Abstract

A VIEW THROUGH THE PERISCOPE:

ADVANCED AND GEOSPATIAL VISUALIZATION OF NAVAL BATTLEFIELDS

by

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Battlefield visualizations have existed for nearly ten thousand years and are found in almost all corners of the world. These may range from simple representations of opposing hunting parties depicted in Neolithic cave art to the examples found in today's military atlases. The practices used to visualize these, almost ubiquitous human acts, have changed along with the sciences, arts, and military technology and strategy. Although the most drastic changes in military technology have occurred within the last century, little advancement has been made concerning battlefield visualization techniques. Essentially, new military technologies and strategies have been visualized with outdated techniques and methodologies.

This study attempts to identify the key trends and deficiencies in battlefield visualizations so that new or alternative techniques may be proposed. Inspiration for these alternative methodologies will come from closely associated academic disciplines that already utilize these techniques. Once these trends and techniques are identified, then an exploration into these innovated battlefield visualization techniques is possible. These new and innovative techniques are important because they advance the discourse of battlefield visualizations and may increase the conveyance of ideas between scholars and the public.

A VIEW THROUGH THE PERISCOPE:

ADVANCED AND GEOSPATIAL VISUALIZATION OF NAVAL BATTLEFIELDS

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Stephen Paul Sanchagrin

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DEDICATION

This thesis is dedicated to my newborn son, Landon Paul Sanchagrin, who has been the single most motivating person in regards to finishing this thesis; as well as Kevin Flanagan, a true friend and great inspiration who passed away in May 2012.

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While the previous individuals gave much support through the intellectual process of thesis development and writing, the following individuals provided the equally as important moral support and encouragement. First and foremost, I would like to thank my wonderful wife Jennifer Sanchagrin, who has not only assisted in proofreading this document, but dealt first hand with my success and failures and provided me with the confidence that allowed me to complete the thesis. Next, none of this would have been possible without the unconditional love and support from my parents, who always encouraged me to do my best and to never give up. Thanks to my friends in the Maritime Program. Especially Tom Horn, whose infectious positive attitude motivated me in times of difficulty. Finally, thanks to Leland and Anna Gelekta who provided me with a place to stay while I completed my final semester at East Carolina University, and ultimately wonderful friendship.

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GLOSSARY OF ACRONYMS

2D	Two-Dimensional
3D	Three-Dimensional
ABPP	American Battlefield Protection Program
CRM	Coastal Relief Model
CVA	Cumulative Viewshed Analysis
EDA	Exploratory Data Analysis
GIS	Geographical Information Systems
GPS	Global Positioning Systems
IDW	Inverse Distance Weighting
KS-520	Key West, South Convoy Designation Number 520
MHP	Maritime Heritage Program
MTW	Medieval Total War
NCT	North Carolina Theater of War, Second World War
NPS	National Park Service
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OLS	Ordinary Least Squares Regression
USN	United States Navy
VR	Virtual Reality

Chapter 1 : INTRODUCTION

Introduction

History tells us few constants exist except for the inevitability of war. This persistent element of humanity predates written records; however, the remains of war exist in almost every corner of the world. Naval warfare has also existed for centuries; however, access to the physical remains, primarily shipwrecks of these human conflicts, has been limited to historians and archaeologists until fairly recently (with the advent of SCUBA) and, more recently, remote sensing technologies like side scan sonar and magnetometry. With access to these additional primary sources (the shipwrecks themselves), maritime historians and archaeologists have developed certain visualization toolsets to analyze the complex movements in naval battlefield landscapes. In a general sense, visualization tools and techniques enable researchers and the public to interpret various data "through representation, modeling, and display of solids, surfaces, properties, and animations" (Richards 1998:339). These tools and techniques are essential to the formation of these interpretations in that "they convey much more information than descriptive approach[es] and/or numerical representation" (Rajani 2009:20).

Initial reviews of the techniques utilized by historians and archaeologists to visualize naval battlefields have remained relatively unchanged for at least half a century. This is despite the fact that maritime warfare has drastically changed. The First World War brought about industrialized and mechanized warfare, and revolutionized the manner and magnitude in which life was lost. For the first time, large armored and motorized naval craft were seen, capable of traversing large distances and engaging the enemy at both home and abroad. Combined with new communication equipment, a new era of a more globalized warfare was ushered in. The Second World War built upon the foundation laid by the previous world war, and included a mature and truly three-dimensional (3D) naval component. This warfare was more complex than previously seen in the centuries past, utilizing surface combatants, in addition to forces underwater and in the air. With this advancement in naval tactics, however, it appears there was no advancement in visualization techniques to accommodate this complex addition. With advanced visualization techniques, it is hypothesized that historians, archaeologists, and the public can gain a better understanding of all aspects of the naval battle as it unfolds, and clarify interpretations of the complexities of naval warfare such as movement, strategy, and the decision-making processes employed in the heat of battle. Investigations of the previous historical and archaeological approaches to battlefield visualization aid in the understanding and selection of advanced visualization techniques. To accomplish this, a systematic survey built upon sound previous research must be developed. This study must have clear objectives and research questions to guide this process, through thousands of years of history, and countless technologies and techniques.

Objectives

This study attempts to examine, critique, and identify essential developments throughout the ongoing process of battlefield visualizations. Starting with Neolithic cave art and ending with modern digital representations, each era will be systematically analyzed. This examination is based upon the development of a research instrument, a form composed of six key variables, and will evaluate a multitude of historical battlefield visualization examples.

Once these developments are examined, key deficiencies will be identified, and ultimately serve as a baseline for historical battlefield visualizations. Equipped with this knowledge, another investigation will occur. The second stage of analysis will focus on academic disciplines which share common ground with battlefield cartography, and attempt to identify key advanced and geospatial visualization techniques that are most applicable to battlefield visualizations. Again, this analysis will utilize an instrument that will aid in the examination of specific examples from these academic disciplines. Ultimately, this stage of the study will result in a series of potential techniques and technologies that could advance battlefield visualizations and lead to greater interpretive value.

Once the baseline is established, and the most applicable advanced and geospatial techniques identified, these new techniques will be applied to naval battlefield visualizations. This application of new visualization techniques will focus on two separate case studies, drawing on previous research from Wagner (2010) and Bright (2012). The first case study will examine small temporal and spatial extent naval battlefields, drawing upon the KS-520 battlefield landscape. These case studies will utilize historical information and important context located in Bright's work (2012). The second case study will focus on large temporal and spatial extent naval battlefields. The supporting information for these visualizations will come from Wagner's (2010) comparative landscape approach of the North Carolina Theater (NCT) of the Second World War, and the resulting products will highlight the power of advanced GIS capabilities and spatial modeling techniques for naval battlefields.

Research Questions

Given the large and varied scope of the study, specific research questions were developed to provide structure. The literature examined in this study covers thousands of years, and ultimately concludes with some of the most advanced visualization techniques available. This study also attempts to adapt advanced statistical methods that have never been applied to naval battlefields. When these elements are combined with the extensive historical accounts, and countless primary sources, the importance of a sound research plan is evident. Therefore, the research questions developed were broken down into primary and secondary questions, and are:

Primary Question –

- What is the potential of recent developments in geospatial visualization for aiding in the analysis and interpretations of naval battlefields?

Secondary Questions –

- What are the most appropriate visualization techniques for small spatial and temporal extent naval battlefields?
- What are the most appropriate visualization techniques for large spatial and temporal extent naval battlefields?
- What are the most appropriate spatial modeling techniques available for naval battlefield visualizations?

These research questions are the most important ones addressed by this study, however, additional less important questions will be answered along the way. Hopefully, through the exploration of these questions, new ideas will result, and guide future research questions relating to naval battlefield visualizations. As with any research, the ultimate goal is to not only answer the specific research questions, but to identify the next frontiers and innovative avenues for subsequent discourse.

Previous Research

This thesis builds upon a multitude of previous works, all of which share one or more of the many components involved in naval battlefield visualizations. The most influential works, however, belong to three primary categories. These main categories are battlefield cartography analysis, naval battlefield analysis with Geographical Information Systems (GIS), and attempts to adapt terrestrial battlefield analysis techniques to naval battlefields.

In terms of cartographic scholars, J.B. Harley is one of the most influential authors. He has dedicated his life to documenting the analysis and histories of the discipline, and written or edited countless books and scholarly publications. In regards to this study, two of his works proved to be an essential source. The first is the most comprehensive scholarly investigation into the history and development of cartography (Harley and Woodward 1987; Woodward 2007a, 2007b), and the second is a book he co-authored with Barbara Petchenik and Lawrence Towner (Harley et al. 1978), which specifically relates to battlefield cartography. Both of these publications were influential in almost every aspect of this study and deserve a closer look.

Any discussion of cartography, whether relating to the battlefield or not, must begin with one of the most comprehensive sources on the history and development of the discipline. The multivolume series, *The History of Cartography* (Harley and Woodward 1987; Woodward 2007a; 2007b), is a premier source for information regarding every aspect of this development. The series highlights all aspects of cartography, and while it does not have a specific military or battlefield focus, it does frequently mention the various connections between the two. These volumes contain thousands of examples of maps, with scholarly descriptions of the technologies and mentalities of the cartographer, and should be included in any cartographic discourse.

The act of recording battlefield events is almost as old as the acts of war themselves. Ancient humans began this practice thousands of years ago, and they are still practiced today. Over the course of human history, the process and the tools for this almost ubiquitous human act have changed drastically with the advancements of sciences and arts. The study of this act, however, has not received as much attention, and previous research relating to the analysis of battlefield cartography and visualizations is sparse. There is one major work which stands above the rest, which deals almost exclusively with the analysis of battlefield cartography, *Mapping the American Revolutionary War* (Harley et al. 1978). This work, while over thirty years old, still has many important lessons and essential analysis in regards to battlefield cartography. It is one of the most comprehensive critiques of the status quo of battlefield mapping, and dissects many common problems associated with poorly executed products. While this publication focuses exclusively on maps relating to the American Revolution, the critiques are relevant to all modern battlefield visualizations. In regards to battlefield cartography literature, this is possibly the single most important resource available, and provides helpful suggestions and cartographic theory that will aid in the production of any map, not just those related to warfare.

The second category of seminal work, which this thesis uses as a foundation, is that of naval battlefield analysis with GIS. For this, attention must be paid to *Waves of Carnage: A Historical, Archaeological, and Geographical Study of the Battle of the Atlantic in North Carolina Waters* (Wagner 2010). This master's thesis is one of the first in-depth, comparative analysis of the NCT. The primary objective of this study was to examine and define the NCT based upon both primary and secondary sources, and sound GIS theory. Wagner also attempted to go beyond historical particularism, which focuses on site and artifact specific surveys, and broadens the scope into a comparative landscape approach. In this view, shipwrecks are seen as artifacts in a greater assemblage, rather than individual sites. By combining this comparative approach with the historical record and GIS technologies Wagner is able to define the NCT, and analyze key trends throughout the battlefield.

Wagner's research provides three essential elements to this study's foundation. First, his use of sound GIS theory serves as an important foundation to any future analysis of the battlefield landscape in the NCT. Secondly, it provides essential historical context, relating to the overall importance of the theater during the Second World War. Finally, it provides the comparative landscape framework utilized. This study will attempt to use a similar approach to Wagner (2010), and view the shipwrecks and elements of the battlefield as a part of a greater artifact assemblage.

The third and final influential publication that informed the foundation of this thesis was *The Last Ambush: An Adapted Battlefield Analysis of the U-576 Attack Upon Allied Convoy KS-520 Off Cape Hatteras During the Second World War* (Bright 2012). In this work terrestrial battlefield analysis techniques were adapted to investigate a short term naval battle off the coast of the North Carolina. Bright utilized basic principles of war, METT-T (Mission, Enemy, Troops, Terrain-Time) analysis, and KOCOA (Key Terrain, Observation and fields of fire, Concealment and cover, Obstacles, and Avenues of approach) analysis in the study to identify the spatial extents and key elements of the battlefield. The primary objective in Bright (2012), was to determine if these terrestrial battlefield analysis tools could be applied to the naval battlefield.

Like Bright's study, the battle of Key West South 520 (KS-520), will serve as a case study for future battlefield analysis in this thesis. The historical context has been provided in Bright (2012), and initial battlefield analysis conducted. Many of the elements from the METT-T and KOCOA analysis will be included in this study. Once again, the shipwrecks and event information from the KS-520 battlefield is viewed in a comparative landscape framework, much like Wagner (2010).

Without these influential bodies of texts, the following study would lack essential historical context. Additionally these sources also provided essential elements of theoretical framework. With the addition of this thesis to the discourse relating to both battlefield cartography, and the Battle of the Atlantic narrative, it is hoped that a lengthy discussion of naval battlefield scholarship will follow.

Thesis Structure

This thesis is divided into seven chapters. The first chapter (this introduction) provides the necessary framework for the rest of the study. It highlights the contributing research that allows for the proper foundation of the study, outlines the objectives, and highlights the primary and secondary research questions. It also examines the importance of not only conducting the study, but also in the selection of the case study sites. Finally, the introduction contains an outline of the study, and details the contents of each subsequent chapter.

The second chapter is the first of a two-part examination into the relevant histories and literature. Specifically, it seeks to examine the progression of battlefield visualizations from the earliest known examples through modern day representations. This spans approximately twelve thousand years, and was thus broken down into three, more manageable periods, the Ancient and Prehistoric, Renaissance, and Modern. The examples found during this stage of the research will serve as data for future analysis, which will attempt to identify key trends and deficiencies. The results of this analysis will help guide further stages of the study.

The third chapter is the second part of the relevant histories and literature examination. Equipped with the knowledge from the previous examination contained in Chapter 2, the third chapter investigates academic disciplines that share a commonality to battlefield visualizations. These disciplines are geography, terrestrial and maritime archaeology, and history. The literature from these disciplines will undergo systematic analysis in search of relevant advanced and geospatial visualization techniques that may be applicable to visualizing naval battlefields. The most relevant examples will provide the framework for future stages of the study.

Chapter 4 contains a detailed breakdown of the methodology for the production of advanced and geospatial visualizations for the two case studies. The first component of the methodology outlines the procedures for the analysis of the histories and literature in the previous two chapters. The previously mentioned analysis will be assisted by the creation of two instruments, which will allow detailed examination of the histories and literature. Following this analysis is the creation of the visualization products for each of the case studies. These products will utilize alternative techniques or technologies. A discussion of the issues and challenges relating to the creation of the of the alternative products is located at the end of the chapter, and will hopefully offer some additional insight for future research.

The fifth chapter is the first of two analysis chapters. It will begin with the results from the two historical investigations, which lead to the establishment of a historical baseline for battlefield visualization and identifies the key advanced and geospatial visualization techniques. Following this analysis is the first alternative visualization technique, which examines a naval battlefield with a small temporal and spatial extent. This section will contain two different visualizations for the Battle of Convoy KS-520. The first product will be a 3D battlefield landscape analysis, which highlights the various viewsheds and areas of interactions between the armed merchant convoy and the lone German submarine, *U-576*. The second visualization will be a two-dimensional (2D) animation of the minutes leading to the attack by *U-576* on the armed merchant convoy. This product will highlight the interpretive strength of animations in small temporal and spatial extent naval battlefields.

Chapter 6 goes beyond simply visualizing historical data and enters the realm of advanced GIS analysis. This chapter contains three products, through two separate approaches. All three visual products examine large temporal and spatial extent naval battlefields. Additionally, these visualizations build upon previous research conducted by Wagner (2010), and examine two different approaches to analytically examining the NCT. The first approach utilizes advanced GIS analysis to produce two battlefield activity surfaces, and then uses animation technology to heighten the interpretive value. The second approach uses spatial modeling techniques to better understand the influences of the physical environment has on dictating where naval battles occur.

The last chapter of this study offers concluding remarks about the previous stages of the research. It summarizes the findings of each stage and offers final critiques of all the visual products. It also contains notes on potential avenues for future research relating to advanced and geospatial visualizations of naval battlefields.

Conclusion

This study builds upon research conducted over the past thirty years, with more recent approaches to visualizing naval battlefields in the NCT being paramount in providing the necessary historical context and theoretical framework. With this foundation in place, a systematic investigation into the histories and literature relating to battlefield visualizations and advanced and geospatial visualizations will be conducted. The results of this analysis will aid in the selection of new adaptations of current technologies to the discipline of battlefield visualizations.

These new adaptations are important. Over the last half century, little advancements have been made in the discipline of battlefield visualization. This is surprising, considering that exponential growth has occurred in military technology with the industrialization of modern warfare and the computer revolution in the sciences. This study hopes to advance the discourse within battlefield visualization and offer new alternative techniques in addition to exploring new advanced methods of analysis. This development of the discourse is long overdue, and new era of advanced and geospatial visualizations is now.

Chapter 2 : A HISTORY OF BATTLEFIELD VISUALIZATION

Introduction

The development of battlefield visualizations was a slow process that began its evolution over ten thousand years ago. It saw its origins with rudimentary depictions of early humans engaging in combat, permanently inscribed on the walls of caves. This process of recording battles continued to evolve alongside various advancements in technology, science, art, and military tactics. With each passing era, civilizations left their mark upon the history of battlefield visualizations.

In an attempt to simplify the task of discussing battlefield visualizations through time, a flow chart has been created, distinguishing various periods and important events (Figure 2.1) during the process and development of battlefield visualizations. This chart, while implying linearity, is more of a basic guideline, rather than an accurate representation of reality. The development of battlefield visualization as we know it today was not simply a linear development, but actually a slow, developing trend toward ever increasing accuracy and realism. What is important to note about this chart is the division of artistic representations from more analytical representations. Once again, there was not a particular date of the schism, rather a general trend that begins with the increased importance placed upon the use of tactics and strategy, which in turn, needed more accurate representations of reality. Also, represented in this chart is the division between the representations of tactics and artistic representations of historic battles. The first can be thought of as more of an analytical tool, whereas the second are more artistic, and attempt to produce a particular emotion. This is not intended to imply that these two products developed on their own separate paths, but merely that these are indeed, two separate products. Later, a more in depth discussion of these two products is necessary, but for now, the emphasis is placed upon gaining a better understand of the general progression of the battlefield map.

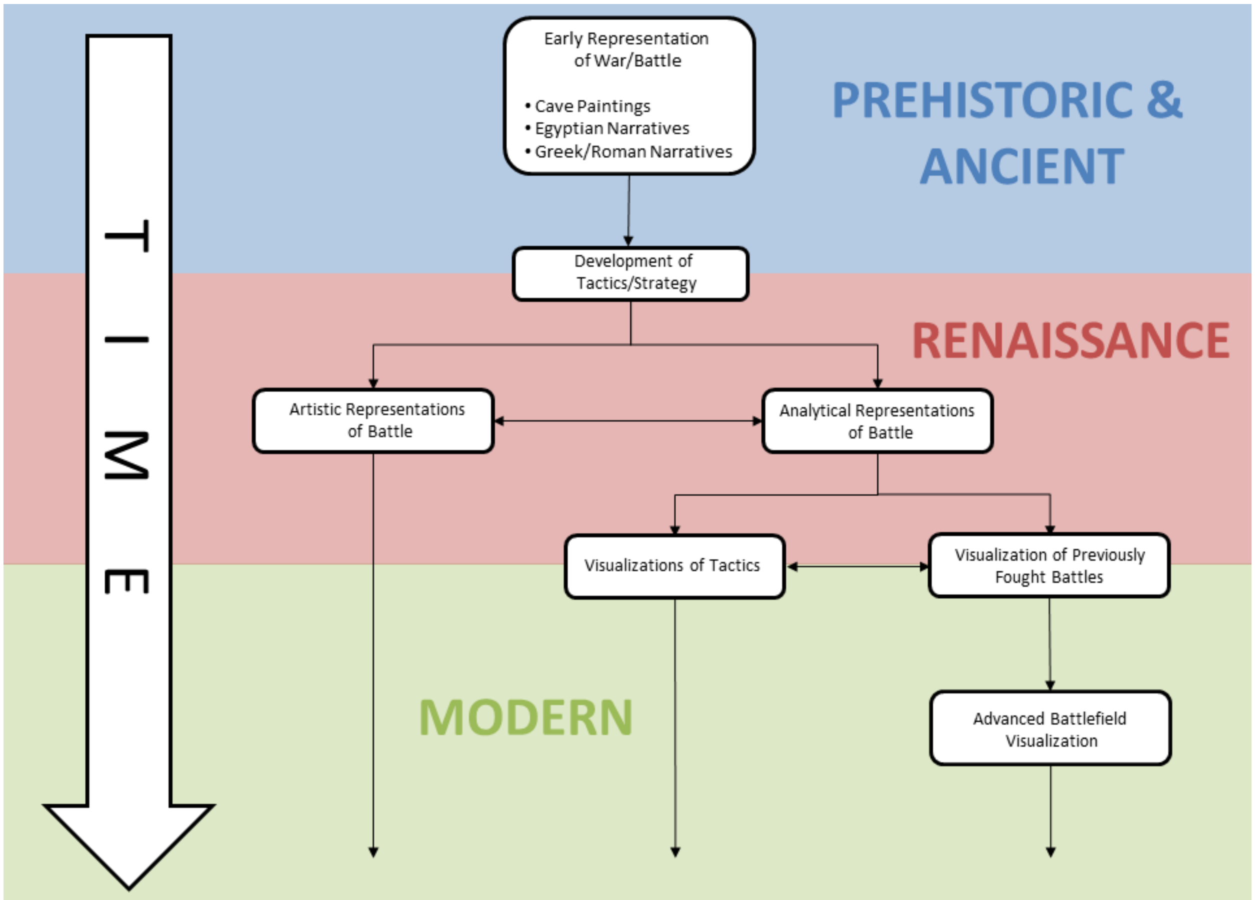


Figure 2.1 Battlefield Visualization Process (Drawn by Author).

The history of battlefield visualizations will now be broken into three general periods for discussion. The first period, Prehistoric and Ancient Battlefield Visualizations, spans the longest time-period, beginning with the earliest example of battlefield representations found in cave art and ending with the medieval period. The next division sees the rebirth of cartography (and battlefield mapping), and identifies key advancements during the Renaissance period. The modern period saw advancements of mapping techniques, from the latter half of the eighteenth through the twenty-first century CE.

One last point is worth examining prior to investigating the advancements in battlefield visualizations, and that is of definitions. John Hale (2007:721) notes debate surround the origin of “military maps,” and that this debate stems from a difference in opinions on definition. Therefore, in the discussion of battlefield visualization that follows, a more inclusive approach has been taken, which allows for a greater consideration of the influences of art in the pre-modern era of battlefield mapping. Had this approach not been taken, the history of battlefield visualizations would be much shorter, and potentially lacking in important historical context.

Prehistoric and Ancient Battlefield Visualizations

The origins of battlefield visualization date to our prehistoric ancestors, with some early depictions of battle dating to the Neolithic period (Keeley 1997). This period spans over eleven thousand years, and can be broken down into three categories. They are prehistoric depictions, written itineraries and ancient Egyptian imagery, and Greek and Roman battlefield visualizations. While this is the longest period from the historical survey, it contains the least amount of examples. This is due to issues with the survivability of imagery. Thought of as proto-maps, most examples are more akin to art.

Prehistoric Battlefield Visualizations

These earliest known examples of human-on-human conflict are found in Neolithic cave paintings, which date to approximately 10,000 BCE. These representations, which clearly depict this conflict (Figure 2.2), are in cave art found in Morella la Villa, Spain. While these representations are rather crude, a simultaneous center advance and flank attack is evident. The participants in this conflict are represented in profile view and are using the very same tools developed for hunting, on each other. Keeley (1997:45) notes that this visualization is possibly depicting members of rival hunting parties battling over access to natural resources. This profile view, a pictographic representation of warfare, will serve as the status quo in battlefield visualization for millennia to come.

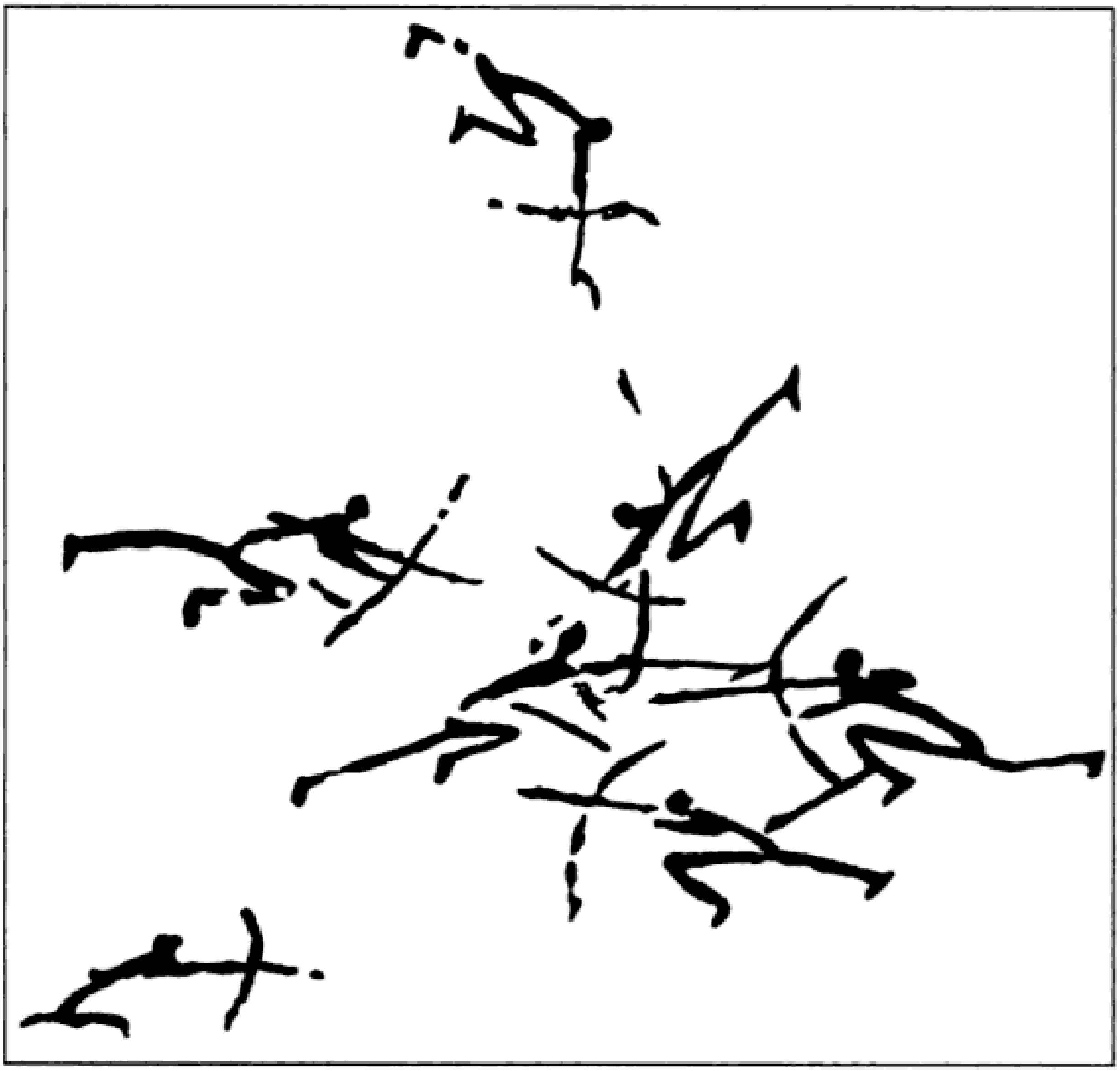


Figure 2.2 Early depictions of battle from the Neolithic Period showing human on human contact (Keeley 1997:45).

Written Itineraries and Ancient Egypt

Examples of early battlefield visualizations are infrequent; but with the origins of writing a framework for more advanced cartographic representations of battles begin to emerge. Sumerian scribes were some of the first peoples to begin establishing written itineraries of surrounding towns, mountains, and rivers between 2500 – 2200 BCE. Although these itineraries lack a visual component, they are representations of geographic data. Millard notes that "the marches of armies to distant goals, and the ventures of traders in search of precious metals and stones, timber and other products, were obvious means by which the scribes learned about their own and foreign lands" (Millard 1987:107). He continues by examining itineraries which detail the routes from Assyria to Anatolia in the nineteenth century BCE, and the marches of Assyrian armies in the early first millennium BCE. The development of these written itineraries is intrinsically linked to the march of armies, and will continue to be so throughout this entire time of ancient battlefield visualizations. Through the majority of these itineraries were written, some included pictorial records of these distance lands, and are found on bas-reliefs that decorate the walls of palaces in Nineveh (Millard 1987).

Pictorial depictions accompanying itineraries are not the only representation of battles and wars during this period. Egyptians of the New Kingdom period (Dynasties XVIII – XX) frequently adorned temples with scenes of battle, often with the pharaoh as a central figure. These images of military conquest are similar in style to the cave art, in that they tend to depict participants in profile view, a trend that will continue throughout the period. What is notably different about these depictions, however, is that, for the first time they depict a sequence of events, not just a snapshot of battle. This type of "picture map" displaying battles is also found in other contexts in the ancient and medieval worlds (Shore 1987; Spalinger 2005). The Egyptians of the New Kingdom, however, were one of the first ancient societies to express such an interest in these representations of landscape and battles, and the inclusion of time events represents a paradigm shift in battlefield visualization.

Egyptians did not limit their visualizations to only terrestrial battles. They also depict maritime battles, with some of the earliest being of King Ahmose in the mid sixteenth century B.C. (Figure 2.3). Although this visualization does not exclusively show maritime warfare, the presence of Egyptian war ships is unmistakable, and is a testament to the style of warfare the Egyptians of the early New Kingdom waged, one primarily dominated by naval encounters. The dominance of naval battles was due to the terrain constraints placed upon warfare in the narrow Nile River valley, which made chariot warfare unsuitable. Once the Pharaohs of the New Kingdom left the Nile River valley for military conquests, the focus shifted toward chariot warfare and, as a result, the depictions of battles later concentrate on the land aspects, rather than the supporting maritime role (Spalinger 2005).

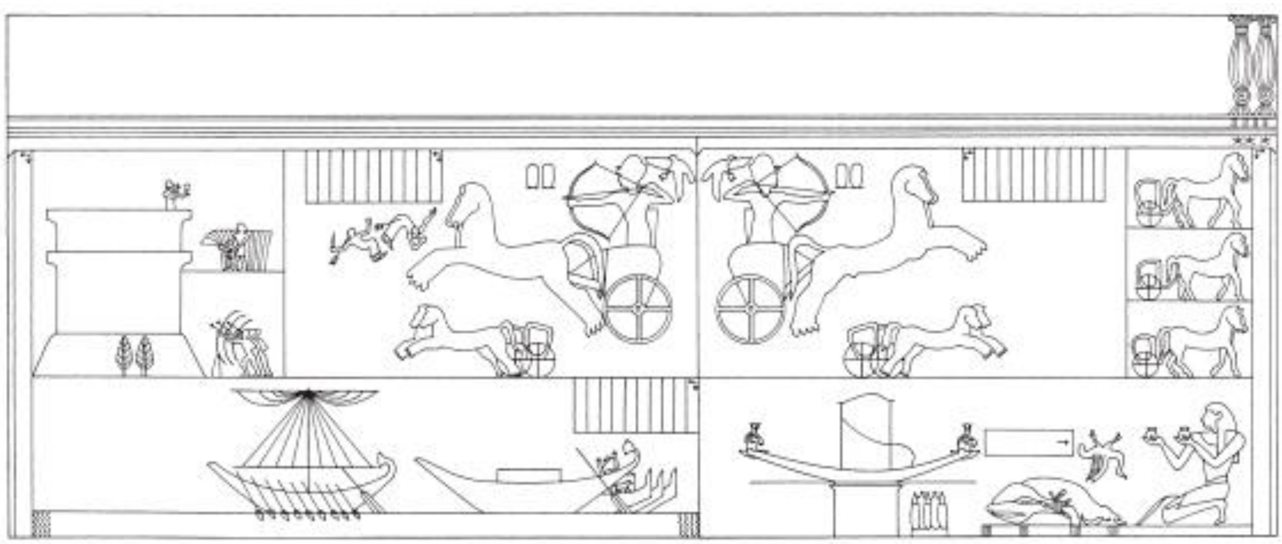


Figure 2.3 New Kingdom Depiction Battle (Spalinger 2007:22).

Greek and Roman Battlefield Visualizations

The ancient Egyptians were not the only civilization that used a narrative style of battle depiction, showing a series of events in one image. One of the earliest visual representations of Greek warfare, which is also notable in that it depicts maritime warfare, is the Thera fresco (Figure 2.4), which dates to the end of the sixteenth century B.C. While this representation appears to be more decorative, it shows elements of the historic past of that society. It depicts a "procession of notables going up the hillside, boats in attacking positions along the shore, and battles being fought inland; and there is the departure of the navy and its subsequent triumphant entry into its home port amid general rejoicing" (Harley and Woodward 1987:132).

Figure 2.4 The Flotilla, Thera Fresco (National Archaeological Museum of Athens. Image edited by Author).

The Thera Fresco is only one example of battlefield representations in Greek art. It is, however, more cartographic than the majority of Greek representations of warfare found during the classical era. Decorative pottery was frequently adorned with depictions of Greek warriors engaged in combat. The enemy in many of these examples are mythological creatures or beasts;

however, the representation of the battle is notable in that it chooses to utilize a profile view almost exclusively (Figure 2.5).

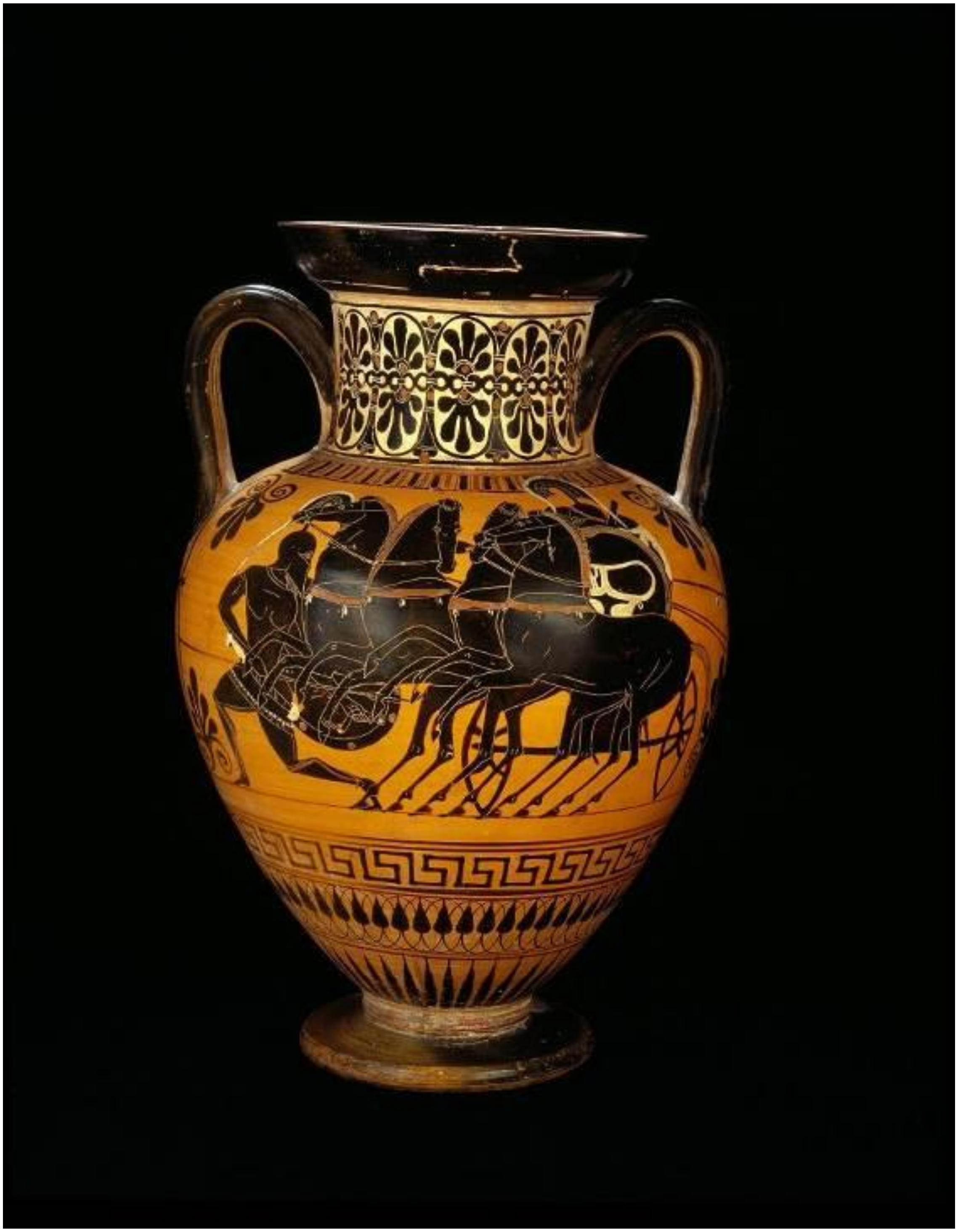


Figure 2.5 Amphora with a battle scene (National Museum of Scotland).

While these battlefield representations are primarily decorative, the ancient Greeks would contribute much to the discipline of cartography over the next few centuries. There was a general growth of science and empirical knowledge that caused a change in cartographic practices during the classical Greek period (5th – 4th century BCE). This change was primarily driven by "both political and military factors and to cultural developments within Greek society as a whole" (Harley and Woodward 1987:148). Even though there were great advancements in science and mathematics at this time, which in turn influenced cartography and the mapping of battles, it is still too rudimentary to regard these examples "as systematic or even reconnaissance mapping – in the modern sense" (Harley and Woodward 1987:149).

It is around the end of the Hellenistic Greek period (1st century BCE) that the first examples of Roman cartography are found. The earliest example of a Roman map is attributed to Tiberius Sempronius Gracchus (Dilke 1987a). This depiction is, once again, of a military encounter. Specifically it displays the Gracchus' victory in Sardinia, which was dedicated to Jupiter. The religious significance is of importance in this depiction, in that this early map was seen as an offering in hopes that Jupiter would look favorably upon the army in the future.

The Roman Empire continued to build upon the cartographic foundations laid by the Greeks, and in doing so developed new mapping instruments. One such instrument that was used by both civilians and the military was the *groma* (Figure 2.6). This instrument consisted of a pole, upon which a small wooden cross was mounted, and at the end of each of arm was a plumb bob. Ultimately this tool would become the primary surveying instrument of the Roman Empire. (Dilke 1987b). These new instruments and techniques resulted in increased accuracy and elevated the importance of maps, but did not result in a shift away from the use of itineraries. There were, however, great thinkers during this period who saw the importance of picture itineraries and maps even though their use took a secondary place in the war machine of the Roman Empire. Vegetius, a civil servant and author of a military manual dating from between 383-395 CE, states the importance of the picture itineraries. In his military manual, he notes:

> In the first place, a commander should have itineraries of all the war zones very fully written out, so that he may thoroughly acquaint himself with the intervening terrain, as regards not only the distance but standard of roads, and may study reliable descriptions of shortcuts, deviations, mountains, and rivers. In fact, we are assured that the more careful commanders had, for provinces in which there was an emergency, itineraries that were not merely annotated but even drawn out in color [picta], so that the commander who was setting out could choose his route not only with a mental map, but with a constructed map to examine (Dilke 1987c:237).

While the writings of Vegetius are the only surviving records that relate to the military use of maps during this period, Dilke believes that, based upon the high esteem Julius Caesar and Agrippa had for maps, their use was established relatively early. He continues by noting that the extent to which Roman expeditions used and carried maps is open to debate; however, the maps that were created and subsequently sent home for analysis were likely to have been created by military surveyors (Dilke 1987c:253).

Figure 2.6 A Roman survey instrument, the *groma* (http://www.the-romans.co.uk).

Aside from the writings of Vegetius in his military manual, there are other written accounts of the use of maps in the first poem of Ovid's *Heroides* (25-16 BCE). In this poem, a soldier describes the sack of Troy and sketches out the events in wine on the on the table, noting the location of various forces and individuals (Dilke 1987c:253). This is noteworthy because it is one of the first written accounts in which impromptu maps are being created by contemporaries to aid in the description of events, rather than official itineraries or maps being for strictly military purposes.

Throughout the duration of the Roman Empire, the importance of maps and their use in all spheres of governance continued to grow. It is interesting to note, that during this time, the use of maps for propaganda also begins. The public display of maps of the Roman Empire's extent was now being used as a tool to increase moral and public opinion (Dilke 1987d:278).

After the decline of the Roman Empire, little advancement in the cartography of war and battlefield visualization continued. Harvey notes, "few maps were drawn in medieval Europe" (Harvey 1987b:238). The focus on written itineraries maintained through this period, and their emphasis was still primarily military in nature. The Venetians continued to create maps with a military focus at this time, with a primary emphasis on the mapping of cities and fortifications (Harvey 1987b:238). It would not be until the Renaissance that battlefield mapping and cartography as a whole would see a revitalization in both new technologies and scope, much like many other areas of science and art.

Battlefield Visualization in the Renaissance

The Renaissance was a time in which great changes were occurring all over Europe. One area of great development and reform was the military and war machines of the various monarchies in Europe (Hale 1985:46). Advancements in portable firearms and artillery technology had a profound impact on the way a society waged war. These advancements caused fundamental changes in the formation of infantry, the injuries the infantryman would sustain, and the design and development of fortifications (Hale 1985:46). A clear shift from engagements in pitched battle towards the prolonged siege was taking place. These advancements occurred during a period in which there was scarcely a year without some sort of armed conflict (Hale 2007:705). Cartography was also advancing at a rapid pace during the Renaissance. Hale notes that, "countries and regions that were being mapped with increased precision and usefulness were at the same time being fought over by armies that had to find their way and were administered by governments that needed to reappraise their defense systems" (Hale 2007:719). There was a major effort by the governments to accumulate previously produced maps and sketches that could be of use in both offensive and defensive military operations. In addition to the collation of available maps, the production of new maps became an important prerogative (Hale 2007:719).

The military themed maps produced during the Renaissance can be broken down into three major categories. The first category is maps relating to offensive maneuvers. Examples of these maps are reconnaissance maps with sketches of the surrounding areas, and notations on key infrastructure, elements of topography, and land cover type. The second types of maps produced during the Renaissance are those that relate to defensive strategy. This area was the primary focus of military mapping during this period, and many examples of this map type remain today. Examples of these are the various maps of city fortifications, fortresses, and strategic defense lines composed of a series of fortresses. The final map type produced, and one with the greatest relevance to the analysis of advanced naval battlefield visualizations, is the printed commemorative map. These maps were commissioned for commemorating major victories. Starting with the Thirty Years' War (1618-1648), these maps were also produced for the military enthusiast. This allowed them to track the actions of their country on the frontiers and abroad (Hale 2007:715).

Each of these three map types saw advancement during the Renaissance. The use of military maps for offensive purposes, primarily aimed at reconnaissance, was of great importance when dealing with armies on the march. Key issues such as the distance between towns, where appropriate food and necessities could be obtained, and landforms and land cover types were presented to aid the military commander in the field while marching to engagements. These offensive military maps were often sketch maps of frontier areas. Even though the use of sketch and reconnaissance maps increased during the Renaissance, their use was only of secondary importance to the field commander. At this point, the use of oral and written cartography was still far more influential in the planning of military maneuvers (Hale 2007:715).

While offensive military mapping was of secondary importance during the Renaissance, defensive mapping was an important activity. During the Renaissance there was increase in the frequency of siege warfare, which was a direct result of advances in weaponry technology. This increase in siege warfare produced a surge in the creation of city fortifications and fortress creation (Hale 1985:55). To construct a fortress, an intimate knowledge of the surrounding area was needed. Key terrain features, which offered any strategic advantage, were utilized in the placement of these fortresses (Torok 2007:1840). This was a commonplace activity all across Europe during the Renaissance (Figure 2.7).

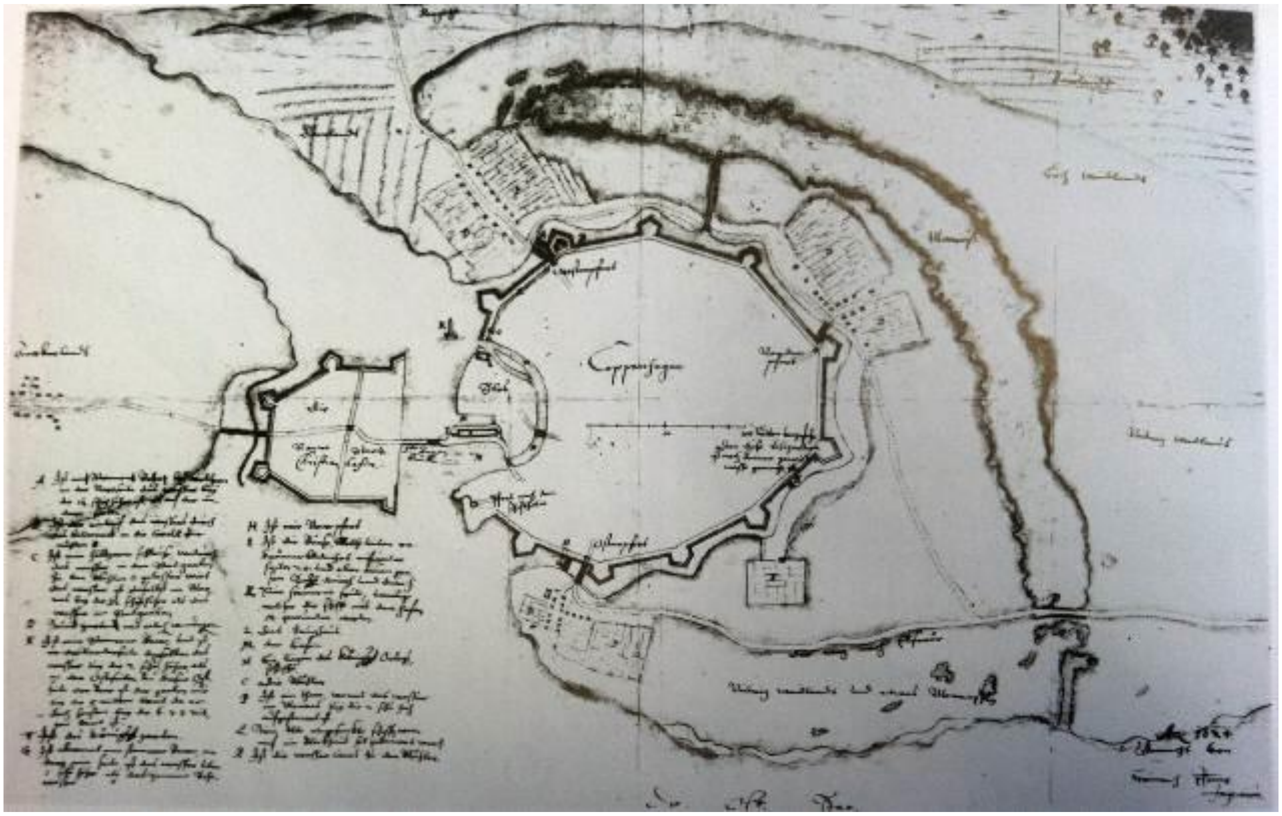


Figure 2.7 Heinrich Thome, Map of Copenhagen and its Environs, 1624 (Mead 2007:1800).

The printed commemorative map is the precursor to the modern battlefield map. Events like the Scottish Campaigns during the mid-seventeenth century saw the most extensive use of maps in a military campaign to date (Figure 2.8). Barber (2007:1595) notes that battlefield sketches of individual engagements seem for the first time to have been used for news maps and propaganda. These commemorative maps were not only commissioned for terrestrial battles. Maritime warfare was also the focus of the news maps and commemorative maps. In the late sixteenth century, Augustin Ryther was commissioned to create engravings to commemorate the English victory over the Spanish Armada (Figure 2.9). It was late in the seventeenth century when military annotations began to be added to general maps, and it is at this point that standardized cartographic representation of troops emerge. These maps can be considered modern due to their more schematic notations (Hale 2007:715). It will not be, however, until the late eighteenth century that the first true examples of the modern battlefield map emerges.

Figure 2.8 Thomas Geminus's Battle of Musselburgh/Pinkie Cleugh, 1547 (Barber 2007:1602).

During the Renaissance, advancements in map production techniques began to emerge as well. At the beginning of the Renaissance, map production techniques were dominated by woodcut block printing. The cartographer would design the map on paper, and then engrave the map onto a wood block. The block would then be dipped into ink, and a print of the map would be transferred onto paper. This technique allowed for easier reproduction, over what is a very time consuming technique of hand map production. Early wood block printed maps were also some of the first maps to ever use the technique of troop generalization (Figure 2.10). This is perhaps due to the difficulty of producing detailed representations of troops in the wooden medium.

Figure 2.9 Agustin Ryther's Depiction of the Battle of the Spanish Armada, 1588 (Library of Congress).

As the Renaissance progressed, so did map production techniques. Following the use of woodcut block printing was the use of wax blocks. These wax blocks served the same purpose as the wood blocks, with the cartographer engraving the map on the block of wax, and then printing the map onto paper. Near the end of the Renaissance, the use of metal engraving begins to appear. First copper and later steel plates were used in the engraving process. This medium of engraving allowed for finer line weights and increased detail. The new medium was also markedly more durable, and many of these metal plates are still in existence today, with prints from the plates available for purchase online (http://www.french-engravings.com).

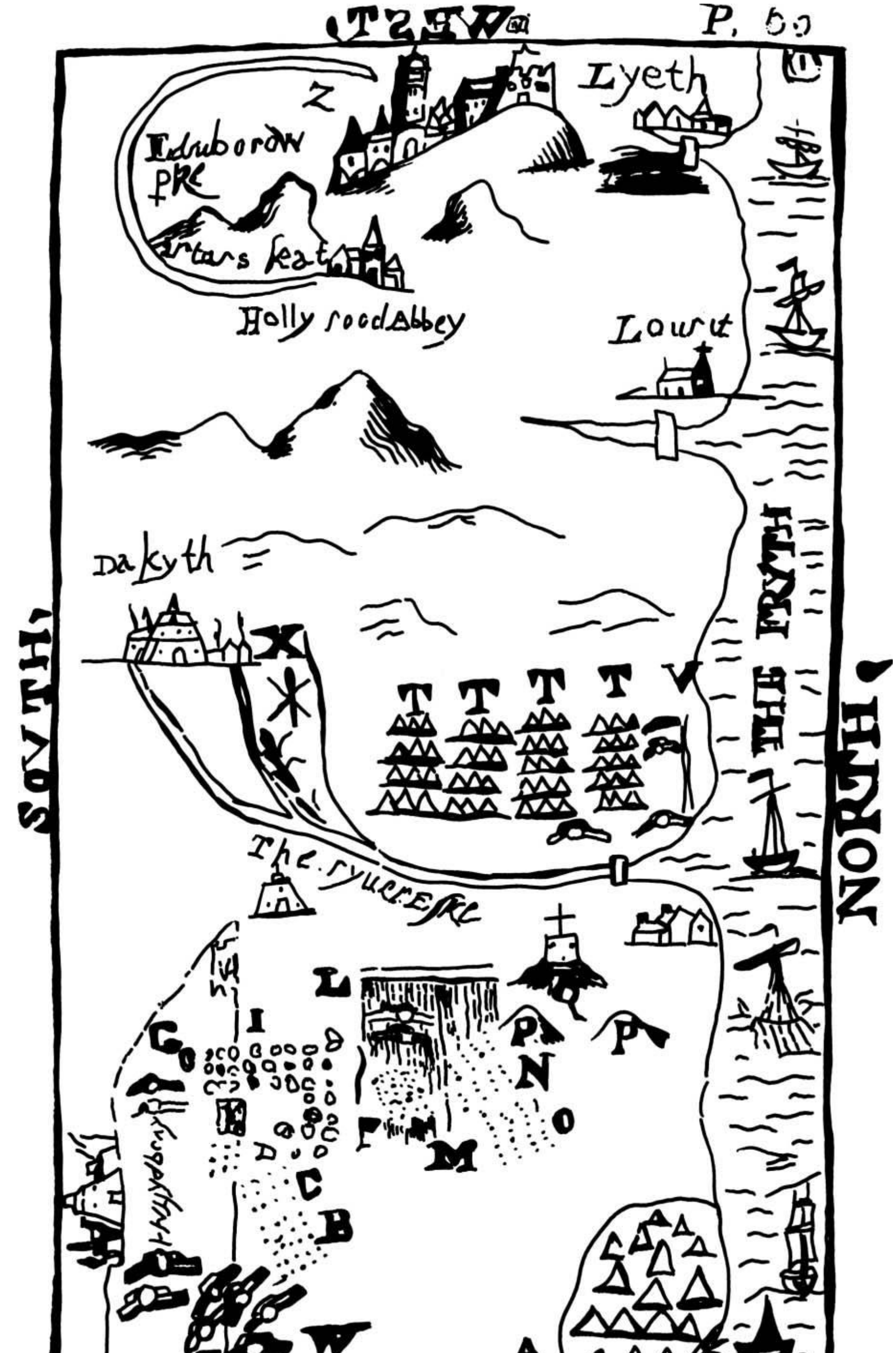


Figure 2.10 Early wood carved block print showing troop generalization of the Battle of Pinkie Cluegh, 1547, first published in 1598 (Pollard 2009:28).

Modern Battlefield Maps of the Late Eighteenth and Onward

As warfare became more complex, it became necessary to simplify cartographic elements. The battlefield landscape now had a variety of combatants, engaging in warfare across larger geographical areas. As a result, there was a shift in battlefield visualization away from rendering the individual soldier or artillery, to generalizing military units as groups. This trend is the birth of the modern battlefield map. This approach to battlefield visualization and mapping has persisted since the late eighteenth century to today. What follows is a breakdown of the modern battlefield visualization by century, starting with the eighteen century.

Warfare in the eighteenth century was similar to the preceding two centuries in that it saw a continual growth in army size, with a general trend towards siege warfare (Anderson 1988:15). With an increase in the use of artillery, topographic survey became paramount. Hale (2007:25) notes that the eighteenth century was a period of almost continual warfare, that the military commanders needed detailed maps for the movement and quartering of troops, and therefore that the modern topographic map was a response to military necessity. It was not until the late eighteenth century, however, that the true modern military maps begin to emerge.

The French Revolution (1789-1799) and the Napoleonic Wars (1803-1815) saw a marked decline in the importance of siege warfare. This decrease in importance was developed in part due to improvements in the mobility of weaponry. Army sizes also increased greatly during this time, and battles became more frequent, resulting in encounters on a larger scale. These armies, however, were fundamentally different from the primarily professional armies of the past. These new, larger armies were for the first time, citizen armies composed of both enlistees and conscripts. Prior to the French Revolution, the average battle contained approximately 50,000 combatants. From the Revolution through the Napoleonic Wars, the average number of combatants rose to approximately 100,000, and in exceptional cases like at Wagram (1809) and Leipzig (1813) with 320,000 and 420,000, respectively. Thoral notes this “trend to mass armies was reinforced by changes in combat tactics” (Thoral 2011:16). In particular, she notes the change from the thin line three men deep, to the dense column formation and the emphasis on the frontal attack.

Due to these fundamental changes in army size and tactics, the average length of combat increased, and often included the pursuit of fleeing armies. Essentially, Thoral notes, “the transition over this period from a war of position to a war of movement was associated with a change of tempo in military campaigns” (Thoral 2011:18). Herein lays the need to develop a method of mapping larger armies, which utilize more complex movements. Thus was born the modern battle map.

Another technological advancement that allowed this map type to proliferate was an increase in both the demand and availability of printed books (Buringh and Zanden 2009:417). By the time of the French Revolution and Napoleonic Wars, it was commonplace to see published works relating to a particular battle, complete with maps, within a year of the event. For example, in 1814, Frederic Shoberl published an account of the events at Leipzig, which occurred between the fourteenth and nineteenth of October, 1813, which contained a multitude of maps representative of this modern style. Another example is John Booth’s account of the battle of Waterloo, also complete with maps, printed in 1816, which was within a year after the historic battle. Booth published a second work relating to the battle of Waterloo the following year (1817) in which he also used this style of mapping. It serves as a good example of the modern battlefield map (Figure 2.11).

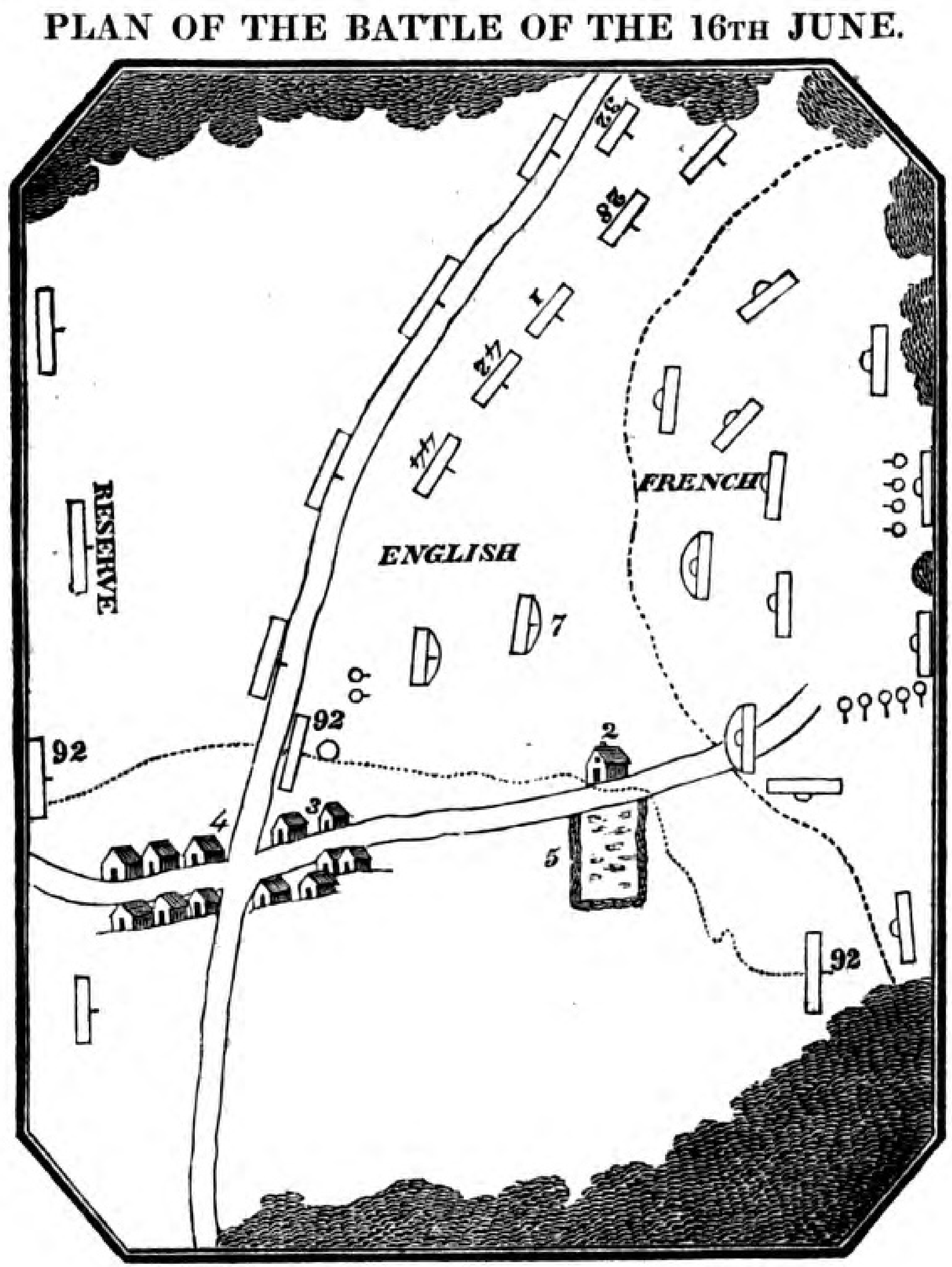


Figure 2.11 One of Booth's representations of the Battle of Waterloo, 1815 (Booth 1817:76).

Not all battlefield maps produced during this time contained only the generalized representations of military units. An example from James Wilkinson’s memoirs (1816) contains battlefield maps that use a system of lettering and numbering to locate key features and military units in addition to generalized representations (Figure 2.12). A key to these numbers and letters is found adjacent to the map, and aides the reader in interpreting key battlefield locations (Figure 2.13). The trend in battlefield mapping at this time, however, is primarily focused on the generalized representations, and this trend survives today.

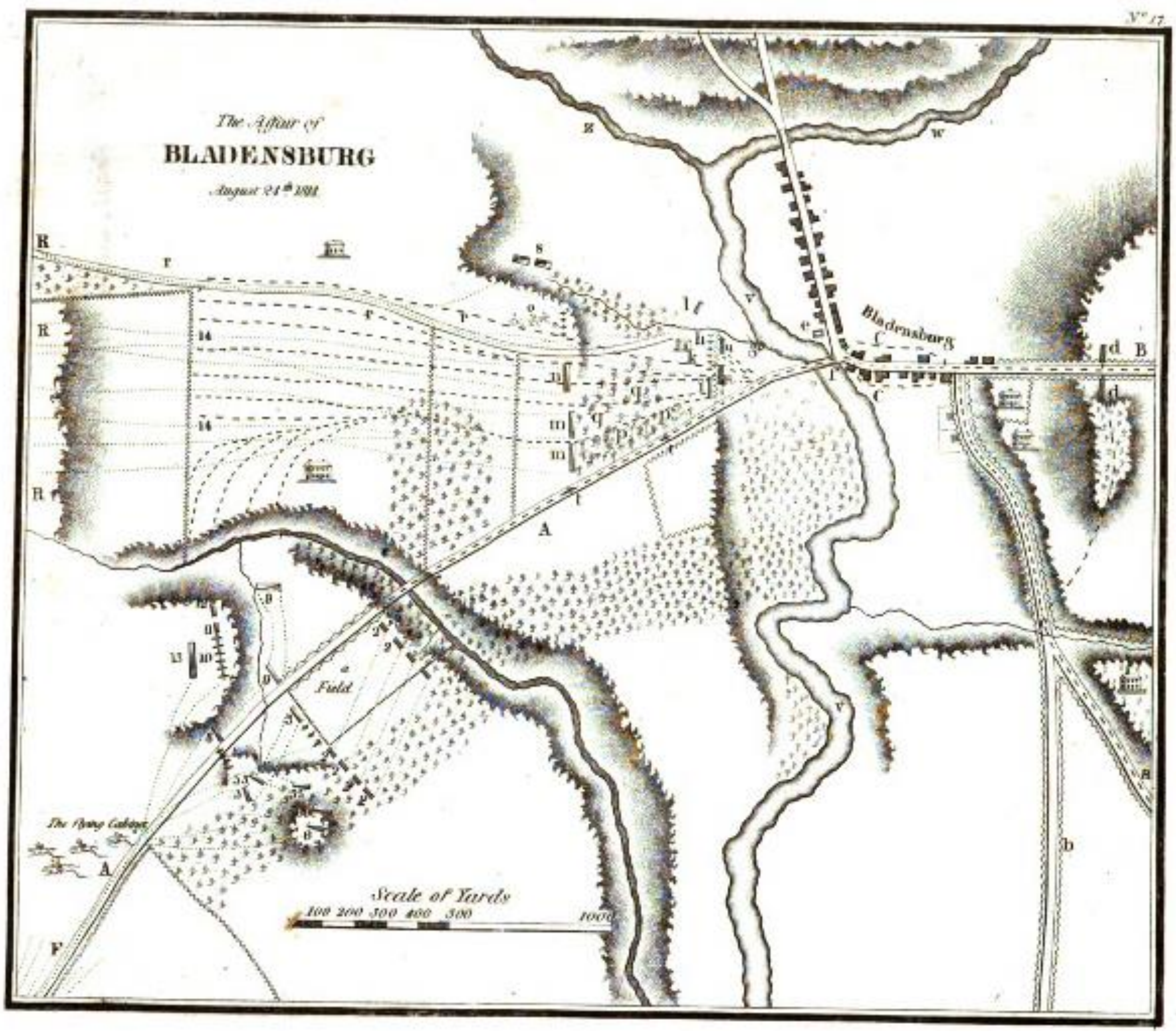


Figure 2.12 Representation of battlefield locations and key terrain features by use of lettering and numbering at the Battle of Bladensburg, August 24, 1814 (Wilkinson 1816:Plate 17).

EXPLANATION OF THE DIAGRAM, No. XVII.

a Route of the British from Long Old Fields.
b Road by the ferries to the Eastern branch and to Alexandria.
c British column divided, the main body ascending the height, and flanking party following the old road.
d d The British here formed, and halted 20 or 30 minutes.
e A strong brick house fortified, but not occupied.
f Bridge over the Eastern branch.
g A large strong mill.
h Battery of 6 pounders—Baltimore Artillery.
i Major Pinkney's riflemen.
k Tobacco house.
l Captain Doughty's riflemen.
m m Stansbury's Brigade.
n 5th Regiment, Colonel Sterret of Baltimore.
o Birch's Artillery.
p p A corn field.
q q Orchard.
r r r Old road to Georgetown.
s Dragoons, regular, Colonel Laval.
t t Two Pieces of Artillery.
u u The right column of the enemy under Major Brown, of the 85th regiment, first formed.
v v Eastern branch of Potowmack.
w North-east do. do.
z North-west do. do.
x Turnpike road to Baltimore.
y Old road to do.
A A Turnpike to Washington City.
B Road to Governor's Bridge, Queen Ann, and Malborough, by which the enemy retreated.
C C The enemy advancing to the attack.
F Retreat of the marines and seamen, the district and part of the Maryland militia, and also Colonel Laval with a troop of the 1st and part of the militia dragoons.
- - - - - March of the enemy.
: : : : : Retreat of the American troops.
R R R Retreat of the Baltimore and other Militia.
2 2 The left wing of the enemy first formed under Col. Thornton.
3 Marines under Captain Miller at a post and rail fence.
4 Commodore Barney with a battery.
5 1st position of seamen.
3 3 2d position of marines.
5 5 2d position of seamen.
22 22 2d ditto. of Colonel Thornton.
6 6 1st position of Colonel Beall with Maryland militia.
6 2d ditto.
8 Colonel Magruder's regiment of district militia.
9 36th regiment of infantry under Colonel Scott.
10 Major Peter with 6 pieces of artillery.
11 Davidson's volunteers.
12 Stull's do.
13 Brent's district militia.
14 Extent of the British pursuit on the left.

Figure 2.13 Key to Wilkerson's battlefield visualization of the Battle of Bladensburg (Wilkinson 1816).

While the majority of published maps during the nineteenth century are of terrestrial battles, there are a few examples of works pertaining to maritime events. One example is Charles Ekins' publication on naval battles of Great Britain (1828). His work contains many depictions of naval battles, utilizes basic hull form representations, and depicts the opposing forces by a change in shade (Figure 2.14). A later publication by Joseph Allen (1853), also pertaining to battles of the British Navy, are not as polished and professional as Ekins', but serve as examples of nineteenth century representations of maritime battlefields.

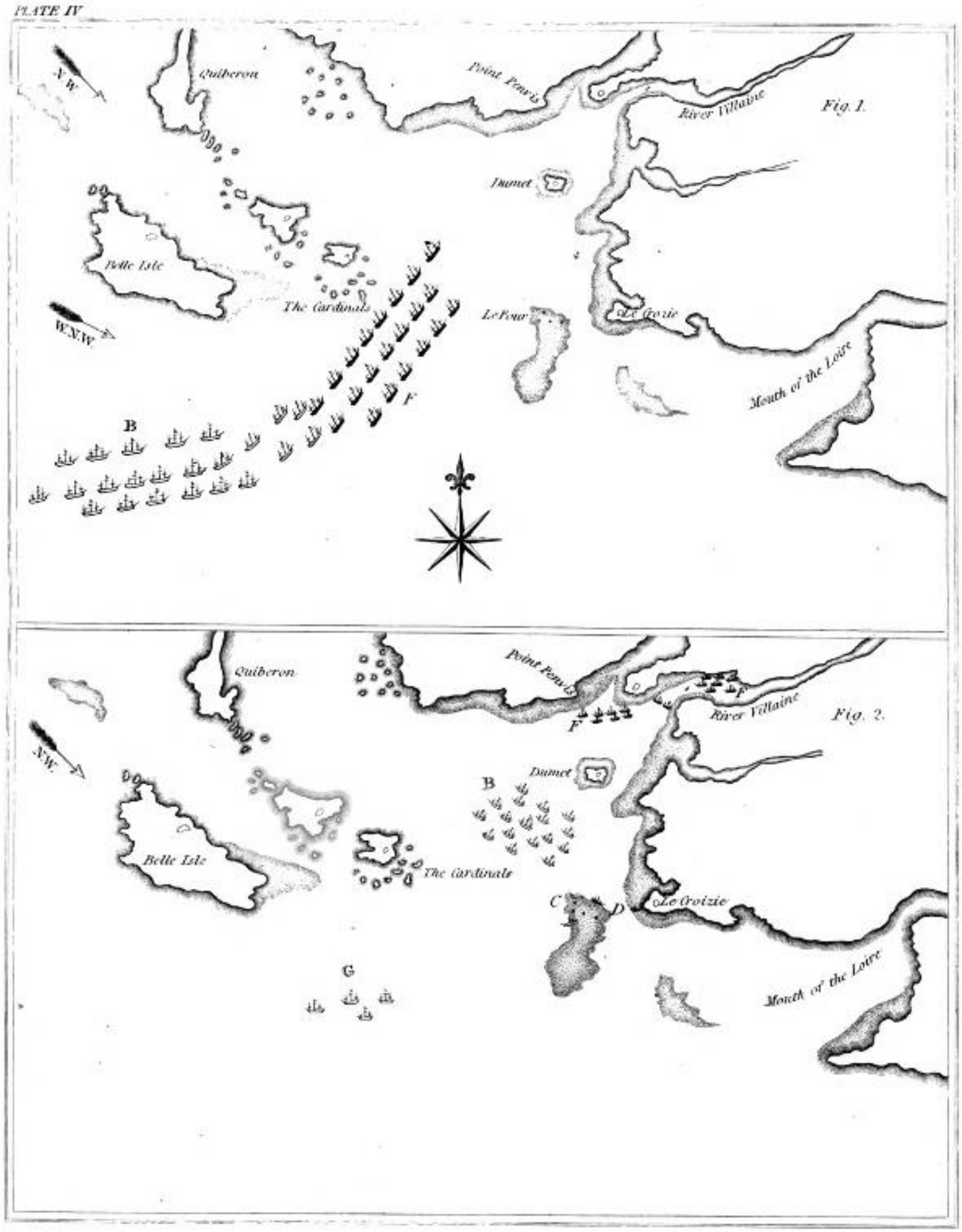


Figure 2.14 Ekins' representation of a naval battle. Opposing forces are denoted by a change in shade (1828:Plate IV).

The twentieth century saw drastic changes and advancements in war fighting capabilities. The First World War was the first major example of warfare that exhibited the new destructive capabilities brought about by the mechanized advancements from the Industrial Revolution. Nancy Ford notes:

> The Industrial Revolution also changed the nature of warfare. As the first decade of the new century came to a close, the extraordinary force of machine power would astonish the world and result in a prolonged world war – a war with unprecedented destruction and shocking loss of life. Between 1914 and 1918, the Industrial Revolution brought not progress, but death (Ford 2008:71).

She continues by noting the destructive nature of the modern "machine" armies, where commanding officers sent solders up against machine guns, advanced artillery, tanks, and poison gases. Two of the most notable advancements in technologies during the First World War were the use of the internal combustion engine and development of the airplane. Ford notes "The invention of the internal combustion engine led to the design and manufacture of thousands of tanks… [that] had the capability of traversing difficult terrain, maneuvering over massive potholes left by artillery shells, and climbing over barbed wire" (Ford 2008:73). The start of the First World War occurred only ten years after the successful flight of the Wright Brother's flyer in Kitty Hawk, North Carolina. During the conflict, aircraft were eventually adopted for military use. Originally only used in battlefield reconnaissance, airplanes quickly developed into machines capable of dropping bombs, essentially turning them into mobile artillery (Ford 2008:65).

Technological advancements were not limited to terrestrial warfare. The world's navies saw marked advancements in technology. This increased their effectiveness at conducting battle. The use of cruisers, destroyers, and massive battleships equipped with enormous artillery was ubiquitous on the world's oceans. The development of the submarine, equipped with terrorbringing torpedoes, sub-chasers, and more advanced marine mines, brought naval warfare into the modern mechanized age. Contemporary maps highlight the complex nature of battles during this mechanized age (Figure 2.15), which utilize complex systems of arrows and lines to denote movements of forces.

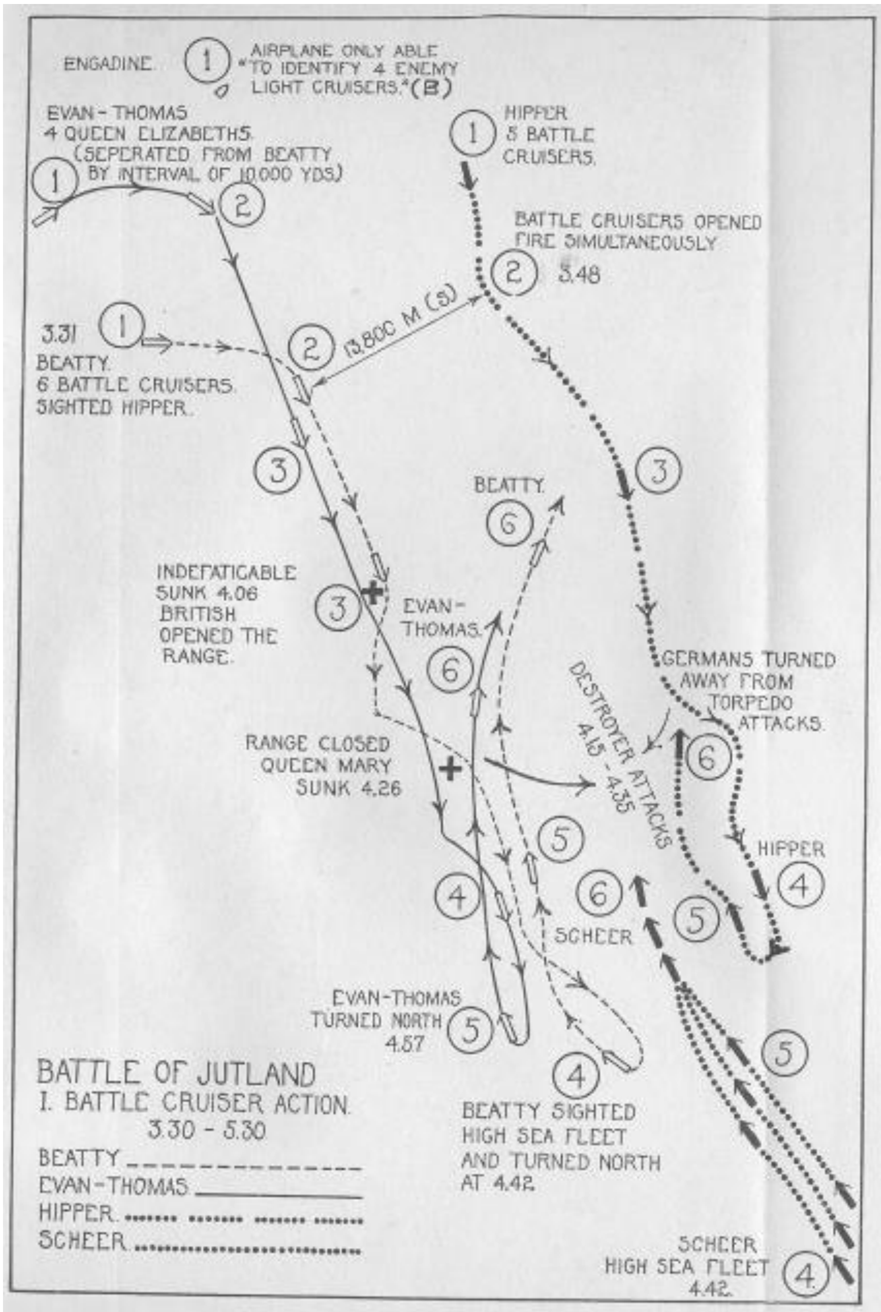


Figure 2.15 Cruiser action during the Battle of Jutland, 1916 (Frothingham 1926:248).

This trend toward mechanization and automation continued throughout the Second World War, as did the increase of importance of both aircraft and subsurface watercraft. Maps created during the Second World War are similar to those from the First World War. They contained detailed information with a multitude of directional arrows and associated text.

The Cold War (1947-1991) was also a time of great military advancement. This nearly fifty-year period contained a great arms race which saw the development of air, naval, and missile technologies that would allow nations to engage in warfare across the globe in a moment's notice. General Wesley Clark, Former Supreme Allied Commander, noted that, by the time of the Gulf War (1990-1991), the weapons of war had changed, and that new precision weapons were considered the weapons of the future. These precision strike weapons developed rapidly during the conflict, first with optical guided missiles and bombs, followed by laser-guided armaments. Both of these required clear weather to operate. The subsequent generation of weapons utilized Global Positioning Satellites (GPS) and could be operated during inclement weather and at night (Clark 2002:9). Andrew Bacevich also notes this trend, and states "The era of mass armies, going back to the time of Napoleon, and of mechanized warfare, an offshoot of industrialization, was coming to an end. A new era of high-tech warfare, waged by highly skilled professionals equipped with "Smart" weapons, had commenced" (Bacevich 2005:20).

The technological advancements during the twentieth century were so great that the means by which nations engaged in warfare were fundamentally changed. With the desire for a quick and decisive battle, one primarily aimed at frontal assault, the technology developed so quickly that it essentially rendered the traditional massed infantry battles obsolete (Hanson 2000:227). During the latter part of the twentieth century, new types of warfare were developed, in which small, loosely organized groups of combatants could take on large, highly organized and well trained forces. These new tactics, called “irregular” or “guerilla” warfare, and other tactics used by non-state organized terrorist organizations, are currently the only real successful means of engagement in the nuclear-armed world of today (Hanson 2000:xxix).

Later in the twentieth century, a revolution occurred in regards to map production that is essential in understanding the development of the battlefield map. This revolution was the birth of computer cartography, and later the development of the GIS. Cromley notes, “the development of computer technology and its applications to graphics have had a profound effect on cartography” (Cromley 1992:1). By adding the ability to systematically and repeatedly map large spatial datasets, a resurgence in battlefield mapping occurred. One of the biggest advantages of GIS technologies and digital frameworks, is that it allows the map creator to replace descriptive and symbolic implementation with a more analytical and nomothetic approach. With this advancement, the producers of battlefield maps have just barely begun to scratch the surface of what is possible with GIS technologies. Examples of digital cartography (Figure 2.16) are abundant in most modern-day battle map atlases (Folly 2004; Keegan 2006; Gilbert 2008).

The real advantage of GIS technologies for map design and production are the ease at which maps can be created. In essence, anyone with the proper training and access to the appropriate software packages can make digital maps. This allows broader access to the toolset of the cartographer. In addition to broader access, GIS technologies allow for greater analysis. This advantage can also prove to be problematic, however. With the increased access and ease to map production also comes an increase in poor map design, and improper analysis. While cartography used to be more of an art form, taking years of practice and experience to master, now anyone with the appropriate datasets and software can create a map.

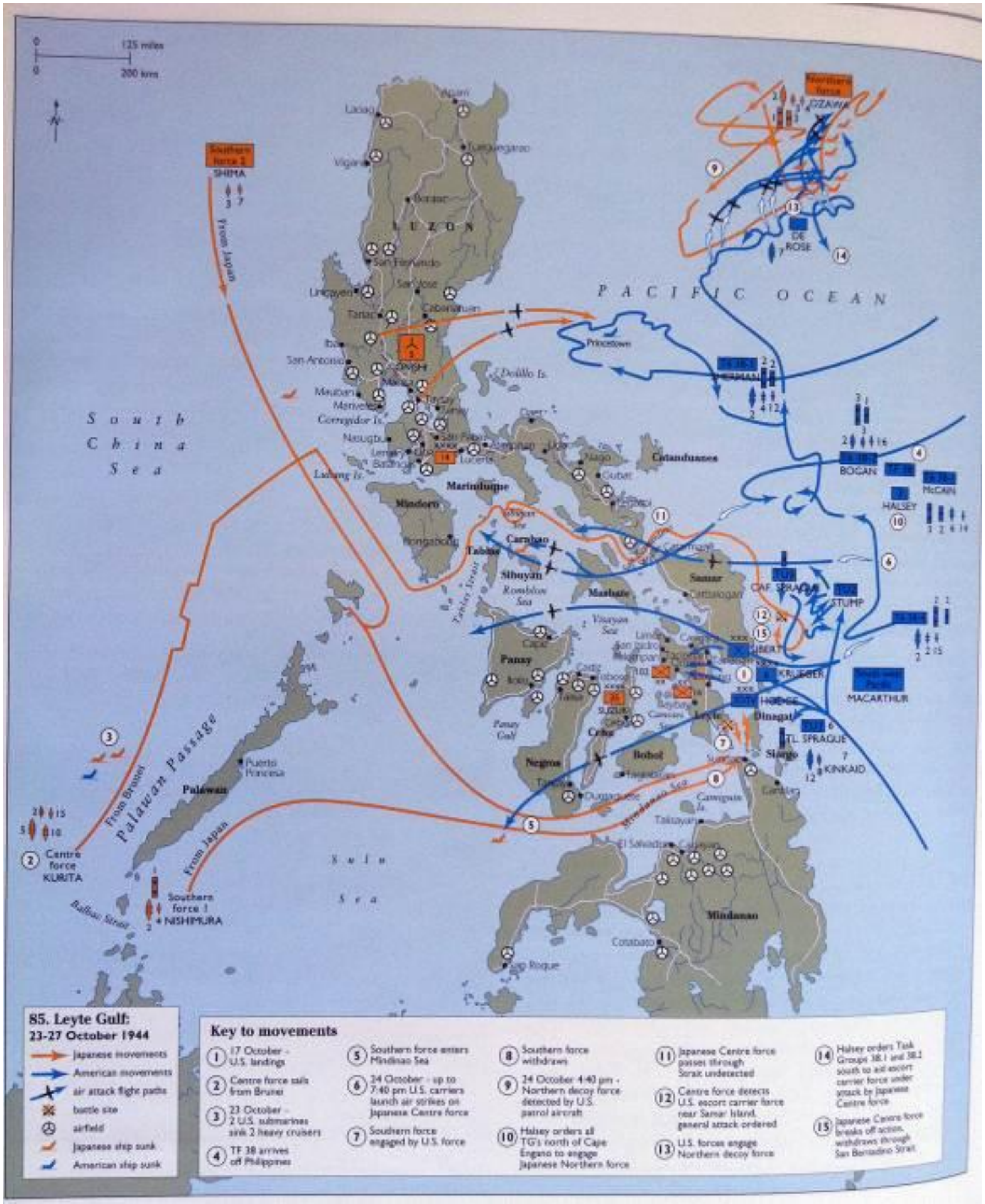


Figure 2.16 Modern battlefield map found in a map atlas - Battle of Leyte Gulf, 1944 (Bradford 2003:150).

Conclusion

This examination of battlefield visualizations, spanning nearly twelve thousand years, aims at identifying key themes throughout the development of representing warfare. Starting with prehistoric representations of war engraved on cave walls and traveling through time to the modern battlefield maps, this history has focused on major trends in technologies and representation style.

Initially battlefield visualizations were more akin to art than their modern cartographic successors. During the Renaissance, however, this changed, and a separation occurred between artistic and cartographic representations of conflict. It was also during this time that the origins of many modern battlefield techniques were developed. It was not until the modern era of battlefield mapping that these techniques grew into maturity, and have now cumulated in the use of computer technology. These trends in battlefield mapping draw from a variety of technological and military advancements, and will no doubt continue to develop. Detailed analysis of these trends and key themes are saved for a later chapter (Chapter 5).

The ultimate goal of this study is to improve upon the status of battlefield visualizations. To accomplish this, a thorough understanding of various uses of advanced and geospatial visualizations in closely associated academic disciplines is necessary. As a result, this study now moves on to the systematic investigation into disciplines closely related to battlefield visualization. It is hypothesized that, in these disciplines, there exists current applications of advanced techniques that can be applicable to battlefield visualizations.

Chapter 3 : ADVANCED AND GEOSPATIAL VISUALIZATIONS

Introduction

The visualization of data is paramount in almost all facets of scientific and academic research. Llobera notes “the importance of visualization has been widely recognized in many different fields, including medicine, genetics, physics, mathematics, and economics, as being a key component in knowledge discovery and interpretation” (Llobera 2011:194). He continues by noting “the ultimate aim of visualization is to render data and information in order to ease communication, insight, and/or understanding” (Llobera 2011:195). There has been a recent increase in the use of data visualization in all scientific and academic disciplines, due to the ever-increasing power of computers combined with the decreasing cost of specialized hardware and software. The result of this has been an increase in the sophistication of computer-generated graphics. Also occurring over the last few decades has been an overall increase in the availability of digital data products. Fields that have seen the largest increase in these data products have also been the disciplines that have seen the largest increase in visualization techniques (Llobera 2011:196). Each of these disciplines exploit various visualization techniques in a variety of manners, however, their end goal is always the same, “to amplify visual perception and cognition in order to ease understanding of data” (Llobera 2011:197). The emphasis placed on the data, the data sources themselves, and reason for the creation of the visualization are the distinguishing characteristics between the disciplines (Llobera 2011:215).

Any representation of reality is the result of a series of compromises, which highlight a desired theme. These compromises sometimes negatively affect understanding or skew the interpretations of the events represented (Ford 2011:3). Oversimplification or abstraction of events is one example of a compromise that may or may not have a negative impact. Cromley states “the abstraction process includes the selection, classification, simplification and symbolization of cartographic information" (Cromley 1992:6), and note the selection of information is determined by the purpose of the map. Advanced forms of visualization are frequent in many areas, ranging from the scientific to the graphics and images found in everyday life. One such everyday example is the Washington D.C. Metro System Map (Figure 3.1), which is an over-simplification of reality designed to show the relative location of the various train stops. This advanced visualization contains a spatial component, and is therefore an advanced geovisualization.

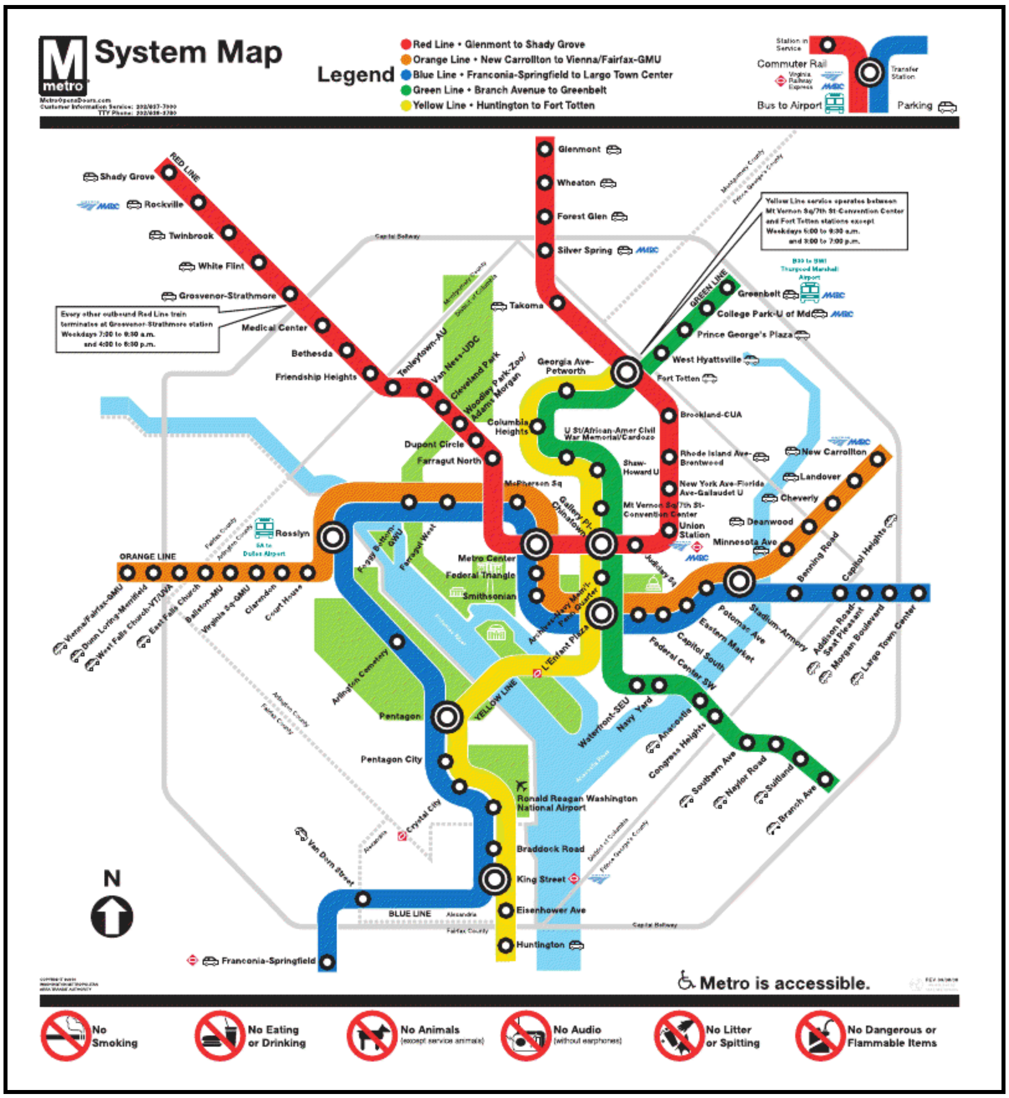


Figure 3.1 Washington DC Metro Map (Washington MetroTransit Authority).

The emerging sub-field of geovisualization draws from a variety of disciplines, much like the larger field of visualization mentioned above. Dykes et al. notes that geospatial visualization is influenced by "cartography, scientific visualization, image analysis, information visualization, Exploratory Data Analysis (EDA) and GIScience to provide, theory, methods, and tools for the visual exploration, analysis, synthesis and presentation of data that contains geographic information" (Dykes et al. 2005:4). They continue by stressing the blurred boundaries between the disciplines and note some of the various difficulties within the field:

> Challenges include determining the limits and advantageous uses of both traditional and novel representations methods, creating meaningful graphics to represent very large, multi-variate spatio-temporal data sets (that may include both three spatial dimensions and time) and the development, use and continual evaluation of innovative tools that take advantage of interactivity, animation, hyper-linking, immersive environments, agents, multi-modal interfaces and dynamic object behaviors (Dykes et al. 2005:5).

Essentially this emerging field attempts to link new technological possibilities with geographical phenomena in a meaningful way.

Examples of advanced visualizations and geovisualizations are products like 2D animations, static 3D images, 3D animations, and immersive 3D virtual reality (VR) environments. The previous examples are presented in order of complexity, with each having various strengths and weaknesses. For example, in regards to the potential of virtual reality in modeling archeological landscapes, Michael Teichmann notes "the use of 3D visualizations forces scholars to make statements concerning the third dimension that can easily be omitted or underrepresented working with traditional 2 dimension plans" (Teichmann 2009:103). He continues by noting that VR can identify gaps in the existing knowledge base, by highlighting problems with data approximation that might not have been identified if only visualized in two dimensions. Furthermore, Teichmann (2009:104) then notes the importance of the associated databases, inherent availability of metadata, and the strengths these visualizations have in regards to flexibility of scale. As previously noted, each of the above-mentioned technologies is not without weaknesses, and each is open to debate. Winterbottom notes the ongoing debate within the use of VR in archaeology. Specifically he states:

> Attempts to brand VR as a fully experiential phenomenological tool ignores the precept that phenomenology must embody history and individual human experience. Whilst VR cannot provide a mechanism for understanding the perceptions of past societies, it can be employed as additional instrument in the phenomenological toolkit; albeit one with a primarily visual emphasis (Winterbottom 2006:1357).

One of the main advantages of advanced visualizations is the ease at which it transitions into outreach and education. They have been noted to increase and "facilitate a better understanding of a historically important but little preserved place" (Teichmann 2009:107). It would seem that the use of various advanced visualization and geovisualization techniques would be well suited for naval battlefield analysis and communication as there is often little visible remains from these culturally relevant encounters. Teichmann concludes his examination into the possible avenues for advanced visualizations by noting:

> Studies regarding the effects of 3D landscape relief have shown that it is very popular among spectators and attract interest and attention, assimilating the effects of archaeological visualizations. Empirical studies have shown that people who had seen a 3D landscape visualization could remember relief information better than persons that were shown traditional 2D maps. 3D landscape visualizations are of particular value for schools, museums and tourism and can be used as part of e-learning for virtual excursions to remote areas or complementary to real excursions (Teichmann 2009:107).

While geovisualizations saw their origin in disciplines such as geography and the environmental sciences, they are not limited to only those arenas. The use of these techniques and technologies are slowly beginning to make their way into all aspects of science and research. Prior to understanding the applications of these geospatial visualization techniques to naval battlefields, an investigation into their uses in a variety of other disciplines is needed. First, the use of these representation techniques within geography will be examined, followed by terrestrial archaeology, maritime archaeology, and finally the use of these techniques in history respectively.

Geography and Advanced Visualizations

Many scientific and academic disciplines have adopted the use of advanced visualization techniques to represent data. These advanced visualization techniques apply to all facets of research from the natural sciences to the social sciences and humanities. Geography was an early discipline to adopt the use of animations and 3D representations in the use of inherently spatial data (Germs et al. 1997; Koninger and Bartel 1998; Losa and Cervelle 1999; Sidiropoulos et al. 2005; Wu et al. 2005; Sidiropoulos and Vasilakos 2006; Meng and Liu 2008). The foundation of these advanced geospatial visualizations, however, originates much earlier with the adoption of computer techniques in the discipline of cartography.

As noted in Chapter 2, computer technology revolutionized the discipline of cartography (Cromley 1992:ix). This dramatic change in cartography originated from the quantitative revolution in geography during the 1960s (Balram and Dragicevic 2008:372). The ease of map production is not, however, the real advantage of computer technology in cartography, it is the preceding spatial analysis. The introduction of the computer facilitated the development of a digital framework, which enables geographers and cartographers to "replace descriptive and ideographic approaches to problem analysis with a nomothetic concern for generalization and theory building" (Cromley 1992:10). Balram and Dragicevic state, "New computer tools, processing algorithms, data interconnectivity, and integrated research have transformed many aspects of traditional cartography into the present day map-based scientific geovisualization" (Balram and Dragicevic 2008:372). They continue by noting that GIS is the predominant technology utilized in these advanced cartographies. It made the map production and preparation process much easier, allowing anyone with the necessary skill sets and access to the appropriate software packages and data to create maps. The introduction of the computer into cartography laid the foundation for more complex spatial analysis and the development of GIS technologies and frameworks.

Since the development and implementation of the digital framework, the growth of geospatial visualizations has been rapidly expanding. Almost all disciplines that study a spatial element have experienced this rapid development. Brooks notes, “the applications for effective GIS visualizations are vast and include environmental analysis and modeling, flood models, geological models and urban planning” (Brooks 2008:279). A brief synopsis of a few utilizations of these advanced geospatial visualization techniques will now be provided. The first utilization examined is the application of geospatial visualizations in the representation of complex data, followed by applications in urban planning, and finally a few miscellaneous examples.

Geographic data spans the whole continuum in complexity. Some data types are extremely easy to represent, and are well suited for 2D formats. Those 2D formats could be a printed map, or an image displayed on a computer screen or projector. Some geographic data, however, is more difficult to display, or represents abstracted ideas. Adding a third dimension when visualizing data can allow multiple variables to be displayed in one representation. A frequent use of a third dimension in inherently 2D data is the representation of time (Kwan 2000; Chen et al. 2011). Kwan’s work utilizes a variety of 3D approaches to visualizing geographic data, however, her most impressive is her “space-time aquarium” (Figure 3.2). The purpose of the study was to compare the various travel-geographies of women of different ethnicities. This visualization shows underlying geographic data, with 3D space-time paths of African American and Asian women superimposed on top. Visualizing this data in a 2D static image format without representing time spatially, in this case in the z-direction, would be difficult, if not impossible.

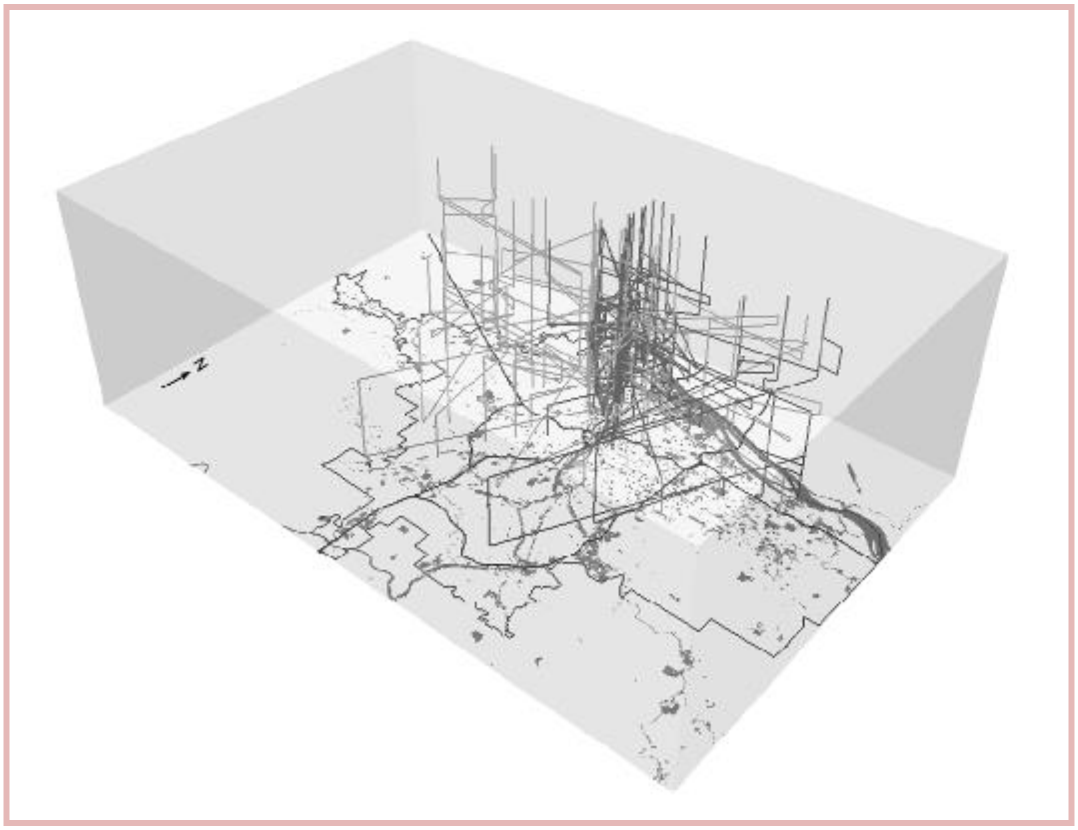


Figure 3.2 "Space-Time Aquarium" showing movement of African American and Asian women (Kwan 2000:197).

The history of advanced geospatial visualizations is long and rich in urban planning. Brooks notes that “as early as the late 1980’s the development and the role of 3D GIS for urban planning was being investigated” (Brooks 2008:280). He continues by noting the importance 3D GIS has on the relatively new sub-discipline of sustainable urban design, which allows researchers and planners flexibility when designing and evaluating new urban growth models (Brooks 2008). Visualization of urban landscapes can be extended into the realm of hazard mitigation. An interesting blending of 3D GIS and counter-terrorism research produced a study in which researchers examined 3D viewsheds related to the prevention of terrorism. Specifically, the viewshed was analyzed alongside distance constraints of various high-powered rifles to determine areas of potential sniper hazards (Figure 3.3).

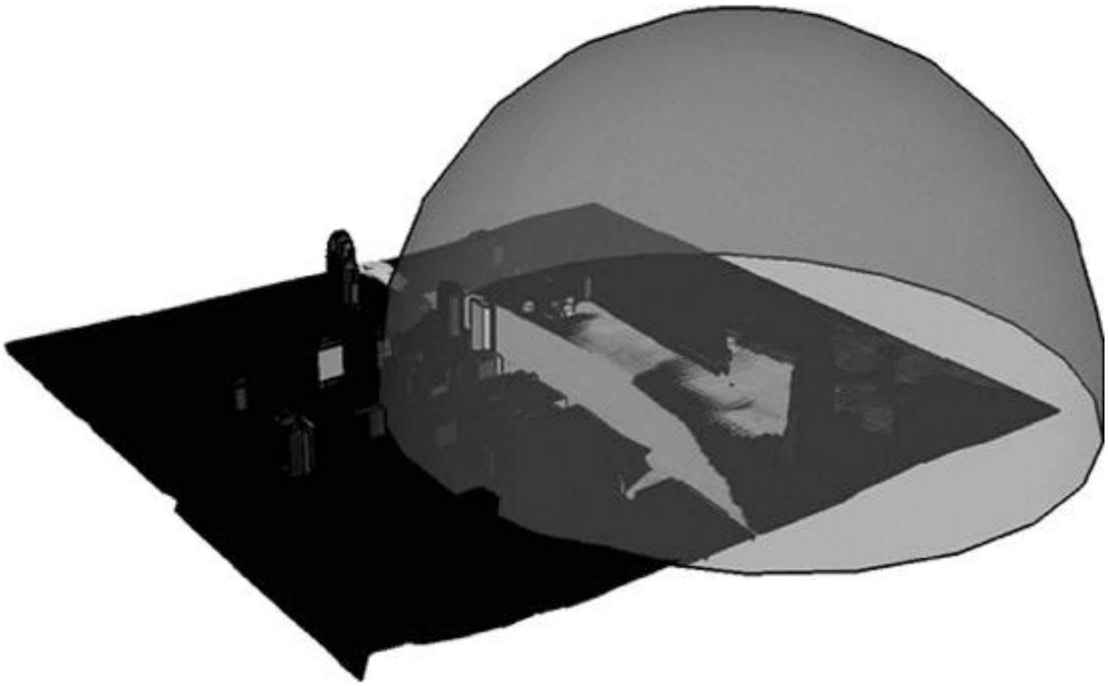


Figure 3.3 Area of threat visualized in 3D from a VS 9mm silent sniper rifle (VanHorn and Mosurinjohn 2010:492).

The use of 3D GIS in hazards and urban planning have been taken to the micro-scale, geographically speaking. For example, various studies have been conducted which utilize interior building space, 3D GIS, and hazards data to determine algorithms for building evacuations (Lee 2007: Tang and Ren 2011).

There are various other examples of 3D GIS usage in geography and other closely related disciplines. The use of 3D GIS has been used in karst mapping (Wu 2008), military applications (Fleming et al. 2009), and studies of demographics (Bell 2000).Whether the use is for visualizing complex karst systems, urban and regional planning, or detailed representations of landforms and terrain modeling, 3D visualizations have allowed geographers and planners the ability to solve complex spatial problems which were previously difficult to interpret utilizing 2D analysis techniques.

Terrestrial Archaeology and Advanced Visualization

The scientific and academic use of advanced and geospatial visualizations are not limited to geography and urban planning, and it is found in other areas of the social sciences like anthropology and archaeology. While the items visualized may be different from those in geography, the techniques are similar. Julian Richards (1998) published an early review of trends in computer applications in archaeology and notes the potential for the use of GIS, animations, and 3D visualizations. While the occurrence of advanced and geospatial visualizations have certainly increased since Richards' publication, Llobera notes:

> Visualization itself is seldom discussed, that is there is little concern with questions about what are the best strategies to display and/or visually explore archaeological information or with alternative ways in which the data may be represented, the merits and limitations of each, etc. Instead, rather than discussing the nature of visualization, these earlier publications treat visualization as a matter of applying existing software. With few exceptions the purpose of visualization in archaeology is largely reduced to a question of illustration and/or digital archiving (Llobera 2011:195).

Essentially, visualizations in archaeology are used as a means to legitimize output, rather than a method for investigation. The use of visualization in archaeology is an important one, however, as Rajani notes "visualization plays an important role in archaeological research and in presenting the results, as they convey much more information than descriptive approach and/or numerical representation" (Rajani 2009:21). The use of these visualizations is a "vessel for preservation, reconstruction, documentation, research and promotion" (Bruno et al. 2009:42).

Regardless of the success, or lack thereof, the use of advanced and geospatial visualization in archaeology dates back to the 1980s with initial uses of GIS (Winterbottom

2006). This early interest in GIS technologies is not surprising considering the importance of the spatial component in the archaeological record (Rajani 2009:21).

After reviewing current literature regarding 3D visualizations in archaeology and anthropology, certain trends emerge. The first trend relates to visualizing virtual archaeological landscapes, often with the aim to recreating the physical remains in a geo-referenced 3D environment (Gutierrez et al. 2004; Ch'ng 2009; Rajani et al. 2009). The next trend identified is the use of highly accurate scanning devices used in the production of virtual models of artifacts and monuments. Finally, the last trend examined is the use of advanced GIS techniques to develop three-dimension viewshed analysis, which can allow researchers to gain additional insight into ancient landscapes.

The 3D visualization of ancient landscapes is a valuable tool for the archaeologist, cultural resource manager, and the public. These models "allow a landscape to be perceived in much more detail than paper maps due to the three-dimensionality of the data layers" (Rajani 2009:21). Another advantage of the 3D landscape visualization is the flexibility of viewpoint. With traditional mapping, it may be difficult to visually highlight various points of view or perspectives in a 2D format (Bruno et al. 2009:42). They are excellent additions to traditional survey methods and can be used in all stages of archaeological study.

Teichmann (2009) offers great insight into the use of 3D visualizations in modeling the archaeological landscape. He examines the use of both scientific and gaming software, and highlights the strengths and weaknesses of both. He notes that although early archaeological visualizations date back to the 1980s, the true potential was not realized until the early 1990s. One of the main advantages advanced visualizations have to offer archaeology, Teichmann notes, is that these products can function both as a “research tool and as a presentation tool to communicate scientific results to a wider audience” (Teichmann 2009:103).

Teichmann provides two case studies, one relating to the scientific visualization (one with a high level of spatial accuracy), and one created with video game technologies, which is, in turn, less accurate but more aesthetically pleasing. The first example is the *Domus Aurea Neroni* project. This visualization was created by the University of Rome, and visualizes the urban palace of emperor Nero. Teichmann notes, “particular attention was paid to the wider landscape and the villa’s setting” (Teichmann 2009:110). The second example presented, is of Laxton Castle and is an advanced visualization created in *Medieval Total War* (MTW) mapmaker, an extension to the MTW video game (Figure 3.4). This visualization was created from a combination of the historic and archaeological record. Teichmann notes that the visualization “gives a better and easier comprehensible understanding of the modeled landscape than the historic map could do” (Teichmann 2009:115).

Figure 3.4 Laxton Castle visualization created in MTW mapmaker (Teichmann 2009:118).

Another current trend in 3D visualization is that of artifact preservation via the creation of accurate virtual models (Riel-Salvatore et al. 2002; Pavlidis et al. 2006; Karauguz et al. 2009). While this technique may be used to create models that are not tied into a greater landscape visualization, it does represent a primary trend in advanced visualization in the discipline. Archaeologists and anthropologists apply this technique for artifacts ranging from the small scale (e.g. lithics) to large scale (e.g. monuments and buildings). There are a variety of software packages available for artifact modeling. These software packages convert measurements taken by hand, laser-scanners, or by means of photogrammetry, and turn them into scaled digital representations (Figure 3.5). These data collection methods are often highly accurate, and produce stunning models. Laser scanning technologies, for example, utilize a laser source and an optic sensor. By utilizing triangulation principles, the scanning device can measure the geometry of the object (Pavlidis et al. 2006). Photogrammetry utilizes computer algorithms to combine a series of digital photographs or scanned images to create a photorealistic 3-D model (Yastikli 2007). Both of these methods of model creation have many avenues for automation, and produce highly accurate digital reproductions.

> The final trend examined here, is the use of 3D viewshed analysis. Winterbottom notes visibility studies are among the most common GIS based archaeological analyses. Developed from long established studies of site prominence, specific questions may be addressed including whether a particular resources are within view of a site or weather a series of contemporaneous sites are within sight of each other (2006:1357).

In his examination of two prominent monument sites, Winterbottom uses 3D virtual environments to extend his GIS-based analysis into the effects of vegetation on the sites viewshed (Figure 3.6).

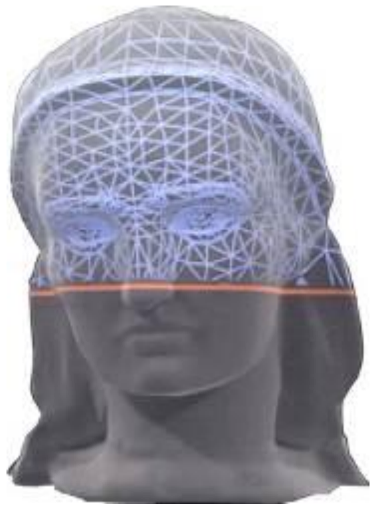


Figure 3.5 Data collected from laser scanning an object (Pavlidis 2006:94).

Figure 3.6 Effects of vegetation on monument viewshed modeled in 3D (Winterbottom 2006:1365).

While these are the three most dominant trends in advanced and geospatial visualization in archaeology, they all share a common feature: their suitability for use in education and outreach. One of the difficulties with these visual products is their dissemination to the various stakeholders and interested parties, whether they are fellow academics, students, cultural resource managers, or the layperson. One interesting recent trend is the development of the Virtual Museums. Bruno et al. states:

> The term 'Virtual Museum' is used to describe two kinds of VR technologies: the first one is a reconstruction of an already existing museum, in which the user can simulate an immersive visit, and enjoy the works of art and the archeological finds; the second one is the ex novo creation of a virtual environment, not corresponding to existing structures in which the user can navigate and watch the reconstruction of the object (Bruno et al 2009:43).

These types of exhibits are exciting because they offer a glimpse into the previously inaccessible aspects of archeological research. Dawson et al. notes "archaeologists have traditionally struggled in their attempts to engage the public in their activities" (Dawson et al. 2011:389). A successful example of a virtual display at a real brick and mortar museum was the digital products of the mass grave in the Weymouth Relief Road excavation (Ducke et al. 2011:376). Another one is the virtual exhibition system, MNEME (from the ancient Greek 'memory'), which displayed 25 Greek artifacts, which were on display at a variety of museums scattered across the Calabria region of Greece (Bruno et al. 2009). One last example of successful public outreach provided here, is the inclusion of Inuit Elders in a VR based exhibit of a Thule whalebone house (Figure 3.7). These three examples highlight the strength of advanced visualization when used for outreach (Dawson et al. 2011).

The consensus is that advanced and geospatial visualizations are underused in archaeology. Over the last decade these techniques have certainly seen great increases in frequency of occurrence, however, that majority of the approaches taken are less analytical, and were primarily developed for outreach. With its origins in GIS and other disciplines dominated with visualization techniques, to the almost ubiquitous level in outreach, the advanced and geospatial visualizations created today are exciting, and their use as an analytical tool is growing.

Figure 3.7 Interactive 3D GIS used in public outreach (Dawson et al. 2011:396).

One final area within terrestrial archaeology that is worth examining is the sub-discipline of battlefield archaeology. This area of archaeology has been successfully utilizing GIS technology for quite some time. The approaches used, however, are typically limited to 2D visualizations and analysis. The representations that Carlson-Drexler (2009:66) utilizes in his investigation regarding the discovery of battery positions at Wilson Creek are an excellent example of utilizing GIS technologies. Carlson-Drexler combines historic research, the archaeological record, and a cumulative viewshed analysis (CVA) to identify the most likely location of Backof's Battery location (Figure 3.8).

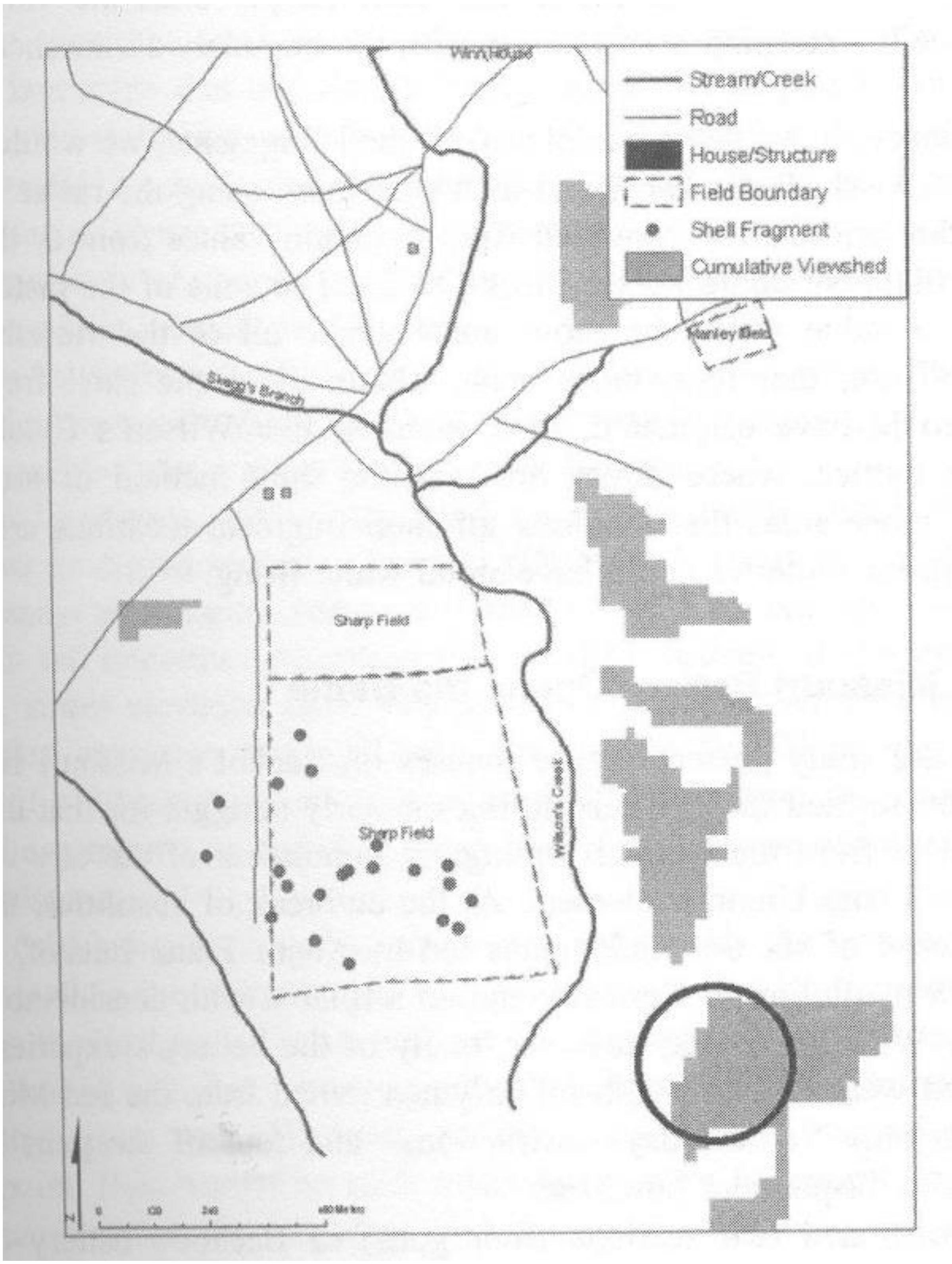


Figure 3.8 Cumulative viewshed for shell fragments fired by Backof's Missouri Battery, The Battles of Wilson's Creek, 13 August 1861 (Carlson-Drexler 2009:66).

Heckman (2009:80) utilized a similar approach in the investigation of battlefield viewsheds, and combined the use of GIS techniques with archaeological remains and the historic record. The most ubiquitous approach of visualizations in terrestrial battlefield archaeology utilizes basic point data to identify archaeological remains, like round balls or bullets, accompanied by basic annotations. An example of this battlefield representation is Reeves (2011:95) which investigates the location of skirmish units based upon archaeological finds (Figure 3.9 and Figure 3.10). Reeves's representation of the battle at Mathew's Hill utilizes basic topographic information in addition to the archaeological remains and basic annotations.

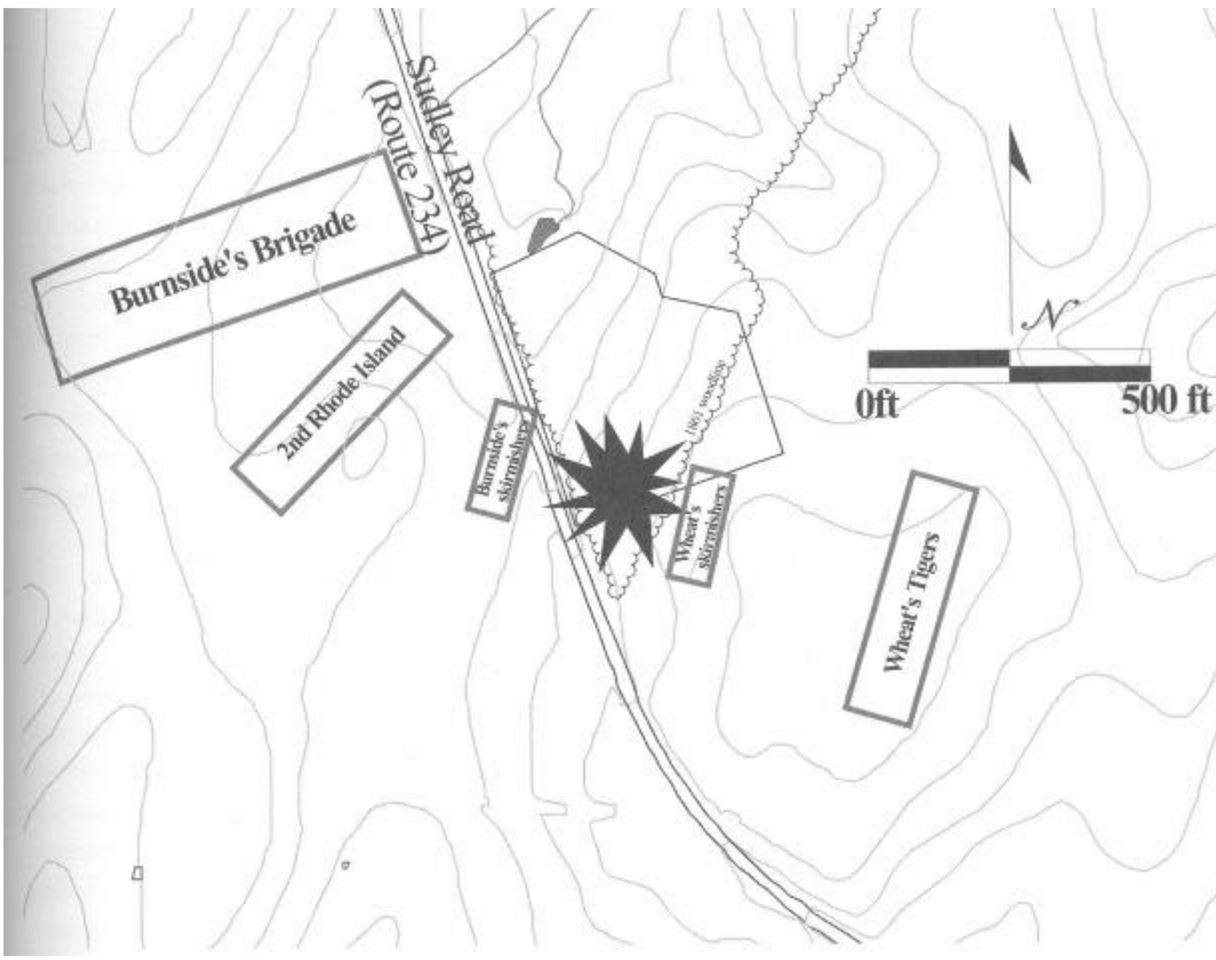


Figure 3.9 Map showing locations of skirmish units based on archaeological finds from Matthew's Hill, The First Battle of Manassas 21 July 1861 (Reeves 2011:95).

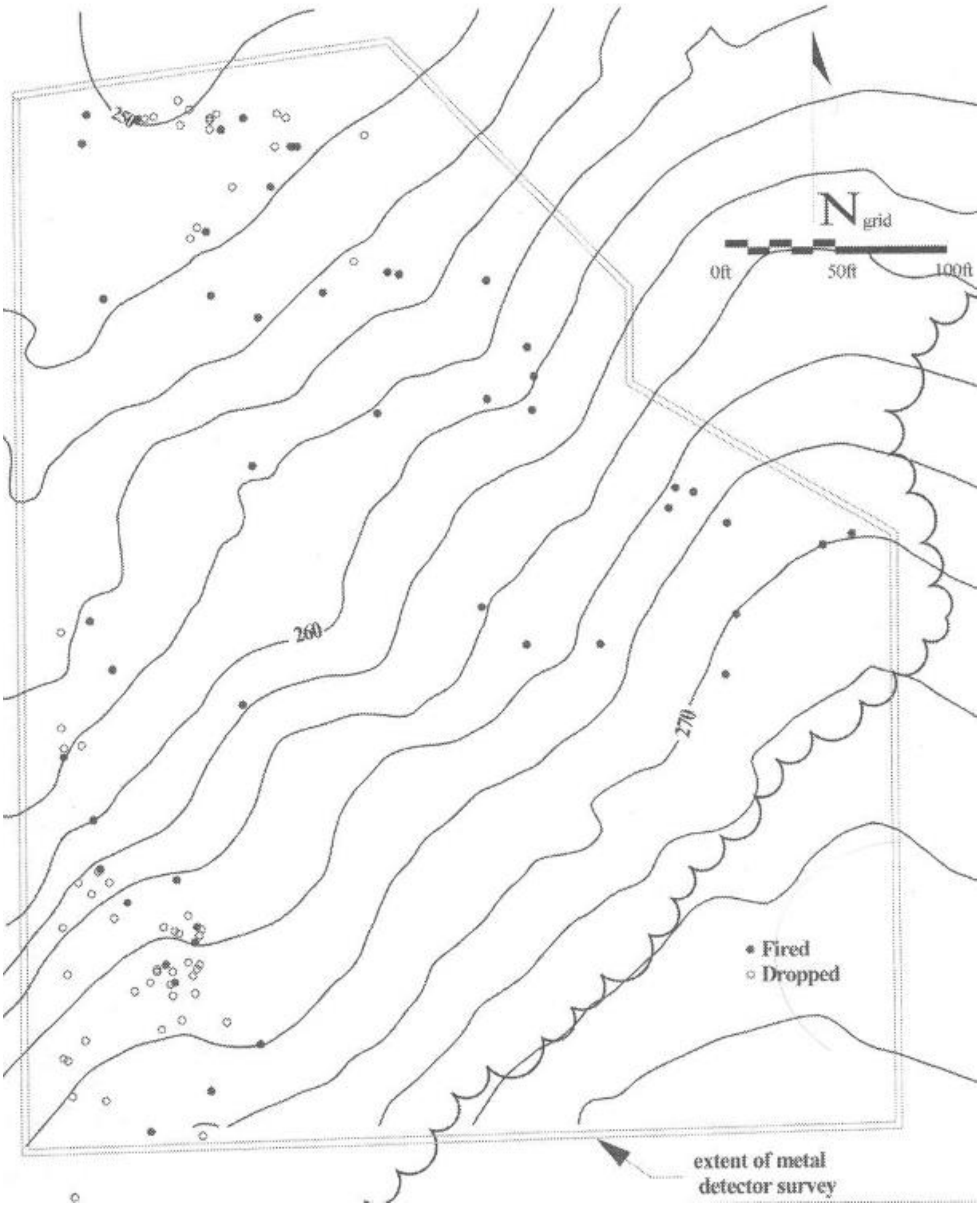


Figure 3.10 Map showing distribution of .69-caliber round-balls recovered from project area at Matthew’s Hill, The First Battle of Manassas 21 July 1861 (Reeves 2011:95).

Maritime Archaeology and Advanced Visualization

Maritime archaeology is a sub-discipline of terrestrial archaeology. It shares various similarities in regards to techniques and theory, however, the execution of those techniques and theories often need special considerations and adaptations due to difficulty with accessing physical remains or artifacts underwater. Additionally, the marine environment poses unique challenges to the archaeologist in terms of advanced visualization. As a result, maritime archaeology contains deficiencies in terms of utilization of advanced and geospatial visualization techniques, much like its terrestrial counterpart.

Currently maritime archaeology's primary application of advanced visualization techniques relates to the process of ship reconstruction (see Campbell 2008; Castro et al. 2008; Diveley 2008). In essence, historical sources combined with archaeological data, allows the researcher to virtually rebuild a particular vessel to scale in a digital environment. While 3D ship reconstruction is often a tool utilized by the maritime archaeologist, the purpose for the advanced visualization technique varies based upon research design. One such investigation not only reconstructs an early seventeenth century Nao, but also utilizes three-dimensional space to gain insight into life aboard the vessel (Castro et al. 2008). In this particular example, the 3D ship reconstruction is used to answer a specific question that perhaps only a 3D model could answer. This question addresses the amount of personal space an individual would have aboard the vessel while underway, and was expressed in a volumetric manner (Figure 3.11). This is an excellent example of a 3D visualization that was utilized in an analytical manner to solve a specific problem. Without the creation of the 3D model, the total volume and area aboard ship would have been extremely difficult, if not impossible, to calculate without fully recreating the vessel at a massive expense.

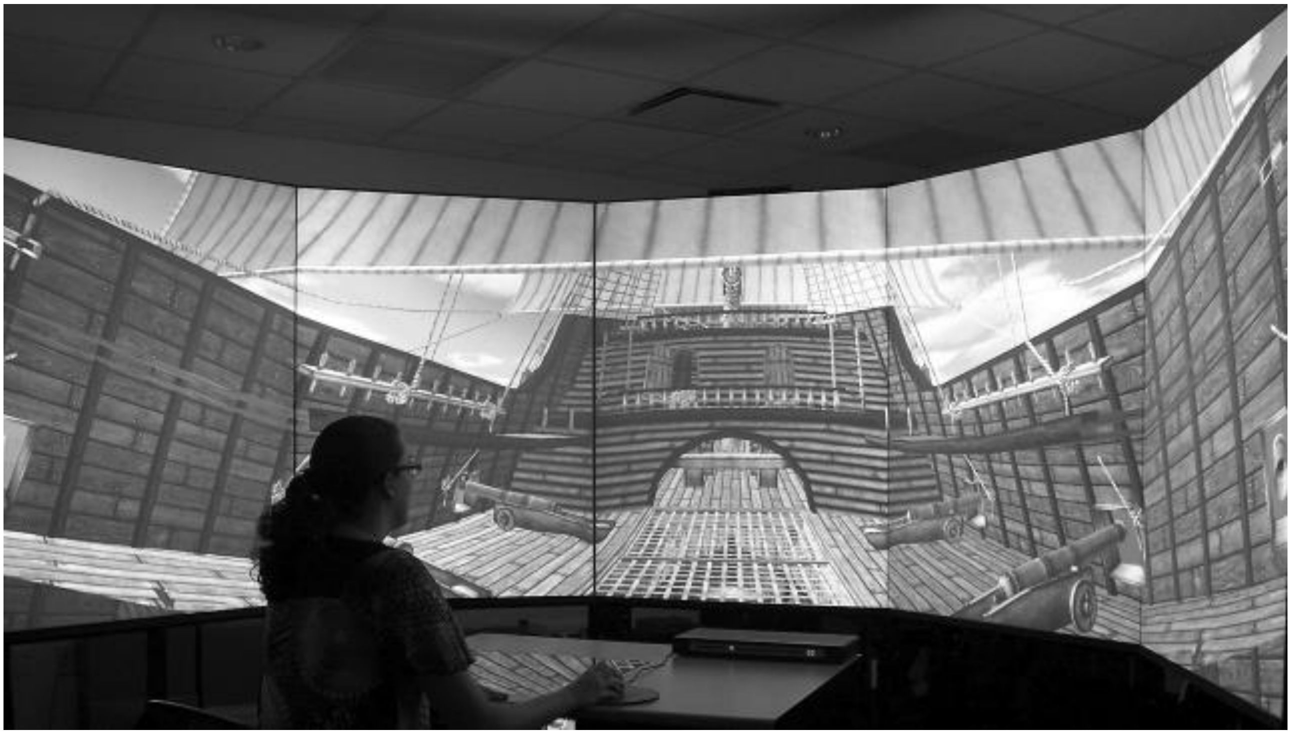


Figure 3.11 Visualizing the Pepper Wreck in a 3D virtual reality environment (Castro et al. 2008:32).

Another example of ship reconstruction in maritime archaeology utilizes 3D visualizations to aid in interpreting not only ship construction techniques, but also the gaps found in the archaeological record (Campbell 2009). Campbell utilized a combination of historic documents and archeological fieldwork in his reconstruction, which then allowed him to make conclusions regarding trends in construction techniques of Confederate ironclads. This type of 3D model is essential to the archaeologist when trying to determine the process of ship construction.

The final example combines the previous two objectives, not only filling the voids of the archaeological record, but also attempting to reconstruct life aboard two Civil War era double-ended vessels (Diveley 2008). Diveley notes the power of this form of "experimental archaeology," in that it allows archaeologists the ability to rebuild the vessel in a virtual space, which is much more obtainable when compared to physically reconstructing the vessel. He continues by noting that much can be learned from these virtual reconstructions relating to construction methods, physical attributes of the vessel, and insight into life aboard the vessels (Figure 3.12).

While these three examples served different purposes in regards to their creation, they all serve a common secondary purpose, preservation. Much like terrestrial archaeology, these ships, now that they have been recorded and reconstructed in 3D, allow future archaeologists to conduct similar investigations and answer new questions without the expensive and time consuming process of resurveying the vessels. These models are also prime candidates for virtual museums, much like their terrestrial counterparts.

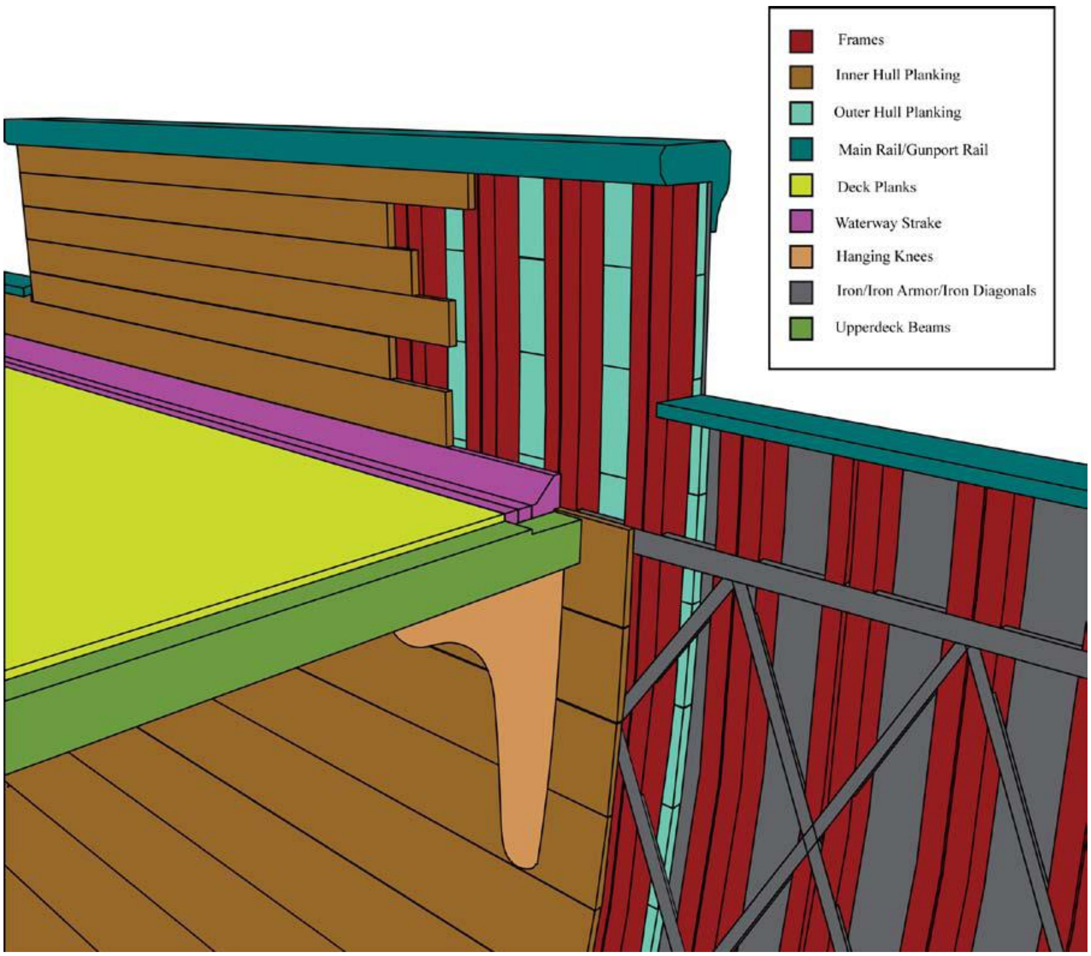


Figure 3.12 3D cutaway of *Otsego* hull components (Diveley 2008:183).

History and Advanced Visualization Techniques

Onno Boonstra notes "it is impossible to conceive history without a dimension of time, and neither is it possible to conceive history without a dimension of space. Space puts a geographical structure to human behavior, and therefore, the history of human behavior can be appraised only when geography is drawn into it" (Boonstra 2009:3). While it is essential that historians consider space, as Boonstra notes, historians also utilize advanced visualizations. The use of advanced visualizations and geospatial visualizations, however, are not as prevalent as traditional 2D maps.

One such example is the artistic renderings of U-boat tactics utilized by the German commanders against the Allied convoy system in Gordon Williamson's book *U-Boat Tactics in World War II* (2010). Ian Palmer illustrated the publication and utilizes a variety of 2D (Figure 3.13) and 3D (Figure 3.14) visualizations to assist in conveying the U-boat tactics. In the 2D representations the advanced visualization techniques utilized are primarily artistic in nature, and while they make the product more appealing, their ability to add interpretation value is questionable.

The 3D visualizations are similar in that they are primarily artistic in nature. They do, however, lend themselves to interpretations not possible in a 2D environment. In the visualization, it would be difficult to effectively convey the U-boat commander's use of the rising or setting sun in approaching an Allied convey. In both examples discussed, emphasis is placed on creating appealing visual representations, not on creating contextual or scale information. Additionally, the representations, while effective, are essentially theoretical visualizations that lack ties to real world events. When examining the 3D visualization, for example, the distance between the convoy vessels is too close, and therefore, not a historically accurate representation of reality.

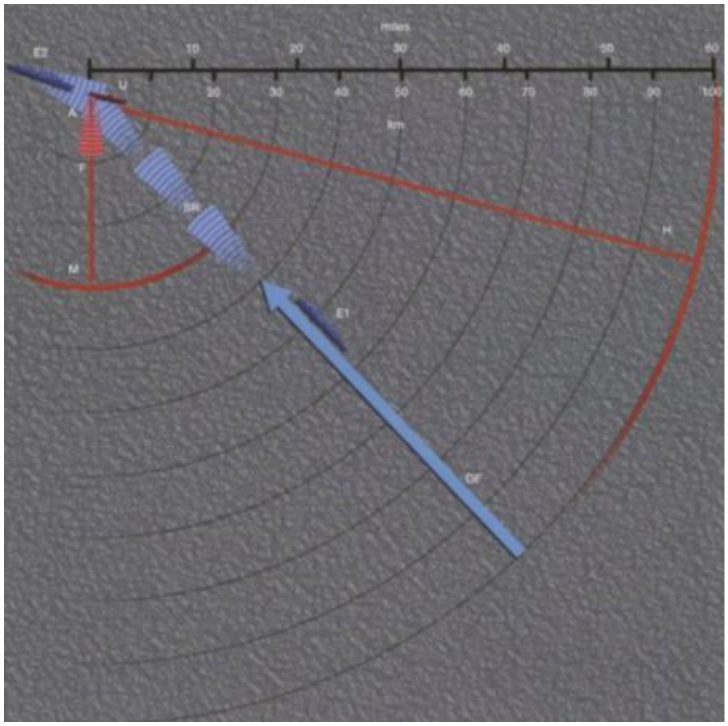


Figure 3.13 Typical effective range of detection equipment used by both U-boats and Allied escort warships in spring 1943 (Williamson 2010:51).

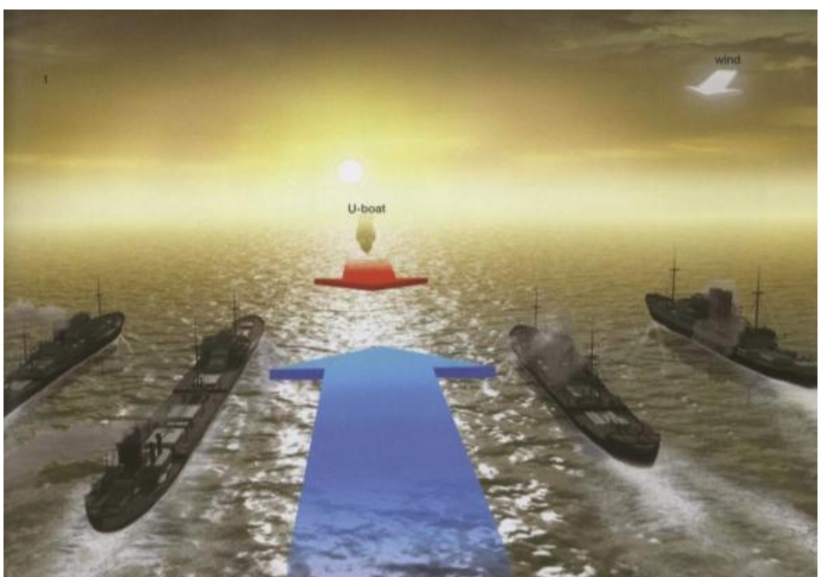


Figure 3.14 3D visualization of the ideal approach for an early morning encounter. This approach allows the U-boat to be concealed by the rising sun (Williamson 2010:11).

Final examples of advanced geovisualizations are found in recently published military atlases (Figure 3.15). These military atlases see a variety of more advanced cartographic design elements. Two works that highlight the majority of these advancements are Brian Reid's *The American Civil War* (2000) and James Bradford's *Atlas of American Military History* (2003). The maps contained in these atlases have a variety of 3D and pseudo-3D visualizations that highlight topography, troop position and basic elements of the physical landscape such as trees, buildings and road networks.

Figure 3.15 3D styling found in a map atlas of the Civil War (Reid 2000:171).

One final source of advanced artistic representations that is worthy of discussion are the products developed by the mass media for entertainment purposes. A prime example of this type of visualization is *Silent Hunter V: The Battle of the Atlantic* video game (Ubisoft 2012

Entertainment). In this game, players can command German U-boats and are faced with key decisions that could ultimately lead to different outcomes of real naval encounters. These products, with their very impressive realism, provide the scholar with little ability to interpret actual events (Figure 3.16).

Figure 3.16 Screenshot from *Silent Hunter V: Battle of the Atlantic* video game (Ubisoft 2010).

Conclusion

Advanced visualizations and geovisualizations are found in a variety of academic disciplines. These visual products often blur the boundaries between these various disciplines and often aid in the interpretation of data. While geography was an early adapter to the use of advanced visualization techniques, it is certainly not alone in their utilization for both scientific and analytical use, and for communicative and educational use. Terrestrial archaeology has a long-standing tradition of advanced visualization and geospatial visualization techniques. Maritime archaeology also utilizes a variety of advanced visualization techniques; however, they tend to be less focused on the geographic elements and place emphasis on ship reconstruction. Finally, history also utilizes a variety of advanced visualization techniques. These disciplines are not the only ones that utilize these techniques. Various other academic and scientific realms make use of the strong analytic and communicative properties of advanced visualizations; however, the above-mentioned areas were covered in detail due to their close relationship and influence on the potential avenues for visualization in regards to naval battlefields.

Chapter 4 : METHODOLOGY

Introduction

The process necessary to answer the research questions outlined in Chapter 1 consisted of four stages. The first stage was an in-depth examination of historical representations of battles. The purpose of this investigation was to accumulate and assess historic battlefield visualizations and to develop a baseline in regards to visualizations of these battles. The second stage of research examined various advanced visualization techniques in other disciplines and assessed their compatibility with naval battlefield mapping. The third stage utilized the most appropriate forms of advanced visualizations to develop alternative visualizations of both short-term and long-term naval encounters. This stage used the battle of Convoy KS-520 as a short-term case study. The second case study focused on the long-term evolution of the North Carolina Battle of the Atlantic Theater. The fourth and final stage of the research utilized various spatial statistical models to extend the analysis of the previous applications of advanced geospatial visualizations. Each stage will be discussed in detail below.

Historical Representations of Battlefields

The research from Chapter 2 was used in the development of the historic visualization baseline and was a necessary component of comparison. Establishing this baseline required the examination of previous visualizations spanning a period of over ten thousand years. While the visualizations that were most important in the analysis and development of the baseline came from the end of the period surveyed, the preceding millennia of representations were needed to provide context. The assessment of these visualizations provided the necessary framework for the comparison that allowed for trend and thematic analysis.

Key elements that related to accuracy, scale, temporal annotations, use of color, and inclusion of explanatory text were the primary focus of the historical investigation. The patterns and trends that emerged from the comparison provided the framework for the second and third phases of this thesis, by addressing key deficiencies that may hinder interpretation. The trends noted in the comparison also highlighted the differing approaches utilized between the historian and the archaeologist. Arguably, the historian and archaeologist are attempting to tell the same story utilizing a different combination of primary sources. This may lead to different interpretations and, as a result, there is the possibility of different visualizations. Ideally, the combination of the historical and archeological record, with advanced geospatial analysis, will allow for better interpretations of the past events.

Partitioning of Historic Battlefield Visualizations

The historical investigation was broken down into three major periods. The rationale behind this decision was based upon two main factors. The first was the availability of primary and secondary sources. The first period examined spanned from the Neolithic period, approximately ten thousand years ago, through the Medieval period. The battlefield visualizations produced in this period are often isolated snapshots and may be the only example for hundreds of years to come. This is in part due to the survivability of these visualizations. As a result, secondary sources were the primary means for data collection. The second period that covered the Renaissance, provided more examples, and as a result allowed for more data collection from primary sources. The third and final period, which covered the eighteenth century onward, provided the most examples. Considering it is the most contemporary period, more primary sources existed, and were therefore used in greater numbers.

The second main factor in the division of the historical investigation was based upon the total number of surviving examples in each period. An attempt was made to balance the total number of sources examined. While one could argue that the Prehistoric and Ancient battlefield-mapping period should have been broken down into smaller blocks, but the total number of surviving visualizations would be insufficient to gain meaningful insight. Finally, while this was not part of the original rationale, it later became apparent that each of the periods had similar themes and visualization styles. This allowed for better comparison between each period and, ultimately, better analysis.

Primary Sources

The access to primary sources greatly depended upon the period examined, as previously noted. Unfortunately, the majority of the sources until the later periods came from secondary sources. Whenever possible, however, primary sources were utilized. The majority of the primary sources came from online digital displays from traditional museums or scanned collections from university libraries. This proved to be an excellent resource for examining historical documents and visualizations that are now on display at museums.

One such source that proved to be essential in the collection of primary sources for the early nineteenth century was the HathiTrust Digital Library (http://www.hathitrust.org). According to the HathiTrust website, it is “a partnership of major research institutions and libraries working to ensure that the cultural record is preserved and accessible long into the future. There are more than sixty partners in HathiTrust, and membership is open to institutions worldwide” (HathiTrust 2012). The online collection has thousands of documents and has provided over 400 published maps from the nineteenth century for this analysis.

Other online sources provided specific examples of battlefield visualizations necessary to complete the analysis. The United States Library of Congress, Geography and Maps Division provided high resolution scans of Augustin Ryther’s visualizations of the Battle of the Spanish Armada. The ability to view this source in a high-resolution digital format allowed for greater analysis than had been previously done based upon examinations of reproductions in print. In addition, the previously examined print reproductions found in Martin and Parker (1999:147) and Worms (2007:1703) only provided one example of the eight total engravings. This allowed for greater analysis of the engravings and the identification of key themes within the series. For the most contemporary periods, recently published books were utilized in this examination. While the information used in the creation of the maps may have come from previous battles or secondary sources, the maps themselves are the objects of study, and unless they are noted as reproductions, they can be considered primary sources.

Secondary Sources

The majority of the sources for the prehistoric and ancient battlefield visualizations, as well as the Renaissance period, came from secondary sources. This was primarily done because of the low survival rate of these sources, and therefore their limited access. For the prehistoric and ancient period, anthropological and archaeological texts were key in the examination (e.g. Spalinger 2005). With the origins of war came the origins of battlefield visualizations. Therefore, texts relating to the topics of the origins of war were examined first (e.g. Keely 1996). From this point to the end of the medieval period, texts were chosen that highlighted the advancements of warfare.

With the development of written histories also came the availability of historical texts. Much like the selection of anthropological and archaeological texts, the historical texts selected were those that discussed general trends in warfare through the period. The selection of these general texts allowed for analysis of these trends and their impact on the creation of battlefield visualizations.

The Renaissance period brought with it not only a marked increase in cartographic techniques, but also an increase in those relating to warfare. This combination of events resulted in a proliferation of battle maps. The cartographic history of the Renaissance has been covered in detail by the two part edited works of David Woodward, *The History of Cartography: Cartography in the European Renaissance* (2007). The primary focus of this work is of cartographic advancements made during the Renaissance, and not on battlefield mapping; however, it still provided many military maps for analysis. Similar to the procedure taken with the prehistoric and ancient periods, various other written works relating to the advancements of military technology were examined. This provided the context for which all of the innovations within the realm of battlefield mapping occurred.

Analysis

Analyses of the primary and secondary sources were primarily qualitative in nature. The process for each battlefield visualization examined included three stages. The first stage determined if the battlefield map was appropriate for advanced and geospatial visualization. The second stage used was the data collection stage. With each of the battlefield visualizations organized and analyzed on an individual level, the third stage consisted of an examination for central themes and trends, and their cartographic elements compared to those outlined by Dr. Cynthia Brewer in her book, *Designing Better Maps: A Guide for GIS Users* (Brewer 2005).

The first stage of the analysis of the historic battlefield representations was aimed at identifying appropriate battlefield visualizations. While this may seem like a relatively straightforward task, when there is a large continuum of battlefield visualizations, it becomes complicated. Some of the representations were more appropriate for this analysis than others. For example, some products analyzed clearly depicted elements of battle; however, they were determined to be too artistic in nature and not appropriate for this analysis (Figure 4.1). While Figure 4.1 may have qualified for analysis in an early period, since this visualization came after the artistic schism, it was not included in the analysis.

Figure 4.1 Woodcut of the Battle of Landsknetchs, 1530 (Hale 1990:Plate 220).

Once a visualization was identified as being worth further analysis, the secondary stage began. For this stage, an instrument was developed in order to maintain consistency. This instrument was a form (Table 4.1), which was linked to a database for future descriptive analysis. This descriptive analysis allowed for the identification of key trends throughout the dataset, which spanned all three periods. The key variables contained in this instrument included: battle period, visualization media, the presence of scale information, use of color, perspective, the inclusion of a time element, and the presence of associated explanatory text to aid in map interpretation.

ID		**Map Name:**	
		Map Creator:	
Map Date:		**Battle Date:**	
Battle Name:			
Period:		**Media:**	
Ancient	☐	**Scale:**	☐
Renaissance	☐	**Color:**	☐
Modern	☐	**Time Element:**	☐
View Point:		**Associated Text:**	☐
Profile	☐	**Comments:**	
Ortho	☐		
Birds Eye	☐		

Table 4.1 Historic Battlefield Instrument.

The instrument had an associated data dictionary (Table 4.2). The purpose of a data dictionary is to define each variable in the instrument, and the data types and values used for storing this information in a database. This information is critical when disseminating the database and increases the transparency of the research.

Once the first two stages were completed, it was then possible to start analyzing these visualizations as part of a larger body of data. Analysis now shifted to the investigation of key themes. To identify these key themes, basic analysis was conducted. The purpose of this analysis was to determine the period in which certain key developments occurred. To accomplish this, a series of charts were developed and trends were noted. Finally, the cartographic elements were examined and compared to Brewer (2005). Issues such as poor use of color, confusing symbology, and improper use of scale are discussed in great detail in Brewer's book, in addition to tips and techniques on overcoming common cartographical shortcomings.

Variable	Description	Data Type	Data Values/ Example
ID	Unique identifier for each map in the analysis	Integer	1 - 500
Map Name	The name of the map, given to it by the map creator	String	Ex: The Battle of Waterloo
Map Creator	The person cited with the creation of the maps	String	Ex: John Booth
Map Date	The date the maps was first published or created	String	mmddyyyy
Battle Name	The name of the battle depicted in the map	String	Ex: The Battle of Waterloo
Battle Date	The date of the battle depicted	String	mmddyyyy
Period	Which of the three study periods the map was created in	Integer	Ancient =1 Renaissance = 2 Modern = 3
View Point	Denotes the viewpoint of the map	Integer	Profile = 1 Orthogonal = 2 Isometric = 3
Media	What media was used in the original production of this map	String	Ex: Wood cut block print
Scale	Was scale information included in the map?	Binary	No = 0 Yes = 1
Color	Was color used in the map?	Binary	No = 0 Yes = 1
Time Element	Was a series of events depicted in the map?	Binary	No = 0 Yes =1
Associated Text	Was there accompanying text, explaining the events of the battle?	Binary	No = 0 Yes =1
Comments	Additional information regarding the map	String	Ex: Excellent visualization

Table 4.2 Data Dictionary for the Historic Battlefield Instrument.

Examination of Advanced Visualization Techniques and their Compatibility with Naval Battlefield Interpretations

The second stage of this research examined various advanced and geospatial visualization techniques in other disciplines. The purpose of this examination was to accumulate and assess potential techniques that were well suited for use in both the cartographic representation and analysis of historic naval battles. The process of identifying these well-suited techniques was straightforward. First, the disciplines most closely related to mapping naval battlefields were identified. Second, the literature within those disciplines was systematically examined for techniques and trends relating to advanced and geospatial visualization. Finally, those key trends were assessed in terms of visualizing naval battlefields.

Mapping Naval Battlefields and Associated Disciplines

Historians and archaeologists routinely study and analyze naval battlefields, resulting in various interpretations of past events. The means by which they analyze these events typically involves an examination of the historic and archaeological record and, more recently, the utilization of GIS techniques. These are not the only disciplines, however, that have resources and techniques that can benefit naval battlefield mapping. Geography, for example, is a discipline that utilizes a great variety of advanced and geospatial visualization techniques that are easily transferable into naval battlefield mapping.

Ultimately, four academic disciplines were identified as being most closely related to naval battlefield mapping. The first discipline examined was Geography. Following Geography was the systematic investigation of Terrestrial Archaeology, which was then followed by the sub-discipline of Maritime Archaeology. Finally, the discipline of History was examined. In addition to these four academic disciplines, a fifth and final area was examined: mainstream media, which includes video game visualizations.

Literature Review

Following the identification of the four academic disciplines and the inclusion of the fifth mainstream media category, each was in turn examined for potential techniques that could be utilized in visualizing naval battlefields. The primary source for information for Geography, Terrestrial Archaeology and Maritime Archaeology were peer-reviewed scholarly publications in leading journals for each respective discipline. Another great resource for this stage of the literature review was published books from seminar studies and other leading scholars. These offer metanarrative level analysis from leading scholars in the disciplines. Maritime archaeology graduate theses were also examined.

The articles found in these leading journals fall into one of two categories. The first was review of technological trends within the disciplines. These articles are important because they highlight the transition from rudimentary visualization techniques to high-tech analytical visualization techniques. The second category of articles was those that focus on specific techniques. These articles are important because they highlight various strengths and weaknesses of each of the techniques in questions, and ultimately provided insight into the feasibility of incorporating them into visualizing naval battlefields.

Investigating mainstream media involved, first, a general survey of potential products. This was done by completing online searches of potential products. Once products were identified various media elements were examined. For example, *Silent Hunter V: The Battle of the Atlantic* (Ubisoft 2012) is a Second World War naval simulation game, in which participants take control of a German U-boat. Media elements examined for the game included promotional material, game play footage, and user reviews.

A similar approach was taken in the analysis of these examples. An instrument was created so that each component of the visualizations could be tracked and analyzed. Once again, the instrument was a form linked to a database (Table 4.3). This instrument contained five key variables which included the use of 3D technologies, the use of 3D technologies for analytical purposes, inclusion of animations, complex spatial analysis, and finally the presence of an interactive component. Additionally, a data dictionary was created to describe and provide examples of each of the key variables (Table 4.4).

ID		**Vis. Name**	
		Vis. Creator	
Discipline:		**Publication Date:**	
Geography	☐	**3D Usage:**	☐
History	☐	**Analytic 3D:**	☐
T. Archaeology	☐	**Animation:**	☐
M. Archaeology	☐	**Complex SA:**	☐
Publication Type:		**Interactive:**	☐
Journal	☐	**Scale:**	
Book	☐	Large	☐
Web Site	☐	Medium	☐
Other	☐	Scale	☐
Comments:			

Table 4.3 Advanced and Geospatial Visualization Instrument.

Analyzing Advanced and Geospatial Visualization Techniques for Naval Battlefields

Once the literature was reviewed trends were identified, and key techniques analyzed for their suitability in visualizing naval battlefields. Visualizing naval battlefields provides an interesting set of problems to overcome. Issues with the large scales experienced at sea and the dynamic nature of naval warfare in general had to be taken into consideration. With these special considerations in mind, each major technique was examined. For example, one technique identified was the use of a 3D hemisphere to represent the area sniper threat in an urban area (Figure 3.3). This representation provides many avenues for implementation within a naval battlefield context, ranging from visibility viewsheds, to displaying weapon range.

Variable	Description	Data Type	Data Value/ Example
ID	Unique identifier for each visualization in the analysis	Integer	1-25
Vis. Name	Name of the visualization	String	Ex: DC Metro Map
Vis. Creator	The person credited with the creation of the map	String	Ex: Washington MTA
Publication Date	The date the visualization was published	Date	mmddyyyy
Discipline	The discipline the visualization was published in	Integer	Geography = 1 History = 2 T. Archaeology = 3 M. Archaeology = 4
Publication Type	Where was the visualization published	Integer	Journal = 1 Book = 2 Web Site = 3 Other = 4
3D Usage	Does the visualization have usage of three-dimensional rendering?	Binary	No = 0 Yes = 1
Analytic 3D	Does the visualization use three-dimensional rendering for analytical purposes?	Binary	No = 0 Yes = 1
Animation	Is the visualization animated?	Binary	No = 0 Yes = 1
Complex SA	Does the visualization have some component of complex spatial analysis? (Ex: viewshed analysis)	Binary	No = 0 Yes = 1
Interactive	Is the visualization interactive?	Binary	No = 0 Yes = 1
Scale	What is the scale of the visualization?	Integer	Small = 1 Medium = 2 Large = 3
Comments	Additional information regarding the visualization	String	Ex: Good example of geovisualization

Table 4.4 Data dictionary for Advanced and Geospatial Visualization Instrument.

After the visualization techniques were examined, they were categorized to fit the type of naval encounter they were best suited for. In this study, as previously mentioned, there are two case studies which vary in both scale and duration, each having a different set of visualization techniques. One visualization technique may be better suited for the short-term case study, or vice versa. Some visualization techniques might be appropriate for both the short-term and long-term case studies.

Alternative Visualization Techniques for Naval Battles

After the first two stages of the research were completed, it was then time to implement the various visualization strategies. With a baseline established it was then possible to identify key deficiencies as they relate to naval battlefield mapping. In addition, closely related disciplines had also been analyzed in terms of potential visualization techniques for naval battlefields. With these two stages complete, it was time to take these key themes and create a new model based upon the critical assessment and apply them to both a short-term case study (KS-520) and a long-term case study (NCT).

Visualizing the Battle of Convoy KS-520

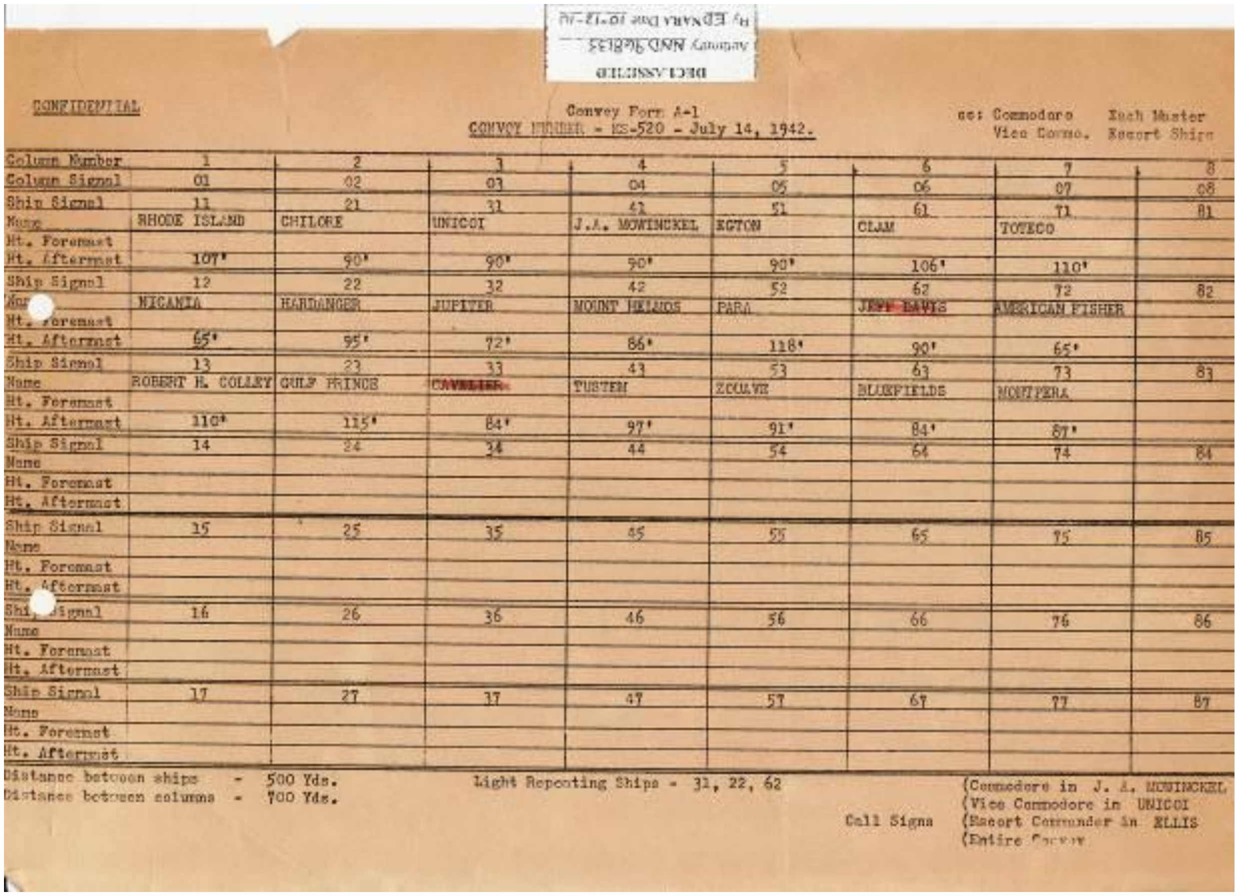
Given the access to archaeological/geospatial data and the opportunities for visualizations it affords, this naval encounter provides an excellent case study. In addition, substantial historical investigations provided a historical framework (Bright 2012). The Battle of KS-520 has also recently been the topic of a recent archaeological investigation. Researchers from East Carolina University, and the National Oceanographic and Atmospheric Administration's (NOAA) National Maritime Heritage Program (MHP) collaborated to fulfill the requirements for a National Park Service's (NPS) American Battlefield Protection Program (ABPP) grant (Bright et al. 2012).

Prior to the First World War, naval battles were typically limited to actions on the water's surface- whether that is on an ocean, lake, or river. These conflicts were essentially locked into a two-dimensional space, and operated on a plane. It was not until the Second World War that the three-dimensional battle was experienced, with surface vessels operating on the ocean, aircraft looking down from above, and the U-boat hunting from below. The Battle of Convoy KS-520 is one such example that was fought in a three-dimensional space and has the potential for heightened interpretations by visualizing it in a virtual 3D environment.

Three advanced geospatial visualizations were selected for the Battle of Convoy KS-520. The first visualization was a 3D viewshed analysis of Axis submarines versus the 3D viewsheds of Allied surface vessels and aircraft. Arguably, this 3D visualization will allow for a better understanding of the interactions between the KS-520 convoy and *U-576*. With the inclusion of various key terrain features such as bathymetry, and artificial navigation hazards such as the Hatteras minefield, a more complete understanding of this naval encounter is possible. The second 3D product was a view of the various fields of fire for the battle participants, which highlights the potential zones of conflict.

The final advanced visualization was a series of short 2D animations showing the attack progression though time. When adding a temporal dimension to visualizations, new interpretations or better understanding of the encounter is possible. Rather than relying on the human mind to make assumptions of the temporal progression through time, mathematical algorithms will be able to produce these animations based upon the battle constraints (i.e. speed of the convoy and torpedo). This results in more uniform interpretation.

The 3D visualization of the Battle of Convoy KS-520 consisted of two stages. The first stage was historical data collection and the second was the model creation and analysis. The historical information needed to create the advanced visualizations came from a variety of primary and secondary sources (Rossler 1989; Bright 2012; Bright et al. 2012). Some of the most helpful sources were declassified documents pertaining to the formation of the convoy and convoy spacing (Figure 4.2), and those that had information regarding vessel length, beam, and draft (Figure 4.3). Additionally, historic documents relating to the Hatteras Minefield were collected and digitized into a GIS data format (Figure 4.4).



CONFIDENTIAL

Convoy Form A-1
CONVOY NUMBER - KS-520 - July 14, 1942.

cc: Commodore Each Master
Vice Commo. Escort Ships

Column Number	1	2	3	4	5	6	7	8
Column Signal	01	02	03	04	05	06	07	08
Ship Signal	11	21	31	41	51	61	71	81
Name	RHODE ISLAND	CHILORE	UNICOI	J.A. MOWINCKEL	EGTON	CIAM	TOTECO	
Ht. Foremast								
Ht. Aftermast	107'	90'	90'	90'	90'	106'	110'	
Ship Signal	12	22	32	42	52	62	72	82
Name	NICANIA	HARDANGER	JUPITER	MOUNT HELMOS	PARA	JEFF DAVIS	AMERICAN FISHER	
Ht. Foremast								
Ht. Aftermast	65'	95'	72'	86'	118'	90'	65'	
Ship Signal	13	23	33	43	53	63	73	83
Name	ROBERT H. COLLEY	GULF PRINCE	CAVELIER	TUSTEM	ZOUAVE	BLUEFIELDS	MONTPERA	
Ht. Foremast								
Ht. Aftermast	110'	115'	84'	97'	91'	84'	87'	
Ship Signal	14	24	34	44	54	64	74	84
Name								
Ht. Foremast								
Ht. Aftermast								
Ship Signal	15	25	35	45	55	65	75	85
Name								
Ht. Foremast								
Ht. Aftermast								
Ship Signal	16	26	36	46	56	66	76	86
Name								
Ht. Foremast								
Ht. Aftermast								
Ship Signal	17	27	37	47	57	67	77	87
Name								
Ht. Foremast								
Ht. Aftermast								

Distance between ships - 500 Yds.
Distance between columns - 700 Yds.

Light Repeating Ships - 31, 22, 62

Call Signs
(Commodore in J. A. MOWINCKEL
(Vice Commodore in UNICOI
(Escort Commander in ELLIS
(Entire Convoy

Figure 4.2 Declassified information regarding formation of the convoy KS-520 (National Archives).

With the data from the primary and secondary sources, it was possible to reconstruct the location and spacing of the individual vessels in the convoy. Spatial modeling was used to place the position of the convoy in its appropriate position in geographic space at the time of attack. Bright et al. (2012) determined the position by taking the reported location of each of the vessels and collapsing them utilizing a line density function within GIS software. This resulted in the most accurate placement of the convoy based upon the best possible data. The results of this analysis can be seen in (Figure 4.5)

CONFIDENTIAL KS-520 JULY 14, 1942 (Sailing Date)

COMMANDER IN CHIEF U.S. FLEET RECEIVED 1942 JUL 15

SHIPS	HT. MAST.	CAR-GO	CON-VOY NO.	SPEED	NAT.	DRAFT	DESTINATION		GUNS
Sunk J.A.MOWINCKEL	90'	Bal.	41	11	T PAN	26'	ARU[illegible]	0500 10	31
UNICOI	90'	Valu.	31	9.5	F US	25'3"	NEW ZEALAND	0503	
LOTON	90'	Bal.	51	9.5	F BR	16'7"	SAN PEDRO DE MACORIS	0506	
Sunk CHILORE	90'	Coal	21	10	F US	24'	TRINIDAD	0509	
CLAM	106'	Bal.	61	9.5	T BR	20'	BEAUMONT	0512	
RHODE ISLAND	107'	Bal.	11	13.5	T US	21'6"	PORT ARTHUR	0515	
TOTECO	110'	Bal.	71	9.5	T US	18'	TAMPECO	0518	
MOUNT HELMOS	86'	Valu.	42	10	F GRK.	21'	ALEXANDRIA	0521	
JUPITER	72'	Gen.	32	10	F NETH.	19'	ARUBA	0524	
PARA	118'	Valu.	52	9.5	F NOR.	21'5"	BOMBAY	0527	
HARDANGER	95'	Valu.	22	10	F NOR.	23'6"	ALEXANDRIA	0530	
X JEFF DAVIS	90'	Valu.	62	9.5	F PAN.	25'	PERSIAN GULF	0533	
NICANIA	65'	Bal.	12	12	T BR.	20'	ARUBA	0536	
AMERICAN FISHER	65'	Bal.	72	10	T US	20'	CORPUS CHRISTI	0539	
TUSTEM	97'	Bal.	43	10	T US	18'	PORT ARTHUR	0542	
X CAVELIER	84'	Gen.	33	10	F BR.	20'	KINGSTON	0545	
ZOUAVE	91'	Bal.	53	9	F BR.	17'3"	FERNANDINA	0548	
GULF PRINCE	115'	Bal.	23	11	T US	21'4"	PORT ARTHUR	0551	
BLUEFIELDS	84'	Gen.	63	8.5	F NIC.	18'10"	HAVANA	0554	
ROBERT H. COLLEY	110'	Bal.	13	13	T US	25'	ATRECO	0557	
MONT PERA	87'	Lumber	73	9	F GR.	24'10"	CAPETOWN	0600	

19

COMMODORE - Capt. N. L. Nichols, USN (Ret).

VICE COMMODORE - Comdr. H. R. Sobel, USN (Ret).

ESCORT COMMANDER - Lieut.Comdr. L. R. Lampman, USN, in USS ELLIS.

X Did not get away

Figure 4.3 Declassified information regarding vessel information of convoy KS-520 (National Archives).

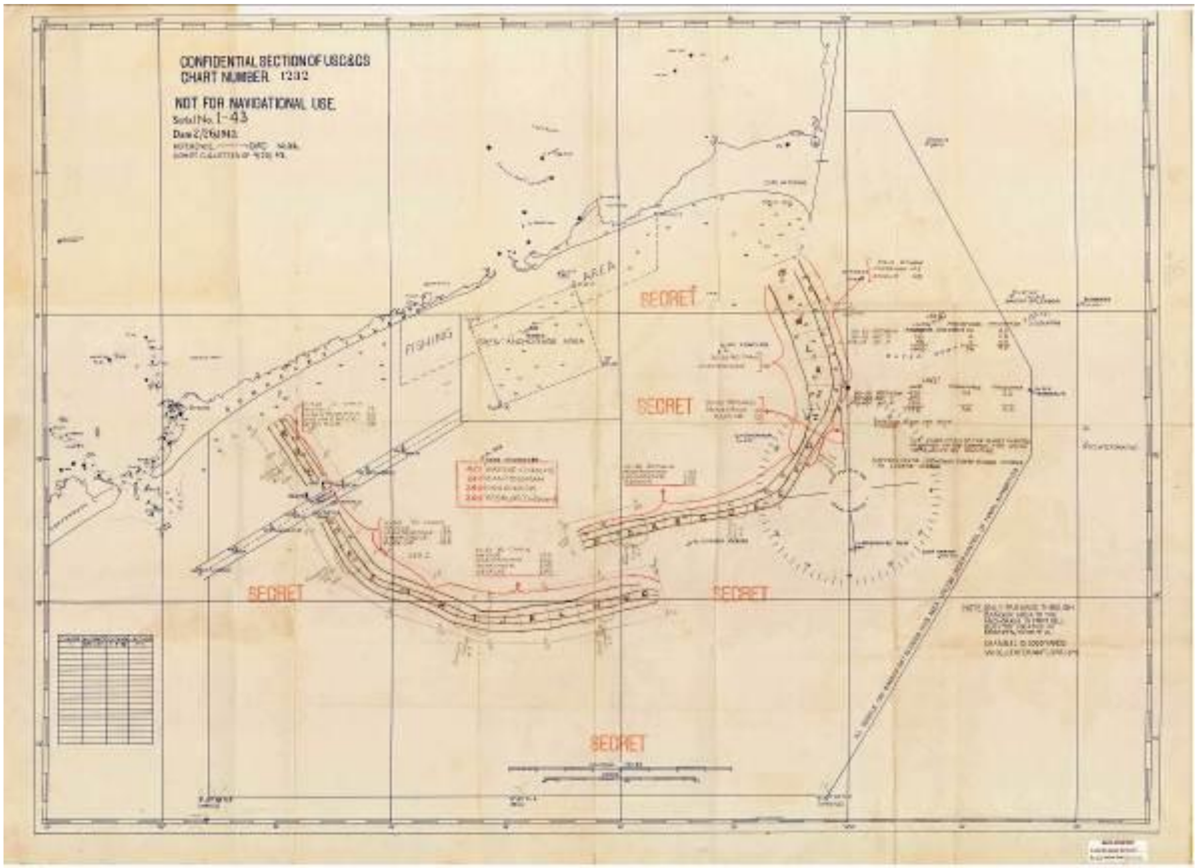


Figure 4.4 Declassified information regarding the position of the Hatteras Minefield (National Archives).

Following the analysis of the potential convoy location was the analysis of the U-Boat location at the time of attack. There are no surviving documents reporting the position of *U-576* at the time of attack, so a series of steps were taken to trace back the torpedoes fired to determine the location. First, the vessels identified as struck by torpedoes were highlighted. Then, based upon the speed of the torpedo and the speed of the convoy, the location of the second and third vessels struck were determined. This step was necessary since the torpedoes and the convoy vessels were moving through both time and space. Once the location of the vessel strikes was identified, a best-fit line was constructed to highlight the possible location of *U-576*. The best-fit line was created by utilizing an Ordinary Least Squares (OLS) regression model. In essence, an OLS regression is a means at examining the relationship between a response or dependent variable (Y) and the explanatory variable (X), expressed in the form of a line (Figure 4.6) (Craven and Islam 2011:224). These variables could be spatial or aspatial. An example of this analysis could be the relationship between cancer (dependent variable) and cigarette smoking (explanatory variable). In this situation, however, the OLS is not used to describe the relationship of two variables. It was adapted to plot a best-fit line utilizing the latitude and longitude of the vessel strikes. Since the torpedoes fire in a straight line it was possible to use the OLS regression model to fit a line through these points and trace back to the point of origin, *U-576*. This was possible because geographic space has both X-coordinates (Latitude) and Y-coordinates (Longitude).

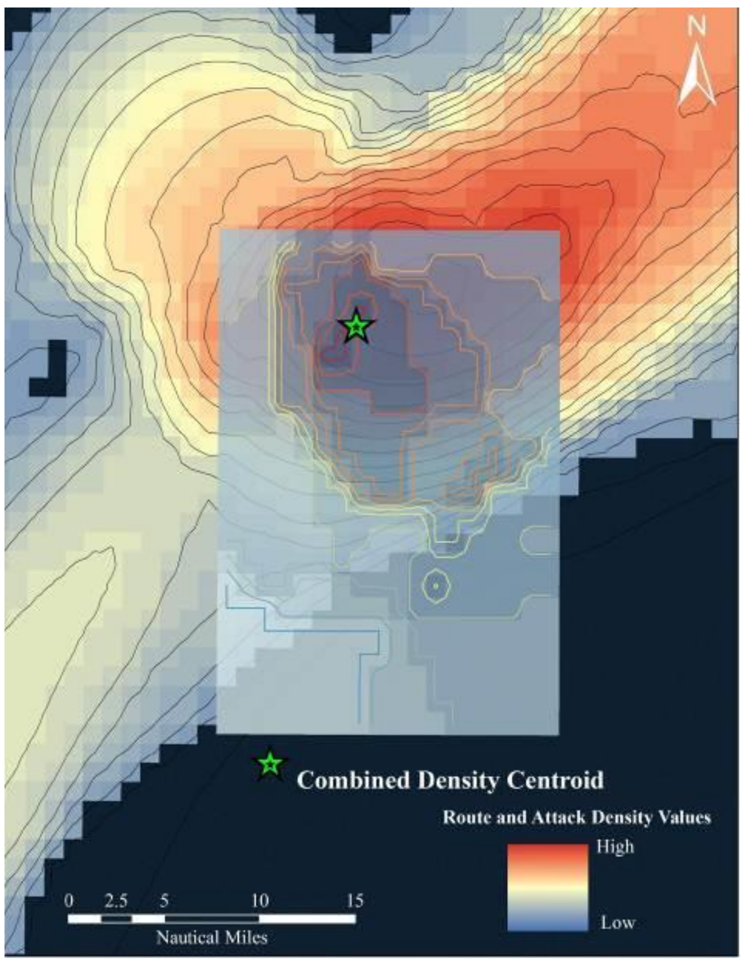


Figure 4.5 Spatial analysis techniques utilized to determine the probable location of the battle of convoy KS-520 (Bright 2012:77).

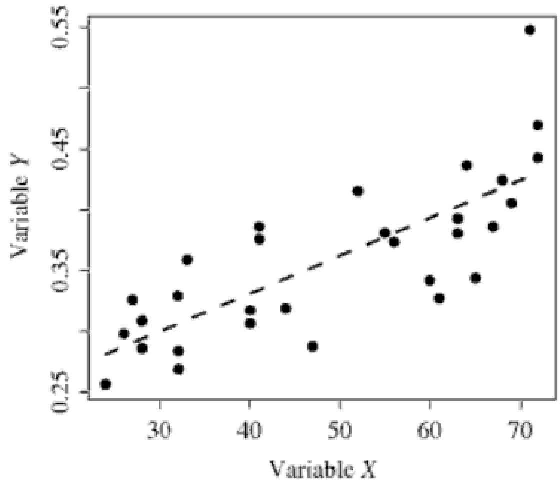


Figure 4.6 Example of an OLS regression (Craven and Islam 2011:224).

Once the location of the convoy and the possible location of *U-576* were established, it was then time to create additional advanced visualizations of the battle. Once again, drawing from the historical research of Bright (2012), escort zones were developed and each of the five escort vessels were positioned in the most appropriate geographic location. Additionally the zones for the air escorts were determined based upon the same historical research. Finally, the various fields of fire and viewsheds were created based on the historic record and placed in the visualization. In Table 4.5 is a summary of the data types used in the advanced visualization.

Layer Name	**Data Type**	**Source**
Convoy	Polygon	Declassified Historic Documents
Escort Vessels	Polygon	Declassified Historic Documents
Escort Zone	Polygon	Bright 2012
Air Escorts	Point	Historic documents
Hatteras Minefield	Polygon	Declassified Historic Documents
Bathymetry	Raster Surface	NOAA Coastal Relief Model
U-576	Polygon	Historic Documents
U-576 Attack Line	Line	Generated by author

Table 4.5 GIS Data Summary.

It was determined that animating the moments of the attack by *U-576* was one of the best options for visualization. Following the basic analysis, the 2D animation process began. First, the convoy location was moved “backwards” in time from the location of the attack based upon the 8 knot speed of the convoy. The location of the convoy approximately 10 minutes prior to the attack was used as a starting point for the 2D animation. From there an image was exported in one minute increments to the point of the *U-576* attack, followed by the subsequent 10 minutes.

Visualizing the North Carolina Theater of the Battle of the Atlantic

Following the visualization of the short-term case study is the visualization of the greater North Carolina Theater (NCT) of the Battle of the Atlantic, which serves as the long-term case study. This phase of the project built upon the research and previously created maps of Wagner (2010). One of Wagner’s visualizations had excellent potential for alternative visualizations. This visualization is shown in Figure 4.7, and highlights the movement of battle activities throughout the Second World War in the NCT. The alternative visualization technique entailed the creation of a 2D surface animation, as opposed to the static point-based map representations. By visualizing the data as a surface rather than a discrete value, and then adding a temporal dimension, it is hypothesized that additional minor hotspots of battle activities will become apparent, leading to a greater understanding of the NCT.

The rationale behind selecting a 2D animation for this visualization was based upon the temporal focus of the data variable. Whenever an image or visualization utilizes a temporal component, such as in the case of Figure 4.7, a 2D animation is an excellent advanced technique. This technique can possibly strengthen or perhaps alter the interpretations of long-term naval battlefield events.

To accomplish this, first the raw data used in the creation of Wagner's map was obtained. Then various spatial statistical tools found in *ArcMap* were used to convert the discrete locations of battle events into a surface, based upon the same time increments (months) utilized by Wagner. Each time increment, therefore, had a static image of U-Boat attack events represented as a surface, showing the continuum of events from high to low. These static images were then used in the creation of a 2D animation.

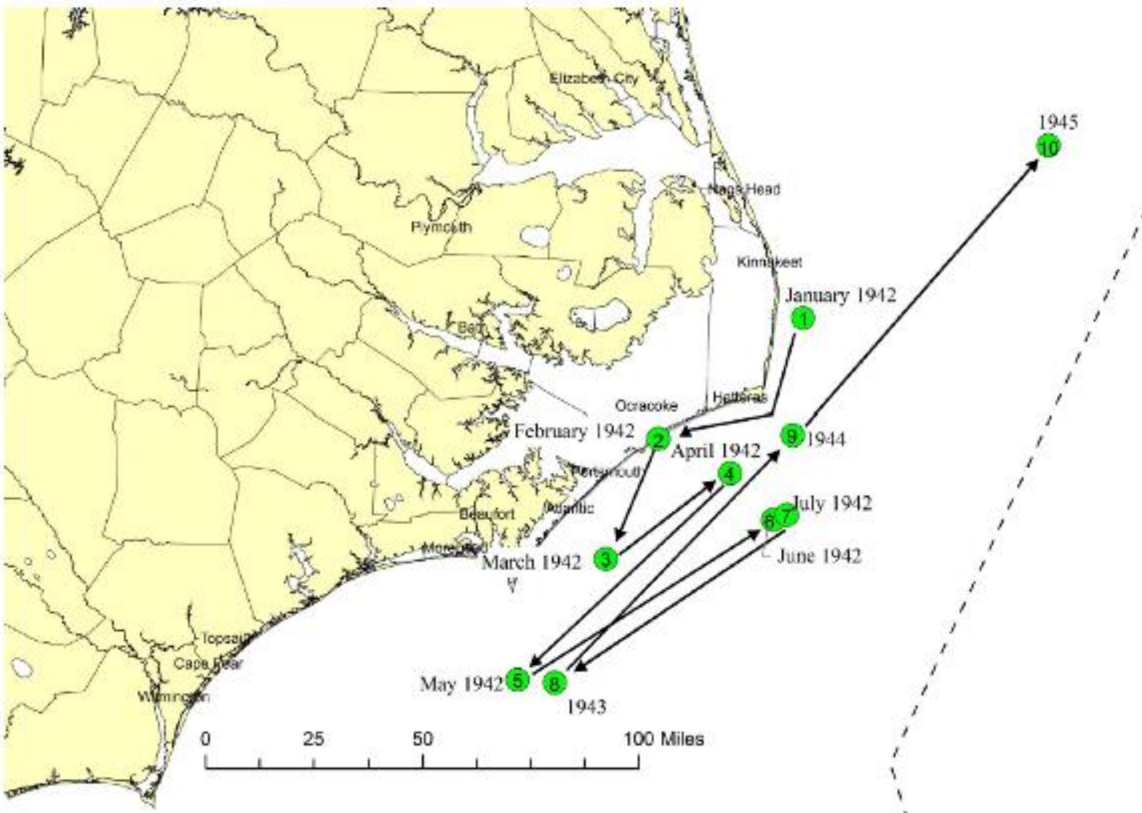


Figure 4.7 Centrality of Battle Activity Throughout the Second World War (Wagner 2010:162).

The dataset used in the creation of the previous example also allowed for additional visualizations. The second visual product created was another type of surface visualization. This time, rather than looking at the distribution of battlefield activities on a monthly basis, this same data was viewed in a cumulative surface. In the prior example, the data frame was "reset" and the information from the previous month removed. In essence, each frame of the animation only highlighted the battle activities for the given month. In this second example, the previous total battle activity was added to the current month's activity, which results in the cumulative surface variable. This allows for additional interpretations of the NCT. Once again, this type of visual product lends itself to animation, and an additional 2D animation was created.

Extension Through Spatial Statistics

The final stage of this research used advanced spatial modeling to extend the completed visualizations. Naval battlefields are prime candidates for statistical spatial analysis due to their inherently spatial and temporal nature. Geographic space is both enabling and constraining (Gotham 2003:724), and it is this dualistic idea of space that allows certain phenomena, such as a naval battle to occur. In regards to the NCT, there are physical constraints in the landscape such as the barrier islands, shoals, and the Hatteras Minefield where it would be, in some cases, impossible for a naval conflict to occur. Enabling aspects of space are elements of the battlefield landscape such as shipping lanes and water depth. The final visualizations for the NCT utilized spatial statistics to examine the battlefield landscape and identify various patterns in the naval conflicts as an aid to further interpretation of the theater.

Most of the analytical measures employed in battlefield analysis are qualitative in nature, leaving a significant opportunity for quantitative analysis. Elements of naval battles, such as key terrain features (bathymetry or distance to coastal landforms such as shoals and barrier islands) and cover and concealment opportunities (poor weather conditions or operations conducted under the cover of darkness), are prime candidates for spatial analysis. While battlefield historians and archaeologists typically consider these two elements essential in reconstructing battlefields, no examples in the current literature examine the potential spatial relationships between these elements for a particular battle, let alone an entire naval theater, within in a spatial statistical framework.

The steps used in examining the NCT, in terms of spatial modeling, were multifaceted and kept intentionally flexible. The first stage in the process was data examination. This initial stage was essential, as the results of this examination guided all further spatial modeling efforts. In this phase, elements of the dataset are examined and key variables were identified. After this stage was completed, it was then possible to determine which path of spatial modeling was most appropriate.

The desired option was to use the most robust forms of spatial modeling available. These methods are forms of multiple regression modeling, and initially there was hope that either binomial multiple regressions or multinomial multiple regressions would be possible. These types of statistical investigations, when used properly, produce excellent representative models of reality, are predictive in nature, and can serve as very powerful investigatory tools when examining spatial phenomena. The second option which is slightly less robust, however more flexible than the previous regression methodologies, is a technique called cartographic modeling. Cartographic modeling attempts to highlight spatial relationships between key terrain features, as opposed to a pure regression based modeling methodology.

Ultimately, the data proved to be unsuitable for the more robust forms of spatial modeling. This resulted in the alternative approach of cartographic modeling, which still provides insight into the various spatial correlations between the physical environment and U-boat attacks in the NCT. The results of this type of investigation produce a probability map and highlight the areas that contain physical characteristics most likely to result in attacks from German U-boats in the NCT.

The workflow for cartographic modeling contains five stages. The first stage identifies the key physical variables for use in the modeling. The second stage handles any data creation and preprocessing. The third stage normalizes the data for use in subsequent classification. The fourth stage is the data classification stage and the fifth, and final stage, is the creation of the probability surface. Each of these stages will now be examined in detail.

The first stage of the cartographical modeling workflow is the identification and categorization of potential physical variables. One such example might be bathymetry. The process of identifying key physical variables consisted of reading through previous naval battlefield literature and selecting the most suitable contributing physical elements to attack events in the NCT. Inspiration for these variables came from the two standard qualitative battlefield landscape approaches, METT-T and KOCOA analyses. Once the potential variables were identified they were categorized according to the methodology outlined in Walsh et al. (1990). In that methodology the authors utilized two main variable types, buffer distance variables (i.e. variables that are based upon a key feature such as a shore line, and with incremental distances buffered from the original feature) and factor weighting variables (i.e. spatial variables that are continuous in nature, and do not originate from a particular key feature). The identified variables were then categorized according to the outlined parameters (Table 4.6).

Variable Name	**Data Type**	**Units**	**Category**	**Data Source**	**Comments**
Depth	Raster	Meters	Factor Weighting	NOAA Coastal Relief Model (CRM)	Bathymetry/Water Depth
Slope Angle	Raster	Degrees	Factor Weighting	User Created	Slope angle of bathymetry
Shore	Raster	Meters	Buffer Distance	User Created	Euclidian distance to shoreline.
100_Fathom	Raster	Meters	Buffer Distance	User Created	Euclidian distance to 100 fathom curve.

Table 4.6 Key physical variables for use in cartographic modeling.

The second stage of the cartographic modeling workflow is the actual creation of the variables and data preprocessing. As with many GIS projects, data often must be manipulated in order to form new data products for use in analysis. Specific variables that were created were slope, distance to shore, and distance to the 100 fathom curve. The only variable that did not have to be created was the depth variable, which was obtained from the NOAA Coastal Relief Model (CRM). Once the variables were created they needed to undergo preprocessing in preparation for data normalization. Each variable was then divided into zones based upon the unit of measurement (Table 4.7).

Variable Name	**Classification Zones**
Depth	250 meters
Slope Angle	5 degrees
Shore	10 nautical miles
100_Fathom	10 nautical miles

Table 4.7 Cartographic modeling variable classification zones.

The third stage involved the data normalization, which standardizes units for analysis. Walsh et al. notes the importance of this stage based upon the assumption that data bias might exist "because of the relative abundance or paucity of sites [attack events] within the study areas" (Walsh et al. 1990:619). To accomplish this normalization, two steps were taken. The first step took the area of the study area and divided by the area of the particular zone. The second step takes the number of attack events per zone and divides that value into the previously obtained value. The results of these calculations are found in Chapter 6.

Once the data was normalized, it is then classified based upon the two categories of factor weightings and buffer distances. The factor weightings categories are each classified based upon a histogram equalization methodology, which resulted in choosing three separate classes. The buffer distance variables are classified into five separate classes based upon the natural breaks methodology. Both of these classification methodologies attempt to produce categories with a similar number of observations to avoid overrepresentation in a given class. With the variables normalized and classified, it is now possible to combine them into a probability surface.

The final step in the cartographic modeling process is a simple addition of all the previous data variables within GIS. The result is a raster dataset with unique values based upon the underlying physical variables. Due to the normalization and classification process completed previously, the values can then be classified into additional classes if necessary. This final raster dataset is the probability surface that shows which physical characteristics of the environment are most suitable for U-boat attacks to occur.

Challenging Aspects of Battlefield Visualizations

Throughout the research, and with implementation of the new methodologies based upon critical assessment of previous examples, various challenges were encountered. These challenges can be grouped into four basic categories. The first category is challenges with the collection of historic maps. The second category is challenges associated with lack of supporting documentation for the reconstruction of the battlefield. The third category relates to technical challenges associated with the software packages used. The final challenge related to data acquisition and preparation problems for the spatial modeling of the NCT.

While conducting the accumulation and assessment of historic battlefield visualizations, two main problems arose. The first was that of under representation from the prehistoric and ancient period. Due to the lack of surviving examples, there were times in which few, if any, examples of battlefield visualizations existed. Sometimes these gaps can cover hundreds of years. Little can be done to overcome this problem.

The second issue related to the collection of visualizations from the modern period. One of the more useful sources of battlefield visualizations from this time were the scanned documents available online through major research institutions, such as HathiTrust Online. One disadvantage of this type of source is the secondary importance placed upon the maps by the individuals digitizing these historic works. Frequently that these published works had foldout maps, and when the book was digitized, the map was not fully unfolded, or just poorly scanned (Figure 4.8). Occurrences like this were relatively frequent and proved frustrating. Attempts were made to locate alternative sources for these documents; however, that proved impossible for many old texts. Many of these maps were too obscured for use in the analysis.

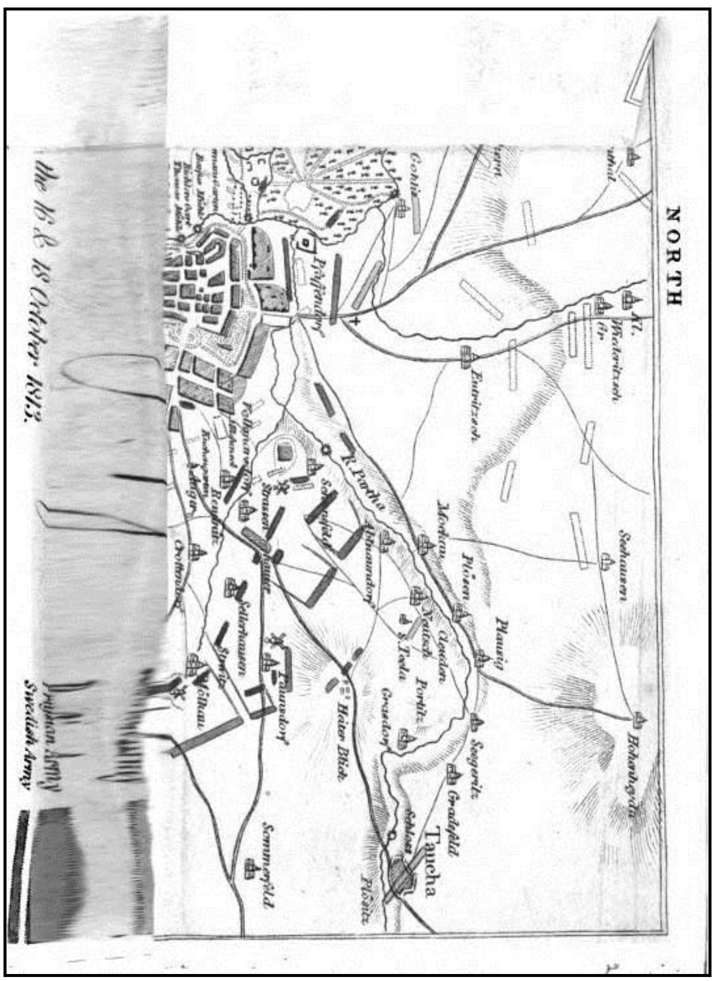


Figure 4.8 Example of poorly scanned map from the mid-nineteenth century (Shoberl 1814:105).

The second category of challenges concerned the availability of historic data containing the case studies when constructing the new advanced visualizations. The main issue was with infrequent or inaccurate reporting of vessel location. The escort vessel of convoy KS-520, for example, only reported their location three times daily and therefore their exact location at the time of attack is unknown. This issue was solved by creating digitized patrol zones for the convoy, and placement of each of the escort vessel in a possible location within that zone. Problems with inaccurate reporting were frequent with the convoy vessels themselves. When the locations were plotted, the distance between the vessels were up to 50 nautical miles apart (Figure 4.9), a distance much farther than the 700 yard guidelines listed in the historical documents (Figure 4.2). It is therefore assumed that vessel reporting was inaccurate. To overcome this, basic line density functions in *ArcMap* were used to create the best possible, and most likely convoy route.

The final challenge encountered during the study relates to data acquisition for the spatial modeling component. This is a common problem when working with data from a variety of sources. Unfortunately this issue is compounded when working with marine data, as these sources are not updated as frequently as their terrestrial counterparts. When working with multiple data sources, sometimes the spatial resolutions are not the same, which impact the outcome of the analysis. If this situation is encountered, the high-resolution data must be resampled to the level of the coarse data. Other times, as was in the case of this study, the spatial extents for the various datasets are not the same. This provides difficult challenges to overcome. Sometimes it is possible to locate additional sources for the missing data, while in other circumstances, no alternative data sources exist.

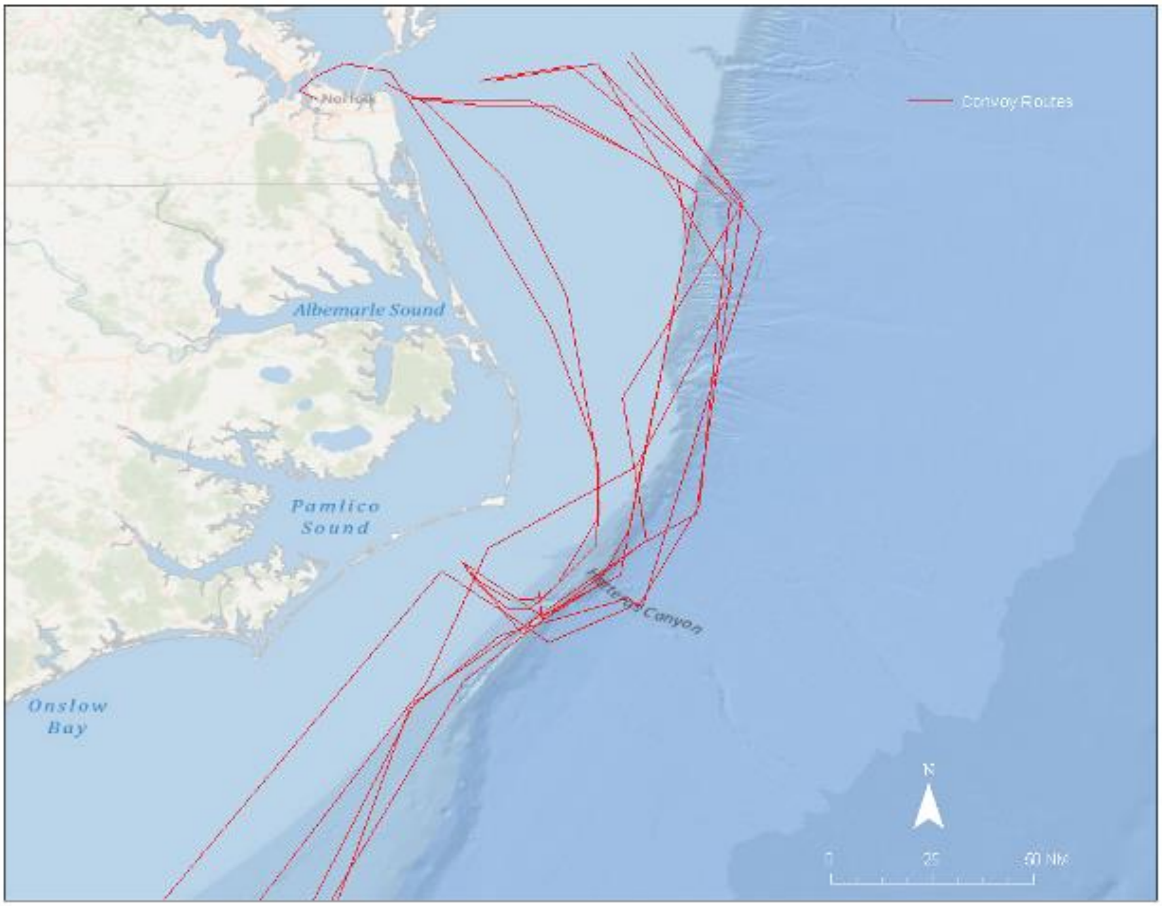


Figure 4.9 Convoy routes highlighting the inaccurate reporting of location by the individual vessels (Source Bright 2012; Drawn by Author).

In this study there were specific problems with mismatched spatial extents. The most problematic datasets were those for bathymetry. In Figure 4.10, the battle events for the NCT are overlaid with the spatial extents of two separate bathymetry data sources. The area of purple is the region that demonstrates where both datasets offer coverage. While the areas in blue, or red, represent areas where only one dataset offers coverage. Additionally, there are eleven attack events for the NCT that are only covered by one of the datasets, and four attack events excluded from both datasets. Unfortunately, there are only a few possibilities for bathymetric data, and ultimately the NOAA CRM bathymetry data was selected.

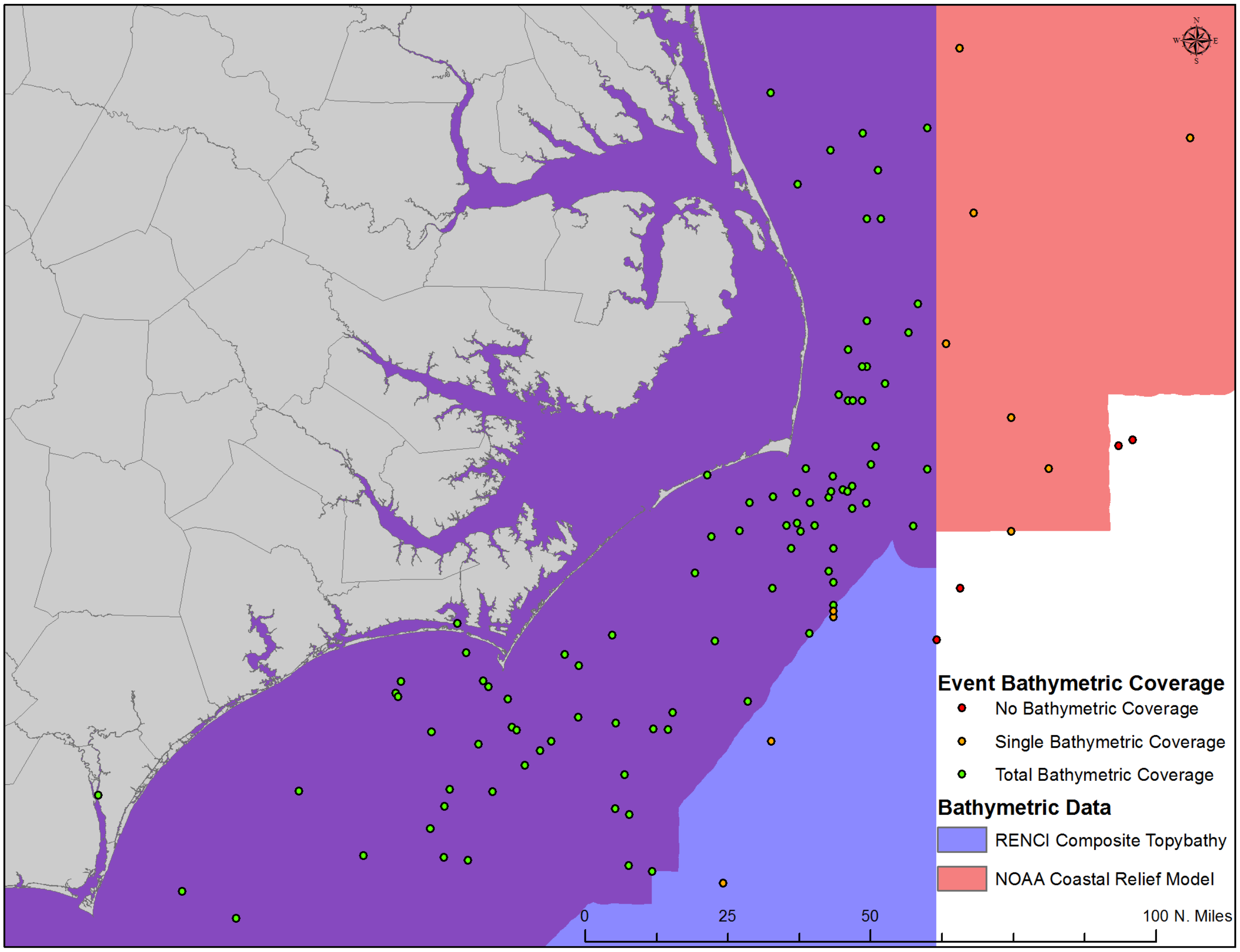


Figure 4.10 Bathymetry sources for the NCT (Drawn by Author).

Even when coverage appears to be adequate, data type becomes another potential issue. One of the factor weighting variables for the cartographic modeling component of the study was benthic slope angle. It was hypothesized by the author that German U-boats would choose to hunt in areas with higher slope values, indicating a U-boat commander's desire for access to deeper water. When the above-mentioned data sources were examined, however, they were all based upon the same source data and are essentially rasterized forms of contour data. When the slope is calculated for the data, the output mirrors the original source contour data, and no meaningful slope values are obtained. Rather than representing the ocean seafloor as a smooth surface, it is seen as a series of abrupt ridges (Figure 4.11). Since the bathymetric data is sourced from NOAA hydrographic surveys, this type of issue was seen time and time again. Ultimately this resulted in additional preprocessing to obtain the factor weighting variable slope. To overcome this issue, the raster grid was converted to a point feature class and re-interpolated using a technique called Inverse Distance Weighting (IDW). This allowed the slope calculation to be completed and render the desired results. The major disadvantage of this process was the time involved in reprocessing the data. Hopefully, as surveying equipment and the computation power of computers increases in the future, better and more flexible data sources will become available.

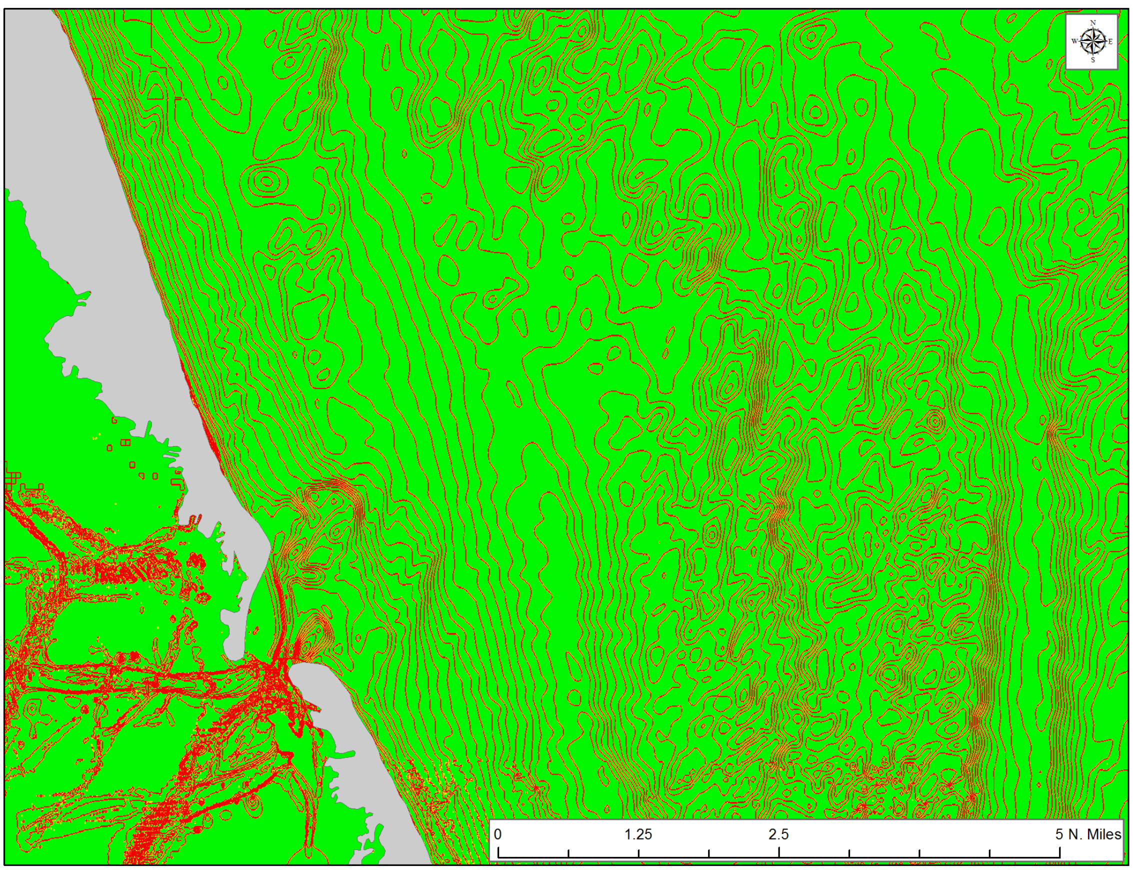


Figure 4.11 Contour artifacts found in NOAA CRM bathymetric data after the slope calculation (Drawn by Author).

Chapter 5 : HISTORICAL ANALYSIS AND APPLICATION OF ADVANCED VISUALIZATION TECHNIQUES TO NAVAL BATTLEFIELDS

Introduction

The development of battlefield visualization from the ancient to modern period has been a long, on-going process. As new technologies developed, they slowly made their way into the process known as battlefield mapping. These new technologies often come from outside disciplines, which share a common theme with cartography and visualization. To better understand which technologies in these ancillary disciplines are best suited for the next generation of battlefield mapping, an in depth analysis of both the history of battlefield visualization and the advanced techniques is required.

To accomplish this, two instruments were created to assess the battlefield visualizations, and geospatial visualization techniques. The purpose of this analysis was to identify trends and locate potential deficiencies in the battlefield mapping. One trend that has been noted for over thirty years is the secondary role placed on battle maps to text. One of the most substantial critiques of battlefield mapping was published by Harley et al. (1978), titled *Mapping the American Revolutionary War*. In this book, the authors focus on the importance of military mapping during the American Revolutionary War, and the published maps and surveys that followed. This work is particularly important to this survey becasue it explores a time in which the modern military map matured. Prior to the Revolution, the modern battlefield mapping approach was still developing, and by the end of the war, it fully developed.

The critiques offered in the book stem from references as far back as 1899, when the authors note the concern that a prominent military historian, J.W. Fortescue, had for battlefield maps. Harley et al. note that, "in the 1899 preface to his [J.W. Fortescue's] thirteen-volume history of the British army, reports that he found battle maps unclear and misleading. He included them in his book, however, because others thought he should have them" (Harley et al. 1978:135). Throughout the last chapter of the book, Harley et al.'s theme is clear, battle maps tend to be unclear and take a secondary role in publications. Their analysis is condensed into two main points:

> (I) That authors and mapmakers evidence little regard for maps as data, as sources of documented and documentable information; and (II) that they also evidence little regard for the meaning of maps, or for the communication of that meaning to readers and viewers. Both these characteristics have their origins in one fact: mapping has been secondary or peripheral to the development of text. With few exceptions, there have been no professional cartographers involved in the making of maps (Harley et al. 1978:139).

Furthermore, the authors note that a few essential questions must be considered before maps are included in publications. First, what is the purpose of this map? Second, what additional information will this map impart on the reader? Finally, what information or data lends itself to visualization? These questions are essential when creating any map and perhaps are even more essential when considering the complexities of battlefield cartography.

Unfortunately, the advice offered in Harley et al.'s publication was not heeded. It seems that, in the decades that have passed since publication, battlefield maps are still an afterthought attached to the body of text. The majority of contemporary battlefield maps violate some or all of the basic tenants of map design. Hence, an attempt to identify other potential avenues for visualization, advanced and geospatial visualizations in other disciplines were carefully examined, in hopes that some of their methodologies could be applied to battlefield mapping. The remainder of this chapter outlines an analysis of key trends within battlefield mapping and analysis of the developments in ancillary disciplines. Once the changes are analyzed and the most appropriate advanced and geospatial techniques are determined, an attempt to integrate the results of the previous analysis into new battlefield products occurred.

Ultimately, two new products were produced based upon the critical assessment of the historical trends in battlefield mapping and the advancements in other associated disciplines. Both of these products used the Battle of KS-520, a short-term naval encounter from the Second World War, as a case study. This battle was selected due to the existing body of research and the elements of the battle were well suited for these advanced and geospatial visualization techniques.

The first product is a 2D animation of the events before and during the attack on convoy KS-520 by the German U-boat *U-576*. Given the short duration of the event, and the relatively small geographic scale, a 2D animation aids in the interpretation of the events leading up to the sinking of the German submarine. The second product of the KS-520 case study is a 3D snapshot of the battlefield landscape. This product highlights the various 3D viewsheds and areas of attack. Given the three-dimensional nature of a modern naval battle, this visualization is essential when examining an event of this manner. Both of these products were designed not only to help informed individuals in interpretations of the events, but may also make battlefield mapping more accessible to the public.

Analysis of Battlefield Visualizations through the Ages

For centuries, the battle events have been mapped by many peoples and for a variety of rationales. Over the course of history, the styles and techniques used in battlefield mapping have also changed. Prior to implementing new techniques into battlefield mapping, an understanding of the previous efforts must be gained. In an attempt to gain this understanding, an instrument was developed (Table 4.1). This instrument was used to analyze each subsequent battlefield visualization in an attempt to identify trends and deficiencies.

A total of 532 maps and visualizations were examined, and of that number, 95 were determined appropriate for analysis by the instrument (Appendix I – History of Visualization Dataset). Of those 95 battlefield visualizations, the majority of them came from the modern era. From each era, most were terrestrial battles. This is not surprising as the survivability of earlier visualizations is a key issue. In all, 55 maps that came from the modern era, 23 Renaissance and 17 ancient visualizations were analyzed (Figure 5.1).

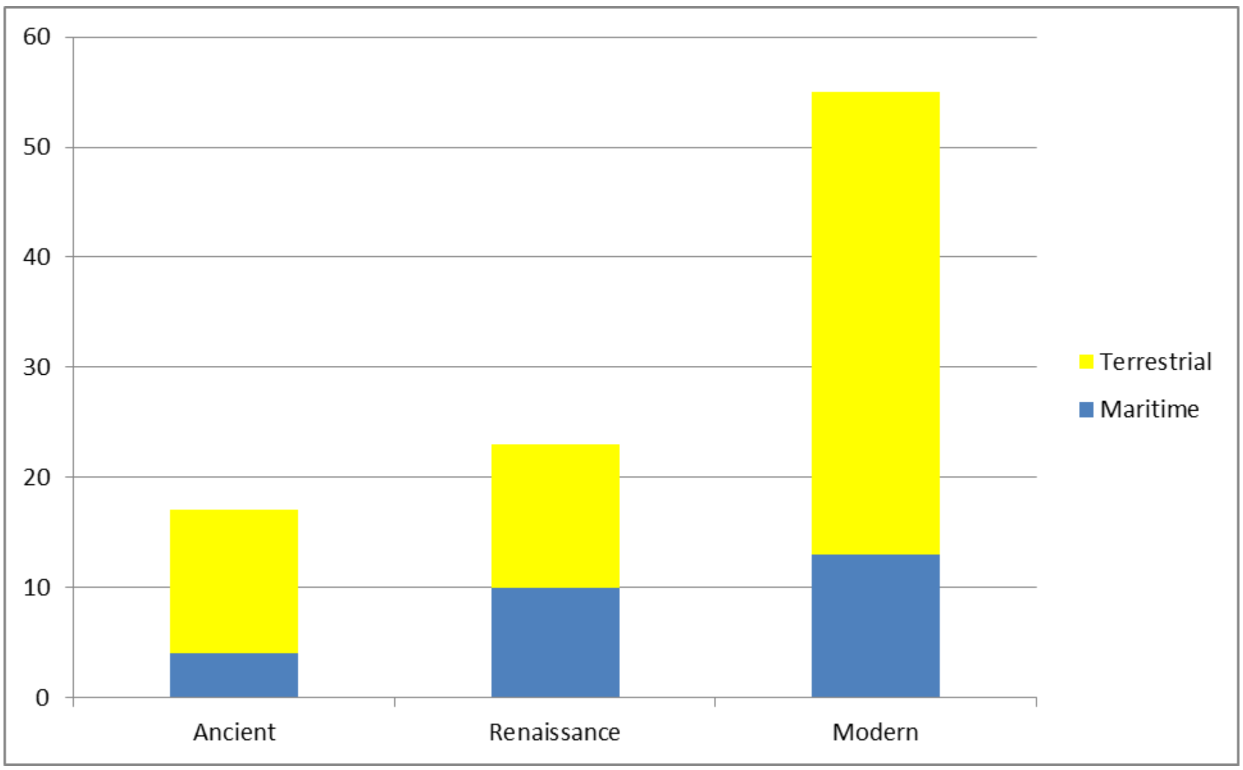


Figure 5.1 Distribution of historic visualizations analyzed (n = 95).

Each of the visualizations examined captures key elements of battlefield mapping for the given period. There were other battlefield visualizations examined; however, the techniques utilized were already represented several times in the database and did not offer any new information. For example, in 1847, T.C. Clarke created four separate battlefield visualizations (*Battle grounds of Palo Alto and Resaca de la Palma*, *The Siege of Monterey*, *The Battle Field of*

Buena Vista, and *The Map of Vera Cruz and Suan Juan de Uloa Position of our Forces*); however they all utilized the exact same techniques to represent land features, military units, and other key battlefield elements. These visualizations were noted, but not included in the in-depth analysis by the instrument. Finally, the overrepresentation of modern battlefield maps is not to be seen as problematic, as these visualizations were the baseline for the new applications of advanced and geospatial visualization techniques.

Prehistoric and Ancient Battlefield Visualization Analysis

These representations, while showing peoples engaged in battle, are very different from current battlefield visualizations. The earliest examples, those found in caves (Figure 2.2), show what is believed to be opposing hunting parties who have turned their weapons, used normally for procuring food, upon each other. These representations are always in profile view and shows a snapshot in time. As rudimentary as these representations are, they still show battle tactics. This type of visualization is found in a variety of locations around the world and persists for centuries.

Examples of battlefield representations abound in the New Kingdom (Figure 2.3). These representations also give the first glimpse into depictions of naval warfare. As with the earlier cave art representations from the Neolithic period, these representations are in profile view, but now include time information. The element of time, however, is not represented in a series of separate images like in more modern representations, but rather all within the same image.

The Thera fresco is another example of battlefield visualization that contains not only a maritime component, but also includes temporal data. The combatants and vessels are once again represented in profile view. Another notable component of the Thera fresco is the use of color, which allows for easier interpretation of the various elements included in the depiction.

None of the representations from this period contain scale information, or any sort of associated text. The lack of scale information or associated text is not surprising. Relative scale information may be inferred by using the height of the combatant as a guide. The purpose of these visualizations is difficult to pinpoint, however, they do appear to effectively communicate the basic elements of battle. Highly accurate scale information is not necessary when examining general battle trends or ideas. This is a common theme throughout all periods of battlefield mapping and will be examined in detail later.

Renaissance Battlefield Visualization Analysis

The Renaissance period was one characteristic of new ideas. It ushered in advancements in science and technology. With these advancements, cartographers were able to create more accurate maps and charts. These improvements trickled down into all realms of cartography, included those associated with wartime activities. Also during this period, a schism occurred between the more artistic representations of these conflicts and the tactical representations.

The artistic representations of the Renaissance period tended to focus on the struggle of the individual. It highlighted themes like the horrors of war, injury, and death. These representations were more akin to their predecessors and were frequently from a profile perspective. The scale of these representations is small, and typically does not show more than the immediate area surrounding the individual.

The more tactical battle maps are the predecessors to the modern battlefield visualization. The scale is generally larger and tends to focus on the surrounding battlefield landscape as well. Key terrain features become paramount in these examples, in addition to the placing of troops. The beginnings of troop generalizations also occurs at this time (Figure 2.8); however, it is not known if this was an intentional inclusion of an innovative cartographic technique or simply a limitation with the woodcut block printing techniques used at the time. Scale information also begins to emerge (Figure 2.9).

Also during this period, the element of time begins to be represented by two primary methods. The first is by the use of a series of images, rather than showing all the events in one image. The second method is the use of directional arrows to denote troop or vessel movement. Examples of both of these techniques are seen in the series of engraving commissioned by Augustin Ryther for the Battle of the Spanish Armada (Figure 2.9). This example clearly utilizes the first technique mentioned. Each of the eight engravings highlights the larger movements within the battlefield landscape. Within the same series of images are directional arrows which highlight further movement through time at an even smaller scale. The combination of multi-scalar and multi-time-scale images to highlight a single encounter is truly the beginnings of the modern battlefield visualization.

During the Renaissance period, maps also started to be printed on paper much more frequently. With the advent of new printing technologies during this time of technological innovation, cartographers were able to engrave their battlefield representations and produce multiple copies of their work. What started with wood engravings, later developed into copper and finally steel prints. The printing process also allowed for the use of colored inks, which result in maps with increased interpretation value that could be easily reproduced.

Modern Battlefield Visualization Analysis

The modern battlefield visualization, if done properly, can truly impart a great deal of information to an informed map-reader. Techniques developed during the Renaissance period continued to mature throughout the eighteenth and nineteenth centuries. New tools for land surveying created more accurate topographical maps, and resulted in more spatially accurate battlefield visualizations. In addition, with the further development of the printing press and the cost of books diminishing, the prevalence of both written works and battlefield visualizations greatly increased. Books, which detailed the events of a particular battle and complete with associated maps, were frequently produced within a year from the conclusion of the battle itself.

Also during this period, with the increase in mobility of the warfighter and an increased importance placed upon strategy and tactics, arose the need to represent this visually. It is due to these factors that the increase use of troop generalization and the use of directional arrows and associated text begin to emerge. In this survey, 44 out of the 55 modern examples utilized this technique. Without these cartographical techniques, it would surely be difficult to convey such complex movements.

Some cartographers executed and developed these new techniques with remarkable success. Others were not so successful and managed to create battlefield maps and visualizations that would accomplish nothing more than confusing the reader. The failures in battle map design can be grouped into four categories. The first is over-complication, followed by poor use of color, improper scale, and finally confusing symbology. Often multiple offenses are found in a particular battlefield visualization.

The first issue with the status quo in battlefield visualization is over-complication. When the cartographer or map creator attempts to insert too much information or content into a single map, the overall purpose of the map becomes muddled. In some circumstances, the purpose of the map may be completely obscured. The excess amount of information displayed in these visualizations could be chronological information, or simply making the scale of the visualization such that too much information is given in a single map extent. This is not to say that that the scale is inappropriate for the visualization, but perhaps when combined with multiple snapshots in time, the map becomes confusing.

The next issue is poor selection of color. The art of color selection is a very important aspect of cartography and there are many guides available to assist the cartographer in proper color selection. One such individual who has devoted much of her professional and academic life to improving cartographic design is Dr. Cynthia Brewer, a professor of Geography at Penn State University. Brewer (2005) contains two chapters on proper color selection and use in addition to a very useful color selection guide in the book's appendix. It has been noted in this research that the majority of battlefield atlases and published modern maps are either unaware of proper color selection, or choose to disregard the recent research that has gone into this area of cartographic theory.

Improper use or lack of scale was noted in 41 out of the 55 modern battlefield visualizations. This problem is not necessarily the same as over-complication, but relates to the purpose of the visualization. What the map creator is attempting to show in the map determines the scale. In some instances, it may be acceptable to have no scale information. However, if the purpose of the visualization is to reconstruct the battlefield for analysis, then scale information is imperative. Another issue relating to improper use of scale is mixing of scaled and un-scaled elements. This conveys a sense of confidence in the un-scaled elements, and unless this is directly addressed in supporting text, the reader may make assumptions which can lead to improper analysis.

The last problem identified in modern battlefield visualizations was the use of confusing symbology. This problem was noted in 23 out of 55 modern battlefield maps. When designing a map, it is important to select and clearly define the symbols or graphical representations used. A common mistake for inexperienced cartographers is to select symbols that are too closely related to other symbols used in the same visualization. Another issue that was noted was the use of symbols too large for the scale of the map, which leads to obscuring other pertinent information. Once again, Brewer's (2005) book contains a chapter relating to the proper use of symbols in cartography and should be consulted by those wishing to create cartographically sound maps and visualizations.

Examples of poorly executed battlefield maps and visualizations are common in the modern era. Little change occurred from the onset of the modern era to now; and the mistakes made in the past, are continually being made today. An early example of a poorly executed map is found in a publication by Captain Levi Scofield (1919), which highlights the battlefield at Franklin, Tennessee on November 30^{th}, 1864 (Figure 5.2). The primary problem with this battlefield visualization is with the symbology. First, the symbols chosen to represent the opposing forces are too similar, with the only difference being a slight change in line weight. While the line weight is subtle enough to note the difference, a different symbol would have been more appropriate. Second, the line weights are too similar to other lines used in the map. For example, the line weight use for the Confederate lines are very similar to those used to represent the roads. The line weights used for the Confederate lines are very similar to those used for the buildings in the town of Franklin. Finally, the symbols used for trees and topography are not defined in the visualizations and are confusing. They either need to be defined, or omitted.

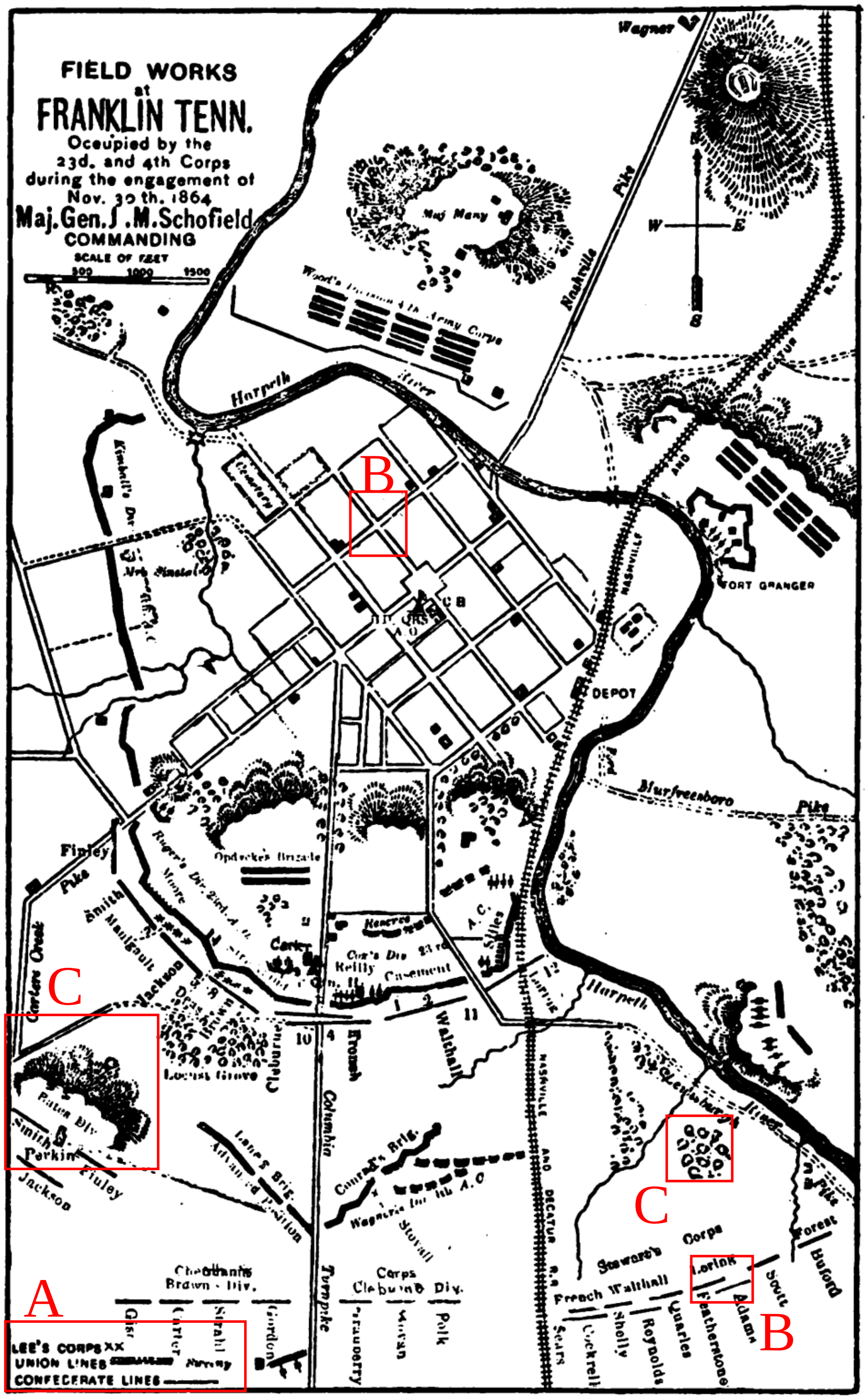


Figure 5.2 Example of a poorly executed battlefield map from the early modern period, showing the field works at Franklin, TN, 1864 (Scofield 1909:22). The area annotated "A" highlights similar line weights between opposing forces, area "B" highlights similarities between Confederate forces and road line weights, and area "C" highlights other miscellaneous and extraneous confusing symbology.

Putnam's *Atlas of the Second World War* (Young 1974) contains poorly executed maps. This example is more contemporary than many of the previous examples and contains the same types of issue. This map highlights the German advances into Soviet territory (Figure 5.3) and has a few notable flaws. First, there is an overload of information. It highlights four different positions of the Russian front. When this is combined with additional contextual information such as political boundaries, city symbology, and military unit labeling, it becomes cluttered and difficult to interpret. Additionally, landform characteristics such as marshes and rivers are also found in the map and further detract from the interpretive value. The multitude and size of the arrows detracts from the position of the fronts. At this scale, the use of multiple snapshots of time makes the map difficult to understand. In addition, the labeling of each individual military unit adds additional information that may not be necessary. The purpose of the visualization is to show the positions of the lines, not the positions of each individual unit. The issue with scale here relates to overall map balance. There is just too much information shown, none of which is particularly inappropriate for the given scale- just an excess of data. The second issue with the map is the similarity in line style for the various fronts. When the three dashed lines are close to each other in the legend it is easy to distinguish between them, however when placed in the complicated mix of symbols and text, they becomes more difficult to differentiate. A better approach would have been to use differing lines styles, or to simply not include so many fronts.

The above example is not all bad, however. The use of color does aid in distinguishing the opposing forces. Additionally the arrows, while they are what the eye is drawn to first and tend to detract from the actual position of the fronts, do a good job to highlight the general flow of the battle. The map would be more successful, however, if their emphases was lessened, combined with an overall reduction in map content. More is not always better.

Figure 5.3 German Advances into Soviet territory during the Second World War (Young 1974:87).

A final example of a poorly executed battlefield map, which is of a larger scale than the previous two examples, focuses on the progression of events during the Battle of the Atlantic during the Second World War (Figure 5.4). In this example there are a areas to critique. First, the overall size of the graphic as it relates to the area of interest is a problem. While one of the largest areas surveyed in this research, the dimensions of the actual image is one of the smallest. The key takes up approximately one third of the overall map canvas and as a result, is not a good use of space. Another issue is the gray/green color scheme which results in difficulty in discerning map features. In addition, elements within the map share similar symbology. For example, the “Major Convoy Lines” uses an almost identical line weight and color as the “Operational limit of Allied land-based bombers: from Sept 1943.” In the defense of the map creator, often it is the publisher that determines color palate availability; however, the book this image is found in is an atlas of the Second World War (Folly 2004). It would follow reason that an atlas would highlight the map and not the associated text, and as a result, the map would have ample space and additional flexibility when color choices are concerned.

While the above-mentioned map accomplishes its original purpose, there is ample room for improvement. If one or more of the issues noted above had been addressed, the overall effectiveness of the map would have greatly increased. Even though this image was published in atlas, it seems that the map took a secondary role to the supporting text.

Trends in Battlefield Visualizations through the Ages

One of the strengths of any comparative analysis is the identification and extrapolation of trends. When the previously examined eras are viewed comparatively, certain trends emerge. The best way to analyze these trends is to view the data visually, rather than in table format. As a result, each key variable was examined across the ages and analyzed.

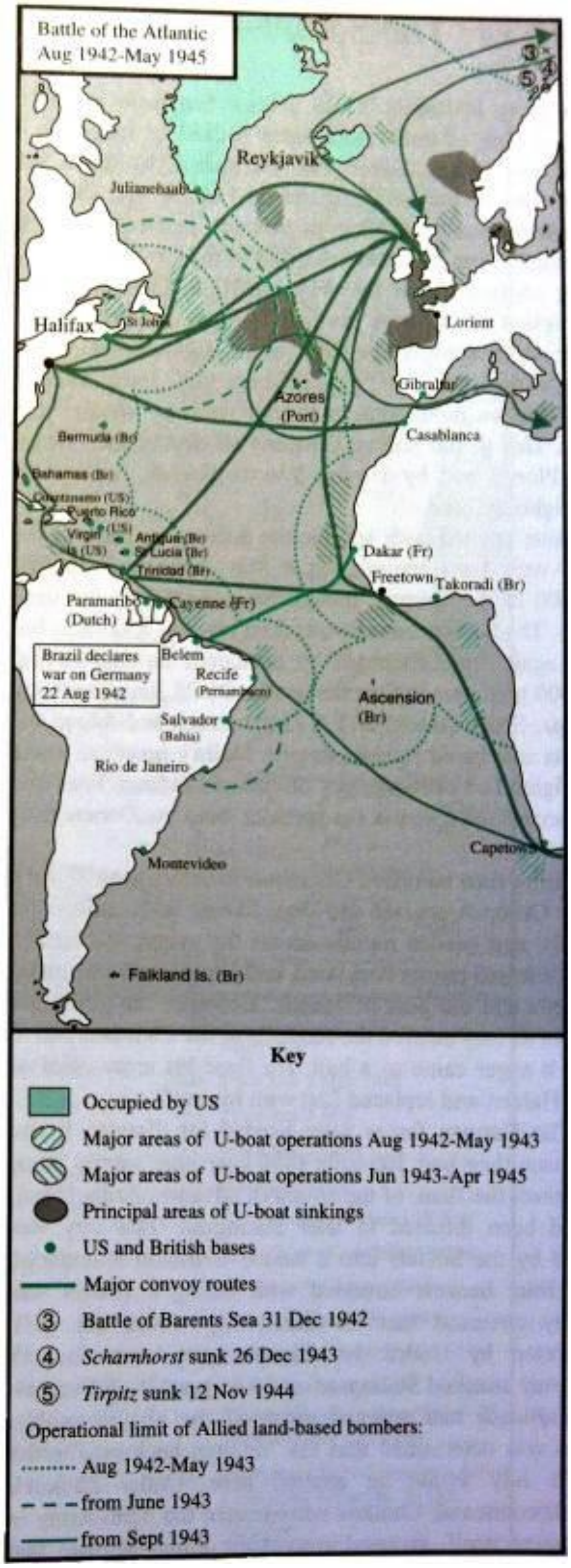


Figure 5.4 Battle of the Atlantic: Aug 1942 - May 1945 (Folly 2004:Map 20).

The first variable examined was the use of scale information (Figure 5.5). What is immediately apparent from Figure 5.5 is the rise of scaled visualizations during the Renaissance period and subsequent decline of usage in the modern era. The cause of this trend is hypothesized to be the relative rapid increase in the use of survey equipment that occurred in the Renaissance period, which is seen in almost all maps and visualizations during the time. Land surveys became more important, and thus the accurate representation of battles followed. In addition, the mobility of the military was increasing and accurate spatial information was necessary. The general shift in military strategy of the Renaissance was towards one that emphasized mobility, as opposed to one primarily focused on siege warfare. The subsequent decline in use of scale information is potentially due to an increased interest in conveying the generalities of the battle. This is seen with an increase in troop generalization, the use of multiple time increments in the visualization, and an increase in the use of associated text that all occurred during the modern period, and is discussed later.

The second variable analyzed was use of troop generalizations in battlefield visualizations (Figure 5.6). The earliest example of troop generalization was found in the mid-sixteenth century (Figure 2.10); however, this was not a technique that was initially adopted. What is notable here is the relatively limited use of this cartographic technique in the Renaissance period followed by a large spike in the modern era. As previously noted, the use of troop generalization was a technique developed to visualize an ever-increasing complex battlefield landscape, along with the use of explanatory text. In addition, the examples of troop generalization from the Renaissance period were all produced using woodcut block printing, a medium that was not known for its ability to render detail.

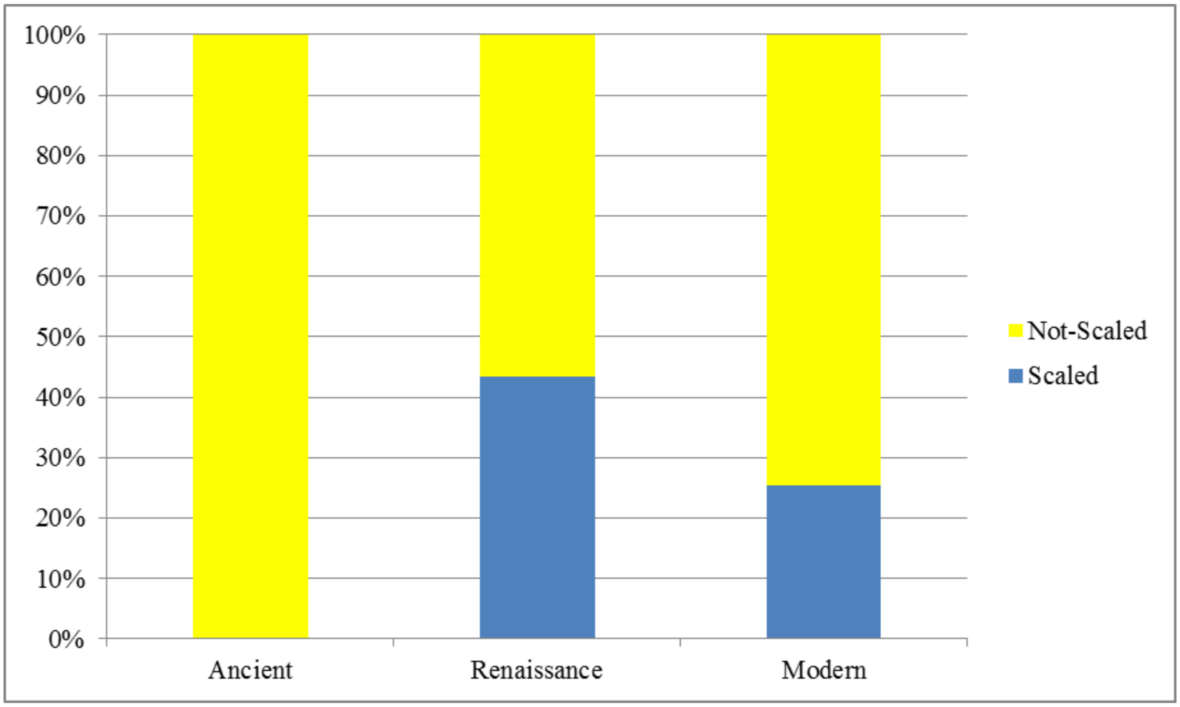


Figure 5.5 Comparative analysis of scaled vs. non-scaled battlefield visualizations (n=95).

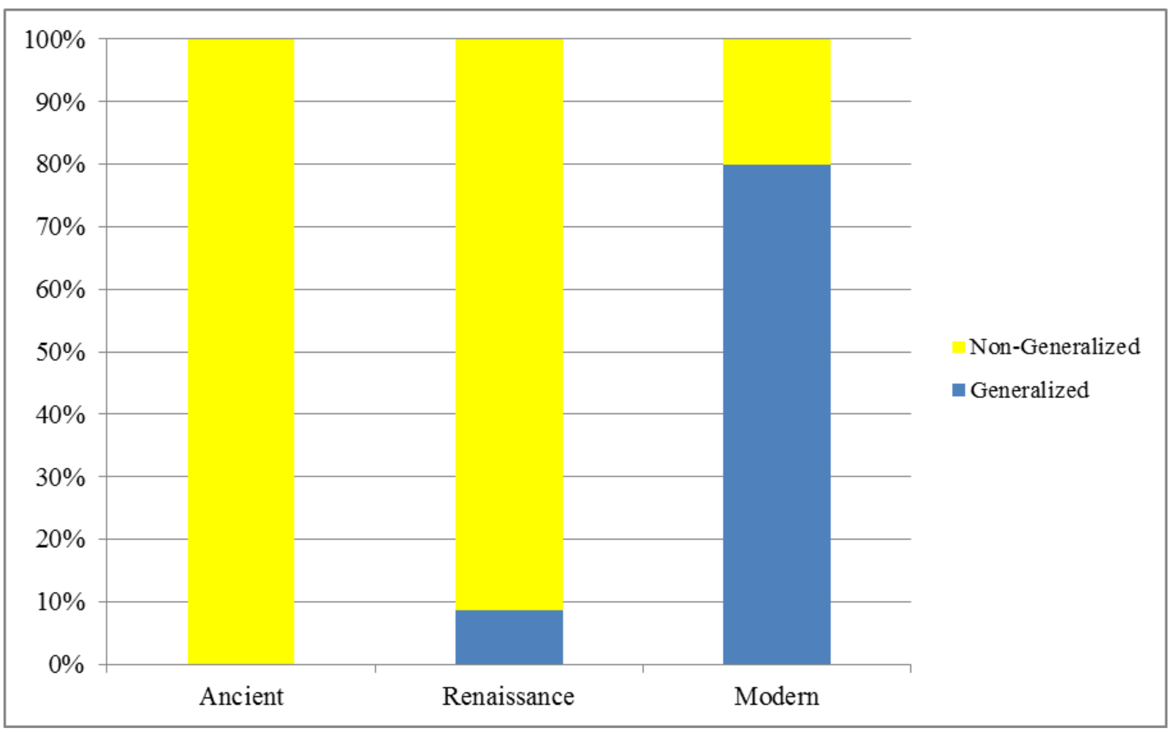


Figure 5.6 Comparative analysis of Generalized vs. Non-Generalized battlefield visualizations (n=95).

The third variable from this analysis was the use of synchronic versus diachronic representations (Figure 5.7). The use of diachronic representations originated as far back as the ancient Egyptians (Figure 2.3); however, was not widely used in battlefield visualizations until much later. A handful of uses were noted in the Renaissance period, most notably the series of engravings detailing the Battle of the Spanish Armada (Figure 2.9). With the advent of modern battlefield mapping, the use of multiple time elements (diachronic scales) became essential in conveying the movement of troops and detailing the various strategies utilized. What is interesting to note, however, is that this practice was not adopted earlier, even though it originated in the ancient period.

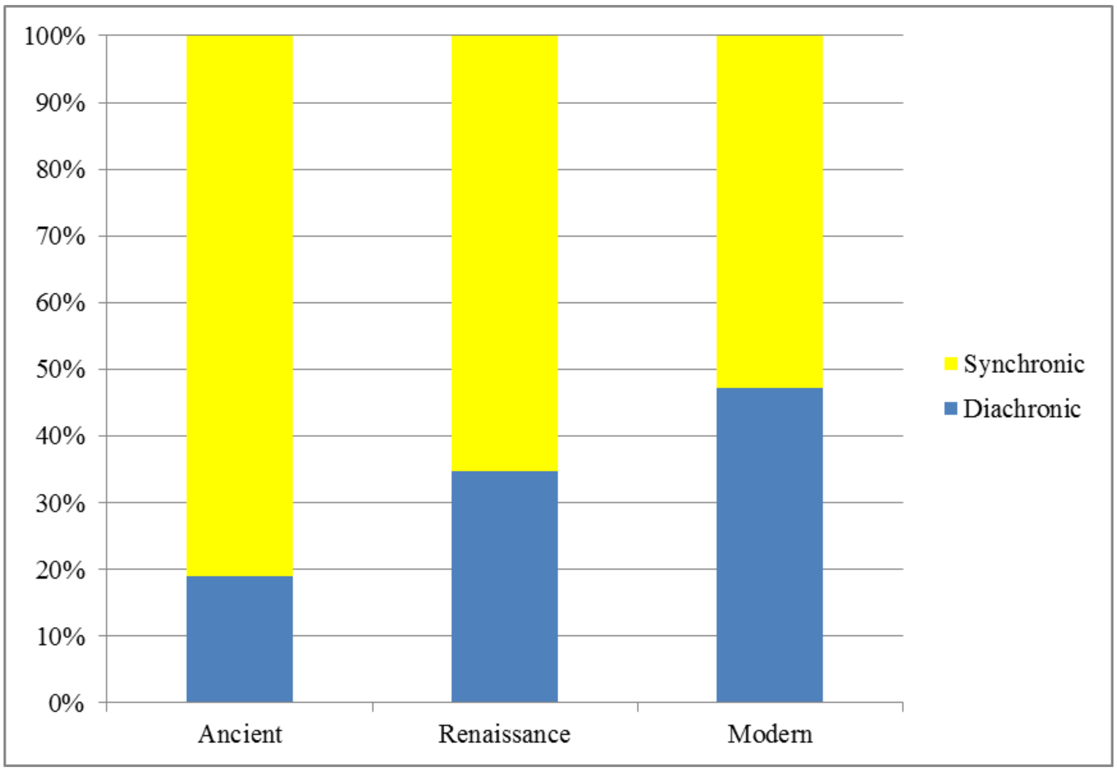


Figure 5.7 Comparative analysis of multiple time elements (n=95).

The last variable examined was the use of associated text (Figure 5.8). This technique saw a marked increase in occurrence which coincided with the increase in battle complexity. This follows reason because as the battles became more complex, cartographers sought additional methods to detail the strategies, and one of the easiest methods was to include explanatory text. The earliest example of this came from a battlefield visualization published in 1548 from the battle of Pinkie Cluegh, which also happened to be the first map to utilize troop generalization (Figure 2.10). This does not necessarily mean that this technique is an advancement in the conveyance of information relating to battlefields. Unfortunately, the addition of text often overwhelms the map-reader, and can actually negatively influence the overall interpretations of the product.

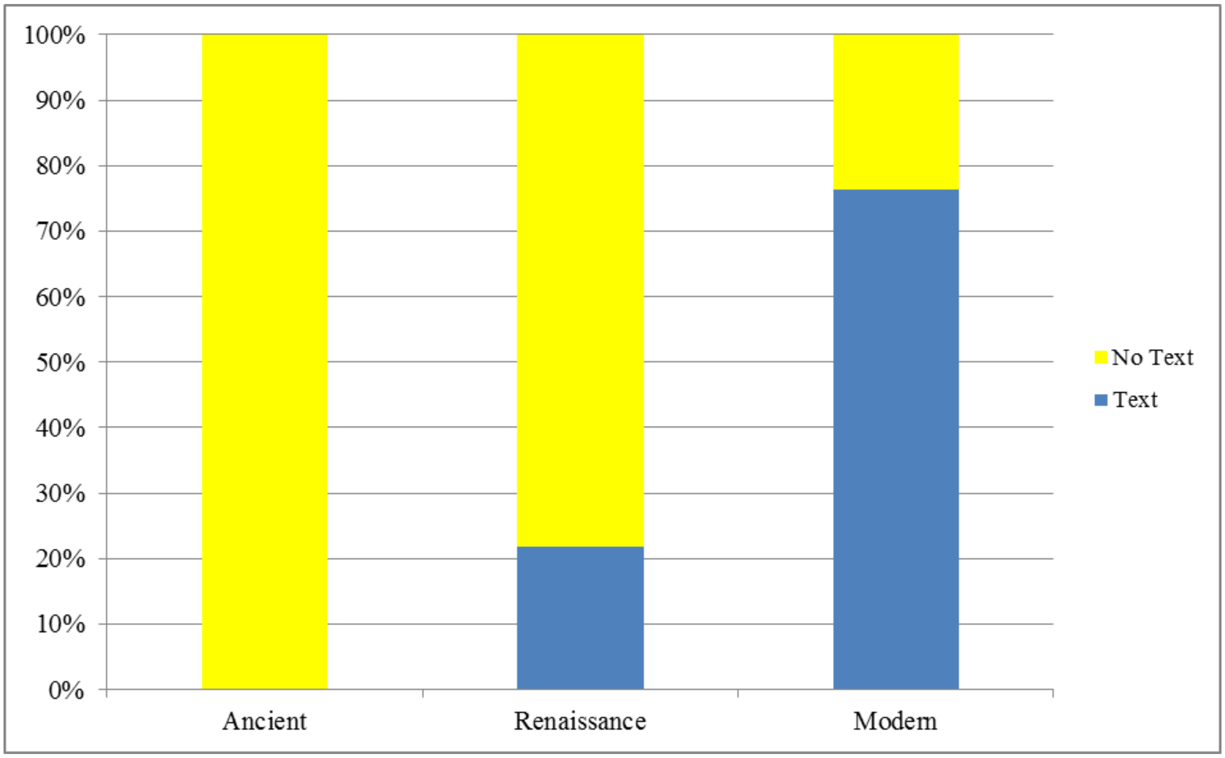


Figure 5.8 Comparative analysis of associated text usage (n=95).

The last variable examined was the use of color. Unfortunately, due to potential reproduction issues, the results are untrustworthy. The majority of the sources examined from the nineteenth century were digitized in black and white and posted in online data repositories. Without physical access to the source documents themselves, many of which are located hundreds if not thousands of miles away, it would be difficult to determine if the original documents were created with or without color. The results of the analysis are included below (Figure 5.9).

The main overarching theme noticed by this comparative analysis is the development of new techniques to deal with advancements in military technologies and strategies. As warfare became more complex, so did battlefield cartography. Just because new techniques have been developed, however, does not mean that they were ultimately styled for visualizing warfare of the time. The majority of the advancements in battlefield cartography were developed during the Renaissance, and brought to maturity during the modern era. Most recently, however, the developments have shifted towards digitally reproducing older, analog techniques. Rather than move away from the use of associated text, the technology used to produce that text has changed.

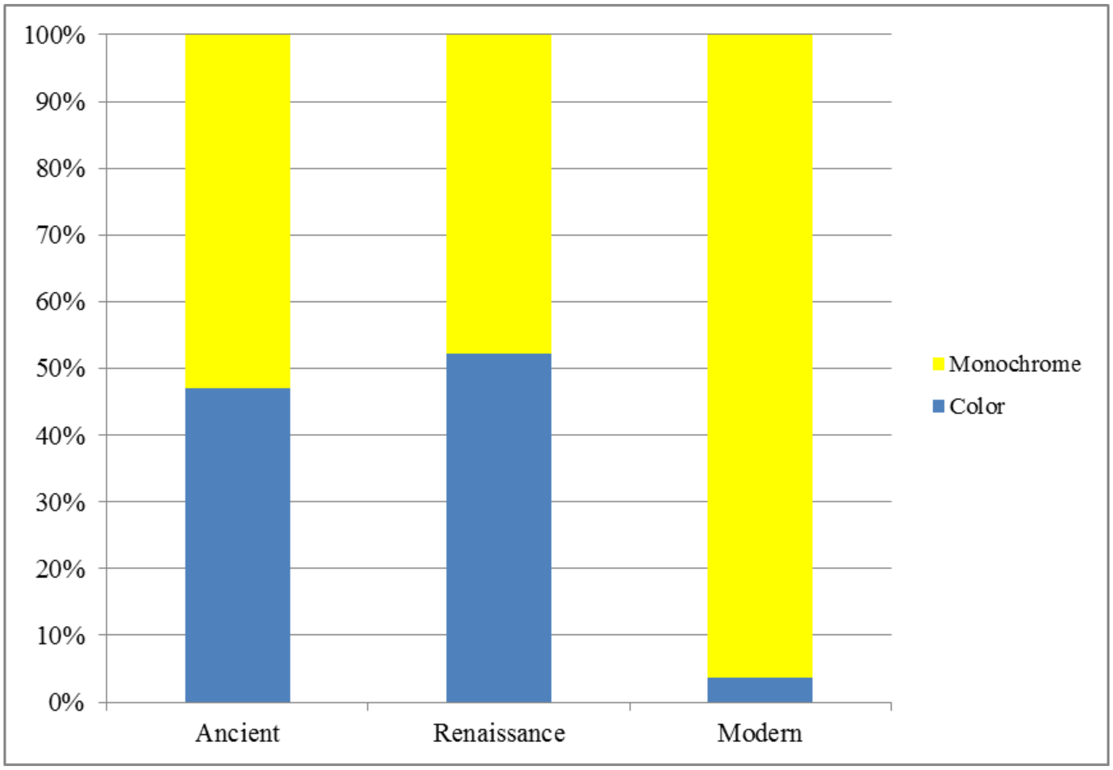


Figure 5.9 Comparative analysis of color usage (n=95).

Visualizing the Battle of Convoy KS-520

There was no shortage of naval battles from the Second World War when the selection of the case study for this research was completed. The Battle of Convoy KS-520, however, possessed all the necessary elements and had an existing body of research to build upon. First, like may U-boat attacks, the battle was relatively short lived, lasting only a matter days from initial torpedo strike to the sinking of the last merchant vessel in the Hatteras minefield. Short encounters require a unique set of visualization techniques, which differ from those utilized in larger naval battlefields that may span days, months, or even the duration of the war. Second, the battle contained elements of warfare in all three planes of movement. With the inclusion of submarine warfare and the use of airplanes, the third dimension suddenly became much more important. With these two elements present, combined with the body of existing research, there would be no better battle to experiment with advance and geospatial visualizations techniques.

The first example presented is reconstructing the KS-520 battlefield landscape in 3D. This case study is important because it combines the analytical use of 3D technology with the more traditional stylistic approaches, or non-scaled approaches found in Williamson 2010 (Figure 3.14). The second example utilizes animation techniques to analyze the same battlefield landscape, starting with the events immediately before the convoy encountered *U-576*. Both of these examples highlight the strengths of each advanced visualization technique and are both considered advanced geospatial visualizations due to the inclusion of the spatial element. Each example will also be examined critically and assessed in terms of deficiencies. Prior to exploring the digital reconstruction of the battle, a brief examination of the historical narrative is necessary.

The Historical Narrative of the Battle of Convoy KS-520

The historic battle of Convoy KS-520 has recently been the topic of both historical and archaeological investigation. The historical components of the battle were extensively examined in Bright 2012. It was also one of the primary focuses of the NOAA Monitor National Marine Sanctuary's (MNS) summer research in 2011 as part of their ongoing Battle of the Atlantic project, and summarized in a joint report submitted by East Carolina University faculty (ECU), and NOAA MNS staff to the NPS ABPP in 2013. These reports and studies are the most recent, and the most extensive. The historical account of convoy KS-520 has been told previously by historians as part of a greater Battle of the Atlantic narrative (Hoyt 1978; Freeman 1987; Hickam 1989; Blair 1996, 2000).

The designation of KS indicated that the convoy was southbound, with a final destination of Key West, Florida. The convoy's port of anchorage was Lynnhaven Roads, VA. Convoy KS-520 consisted of 19 merchant vessels. Additionally, five escort vessels accompanied KS-520. The convoy spacing was reported to be 500 yards between ships, and 700 yards between columns. The convoy formation at the time of attack can be found in Figure 5.10. It is worth noting that convoy vessel *Chilore* was reported as being 600 feet ahead of post at the time of attack, and is represented as such in all future visualizations. It should also be noted that the convoy was escorted by aircraft (Freeman 1987).

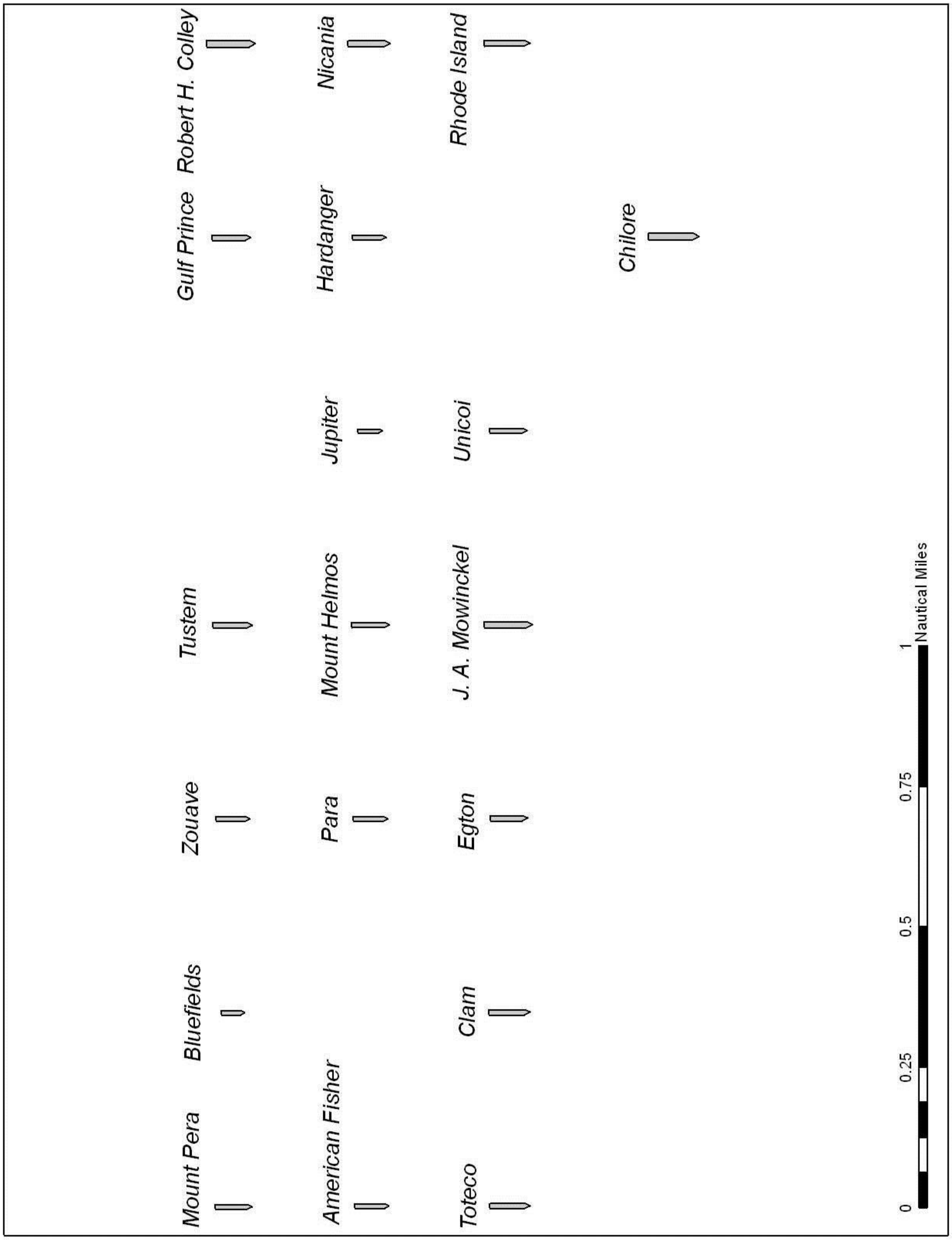


Figure 5.10 Convoy KS-520 formation at the time of attack (Drawn by Author).

Additional information regarding the convoy vessel types and nationality can be found below (Table 5.1). Similar information is provided for the escort vessels in Table 5.2.

Vessel Name	**Vessel Type**	**Nationality**
Mount Pera	Freighter	Greek
Bluefields	Freighter	Nicaraguan
Zouave	Freighter	British
Tustem	Tanker	American
Gulf Prince	Tanker	American
Robert H. Colley	Tanker	American
American Fisher	Tanker	American
Para	Freighter	Norwegian
Mount Helmos	Freighter	Greek
Jupiter	Freighter	Dutch
Hardanger	Freighter	Norwegian
Nicania	Tanker	British
Toteco	Tanker	American
Clam	Tanker	British
Egton	Freighter	British
J.A. Mowinckel	Tanker	Panamanian
Unicoi	Freighter	American
Chilore	Freighter	American
Rhode Island	Tanker	American

Table 5.1 List of vessel in convoy KS-520, showing vessel type and nationality (National Archives).

Vessel Name	**Service Branch**	**Vessel Type**	**Vessel Designator**
Ellis	U.S. Navy	Destroyer	DD-154
McCormick	U.S. Navy	Destroyer	DD-223
Icarus	U.S. Coast Guard	Cutter	WPC-110
Triton	U.S. Coast Guard	Cutter	WPC-116
Spry	U.S. Navy	British Flower Class Corvette	PG-64

Table 5.2 Convoy KS-520 escort vessels (ABPP 2012; Bright 2012).

In an attempt to simplify the battle activities of during convoy KS-520's southbound journey, the various historical and archeological sources were compiled to create a summary for battle activities (Table 5.3).

Date	**Time**	**Description**	**Source**
17 June 1942	N/A	*U-576* began fifth war patrol, departing from St. Nazair, France.	Blair 1996; Bright 2012
10 July 1942	N/A	*U-576* arrived off the coast of North Carolina.	Blair 2000; Bright 2012
13 July 1942	N/A	U-576 reported damage to its main ballast tank.	B.d.u 1942; Bright 2012
14 July 1942	0430 EWT	Convoy KS-520 departs anchoarages at Lynnhaven Roads, VA	Fengar 1942a-1942u
14 July 1942	1330 EWT	Convoy KS-520 cleared the Chesapeake minefield.	Bright 2012
15 July 1942	0700 EWT	Convoy KS-520 rounded Cape Hatteras, NC.	Freeman 1987; Bright 2012
15 July 1942	1600 EWT	Convoy escort USCG *Triton* pick up sonar contact.	USCG 1942b; Bright 2012
15 July 1942	1605 EWT	Convoy escort USCG Triton dropped three depth charges.	USCG 1942b; Bright 2012
15 July 1942	1610 EWT	Convoy escort USCG Triton dropped five additional depth charges.	USCG 1942b; Bright 2012
15 July 1942	1615 EWT	Two torpedoes strike convoy vessel *Chilore*.	Bright 2012; ABPP 2013
15 July 1942	1616 EWT	Torpedo strikes convoy vessel *J.A. Mowinkel*.	Bright 2012; ABPP 2013
15 July 1942	1617 EWT	Torpedo strikes convoy vessel *Bluefields*.	Bright 2012; ABPP 2013
15 July 1942	1617 EWT	Convoy escort aircraft begin dropping depth charges.	Bright 2012; ABPP 2013
15 July 1942	1617 EWT	Convoy escort vessel *Spry* noted smoke originating from the water at the center of the convoy.	Bright 2012; ABPP 2013
15 July 1942	1619 EWT	Convoy escort vessel *Ellis* made sonar contact, drops two depth charges.	Bright 2012; ABPP 2013
15 July 1942	1627 EWT	Convoy vessel *Bluefields* sinks, with the entire crew abandoning ship.	Bright 2012; ABPP 2013
15 July 1942	1641 EWT	Convoy escort vessel *Ellis* continues pursuing sonar contact, dropping an additional 13-15 depth charges.	Bright 2012; ABPP 2013
15 July 1942	1642 EWT	Convoy vessel USS *Spry* rescues 20 out of 24 crew from convoy vessel *Bluefields*.	Bright 2012; ABPP 2013
15 July 1942	1646 EWT	Convoy escort vessel USCG *Icarus* recues the remaining 4 crew members from convoy vessel *Bluefields*.	Bright 2012; ABPP 2013
15 July 1942	1652 EWT	Convoy escort vessel USS *Spry* made sonar contact and drops one depth charge.	Bright 2012; ABPP 2013
15 July 1942	1718 EWT	Convoy escort vessel USS *McCormick* leaves convoy to pursue U-576, while	Freeman 1987; Bright 2012; ABPP 2013

Date	Time	Description	Source
		remaining vessel make way for Hatteras Inlet, NC	
15 July 1942	1800 EWT	Convoy escort vessel USS *McCormick* made sound contact and dropped depth one charge.	Freeman 1987; Bright 2012; ABPP 2013
15 July 1942	1800 EWT	Convoy escort vessel USS *Spry* radioed *J.A. Mowinckel*, expressing concern over the course set and the proximity to the Hatteras Minefield.	Freeman 1987; Bright 2012; ABPP 2013
15 July 1942	1801 EWT	Convoy vessel *J.A. Mowinckel* radioed back USS *Spry* attempting to reassure the escort vessel.	Freeman 1987; Bright 2012; ABPP 2013
15 July 1942	1819 EWT	Convoy escort vessel USS *Spry* radioed *J.A. Mowinckel*, requesting a course change based upon proximity to the Hatteras Minefield.	Freeman 1987; Bright 2012; ABPP 2013
15 July 1942	1845 EWT	Convoy escort vessel USS *McCormick* makes way to rejoin convoy.	Freeman 1987; Bright 2012; ABPP 2013
15 July 1942	2050 EWT	Crew of convoy vessels *J.A. Mowinckel* and *Chilore* abandon their damaged and sinking ships.	Bright 2012; ABPP 2013

Table 5.3 Battle of convoy KS-520 events summary.

Reconstructing the KS-520 Battlefield Landscape in 3D

Short-term naval battles from the Second World War lend themselves nicely to visualization in 3D. The battle of Convoy KS-520 was a prime example in that it contains elements of submarine, surface, and aerial warfare. The first visualization created for the battle was an aerial view of the conflict, which highlighted the overall battlefield landscape (Figure 5.11). The purpose of this visualization was to give the map-reader a better understanding of the spatial relationships within the landscape, and provide a glimpse into the various three dimensional viewsheds. The data represented in this visualization is well suited for three-dimensional display and would be difficult to articulate in support text. This particular battle has a variety of participants, each with their own 3D viewshed.

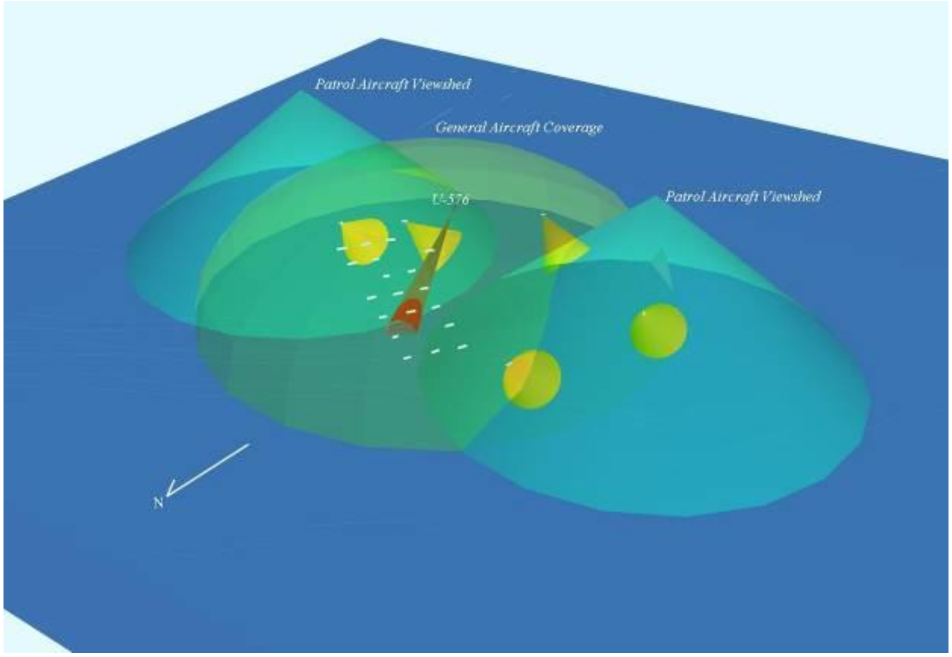


Figure 5.11 Convoy KS-520 Battlefield Landscape (Drawn by Author).

When the map-reader first looks at this visualization, the vastness of ocean combat immediately becomes apparent. What is also clear is the relatively small 3D viewsheds in comparison to the overall scale of the landscape. It is difficult to view the entire battlefield from such a perspective. This notion brings to the forefront one of the primary difficulties when viewing complex visualizations in 3D. Essentially, it is a compromise between what can be fit in a particular image versus what is desired for display. This is the same struggle faced by cartographers creating traditional paper maps, however, the use of 3D technologies and viewing software gives an added advantage. Since this information is stored in a computerized system, it can be systematically manipulated and subsequent images exported out. Another alternative is the transfer of the original digital file that can be loaded into the appropriate software package, which then allows the map-reader to explore the battlefield landscape. The distribution of electronic media with publications is becoming more prevalent. Students purchasing new textbooks often have a Compact Disc (CD) or Digital Video Disc (DVD), or even a hyper-link to an eternal web site that contains ancillary data.

Another advantage of the 3D battlefield landscape visualization is the ability for the visualization software to have built-in scale dependencies. If at larger scales less information is required, settings in the software package can be specified to only display when a certain scale range is met. This also solves the problem of displaying scale dependent data. An example of this is historically gathered coordinate data. The accuracy of this coordinate data does not have the spatial accuracy of modern data collected. It would be therefore inappropriate to assume that this data has such a high-level accuracy.

One problem with viewing data in a 3D environment is with perspectives. With elements of the naval battlefield visualized in 3D, a common problem is the obscuring of battlefield participants. Because these elements fill 3D spaces, they can sometimes obscure elements behind them. A balance between element transparencies and perceptive angles ensues. Often framing an adequate screen shot of a 3D environment is more of an art form and requires substantial amounts of time exporting out a multitude of images, in an attempt to get the perfect image. Continuing with the 3D battlefield landscape of Convoy KS-520, another view is examined. This time, rather than focusing on 3D viewsheds, fields of fire were examined. In a traditional terrestrial battle or a naval battle prior to the use of submarine and aerial warfare, a two dimensional view is sufficient. With the addition of these new battlefield planes, it is difficult to visualize these fields of fire in 2D, and even more difficult to describe them textually. The 3D representation of these fields of fire in 3D is an excellent way to communicate their relationships (Figure 5.12).

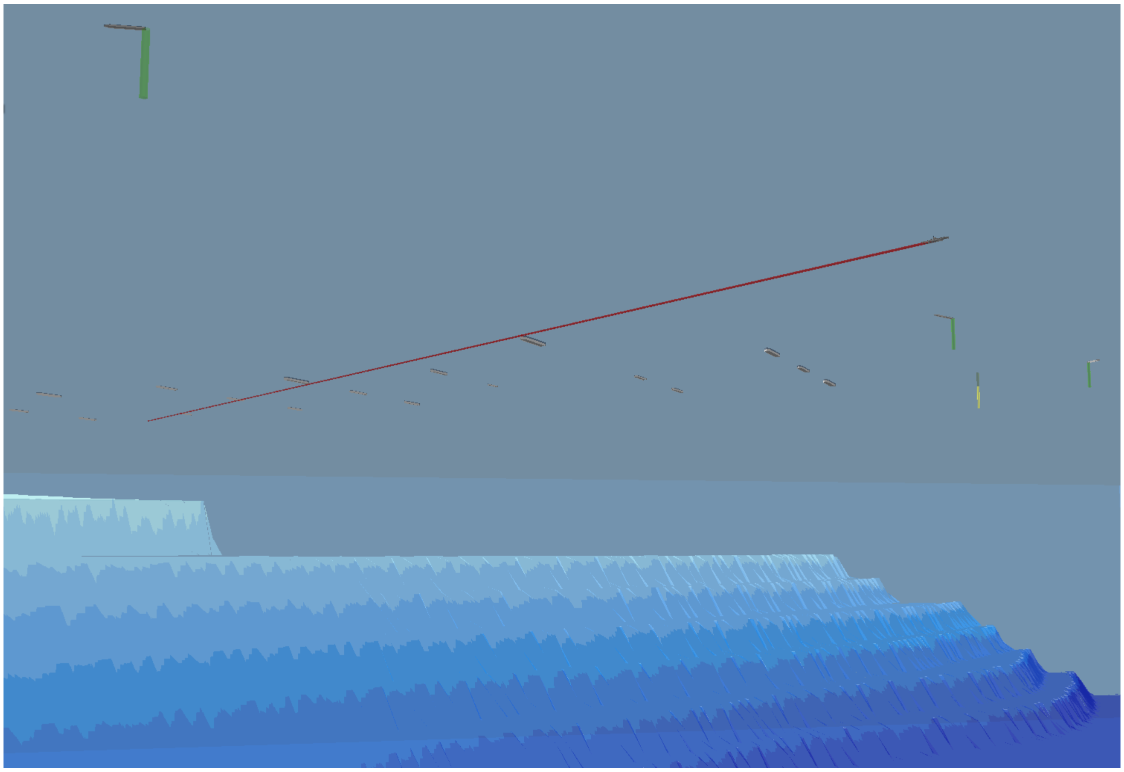


Figure 5.12. Fields of fire from the battle of Convoy KS-520 landscape with the emphasis placed on the overall relationships of *U-576* to the convoy (Drawn by Author)

These images still struggle with the same problems from the first visualization of the battle of Convoy KS-520. The major issue at hand is attempting to display the entire battlefield landscape in a single image. The distances are great and the fields of fire are limited. It may be necessary to offer multiple vantage points to capture the desired theme or purpose of a given visualization. A secondary vantage point (Figure 5.13) highlights the limitations of depth charges, while the first visualization highlights the overall relationship of the *U-576*'s field of fire to the convoy. This entire problem can be overcome, if the digital files used in creating the still images are disseminated with the textual descriptions as mentioned above. A final alternative would be to pre-record a "fly-through" of the 3D animation and distribute that, rather than the original file. This adds a level of control over the content, which may be more desirable than distributing the media directly. This ensures that the visualization is viewed in the most appropriate manner and that key elements of the visualization are not overlooked. The use of animations is a good middle ground, between staging a series of images and distributing the original media.

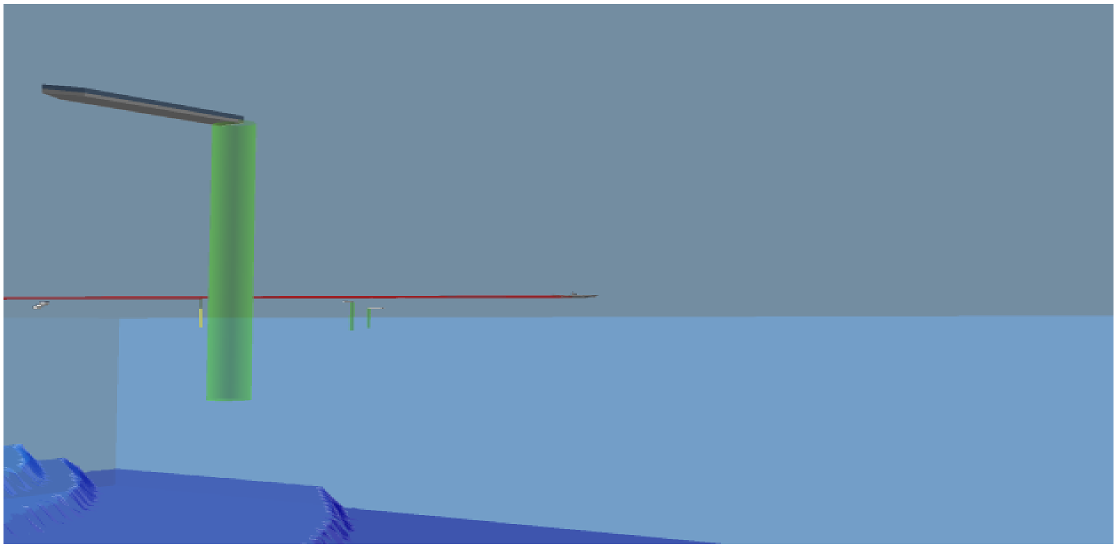


Figure 5.13 Field of fire emphasizing the effective range of escort depth charges (Drawn by Author)

This type of animation is different from the animation discussed in the second example of this case study found below. That animation is highlighting dynamic events, whereas the animation listed above, is merely one that highlights different vantage points of a static environment. Both animation types have their own appropriate usage, and both should be considered when visualizing complex naval battles.

Examination of the KS-520 Battlefield Landscape through Time

All battles, whether terrestrial or maritime, are complex and dynamic events. There are often multiple players involved, each moving about in different ways, much like a dance. A dance is hard to describe by text alone, and while a series of static images may help convey the basic elements of a dance, that too fails to capture the true dynamism. The most appropriate way to capture this dynamic element is by utilizing an animation.

The battle of Convoy KS-520 contains elements that are well suited for animation. The two main dynamic elements involved are the convoy itself, and the torpedoes. The torpedoes were assumed to be a Type G7e (Figure 5.14), and the convoy was presumably traveling approximately eight knots (Bright 2012). Bright 2012 concluded that the torpedo was of G7e type based upon the historical record. He notes "The [United States Navy] USN pilots from Scouting Squadron Nine stated no torpedo wakes were present during *U-576's* attack, indicating the U-boat was most likely firing G7e torpedoes" (160). This information is very helpful when animating the battle, however, it is still missing some key information.

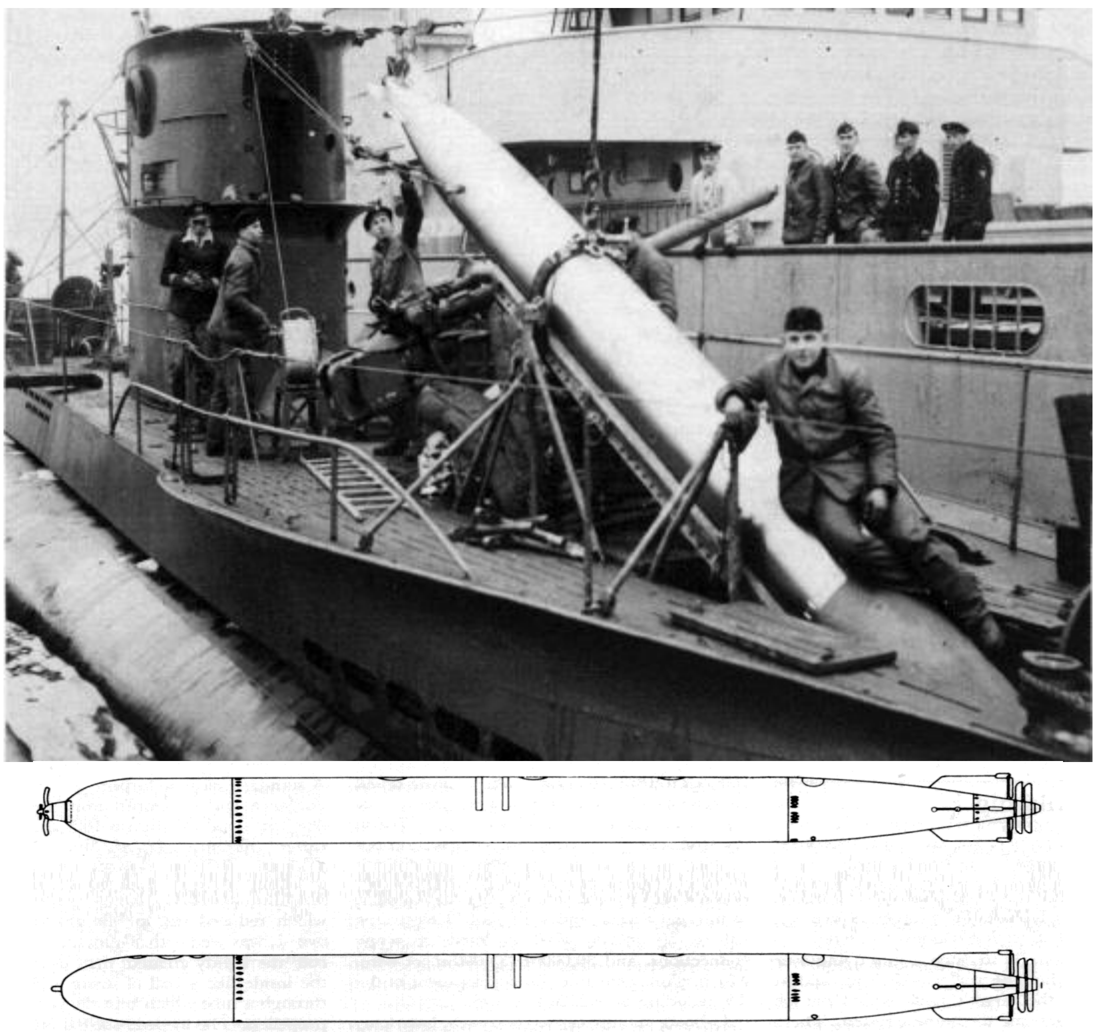


Figure 5.14 The German G7e torpedo (Campbell 1985:261-261 in Bright 2012:161).

There are nine designations within the type G7e torpedo, with four different possible speeds of travel (Table 5.4). An animation is an excellent method of further predicting the torpedo designation. The travel speed, and hence the distance between a given unit of time, should be dictated by the torpedo vessel strikes. The accounts of the U-boat attack by convoy participants note that there was approximately four minutes between the torpedo strike of *Chilore* and *J.A. Mowinckel*, and six minutes total from the first strike to the explosions on *Bluefields* (Bright 2012). Additionally, an animation can also render information regarding the structure of the convoy itself.

Designation	**Speed (knots)**	**Range (km)**	**Length (cm)**
TII	30	50	716.3
TIII	30	50	716.3
TIIIFatII	30	50	716.3
TIIIaFatII	30	75	716.3
TIIIaLut I/Lut II	30	75	716.3
TIIIb	18.5	40	716.3
TIIIc	18.5	40	716.3
TIIId	9	570 (approx)	1,100
TIIIe	20	75	716.3

Table 5.4 Designations of Type G7e torpedoes (Rossler 1989).

In order to further identity the torpedo designation and to gain a better understanding of the convoy structure, a series of 2D images and an animation were created. The first image (Figure 5.15) is more akin to a traditional battlefield map in that it represents the dynamic process in a static image. The data used to create the image was taken from the historical record (Bright 2012), and a scaled representation was created. Through the use of basic statistical measures described earlier (Chapter 4), a best-fit line was created. Even though attempts were made to take into consideration the speed of the convoy relative to the speed of the torpedoes, it is difficult to assess the accuracy of this prediction without viewing it in an animated format.

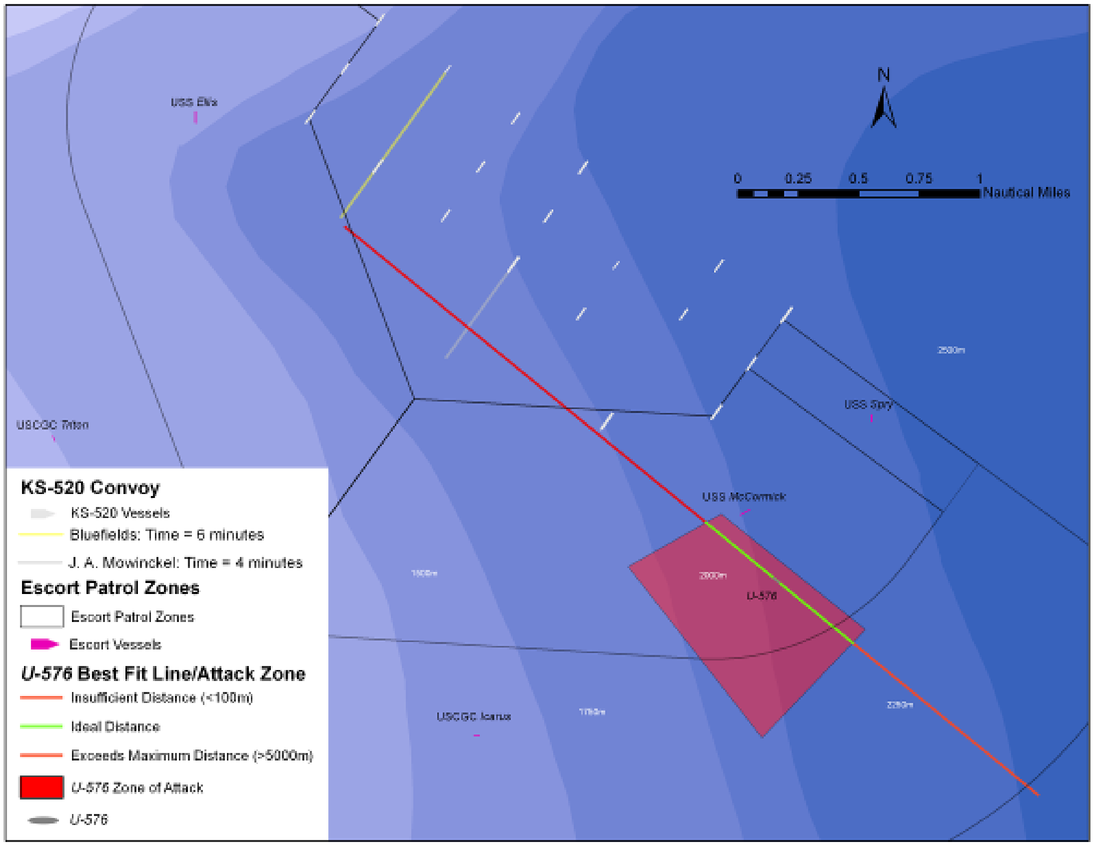


Figure 5.15. Traditional representation of the events leading up to *U-576*'s attack on Convoy KS-520 (Drawn by Author).

While it is clear from the static representation that the paths of the convoy and of the torpedo salvo fired by *U-576* seem to intercept, it is easier to interpret when animated. When the various time intervals were included and the animation was created, it quickly became apparent that the torpedo could not have been of designations TII, TIII, TIIIFatII ,TIIIaFatII, or TIIIaLut I/Lut II. The speed at which these torpedoes travel, 30 knots, would not have allowed for *Chilore*, *J.A. Mowinckel*, and *Bluefields* to be struck in the times noted in the historical record. The overall attack would have occurred in approximately half the given time, and the vessel simply would not have been in a location where they could have been hit. Additionally, the TypeIIId would have traveled too slowly for the specific characteristics of this attack event. This leads to the conclusion that the torpedo type must have been either of the TIIIb, TIIIc, or TIIIe designation. The resulting animation utilized a torpedo speed of 18.5 knots (Figure 5.16).

This example highlights the powerful analytical nature of advanced geospatial visualization techniques. In this particular situation these techniques were effectively used as forensic tool, which ultimately offered a greater understanding of the battle events. Without viewing these events in a diachronic, georeferenced environment, the particular question of torpedo type would have been difficult, if not impossible to answer. The use of advanced geospatial visualization techniques as a forensic tool could be extended to many historical and archaeological questions where elements of both time and geographic space are present.

The placement of *U-576* within the best-fit line is difficult to determine, and ultimately proved to be problematic. The best-fit line was colored to represent zones of effective torpedo use. The red zones indicate areas where the torpedo range is exceeded, or the minimum required distance to an enemy vessel was violated. The resultant green zone on the best-fit line represents the ideal attack position along this line. Since it is impossible to determine the amount of time between the firing of the torpedo and the first vessel strike, three possible locations were placed upon the line. The first location is represented as a red dot and assumes there was one minute between the firing of the torpedoes and the striking of *Chilore*. The next two positions assume there was an additional minute and two minutes of underwater travel time for the G7e torpedo. Based upon the historical account that *U-576* surfaced in the center of the convoy after the attack, the closest attack position was used in the animation.

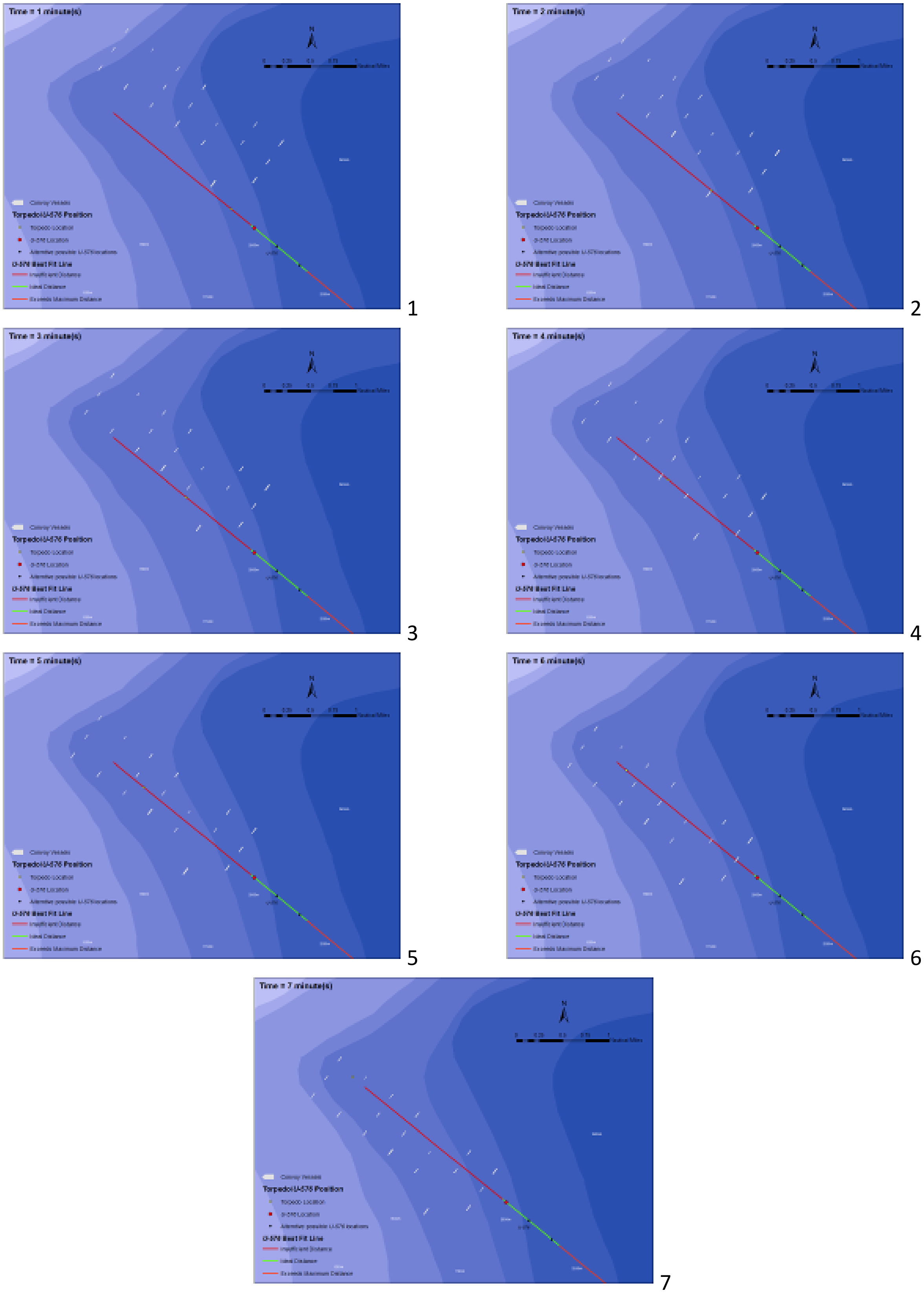


Figure 5.16 Snapshots of KS-520 animation. Time intervals = 1 minute (Drawn by Author)

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In regards to the structure of the convoy, the animation offers additional insight. First, the position of *Chilore* is examined, followed by the position of *J.A. Mowinckel*, and finally *Bluefields*. The location of *Chilore* was reported to be 600 yards ahead of its appropriate position within the convoy (Freeman 1987). This account seems to corroborate with evidence produced in the animation (Figure 5.17). In Figure 5.17, the location of the torpedo and the location of *Chilore* align almost perfectly. This agreement between convoy speed, torpedo speed, and the information from the historical record, result in the conclusion that *Chilore* was in fact 600 yards ahead of position.

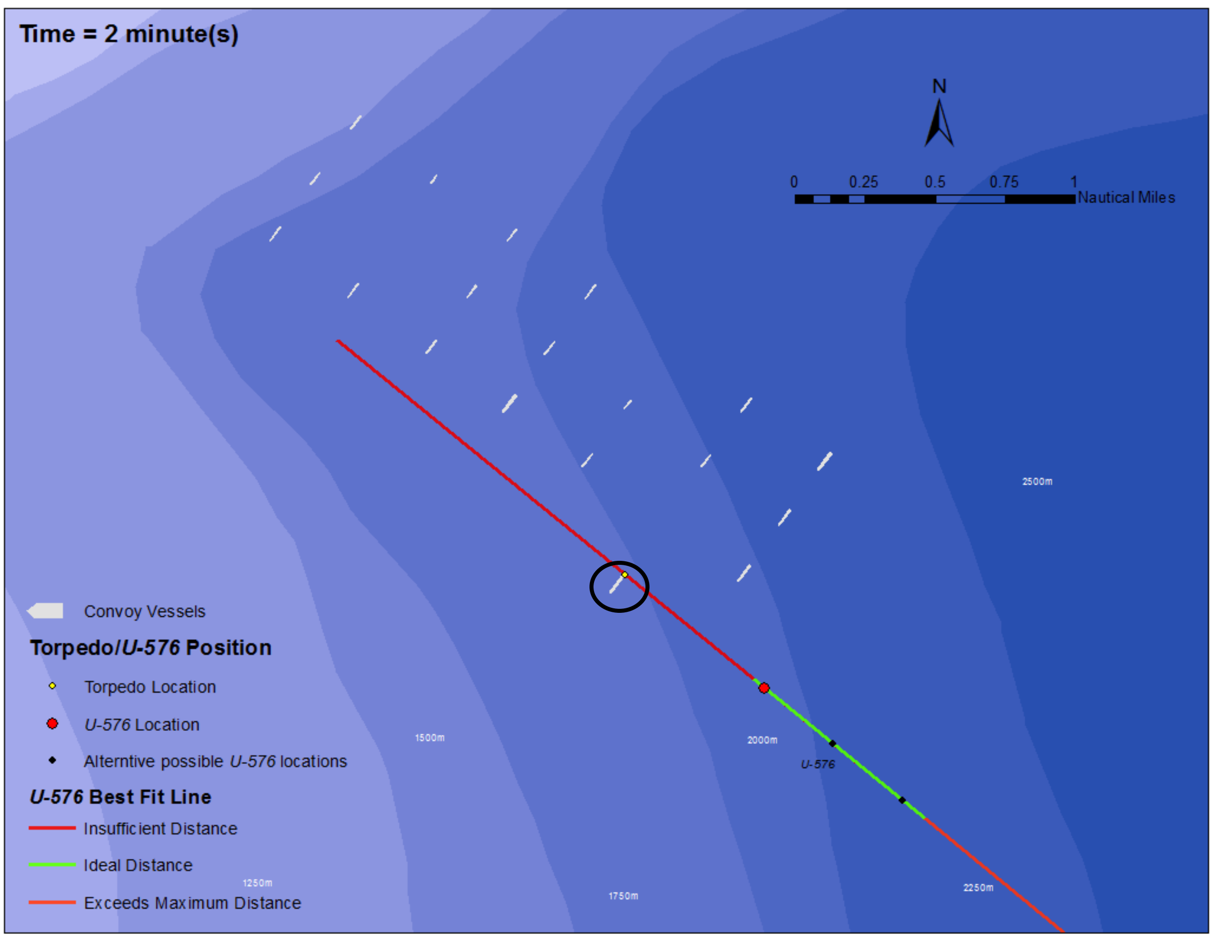

Figure 5.17 Screenshot from the Battle of Convoy KS-520 animation, highlighting the torpedo hit on *Chilore* (Drawn by Author).

The position of *J.A. Mowinckel* and the speed of the torpedo do not corroborate as well as with *Chilore* (Figure 5.18). The distance between the location of the Allied merchant vessel and the supposed position of the torpedo, four minutes after the strike on *Chilore*, is approximately 480 feet (146 meters). One of two possibilities easily explains a distance of this magnitude. The first is that *J.A. Mowinckel* was also out of position, but by a much smaller margin. The second possibility is that, perhaps, the captain of the merchant vessel changed course upon observing the attack on *Chilore*.

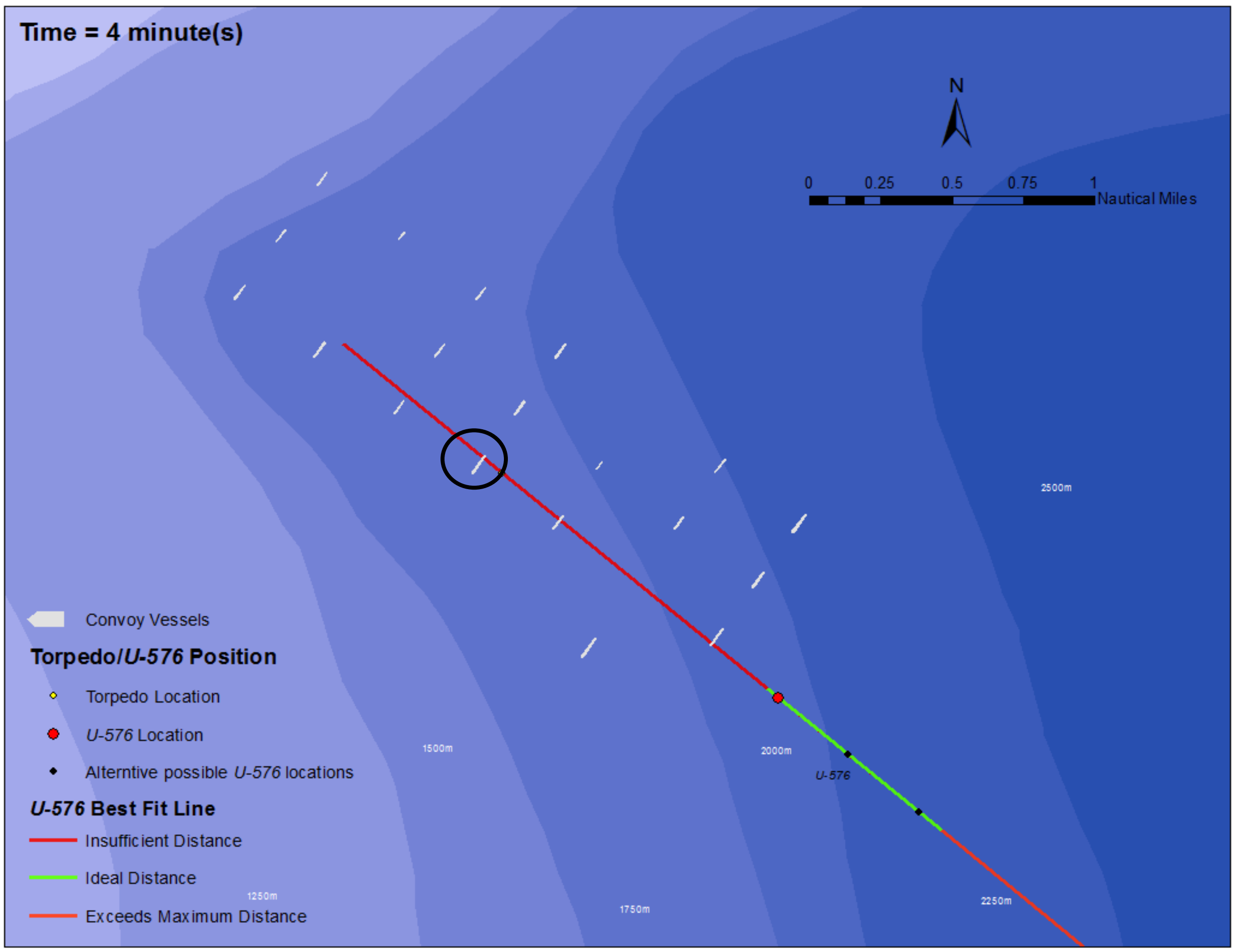

Figure 5.18 Screenshot from the Battle of Convoy KS-520 animation, highlighting the torpedo hit on J.A. *Mowinckel* (Drawn by Author).

The final position examined was the location of *Bluefields* and the estimated location of the torpedo (Figure 5.19). Once again, these two locations do not corroborate as well as in the situation of Chilore. The merchant vessel appears to be further behind the appropriate position. The distance in this situation is approximately 1000 feet off. Once again, like in the example with *J.A. Mowinckel*, either *Bluefields* was simply out of position prior to the attack, or altered course after witnessing the preceding attacks.

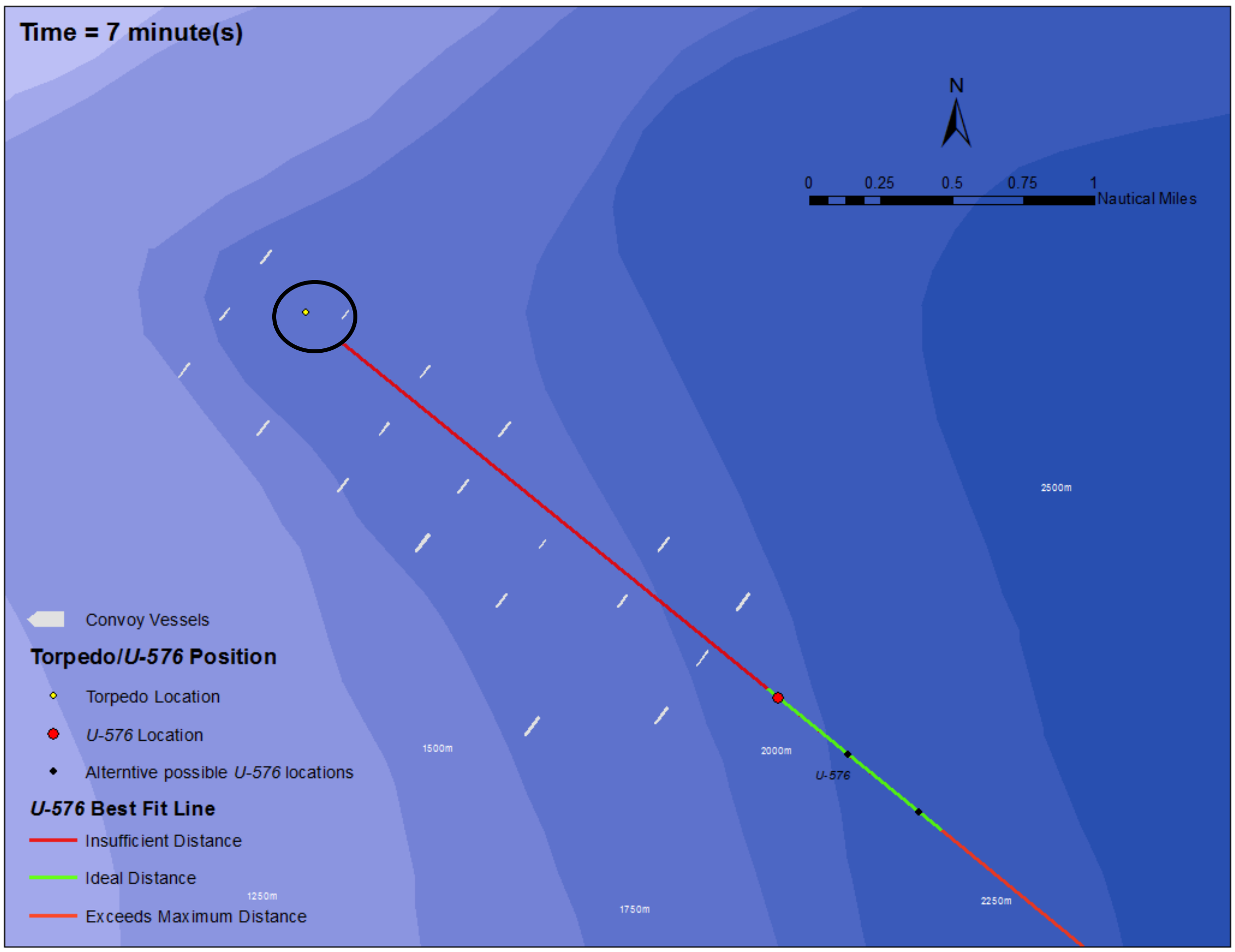

Figure 5.19 Screenshot from the Battle of Convoy KS-520 animation, highlighting the torpedo hit on *Bluefields* (Drawn by Author).

The obvious downfall of using animations is that of distribution. The purpose of the animation makes no difference, whether it is analytical or communicative, sharing it becomes problematic. Much like any digital content, there are two main ways to distribute the visualizations. The first being by means of physical media, such as on a CD or DVD, and the second is via the Internet. The Internet is thought to be the preferred method at this time. Issues concerning lost or damaged physical media are not found with Internet-based distribution. In addition, if updates to the visualization are required, they can be completed and then replace the current outdated versions online. Users can be assured to always have the latest version, rather than relying on physical media.

Both 3D technology and the use of scaled, analytical animations are not currently found in the existing literature of battlefield visualization. Short-term naval events, like the battle of Convoy KS-520, are well suited for these new types of visualization. Depending on the purpose of the visualization, the scale, and the available data, one method may be preferential over the other. When designing battlefield visualizations both techniques ought to be considered, their limitations examined, and if applicable, utilized.

Conclusion

The progression of battlefield mapping and visualizations has been one of continual growth. This progression started with etchings on cave walls during the Neolithic period and has culminated in what is referred to here as the modern battlefield map. An instrument was developed to investigate this progression with the ultimate goal of establishing a baseline of current battlefield visualizations. It was determined that there has been little change to the modern battlefield map over the last two centuries. This is a surprising realization based upon the extreme advancements in technology over that same period, and it was this realization that led to an investigation into other closely related disciplines to find potential technologies and techniques that could be used to advance the current state of battlefield mapping.

To properly assess the uses of advanced technologies and techniques in other disciplines, a separate instrument was developed. The results from this analysis demonstrated that there were two main techniques that were most applicable to use in battlefield visualization. This was based upon their ability to model complex processes and the ability to incorporate a spatial element. These two technologies, the use of 3D and 2D animation, were then used in two separate case studies of the battle of Convoy KS-520.

The first example, the use of 3D technologies to visualize the battlefield landscape, was used to examine the various three dimensional viewsheds and the fields of fire. These two elements of the battlefield landscape are well suited for visualization in 3D due to their complex spatial relationships. Describing these relationships in text or viewing them in 2D fail to convey their true relationships and interactions.

The second example, the use of 2D analytical animation, was used to examine the probable location of *U-576*. While the battlefield landscape can be recreated in a static environment, viewing these dynamic processes in the form of an animation more closely represents reality, and therefore aids in interpretation. The same animations that were used in the analysis of the landscape are also excellent communicative devices for the interested individual. Both of these examples have limitations however, and it is overcoming these limitations that also must be considered when choosing to incorporate these techniques into research projects. The main issue is with distribution. While there are many avenues for distribution, some may be more appropriate than others given the circumstances and requirements of the research.

Both of these examples are for short-term naval encounters. There is still the question of how best to analyze and visualize long-term naval encounters. These visualizations not only operate on a longer time scale, but also cover much larger geographical extent. Special considerations must be taken into account when visualizing these events and will be examined in the following chapter.

Chapter 6 : EXTENSIONS THROUGH SPATIAL STATISTICS

Introduction

Historically, naval battlefield have been visualized in a very similar fashion for the last 500 years, featuring basic hull form representation, frequently with arrows denoting vessel paths for small spatial and time extent battles (Figure 2.14), and simple arrows and text for larger extent battles (Figure 5.3). Some alternative means for visualizing smaller extent battles was given in Chapter 5, however the methods used to analyze those battles require substantially different approaches to those with larger extents. Based upon deficiencies identified in the previous chapters, a new method of examining and analyzing large-scale naval battlefields is proposed, a methodology based upon analysis of battlefields by means of complex spatial analysis. No longer is a simple map utilizing arrows and text sufficient to gain in depth understanding of the battlefield landscape.

With the addition of computers and large georeferenced databases, or geodatabases, new analysis is possible. Variables that previously could only be mentally visualized based upon limitations of analog methodologies can now be examined fully in a digital media. This extension of analysis not only makes possible visualization of new variables and data, but also extends the reach of the analysis to a wider audience. This is accomplished by giving the researcher the ability to convey complex ideas -- once limited to his or her mental map of the events, which was created by a unique skill set that may have taken years to develop -- in a visual medium, where historically this analysis was left for explanatory text.

The following is a brief introduction into some of the possible new methods for extending the existing methods of large extent mapping based upon complex spatial analysis using GIS. The methods used below are arranged in order of complexity, starting with more basic forms of spatial analysis, and ending with the most advanced. Some of the examples below not only extend the analysis by utilizing these complex spatial analytical techniques, but also lend themselves to some of the advanced visualization techniques used in Chapter 5, which make them extremely robust tools for battlefield analysis.

The first method examined below takes the historical battlefield event data used in Wagner (2010), which is arguably already a step beyond the basic large extent battlefield visualizations, and uses a combination of spatial analysis and animations to better understand the trends in the NCT of the Second World War. Two different examples are given, each focusing on these trends, and highlighting some of the advantages simple GIS-based spatial analysis offers. The second method examined attempts to examine potential key physical variables that may or may not dictate the occurrences of U-boat activities in the NCT during the Second World War. To accomplish this, key spatial variables were identified, and a series of spatial analytical measures were taken in an attempt to identify some possible correlations between the physical battlefield landscape and U-boat attacks.

Both of these methods go beyond basic examination of the historical or archaeological records, in an attempt to gain some deeper understanding of the battlefield landscape. The prior visualizations in Chapter 5 were examples of new and inventive methods for visualizing the same historical and archeological variables, while the visualizations included in this chapter attempt to go beyond simply mapping the basic interactions between two opposing forces, and highlight the less obvious, but potentially more informative elements of the battlefield.

Advanced Temporal Analysis of the NCT

When examining a naval battlefield landscape for an entire major theater of operation, like the NCT, there is likely going to be some temporal changes or shifts. Historically this type of analysis has been highlighted by showing the extent of the theater accompanied by arrows and dates, and the actual analysis is left to the readers ability to infer these changes through time on their own. An example of this method is Figure 5.4, which clearly show the progression of battlefield activities in the Atlantic Ocean during the Second World War. In this example, there are a variety of labeled zones and arrows, but the overall purpose of the visualization is to highlight the shifting areas of importance in the theater. The methods used to create these zones and arrows were probably based upon the expertise of the author, rather than based upon true spatial analysis. In Wagner (2010), battlefield data was imported from the historical and archaeological record into a geodatabase, and computer-based spatial analysis was utilized to create maps of the NCT (Figure 4.7), which are similar to those found modern military atlases. This type of approach is much more methodologically sound, and is based upon the underlying rigorous computation ability of modern spatial analysis software.

To further extend the work done by Wagner (2010), the same dataset was used, and new techniques examined. The main deficiency with Figure 4.7 is that it only shows the statistical central point of the given month, and hides the contributing attack events that lead to that central point. It is a good tool when explaining the general trends of the NCT, but may oversimplify the battlefield landscape. Two different approaches were taken to view the temporal changes in the NCT. The first approach was examining the month-by-month changes as a surface, rather than a central point, in an animated form. The second approach was examining the cumulative sum of battlefield activities viewed, once again, as a surface, and animated. By exanimating these two separate, but complementary products, it was hypothesized that a better understanding of the over battlefield landscape would be possible.

Advanced Monthly Analysis of the NCT Battlefield Landscape

The NCT, like most battlefields, saw changes over time. Examination and analysis of these changes can allow historians and archaeologist greater insight into the acts of naval warfare. Previous examples may hide or skew interpretations, whether intentional or not, based upon certain deficiencies such as oversimplification. By including representation of all battle activities, not just their statistical centers, a greater understanding of the overall battlefield landscape is possible.

The approach taken here was to visualize the battlefield activities in the NCT as a continuous surface, rather than a discrete point. This surface can be thought of as being similar to a precipitation, or rainfall map (Figure 6.1). In this example of a precipitation map, what is visualized is not just the discrete location which is going to receive the most rainfall, but a continuous surface which shows not only the location of high rainfall represented by yellows or reds, but also areas which are receiving less rainfall represented by areas of greens and blues. By taking this approach, the National Weather Service (NWS), is able to give the public a better idea of whether or not to pack an umbrella, than if they just showed a point where, for that given moment in time, the statistical central point was located. The NWS provides a surface animation that allows the public to not only see the surface at a particular moment in time, but to make inferences about where the weather system may be moving by drawing upon their previous experiences with weather systems, and ultimately increase their confidence in their decision of bringing appropriate rain gear.

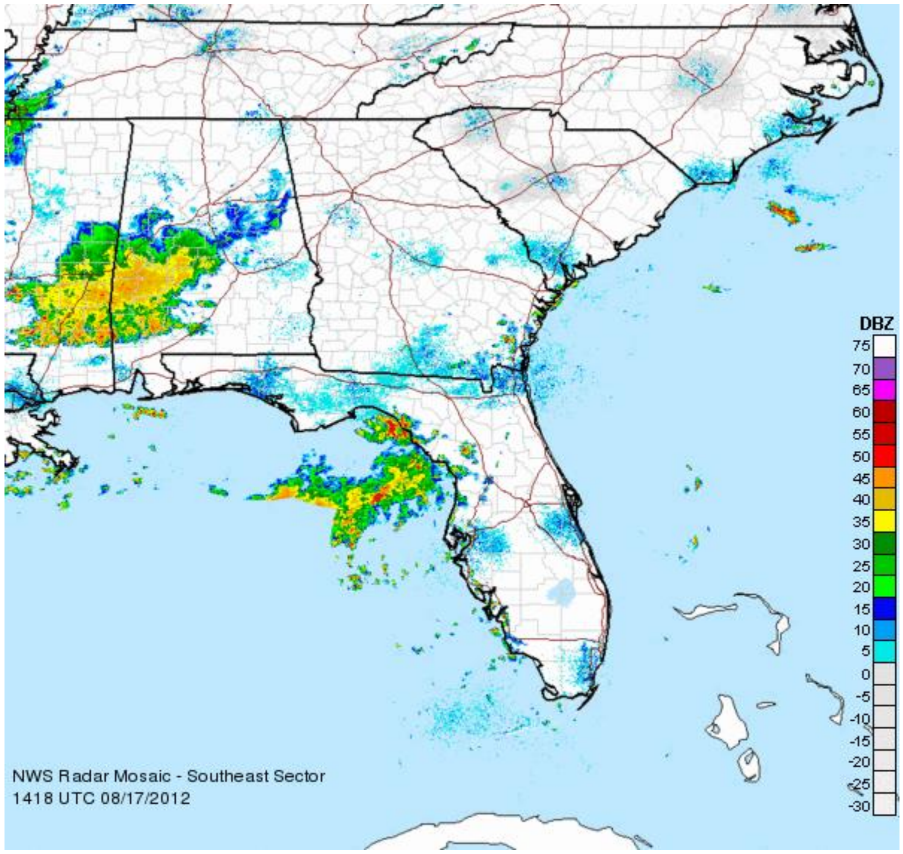

Figure 6.1 NOAA National Weather Service precipitation map of the Southeast United States (NOAA NWS).

Much like the NWS, the example below (Figure 6.2), visualizes the battle events of the NCT with a surface. In this example, areas of lower battle activities for a given month are represented by a lighter shade of green, and areas with higher battle activity levels are represented with a darker shade of green. Once again, each of the images provides a snapshot for the given month, but the real power of analysis lies within the animated product. While it is impossible to animate the below series of graphics here within this body of text, each snapshot is given with a corresponding number to allow the reader to see where the distribution of battlefield activities were, month to month from January 1942 through July 1942 in the NCT. As previously mentioned in Chapter 5, there are alternative methods for distributing digital media, and it is recommended that these methods be utilized when disseminating research.

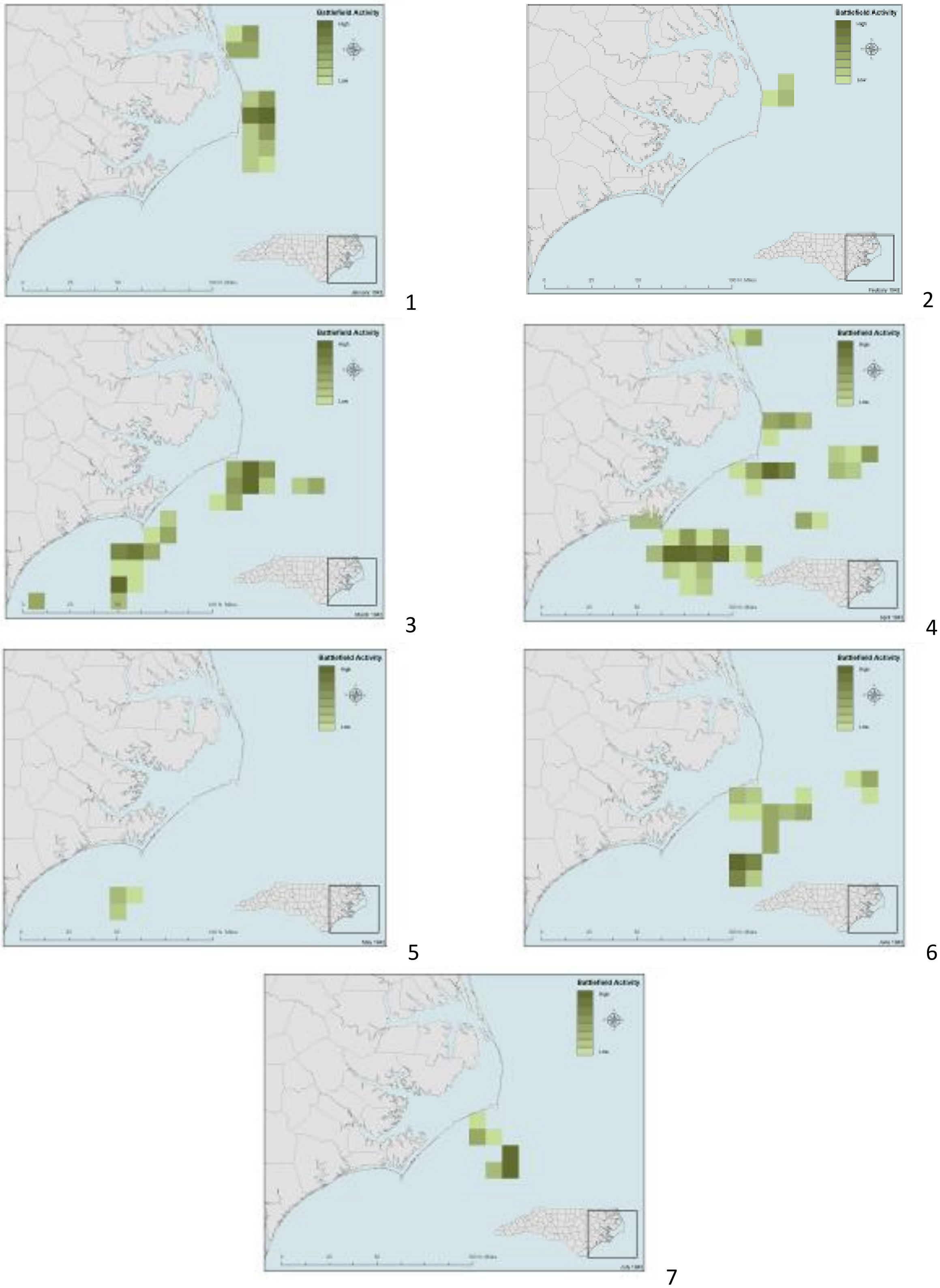

Figure 6.2 Monthly battle activities in the NCT represented as a surface (n = 54; t = 1 month, Drawn by Author).

What this series of images highlights is that there is not just one area of interest during any given month during 1942. There are in fact many hotspots of battle activities, which are all but lost when viewed as one discrete location, whether that location is viewed as point as in Figure 4.7 or polygonal area in Figure 5.4. For example, there is a clear shift in battle activities from the northern Outer Banks of the North Carolina coast in January 1942, to the southern Outer Banks and Crystal Coast area off Morehead City in March. The next month, April 1942, is perhaps the most interesting in terms of visualizing the NCT as a surface. The distribution is less clustered in one geographic region than the previous three months. This is important because, when the battle activities are visualized as a mean central point, there is no way to predict if that central location is representing tight clustering at that location or a larger spatial distribution, like in the case of April 1942 (Figure 6.3). Additionally, there is no way to judge the magnitude of the battle activities either. With the example of April 1942, hypothetically speaking, if the surface's spatial distribution was identical, but the overall battle activities were less per unit area, the resulting battle centroid would still be located in the same location.

Visualizing naval battlefields as a continuous surface, much like a precipitation map, clearly has its advantages. It not only highlights the areas of the battlefield landscape that have the highest activities, but also those that had less. This allows for a more complete view of the battlefield, and avoids the problem with oversimplification caused by reducing these activities down to a central point. Even if that same area is visualized as a larger polygon, like in Figure 5.4, there is still important information excluded. This previous example is not the only way to visualize a naval battlefield as a surface, however, as the next example takes this concept one step further, and provides addition insight into the complex landscape of the NCT.

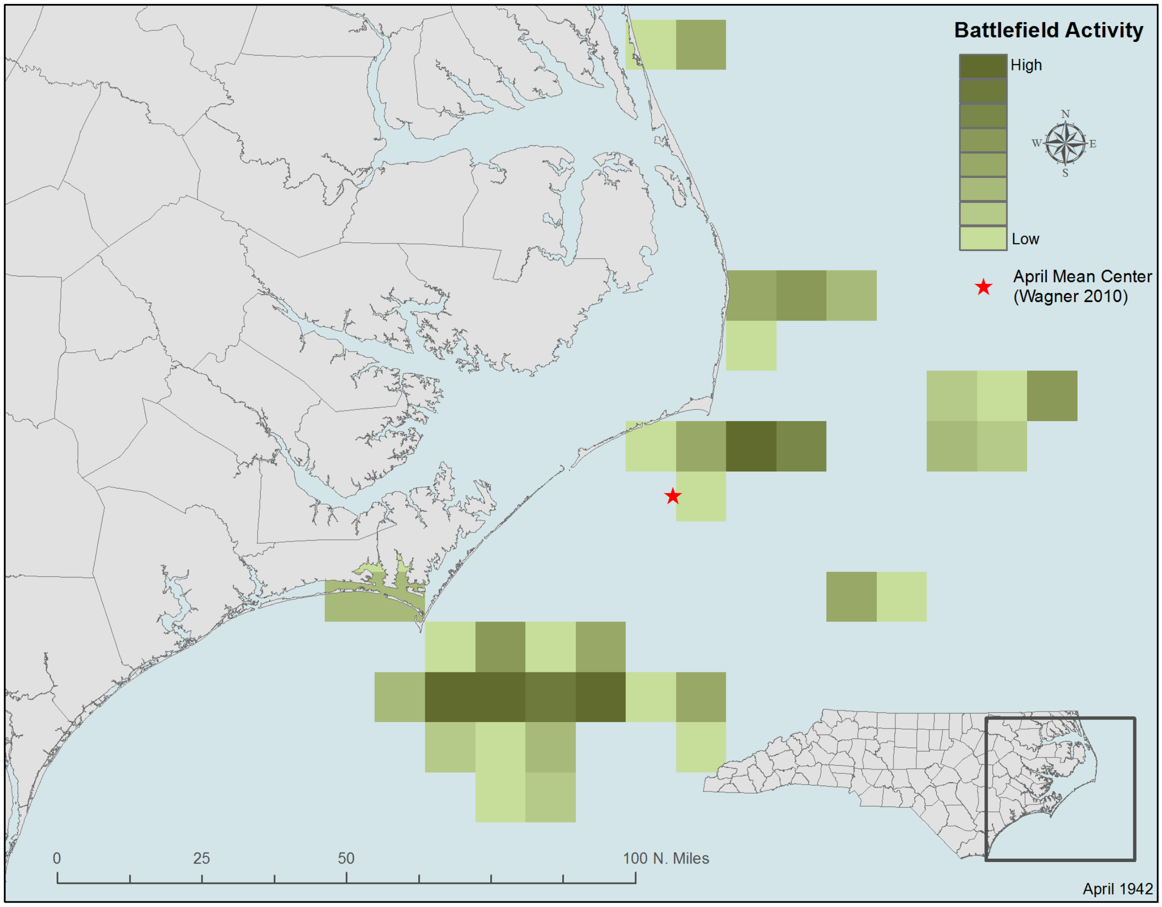

Figure 6.3 Surface visualization of battlefield activities during the month of April, 1942, overlaid with the monthly battle mean center (n = 54, Drawn by Author).

Cumulative Monthly Analysis of the NCT Battlefield Landscape

In the previous example, the NCT was viewed in a similar manner to a precipitation map from the NWS. The precipitation maps of the NWS are not the only digital product offered, however, and a quick visit to their website will reveal a whole suite of advanced visualizations. Another interesting product offered is a cumulative view of precipitation (Figure 6.4). In this example, the rainfall totals for each pixel were added for a given period. The values range from a light green, which equals less than one half inch for the previous 6 hours, up to dark reds and purples, which represent over two and a half inches of rainfall. This particular visualization is a powerful tool for those interested in both local rainfall amounts, and those that may be concerned with localized flash flooding. That data used in the creation of the cumulative map is also an important tool, and can be animated. This animation allows for a better understanding of the temporal distribution of localized rainfall.

The battle events in the NCT can also be viewed in a similar manner to this additional NWS product. The previous example of battle events in the NCT (Figure 6.2), can be added together to form a cumulative surface. In the example below (Figure 6.5), each individual month was added to sum of the previous months battle activities. The result is a series of images in which a cumulative surface builds, and the overall battlefield trends emerge.

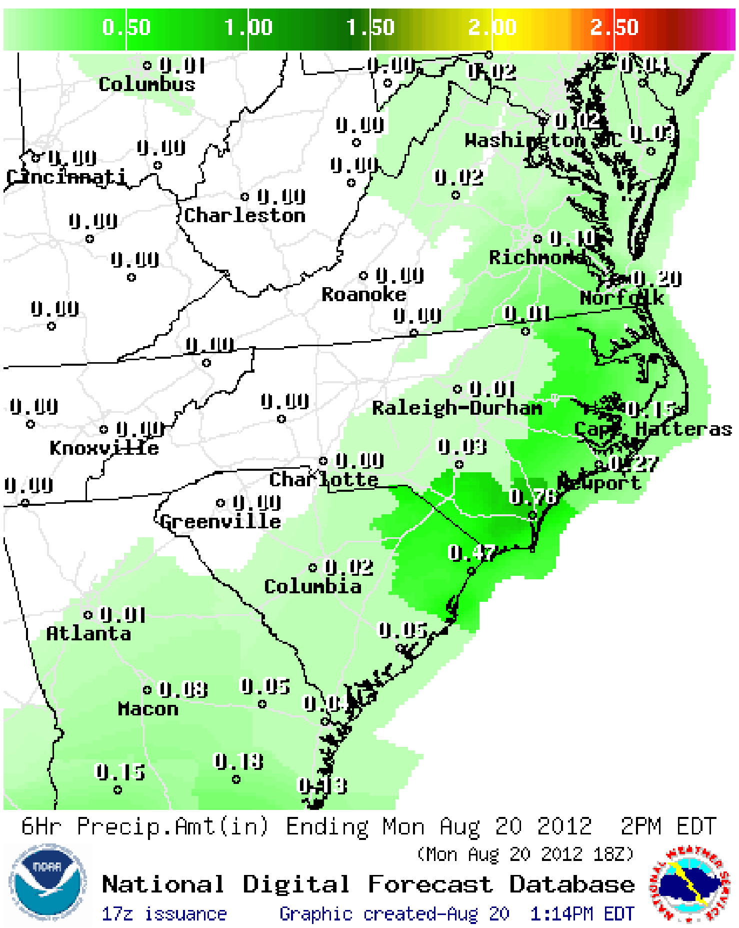

Figure 6.4 Cumulative precipitation (NOAA NWS).

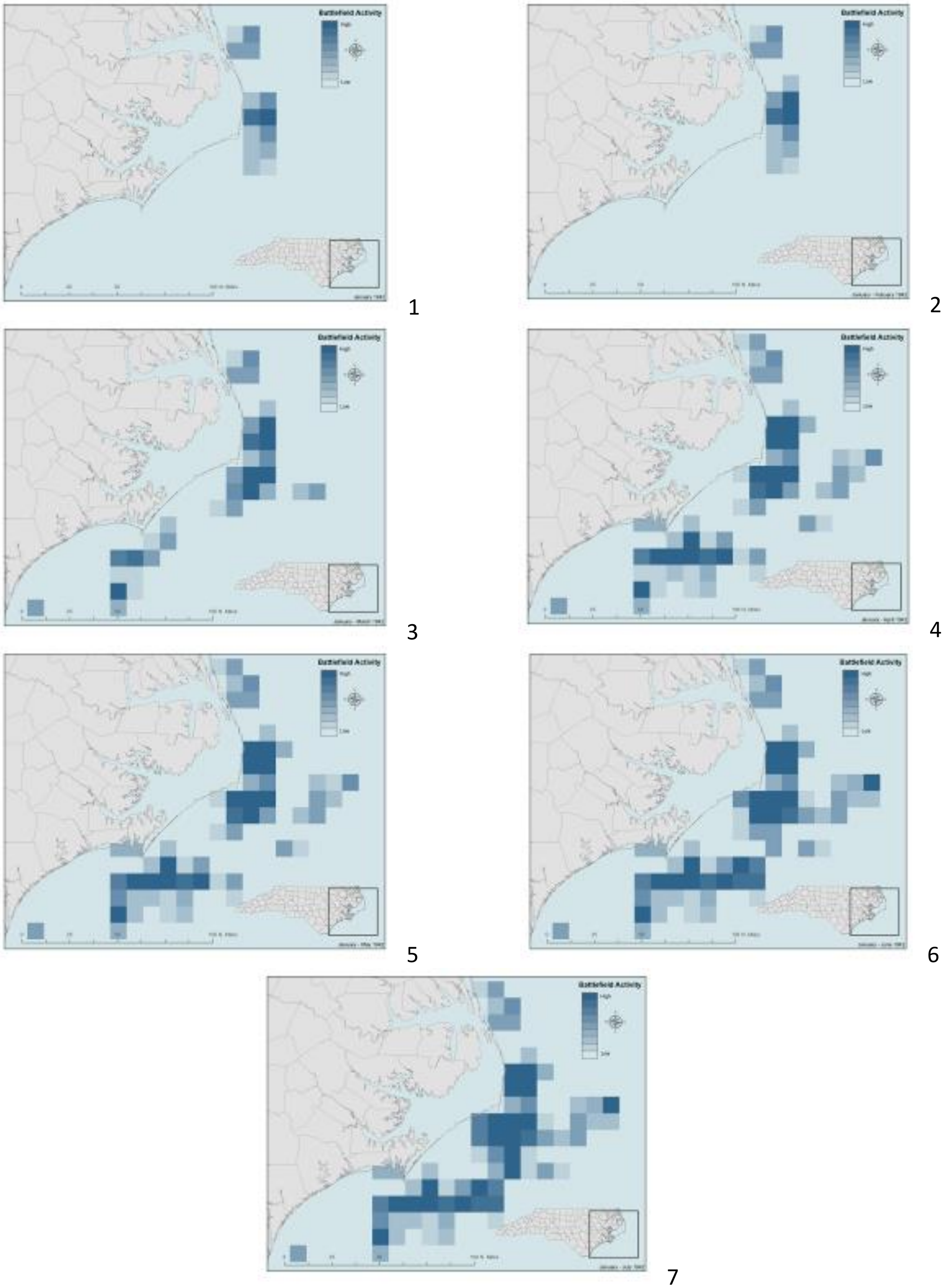

Figure 6.5 Cumulative Monthly Totals for the NCT (n = 54, t=1 month, Drawn by Author).

In this example, pixels with a light blue shade represent low cumulative battlefield activities and pixels with a darker blue shade represent the higher values of cumulative battlefield activities. Just like the cumulative example from the NWS, this visualization highlights the areas that received the highest amounts of battle activities for a given period. Additionally, the series of images produced are well suited for animation; however, for the purpose of visualization in this written text, they are viewed as a series of snapshots. These products could be distributed either by means of physical media such as a DVD or CD, or by digital online distribution through a web site.

The main advantage of this visualization over the previous example from the NCT is ability to identify major areas of battle activities that persisted through time. The previous example highlighted the area with the highest values for a particular month, but lack the ability to convey the areas in the NCT which consistently had high levels of battlefield activities during the first half of 1942. Additionally, because this visualization is viewed as a continuous surface, it has the same advantage over the simplified mean center calculation. When the mean center calculation is overlaid for the first half of 1942, similar results are seen (Figure 6.6). Once again, much like in the previous example of April 1942, the statistical center is actually located in an area which saw relatively little to no battle activities for the given year. This is yet another example of the advantages of visualizing battlefield activities as a surface, and an excellent choice for the NCT.

There are alternative ways to represent surface data, however. Perhaps the most common way is to simply utilize the raw value with a type of gradation in color (Figure 6.2 and Figure 6.5). This type of visualization is most common when examining precipitation, but another commonly used continuous data source is visualized in completely different manner. This other data source is elevation. One of the most recognizable map products are USGS topographic map products (Figure 6.7). In these maps, elevation data is represented by a series of lines, which follow areas of equal elevation, or contours. This method of representing a surface as a series of contours can be applied to land elevation or bathymetric depths, or even the battle activities of the NCT. The main advantage of this technique when applied to the NCT is that it makes zones of equal battle activity more readily identifiable. One downfall of the contouring method is that the methods used to create these contours further reduces the overall map accuracy. This is can be seen in Figure 6.8, where there are contours that extend passed the raster cells.

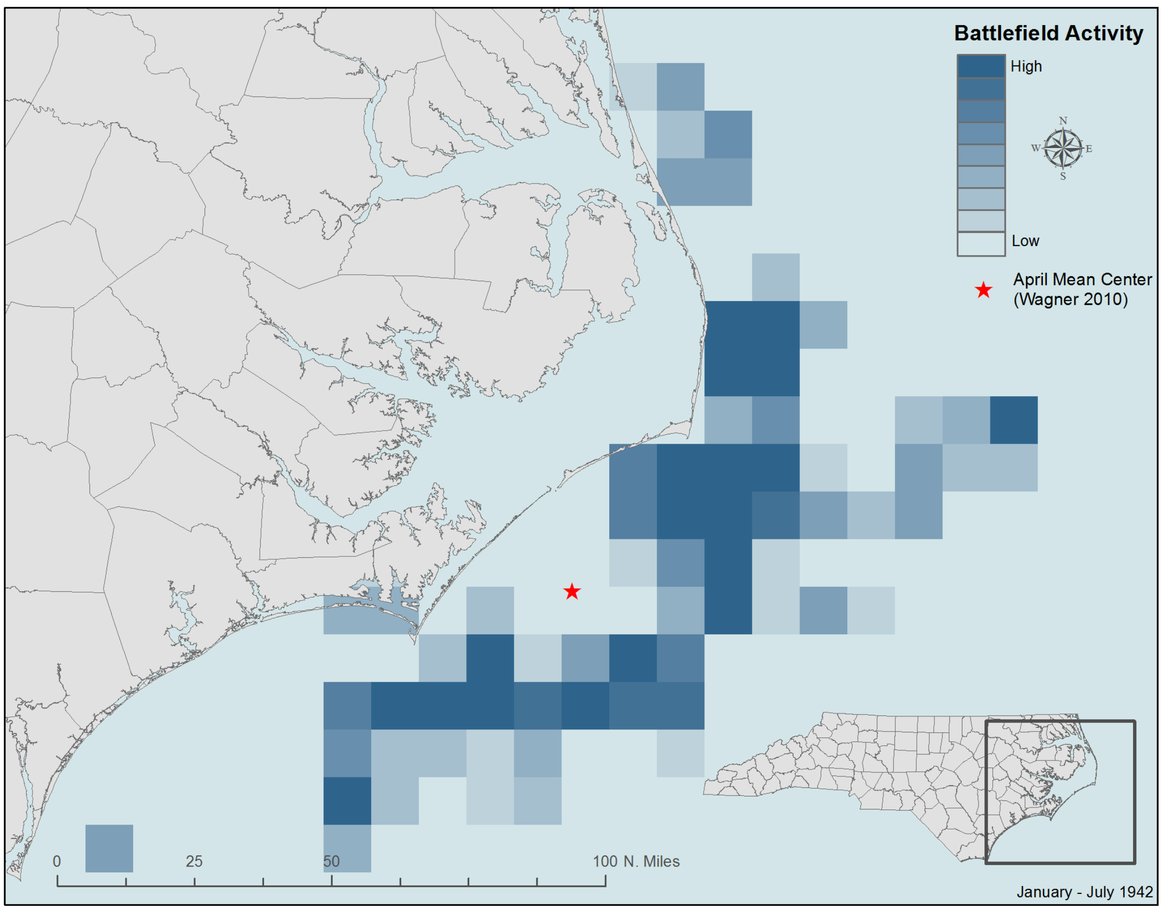

Figure 6.6 January - July 1942, cumulative surface overlaid with the 1942 mean center (n = 54, Drawn by Author).

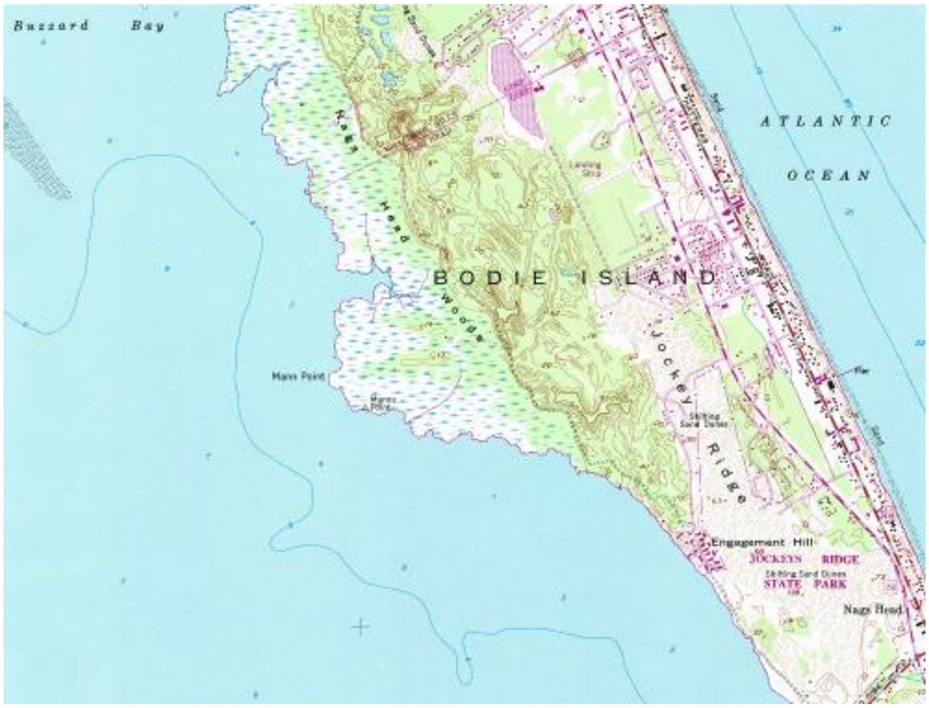

Figure 6.7 USGS topographic map highlighting contour lines (USGS 2012).

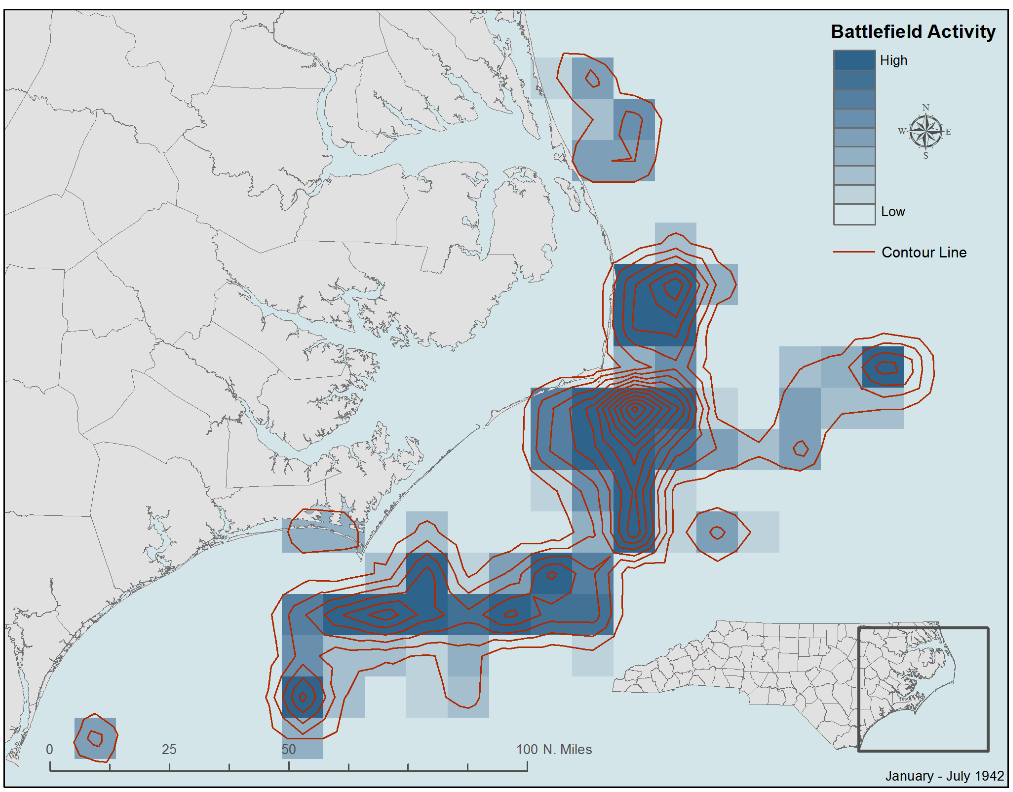

Figure 6.8 Cumulative battlefield surface overlaid with surface contours (n = 54, Drawn by Author).

Both of these examples highlight some of the more robust analysis modern GIS software is capable of in terms of visualizing naval battlefields. While these offer insight into the trends throughout the battlefield landscape, they do not offer as much insight into why those battle events occurred where they did. Modern GIS software and complex spatial analysis can potentially offer additional insight into this question as well.

Spatial Modeling and the NCT

One of the greatest strengths of modern GIS software is the ability to replace common sense analysis with rigorous, complex spatial analysis. In terms of spatial modeling of the NCT, the methodology was initially left flexible, to allow for potential issues with the data, as was previously noted in Chapter 4. This flexibility would allow for the most meaningful results possible in the event of data limitations. Ultimately, the utilized methodology followed the following progression. Initial exploratory data analysis was conducted. The results of this analysis, which would guide the modeling process, determined the most appropriate method to be a technique called cartographic modeling. Unfortunately the data did not allow for the most robust forms of spatial analysis, however, the cartographic modeling still renders insight into the correlations between physical elements of the battlefield landscape and attack events in the NCT.

Cartographic Modeling

There currently exists a multitude of spatial modeling techniques available thanks to the integration of the computer into spatial statistics. Each spatial modeling technique has strengths and weakness, however, some are more robust than others. Cartographic modeling is one such technique. While it is not as robust as some, it can still produce meaningful results, while overcoming some common data issues that may potentially plague more powerful techniques. Cartographic modeling is a process by which spatial variables undergo a series of steps, and ultimately produces a probability surface. First, the variables are defined and identified. Next they are categorized, and then normalized. The variables are then weighted and ultimately added together to form a probability surface (Figure 6.10).

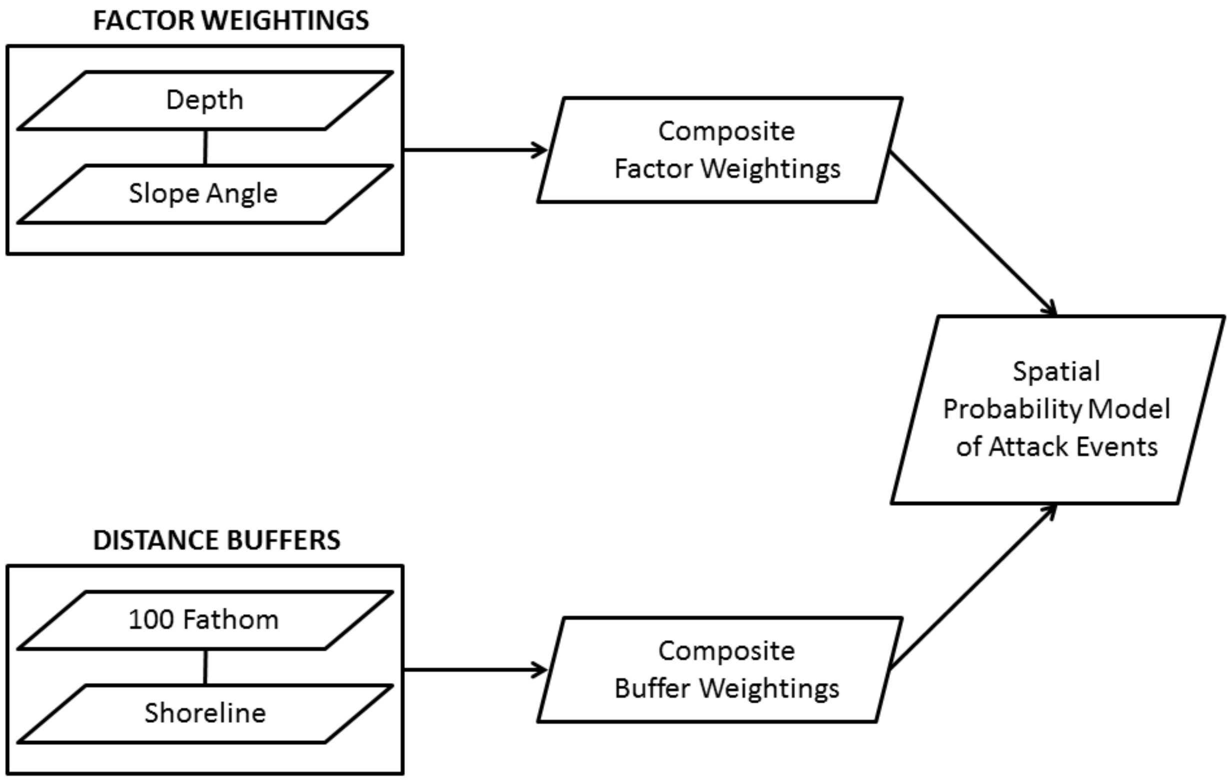

Figure 6.9 Cartographic Modeling workflow (Drawn by author).

To perform cartographic modeling in the NCT four variables were identified and preprocessed for further analysis (Table 4.6). There were issues with data collection and preprocessing which were noted in Chapter 4. These issues were dealt with as best they could prior to undergoing the remainder of the processing. The next step involved data categorization and normalization. The four original variables were ultimately categorized into 36 sub-variables, and then normalized. This was completed using GIS software. The normalization process takes the area of each variable sub-category and calculates it as a percentage of total area, and then further normalized the variables by the attack events. The results of this process are found in Table 6.1.

	Variable	Attack Events	% Total Area (NM^2)	Normalized Frequency
	100 FATHOM(NM)			
1	10	26	715.3	0.036345575
2	20	10	1886.9	0.005299744
3	30	9	1681.2	0.005353351
4	40	3	1138.3	0.002635435
5	50	0	844.3	0
6	60	0	563.1	0
7	70	1	391.9	0.002551329
8	80	0	220.2	0
	SHORELINE(NM)			
1	10	6	2426.009591	0.002473197
2	20	24	2401.647393	0.009993141
3	30	6	2373.401705	0.002528017
4	40	10	2352.41861	0.004250944
5	50	2	1782.997425	0.001121707
6	60	0	908.926314	0
7	70	0	792.7131488	0
8	80	1	558.9952372	0.001788924
9	90	0	266.9287537	0
10	100	0	22.91609328	0
	SLOPE ANGLE			
1	0 – 5 degrees	48	12179.85984	0.003940932
2	5 – 10 degrees	0	584.9289076	0
3	10 - 15 degrees	1	176.1711115	0.0056763
4	15 – 20 degrees	0	25.29225308	0
5	25+ degrees	0	2.623980146	0
	DEPTH(m)			
1	250	40	55.5358557	0.720255401
2	500	3	483.1610762	0.006209109
3	750	0	755.0636011	0
4	1000	0	665.9114243	0
5	1250	0	542.0748457	0
6	1500	1	455.4951805	0.002195413
7	1750	0	256.5846843	0
8	2000	0	196.8068982	0
9	2250	0	164.9207811	0
10	2500	0	118.0598249	0
11	2750	2	119.0237026	0.016803376
12	3000	1	516.1673756	0.001937356
13	3250	0	944.4851119	0

Table 6.1 Normalized frequencies of model variables.

Once the data was normalized, it was then reclassified and weighted. Factor weightings were reclassified into three categories and distance buffers were reclassified into five categories, based upon the methodology outlined in Walsh et al. 1990. This process prepared the variables for the final stage of the analysis, the addition of the composite buffer weightings and the composite factor weightings. The two composite surfaces were added together, which resulted in the probability surface. The resulting surface had seventeen independent zones (Figure 6.10).

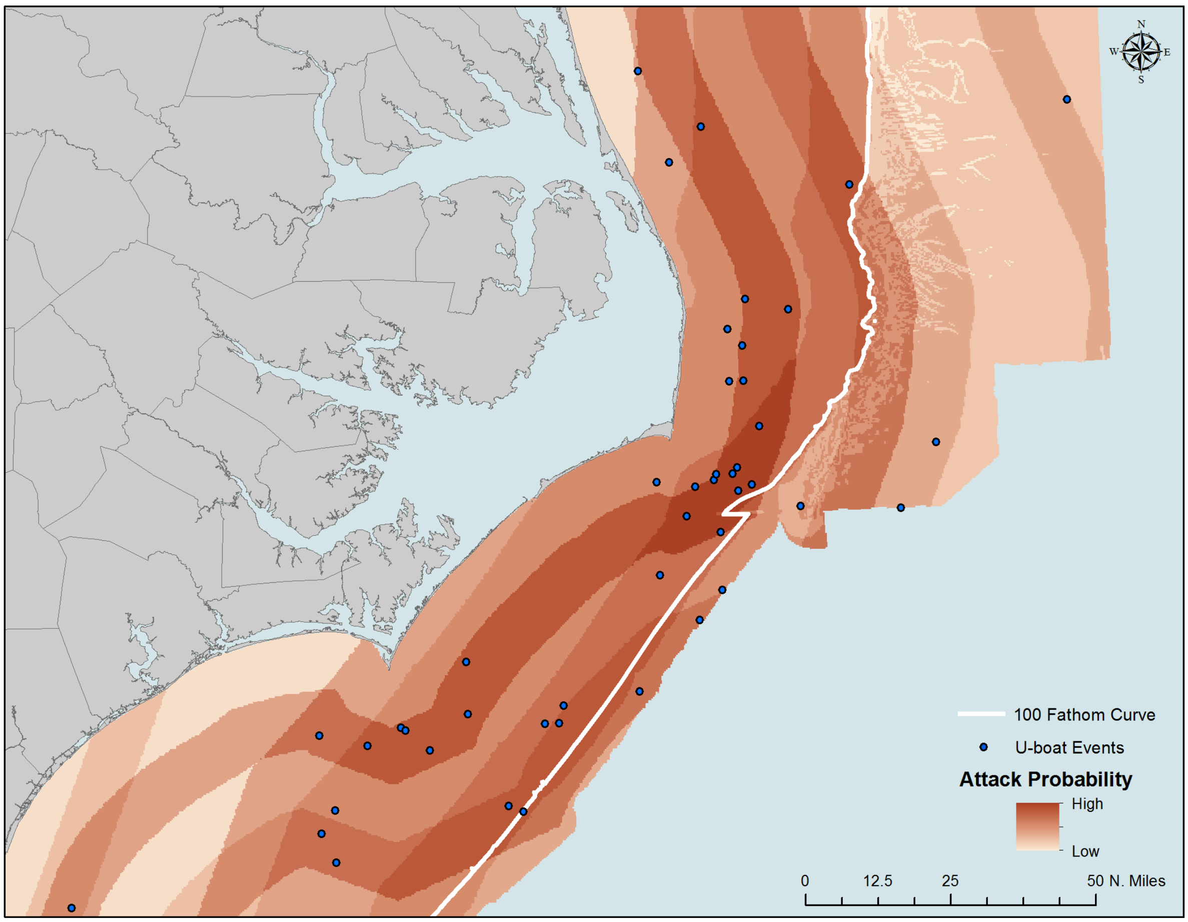

Figure 6.10 Probability surface for attack events in the NCT (n = 54, Drawn by Author).

Upon initial review of the probability surface, cartographic modeling is a relatively successfully adaptation for visualizing and analyzing a naval battlefield. Not only has this technique never been applied to a naval battlefield, but also this is the first adaptation to any battlefield. High values in the probability surface are represented in the darkest red, and low values with lighter red. The spatial coverage of each probability zone is noted in

Table 6.2. The 100-fathom curve and U-boat attack events were added to this visualization to provide context.

Attack Probability	**Coverage (NM)**	**Coverage (%)**
High	151.6806301	1.175275
	1128.238575	8.741987
	156.0539304	1.20916
	1644.725333	12.74391
	304.5274737	2.359585
	82.80115129	0.641572
	1191.286986	9.230509
	1285.021388	9.956796
	191.9149924	1.487025
	147.8904366	1.145907
	2396.204092	18.56663
	1.530655085	0.01186
	485.8007688	3.764154
	1610.030485	12.47508
	8.892377163	0.068901
	1835.765666	14.22415
Low	283.6085208	2.197498

Table 6.2 Spatial coverage of probability.

The probability surface highlights a pocket of high probability off the south east coast of Cape Hatteras, represented in the darkest shade of red. This area is within close proximity to the 100-fathom curve and the shoreline. This is important because it indicates two things. The first is the proximity to the 100-fathom curve, important because merchant vessels used this curve as guideline when traveling in convoy (Bright 2012), and because it is approaching the limits of the test crush depth of the U-boats operating in the NCT. 100 fathoms is approximately 182 meters, and the various U-boats operating in the NCT were rated to approximately 230 meters (Table 6.3). This might be indicative of a U-boat commanders desire to operate in deeper water, which would presumably offer added opportunities for concealment. The second major indicative element of this area of high probability is the funneling effect of the topobathy, or elevation-bathymetry environment. It is at this point that the 100-fathom curve comes into the closest proximity of the shoreline. While this funneling effect is not a new interpretation of the battlefield landscape (Bright 2012), this is the first time that this effect has been spatially modeled.

U-Boat Type	**Number in NCT**	**Crush Depth**
VIIB	1	230m
VIIC	12	230m
IXB	2	230m
IXC	5	230m
IXC/40	1	230m

Table 6.3 Type, number, and crush depths for German U-boats operating in the NCT (Wagner 2010; Rossler 1989).

Critiques and Comparative Analysis of Spatial Modeling

The modeling technique is not without critique, however, as artifacts from the primary data sources are visible. The most notable are the striations seen throughout the probability surface. This is potentially due to multiple variable correlations, or variables that share a similar orientation. For example, depth and distance from shore are correlated, and share the same west to east orientation. The variable that was not correlated, slope, is responsible for the "feathering" of the probability surface off the outer banks and east of the 100-fathom curve. The remainder of the surface was not affect by this variable due to limited to no slope angle found on the continental shelf itself.

An attempt to correct some of the striations was made by re-interpolating the surface. Data points were extracted from the probability surface, and then smoothed by utilizing IDW. A new, more evenly distributed surface was created (Figure 6.11). One downfall of this process was a reduction in overall raster resolution, but the key elements of the surface are still visible.

The purpose of this was to smooth the original probability surface in an attempt to eliminate artifacts of the original variables, and in regards to that is thought to have been successful.

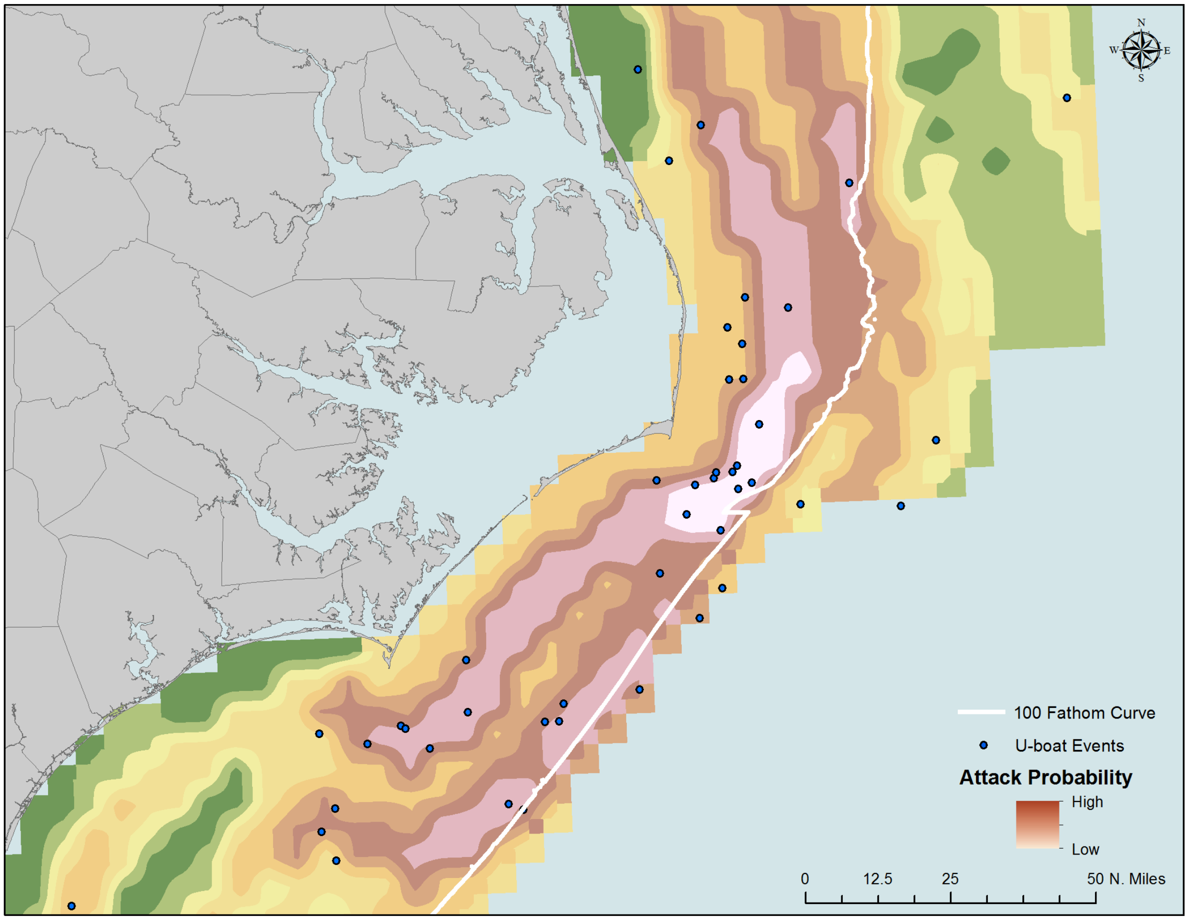

Figure 6.11 Alternative view of the probability surface after smoothing utilizing IDW (n = 54, Drawn by Author).

The cartographic model could be improved if better variables were available. One possible addition is ocean currents. Another is distance from known hazards to navigation such as the Hatteras minefield, or from air support locations. A final option could be shipping lanes. Some of the previous suggestions would contain similar issues with correlations and orientation, however. Shipping lanes is a perfect example, as these run parallel to the shoreline, and use the 100-fathom curve as a reference depth. While some of these variables could be created more easily than others, and some with less correlation, in the future more work should be conducted experimenting with the total number of variables used and their data type. For the purpose of this study, however, the variable selection was adequate to test the methodology on a naval battlefield.

One final comparison of two of the NCT visualizations is in order. This final comparison examines the January through July 1942, cumulative surface analysis with the cartographic modeling probability surface (Figure 6.12). When these two visualizations are overlaid, similarities should be apparent, and indicate corroboration. The darker blue areas in Figure 6.12 represent the highest areas of battle activities for the first half of 1942, while the light blue represents the area which saw moderate to low battle activity. The areas of overlap are indicated by various shades of purple. The areas of the darkest purple indicate the locations where both products indicated high battle activity and the lighter areas represent lower battle activity. Once again the area with the darkest purple is just south east of Cape Hatteras.

While the cartographic modeling methodology was successful and saw agreement with the cumulative surface analysis, there are still other more robust forms of spatial model available. As mentioned in Chapter 4, the entire realm of regression-based modeling has yet to be utilized on a naval battlefield landscape. Had the data been suitable for that type of analysis, the results of a comparison between cartographic modeling and the regression analysis would have proven interesting.

Conclusion

Naval battlefield visualizations have utilized the same techniques for nearly 500 years. The typical procedure employs a basic hull form representation, directional arrows denoting vessel paths, and associated blocks of text. Chapter 5 highlighted some new possibilities for visualizing naval battlefields based upon a formal analysis of historical map creation, and recommendations based upon a rigorous survey of associated disciplines. Those examples, however, were for naval battlefields with small spatial and temporal extents. The methods used to analyze larger scale battles are different, and require alternative toolsets. Based upon the earlier analysis, new alternative methods were developed and utilize more complex spatial analytical techniques.

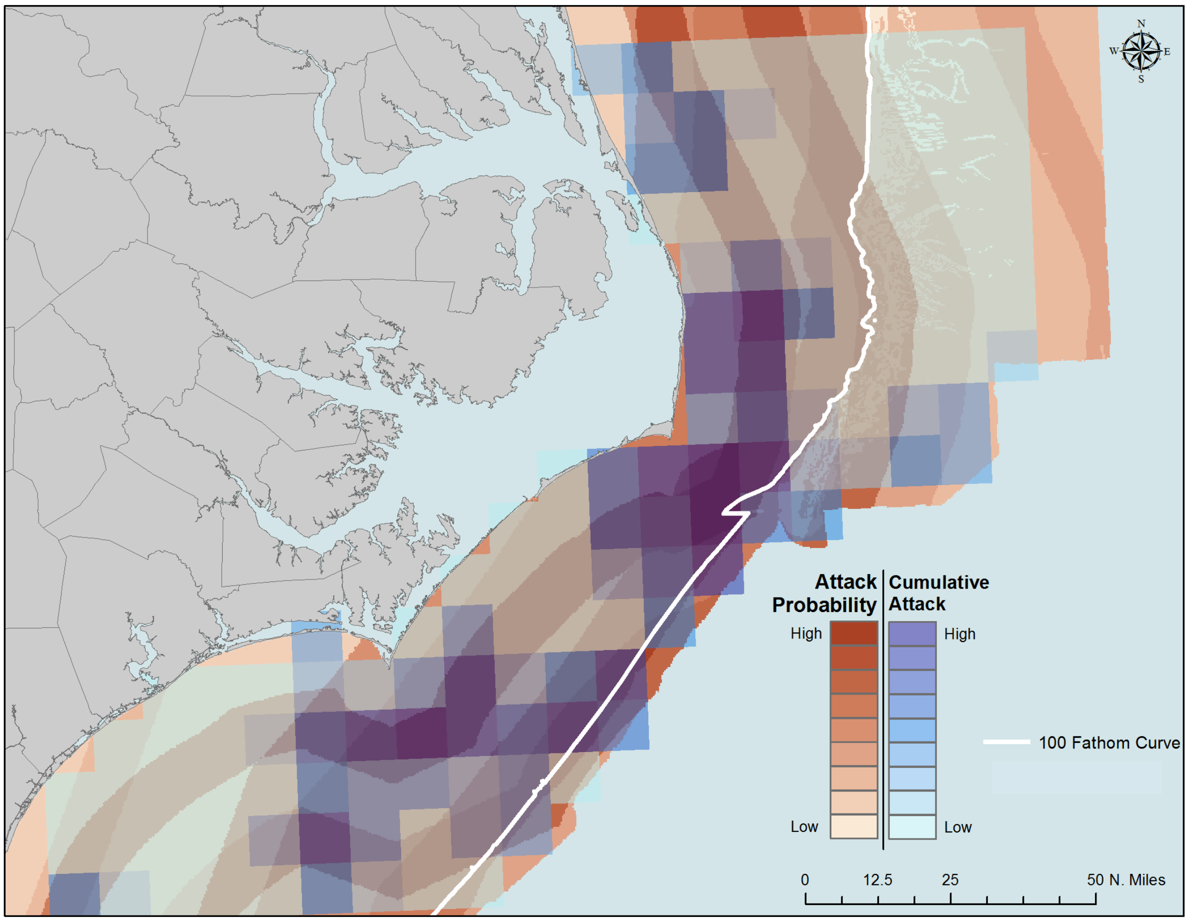

Figure 6.12 Comparative analysis of the cumulative surface and the cartographic modeling probability surface (n = 54, Drawn by Author).

Battlefield landscapes have evolved into a complex system, and simple maps, utilizing insufficient techniques, detract from important interpretations. The addition of computers and GIS technologies into the cartographers' toolset allows for new and germane analysis.

Geodatabases now allow for consideration of variables previously impossible to create, but which can now be fully integrated into studies of battlefield landscapes. These new techniques and technologies also offer new opportunities for outreach, and dissemination of these new digital products are able to reach wider audiences by means of the internet.

New techniques such as surface analysis and cartographic modeling are pushing the envelope of battlefield visualizations. When they are combined with other advanced geospatial techniques like 3D imaging, or animation, these interpretive tools become even more powerful. The examples provided here are only the beginning of what is possible, and hopefully a step in the right direction. A discussion regarding these new tools needs to be had, and it is hoped that this study can serve as a foundation for other future studies.

Chapter 7 : CONCLUSION

One of the most persistent elements of humanity is the ever-present act of war, which has been represented for thousands of years in a multitude of ways. Early humans felt this act was significant enough to inscribe these events in caves. These early humans depicted opposing hunting groups battling in a profile view. While examples in the earliest days of battlefield visualization are sparse, the methods utilized persevered and proliferated for centuries. The ancient Egyptians took a similar approach to representing war. Once again, the participants in battle were seen from the side in a profile view, however, they included a new element to their visualizations, that of time. The ancient Greeks also adopted this technique, and while the artistic elements of the two societies' visualizations are different, the underlying approach is the same. The Greek and the Romans contributed much to the discipline of cartography and survey, and introduced new tools to collect accurate spatial information. These advancements were quickly highlighted in the cartographic products, many of which served military purposes. This process of advancement was not continuous, however, and ultimately came to a halt during the medieval period.

The Renaissance saw a rebirth of science and the arts. This rebirth was also present in cartography. Maps were being produced in never before seen quantities. Once again, many of these maps were created for military purposes. During this period, new military techniques and technologies were also being created, and with those, new strategies emerged. To better represent some of these new strategies, innovative cartographical techniques were developed. These techniques, however, did not permeate through the discipline as a whole and it would not be until the end of the Napoleonic period, and the birth of the modern ways of wars, that these cartographic tools would be more permanently integrated.

The decades that followed the Napoleonic Wars were fraught with conflict. Casualty rates rose and the effectiveness of military technology increased. With the advent of Industrialism came new and terrible methods of waging war. The First World War was the first widespread military conflict that saw the use of such new technological terrors as motorized artillery, tanks, and poison gas. The naval battlefield was too forever changed, as it was now dotted with steel hulled surface ships, and submarines that could strike unseen from beneath the sea surface. Yet this war was only the beginning. The Second World War saw these technologies to maturation, with death tolls continuing to rise as improvements made these technologies all the more efficient. It is interesting to note that, over this period of rapid technological advancement matched with advancements of strategy, there was no advancement in cartographic techniques to represent these fundamental changes to the battlefield. In previous eras, there was a direct correlation between advancements in military technology and advancement in battlefield visualizations. What is surprising is that, also during this period, there have been cartographic and technological advancements well suited for battlefield visualizations that may increase the understanding of these past events. This is where this study gains its relevance.

This study is possible because previous scholars have laid a solid foundation. It builds upon research conducted over the past thirty years that covers topics from cartography to U-boat activities off the coast of North Carolina. This foundation allowed for a systematic investigation into the history of battlefield visualizations and advanced and geospatial visualizations. The results of this analysis aided in the selection of new adaptations of current technologies to the discipline of battlefield visualizations.

New instruments were developed to measure the changes in both battlefield visualizations and these potential new technologies. They surveyed a variety of variables and key trends were identified. Some of the more important trends related to the use of old cartographic technologies with new military strategies. Techniques like 3D visualizations and 2D animations are currently being used in a variety of academic disciplines, and seem well suited for use in battlefield visualization. These new adaptations are important, because they extend the discourse of battlefield mapping and have the potential to offer new insight and methodologies for explaining old phenomena. No longer is common sense analysis sufficient when the tools for more rigorous investigations exist. This study hopes to advance the conversation within battlefield visualization, which is long overdue.

This study utilized a multiscalar approach to battlefield visualizations. It was hypothesized that naval battlefields, with differing spatial and temporal extents, would require different advanced and geospatial visualization techniques. After reviewing the current advanced visualization landscape, it was determined that small extent naval battlefields should utilize techniques like 3D visualizations and 2D animations. Additionally, the larger battlefields should utilize more advanced forms of spatial modeling and 2D animations. Two case studies were chosen based upon the availability of previous research, which also contributed to the foundation of this study. The first case study was the battle of convoy KS-520. This conflict had a small extent, in terms of both spatial extent and temporal span. It was successfully visualized in 3D, and 2D animations were created. These tools provide new glimpses into this specific battle, and may be able to assist in new interpretations. Additionally, the techniques utilized here are easily transferable to other small-scale naval battlefields.

The second case study examined in this multiscalar project was the greater NCT. The coastal waters of North Carolina played a significant role in the over-arching Western Atlantic Theater during the Second World War. No other state saw as much loss of tonnage during the war. The first examples created from the NCT were attempts to better understand the distribution of battle activities throughout the first half of 1942. This period was the most active in the NCT, and had been previously examined in other studies. Alternative methods were developed, which resulted in the production of two separate surface animations of battle activities. The second stage of visualizing the NCT was an investigation into the most appropriate methods of spatial modeling. This required careful analysis of the available data, and ultimately a technique called Cartographic modeling was settled upon. This technique examined key physical variables and resulted in a probability map. While this technique is not without critique, it was thought to be a successful adaptation of a methodology never before tested on a naval battlefield.

The ultimate goal of this study was to improve upon the current status of battlefield visualizations. The primary research question of "What is the potential of recent developments in geospatial visualization for aiding in the analysis and interpretations of naval battlefields?" has been answered. There are many new opportunities for visualizations. The baseline has been developed, and now that it is known that there is room for improvement, it is up to future researchers to continue to push the envelope. The secondary research questions were also answered. Both small-scale and large-scale naval battlefield can be visualized in innovative ways, and each have their own set of appropriate methods.

Observations

Naval battlefield mapping, visualization, and analysis provide an interesting set of problems and challenges that are unique to the particular environment. Many of these challenges are not found in the realm of terrestrial visualizations. These problems are broken into two main categories:

problems of data availability and problems of scale. Each of these challenges are worth discussing briefly, in hopes that future research may find new methods for overcoming them.

The first challenge concerns issues with data availability, and is perhaps the most problematic. For centuries, human beings have been collecting data and mapping the world around them. Unfortunately, until recently, the majority of this data has been limited to the terrestrial environment. This results in an overall lack of good source data for naval battlefield visualizations, which can take two forms. The first is the historic representations of space at sea. The ocean is a vast environment, and until recently traversing it was a very impressive feat. One of the key problems with travel at sea was accurately understanding and reporting position. Terrestrial reporting of location is often aided by natural aids to navigation such as key mountain ranges or rivers, which aided in identifying specific locations by providing added context. At sea, however, these natural aids to navigation do not exist and it was not until fairly recently with the advent of satellite based navigation and GPS technologies that precise locations upon the sea surface could be identified. Even as late as the Second World War, the reporting of locational positions at sea were relatively inaccurate. This provides a great challenge when attempting to spatially model naval battlefields.

The lack of spatial data can also take the form of missing environmental data. Until recently, mankind has been more concerned with the terrestrial environment than the maritime. As a result, data products for elements of the marine environment, such as bathymetry, are often produced less frequently. Additionally, the products are also less accurate than their terrestrial counterparts. This issue was seen firsthand when attempting to model the NCT. There simply was not an adequate data source available in terms of bathymetry.

The second major category of problems with naval battlefield visualizations relates to issues with scale. The distances traversed in naval battles can be great. The vessels themselves are particularly small when compared to the scale of the battlefield landscape, which makes the landscape difficult to accurately represent. Compromises must sometimes be made between scale and map readability. This is one place, however, where advanced and geospatial visualizations excel. The flexibility of a digital environment allows for elements of the battlefield landscape to be viewed from a variety of scales and vantage points. This permits the use of scaled graphics in the marine environment.

The challenges listed here are not insurmountable. With appropriate planning and preparation, the naval battlefield can be successfully visualized. This study is proof that these challenges can be overcome. They key to creating advanced and geospatial visualizations of the naval battlefield lies with flexibility and creativity. While issues with data availability and challenges with scale may prove frustrating, that is simply part of the process.

Avenues for Future Research

This study is not the final chapter in advanced naval battlefield visualizations. It has successfully adapted current innovative geospatial technologies to the naval battlefield, however, there is still much left unstudied. Future research could potentially follow two separate avenues. The first is down the path of comparative analysis. The battlefield selected was from a modern era, and only represents a very small fraction of naval battlefields over the course of history. Future studies should investigate the possibility of battlefields from different periods and the application of the various advanced techniques. Perhaps there are still other techniques that would be even more appropriate for naval battlefields from different periods.

The second avenue for future research continues the process of adapting spatial modeling techniques to the naval battlefield. While this particular dataset was not appropriate for the most robust forms of spatial modeling, like logistic regression, others may be. Future studies should examine a variety of naval battlefields and focus specifically on the adaptation and comparison of a variety of spatial modeling techniques. In the future, historians and archaeologists could potentially have a toolset filled with advanced modeling techniques to draw from when analyzing the naval battlefield.

Conclusion

For thousands of years humans have been engaging in the act of war. They have left their imprint on both the physical world in terms of battle remains and in the historic record. This study attempted to investigate the progression of the recording of naval battles from the genesis of the practice, nearly ten thousand years ago, to the present. This study not only examined this progression, but also attempted to build upon it. It offers various alternative methodologies and attempts to extend the discourse. Critiques of the methodologies were listed and common problems identified.

Based upon the successes and failures of the methodologies, future research avenues have been identified. These avenues may take the study of battlefield visualizations and analysis in different directions, but it is important that this course of action continues. No longer is it acceptable to wait over thirty years to heed the advice of prominent scholars. The time to continue the conversation of battlefield visualizations is now.

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APPENDIX I – HISTORY OF VISUALIZATION DATASET

KEY

Variable	Value	Variable	Value	Variable	Value
Period - Ancient	A	Media - Carving	CA	Type - Terrestrial	T
Period - Renaissance	R	Media - Ceramic	CE	Type - Maritime	M
Period - Modern	M				
		View - Isometric	IS	Yes	Y
Media - Engraving	EN	View - Ortho	OR	No	N
Media - Print	PR	View - Profile	PO		
Media - Sketch	SK				
Media - Tapestry	TA				

ID	MAP NAME	MAP CREATOR	MAP DATE	BATTLE NAME	BATTLE DATE	PERIOD	VIEW	MEDIA	SCALE	COLOR	TIME	TEXT	GENERALIZED	TYPE
1	Positions: Occupees en Italie le jour de la Bataille par les Armees	Alexandre	1806	Battle of Marengo	06/14/1800	M	OR	PR	Y	N	N	Y	Y	T
2	Battle of Marengo	Alexandre	1806	Battle of Marengo	06/14/1800	M	OR	PR	N	N	Y	N	Y	T
3	Battle of Marengo	Alexandre	1806	Battle of Marengo	06/14/1800	M	OR	PR	N	N	Y	N	Y	T
4	Battle of Marengo	Alexandre	1806	Battle of Marengo	06/14/1800	M	OR	PR	N	N	Y	N	Y	T

ID	MAP NAME	MAP CREATOR	MAP DATE	BATTLE NAME	BATTLE DATE	PERIOD	VIEW	MEDIA	SCALE	COLOR	TIME	TEXT	GENERALIZED	TYPE
5	Battle of Marengo	Alexandre	1806	Battle of Marengo	06/14/1800	M	OR	PR	N	N	Y	N	Y	T
6	Battle of Minorca	Joseph Allen	1853	Battle of Minorca	05/20/1756	M	OR	PR	N	N	Y	Y	N	M
7	First Battle of Ushant	Joseph Allen	1853	First Battle of Ushant	07/27/1778	M	OR	PR	N	N	Y	Y	N	M
8	Battle of Grenada	Joseph Allen	1853	Battle of Grenada	07/06/1779	M	OR	PR	N	N	N	Y	N	M
9	Battle of Saintes	Joseph Allen	1853	Battle of Saintes	04/12/1782	M	OR	PR	N	N	Y	Y	N	M
10	Battle of the Nile	Joseph Allen	1853	Battle of the Nile	08/01/1798	M	OR	PR	Y	N	N	Y	N	M
11	Map of Battles on Bull Run near Manassas	Waters & Son N.Y.	1862	Battle of Bull Run	07/21/1861	M	OR	PR	Y	N	Y	Y	Y	T
12	A Sketch of the Battle of Waterloo fought Sunday June 18 1815	John Booth	1816	Battle of Waterloo	06/18/1815	M	OR	PR	Y	N	Y	Y	Y	T
13	Plan of the Battle of the 16th June	George Jones	1817	Battle of Waterloo	06/18/1815	M	OR	PR	N	N	N	Y	Y	T

ID	MAP NAME	MAP CREATOR	MAP DATE	BATTLE NAME	BATTLE DATE	PERIOD	VIEW	MEDIA	SCALE	COLOR	TIME	TEXT	GENERALIZED	TYPE
14	Map of the country occupied by the Federal and Confederate Armies on the 18th and 21st of July 1861	T.B. Warder and Jas M. Catlett	1862	Battle of Young's Branch	07/21/1861	M	OR	PR	Y	N	N	N	Y	T
15	Battle Field of Young's Branch or Manassas Plains. Battle Fought July 21, 1861	T.B. Warder and Jas M. Catlett	1862	Battle of Young's Branch	07/21/1861	M	OR	PR	Y	N	N	Y	Y	T
16	Battle Grounds of Palo Alto and Resaca de la Palma	T.C. Clarke	1847	Battle of Palo Alto	05/08/1846	M	OR	PR	N	N	N	Y	Y	T
17	The Siege of Monterey	T.C. Clarke	1847	The Siege of Monterey	10/09/1846	M	OR	PR	N	N	N	Y	Y	T
18	The Battle Field of Buena Vista	T.C. Clarke	1847	The Battle of Buena Vista	02/23/1846	M	OR	PR	N	N	N	Y	Y	T
19	The Map of Vera Cruz and Suan Juan de Uloa: The Position of our Forces	T.C. Clarke	1847	Siege of Vera Cruz	03/09/1847	M	OR	PR	N	N	N	Y	N	M
20	Plate VI	Charles Ekins	1828	The Battle of Navarin	10/20/1827	M	OR	PR	N	N	N	Y	N	M
21	Plate VI	Charles Ekins	1828	The Battle of Navarin	10/20/1827	M	OR	PR	N	N	N	Y	N	M

ID	MAP NAME	MAP CREATOR	MAP DATE	BATTLE NAME	BATTLE DATE	PERIOD	VIEW	MEDIA	SCALE	COLOR	TIME	TEXT	GENERALIZED	TYPE
22	Plate X	Charles Ekins	1828	The Battle of Navarin	10/20/1827	M	OR	PR	N	N	N	Y	N	M
23	Plate X	Charles Ekins	1828	The Battle of Navarin	10/20/1827	M	OR	PR	N	N	N	Y	N	M
24	Battle of Bunker Hill	Charles P. Emmons	1843	Battle of Bunker Hill	06/17/1775	M	OR	PR	N	N	N	Y	Y	M
25	French Army on the night of the 15th	George Hooper	1862	Battle of Waterloo	06/18/1815	M	OR	PR	N	N	N	Y	Y	T
26	Plan of the Battle of Bosworth and the Neighbourhood, June 17th 1789	W. Hutton	1789	Battle of Bosworth Field	08/22/1485	M	OR	PR	N	N	N	Y	Y	T
27	Plan of the Battle of the 16th June	George Jones	1852	Battle of Waterloo	06/18/1815	M	OR	PR	N	N	N	Y	Y	T
28	Battle of Waterloo about 12	George Jones	1852	Battle of Waterloo	06/18/1815	M	OR	PR	Y	N	Y	Y	Y	T
29	Middle of Battle	George Jones	1852	Battle of Waterloo	06/18/1815	M	OR	PR	Y	N	Y	Y	Y	T
30	Siege of Quebec	Benson J. Lossing	1848	Siege of Quebec	09/13/1759	M	OR	PR	Y	N	N	Y	Y	T

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31	Battle of Bunker Hill	Benson J. Lossing	1848	Battle of Bunker Hill	06/17/1775	M	OR	PR	N	N	Y	Y	Y	M
32	Seat of War in New Jersey	Benson J. Lossing	1848	The First Battle of Trenton	12/26/1776	M	OR	PR	N	N	N	Y	Y	T
33	Battle of Long Island	Benson J. Lossing	1848	Battle of Long Island	08/27/1776	M	OR	PR	N	N	Y	Y	Y	T
34	Battle of Stillwater & Sratoga	Benson J. Lossing	1848	Battle of Saratoga	09/19/1777	M	OR	PR	N	N	N	Y	Y	T
35	Battle of Brandywine	Benson J. Lossing	1848	Battle of Brandywine	09/11/1777	M	OR	PR	N	N	N	Y	Y	T
36	Siege of Savannah	Benson J. Lossing	1848	Siege of Savannah	09/12/1777	M	OR	PR	N	N	Y	Y	Y	T
37	Battle of Monmouth	Benson J. Lossing	1848	Battle of Monmouth	06/28/1777	M	OR	PR	N	N	Y	Y	Y	T
38	Battle of Hobkirks Hill	Benson J. Lossing	1848	Battle of Hobkirks Hill	04/25/1781	M	OR	PR	N	N	Y	Y	Y	T
39	Battle of Guilford C.H.	Benson J. Lossing	1848	Battle of Guilford Court House	03/15/1781	M	OR	PR	N	N	Y	Y	Y	T
40	Operations on the Hudson 1780	Benson J. Lossing	1848	Operations on the Hudson	1780	M	OR	PR	N	N	Y	Y	Y	T

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41	Siege of Yorktown	Benson J. Lossing	1848	Siege of Yorktown	10/19/1781	M	OR	PR	N	N	Y	Y	Y	T
42	Plan of the Battle of Leipzig on the 16 and 18 October 1813	Frederic Shoberl	1814	Battle of Leipzig	10/16/1813	M	OR	PR	N	N	Y	Y	Y	T
43	Battle of Waterloo	W. Siborne	1845	Battle of Waterloo	06/18/1815	M	OR	PR	N	N	N	N	Y	T
44	Battle of Waterloo before 8 o'clock P.M.	W. Siborne	1845	Battle of Waterloo	06/18/1815	M	OR	PR	N	N	N	N	Y	T
45	The Brigade at New Madrid and Island no. 10	Charles H. Smith	1909	Battle of Island N. 10	02/28/1862	M	OR	PR	Y	N	N	Y	N	M
46	Battle of Corinth Oct 3rd and 4th 1862	Charles H. Smith	1909	Battle of Corinth	10/03/1862	M	OR	PR	N	N	Y	N	Y	T
47	Lines of Battle Oct 3rd and 4th, 1862, At Corinth, Miss. Rebellion Record, Vol. 17	Charles H. Smith	1909	Battle of Corinth	10/03/1862	M	OR	PR	N	N	Y	Y	Y	T
48	Sherman's Atlantic Campaign. Chattanooga to Atlanta	Charles H. Smith	1909	Atlanta Campaign	05/07/1864	M	OR	PR	Y	N	Y	N	Y	T
49	Battle Lines, Atlanta, GA., July 22nd, 1864	Charles H. Smith	1909	Atlanta Campaign	07/22/1864	M	OR	PR	N	N	N	N	Y	T

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50	Battle Lines, Ezra Church, Atlanta, July 28th, 1864	Charles H. Smith	1909	Atlanta Campaign	07/28/1864	M	OR	PR	N	N	N	N	Y	T
51	Atlanta to Savhnna. Sherman's March to the Sea. Nv. and Dec. 1864	Charles H. Smith	1909	March to the Sea Campaign	11/15/1864	M	OR	PR	Y	N	Y	N	Y	T
52	Field Works at Franklin Tenn. Occupied by the 23rd and 4th corps during the engagements of Nov. 30th 1864. Maj Gen. M. Schofield Commanding	Levi T. Scofield	1909	Battle of Franklin	11/30/1864	M	OR	PR	Y	N	N	N	Y	T
53	Sketch of the St. Lawrence from Cornwall to Grand River	James Wilkinson	1816	Battle of Chateaguay	10/26/1813	M	OR	PR	N	Y	Y	Y	Y	T
54	The Affair of Bladensburg, August 24th 1814	James Wilkinson	1816	Battle of Bladensburg	08/24/1814	M	OR	PR	Y	N	Y	Y	Y	T
55	Battle of Culloden	John Finlayson	1746	Battle of Culloden	1746	M	OR	EN	N	Y	N	Y	Y	T
56	Battle of Glenshiel	Bastide	1716	Battle of Glenshiel	1716	R	IS	PR	Y	Y	N	N	Y	T
57	Depiction of the Capture of Geldern	Hogenberg	1587	Capture of Geldern	1587	R	IS	EN	N	N	N	N	N	T

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58	Map of the Frisian Village of Dronrijp from the Robles Atlas	Unknown	1572	Robles Battle	1572	R	OR	SK	N	N	N	N	N	T
59	The Tapestry of Leiden	Joost Jansz	1587	Siege of Leiden	1574	R	OR	TA	Y	Y	N	N	N	T
60	News Map	Claes Jansz	1624	Siege of Breda	1624	R	OR	EN	N	N	N	Y	N	T
61	Pourtrait de la Rochelle & des Forteresses que led Rebelles y ont Fait Depuis les Premiers Troubles Jus[q]u a Present	Francois Desprez	1573	Siege of La Rochelle	1573	R	IS	EN	N	N	N	Y	N	T
62	The English Victore Againste the Schottes	Thomas Geminus	1547	Battle of Pinkie Cleugh	1547	R	IS	EN	N	N	N	N	N	M
63	Invasions Map of Great Britain	John Speed	1603	Invasions Map of Great Britain	1066-1588	R	OR	TA	Y	Y	Y	N	N	T
64	Dinish Island and Vicinity	Unknown	1602	British Troops moving toward rebel strongohld of Dunboy	1602	R	IS	SK	N	N	N	Y	N	T
65	Woodcut plan detailing Scottish Wars	Richard Grafton	1548	Scottish Wars	1548	R	OR	PR	N	N	N	Y	Y	T

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66	Plan of the Attack on Brighton	Anthony Anthony	1539	Attack on Brighton	1514	R	IS	EN	N	Y	N	N	N	M
67	Map of Southeast Ulster	Richard Bartlett	1602	Queen Elisabeth's Irish Wars	1594-1603	R	OR	EN	N	Y	N	N	N	T
68	Expeditionis Hispanorum in Angliam vera descripto. Anno Do: M D LXXXVIII - Map 1	Robert Adams	1590	Battle of the Spanish Armada	1588	R	OR	EN	Y	Y	Y	N	N	M
69	Expeditionis Hispanorum in Angliam vera descripto. Anno Do: M D LXXXVIII - Map 2	Robert Adams	1590	Battle of the Spanish Armada	1588	R	OR	EN	Y	Y	Y	N	N	M
70	Expeditionis Hispanorum in Angliam vera descripto. Anno Do: M D LXXXVIII - Map 3	Robert Adams	1590	Battle of the Spanish Armada	1588	R	OR	EN	Y	Y	Y	N	N	M
71	Expeditionis Hispanorum in Angliam vera descripto. Anno Do: M D LXXXVIII - Map 4	Robert Adams	1590	Battle of the Spanish Armada	1588	R	OR	EN	Y	Y	Y	N	N	M
72	Expeditionis Hispanorum in Angliam vera descripto. Anno Do: M D LXXXVIII - Map 5	Robert Adams	1590	Battle of the Spanish Armada	1588	R	OR	EN	Y	Y	Y	N	N	M
73	Expeditionis Hispanorum in Angliam vera descripto. Anno Do: M D LXXXVIII - Map 6	Robert Adams	1590	Battle of the Spanish Armada	1588	R	OR	EN	Y	Y	Y	N	N	M

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74	Expeditionis Hispanorum in Angliam vera descripto. Anno Do: M D LXXXVIII - Map 7	Robert Adams	1590	Battle of the Spanish Armada	1588	R	OR	EN	Y	Y	Y	N	N	M
75	The Military Boarder on a 1563 Manuscript Map	Janos Choron	1564	Boarder between Lake Balaton and the Danube	1563	R	Other	SK	N	N	N	N	N	T
76	Printed Leaflet	Natale Angielini	1565	Habsburg Campaign of Lazarus Schwendi	1565	R	IS	PR	N	N	N	Y	N	T
77	Geographical Maps	Semyon Ulianovich Remezov		Unknown		R	IS	EN	N	N	N	N	N	T
78	Drawing made for Gaspar de Robles	Unknown	1572	Invasion of the Netherlands	1572	R	OR	SK	N	N	N	N	N	M
79	Neolithic Cave Panting 1	Unknown	10000 BCE	Battle between two groups of archers	10000 BCE	A	PO	PA	N	N	N	N	N	T
80	Prehistoric rock painting	Unknown	Unknown	Battle between San foragers and Bantu Farmers	Unknown	A	PO	PA	N	N	N	N	N	T

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81	Iron Age Warrior Image	Unknown	Unknown	Unknown	Unknown	A	PO	PA	N	N	N	N	N	T
82	Battle Cave 1	Unknown	Unknown	Unknown	Unknown	A	PO	PA	N	Y	N	N	N	T
83	Battle Cave 2	Unknown	Unknown	Unknown	Unknown	A	PO	PA	N	Y	N	N	N	T
84	Steepside	Unknown	Unknown	Unknown	Unknown	A	PO	PA	N	N	N	N	N	T
85	Beersheba	Unknown	Unknown	Unknown	Unknown	A	PO	PA	N	Y	N	N	N	T
86	Amphora 1	Mantimenes Painter	520 BCE	A Battle Scene	520 BCE	A	PO	CE	N	Y	N	N	N	T
87	Middle Corinthia Cup	Cavalcade Painter	580 BCE	Unknown	580 BCE	A	PO	CE	N	Y	N	N	N	T
88	Hoplite Phalanxes	Chigi Painter	650 BCE	Hoplite Phalanxes in Battle	650 BCE	A	PO	CE	N	Y	N	N	N	T
89	Cleveland Dinos - Warships	Unknown	570 BCE	Warships	570 BCE	A	PO	CE	N	Y	N	N	N	M
90	Madrid Dinos - Warships	Unknown	570 BCE	Warships	570 BCE	A	PO	CE	N	Y	N	N	N	M

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91	Roman Soldiers Sacking a Village - Column of Marcus Aurelius	Unknown	Unknown	Unknown	Unknown	A	PO	CA	N	N	N	N	N	T
92	Ramesse II: Attack against Dapur	Unknown	1200 BCE	Ramesse II: Attack against Dapur	1200 BCE	A	PO	CA	N	N	Y	N	N	T
93	Battle Reliefs of King Ahmose	Unknown	1500 BCE	Battle Reliefs of King Ahmose	1500 BCE	A	PO	CA	N	N	Y	N	N	M
94	Seti I against the Hittites	Unknown	1200 BCE	Seti I against the Hittites	1200 BCE	A	PO	CA	N	N	Y	N	N	T
95	Ramesse III: Naval Battle Against the Sea Peoples	Unknown	1100 BCE	Ramesse III: Naval Battle Against the Sea Peoples	1100 BCE	A	PO	CA	N	N	Y	N	N	M