the surface, and by extent any surface artifacts. In some instances, this lack of visibility resulted in no material being collected. These recorded zero values are representative of not being able to see artifacts on the surface. As these “zero” points don’t directly represent the potential amount of material on the surface, the potential for false zeros will need to be addressed. One of the primary benefits to the application of spatial statistics to determine the significance of the hot-spots is the better utilization of exploration time and resources, as researchers can focus on the areas that are classified as significant. The derived interpolated distribution for the material will produce an actionable representation of where the material currently sits on the modern surface. This analysis will be the first step in understanding where material is located but does not directly addressed why the material is there. Through the passage of time the material may have been moved through environmental and cultural processes. Therefore, the results of this analysis will lead to a further study as to the locational integrity of these classified ‘hot-spots’ and if the distribution pattern of the material is the result of environmental processes is it possible to derive where it originated from.

2.3.2.1 Defining 'hot-spots' – a spatial analysis

Preliminary discussions of the survey detail how the transects, both collection points and accompanying note-taking on the 20m swathe either side of the 10m segments, part-served to locate 'hot-spots' worthy of further investigation through gridding (Carter et al., 2016, 2017). At no point however was this concept of 'hot spot' quantified, i.e., what made a particular accumulation of surface artifacts noteworthy in the larger site-wide context? To this end Moran's I and Getis Ord statistical tests were applied to determine whether there was clustering of material for each temporal period. Simply stated, could we define non-random concentrations of material, (a) amongst the overall mass of survey material, and (b) within the distribution of chronologically specific artifacts.

The conceptualization for all the test was set to inverse distance and with the distance method being set as Euclidean. A fundamental concern with solely relying on these tests was the spatial and coverage biases introduced by the transect and grid coverage of the surveys. This bias can be attributed to the various areas of development and restricted area access. The spatial bias introduced into the data through the layout of the surveys limited the spatial tests possible, as most traditional spatial analytical approaches require spatially continuous datasets. A Monte Carlo random labeling simulation test was used to determine which areas of the distribution are significant concentrations of material compared to random distributions of material. This type of comparative analysis is often implemented in biological studies where observed positions are not spatially continuous (Smith, 1998). Using this approached ten thousand randomly labeled distributions were generated for each chronological data set (Baddeley et al., 2014; Smith, 1998; Wiegand et al., 2016). At each survey point a simulation envelope that encapsulates material values that are within two standard deviations based on simulated distributions was determined (Smith, 1998). This provided a numerical value for each chronological period that could be used to determine the significance of assemblage size.

The survey data is representative of the material found on the modern ground surface. A predictive interpolated surface was created based on this data to represent the estimated amount and distribution of varying surface material by chronological period. The surface density of lithic materials was estimated and mapped as hot-spots using Empirical Bayesian Kriging (EBK)(Krivoruchko and Gribov, 2012). Kriging is a statistical technique for optimal spatial prediction that uses a semivariogram modelling to quantify the spatial dependence within the data, by accounting for the distance and direction between the data points (Bevan & Conolly, 2009; Krivoruchko, 2012; Moyeed & Papritz, 2002). EBK is an implementation of kriging that accounts for the uncertainty in semivariogram estimation by generating a large number of empirical simulated semivariograms (Krivoruchko, 2012). An EBK interpolation surface was generating for each chronological period using 10,000 simulated exponential semivariograms and an empirical data transformation.

The interpolated distribution surfaces gave an indication as to how the material was spread across the modern surface. These surfaces were further analyzed to determine what areas have significant concentrations of material. The areas of the interpolated distribution surfaces that are greater than the value envelope was determined to be statistically significant and help to identify the concentration of material that constitute significant hot-spots (Baddeley et al., 2014; Smith, 1998; Wiegand et al., 2016).

2.4 RESULTS

2.4.1 Survey Results

A two-stage process was employed to sort and classify the collected lithic materials into four age groupings (Fig. 2.3B). The total number of lithics were counted for each survey point and classified as either diagnostic or non-diagnostic material. The material was counted for each point and was classified as either chronologically diagnostic material or non-diagnostic material. The total lithic counts at each point varied across the site with most of the artifacts collected on the south-western slope of the southern peak (Fig. 2.3A). Approximately 75% of all collected material was classified as non-diagnostic. The diagnostic material is then categorized based on predetermined characteristics and features of the different lithics and stone tools from the different periods (Fig. 2.4). Material that is indicative of artifacts from the Lower Paleolithic, Middle Paleolithic, Upper Paleolithic and Mesolithic Periods were found. There were also a few artifacts and pieces of pottery from the Neolithic and Bronze Age periods. Most of the diagnostic dates to the Mesolithic period, however the presence of the much older Paleolithic artifacts adds to the archeological significance of the site. The diagnostic breakdown of the collected material is illustrated in Fig. 2.3B. Of this material, approximately 7470 items are claimed to be chronologically diagnostic based on their exhibiting typo-technological traits of Lower-Upper Palaeolithic and Mesolithic regional industries (Table 1). Excavation on the upper western slopes have since recovered large quantities of artifacts from sealed stratified colluvial (hillslope) deposits 3.8m deep, with associated luminescence dates providing a series of *terminus ante quem* determinations of 13 – 200 kya, with clear proof of Mesolithic, Upper and Middle Palaeolithic activity (Carter et al. 2019).

Category	**Number of Collected Pieces**
Non-Diagnostic Material	22201
Diagnostic Material	
Lower Paleolithic Material	158
Middle Paleolithic Material	755
Upper Paleolithic Material	2389
Mesolithic Material	4059
Sub-total Diagnostic Material	*7261*
Total Material Collected	**29562**

Table 2.1: Detailed breakdown of the total material collected during the SNAP Pedestrian survey during both 2013 and 2014 seasons. Further breakdown of Diagnostic Material based on their chronological period.

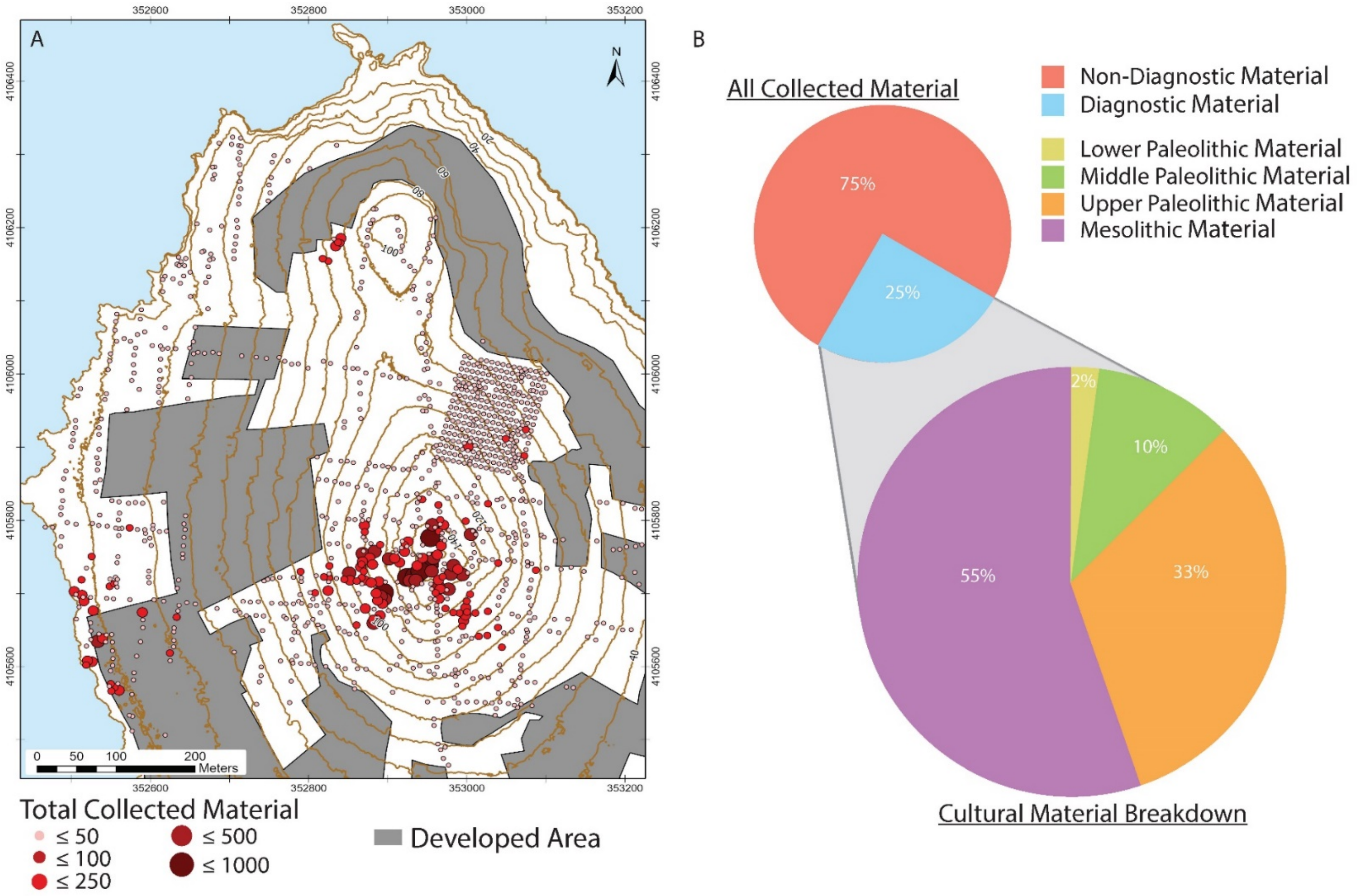

Figure 2.3: A) Total amount of surface materials collected. B) Breakdown of diagnostic materials by age.

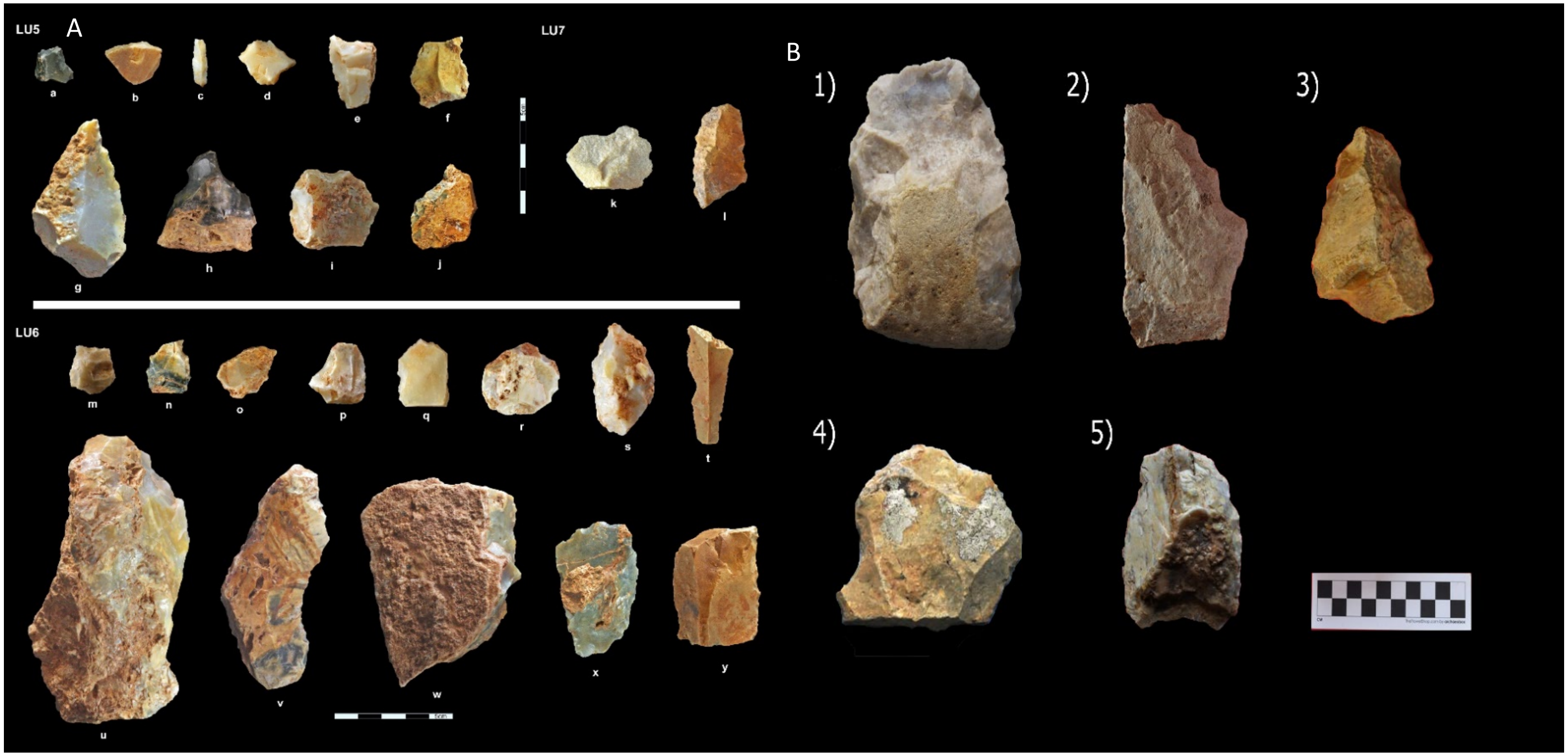

Figure 2.4: A) Selection of artifacts excavated from LU5 to LU7 of excavation trench DG-A/001.Sourced from Carter et al. (2019) B) Examples of main Lower Paleolithic stone tool types from Stelida. Sourced from Skarpelis et al. (2017)

2.4.1.1 Vegetation based data refinement

The Mediterranean vegetation across the hill was categorized into barren, dense vegetation and shrublands (Fig. 2.5A). The dense vegetation is comprised of woody evergreen shrubs (maquis or garrigue) that are short in stature with sclerophyllous leaves (Shoshany, 2000). The shrubland is comprised of knee-high evergreen and deciduous woody shrubs (phrygana) (Shoshany, 2000). During the pedestrian survey, in those instances where a transect point fell in the midst of dense shrubland, the vegetation would be pushed aside (if possible) in an attempt to view the ground surface and any artifacts that may be laying there. Where the collection points were obstructed by dense vegetation, it was noted that surface material was neither visible, nor collected, resulting in a collection point of zero. As a result, all zero dense vegetation collection points were removed from the data set to reduce the number of potential false zeros. This data scrubbing reduced the number of collection points from 1656 to 1107 (Fig. 2.5B). It is believed that there several other influential factors as to whether a collection point contained cultural material, not exclusively the presence of abundant vegetation, such as hillslope, fluvial and aeolian processes.

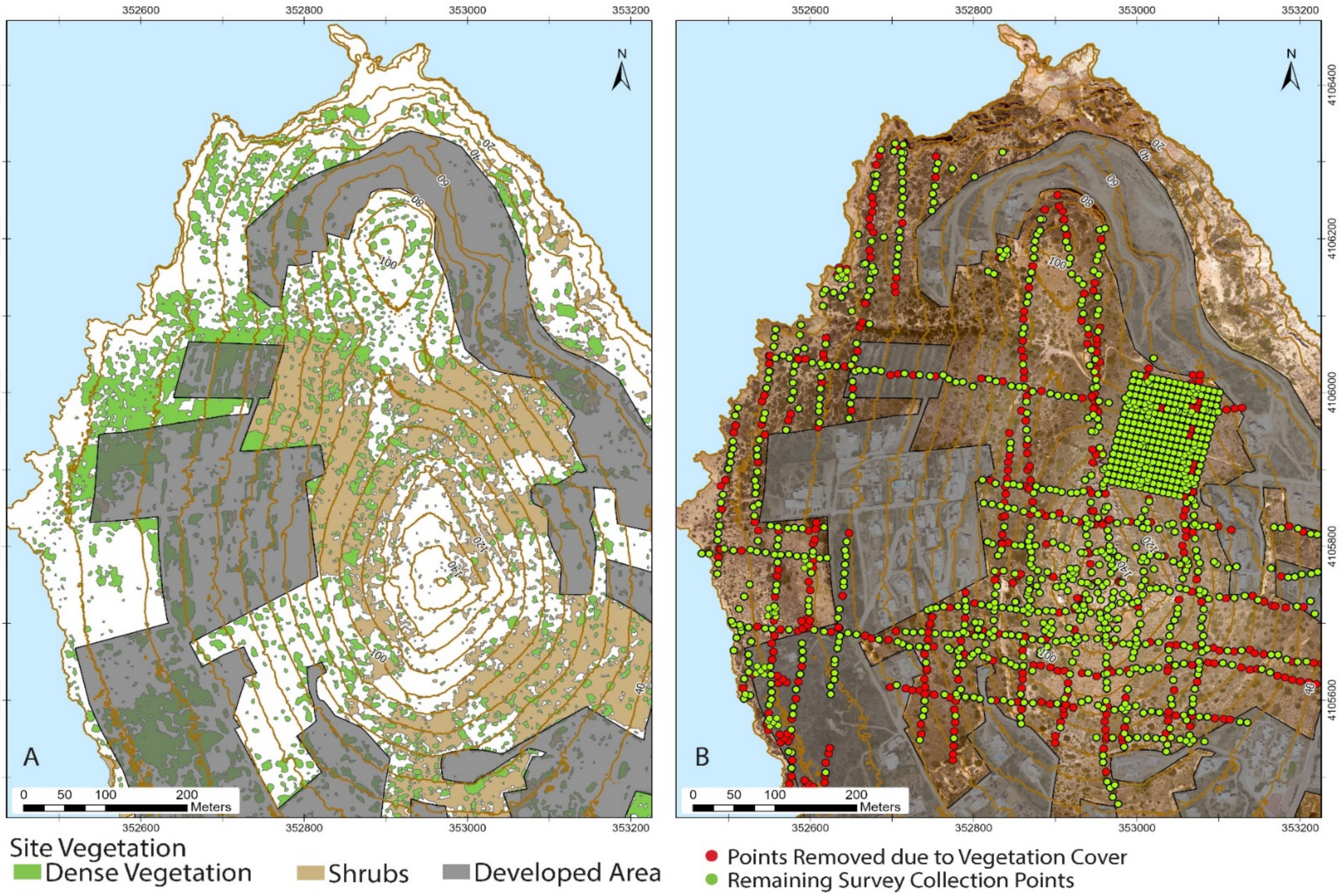

Figure 2.5: A) Image classified areas that represent the heavily vegetated areas and sparsely vegetated sclerophyll shrub area. B) Refined surface survey collection points showing points removed due to vegetation cover.

2.4.2 Spatial Statistics

Preliminary spatial analytical tests were conducted on the data sets to provide an initial insight into the spatial positioning of the material. The results from the Moran's I test indicated the data in all four of the chronological periods are autocorrelated, meaning that they have some sort of spatial dependency or pattern (Table 2.2). We emphasize how these results are dataset contextual, rather than generic, i.e., at one end of the scale within the context of a total of 4059 diagnostic Mesolithic artifacts a concentration of 11 is deemed significant, while at the other end a grouping of two Lower Paleolithic diagnostics is considered statistically significant within a larger dataset of 158 pieces (Table 2.1). The test results further indicated that there is less than a 1% likelihood that the artifact clustering is the result of random chance. The Getis Ord analysis indicated that the clusters were concentrations of high value collection points for all datasets (Table 2.2). This pattern of high value clustering is thus unlikely to be the result of random chance.

Moran's I Spatial Autocorrelation Test			
Chronological Period	*Moran's Index*	*Expected Index*	*Z-Score*
Lower Paleolithic	0.101362	-0.000605	12.6572
Middle Paleolithic	0.092654	-0.000605	12.169820
Upper Paleolithic	0.189132	-0.000605	24.285291
Mesolithic	0.331955	-0.000605	40.948669
Getis Ord* Clustering Analysis			
Chronological Period	*Observed General G*	*Expected General G*	*Z-Score*
Lower Paleolithic	0.005688	0.001451	9.285132
Middle Paleolithic	0.006330	0.001451	9.625732
Upper Paleolithic	0.007468	0.001451	14.69
Mesolithic	0.008558	0.001451	19.172241

Table 2.2: Initial results from spatial diagnostic tests. Moran's I test and Getis Ord values for the four chronological periods captured by the pedestrian survey material. A positive value of Moran's index indicates clustering and negative values indicate dispersion.

2.4.3 Lower Paleolithic Material

The collected Lower Paleolithic (LP) material represents diagnostic material that was found to be characteristic of tools from well-dated excavations in Greece and the surrounding region of greater than 250 kya. A total of 158 pieces of LP material were collected across the site. While most collection points did not contain any LP artifacts, there are a few where the assemblages comprised 15% to 33.33% of the total LP dataset (Fig. 2.6A). Most of the LP material was found on the slope near the coast in the far north-west corner of the site (Fig. 2.6A). Here the collection point diagnostics were 66.6% to 100% comprised of LP. There is also a significant amount of LP material, up to 9 pieces at a single collection point, found on the eastern mid slope in the area where the more intensive large grid survey was conducted. Locations with significant amount of LP material, defined as any assemblage with 2 or more pieces, estimated on the surface are found in isolated areas of the northwestern and northern coasts, as well as the eastern mid slope (Fig. 2.6A).

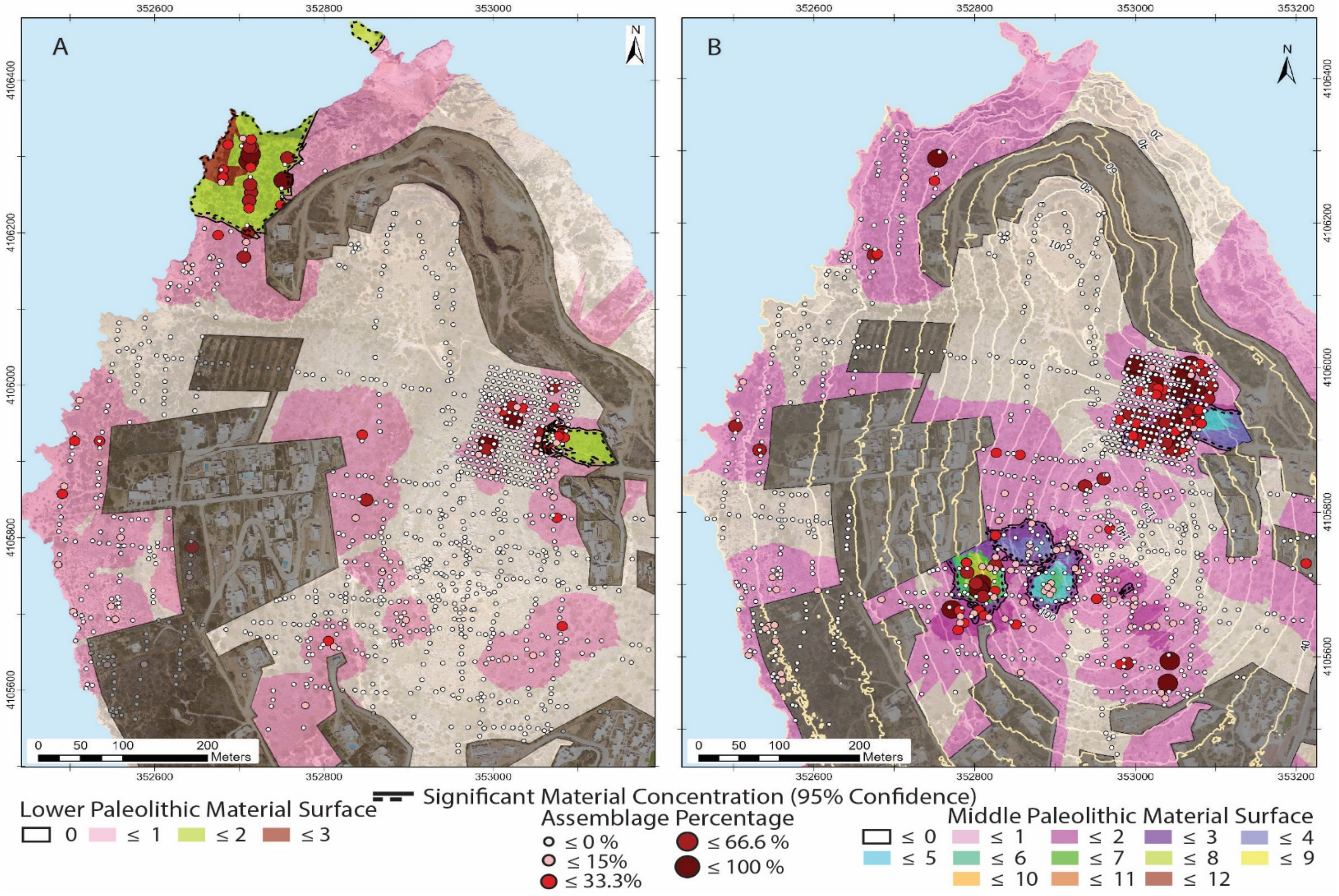

Figure 2.6: A) Distribution of all Lower Paleolithic material and their respective assemblage percentage B) Distribution of all middle Paleolithic Material and their respective assemblage percentage

2.4.4 Middle Paleolithic Material

The Middle Paleolithic (MP) assemblage is comprised of those artifacts diagnostic of tools made in the larger region between from 250 – ~40 kya, which in Greece are associated with Neanderthal populations (Harvati et al., 2009). In total 755 MP diagnostics were collected. Most collection point assemblages did not contain any MP material. The points that did contain MP material comprised 15% to 66% of the total material in those assemblages (Fig. 2.6B). There are some singularity points that had high concentration of MP artifacts, but all surrounding points lack the significant material to define coverage. Most of the MP material is found on Stelida's south-western mid-slope, located below the chert outcrops (Fig. 2.6B). Like the LP distribution there is a significant amount of MP material found on the eastern mid-slope in the area where the large grid survey was conducted. The greatest concentration of MP material from a single collection point was 68 pieces, which is located near the centre of the hot-spot on the western slope of the hill. Significant assemblages of MP material were statistically calculated as those containing three or more artifacts.

2.4.5 Upper Paleolithic Material

Upper Paleolithic (UP) material constitutes those artifacts characteristic of tools produced in the Aegean from around 40 – 11 kya, and are associated with the appearance of *Homo sapiens* in the region (Douka et al., 2011). There were 2389 UP diagnostics recovered from the survey. Most of those collection points containing UP material were located on the slopes of the higher southern peak in areas just below the chert outcrops (Fig. 2.7A). In particular, the UP material is concentrated on the slopes to the south-west and south-east of the southern peak. There is also a concentration of material on the south-east mid-slope of the northern peak, caught between the northern outcrop exposures and an area that once had a natural spring (Fig. 2.7A). An assemblage of UP material was statistically calculated as significant if there were more than eight pieces collected at the point. The most UP material that was found at a single point was 150, while the average across the site was about two.

2.4.6 Mesolithic Material

The Mesolithic (M) artifacts represents that material diagnostic of those tools being made by later *Homo sapiens* populations in the Aegean between around 11 – 9 kya (Kaczanowska & Kozlowski, 2014). M material is the predominant diagnostic artifact type, found across the site. The number of collected M pieces was greater than all the other periods combined, with a total of 4059 artifacts. The majority of the M Material was found around the southern peak of the site (Fig. 2.7B). Most of it was found as a carpet of material that starts at the top of the outcrops around the southern peak and cascades down towards the mid-slopes on both flanks. Unlike the other periods, material from this period is quite abundant with the largest number of pieces found at a point being 171. A M Assemblage area is calculated as being relatively significant statistically if it contains 11 or more pieces.

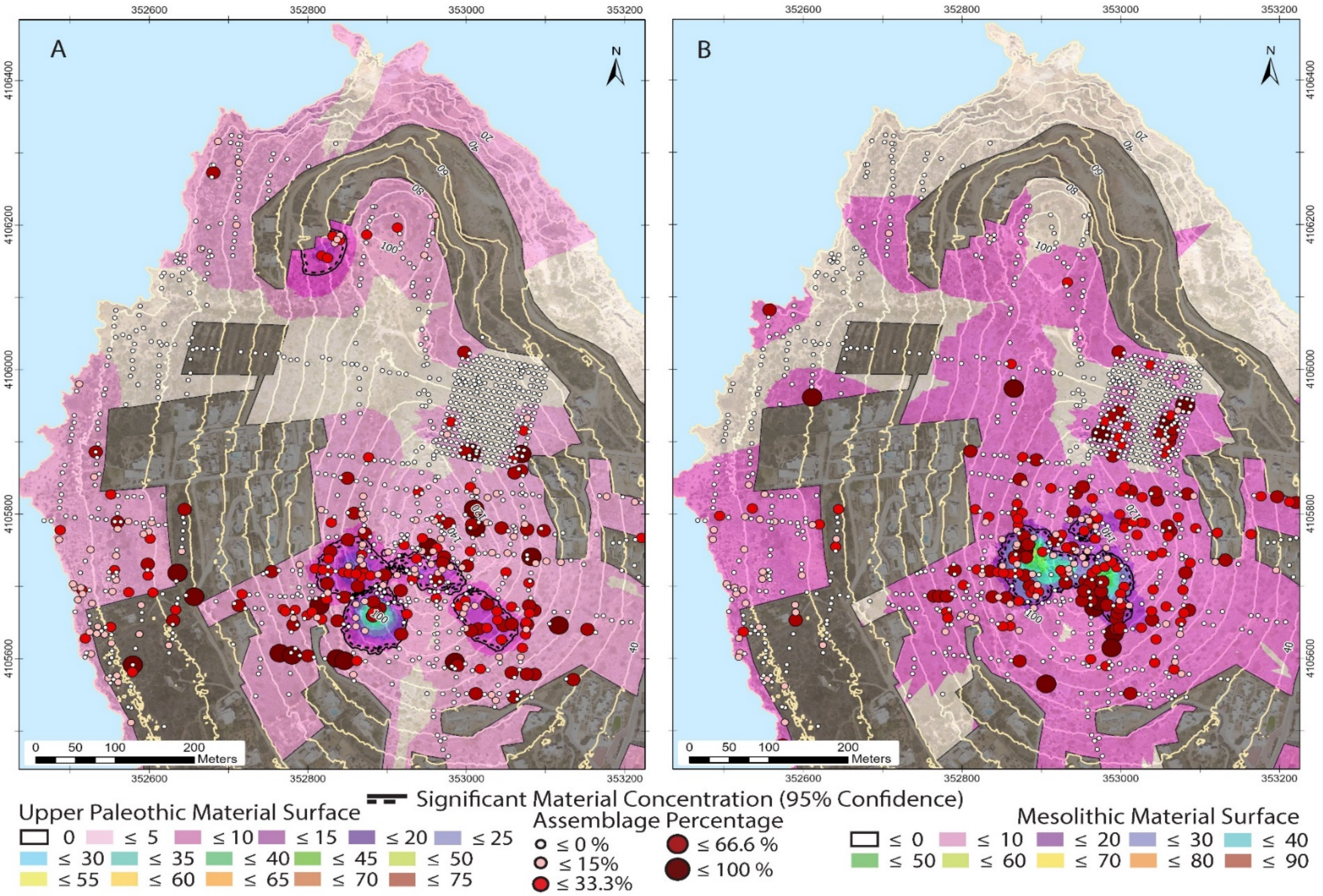

Figure 2.7: A) Distribution of all Upper Paleolithic material and their respective assemblage percentage B) Distribution of all Mesolithic material and their respective assemblage percentage

2.5 DISCUSSION

2.5.1 Spatial distribution of lithic materials

The initial spatial analysis of the data for the different chronological periods indicated that there was a clustering of collections points that contained various diagnostic material. For all four of the chronological periods, the observed clustering is very unlikely to have been caused by a random distribution and it can be therefore inferred that there are some cultural events and process that have resulted in the observed pattern. While these analyses indicated the clustered points were most likely identifying hot-spot areas for each chronological period, the results of these test do contain some bias. Due to the spatial coverage of the survey collection points the results from this analysis is informative but subject to skepticism. Therefore, further analytical steps needed to be implemented to support the initial findings. A random labeling simulation analysis was performed on the data which confirmed that the hot-spots identified in the initial analysis were statistically significant and very unlikely to be the result of random processes. Following this information, EBK was used to create valuable predictive surface distribution surfaces.

The LP material represents the oldest diagnostic material found at the site. While it was not uniformly distributed across the site, the analysis indicated that finding two or more pieces on the surface is significant. In comparison, MP, UP and M required more pieces at a single collection point to be considered a significant cluster (3, 8 and 11 pieces respectively). The increase in the significance minimum value between the chronological periods is the direct result of the quantity of material that was collected at the site.

There are some interesting patterns that emerge when comparing the distributions of chronologically diagnostic artifacts. Initially the raw material seemed to have been extracted at the northern part of the site as well on the eastern slope. During the MP, activity shifted from the northern peak to the southern peak, specifically exploiting the material at the outcrops on the south-west slopes, indicated by the abundance of MP and younger material found in this area. During this period, the activity in the area was concentrated on the outcrops or on top of the hill. These spatial reconfigurations of activity over time might in part relate to distinct preferences in raw material selection, as more recent detailed geo-archaeological studies of the outcrops have distinguished clear intra-source differences in the knapping quality and color of Stelida chert (T. Moutsiou pers. comm.).

The patterns in the distribution of the material at this site may be the direct result of cultural activity, however there are several environmental processes that may have also impacted the distributions. The older LP and MP material is located further down slope from the outcrops then the relatively younger UP and M material. This could be the result of the fact that the older material has been present on the site longer and has therefore had more time subjected to the taphonomic formation forces and processes, and that the LP and MP artifacts tend to be larger and heavier than those of UP and M date, whereby they would be more susceptible to downslope movement (Doyle, 2018; Rick, 1976).

2.5.2 Survey Design and Archeological Implications

The predictive distribution maps provide an important analytical insights pedestrian survey data . It has quantitatively defined ‘hot spots’, i.e., areas of the site where particular periods of activity are concentrated in a statistically meaningful manner. These results indicate more than one area of dedicated human activity by period, and also spatial changes in tool material procurement and manufacturing practices over time, which may relate to diachronic changes in the raw material choice.

The next stage of analysis, detailed in a companion paper (Chapter #2), is to critically reflect on the locational integrity of these artifact concentrations. Do the hot-spots represent material eroding *in situ*, and these are the loci we should be targeting for excavation to shed more detailed light on specific periods of activity (‘X-marks-the-spot’)? Or, do these artifacts represent accumulations of material redeposited by environmental and/or cultural processes such as erosion, downslope sediment transport or modern anthropogenic disturbance (e.g., agriculture, residential developments)?

The spatial coverage and data collection for this study yielded results that are significant and viable for the current application, there are however still some limitations and biases. Some spatial bias was introduced due to the transect coverage of the initial pedestrian survey and surface collections. In future survey work, project designs should have greater effort placed on more continuous spatial coverage and sampling of the areas of interest. A more uniform survey, with equidistant spacing of transect lines and collection points would improve the spatial resolution of hot-spots and limit errors due to spatial sampling bias. The survey design and layout to a large extent will be constrained by the terrain and vegetation cover, which ultimately may limit collection in some areas of the site. Initial and continual checks should help to ensure that the area receives maximum coverage (the available area that is not restricted by modern development). More detailed observations regarding the collection points physical characteristics are also of significant benefit when cross referencing data such as vegetation cover. For example, having elevation and slope measurements, photos of the vegetation coverage and notes regarding the perceived vegetation density will help during the analysis of potential false zeros. In addition, having these notes will help when evaluating the accuracy of the predicted surface material concentrations.

2.6 CONCLUSION

This study has applied spatial analysis and SfM photogrammetric techniques to mapping the surface artifact distribution at Stelida and has produced a series of maps which predict ‘hot-spot’ areas with significant concentrations of materials where further exploration work is warranted. The approach outlined in this thesis provide valuable tools to the archeological team and data that can be further analyzed to help complete the interpretation of the site. Based on the predictive maps of the distribution of artifacts for each age grouping is different. LP materials are found primarily on the northwestern coast and eastern mid-slope. MP materials were found on the eastern mid-slope as well as the western mid-slope. UP and Mesolithic materials were most abundant on the upper south-western slopes of the southern peak, comprising clitter slopes made up of materials that had cascaded downslope from outcrops.

2.6.1 Future work

The results of this study provide important baseline data for future survey and excavation work at Stelida. Future work will include a more detailed analysis of the degree of influence of geomorphic processes (e.g., hillslope erosion, fluvial runoff, mass movements) on shaping the artifact distributions is the next analytical step for this data. Geoarchaeological research is ongoing at Stelida to understand the different geomorphic processes and depositional environments. Further research is also being conducted to trace the material back up the slopes to find where they may have migrated from. Additional research can look into the effect of potential artifact traps such as agricultural terraces and vegetation density. Further research could also be taken to link specific artifact types to specific raw material outcrops or locations cultural activity.

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CHAPTER 3 EVALUATING GEOMORPHIC CONTROLS ON SITE FORMATION PROCESSES AND SURFACE ARTIFACT DISTRIBUTION USING DRONE-BASED AERIAL PHOTOGRAMMETRY: A CASE STUDY FROM THE STELIDA PREHISTORIC QUARRY (NAXOS, GREECE)

ABSTRACT

The implementation and application of Geographic Information Systems (GIS) and spatial analysis has become common practice in many archaeological projects. As part of the *Stelida Naxos Archaeological Project* (SNAP) , we employed spatial analysis methods and the RUSLE (Revised Universal Soil Loss Equation) erosion model to determine the contextual integrity (lack of disturbance) of surface archeological finds and to assess the influence of geomorphic processes in their distribution. The double-peaked hill at Stelida comprises a chert source exploited for stone tool making from ≥250,000 – 9,000 YBP. The GIS analysis considered both environmental variables (chert source outcrop location, topography, vegetation cover), and cultural factors (prehistoric raw material choice, modern disturbance) as possible controls on artifact distribution. Unmanned Aerial Vehicle (UAV) photography was used in a structure from motion (SfM) workflow to create a georeferenced orthomosaic and digital elevation model (DEM) for the RUSLE analysis. The DEM and RUSLE models were used to evaluate the effect of fluvial and gravity-driven erosion processes, on surface artifact distribution. RUSLE modelling identified steep side slopes (>10 degrees) with minimal vegetation cover as areas of high erosion potential and moderately to densely vegetated areas as zones of low erosion potential. The modelling indicates that most surface artifacts have a low level of contextual integrity, having been displaced from their original loci of deposition through geomorphic processes. Conversely, for all prehistoric periods – except the Lower Paleolithic – the analysis indicated that small areas with high contextual integrity, i.e., where artifact accumulations reflect loci of past cultural activities,

rather the final resting place of redeposited material. The methodology devised for this study can not only inform and guide further archaeological investigations at Stelida but can be redeployed more broadly to aid excavation strategies on sites where a preliminary stage of surface studies have been undertaken.

KEYWORDS: UAV drone survey, Structure from Motion, spatial analysis, artifacts, predictive mapping, erosion mapping, RUSLE

3.1 INTRODUCTION

A primary aim of archaeology is to interpret the past based on remnants in the present (Conolly & Lake, 2006; Kelly & Thomas, 2013; Peregrine, 2016; Renfrew & Bahn, 2007). This is rarely a straightforward endeavor, as through time the traces of human activity become less familiar to us (issues of alterity), is part-lost (e.g., rotting of organics), and can undergo significant processes of modification (e.g., erosion) whereby an archaeologist might often be dealing with a partial data-set that is no longer in its original context of deposition. The issue of taphonomy, i.e., how archaeological deposits came to be – and by extent their integrity - is one that archaeologists have long reflected upon, and devised methods to critically appraise (cf. Schiffer, 1972, 1983; see also French 2003; Gouma et al., 2011; Howland et al., 2014; Hull, 1987; Matthews et al., 1997, etc.). The archaeological record can be modified by both environmental and cultural factors, the former including geomorphological processes, and the influence of vegetation and animals, while the latter can comprise agricultural practices and landscape modification (e.g., terracing, bulldozing, quarrying, construction etc.).

In this study, we focus not on the integrity of buried deposits revealed by archaeological excavation, but on how one might interpret the site-wide distribution of *surface* artifacts. Pedestrian surface survey based archaeological fieldwork is a long-established and non-invasive means of both site location at the regional scale, and site-specific analysis at the local scale (cf. Alcock and Cherry, 2016; Banning, 2002; Schiffer et al., 1978). In these instances, the archaeologist is almost always dealing with a lack of contextual integrity in that the artifacts on the modern land surface are only visible because they have been disturbed in some way from their original place of resting. This could however be a case of relatively minor displacement where the finds are being exposed from their original place of burial, whereby the surface finds' location and character might largely reflect what once occurred on this part of the site. In such instances an archaeologist might then excavate in just that spot to reveal further, better quality information about those past activities. Conversely, there are instances where surface artifacts have moved not inconsiderable distances from their original deposit, having washed down erosion gullies, or been displaced by the construction of footpaths, or terracing. In such cases it would be pointless to excavate where we find these surface artifacts if our aim was to know more about how these items were originally used and discarded. It is thus necessary to critically reflect on the processes that underpin the distribution of artifacts across a site or landscape in order to appreciate more clearly this issue of data/contextual integrity. The majority of these processes have predictable effects on the landscape and can be measured and estimated. Taking approaches to better understand influential factors results in a better understanding of past activity (Bevan et al., 2013; Kvamme, 2012; Tartaron, 2003).

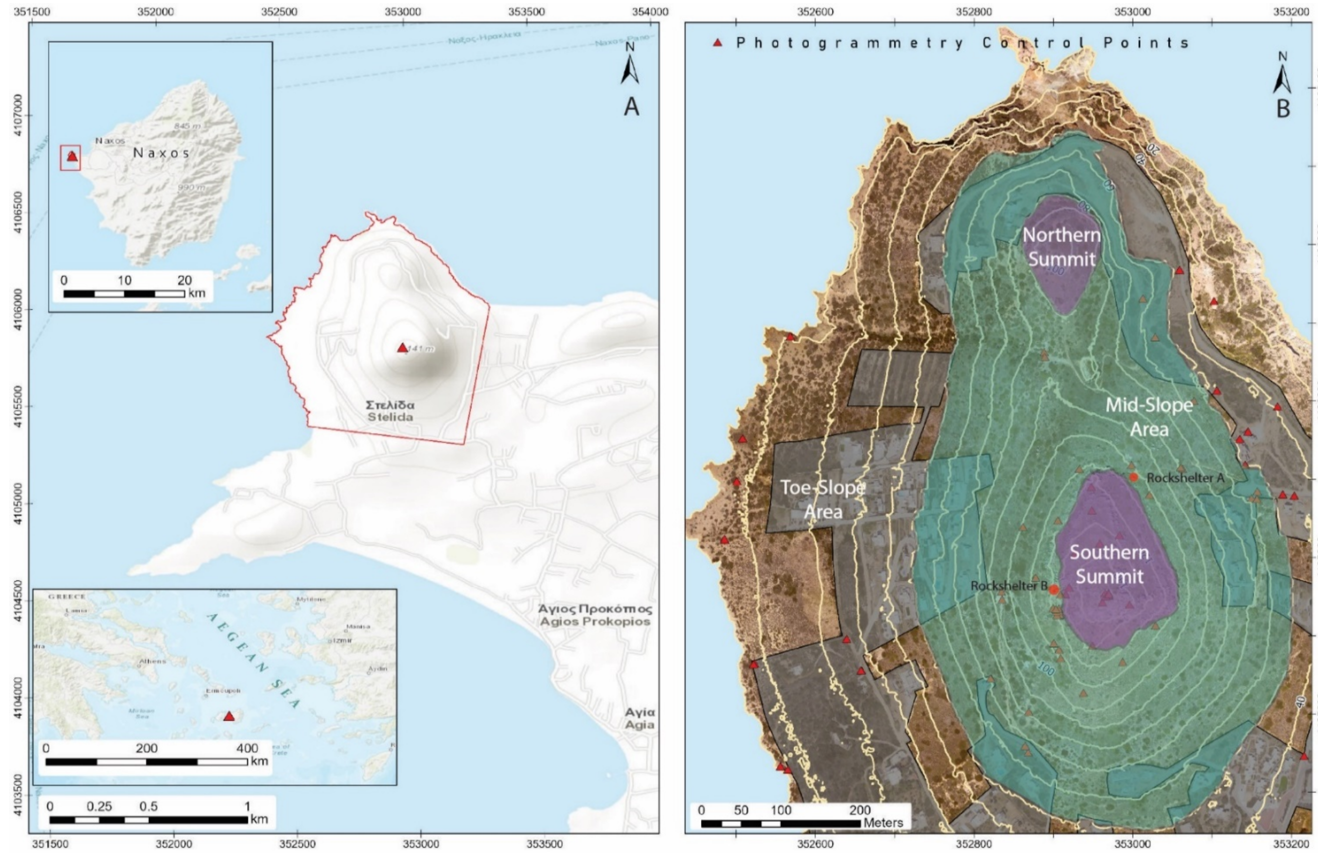

Figure 3.1: A) Location of Stelida Naxos in the Aegean Sea. B) Orthomosaic of Stelida showing surface features and the locations of ground control points used in computing the DSM. Locations of categorized survey sections (Summit, Mid-Slope and Toe-Slope areas) and rock shelters (A and B) also shown.

Geomorphological processes have a large influence on the archeological record and how the information is interpreted (Barton et al., 2002; Bevan & Conolly, 2004; Gould, 1997; Gouma et al., 2011; Howland et al., 2014, 2018; Mitasova et al., 1996; Tartaron et al., 2006). The movement of sediment on the site via erosional and depositional processes can have significant impact on the location and preservation of surface archeological finds (Bevan & Conolly, 2009; French & Whitelaw, 1999; Gouma et al., 2011; Howland et al., 2018; James et al., 1994). The degree of influence of geomorphic processes on artifacts can be viewed as the direct result of the site's geology, sedimentology, climate, and tectonics (Bevan & Conolly, 2009; Evelpidou, et al., 2018; Gouma et al., 2011; P. A. James et al., 1994; Schiffer, 1972; Skarpelis et al., 2017). Earthquakes, gravitational driven slumping, flash floods and precipitation driven erosion are examples of some geomorphic process that may alter the position of archeological material on the surface. The heavier the rainfall an area gets or the more tectonically active a region is the more likely there is to be an erosional or mass movement event. By assessing the erosional potential on the area, we can reflect on the potential that material has moved from its original context. In addition to the soil itself, the surface vegetation of the area also plays a significant role in how the material moves across the site. Vegetation helps to prevent soil erosion and can act as artifact traps as material travels down slopes (Descroix et al., 2001; Loch, 2000; Zhang et al., 2004; Zhou et al., 2008). Agricultural activity such as land clearing/plowing and terrace creation can severely impact the integrity of the surface material. Modern development also can significantly alter the integrity of the distribution of surface material (Fig. 3.1B) (Panagos et al., 2015). While agricultural and development actives are important to consider, their direct impact on distributions is difficult to model and comprises a potential area for future research. The influence of vegetation cover and modern development can be incorporated into erosion potential models through the use of coverage and management variables (Panagos et al., 2015).

The Stelida study site is located on Naxos in the Cycladic islands of the southern Aegean (Fig. 3.1A), an island landscape that is characterized by steep topography, and which has experienced extensive drought periods followed by heavy rainfall starting 12 kya (Koutsoyiannis et al., 2019). As a result, soils here are very susceptible to erosion (Gouma et al., 2011; James et al., 1994; Van der Knijff et al., 2000). These factors can result in the long-term geomorphological development requiring archaeologists to critically appraise the impact of these processes on archaeological sites and the character and spatiality of their surface artifact assemblages (Bevan & Conolly, 2006; French & Whitelaw, 1999; Gouma et al., 2011; Howland et al., 2018; James et al., 1994; Tartaron et al., 2006). In an effort to better understand the relationship between the geomorphic processes and the surface assemblages, archeological projects have been introducing geomorphological studies into their archaeological surveys (Barton et al., 2002; French & Whitelaw, 1999; Gouma et al., 2011; James et al., 1994). An example of the implementation of this concept is shown in the work of the *Eastern Korinthia Archaeological Survey* in the ancient city of Corinth in Greece (Tartaron et al., 2006). This study utilized interdisciplinary methodology (archaeology, geological sciences, and GIS) to study the influence of geomorphic and cultural post-depositional processes that effect the movement and taphonomic condition of the artifacts (Tartaron et al., 2006). The study was conducted with the idea that stone tool artifacts are 'anthropogenic clasts' that once discarded are subject to same geomorphic processes as natural clastic sediments on hillslopes (Tartaron et al., 2006). Another example of an implementation of this approach is the work by Howland et al., (2018) on the Khirbat Nuqayb al-Asaymir Iron Age site in southern Jordan. They used surface survey data to generate a distribution map of cultural material. They then used low-altitude aerial photography to capture images of the study area and created a 5 cm resolution DEM using a SfM workflow. From this data they created a Revised Universal Soil Loss Equation model to estimate the relationship between the cultural material and erosion distribution, which gave a better understanding of site activity.

In this study we evaluated the influence of geomorphic factors on the distribution and integrity of surface archeological finds at the Stelida early prehistoric (Early Paleolithic- Mesolithic) site in Naxos, Greece. The artifacts, consisting of stone tools and associated manufacturing debris, were collected by a pedestrian survey over two field-seasons in 2013-14 undertaken by the *Stelida Naxos Archaeological Project* (SNAP). Amongst the mass of 30,000+ systematically collected artifacts are pieces that can be dated on the basis of their form and technical specificities from the Lower Paleolithic to Mesolithic (≥250,000 – 9000 years old), i.e., material culture that was made, and discarded from the Middle Pleistocene to Early Holocene by Neanderthals (and possibly earlier hominins) and *Homo sapiens* (Carter *et al* 2014, 2016). For this study a model-based approach was taken to analyze the sediment movement across the surface. The artifact distribution across a landscape does not always occur as discrete homogeneous concentrations that can be interpreted as sites (or in this instance intra-site activity loci), however with the implementation of systematic surveying methods, information collected at different spatial resolutions can be combined in order to visualize site activity (Cherry et al., 1988; Mee & Cavanagh, 1998). Through the use of remote sensing technologies valuable information can be gathered from a relatively large area with relative ease (Agüera-Vega et al., 2018; Barceló et al., 2003; Bellezza Quater et al., 2014; Bevan & Conolly, 2006, 2009; Eltner et al., 2018; Fonstad et al., 2013; Oczipka et al., 2009; Smith et al., 2014). Specifically, the implementation of UAV-based data capturing and Structure from Motion (SfM) photogrammetric workflows in many disciplines has become prevalent, allowing the acquisition of a vast amount of information in a time saving and cost-effective way (Agüera-Vega et al., 2018; Barceló et al., 2003; Bellezza Quater et al., 2014; Bevan & Conolly, 2004, 2009; Eltner et al., 2018; Fonstad et al., 2013; Gouma et al., 2011; Hill et al., 2009; Howland et al., 2014, 2018; Oczipka et al., 2009; Smith et al., 2014; Whitelaw et al., 2006). This project applies some of these workflows to Stelida in order to derive key environmental variables required for erosional modeling. This case study aims to inform the growing number of archaeological projects that implement these techniques in archeological project design, and the study of taphonomy.

3.2 STUDY AREA

3.2.1 Physical Setting and Geology

The Stelida study site occupies a 1.5 km^2 rocky headland on the northwestern shore of the central Aegean island of Naxos (Fig. 3.1A). The headland comprises a steep, dual peaked hill, with a southern peak reaching 151 m.a.s.l. The hillslope gradient is on average 30% on the shoulder and back slope with shallower slopes on the summit, foot and toe sections (Fig. 3.1B). The coastline at the foot of the hill is characterized by vertical cliffs of eroded sections of Quaternary sediments that meet the sea. Naxos is located in the Attico-Cycladic belt of the Hellenides (Skarpelis et al., 2017). Geologically, the entire island is comprised mostly metamorphic Mesozoic rocks, known as the Cycladic Blueschist Unit (CBU), surrounding a migmatite dome (Evelpidou et al., 2012; Skarpelis et al., 2017, Rye et al., 1976). At Stelida, granodiorite intruded up into the CBU approximately 13 to 12 mya (Evelpidou et al., 2012; Piper et al., 1997; Skarpelis et al., 2017). The southern half of Stelida is underlain by granodiorite bedrock, while the northern half has a sedimentary rock base, with the two halves being separated by a detachment fault which is believed to extend to the Molos peninsula on the neighboring island of Paros (Fig. 3.2). This feature is part of a larger fault system that was active ~13 to 9 mya (Skarpelis et al., 2017). Shales, sandstone and conglomerate rocks underly the northern section that formed from detrital marine, lacustrine and fluvial deposits from the Miocene age (Fig. 3.2) (Skarpelis et al., 2017).

The hill is composed of siliceous chert, which outcrops in various locations differing in elevation and height (Fig. 3.2). The chert origin has been ascribed to the alteration of the sedimentary protolith by hydrothermal alteration. The hydrothermal alteration was likely produced by movement of fluids along the west-east trending Naxos-Paros detachment fault (Fig. 3.2) which separates the Mesozoic sedimentary strata from a granodiorite intrusive body along the southern margin of Stelida (Evelpidou et al., 2012; Piper et al., 1997; Skarpelis et al., 2017). Variations in the colour and composition of the chert are due to the varying lithologies of sedimentary protoliths. The chert outcrops above the western slopes are taller (up to 10 meters high) than those on the east. The chert outcrops provided raw material for the production of lithic tools and are the central feature of the hill that influenced early human activity at the site (Carter et al., 2014, 2016, 2019; Skarpelis et al., 2017).

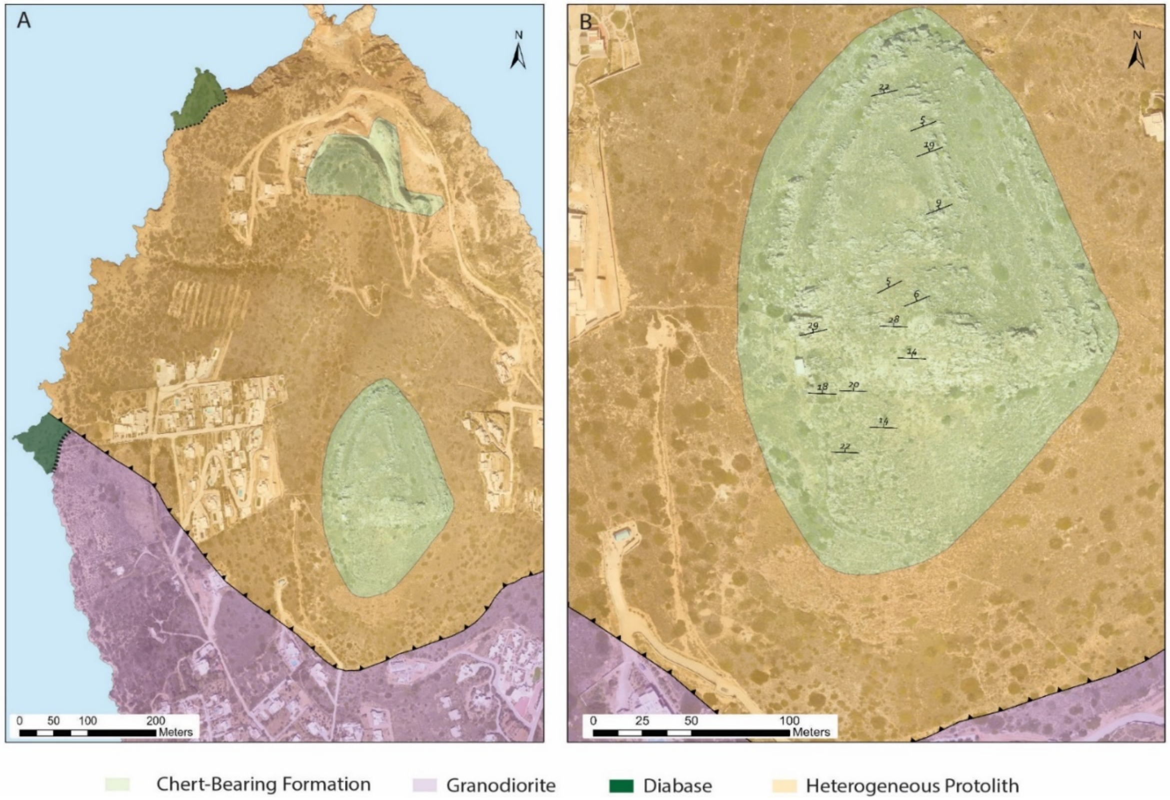

Figure 3.2: Bedrock geology map of Stelida (modified from A. Klein and T. Kinnaird, University of St Andrews (June 2017). B. Strike and dip of chert beds on southern Stelida peak. The Oligocene-Miocene (O-M) clastic sedimentary rocks are juxtaposed against the Miocene granodiorite along a northward dipping west-east detachment fault (Moutsouna fault; Rabillard et al., 2018). Chert deposits were formed by silicification of O-M clastics by hydrothermal fluids migrating along the detachment fault. The O-M protolith rocks are covered by a variable thickness of Quaternary alluvial and colluvial deposits.

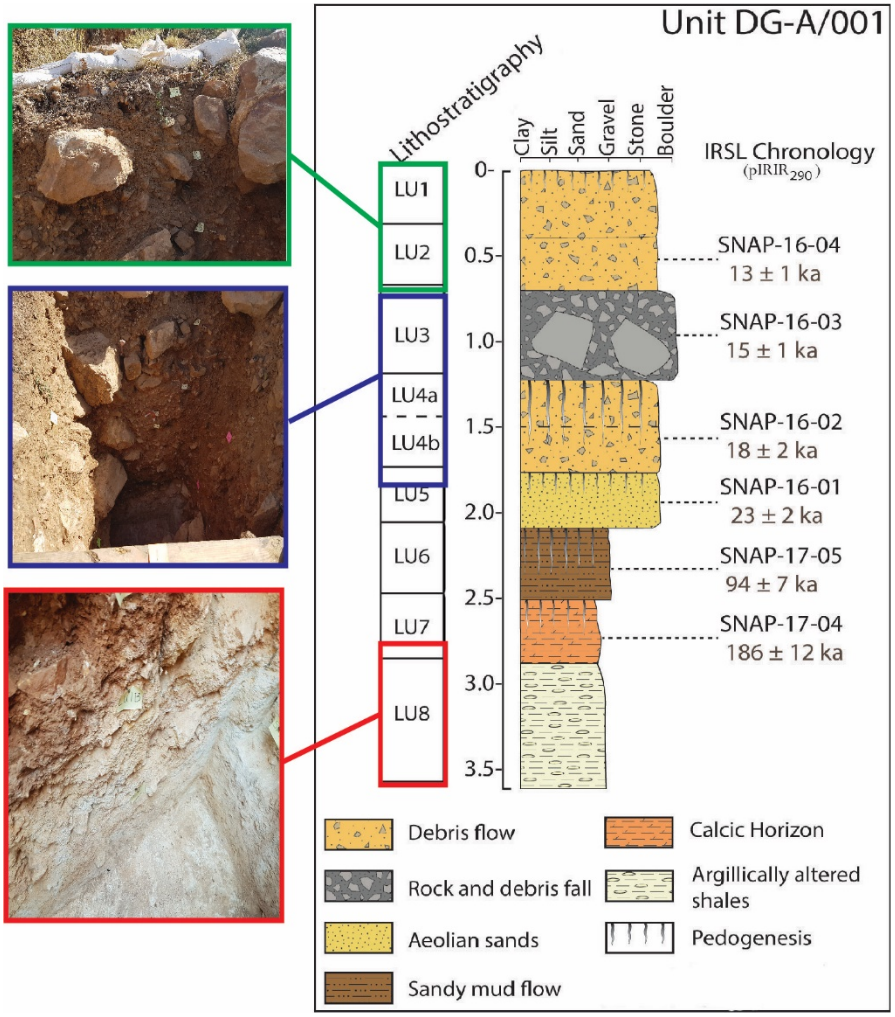

Figure 3.3: Lithostratigraphy of excavation unit DG-A/001 with IRSL dates (modified from Carter et al., 2019). With images of sections of the whole lithostratigraphic profile.

The bedrock surface at Stelida is overlain by a variable thickness of Quaternary and Holocene unconsolidated sediments (Evelpidou et al., 2010; Carter et al., 2019; Holcomb, 2020). Excavations a number of locations have revealed up to eight lithostratigraphic units (LU1-8; Fig. 3.3), consisting of stratified colluvial deposits spanning the past 180 kya. At site DG-A/001 (Fig. 3.3) surficial sediments are in excess of 4 m in thickness and overlie thin regolith and silt-loam paleosol developed over bedrock (Holcomb, 2020) . Overlying the paleosol is a debris flow unit (LU-7) dated to ~ 186 ± 12 kya, to the MIS 7 interglacial period (Carter et al., 2019; Holcomb 2020). At the top of the debris flow unit paleosol with root casts indicating a stable period of soil development (Holcomb, 2020). LU-7 is overlain by sandy-mudflow unit (94 ± 7 kya) and aeolianite with paleosols which indicate a period of cooler, wetter climate and enhanced weathering at the end of the last interglacial period (Carter et al., 2019). The last glacial maximum (LGM) is recorded by a sequence of aeolian sand (~23 ± 2 kya) and debris flows deposited at ~18 ± 2 kya (Carter et al., 2019). At the top of the sequence, inversely-graded, coarse-grained debris flows and rock and debris fall units record the transition to post-glacial environments at the end of the last glaciation (ca. 15-13 ± 1 kya)(Carter et al., 2019). These units represent a time when there was increased erosion and frequency of mass movements on hillslope at the end of the Pleistocene (Carter et al., 2019). The uppermost lithostratigraphic unit (LU-1) was comprises Holocene-age debris flows and sheet-flow deposits which rest unconformably over older debris flow units.

Stratigraphic studies at Stelida (Carter et al., 2019; Holcomb, 2020) demonstrate that the surficial deposits span more than 180 kya and record several major shifts in depositional environment associated with change in climate and geomorphic processes. While these data provide new insights in to geological development of Stelida it is difficult to predict how changes in depositional environments and hillslope processes in the past would have altered the surface distribution of lithic materials. Therefore, a primary focus of this study was to quantify the pattern of erosion on the modern hillslope and to evaluate whether the modern hillslope geomorphic processes are a control on the spatial distribution of diagnostic materials on the modern surface.

The climate of Naxos is characterized by hot, dry summers and cool, wet winters (Evelpidou et al., 2018; Koutsoyiannis et al., 2019; Panagos et al., 2016). The average annual precipitation is 390 $mmyr^{-1}$ (calculated from data from the Hellenic National Meteorological Service) with most rainfall occurring during winter months. The arid summer months produce hardpan soils which are highly susceptible to erosion by flash-flood events during high rainfall events during the winter (Evelpidou et al., 2018; Koutsoyiannis et al., 2019; Panagos et al., 2016). The downslope transport of surface artifacts by hillslope processes is therefore most active during winter months when flash flooding triggers sediment gravity flows and fluvial dissection of hillsides.

The archaeology of Stelida was discovered in 1981 during an island-wide survey by the École Française D'Athènes but had been previously noted during a geological mapping work by Roesler in the late 1960's (Treuil, 1983). These studies documented the chert source materials and associated artifacts (Roesler 1969; Sériadès, 1983), but the area remained unexplored until 2000 when the Greek Ministry of Culture conducted salvage excavations ahead of land development projects (Legaki, 2012; 2014). The Stelida lands and immediate environs are under increasing pressure for development for tourism and residential housing, which has accelerating the timeline for archaeological investigations (Carter, 2017). Thanks to the earlier work by local archaeologists, the upper portion of the hill has protected ('Alpha Zone') status from the Greek Ministry of Culture as a result of salvage excavations lead by the Museum of Naxos (Carter, 2017; Carter et al., 2018), whereas the lower flanks ('Beta Zone') can be developed once archaeological research has been conducted. Pre-development 'rescue' excavations by representatives of the Ministry identified artifacts believed to be diagnostic of the Middle to Upper Paleolithic and Mesolithic periods (Legaki, 2012, 2014). The presence of early Pleistocene activity on the island makes the site significant, as the conventional wisdom until recently was that none of the Mediterranean islands had been colonized until the Neolithic (Holocene) (Cherry 1981).

SNAP was established in 2013 with the aim of clarifying and characterizing the archaeology of Stelida in the context of recent claims that certain Aegean islands did have pre-Neolithic activity, discoveries that potentially had implications for the maritime history of the Mediterranean, and our understanding of pre-*sapiens* technological and cognitive capabilities (Runnels et al., 2014). The project was directed by T. Carter of McMaster University, and conducted under the auspices of the Canadian Institute in Greece, with permission from the Greek Ministry of Culture. The initial iteration of SNAP was a pedestrian survey and geological mapping project during the summers of 2013-14 (Carter et al. 2014, 2016; Skarpelis et al 2017). In 2015 SNAP shifted from survey to excavation, and became an official collaboration with the Cycladic Ephorate of Antiquities, now co-directed by T. Carter and D. Athanasoulis (Carter 2017, Carter et al. 2017), and the project remains ongoing today (www.stelida.org).

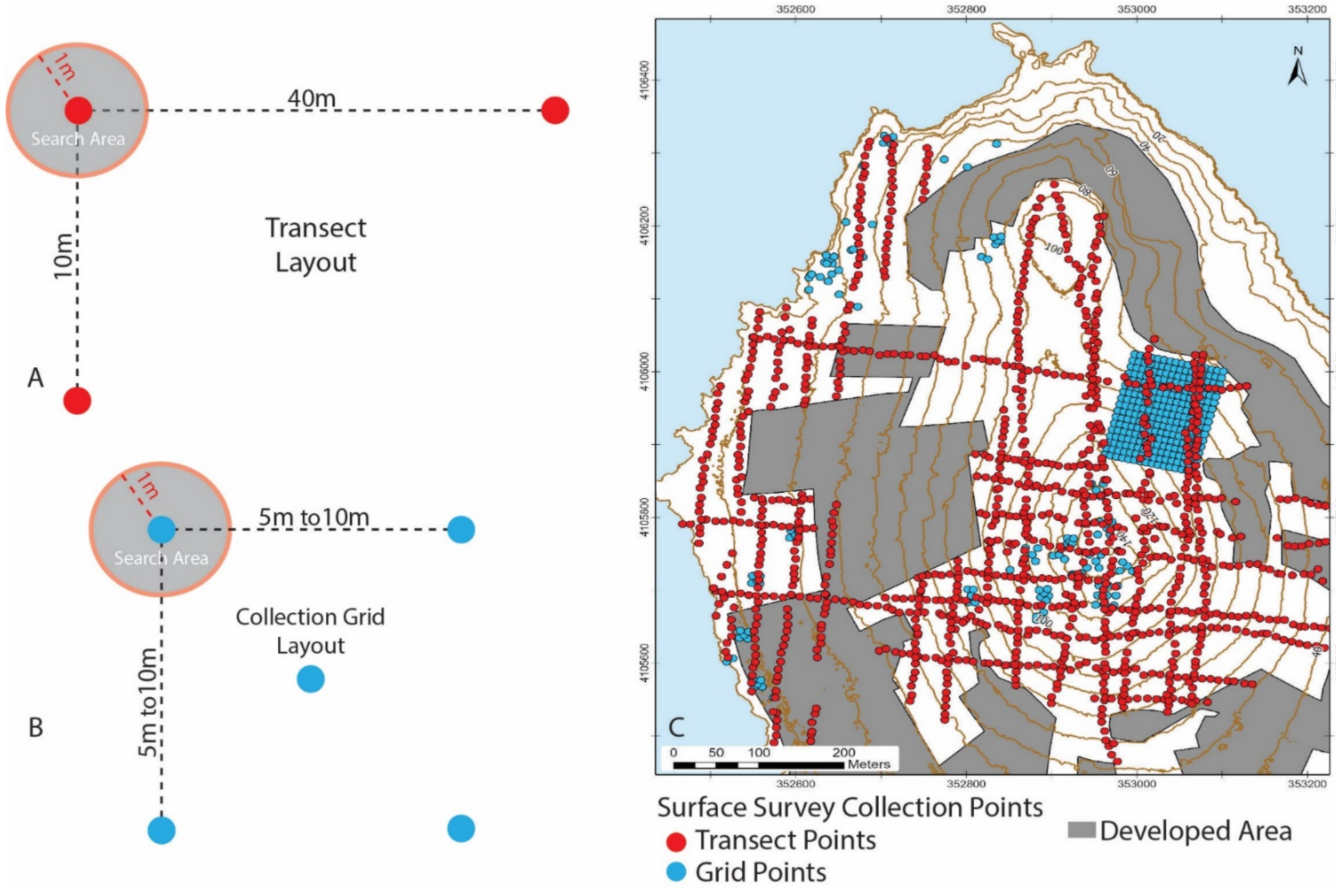

Figure 3.4: A) Layout of the survey collection transects. B) Layout of the survey collection grids. C) 2013-2014 pedestrian survey showing location of transects and grid survey points. Grey-shaded areas indicate residential areas and private property where survey work was limited by infrastructure or restricted property access.

3.2.2 2013-14 Pedestrian Survey

A surface pedestrian survey was collected in 2013-2014 by four pairs of archaeologists walking linear transects oriented to the cardinal directions and established in relationship to the site grid centred on a trigonometrical station on Stelida's southern peak (Fig. 3.4). Methodologically, the aim of the pedestrian survey was to map the surface distribution and extent lithic artifacts to guide excavation work. This was achieved by the collection of all material culture within a 1 m^2 radius at 10 m sampling intervals along the transects (Fig. 3.4). The transect lines were established using tape and compass, and collection points were recorded with photographs and with GPS units. At each collection point, a suite of supplementary information was also recorded to help us critically reflect on the integrity of these archaeological data, such as surface visibility / vegetation cover, angle of slope and other features deemed to be significant (see discussion below).Transect lines were initially established at 40m intervals, and in some cases leapfrogged out further to roughly locate the outer limits of those area(s) containing scatters of lithics. Field walkers also took note of surface conditions and artifact density 20 m either side of their transects, i.e., to cover all parts of the site between the survey lines. By the project's end a total of 36.8 ha had been covered, with 29 survey transect lines walked, ranging from 70 – 820m in length.

In addition to systematic walking of transects, the team also employed a more targeted collection procedure focusing on those areas of interest based on the density and/or character of the lithic material found there (as determined by transect results, or field observations). These study units were mainly in the range of $1m^2$ – $15m^2$, though one 70 × 80m grid was established on the eastern flanks in front of rock shelter A (Fig. 3.4). These collection units were designed to compare the nature and date of activity at different parts of the site, and to explore internal variability within these areas of interest. The grids involved a systematic collection procedure, with the recovery of all surface material culture from at least one $1m^2$ unit. Where grids comprised a simple $1m^2$ unit these acted a stand-alone collection points, while in the case of larger sampling units, for example a 5 × 5m square, all artifacts were systematically collected from 1m² collection units located in the four corners, and centre-point, thus providing us with a 20% sample of the total area.

The survey led to the collection of over 30,000 artifacts, the vast majority being chert tools and flake debris. Of this material, approximately 7470 items are chronologically diagnostic based on their typo-technological traits of Lower-Upper Palaeolithic and Mesolithic regional industries (Table 3.1). Subsequent excavation has recovered large amounts of cultural material from stratified colluvial contexts, with associated luminescence dates providing several *terminus ante quem* dates indicating exploitation of Stelida chert for toolmaking from ~13,000 to ≥200,000 years ago (Carter et al., 2019).

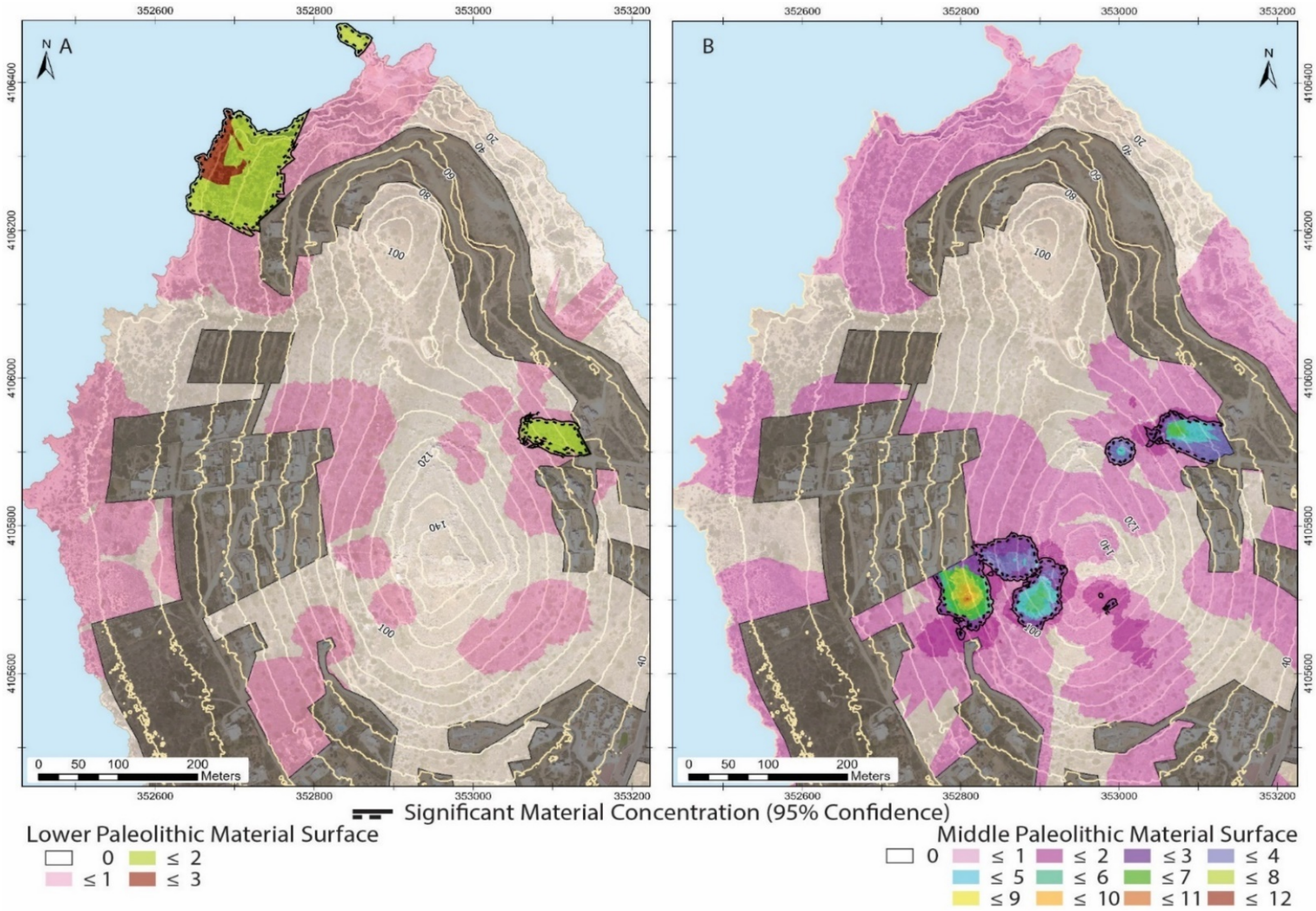

Figure 3.5: A) Distribution Lower Paleolithic materials. B) Distribution of all Middle Paleolithic material.

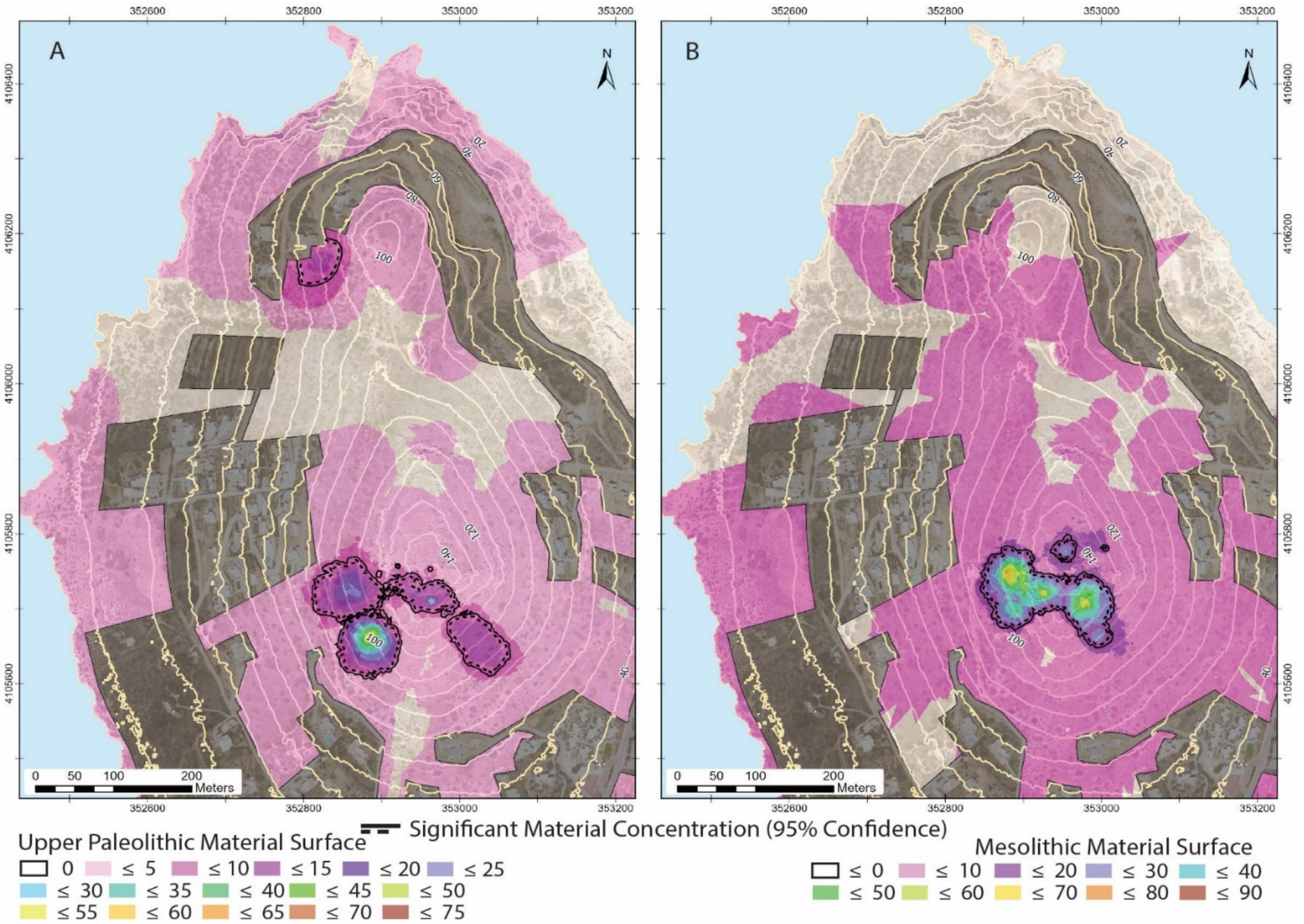

Figure 3.6: A) Distribution of all Upper Paleolithic material B) Distribution of all Mesolithic material and respective percentage of total assemblage.

3.2.3 Analysis of Surface Material Clustering

The primary objective of critical analysis of the survey data is to identify areas that could be classified as 'hot-spots'. 'Hot-spots' are locations with a significant concentration of cultural material and is therefore an area that is worth further exploration. A spatial statistical analysis was conducted in order to delineate these significant clusters from the obscuring, overall material distribution. The survey data was divided and analyzed based on the four chronological periods that were represented by the diagnostic material (Lower Paleolithic LP, Middle Paleolithic MP, Upper Paleolithic UP and Mesolithic M). The survey data was refined and then used in a Monte Carlo random labeling simulation test in order to determine the threshold values that are need before a chronological period's concentration is considered to be significant (Chapter #2). LP material assemblages with two or more pieces were considered significant statistically, while 3, 8 and 11 were the determined threshold values for MP, UP and M respectively (Chapter #2).

The next step was to create predictive interpolated surfaces to identify areas with significant artifact concentrations, and to identify the location of 'hot-spots'. Empirical Bayesian Kriging (EBK) was employed to produce these interpolation surfaces (Chapter #2). EBK used 10,000 simulated exponential semivariograms and an empirical data transformation to produce rasters for each chronological period which illustrated the predicted surface concentrations for the diagnostic material (Chapter #2). The resulting distribution surfaces and locations of the specific 'hot-spots' are presented in Figures 3.5 and 3.6. The determined clustering of this material is unlikely to be the result of a random distribution and it is inferred that the pattern may be the direct result of cultural activity or environmental processes (Chapter #2).

A question which arises from this analysis, is what is the contextual integrity of these significant clusters? The principle here was that we know a significant amount of diagnostic material is clustered together in a specific area (hot-spot), however, is this material representative of cultural activity at that location or has there been post-depositional migration as the result of cultural or geomorphic processes? Apart from the possession of a detailed record of the movement of the material through the passage of time, trying to model the changes in material distribution due to cultural activities becomes difficult and would require a focused study. The influence of geomorphic processes on the artifact distribution is more tangible to estimate as information can be derived from physical characteristics of the surroundings. Previous research show that the site has been subjected to numerous mass movement and erosional events, therefore it is a reasonable assumption that fluvial and gravitational processes might have altered the position of some artifacts. This study aimed to compare the erosional potential of the site and compare any patterns of erosion to the position and shape of the derived 'hot-spots'. Topographical data, sedimentary data and hydrological data all needed to derived in order to achieve this aim.

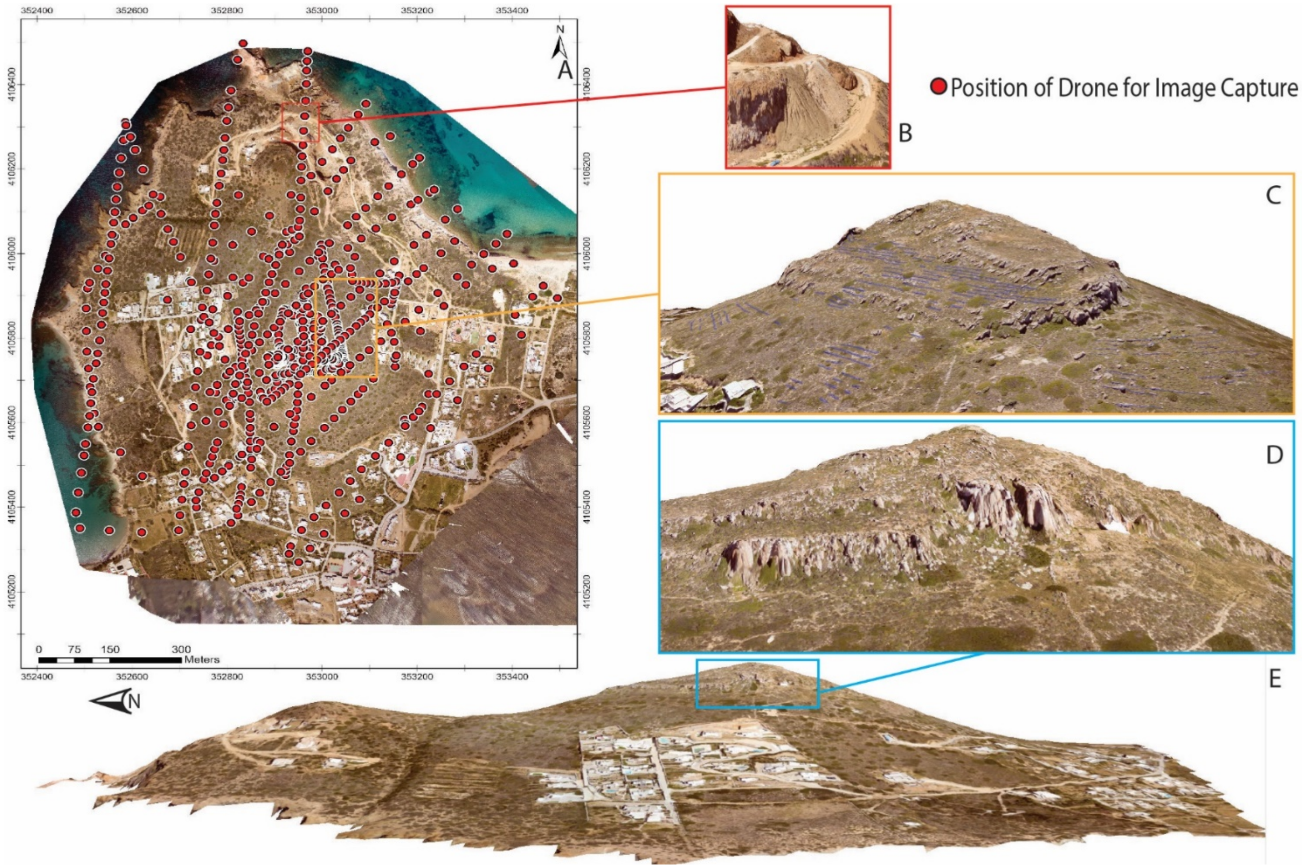

Figure 3.7: A) Orthomosaic showing UAV image capture positions. B) Alluvial fans located in the northern quarry section of the hill. C) Interpreted locations of agricultural terraces on the Stelida eastern slope. C) View of the chert outcrops at the top of the western slope of Stelida. E) Orthomosaic overlain on DSM.

3.3 METHODS

3.3.1 UAV Survey

In 2016, a UAV photogrammetry survey was acquired over a ~1.4 km^2 area at Stelida using a DJI Phantom 3 drone (Fig. 3.7A). The survey included the area covered in the 2014 pedestrian survey. A total of 1011 photos (12.4 megapixel) were taken at a constant capture altitude of 100 m, providing a ground resolution of ~5 cm. Agisoft Metashape software was implemented as the SfM platform. The 3-D model was georeferenced using 8 ground control points (GCPs) on the hillside (Fig.. 3.1B) measured using a Topcon RTK Differential-GPS (DGPS). GCP point positions were post processed using the URANUS system of permanent reference stations located across Greece (Tree Company Corporation; https://www.treecomp.gr/positioning). An additional 268 GCPs were captured using a ProMark3 D-GPS system and processed using Natural Resources Canada CSRS-PPP online tool (https://www.nrcan.gc.ca/maps-tools-publications/tools/geodetic-reference-systems-tools/tools-applications/10925).

The resulting positional accuracy of the GCPs was ~2 cm in the X-Y positioning and ~3 cm in elevation (Z). Points located in areas adjacent to vertical outcrop faces had the greatest variation in positional accuracy due to more limited satellite coverage. A selection of 84 GCP’s were used in the Agisoft workflow to georeference the 3-D model (Fig. 3.1B) and the remaining 184 points were used as quality control checks for the computed DSM elevations. From the model, a 3-D mesh of the hill (Fig. 3.7E), an 8 cm orthomosaic of Stelida as well as a 9 cm DEM were derived. In comparing the DEM with the quality control points, the average difference in elevation was ~3 cm with the largest errors occurring on the edges or at the base of the outcrops. The DEM was further refined through the manual removal of all man-made features (e.g., buildings, roads) in order to simplify the DEM into a DSM. This DSM data layer was key component for the geomorphic analysis (Fig. 3.8A).

3.3.2 Terrain Modelling

As a first step in soil erosion modelling, a Digital Surface Model (DSM) was constructed for Stelida (Mitasova et al., 1996). A number of acquisition methods were explored, the desired product was a high-resolution DEM in which characteristics such as slope, curvature and hydrodynamic variables could easily be derived. The 1011 drone photos were added to a new project in Agisoft and the 84 GCPs were flagged in as many photos as possible. The photos were aligned according to the image capture locations and the position of the GCPs using the UTM zone 35N coordinate system. Following the photo alignment, the program then generated a dense point cloud of all the key points identified within the photos. Agisoft then categorized the points to facilitate point filtering (e.g., ground, vegetation, building/structures, water, etc.). The classified points were using in conjunction with manual editing to remove error points, buildings and large vegetation, leaving only the points that represent the surface. The surface dense point cloud was then used to generate a 3-D mesh of the hill, which was then used to calculate the DSM for the site.

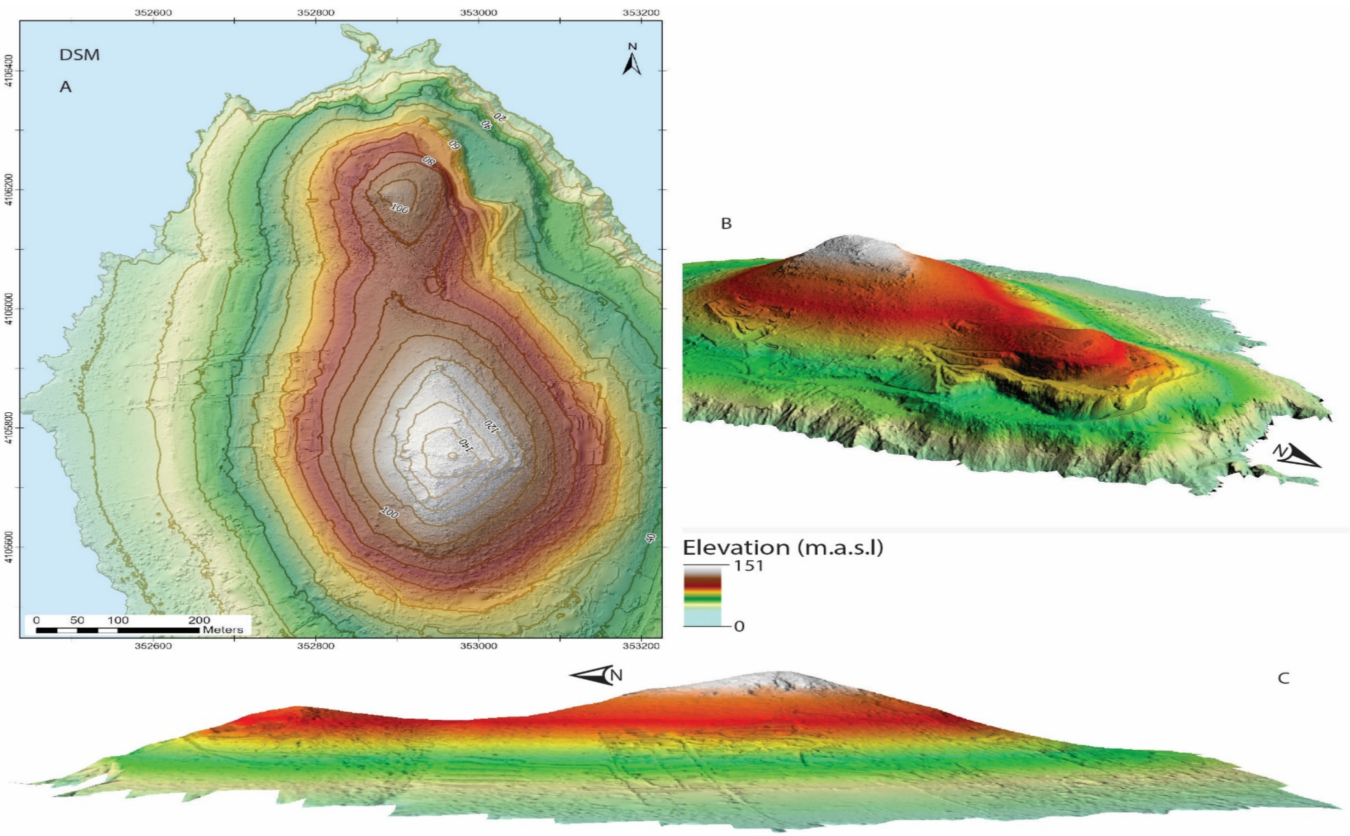

Figure 3.8: A) SfM-derived digital surface model (DSM) of Stelida. B) Southwestern 3-D view of Stelida DSM. C) 3-D view of the western slope of Stelida's DSM.

3.3.3 Surface Hydrologic Modeling

One key assumption for this study is that the downslope movement of soil and surface artifacts by fluvial and hillslope processes will be influenced by the surface relief and microtopography. To further the understanding these processes, the hillslope hydrological parameters were calculated using ArcGIS Pro tools. Flow direction was calculated first, which produced a raster representing the water runoff direction for each cell, based on the elevation of the cells. Next, the D8 modeling algorithm was employed to model the direction of the steepest downslope neighboring cells. The flow direction raster was visualized as a series of vectors (arrows) on the surface to help visualize the direction of water movement on the surface. The next step in this analysis was the delineation of drainage basins and divides using the Basin Tool (Fig. 3.11). This tool uses the D8 flow direction raster and identifies the ridge lines between the different basins. The drainage basins represent the surface areas where the flow of water will contribute down to the same pour point. These mapped drainage basin network help with understanding how materials may have moved across the surface. While the basin raster helps to understand fluvial movement across the whole of the hill, an effort was made to focus on the areas of material concentration. The identified material 'hot-spots' where used as pour point with the Watershed Tool. This tool uses the flow direction raster to delineate the extent of the upslope area, where water/soil will flow down into the hot-spot area. These watersheds represent the potential contribution area where material may have been transported from (Fig. 3.12 and 3.13). In a final step, the DSM was resampled to a 2 metre grid cells size and the slope angle calculated. Visual analysis was conducted to identify surface depressions and areas of slope change and how these locations relate to the distribution of material.

3.3.4 Erosion Modeling

The DSM provided a basis for modeling of soil erosion and sediment transport across the site. Soil erosion modelling employed an implementation of the Revised USLE (RUSLE) in ArcGIS Pro (Wall et al., 2002). This empirical model predicts the long-term average annual rate of slope erosion based on rainfall pattern, soil type, surface topography, crop systems and agricultural management practices (Esther, 2009; Renard & Freimund, 1994; Wall et al., 2002). RUSLE was used in this study to quantify erosion and downslope transport of colluvium, which is an important geomorphic control of the surface material. RUSLE permits quantitative information regarding seasonal variations in erodibility, irregular slopes and vegetation (Lim et al., 2005; Wall et al., 2002). This empirical model was utilized due to its simple implementation and history of use. The model is used in conjunction with the DEM to identify locations vulnerable to erosion (Lim et al., 2005; Mitasova et al., 2013; Renard & Freimund, 1994; Wall et al., 2002). The RUSLE empirical model (Fig. 3.9) computes the soil loss per unit area (A) as:

$$A = RKLSCP \qquad \textit{Eq. 1}$$

where R is the rainfall or runoff factor, K is the soil erodibility factor, L is slope length factor, S is slope-steepness, C is the cover and management factor, and P is the support practice factor. The computed soil loss A is expressed tonnes $ha^{-1}yr^{-1}$.

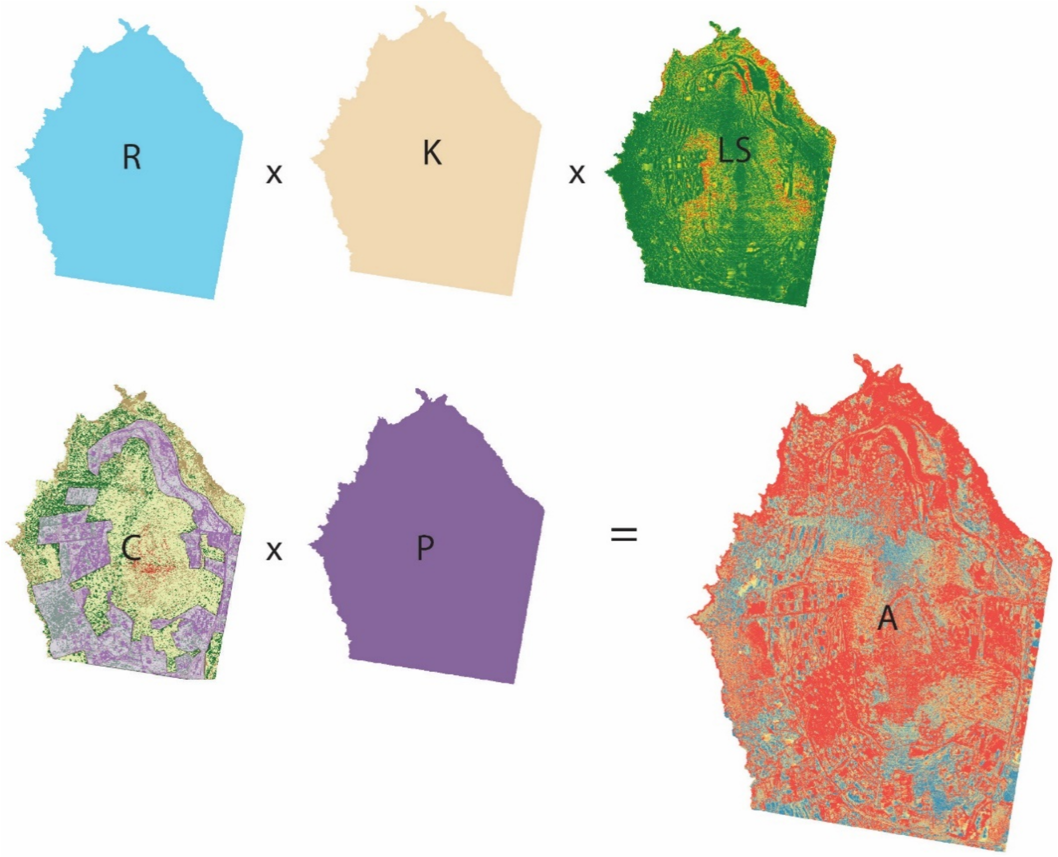

Figure 3.9: Graphical representation of the RUSLE model component. R = runoff factor, K = soil erodibility, L = slope length, S = slope steepness, C = cover and management factor, P = support practice factor.

Agricultural areas of the arid regions of the Mediterranean are very susceptible to soil erosion due to annual cycles of drought followed by intensive rainfall on fragile soil and low vegetation cover (Fig. 3.10) (Capolongo et al., 2008; Evelpidou, et al., 2018). It is common for areas in this region to lose 20-40 tonnes per hectare in a single storm every two or three years (Capolongo et al., 2008; Evelpidou, et al., 2018; Panagos et al., 2016). The rainfall factor (R) used for this study was 1422.939 (MJ mm/yr/ha/hr). This value was derived using long term weather data collected between 1971 to 2018 by the Hellenic National Meteorological Service at the Naxos Airport weather station (Hellenic National Meteorological Service). The calculated monthly rainfall averages were used in a

R factor calculation developed by Panagos et al. (2016) for Greece (Renard & Freimund, 1994; Wischmeier & Smith, 1978).

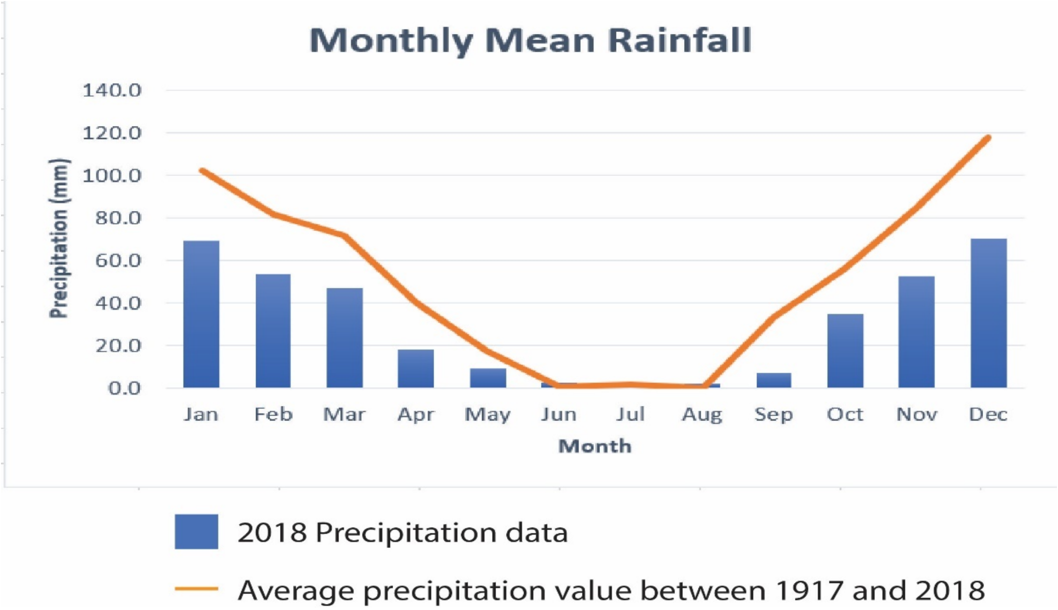

Figure 3.10: Graph of the monthly precipitation values at Naxos for 2018. The precipitation graph is representative of the climatic trend of the last 50 years (Hellenic National Meteorological Service).

The soil erodibility factor (K) was also derived using a high-resolution dataset for soil erodibility across Europe (Panagos et al., 2014). The predominant soil type at Stelida is poorly-sorted silt-loam with a relatively high percentage of intermixed stone fragments (stoniness ~60%), which yields a K value of 0.0229 ((t hr)/ha/MJ/mm) (Panagos et al., 2014). The slope-length (LS) value was derived using the Stelida DSM and SAGA (System for Automated Geoscientific Analyses) LS factor tool. This factor accounts for both the steepness of the slope and the horizontal distance associated with slope change. The LS factor calculation was set to use Desmet and Govers equation, which uses a unit-contributing area approach to better capture of more complex topography (Desmet & Govers, 1996; Foster & Wischmeier, 1974; Panagos et al., 2015).

The surface coverage (C) factor was created using a supervised classification of the high resolution orthomosaic surface image of the site, in order to determine the different classifications of land cover. The landcover of the site was classified as Sclerophyllous vegetation (thick vegetation), sparsely vegetated areas, barren, bare rocks, water and buildings/developed areas. The C factor values were determined from a previous study estimating the soil erosion cover-management in Europe (Panagos et al., 2015). The orthomosaic image of the area was classified using these values to create a C factor raster. Since the area on the site is no longer actively used for agriculture and there are spares records of agricultural practices across the area, the P factor value was set based on the present-day conditions (P=1, No conservation Practices). All the required variables were made into representative raster datasets and then multiplied together using a raster calculator.

3.4 RESULTS

3.4.1 3-D Digital Surface Model (DSM)

One of the products produced by the SfM workflow was a high-quality 3-D mesh model of the study area (Fig. 3.7E). The model was textured using the high-resolution orthomosaic of the surface to aid in the interpretation of topographic and RUSLE data as well as helping to visualize physical features of the site. During research projects where you have limited access to your study area these 3-D models allow one to revisit areas or to verify field observations. The 3-D model is detailed enough to capture a number of key physiographical features. The overall slope and profile of Stelida was captured effectively (Fig.. 3.7E). The shape and height of the chert outcrops around the southern summit is represented and locations of abrupt elevation change can be observed (Fig. 3.7D). Other features such as abandoned agricultural terraces can be traced on this model whereas some of these terraces are difficult to decern in the field (Fig. 3.7C). Some of the buildings, retaining walls and vegetation are low lying or recessed into the hill slope, which obscures the surface model detail in some areas. Some alluvial fans deposits can be picked out in the hill’s northern section (Fig. 3.7B).

The 3D representation of the topology of the site was of extreme benefit during the interpretation of how erosional processes might have influenced the movement of diagnostic material across the modern surface.

3.4.2 Soil Erosion Potential

The estimated surface erosion potential for the site is represented by the computed soil loss (A) raster which has a representative resolution of ~9 cm (Fig. 3.8). The soil loss was categorized into five different classes following Howland et al. (2018b). A sediment loss risk potential of 5 tonnes $ha^{-1}yr^{-1}$ or less is considered to be low and areas with a potential of 50 tonnes or more is considered to be extreme. Due to the site soil characteristics and frequent flash flooding, a large volume of sediment erosion and transport can occur within a single storm event (Carter et al., 2019, Capolongo et al., 2008; Evelpidou, et al., 2018; Panagos et al., 2016). A large area of the site (22 ha) is classified as having an extreme or severe soil loss potential and these areas are mostly barren of soil with exposed bedrock. Areas that have minimal to low loss potential are associated with thick vegetation cover, where plant roots serve to anchor the soil and foliage limits raindrop impact and soil erosion (Vaezi et al., 2017). Areas with the potential for moderate soil loss are found mostly in the areas of sparse vegetation and in areas bordering thickly vegetated areas. The erosion potential mapping also included built up areas, but these were disregarded in the analysis due to the extensive landscape alteration.

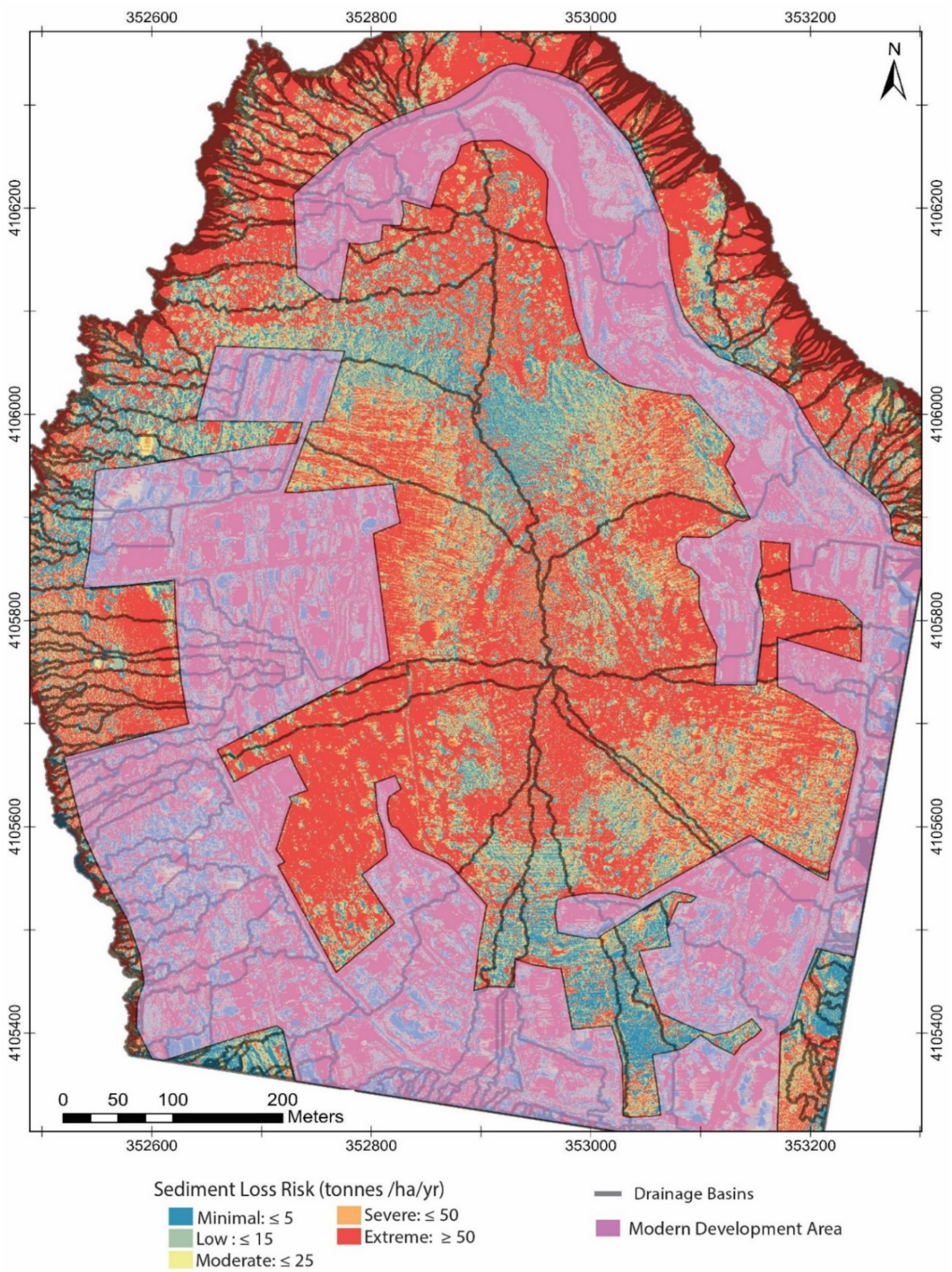

Figure 3.11: RUSLE soil erosion risk map. Soil loss potential is given in tonnes per hectare per year. The greatest potential for soil loss is on the steep sparsely vegetated side slopes, which are subject to overland flow during high rainfall events. Developed areas have high potential due to impervious surfaces and were excluded from the analysis.

Based on the surface hydrological analysis conducted, it is evident that the highest concentrations of diagnostic artifacts are contained within drainage basins with headwater areas in the southern peak. The southern peak has the largest surface areas of outcropping chert and was likely the primary locus for raw material extraction and stone tool production (Carter et al., 2019). Significant concentrations of surface artifacts have also been identified on the northern peak but due to development and the limited property access the remaining analysis is focused on the material distribution on the southern peak. (Fig. 3.5, 3.6) (Chapter #2). The significant material hot-spot areas were isolated for each of the different time periods. Using these areas as the pour points, watersheds were derived for each hot-spot area.

Chronological Period	**Potential Up-Slope Contribution area (m^2)**
Lower Paleolithic (LP)	12,050
Middle Paleolithic (MP)	20,524: 12,800 (eastern slope), 7,724 (western slope)
Upper Paleolithic (UP)	6,927
Mesolithic (M)	1,998

Table 3.2: Potential up-slope material contributions to material hot-spots from the southern peak for each of the chronological periods studied.

These watersheds represent the potential upslope contribution area where the material could have originated from based on the surface hydrology. The eastern MP hot-spot (MP1, Fig. 3.12D) has the largest contributing area at 20,524 m^2 and the Mesolithic hot-spot the smallest area of only 1,998m^2. LP distribution has the largest contribution area for a single hot-spot. Initial analysis shows that the potential contribution area for surface material decreases as the diagnostic material becomes younger. The older material is located further down the slopes then the younger material. Assuming that each piece has the potential to move, the further down the slope an artifact is the larger the upslope contribution area becomes. Therefore, the longer the material has been present on the site the larger the potential migration area. The results of the erosion potential model, the potential material contribution areas and the surface flow direction were used to gain further insight into how geomorphic processes might have shaped the resulting concentrations of surface material around the southern peak including the movement pathways and concentration of material (Fig. 3.12, 3.13).

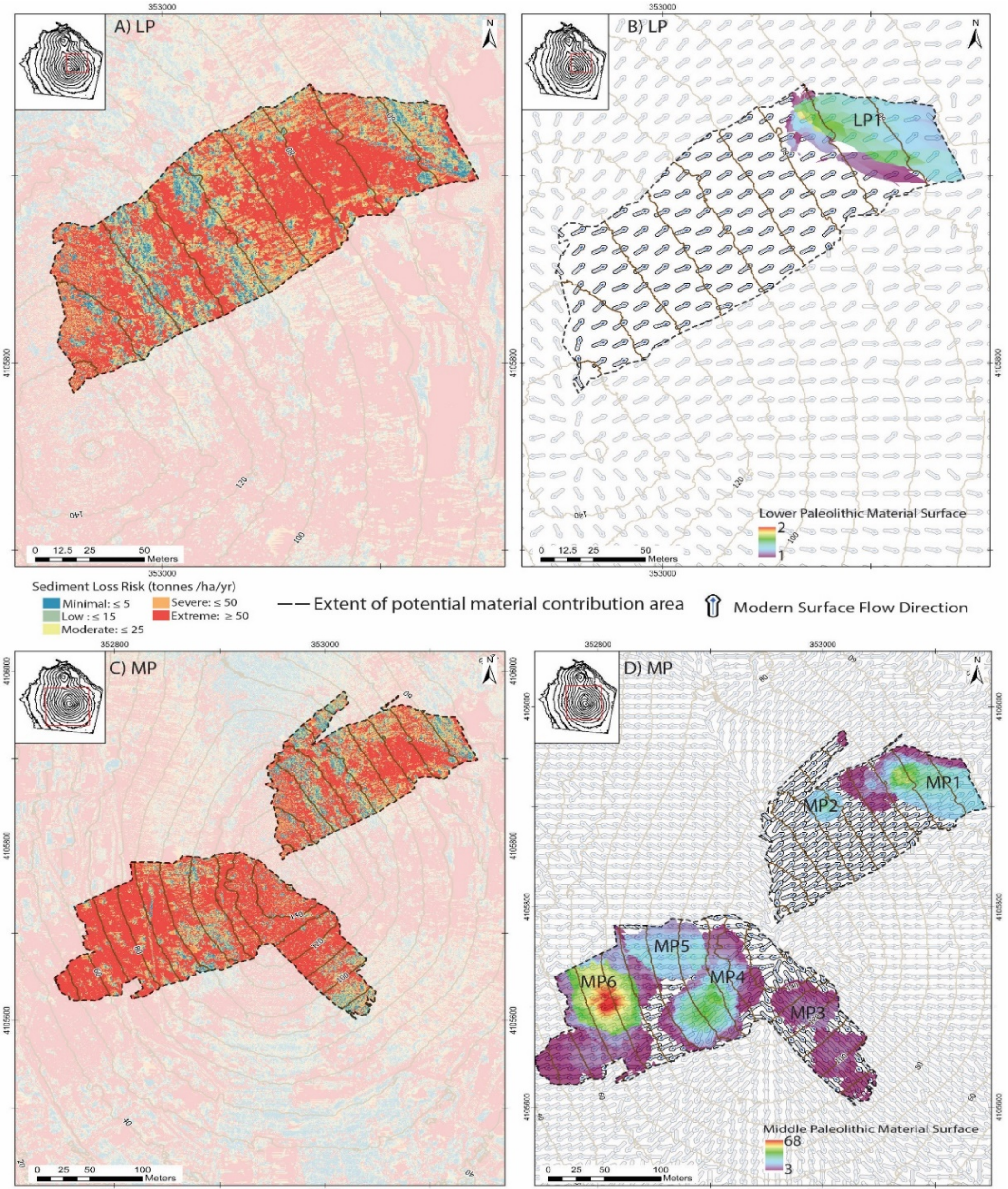

Figure 3.12: A) RUSLE soil loss potential and upslope contribution area for the LP hot-spot on the eastern slope of the hill. B) Colour contoured LP hot-spot with flow vectors. C) RUSLE soil loss potential for upslope area for the MP material hot-spots. D) Colour contoured MP hot-spots with upslope contribution area and flow vectors. Note five distinct clusters of MP materials.

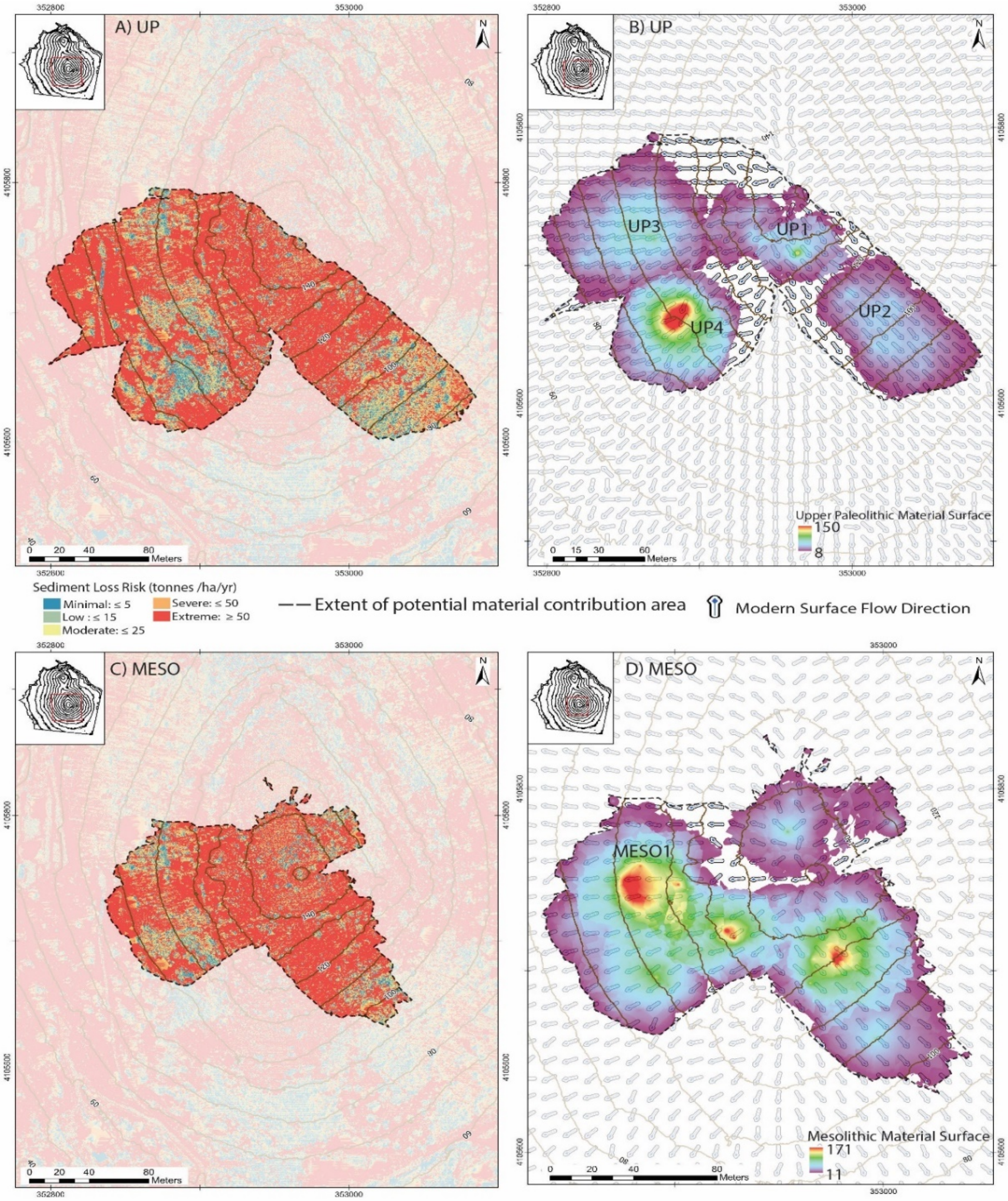

Figure 3.13: A) RUSLE soil loss potential and upslope contribution area for the UP hot-spot on the western slope of the hill. B) Colour contoured UP hot-spot with flow vectors. Note four distinct clusters. C) RUSLE soil loss potential and upslope contribution area for the M material hot-spots across the southern peak. D) Colour contoured M hot-spots with upslope contribution area and flow vectors. Note three cluster areas.

3.5 DISCUSSION

3.5.1 Geomorphic processes

The slopes of Stelida are covered by a variable thickness of unconsolidated Quaternary sediments, which include aeolian deposits, debris and mudflows intercalated with thin paleosols(Fig. 3.3) (Carter et al., 2019; Evelpidou et al., 2010). The MIS 7 Interglacial Period was characterized by debris flows which covered the weathered bed rock of the hill (Carter et al., 2019). and by mudflows during the last (MIS 5) interglacial period (Carter et al., 2019). During the LGM aeolian sand was deposited on the hillslope (Carter et al., 2019) and during the Upper Paleolithic (~18 ± 2kya) until present, debris flow deposition dominated (Carter et al., 2019**).** There are a number of unconformities surface, which also indicated prolonged hiatuses in deposition and likely erosion of surficial sediments. The preserved stratigraphy at Stelida must therefore be considered as only a 'snap-shot' of the geomorphic processes over the last 180 kya.

This stratigraphic record demonstrates that Stelida's landscape development has involved several shifts in environment, climate and depositional processes (e.g., Fig. 3.3). The mudflow units (LU-6; Fig. 3.3) were deposited during the last interglacial (MIS 5c) with higher sea-level and indicate increased chemical weathering under warmer climate and with increased precipitation. The aeolian deposits formed the last glacial maximum when sea-level was more than 120 m below present and sand was transported by from the exposed shelf to Stelida's slopes. During this cooler, drier period of net aeolian deposition, cultural material would likely have been covered by sediment and hillslope erosion may have been more limited. During the LGM the sea levels were lower which exposed sands that were blown up onto the hill by cold winds. The shift back to debris flow deposition at the end of the LGM, as the region began to warm, and sea-levels rose indicates increased precipitation, slope instability and erosion. Debris flows were likely triggered by slope instability and possibly tectonic processes. Like other Cycladic islands, Naxos has a warm, temperate climate with more precipitation during the winter months (Evelpidou, Polykreti, et al., 2018). At present, the average annual rainfall for the island is about 400 mm/year, however the island is subjected to very intense rainfall events which often result in flash flooding (Evelpidouet al., 2018). Under the current climate conditions, hillslope fluvial processes, and most sediment is eroded and transported by surface water flows in streams and as a result of slope wash. Mass movements (e.g., debris and mudflows) resulting from slope instability and failure are less common in the modern environment when compared to the LGM. This is evident in the lack of well-developed modern debris flow lobes on the modern hillslopes and the dominance of sheet wash deposits in the upper part of the shallow stratigraphy. Sheet floods and channelized fluvial flows triggered by flash floods events are the dominant modern hillslope processes affecting the surface distribution of surface lithic artifacts.

At Stelida, the lithic materials provide evidence of past activity, however specific information pertaining to the original location of those events require further analysis to discern their whereabouts. There is always some uncertainty in archeological interpretation of past events, therefore consideration needs to be given to as many sources of uncertainty as possible. Through visual interpretation of the geomorphological variable representations, we aim to gain further insight into the integrity of the material distributions. Within the geomorphic data the areas of interest are those that have sudden slope change and where extreme and severe sediment loss potential areas meet minimal to low loss. The modern climate of Naxos results in flash flooding or intensive surface mass movement intermittently throughout the course of several years. As surface flow encounters changes in the slope it alters the velocity of the flow and as a result the sediment suspension capacity of the flow decreases (Beuselinck et al., 1999; Molina et al., 2009; Schumer & Jerolmack, 2009). Therefore, areas with a decrease in slope are potential locations for sediment deposition from surface flow. If material concentrations are found in these areas of slope change, it can be inferred that the material has been transported and deposited due to surface flow. Similarly, areas that have surface vegetation or regions where there is a boundary between high and low erosion potential are also known to be sediment deposition centres for suspended material (Descroix et al., 2001; Fen-Li, 2006; Loch, 2000; Zhang et al., 2004; Zhongming et al., 2010; Zhou et al., 2008). Therefore, if the material is being concentrated in vegetated areas or at the boundaries between erosion potential, it indicates the distribution of artifacts is likely the result of movement due to surface flow hydrological events.

3.5.2 Lower Paleolithic Material

Overall, there is very little Lower Paleolithic [LP] material recognized across the site (≥250,000 BP), however the results from the previous study (Pitt et al., 2020) indicate that finding two pieces from this period significant. There are however two LP hot-spots worthy of discussion. The first is located on the western flanks of the northern peak, however the integrity of this material is potentially compromised by modern development. There are a few buildings and road-cuttings up-slope from this artifact cluster, developments that could have served to redeposit the archaeological material down from its original position. With restricted access preventing further observation at the present time, focus shifts to the second concentration of LP material located on the north-eastern slope of the southern peak (LP1). This LP hot-spot is located in an area with thick, low-lying vegetation, where the potential erosion is predominately minimal to moderate (Fig. 3.12 A). This concertation of material is located at a point of slope reduction, with high erosion potential upslope and a low erosion potential downslope. The LP material is found the furthest away from the raw material outcrops, with approximately 62m to the edge of the hot-spot and approximately 74m to the highest concentration area. The pattern of surface flow indicates preferential flow away from the peak and in the direction of the hot-spot spread (Fig. 3.12B). The diagnostic LP material is the oldest material on the site resulting in a greater time for geomorphic influence on the distribution of the material. Due to this, the potential contribution area for the LP materials is the largest of any of the periods for a single hot-spot. The concentration of LP material resides at the boundary between high and low erodibility, at a location of decreasing slope and with a distribution that follows the surface flow trajectory; this indicates that the integrity of the distribution of LP material has been compromised and the material has most likely moved from its original depositional context. The potential contribution area for this hot-spot area helps to narrow down the up-hill area where material may have migrated from.

3.5.3 Middle Paleolithic Material

The second oldest diagnostic material on at the site relates to the Middle Paleolithic [MP] period (ca. 250,000 – 44,000 BP). In contrast to the LP material, all significant concentrations of MP material are found in proximity to the chert outcrops of the southern peak. The lower hot-spots on the north-eastern slope overlap the LP hot-spot and therefore have similar depositional context (Fig. 3.12C and D, MP1). The hot-spot has a relatively large potential contribution area which acts as depositional area due to slope and erosion characteristics as noted above. The shape of the distribution of material is reflective of the surface flow direction and leads to the assumption that the location to the material has been significantly altered over time. A second hot-spot is located further up the north eastern slope (around rock shelter A, MP2). This hot-spot is within a vegetated area that has predominately minimal to low soil loss potential. The hot-spot is relatively close to the raw material outcrops and situated in a slight depression that once contained a natural spring. The material at this location does not have a vast contribution area and if the material has migrated due to geomorphic processes it can only have traveled a relatively small distance. These observations strengthen the integrity of the location of this material as a potential site of activity, i.e., it might be worth excavating here if the archaeologists' aims were to shed light on MP activity at Stelida. Most of the MP material is found on the southern peak's western and southern slopes. Observations regarding the hot-spots on the southern slope (MP3) indicate that the material began further upslope next to the outcrops and over time has been transported downslope. The material is found clustered in areas of vegetation and slope gradient change as it migrates down slope in the direction of flow. The integrity of the distribution of material decreases as the distance from the outcrop increases as it implies more significant modification due to geomorphic processes. The material distribution on the western slope is more complex. The two higher hot-spots (MP4 and MP5) on the slope (above 100 m.a.s.l) have similar contextual locations in which they are both located in close proximity to the outcrops. The RUSLE model indicates that the area above the outcrops have high erosion potential, showing that material located on top may erode off the hilltop onto the flanks. Within these hot-spots, the concentration of material is highest in areas at the boundary of high and low erosion area with vegetation. The two hot-spots exist in different drainage basins from one another and their overall shape follows the direction of surface flow, with more material being found in areas where there is lower erosion and slope decreases. Based on these findings, these hot-spots are likely influenced by geomorphic processes and material has moved from the original depositional location. The greatest concentration of MP material is found within the hot-spot located 100m from the closest outcrop on the mid-western slope (MP6). This hot-spot is located in an area of severe to extreme erosion potential and contains primarily sparse vegetation. In addition, the area is having a predominant slope of 30 degrees with only minor variations. The shape of the distribution does not follow the surface flow directions and the centre of the hot-spot straddles two different drainage basin. All of these site characteristics differ significantly from those observed at the other MP hot-spots, indicating a different underlying depositional context where the material has been minimally impacted by geomorphic processes. The material found in this hot-spot is likely near its original position of deposition and has been brought to the modern surface through erosion of the overlying sediments.

3.5.4 Upper Paleolithic Material

The material diagnostic of the Upper Paleolithic [UP] period (ca. 44,000 – 11,000 BP) is found predominately at the summit, and on the western and southern slopes of the southern peak. The distribution of this material follows similar trend to most of the MP material in which the majority of the materials are found in areas of thick vegetation with low erosion potential and in areas with decreases in the slope. The diagnostic material is situated around the summit (Fig. 3.12 (UP1)), on top of the outcrops. Most of the distributions indicate influence of geomorphic processes with elongated hot-spot morphology following the surface flow (UP2). The material appears to have cascaded down from the hilltop outcrops, or away from the base of the chert exposures indicative of material that has been displaced from its original depositional location.

The largest concentration of UP material is found in the hot-spot that is on the western mid-slope, further upslope from the largest MP concentration (UP3). The limited extent of the hot-spot down slope from the outcrops indicates that there was minimal material contributed from on top of the outcrops. The elongated shape indicates that there was some alteration due to surface flow; however, the change is not to the same extent as the other distributions of UP material. The highest concentration of material in the hot-spot is found in a thick vegetation area where there is a natural depression and a minimal to low erosion potential (UP4). The highest concentration part of the hot-spot is located near the location of a historical natural spring. While the material in this hot-spot may have been concentrated in the natural depressions and vegetated areas overall the material has not migrated a significant distance from its initial depositional location. In summary the integrity of observations made regarding most of the UP-material hot-spots is uncertain due to the alterations due to geomorphic process, however the mid-slope hot-spot has greater contextual integrity.

3.5.5 Mesolithic Material

The youngest and most abundant material is diagnostic of the Mesolithic period (ca. 11,000 – 9,000 BP). This diagnostic material is smaller and lighter than the other studied periods. This material is found at the summit, and the western and southern slopes of the southern peak (Fig. 3.13). Unlike the material from the other periods a large portion of Mesolithic material is still found around the summit on top of the outcrops and cascading down channels in the outcrops. The hot-spot is elongated in the direction of surface flow. The larger concentrations of material within the hot-spots are located within vegetated area with minimal to low erosion potential and at the boundary where there is a decline in slope, similar to most of the hot-spots from the other periods. The largest material concentration is located in an area of vegetation near the base of the outcrop with a protected opening (rock shelter B, MESO1). Based on the shape of the hot-spot and the characteristics of the area it is evident that there is some influence of geomorphic processes on the position of the artifacts. However, there is a relatively small contribution area for this material as it has remained near the summit, and on top of the outcrops indicating most of the material will have been repositioned within the hot-spot areas themselves. Therefore, the observed distribution of Mesolithic material has not migrated significantly from its original deposition location and thereby strengthening the integrity of further analysis.

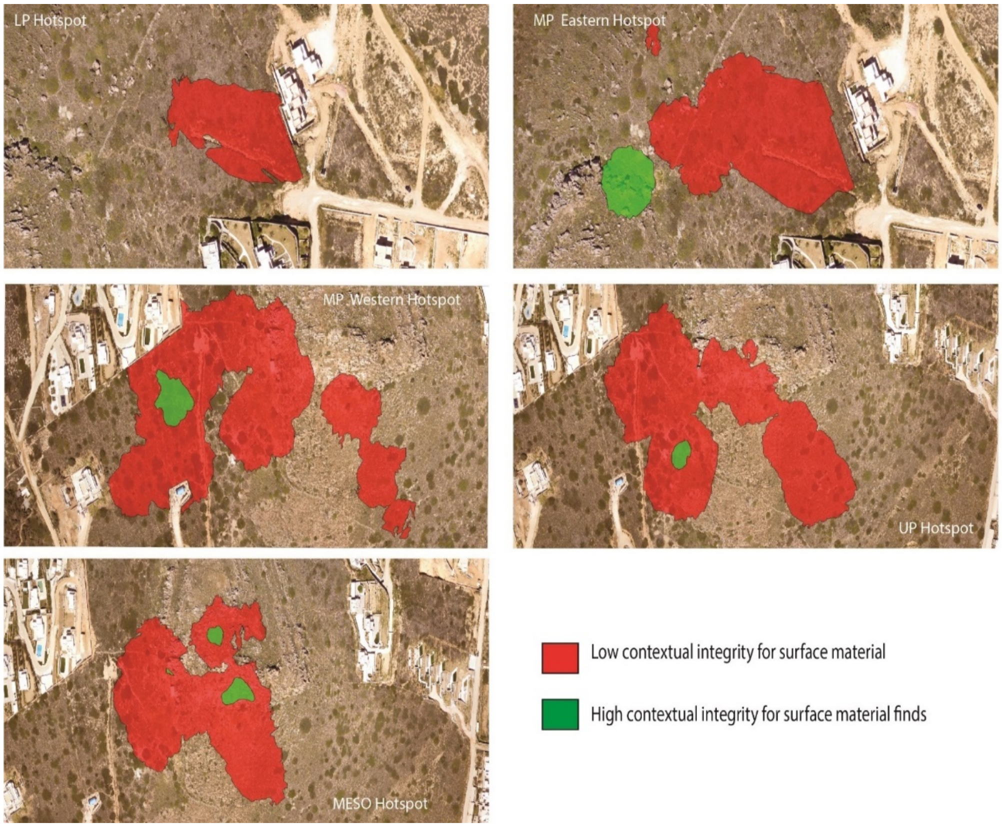

Figure 3.14: The resulting interpretation of contextual integrity of the significant surface material concentrations

3.5.6 Summary

Across the site, in proximity to areas of chert outcrops, material is concentrating in areas of greatest slope change, which represent boundaries between zones high and low erosion potential. Artifacts in these areas are more likely to have moved from their original site of deposition. These areas are likely to have low contextual integrity (represented as red on Fig. 3.14) and observations regarding cultural activity should account for such material movement. There are areas where the surface material does not indicate significant alteration due to geomorphic processes (areas shown in green on Fig. 3.13). All LP material shows the indication of alteration and therefore all is considered to have low contextual integrity. Most of the MP material has low integrity however there are two areas that indicate lower levels of alteration. Areas of MP material concentrated on both the eastern and western mid-slopes are not at areas of slope change and are in the middle of areas of high erosional potential. The MP material on the eastern slope is located near the location of historical spring. Similarly, most of the UP and Mesolithic material areas have low contextual integrity with a few areas where the surface material has higher integrity due to less indication of alteration. The area of UP material on the western slope, is located in a thick vegetated area near the site of another historical spring. This area has a high concentration of material with minimal indication of erosion and alteration. There is no clear indication that the material present in this area has migrated far from its original depositional site. There are three Mesolithic material areas that have a higher integrity evaluation. There are two locations around the summit of the site around, on top of the outcrops. These areas have minimal change in slope and are in high erosion potential areas. There is also a concentration of material that is located just in front of a natural rock shelter, at the base of the outcrop.

In total, there are six ‘hot-spot’ locations that are interpreted to have high contextual integrity. The high integrity MP lithic hot-spot located on the western mid slope and the largest M hot-spot located on the southern summit, are interpreted to be concentrations of lithics that are being exposed at surface due the deflation of Pleistocene deposits rather than active sites of deposition (depocentres) linked to modern hillslope process, as these locations are in zones of high soil loss potential with minimal changes in slope. While the other four high integrity hot-spot areas do show some influence of modern hillslope processes, they demonstrate a lesser degree of taphonomic alteration than the other surrounding surface material and have most likely not migrated far from their original point of deposition. These higher integrity areas are locations that would benefit from further exploration and stratigraphic excavation as there is the potential that material is *in situ*.

3.6 CONCLUSION

This study used previously established significant concentrations of diagnostic artifacts on the surface of Stelida (Pitt et al., 2020) to determine the material's contextual integrity through a consideration as to whether cultural activity or geomorphic processes were dominating the observed distributions. Visual analysis of the significant surface material areas, the RUSLE model, vegetation cover and other physical characteristics such as slope was conducted to determine hot-spot location integrity. The majority of the hot-spots showed characteristics indicative of significant impact of geomorphic processes. These hot-spots had material concentrations in areas of thick vegetation, low erosion potential and slope change. The elongated shape of these hot-spots and orientation downslope indicate influence from surface flow and the distribution of drainage basins.

The oldest material on the site from the LP shows extensive process alteration, leading to the assessment that there is very little integrity in any cultural activity observations made based on the material's location alone. The next oldest material (MP) follows in the same observation for most of the areas where the material is found. However, there is a MP hot-spot on the western slope that shows minimal geomorphic influence, leading to greater integrity in observations about this area and warranting further investigation. The diagnostic material of the two younger time periods (UP and M) at this site also follow the trend of overall alteration throughout time. In contrast to the other periods, there are hot-spots located close to the summit and the outcrops in which the material has not migrated far from the original location and therefore, observations in these locations have greater integrity then the material from the two older periods and the material that is located further down slope. There a significant concentration of UP material that is located on the western slope which shows less alteration then other hot-spots, making it an area for further exploration. The hot-spots from with M materials were impacted by physical processes, however the small potential area of migration limits the movement and cultural observations can be made for specific areas of the hill.

While the results from this study are not definitive, they provide valuable information to the archeological team as SNAP continues with specific areas identified for further study and exploration. Through the physical properties of the sites the distribution pattern of the surface material the relative influence of cultural and physical influences can be determined. This has provided understanding of the impact of the geomorphology of a site on material distribution and the critical characteristics which are associated with material concentrations. Future work on this site could include further analysis of the material, linking the raw material composition to the artifacts would provide more information on the movement of the materials at this site to determine spatial relationships between the material of a tool and where it is uncovered. An additional study could also look at whether agricultural terraces act as artifact and soil traps. The implementation of a similar interdisciplinary methodology could work universally for other archeological studies. A systematic pedestrian survey followed by a spatial statistical analysis of the results will help to identify 'hot-spots'. By then preforming an analysis of the terrain and the potential influence of geomorphic processes, time and resources can be utilized effectively to achieve research goals with a greater understanding of the layout of the site. The use of this analytical approach can be implemented whether you are working in Americas, Eurasia or Australasia.

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CHAPTER 4 : SUMMARY AND CONCLUSION

4.1 SUMMARY OF RESEARCH RESULTS

The purpose of this study was to use statistical analyses to define, visualize and explore the distribution of artifacts from the main four chronological periods represented at the site based on pedestrian survey data, UAV imagery and high resolution DGPS collection surveys. The results of this part of the study quantified the size and location of diagnostic material 'hot-spots'. Statistics indicated that the distribution of the material was not the result of random chance and that post-depositional processes played a role in the shaping of the material distributions. To determine the integrity of the identified hot-spots, soil erosion models and hydrological models were created. The results of the analysis categorized the chronologically diagnostic surface material based on the level of contextual integrity, with most classified as having low integrity, i.e., displaced from their original loci of deposition through geomorphic processes. Conversely, for all prehistoric periods – except the Lower Paleolithic – the analysis indicated that small areas with high contextual integrity, i.e., where artifact accumulations reflect loci of past cultural activities, rather the final resting place of redeposited material.

4.1.1 Spatial Analysis of Surface Material

Initial spatial analysis on the entirety of the pedestrian survey dataset does not indicate clustering or preferential patterning of the distribution of the present surface material. However, there is generally a greater proportion of diagnostic material located across the upper portion of the southern peak which masks any other patterns in the distribution of material. The analysis conducted on the four diagnostic periods separately showed more defined clustering of material assemblages. Random labelling simulation analysis was performed on the data for each of the chronological periods to indicate that the clustering was not the product of random distribution in addition to identifying the assemblages that are large enough to be considered statistically significant. Empirical Bayesian Kriging surfaces were created for each period of activity which visually represented the distribution of surface material for each period and indicates the clustered areas that are considered to be significant.

The oldest material at the site is diagnostic of the LP and while not greatly abundant on the surface finding assemblages of two or more pieces are considered to be significant. In contrast assemblages with 3 or 8 pieces of diagnostic material from the MP and UP respectively are considered to be significant. The most abundant type of material is diagnostic of the Mesolithic Period. Based on the performed analysis assemblages containing 11 pieces or more are considered significant at this site. The differences in the significant quantity minimum are correlated to the difference in the amount of diagnostic material found for the different chronological periods.

The distribution of hot-spots for each of the main periods of human activity at Stelida helped elucidate underlying cultural and environmental processes at the site. During the LP, the raw material was exploited at both peaks, however, most of the diagnostic material was located on the slopes of the northern peak. There is a notable transition during the MP from the activity at the northern peak to the primary exploitation of raw material at the southern peak, specifically on the south-western mid-slope. Material from the later periods, UP and M, are found predominately on the upper portion of the south-western slope. The M material is found slightly further up-slope then most of the UP material, in large assemblages that carpet the surface and cascade down the raw material outcrops.

The observed positional pattern of the surface material may be the direct result of cultural activity, however, the are many geomorphic processes that may have altered the position of the material after deposition. The older material that is from the LP and the MP has been present on the site for the longest period and is located further downslope from the outcrops when compared to the relatively younger UP and M material. The older material has had more time to be subjected to geomorphic processes, resulting in greater potential from positional alteration. This study has provided a predictive surface map of chronologically diagnostic material which indicate where it is most likely to be found, and therefore where further exploration should be conducted. The methodology applied in this study can be used at other archeological sites after preliminary surveys have been completed, to aid in planning of further field investigations and to understand the processes occurring at these sites. Analysis of Assemblage Contextual Integrity

Utilizing the predictive surface map and the location of the hot-spots of period-specific material determined in the first study, further spatial analysis was conducted to determine the integrity of the surface assemblages. Data from a UAV photographic and DGPS surveys were used in combination with an SfM workflow to create a digital elevation model (DEM) and orthophoto of the site. These were used to determine site characteristics including slope and aspect, type of vegetation, extent of drainage basins, and surface flow direction. These characteristics were then used to model the hydrological and geomorphic processes across the site.

Using the derived physical measurements and variables from other research studies, a RUSLE model was applied to classify the area based on the surface's erosion potential. It is observed in this analysis that most of the larger material assemblages are concentrated in areas along the boundaries of slope change and the boundaries of high to low erosion potential. It is interpreted that the material that is found in these areas are likely to have been moved from their original depositional location by environmental processes. These assemblages have low contextual integrity and a correlation between the location of the material and past cultural activity should consider this movement. All diagnostic material patterns associated with LP indicated low integrity due to the indicated high level of taphonomy. The majority of the material assemblages from the other three chronological periods also indicate a high amount of migration and alteration due to post-depositional processes. There are two MP assemblage area that have high integrity on the eastern and western mid-slopes. A large assemblage of UP material has some integrity as it was found in an area with minimal erosion potential and post-depositional alteration on the western slope in a heavily vegetated area located near a historical spring location. Several of the M material hot-spots are also considered to ha high integrity as the results indicate minimal alteration due to geomorphic processes. Based on the results from this study there is no clear indication that the highlighted high integrity assemblages have migrated far from their original depositional position and are locations that would benefit the further investigation.

Most of the material assemblages across the site were determined to have minimal integrity when trying to infer observations regarding past cultural activities. Material from some of the chronological periods have been present on the site for a longer period and therefore have had longer to migrate through environmental processes. In general, the older the material the further the material was located away from the summit and the raw material outcrops. The elongated shape of the material hot-spots along the drainage basins gives further indication of influence from the surface flow. This portion of the overall study has provided an understanding of the impact of geomorphic processes on the historical material across the site which can be used during further exploration and excavation efforts in this area. Utilizing soil erosion models and hydrological models provides a strong basis to interpret the integrity of artifact assemblages, aiding in investigations of these sites and ensuring that alteration due to environmental processes is identifiable from cultural processes.

4.2 RESEARCH LIMITATIONS

This research had some physical limitations, the largest overall being physical distance where the area of research is located in a different country, with a limited window of availability. With the archeological project only being active during the summer months, all data collection needed to be collected then. While on-site there is some further restriction as landowner permission is required to access some of the areas and in some instances, access was not given. In addition to physical limitations, there were also some analytical limitations. The pedestrian survey was conducted previously, therefore the initial analysis can only be conducted on the information from the datasets produced at that time. The vegetation, verticality and overall lay of the land dictated where collection points were placed during the pedestrian survey. As a result, the survey data did not have the ideal continuous uniform coverage, as one would like, and this was accounted for through the use of random labelling simulations in the analysis to aid in identifying and reducing the impact of spatial bias within the dataset.

Ultimately the spatial coverage of the survey collection points introduces some uncertainty into the results of this study. There are also some limitations in the produced erosion model as many of the environmental and physical characteristics for the site were generalized using values derived from studies at other locations. While the size of the overall area and the resolution of the available data yielded an acceptable result producing or acquiring high-resolution data for some of the variables may yield a better resulting model. For example, acquiring a detailed soil map or dataset will help to fine tune the soil erodibility variable in the RUSLE model. Finally, there is some spatial error in the resulting DEMs from the SfM workflow, as a few of the ground control points were created using notable physical features. Having an opportunity to conduct a more uniform UAV survey with more ground control point targets may result in reduced error values.

4.3 BROADER IMPLICATIONS

The surface material distribution maps and the accompanying evaluation of the assemblage’s integrity provide invaluable information to the archeologists and researches of SNAP. This work highlights the importance of utilizing spatial statistics to analyze archaeological artifact distribution, as a method of determining areas of cultural relevance at a site as well as to guide further archaeological surveys. Members of the team can now see where collected material has come from and its relationship to the natural setting. The results help to support predictions regarding historical activities and how it changed over time. The information from this work will be used to help the research team in designing future exploration work and the effective utilization of time and resources. This study adds to the case studies about the utilization of spatial analysis and GIS for archeological projects. In addition to adding to research into the use and deployment of UAVs for data collection and the employment of SfM workflows. Through technological advancements and availability, the utilization of UAVs and SfM workflows will continue to become more common practice, in a multitude of disciplines. The implementation of this methodology could work universally for other archeological studies. A systematic pedestrian survey followed by a spatial statistical analysis of the results will help to identify 'hot-spots'. By then preforming an analysis of the terrain and the potential influence of geomorphic processes, time and resources can be utilized effectively to achieve research goals with a greater understanding of the layout of the site. The use of this analytical approach can be implemented whether you are working in Americas, Eurasia or Australasia.

4.4 FUTURE WORK

These studies have provided a robust spatial analysis of the collected surficial dataset which has defined significant clusters of artifacts and determined the integrity of these 'hot-spots'. From this, it is clear that spatial analysis can and should be applied in archaeological investigations to improve the understanding of the distribution of artifacts and to guide further excavations to increase the chance of substantial high integrity finds. This methodology can be adapted and implemented in other archaeological research projects in other regions of Greece or across the globe. Any archaeological site in which the material is found distributed within a region, primarily on or near the surface, would benefit from this type of investigation. The research methods used in this study can also be applied in other disciplines, in which there is similar surface data collected. In many projects, it is important to investigate the integrity of perceived distributions of many different types of material (e.g., biological study of vegetation clusters), which can be accomplished using the methods of these studies.

The type of pedestrian survey used as the primary dataset for this study created significant spatial biases in the analysis which had to be addressed though the use of random labelling simulations. This increased the number of assumptions associated with the method and may have overlooked areas of potential significance (if they were not surveyed). While the survey dataset was not optimal for this type of analysis, it was adequate for the methodology to produce meaningful preliminary investigation results. Future sampling procedures and survey parameters should be augmented to provide more optimal datasets. Future effort should put into establishing a continuous survey grid, where there is uniform coverage across the entire site. Similar to how the large grid was set up on the eastern slope, but across the whole site. The orientation of the collection grid is not as important as the uniform coverage. In addition to material collection, soil samples at some of the collection points would also aid in increasing the resolution of the pertinent soil data. Elevation, vegetation density/coverage, and slope angle are other useful variables that should be measured as often as possible. Conducting a survey in this manner would help to eliminate some of the bias and uncertainty in the results of this methodology.

The results of this preliminary analysis provide actionable intelligence for the SNAP team to better commit time and resources. These results can further be refined through future research involving high resolution soil information or development of a more accurate DSM. Artificial surface roughness in the current DSM is the result of low lying vegetation altering the dense point cloud. Collecting data from a drone with a lidar or multi-spectral sensor could refine the

DSM further. The produced data from this research could also be used in future research into the relationship between where the material is found and the type of raw material it is made from. Another area of future research is the investigation into whether agricultural terraces act as artifact and soil traps. This projects methodology has identified areas of significant material hot-spot and integrated their integrity. While these are preliminary findings they provide further information about this important archeological site and helps to provide a foundation for future exploration.