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ARCHAEOLOGICAL OCEANOGRAPHY OF INUNDATED COASTAL PREHISTORIC SITES

BY

DWIGHT F. COLEMAN

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
IN
OCEANOGRAPHY

UNIVERSITY OF RHODE ISLAND

2003

ABSTRACT

The field of shallow underwater archaeology has grown significantly during the last century, especially since the development of advanced technologies such as the self-contained underwater breathing apparatus (SCUBA). Other advanced technologies, such as high-resolution geophysical surveying systems and robotic undersea vehicles, which have been used extensively in the oceanographic sciences during the last several decades, are now being used in the archaeological sciences to investigate underwater sites representing human history. These technologies, in addition to the oceanographic and geophysical methodologies for exploration, prospecting, and site surveying, now form the technological basis of the nascent discipline of "Archaeological Oceanography." This discipline combines the traditional methodologies of archaeology with those of oceanography to search for, investigate, document, sample, and analyze submerged cultural remains. For the most part, these remains are shipwrecks, but other submerged sites, such as drowned prehistoric terrestrial sites, have been discovered and recognized as significant to our understanding of human history. The major process by which these sites become submerged is the inundation of low-elevation land masses due to the rising level of large bodies of water, both marine seas and inland freshwater lakes.

It is well-established that prehistoric human populations existed in coastal environments. Since the last Ice Age, about 20,000 years before present, global sea level has risen more than 100 meters in response to melting continental ice sheets. Nearly all present-day coastal embayments, lagoons, coves, inlets, fjords, channels, sounds, and shallow outer continental shelves throughout the world were exposed above sea level for several millennia as the glaciers retreated. In addition, the shorelines of most large inland lakes were at a much lower level during the dry times associated with the last Ice Age. The exposed low-elevation coasts, in addition to interior lake shorelines and adjacent landscapes, were gradually or, in some cases, catastrophically flooded by rising water levels. Any sites of human occupation along these coasts are now under water and draped by modern sediments. Many shallow water prehistoric archaeological sites have been discovered throughout the world, but systematic approaches to the survey of these sites have been infrequent and poorly defined.

Some researchers hypothesize that prehistoric humans migrated along coastal routes, but this has yet to be definitively proven. Most of these coastal routes followed shorelines that are now submerged on the continental shelves. In addition, inland bodies of fresh water would have been attractive to prehistoric humans during the last Ice Age as a valuable resource during a very dry climatic period in recent earth history. The paleo-environmental and archaeological features of these coastal settings are now preserved in the shallow offshore geologic record. Oceanographic and geophysical methodologies are directly applicable to the investigation of these features and used to study the “underwater environmental archaeology” of potential sites. Several diverse submerged coastal regions have been intensely surveyed for their prehistoric archaeological potential, and these represent the case studies presented in this investigation.

Offshore southern New England, in the vicinity of what is now Block Island, was once a habitable coastal environment that has now been naturally inundated by about 100 meters of rising ocean water. This environment, which was located along the fringe of the glacial ice during its maximum extent, has also been slowly uplifted by glacial rebound and reworked by modern coastal oceanographic processes. A number of archaeological sites have been found on Block Island, and exploration off its southern and western coasts has revealed an interesting landscape that would have been favorable to early human populations. Several ancient river channels and coastal lagoon features were investigated using geophysical mapping methods and sediment coring. Although further visual investigation is required, the submerged environmental archaeology of a paleo-Block Island reveals significant potential for the discovery of ancient human occupation sites.

During a dry time period critical to the advance of people in the New World, ancient Lake Huron was at a substantially lower elevation. From about 10,000 to 8,000 years before present, the shores of the lake were as much as 120 meters lower in elevation. Gradual refilling of the Lake Huron basin has occurred since that time, thereby inundating and preserving any potential sites of human occupation near the shoreline. A number of prehistoric archaeological sites and Pleistocene mammal remains have been discovered near the basin. Detailed mapping and exploration in Thunder Bay National Marine Sanctuary, off northeastern Lower Michigan, has revealed a number of submerged sinkholes, part of an evaporite and limestone karst geologic formation that can be traced onshore. Several sinkholes were

investigated using geophysical mapping techniques and visually explored using a remotely operated vehicle. One sinkhole that was discovered in 90 meters water depth contains a unique deposit that could yield human cultural material, and this site will be the focus of future intensive geologic and archaeological sampling.

The Black Sea was once an isolated, inland, freshwater lake. Several advanced Neolithic cultures are known to have populated the surrounding coastal regions of the Black Sea. For this and other reasons, the region is an ideal location to explore for inundated archaeological sites. This body of water is suspected of being catastrophically inundated by rising marine water about 7,500 years ago. The inundation would have driven away the coastal population, but the sites that represent their habitat could be preserved in what is now a shallow marine setting, up to about 150 meters water depth. In addition, and due in part to the inundation, the deep waters of the Black Sea are devoid of oxygen, which means submerged archaeological sites near and below the anoxic interface are very highly preserved, as no organisms can exist to destroy them. Exploration off the northern coast of Turkey in the southern Black Sea and off the western Black Sea coasts of Bulgaria and Romania has resulted in several interesting discoveries that could represent significant archaeological sites. One location in particular contained what appeared to be a stone and wooden structure that sat atop a topographic high point at about 95 meters water depth in the submerged landscape. This has enormous potential to represent a significant pre-flood Neolithic archaeological site, and will be intensely examined and sampled using an advanced remotely operated vehicle system during a future expedition.

Although these case studies do not confirm or deny the existence of inundated prehistoric cultural sites in these locations, they do represent examples of diverse environmental settings that responded differently to the geologic and oceanographic processes following the last Ice Age. More work clearly needs to be done in this field, on the sites mentioned here and elsewhere, to learn more about the existence and preservation of submerged prehistoric archaeological sites. There is great potential for significant archaeological discoveries to be made using the available advanced oceanographic technologies to investigate submerged landscapes. Many mysteries surrounding the evolution, adaptation, and migration of the human species throughout the world could be solved by more detailed and advanced underwater exploration using the archaeological oceanographic approach described here.

ACKNOWLEDGEMENTS

This doctoral dissertation is a direct result of nearly four years of nonstop research, proposal writing, report writing, intense planning, design, engineering, and field work, coordinated and led primarily by myself, my supervisor, Dr. Robert Ballard, and the staff at the Institute for Exploration (IFE) in Mystic, CT. During that time, eight successful oceanographic expeditions were conducted that directly relate to the research presented here. These include two expeditions off Block Island, RI; two expeditions in Lake Huron, off Alpena, MI; and four expeditions to the Black Sea, two off northern Turkey and two off Bulgaria. During this time, I played an instrumental role in four other expeditions that are unrelated to this dissertation. Twelve expeditions in fewer than 4 years have kept me very busy. Fortunately, circumstances permitted me to complete this dissertation without a major overhaul of my academic career at URI. Thanks to the encouragement and support of a large number of individuals, much of the work I've been involved in professionally as an employee of IFE is synthesized and presented in this dissertation.

First and foremost, I thank Dr. Robert Ballard, President of IFE and my major professor at the University of Rhode Island Graduate School of Oceanography (URI/GSO), for his generous support and continual encouragement. Bob hired me in the spring of 1999, and a few weeks after that, we were on a fishing boat off Sinop, Turkey, using side-scan sonar to map the submerged landscape that was suspected of being inundated by a major catastrophic flood. Immediately we worked very well together, and since then I have instilled a lot of confidence in Bob, and he has entrusted me with some significant responsibilities, including leading several oceanographic expeditions for underwater archaeology. Bob has a gift for success in making science not only exciting, interesting, and fun, but extremely productive as well. If it were not for his support, the research presented in this dissertation would not have been possible. Thank you, Bob, for everything.

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This dissertation is dedicated to my two sons, Cameron and Spencer. Their love and admiration make me a very happy and lucky man. Cam and Spence are two smart and happy kids who have taught me some important things about life and have made my world quite a wonderful place.

PREFACE

This dissertation is about the marine geology and underwater archaeology of inundated prehistoric sites. It begins with several chapters that basically provide a concise background on the geology, oceanography, climatology, and archaeology of the last Ice Age, with a focus on the effects of sea level rise on the coastal environment. The first chapter provides a brief introduction to the subject matter of this dissertation. Chapter 2 presents background and some details about the effects of glaciations, taking an earth science approach. Chapter 3 takes an anthropological approach, and presents background and some details about the prehistoric period and early humans in the Ice Age environment. Chapter 4 documents the methodological approach for exploring and investigating submerged terrestrial sites of human occupation that were flooded by rising water levels. This chapter introduces a new discipline of “archaeological oceanography” by establishing the oceanographic criteria for archaeological exploration and site survey. Several case studies are then presented, each representing a distinctive geological and archaeological environment. Chapter 5 focuses on the Block Island project. Located just offshore from southern New England, Block Island is in an open ocean setting of the North Atlantic that was situated exactly along the glacial margin at the ice’s southern limit. Chapter 6 focuses on the Thunder Bay project, in Lake Huron, which is a large inland lake that was completely covered by ice during the last glacial advance. Chapter 7 focuses on the Black Sea project. The Black Sea is a very large inland sea situated between Europe, Asia, and the Middle East that was a large freshwater lake during the last Ice Age, and was near the heart of early, advanced, human cultures. Chapter 8 represents a synthesis of the work presented in the earlier chapters to create a new paradigm for underwater archaeology – the combination of oceanographic science with prehistoric archaeology – that will pave the way for future work in this nascent discipline, archaeological oceanography.

This dissertation is presented in standard format, with detailed chapters for each component of the work. Variations of the chapters that pertain to the case studies have been or will be published in peer-reviewed scientific literature. In most cases, the field work presented in this dissertation was conducted with the primary scientific goal being the investigation of shipwrecks. This is the case for the Black Sea and Thunder Bay projects, but not for the Block Island project. For the Black Sea and Thunder

Bay, however, shallow water depths were surveyed with the secondary scientific goal of exploring for signs of human habitation on the shallow shelf. Each case study represents part of much larger overall project, with methods and results discussed only for portions of the project that specifically pertain to the subject matter of this dissertation. Some of the research findings from these projects have been reported elsewhere. For example, early work that led to the Block Island project was published in the following:

Uchupi, E., Driscoll, N., Ballard, R. D., and S. T. Bolmer, "Drainage of late Wisconsin glacial lakes and the morphology and late quaternary stratigraphy of the New Jersey – southern New England continental shelf and slope," *Marine Geology* 172 (2001): 117-45.

Some results from the Thunder Bay project were published in:

Coleman, D. F., "Underwater Archaeology in Thunder Bay National Marine Sanctuary, Lake Huron – Preliminary Results from a Shipwreck Mapping Survey," *Marine Technology Society Journal* 36 (2002): 33-44.

For the Black Sea marine geology project, the initial findings were published in:

Ballard, R. D., Coleman, D. F., and G. Rosenberg. "Further Evidence of Abrupt Holocene Drowning of the Black Sea Shelf." *Marine Geology* 170 (2000): 253-61.

And for the Black Sea underwater archaeology project, results were published in:

Ballard, R. D., Hiebert, F. T., Coleman, D. F., Ward, C., Smith, J. S., Willis, K., Foley, B., Croff, K., Major, C., and F. Torre, "Deepwater Archaeology of the Black Sea: The 2000 Season at Sinop, Turkey." *American Journal of Archaeology* 105 (2001): 607-23.

There are several common threads among the case studies. Firstly, the methodology is similar for each project and primarily involves bathymetric mapping, side-scan sonar surveying, high-resolution reflection seismology (sub-bottom profiling), and geological sampling (especially coring). Secondly, an oceanographic similarity is that, for each case, the amount of sea level rise is nearly the same, between about 100 and 150 meters. Thirdly, an archaeological similarity is that for each case, we were exploring for sites occupied by humans around the same time period, roughly 10,000 – 8,000 years before present. The primary difference is that the region represented in each case responded very differently to the effects of glacial unloading, isostatic rebound, meltwater influx, sea (lake) level rise, and modern (Holocene) sedimentation. A secondary archaeological difference is in the technological and cultural disparities between Old World and New World people. All of these similarities and

differences will be made obvious in the text of the dissertation. However, each case study will be evaluated independently, with an assessment of the effectiveness of the methods used, along with a recommendation for improvement and/or changes in techniques. Hopefully, this evaluation will lead to proposed advances in archaeological oceanographic methods related to the investigation of inundated prehistoric sites.

Although it is not a subject of this dissertation, shipwreck archaeology deserves to be mentioned here. The methods and synopsis presented for underwater prehistoric archaeology can be easily applied to the investigation, mapping, and analysis of shipwreck sites. However mapping and interpreting the submerged landscape is less important for shipwreck archaeology, for example, than exploring suspected ancient trade routes and searching off ancient seaports. In fact, the primary focus of the Thunder Bay project was to explore for new shipwrecks within and surrounding the sanctuary and two were actually found. It was quite a bonus to discover the sinkholes within the sanctuary and then learn of their potential for prehistoric archaeology. For the Black Sea project, exploration for well-preserved ancient shipwrecks in the anoxic deep water was the primary goal, with a secondary goal to search for pre-flood habitation sites. Both goals are archaeologically significant.

Another point to clarify is that this dissertation presents and evaluates methods for exploring, mapping, and visually investigating submerged archaeological sites in detail but does not focus at all on the material excavation of these sites. The focus here is on survey only, and therefore does not involve the added complications of artifact recovery and conservation. This, however, is a very important topic for the new discipline of archaeological oceanography. Typically, underwater archaeological sites have been excavated in the past using SCUBA and associated techniques. The oceanographic world has now opened the door for archaeologists to use more advanced robotics, manipulation, and acoustic and visual imaging techniques to conduct deep-sea excavations, but that work is in its infancy and remains as a topic for future discussion elsewhere.

Throughout the text several ages are reported from the results of radiocarbon dating, especially in the chapters on case studies. Except where noted, these ages are given in radiocarbon years before present, without applying a correction to convert them to calendar years. The reason for this is to be consistent with other conventions for reporting dating results in the scientific literature.

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CHAPTER 1

INTRODUCTION

Unexplored regions on the submerged continental shelves and associated near shore environments could hold the clues to unraveling some of the mysteries about the expansion of human populations following the last Ice Age (Flemming, 1985; Renfrew and Bahn, 2000). Exploration for and discovery of submerged terrestrial sites has only occurred during the last few decades. Many known prehistoric underwater archaeological sites were accidentally found by local divers or fishermen in relatively shallow water depths (Flemming, 1985). Very few site discoveries resulted from systematic archaeological survey work, and virtually no definitive *in situ* cultural sites have been found in deeper water further offshore. Conducting prehistoric archaeology under water is costly and difficult for a variety of reasons and not many funding agencies sponsor this kind of research. By initiating and carrying out research and exploration in underwater prehistoric archaeology, the potential for answering significant anthropological questions exists. How, where, and why did Ice Age humans migrate and populate new regions on the planet? What was the nature of their subsistence? What types of environments did they prefer to occupy? How widespread was their occupation? State-of-the-art oceanographic technologies can and should be used to help answer these and other questions by systematically surveying, exploring, and intensely studying the submerged environments inundated by the latest transgression.

It is well-established that prehistoric human populations flourished during and following the last Ice Age. However, details about the nature of post-Pleistocene/Holocene human evolution and migration remain poorly known and controversial. There is a strong consensus that they may have followed coastal routes and favored these environments for a variety of reasons including abundance of food, ease of transportation, presence of sheltered areas, and a wealth of natural resources (Butzer, 1971). As sea level rose in response to melting glaciers, these coastal environments were inundated, and the evidence for this ancient human habitation now lies primarily underwater, at depths down to 120 meters on the continental shelves. By fully characterizing the submerged landscape and

reconstructing the paleo-geography of the continents, including identifying paleoshoreline features, underwater caves, ancient river channels, presently submerged hills, wetlands, and rocky shelters, an archaeological baseline can be established to identify regions in the ocean for further exploration for potentially important archaeological sites. Discovery of new sites that now lie under water could be extremely beneficial to anthropological science and human history, especially in the New World, where our knowledge of prehistory is limited.

Nearly three percent of the earth's dry land surface, representing about 4 million square kilometers of habitable land, was flooded between approximately 20,000 and 5,000 years ago (refer to Figure 1.1 for time scales). During this time, both humankind and the natural environment experienced rapid and extreme change. The earth's climate warmed and sea level rose more than 100 meters in response to the melting glaciers (Fairbanks, 1989). Complicating this picture, the deglaciation of the continents caused the elevation of the land to adjust isostatically. This adjustment of the crust results in the land moving vertically relative to sea level, but this effect is regional not global. This isostatic adjustment is still occurring today in certain regions. Land subsidence and uplift occurs naturally, but on very long time scales. Other local and regional effects on the land/sea interface include tectonic and volcanic processes that can both catastrophically or gradually change the landscape.

The last 20,000 years in earth's history includes the end of the last Ice Age and spans the transition from the late Pleistocene Epoch into the Holocene Epoch (Figure 1.1). This was a period of rapid change in earth's climate. During this time period, a few noteworthy climatic episodes occurred. The Younger Dryas event, a brief episode about 11,000 years ago when climate was very cold and dry, is characterized by a less abrupt rise in sea level between two very rapid rise pulses (Fairbanks, 1989). The "Little Ice Age" was another brief, cold episode from about the 16th to 19th centuries A.D. when the global average temperature was about 1 degree colder than today, spawning a short re-advance of glaciers (Mann et al., 1999). In human history, the last 20,000 years represent a time of rapid and extreme change in culture and population. The cultural periods represented for the Old World include the late Paleolithic, Mesolithic, and Neolithic of the Stone Age, transitioning to the Chalcolithic, Bronze Age, and Iron Age in more recent times (Figure 1.1). For the New World, we see humans enter for the first time around 13,000 years ago (Flemming, 1985), followed by the Paleo-Indian, Archaic,

Woodland, and Contact periods. The rapid advance of cultures in the Old World and spread of humans into the New World are arguably the most significant processes in human history during this time period following the last Ice Age.

Throughout the late Quaternary, human population on earth grew rapidly, especially in Africa during the Paleolithic (Reich and Goldstein, 1998). Around the time of the agricultural revolution, near the Pleistocene-Holocene transition, the population growth rate increased from about 0.0015% per year to 0.1% per year (Renfrew and Bahn, 2000). Today the global population growth rate is about 2% per year, with more rapid growth in less developed countries (Miller, 1988). In the United States during a 50 year span from 1960 projected to 2010, human population in the coastal zone (defined by counties bordering coastal features of the Atlantic Ocean, Gulf of Mexico, Pacific Ocean, and Great Lakes) will have grown by nearly 60% from 80 million to 127 million individuals (Culliton et al., 1990). Today, about 38% of the world's population lives within 100km of the coast and about 49% of the world's population lives within 200km of the coast (CIESIN, 2002). A separate statistic indicates about 25% of the world's population lives below the 50m elevation and about 36% of the world's population lives below the 100m elevation. So by today's statistics of the world's population distribution (based on calculations from CIESIN, 2002), a very large percentage of the people that inhabit the earth either live close to the coast or at low elevations, or both (Table 1.1; Figure 1.2). These are the people that would be most affected by rising sea level. Although there are not valid statistics available on population distributions for prehistoric times, one can speculate that it would be similar to the distribution of today, in terms of population percentages, except at a much smaller absolute scale. If this were true, according to modern statistics, nearly half the people that lived during the last Ice Age would have settlements near the coastal zone, just like modern humans.

At the time of glacial melting, modern human populations flourished and had spread along coastlines throughout the Old World and into the New World. As humans adapted to the warming climate and rising sea level, they organized socially, settled in new coastal environments, and became more technologically advanced (Yesner, 1980; Renfrew and Bahn, 1991). Coastal sites of human occupation from this time now lie beneath the oceans and marginal seas. Many coastal settlements that were inundated by rising seas, either gradually or catastrophically, must exist today as underwater

archaeological sites. By studying these sites, archaeologists and marine scientists will learn a great deal about both human and natural history and their environmental association. The preservation potential is greater for submerged archaeological sites compared to terrestrial sites, but little is known about their abundance and distribution. Due in part to rapidly advancing marine technologies, archaeologists and oceanographers can now locate and precisely survey and sample these submerged cultural sites, opening up a new frontier in marine archaeology. However, a comprehensive methodological approach for this new interdisciplinary field that incorporates both archaeological and oceanographic techniques does not exist. By merging oceanographic mapping, geophysical prospecting methods, and archaeological survey methods, a new methodology can be created and verified.

Exploration of the submerged continental shelf, up to about 120 meters water depth, for inundated archaeological sites relies on geophysical prospecting tools and oceanographic survey techniques. With the support of recent technological advancements, a new scientific discipline has emerged that combines the fields of archaeology, oceanography, geophysics, and deep submergence engineering. This new field of “Archaeological Oceanography” is truly multidisciplinary in nature and reaches far across both social and physical sciences. The collection and analysis of artifacts from documented underwater contexts will advance our understanding of prehistory and anthropology. The analysis of marine geophysical data and geological samples will advance our understanding of recent and diverse earth system processes. In combination, the multidisciplinary nature of this young science will advance our understanding of the cultural evolution of humans in association with their changing natural environment.

The marine environment is an ideal setting for archaeological research for many reasons. Firstly, millions of linear kilometers (depending of course on how precisely one measures the length) of the habitable continental coastline were inundated by the latest marine transgression. Undoubtedly, landward of these submerged coastlines, there is an abundance of undiscovered archaeological sites, representing a new and untouched scientific landscape. There is high preservation potential for both organic and inorganic ancient material. In addition, and perhaps most importantly, the discovery of submerged terrestrial sites along “land bridges” between continental landmasses or along drowned coastlines could definitively prove the existence of suspected early human migration routes. Lastly,

archaeological oceanography will directly benefit from advances in marine technology for surveying, imaging, and sampling. This final point is important for the protection of submerged cultural sites in that sites could be digitally imaged with such high resolution that a minimum amount of sampling would be required for adequate site characterization.

The tools and techniques of marine geological mapping have been continually advancing during recent years, with improved resolution and data processing capabilities. These techniques have been applied to underwater archaeology (Muckelroy, 1978), but not extensively. Many archaeological surveys in shallow water, particularly in the Mediterranean (Bass, 1975), were on sites previously and randomly discovered by fishermen or local divers. In addition, detailed geophysical investigations of archaeological sites, particularly in the deep sea, can often be cost-prohibitive. For this reason, there has not been a great deal accomplished to date.

Throughout the following chapters, theoretical discussions and operational methodologies pertaining to the underwater archaeology of inundated sites will be presented, followed by observational case studies, where the theories and methods will be tested. The case studies focus on several diverse regions (refer to Figures 2.1 and 2.2 for maps showing the case study locations relative to Ice Age glaciers) that were affected differently by the last glaciation. Humans also adapted and evolved differently in each region presented in the case studies. Finally, this research will be synthesized and put into the context of “archaeological oceanography.” This new scientific discipline is rapidly emerging and scholars in the more traditional fields of archaeology and oceanography are realizing its importance.

Many submerged prehistoric sites have been documented in shallow water in near-shore environments. A majority of these are from Neolithic times (Archaic in the Americas) or later and became inundated during a steady and slow rise in sea level. The discussions and case studies that follow present the potential for examining older sites (12,000 – 8,000 years BP) in deeper water (110 – 10 meters) and currently situated many kilometers offshore. This time span represents the period of the most rapid rise in sea level following the last glaciations, yielding the greatest preservation potential of inundated sites. Very few ancient sites have so far been located in these depths and distances from shore, yet this is a very significant period in human history.

Geological Time Scale

Archaeological Time Scales

Figure 1.1. Geologic and archaeological time scales for the Late Quaternary. Boundaries between adjacent periods are approximate and depend on locality. For example, the early Chalcolithic Period is defined by the first appearance of copper metallurgy at a particular locality, which varies significantly from place to place.

PERCENTAGE OF POPULATION WITHIN DEFINED GEOGRAPHIC SETTINGS

Continent	Elevation (meters above sea level)					Distance from coast	
	0 - 5	5 - 10	10 - 25	25 - 50	50 - 100	100 km	200 km
Africa	3%	2%	4%	5%	7%	33%	48%
Asia	7%	4%	9%	10%	12%	39%	49%
Europe	4%	2%	5%	8%	17%	39%	55%
North America	5%	3%	7%	8%	10%	44%	53%
Oceania	13%	5%	7%	10%	13%	85%	95%
South America	5%	2%	6%	6%	8%	49%	66%
World	6%	3%	7%	8%	11%	38%	49%
Cumulative	6%	9%	16%	24%	36%		

Table 1.1. For each continent, the percentage of the population that lives within the defined geospatial zone is listed. The global cumulative population by elevation zone is also computed for display in Figure 1.2. Data was computed from raw population density grids, based on 1995 census information. Source of data: CIESIN, Columbia University, 2002. National Aggregates of Geospatial Data: Population, Landscape and Climate Estimates (PLACE).

Figure 1.2. Percentage of world's current population within particular geographic settings. Dashed line represents population percentages within defined elevation ranges. Solid line represents population percentages within defined distances from the coast. Data source as in Table 1.

CHAPTER 2

LATE QUATERNARY GEOLOGICAL OCEANOGRAPHY

The Last Glacial Maximum

The Quaternary Period, the latest geologic period in the Cenozoic Era, began nearly 2 million years ago, and represents the time of ice ages. Throughout this time period, several glacial/interglacial episodes transpired, as the continental ice sheets waxed and waned over large spatial scales during the Pleistocene Epoch, which spans most of the Quaternary Period from its beginning (Erickson, 1990; Whyte, 1995). Each glacial period was long in duration and was followed by much shorter duration interglacial periods. The Holocene Epoch, which is the most recent period in earth history that began about 10,000 years ago, represents the interglacial period in which we are currently living. During the Pleistocene, as the polar ice caps grew and shrank, continental glaciers advanced and retreated, and sea level rose and fell in response. The absolute elevation of the earth's crust also fluctuated in response to glacial loading and unloading. About 20,000 years ago, during the most recent ice age, glaciers reached their southern terminus. At this time, when about one third of the earth's surface was covered by ice (Erickson, 1990), the glaciers began to recede. This time represents the Last Glacial Maximum (LGM), and in the Northern Hemisphere continental glaciers dominated much of North America and Eurasia (Figure 2.1). This latest glaciation is referred to as the Wisconsin glaciation in North America and the Würm glaciation in Eurasia.

During the Wisconsin glaciation, two ice sheets dominated northern North America (Figure 2.2). The Laurentide ice sheet emanated from the Arctic Circle and spread throughout central and eastern Canada and the northern United States. The Cordilleran ice sheet emanated from the Canadian Rocky Mountains and spread throughout the higher elevation regions of western North America. During the Würm glaciation, the Fennoscandian ice sheet spread from Scandinavia and the British Islands into northern Europe. Elsewhere around the globe, alpine glaciers grew and spread throughout high elevation mid-continent regions. The Antarctic ice sheet covered the entire continent and spread into the surrounding oceans. Massive ice shelves formed in both hemispheres and during the LGM, it is

estimated that ice covered half of the world's oceans (Erickson, 1990). This most recent ice age is the one that had the most significant effect on the earth as we know it today, and is also the one we know most about because it is represented in the recent high-resolution geologic record. The glacial geology of the Ice Age (noted in capital letters to define the most recent ice age) is recorded in the terrestrial landscape that is observed today. Regions that were immediately beneath or proximal to the ice during this time were directly affected by erosional and depositional process associated with the glaciations. Geomorphologic features of the earth's uppermost crust were created by these processes. Glacial and periglacial landforms from the LGM, as they are observed today, have been further modified by eustatic (adjustment of sea level) and isostatic (adjustment of crustal elevation) processes.

Characteristics of Quaternary climate are recorded primarily through ice and sediment cores. These provide high-resolution indicators of past climate, and major climate transitions are well-defined in the core record. Ice cores, from the Greenland and Antarctic ice sheets for example, directly record changes in the earth's global atmosphere, and represent a very precise climate record for the most recent past. Sediment cores from inland lakes record regional climate changes and changes to the terrestrial landscape. These can be used to resolve climate transitions further back in the geologic record. Deep-sea sediment cores directly record events even further back in the geologic record. These marine sediment records indicate both oceanographic and climatic change and their interrelationship. The scientific disciplines of paleoclimatology and paleoceanography decipher the earth's past climate using evidence primarily found in ice and sediment cores.

Environmental change during and following the LGM was extreme (Adams et al., 1999). Throughout the late Quaternary, abrupt changes in climate brought about abrupt changes in glaciers, which brought about abrupt changes in land elevation and global sea level. All of these changes resulted in dramatic change to the coastal environment, primarily by changing the interface between water and land. Through years of ice age geologic and climatologic research, there is a solid understanding of the causes and effects of late Quaternary environmental change since the LGM. However, how this has influenced human habitation along the changing coastlines remains poorly understood. Catastrophic environmental change would influence human populations quite differently than gradual environmental change. If the changes were not catastrophic, then they would still be

abrupt on a geologic time scale, and have a significant impact on people. Despite the rate of change in sea level, or the rapidity of flooding, it remains a fact that sites of human occupation in coastal settings now lie underwater. The rate of submergence, however, would significantly influence the state of preservation, the volume of overburden, and the redistribution of material.

Eustasy

Eustasy refers to variation in the globally averaged absolute elevation of the sea. This is quite different from relative changes in sea level for specific regions. However, in order to better understand relative sea level change, a firm understanding of absolute sea level change is necessary. Eustatic change in sea level results from change in the total volume of water in the ocean basins. A significant control on this volume is change in global ice volume. When polar ice caps and large continental ice sheets grow, global sea level is lowered. When they melt, global sea level rises. Both relative and absolute sea level change are recorded in the geomorphologic and stratigraphic record. Features of the geomorphologic record important to determining sea level history are the relative positions of ancient shorelines (van Andel, 1989). Fossils in the marine stratigraphic record can be used to determine an oceanic oxygen isotope curve, which can be used to determine the volume of water stored in continental ice sheets (Chappell and Shackleton, 1986). Absolute dating, typically by the radiocarbon method and the uranium-series radioisotopic method, of the shorelines and cores, puts the correlation in a temporal reference frame. A eustatic sea level curve, such as for the Quaternary Period, can then be created (Figure 2.3, upper right) that is based on the correlation and chronology.

For a finer-scale eustatic sea level curve for the late Quaternary period since the LGM, cores from submerged coral reefs in Barbados were analyzed and dated (Fairbanks, 1989). These particular coral formations always grow within a few meters of sea level. Corrections had to be made for the uplift of the Barbados platform and for the conversion from radiocarbon years to calendar years. The curve reveals a relatively slow and gradual rise in global sea level from about 18,000 years before present until about 14,000 years before present, followed by a steady and very sharp rise from about 14,000 to 6,000 years before present, then followed by another more gradual rise until the present day (Figure 2.3; Fairbanks, 1989). During the sharp rise, a relatively brief period of slower rise is represented by the

Younger Dryas Event. In all, according to this data, about 120 meters vertical rise of the global ocean has occurred during the last 18,000 years. This curve is widely cited and considered the standard sea level rise curve for the late Pleistocene and Holocene Epochs. Adjustments must be made to this curve in order to apply it to the shoreline positions and sea level rise history for particular sites, once local and regional isostatic and tectonic effects are determined. Interestingly, as illustrated in Figure 2.3, the sea level drop during the LGM is greater than at any other time during the previous 100,000 years. Therefore, around the same time as the expansion of human population and peopling of the New World, sea level was at its lowest. The steepest part of curve in Figure 2.3 is between about 14,000 and 6,000 years before present. During this 8,000-year time interval sea level rose about 100 meters. That represents a rate of more than one meter per century, which is quite rapid by geological standards. This time period spans from the late Pleistocene into the early Holocene and includes several cultural periods in both the Old and New World. In Europe and Asia, the late Paleolithic, Mesolithic, and early Neolithic time periods are represented and in the Americas, the Paleo-Indian and early Archaic periods are represented.

Hypsometry refers to the measure of the amount of land at particular elevations relative to sea level. Presently, about 71 percent of the earth's surface is covered by ocean water and 29 percent is continental land (Figure 2.4). The bimodal distribution peaks represent the average elevation of land above sea level (more than two-thirds between 0 and 1000 m) and the average depth of the ocean below sea level (more than one third between -4000 and -5000 m). This bimodal distribution is due to the fact that there are basically two types of crust on earth, less dense continental crust and more dense oceanic crust. As illustrated in Figure 2.4, the cumulative distribution of land area above sea level would substantially increase if sea level were about 100 meters lower than at present, such as during the LGM. The result would be an increase in total land surface area by an additional 3 percent (or about 1 percent of the total earth's surface area). This represents about 5 million square kilometers of coastal land. Much of this additional land surface would have been covered in ice during the LGM; nevertheless, an enormous amount would have been exposed and habitable. This statistic does not take into account fluctuations in land elevation due to isostasy, however, but it crudely illustrates the point that inundated land masses represent an extremely large area. One percent of the earth's surface, exposed as it was

during the LGM, is actually about 3 percent of the continental surface area. This fact, that about 3 percent of the continents were flooded by eustatic rise in sea level, can stand alone in illustrating the importance eustasy had on humans.

Isostasy

The earth's rigid lithosphere, which floats on the weaker asthenosphere, will deform due to loads contributed by the earth's crust (including continental and oceanic crustal rocks and sediment), water, and ice. The elastic lithosphere flexes under the load, and the plastic asthenosphere flows to accommodate its flexure (Figure 2.5). The basic result of the isostatic adjustment is a net vertical increase or decrease in crustal elevation. The amount of vertical displacement is a function of the density and thickness of each layer, based on Archimedes' principle. Removal of ice sheets, erosion of the continental crust, and deposition of sediment on the shelf are processes that cause the isostatic equilibrium to adjust. This adjustment is responsible for localized and regional shifts in the elevation of the land relative to the ocean. In some cases, this amounts to significant displacements. Such is the case for Fennoscandia, where a very large amount of ice was removed from a continental landmass, which is surrounded to the north and west primarily by oceanic crust (Figure 2.6). At the point of maximum vertical displacement, more than 800 meters of uplift occurred as a result of glacial unloading (Mörner, 1980). There is a region of zero net vertical displacement, and as illustrated in Figure 2.6, this follows near the present-day northwestern Scandinavian shoreline. Landward of this region, ancient shorelines have been uplifted and seaward of this region, ancient shorelines remain submerged. Because the earth's asthenosphere must flow beneath the uplifted lithosphere, the effect is to further lower the shorelines offshore, according to a sinusoidal-shaped power law function. This example of isostatic adjustment of Scandinavia is extreme, however.

Isostatic uplift of the continents due to melting glaciers causes changes in the land/sea interface. As the land rises, the shoreline does as well, and a new shoreline forms at a lower level. This is not the case for inland bodies of water, such as the Great Lakes, where the lakes themselves would also adjust isostatically with the land, so there would be little change in shoreline elevation, unless the lake level was fluctuating. On continental margins, if the rate of isostatic uplift was perfectly synchronous with

the rate of sea level rise, the shoreline would not change at all. This is almost never the case. The disparity between these rates results in a net relative sea level rise or lowering. This is commonly the case, especially in higher latitudes where isostatic uplift is significant. It is very difficult to determine absolute sea level change, except in regions where the land elevation has been stable, because it is difficult to distinguish between isostatic and eustatic effects on shoreline elevations. For archaeological purposes, however, the relative change is more significant. If the sea rises and falls relative to the land, or the land rises and falls relative to the sea, then the net effect is the same.

Tectonics, Volcanism, and Other Geologic Processes

Tectonic and volcanic processes can significantly affect the elevation of land and, therefore, relative sea level. Mass wasting events that coincide with eruptions or earthquakes can redistribute rock and sediment, thereby shifting the load on the earth's crust. Similar to the way glacial loading and unloading can cause isostatic adjustment of the crust, sediment loading and unloading due to volcanic and tectonic processes can also have an isostatic effect.

In addition to the effect on landscape and environment, volcanic and tectonic events can significantly influence sites of human activity located near the event sources. Notable volcanic eruptions that have wiped out the population of entire regions have also preserved archaeological sites in the deposits. Pompeii and Herculaneum, ancient cities near the present day Bay of Naples, Italy, were both destroyed and preserved by volcanic ash and pyroclastic flow deposits from the eruption of Mt. Vesuvius in A.D. 79 (Harris, 2000). Another notable eruption is that of the volcano on Thera (Santorini) in the Aegean Sea, during the 17th century B.C. Here, the late Bronze Age Minoan city of Akrotiri lies covered by volcanic deposits from the eruption.

Some other natural processes can influence relative sea level rise and land elevation. Non-tectonic isostatic subsidence and uplift can occur in regions of extremely high sedimentation and in regions where mass wasting is prevalent. For example, in the coastal deltaic environments of large river systems, these features can collapse, and occasionally sink under water due to the massive deposition of river sediment over time. Processes such as these have occurred in the Nile delta region of the

Mediterranean Sea, on the Egyptian coast. Parts of the ancient city of Alexandria have subsided into the sea and exist there today as underwater archaeological sites (Goddio, 1998).

The evolution of shorelines and coastal geological features also depends on the position of the coast on the continental margin relative to significant tectonic features. Passive continental margins, such as those surrounding the Atlantic Ocean behave much differently than active continental margins, such as those surrounding the Pacific Ocean - likewise for the passive margin associated with North Africa in the southern Mediterranean Sea and for the active margin associated with southern Europe in the northern Mediterranean Sea. For coastlines on the leading edge of a continent, like along the California coast, the land is subjected to more vertical dynamics of subsidence and uplift (van Andel, 1994). For coastlines on the trailing edge of a continent, the vertical movements of the land relative to the ocean are often less pronounced. These dynamics are functions of the controlling plate tectonic processes and general occur during long time scales.

Global-scale magmatic activity can also influence relative sea level. These processes are worth mentioning here, but not in great detail. The internal dynamics of the earth's outer core and mantle govern the rate at which magma is supplied to shallower levels in the earth's crust, and this can, in turn, govern global eustatic sea level changes. During the Cretaceous period, for example, a large magma supply caused rapid seafloor spreading throughout the mid-ocean ridge system, increasing its volume, and displacing seawater out of the ocean basins (van Andel, 1994). This process did not influence sea level during the Quaternary period, however.

Inundation

Relative sea level rise causes low-lying coastal plains to become inundated. The rate of inundation, which equates to the rate of transgression, strongly influences the adaptation of the coastal environment and the destruction or preservation of coastal geomorphologic features (Belknap and Kraft, 1981). Preservation of fragile features of the coastal landscape, including man-made structures, also depends on the rate of inundation. This rate also influences the formation of coastal features such as beaches and lagoons. Gradual inundation would tend to destroy features through the process of erosion, especially by wave activity and shoreface erosion. Rapid inundation could preserve features, depending

on the total vertical rise of the sea or lake relative to land. The horizontal distance of the inundated region is a function of the slope of the coastal feature (Figure 2.7). A large amount of flat, low-lying land will be inundated with a small rise in sea level, whereas steeper terrain would not be inundated nearly as much with the same sea level rise.

The preservation of coastal features following a marine transgression depends on a number of different factors. Belknap and Kraft (1981) have extensively studied the continental shelf and coast off Delaware to examine the evolution and preservation of coastal geologic features in response to the latest Quaternary transgression. These authors concluded that shoreline elements on the outer shelf have a significantly higher degree of preservation than features on the inner shelf. This is primarily due to the rate of relative sea level rise, which was determined to decrease with time. Other factors that control preservation of geologic features are wave energy, amount of erosion, sediment supply, and tidal range (Belknap and Kraft, 1981). For the Delaware coast, the shoreline elements include primarily barrier beaches and lagoons. The barrier and dune sediments are less likely to be preserved than the lagoon sediments. A study of the Louisiana coast, at the Mississippi River delta, revealed sediment sequences of barrier beach systems, such as dunes, spits, and bars, do not survive marine transgressions, but evolve and transform into low-relief sandy offshore shoals (Penland et al., 1988).

If the Belknap and Kraft model is correct, as they predict, then preservation of coastal features should be found far offshore on the distal shelf, in deep water. This location also happens to be where the Late Quaternary sedimentary deposits are thinnest (Uchupi et al., 2001). Therefore, this same region could represent where sites of human occupation are best preserved and exposed. This is a hypothesis that needs further testing, however.

Figure 2.1. Maximum extent of ice cover (CLIMAP maximum model) in the Northern Hemisphere during the Last Glacial Maximum (modified from Clark and Mix, 2002 after Denton and Hughes, 1981). Ice sheets identified by letters: C = Cordilleran; L = Laurentide; I = Innuitian; G = Greenland; B = British; S = Scandinavian; Ba = Barents Sea; and K = Kara Sea. The location of the Black Sea, one of the case studies, is indicated.

Figure 2.2. Extent of ice cover in North America during the Last Glacial Maximum (modified from Dyke, et al., 2002). The locations of Lake Huron and Southern New England, two of the case studies, are indicated.

Figure 2.3. Sea level rise curves for the Late Quaternary Period (upper right; after van Andel, 1989) and since the Last Glacial Maximum (lower left; after Fairbanks, 1989). Region in red represents very rapid rise in sea level of about 100 meters between about 6,000 – 14,000 years BP.

Figure 2.4. Modern hypsometric curve illustrating the effect that lowering sea level by 100 meters increases the total land area by about 1 percent. Histogram shows the frequency distribution of land elevations (blue bars and red line). The cumulative distribution is indicated by the green line.

Figure 2.5. Isostasy, or the gravitational equilibrium among the earth's upper layers. The earth's crust, which is part of the rigid lithosphere, but separated here for illustration purposes, causes the asthenosphere to deform to accommodate density fluctuations caused by adding or removing ice or redistributing sediment. The effect is vertical adjustment of the upper layers, based on Archimedes' principle, as illustrated in the lower part of the figure. For $\rho_1 > \rho_2 > \rho_3$, if the top layer is removed, the bottom layer would buoy-up the middle layer.

Figure 2.6. Post-glacial isostatic rebound of Fennoscandia. Uplift in meters above sea level (Fischer, 1995; after Mörner, 1980).

Figure 2.7. Inundation of the coastal margin due to eustatic sea level rise. For relatively flat margins (upper panel), a large area is inundated due to a small rise in sea level. For gently sloping margins (middle panel), substantially less area is inundated with the same rise in sea level, and likewise, for steeply sloping margins (lower panel), even less area is inundated with the same rise.

CHAPTER 3

PREHISTORIC COASTAL ARCHAEOLOGY

Early Human Populations

The Quaternary Period, as discussed in the previous chapter, not only represents the time of ice ages, but also represents a productive time in human evolution and population expansion. In the early Pleistocene, about 1.7 million years ago, *Homo erectus*, a precursor to modern humans, began to emerge in East Africa (Wells, 2002). Material clues to their past are rare, however. About 100,000 years ago, *Homo sapiens* began to emerge in Africa with skeletal remains looking more like that of modern humans. Wells (2002) reported on genetic studies (from male Y-chromosome DNA analyses) that indicate all modern humans are descended from a common group of ancestors in Africa around this time. In addition, Neanderthal populations emerged and expanded throughout Europe, and *H. erectus* spread into Southeast Asia (Wells, 2002). By late Paleolithic times, around 30,000 years ago, anatomically modern *H. sapiens* were the only surviving hominid species (Wells, 2002). *H. sapiens* had different physical features compatible with their technological advancements, less evidence of physical injuries, and enjoyed a longer life span compared to other early hominids (Haviland, 1997). The Upper Paleolithic is also characterized by widespread migration of humans. By about 50,000 years ago, humans migrated out of Africa and into Indonesia, New Guinea, and Australia, which was a joined land mass resulting from glacial sea-lowering (Wells, 2002). However, it was not until about 13,000 years ago that humans migrated into the Americas (Flemming, 1985).

The maritime landscape favored coastal adaptations of early humans for a variety of reasons. In Mesolithic times, people that had not yet adapted agriculture were organized socially primarily in mobile hunter-gatherer groups (Renfrew and Bahn, 2000). The amount and variety of subsistence resources in coastal environments is far greater than in other environmental settings. All rivers, streams, and tributaries eventually flow to larger bodies of water. Therefore the coastal environments that surround these larger bodies of water are commonly crossed by rivers, which are the primary fresh water resource. Other natural resources found in coastal environments include shellfish, fish, and marine mammals. There is evidence that shellfish were collected and used by humans living along the

Mediterranean coast of southern France between 235,000 and 400,000 years ago (Flemming, 1985). Also, many lithic resources are found in coastal settings, where erosion of bedrock and glacial depositional processes produce stones that were used to manufacture tools. In addition, coastal regions afford ample opportunity for travel by personal watercraft (such as the canoe), as these relatively low-lying regions are typically very accessible. This enabled early humans to expand their hunting and gathering regimes by traveling through rivers and coastal lagoons and along the shores of bays (Yesner, 1980).

Land Bridges and Migration Routes

The dispersal of human populations and their pattern of settlement depend on their ability to adapt to certain environmental conditions. This ability for adaptation depends on their culture and technological advancement (Butzer, 1971). The material aspects of human culture are a significant determining factor in their adaptation to changing environments. These include economy, technology, settlement, and land use (Butzer, 1971), aspects that are all interconnected.

Human migration out of Africa, Europe, and Asia and into North/South America and Australia had to include either the use of personal watercraft or the following of routes across presently submerged land bridges (Wells, 2002; Figure 3.1). This is a necessary fact as it would be otherwise impossible to get to these places. The only place where humans could have crossed into the Americas is from Siberia across the Beringia land bridge into Alaska, now occupied by the Bering Strait. The only place where humans could have crossed into Australia and New Guinea is across the Sunda-Sahul land bridge from Indonesia. The appearance of the first humans in these remote regions (compared to Africa and Eurasia) definitively correspond to times of lower sea levels when the shallow bodies of water that separate these land masses were exposed dry-land surfaces. As illustrated in Figure 3.1, the dispersal pattern emanating from Africa to the farthest reaches of the world (barring Antarctica) required land-bridge crossings. Aside from the Beringia and Sunda-Sahul, land bridges were most likely used to get people to the British Isles, Japan, and most of the Indonesian island chain. Possible land bridges could have been used by humans crossing the Mediterranean Sea as well (Flemming, 1985).

In addition to human populations, the introduction of new animal species into New World environments was made possible by the exposed land bridges (Butzer, 1971). Perhaps human populations followed animal migration routes. Like many indirect lines of evidence, human migration across the land bridges is unsubstantiated, and therefore is a controversial subject among anthropologists. This controversy is due to the fact that no underwater *in situ* sites with material evidence for human occupation have been found along suspected submerged migration routes, such as on the Beringia or Sunda-Sahul shelves (Flemming, 1983). One could always argue that humans used boats for crossings, but this seems like a losing debate. Until a prehistoric human site is found on a submerged land bridge, the debate will continue.

The Beringia land bridge (Figure 3.2) occupied large portions of the Chukchi and Bering Seas during times following the LGM. As sea level rose, the total area of the land bridge diminished. As illustrated in Figure 3.2, at 18,000 years BP, according to the Barbados sea level rise curve (Fairbanks, 1989), sea level was about 120 meters lower and at 10,000 years BP sea level was about 60 meters lower than the present day level. At either time, an enormous expanse of the submerged shelf was exposed, especially to the north beneath the Chukchi Sea. At 10,000 years BP, still more than 1,000,000 additional square kilometers of dry land was exposed between Siberia and Alaska. In fact, due the shallow nature of the Bering Strait, a land bridge existed until only about 5,000 years ago, permitting humans to migrate without the use of watercraft.

Due to more extreme water depths, the Sunda-Sahul land bridge never actually connected dry land masses together (Figure 3.3). However, large portions of the shallow shelves surrounding the present day islands were exposed to join together large groups of islands and narrow the gap between the Sunda and Sahul shelves. When humans first entered Australia around 50,000 years ago (Wells, 2002), the islands were actually farther apart than at later times, yet closer together than today. Therefore, the use of personal watercraft was a necessity in order to permit crossing between adjacent land masses.

Underwater Coastal Archaeological Sites

Numerous prehistoric sites have been found in coastal environments throughout the world. For purposes here, only sites in Europe and North America are discussed. A number of these sites,

especially in the Mediterranean region, are associated with ancient harbors and seaports that have become submerged during approximately the last 5,000 years, and exist today in relatively shallow water. Again, for purposes here, only sites that became submerged prior to 5,000 years BP are discussed. Prior to 5,000 years BP sea level rise was very rapid, then tapered off. During the last 5,000 years sea level rise was much more gradual and coastal and submerged archaeological sites are more abundant than during previous times.

In the Mediterranean Sea, along the south coasts of Spain, France, Italy, and Greece, a number of submerged caves have yielded clues about human occupancy during times of lower sea level (Flemming, 1983). These caves, with entrances that lie underwater along limestone sea cliffs, provided shelter for Paleolithic and later human populations. Many of them contain lithic artifacts and hearths, and are adorned by rock art, especially the Cosquer cave (Clottes and Courtin, 1996). In northern Europe, off the Dutch coast, a number of significant submerged prehistoric sites have been discovered and documented. Inundated Mesolithic sites in the North Sea contain well-preserved remains of human inhabitants and associated artifacts including fragile fishing implements manufactured from bone and antler (Verhart, 1995).

In British Columbia, Canada, off the Queen Charlotte Islands, researchers mapped a submerged terrestrial landscape of paleo-river channels and paleoshoreline features. Associated with these features were lithic artifacts and faunal remains that indicate human occupation of this coastal environment around 10,000 years BP (Josenhans et al., 1995; Fedje and Josenhans, 2000). Also in North America, inundated Paleo-Indian and Archaic period sites have been discovered in the Gulf of Mexico, off the Florida coast and near the submerged Sabine River valley, off the Texas and Louisiana coast (Stright, 1990). These discoveries include lithic artifacts and shell midden deposits found near submerged paleoshoreline features. Other Pacific and Atlantic inundated sites have been found on the shallow shelf, including mostly isolated finds, but some of the most significant sites were discovered in Florida. Two inundated limestone sinkholes in Florida were investigated and a diverse assemblage of submerged archaeological and faunal material was discovered and dated to between 10,000 and 13,000 years BP (Stright, 1990). In Warm Mineral Springs, human burial remains, faunal remains, and lithic tools were found in a high-state of preservation due to the anaerobic conditions at a depth of about 13 meters in the

sinkhole (Clausen, 1975). Nearby, in Little Salt Springs, at a depth of about 26 meters in the sinkhole, two wooden stakes were found embedded between the plates of a tortoise shell (Clausen et al., 1979).

Preservation of human cultural remains under water depends on a number of factors. If artifacts are exposed on the seafloor, then they most likely will be lithic in nature. Figure 3.4 illustrates the *in situ* presence of stone mortars found off southern California (Masters, 1983). These mortars (and hundreds of other mortars previously discovered) lie in shallow water depths off La Jolla Shores. Other lithic artifacts from this site have been documented, including pestles, scrapers, and projectile points (Masters, 1983). Clearly, as made evident here, stone artifacts can survive inundation. Figure 3.5 shows a submerged stone wall, part of a dwelling structure, which became submerged following the Holocene transgression in the Aegean Sea (Flemming, 1969). Both of these examples reveal the preservation of stone artifacts that were indisputably manipulated by humans. Non-lithic artifacts would be much less likely to survive in underwater environments unless they are buried in the shallow sediment. Figure 3.6 illustrates the degradation of organic remains due to inundation. A lakeside dwelling built primarily of organic material (such as wood and reeds) that becomes inundated by rising water levels would not survive very well. The process would erode away nearly the entire dwelling, leaving behind only what becomes buried, such as the wooden structural posts (Figure 3.6).

For submerged sites of human occupation on the continental shelf, preservation is strongly dependent on the rate of inundation and the slope of the shelf (Stright, 1995). Bursts of rapid sea level rise during the Late Quaternary transgression could have preserved ancient sites on the continental shelf. A surge around 14,000 years BP raised sea level at a rate of about 3.7m/100 years; and a second surge around 11,000 years BP raised sea level at a rate of about 2.5m/100 years (Bard et al, 1990). Such bursts in sea level rise at these times are important to the preservation of inundated sites, and these times represent significant periods in human history, especially in North and South America.

Figure 3.1. Possible migration routes of ancient human populations out of East Africa, throughout Europe and the Middle East, into Asia and eventually into Australia via the Sunda-Sahul land bridge and into North and South America via the Beringia land bridge (modified after Wells, 2002). Data for each path is based on Y-chromosome DNA studies (Wells, 2002).

Figure 3.2. Extent of the Beringia land bridge 18,000 years ago (blue, 120m depth contour) and 10,000 years ago (red, 60m depth contour) based on the eustatic sea level rise curve (Fairbanks, 1989).

Figure 3.3. Extent of the Sunda-Sahul land bridge 18,000 years ago (blue, 120m depth contour) based on the eustatic sea level rise curve (Fairbanks, 1989) and 50,000 years ago when sea level was higher prior to the Last Glacial Maximum (red, 60m depth contour) based on the Quaternary sea level rise curve (van Andel, 1989). No dry land connection could have existed based on the extreme water depths between islands

Figure 3.4. Two Paleo-Indian mortars found *in situ* off La Jolla, California in 3-4m water depth (Masters, 1983).

Figure 3.5. A submerged stone wall from a dwelling off Greece, in about 3 meters water depth (Flemming, 1969).

Figure 3.6. Artistic depiction of the inundation of a Neolithic lake village - Charavines, along Lake Zurich in Switzerland: (1) as it exists today; (2) during rising lake levels; and (3) during the Neolithic (Blot, 1995; after Bocquet 1994).

CHAPTER 4

ARCHAEOLOGICAL OCEANOGRAPHIC METHODS FOR UNDERWATER SITE SURVEYS

Introduction

Geophysical prospecting techniques for land-based archaeological studies are fairly well-established. For the most part this is true for marine archaeological studies as well (Oxley and O'Regan, 2001). In addition, oceanographic survey techniques that focus on mapping and exploring the marine environment are well-established. However, traditional oceanographic methodologies are not typically applied to marine archaeology. A major limiting factor that influences this is the high cost. For example, the current operational cost for using an ocean-class research vessel can be more than \$20,000 per day. Deep submergence vehicle systems and advanced geophysical survey equipment that are used with these research vessels can cost more than \$10,000 per day. The total cost for one day of shipboard operations could be enough to fund an entire season of a terrestrial archaeological site excavation. But this example really does not represent a fair comparison. Such daily costs associated with doing research at sea are typically devoted to the study of natural history phenomena in the oceans and on the ocean floors. The following questions can be asked: Is the study of human history beneath the sea just as important as the study of natural history beneath the sea? Are cultural resources as significant as natural resources? Should federal dollars be equally spent to protect these resources? Should archaeology be federally funded to the same level as other oceanographic sciences? If the answer is yes to any of these questions, then we can justify the cost of conducting "archaeological oceanography." Many of the well-established geophysical tools and techniques that have been employed by archaeologists in shallow water can also be used on larger ships and in deeper water, thereby employing an oceanographic approach. Deep water oceanographic techniques do not differ greatly from shallow water techniques, but a focus here is to present methodologies for surveying that optimize time onboard expensive scientific research vessels.

Archaeologists have used side-scan sonar, subbottom profilers, magnetometers, and visual imaging techniques, although not nearly as extensively as SCUBA techniques, to search for and map submerged sites, especially shipwrecks (Oxley and O'Regan, 2001). For exploration and mapping of terrestrial

sites, use of ground-penetrating radar (GPR) has become more widespread to acoustically image the subsurface details of sites. Collection of sediment cores to groundtruth the GPR data and to characterize the depositional context of terrestrial sites is also common in terrestrial site surveys. In a similar manner to the way these geological techniques have been employed to investigate terrestrial archaeological sites, oceanographic techniques are now being employed to investigate underwater archaeological sites. These will be discussed below.

Established Archaeological Survey

Archaeological survey strategies and techniques, particularly for terrestrial sites, are well-established (Banning, 2002). These strategies include different approaches for exploration, reconnaissance surveying, and intensive site surveying. Regional scale surveying techniques (Dunnell and Dancey, 1983) and sampling strategies (Nance, 1983) are also well-established, but these are also mainly for terrestrial archaeology. Archaeological survey can involve different techniques and methodologies, depending on the site. From a theoretical standpoint, there should be almost no difference between surveying on land or under water, except for the obvious logistical differences. For example on land aerial photographs can be used as a base map similar to the under water use of side-scan sonar mosaics. From a practical standpoint, however, there are significant differences. Firstly, many underwater sites are in regions of very poor visibility. Therefore surveyors must rely more on acoustic strategies than visual strategies. Secondly, survey techniques for shipwreck archaeology differ from the techniques for surveying terrestrial (including inundated) sites. Ancient shipping trade routes or more modern naval battle locations – regions where shipwrecks would be expected for example – would have well-defined boundaries that would bias the survey strategy. Thirdly, and perhaps most importantly, underwater surveys are much more difficult logistically, and the rigid limits set by cost, time, and weather for work at sea could significantly influence survey strategies.

In order to complete a well-planned archaeological survey, whether on land or under water (shipwrecks or inundated terrestrial sites), the entire region of interest should be mapped and investigated, even if there are no suspected sites in parts of the survey region. Not finding sites in particular locations provides scientific data and evidence to support the regional archaeological

interpretation. For example, to search for shipwrecks along suspected trade routes, surveyors must also search away from the suspected trade routes to verify working hypotheses about delineation of the suspected routes.

Established guidelines for underwater survey exist, primarily for the purposes of cultural resource management. Several federal agencies in the United States, such as the Army Corps of Engineers, the Minerals Management Service, the National Park Service, and the National Oceanic and Atmospheric Administration, either suggest or require survey operations to follow their guidelines. These guidelines vary depending on the particular archaeological sites and the scope of work. For the most part, the survey guidelines were established to protect submerged cultural resources from being damaged by activities that involve disturbance of the seabed, such as dredging, construction projects, and oil well drilling. Compliance with the National Historic Preservation Act of 1966 is a requirement, and a complete site survey and characterization is necessary and must be approved prior to further site activity. Also, many individual coastal states have rules and regulations in addition to the requirements by federal law. In addition, international organizations such as UNESCO (United Nations Educational, Scientific and Cultural Organization), have worked to develop international guidelines and codes of ethics for conducting archaeology under water.

A variety of geophysical methods have been used in land-based archaeological exploration and surveying, including, but not limited to, satellite remote sensing, airborne imaging, ground-penetrating radar, and magnetic techniques (Renfrew and Bahn, 1991). These are primarily tools for prospecting. Other terrestrial archaeological methods that involve geophysical techniques include archaeomagnetism, radioisotope studies, dendrochronology, palynology, paleontology, and provenance studies. These are primarily analytical methods and are useful in absolute dating and understanding past environmental conditions and archaeological associations. For buried terrestrial archaeological sites, a regional sampling strategy can be employed to test for and potential discover sites (Nance, 1983). This could include coring or excavating test pits situated in high-probability locations.

For the marine environment, similar sets of prospecting and analytical techniques exist. The primary focus here will be on marine geophysical exploration and surveying techniques; however, techniques analogous to those used on land can be used once an archaeological site is identified for

higher resolution investigations. Intrusive techniques have been employed as part of the survey phase of underwater archaeology (Oxley and O'Regan, 2001). This primarily involves limited sampling of material from the site to better characterize and understand its nature, such as the collection of organic material for radiocarbon dating. Excavation, such as trial trenching on land to test whether or not a site exists, is intrusive and can be very destructive, and this is not very practical for investigating underwater sites (Oxley and O'Regan, 2001). Techniques for underwater site excavation are well-established (e.g. Green, 1990), and typically involve intensive surveying to carefully map the site prior to excavation and subsequent site disturbance. New oceanographic methodologies that employ ROV systems for high-precision site surveys can now be utilized in both shallow in deep water settings (Foley and Mindell, 2002).

Archaeological Oceanographic Surveys

The nature of the survey strategy is dependent on whether or not archaeological sites are known to exist within the region to be surveyed. Exploratory and reconnaissance surveys can take many forms; however, for targeting inundated archaeological sites, certain methodologies work better than others. A full range of geophysical methods can be applied to archaeological oceanography, and these methods help to define this new field. Interpretation of the survey data will help to delineate sites for further exploration and detailed investigation. These oceanographic methods include bathymetric mapping, side-scan sonar surveying, high resolution reflection surveying (including subbottom profiling and lower frequency seismic methods), magnetometer surveys, and visual imaging surveys using remotely operated vehicle (ROV) systems (Oxley and O'Regan, 2001). Other geophysical methods, including electrical resistivity and marine gravimetry methods, can be used to explore for and characterize underwater archaeological sites.

For inundated site surveys the strategy must be different from shipwreck mapping surveys because prehistoric sites are typically buried in the shelf sediment. The process of coastal inundation due to rising sea level is generally destructive to archaeological sites. If sites are rapidly buried, there is a greater chance for preservation of delicate materials. But for the most part, what survives are the non-delicate cultural and human remains – lithic artifacts (stone tools, points), kitchen middens (mammal

and fish bones, shells), gravesites (human bones and associated artifacts), stone foundations of dwellings, pottery, hearths, postholes, and other cultural features. Remote sensing methods would not typically be able to distinguish these cultural remains from natural features on and in the sediments. Visual methods must be used to identify specific anthropogenic features from natural features.

A new methodological approach is presented here that involves both remote sensing and visual inspection techniques. The remote sensing strategy is used to identify potential archaeological environments on the seabed – paleoshorelines, ancient river channels, tidal inlets, lagoons, and embayments. Once these features are located through geomorphologic analysis, a systematic approach to develop the visual survey is used to target regions where submerged archaeological sites are predicted based on the environmental setting. One aspect of the archaeological oceanographic survey methods presented here that is common to all techniques is accurate and precise navigation. By employing the Global Positioning System (GPS) navigation can be accurate to within a couple of meters using differentially corrected signals. For the case studies presented in later chapters, the geophysical techniques utilized are bathymetric mapping, side scan-sonar imaging, sub-bottom profiling, video and still camera photography, and geological sampling. These will be described below.

Side-Scan Sonar Surveying

Side-scan sonar is commonly used to acoustically map the seafloor. A side-scan sonar towfish is typically deployed off a survey vessel and towed behind the ship through the water at a given altitude above the seafloor (Figure 4.1). *Echo* is an example of a side-scan sonar towfish (Figure 4.2). For use of this particular system, the towfish is tethered to a depressor weight that acts as a heave-compensator, thereby allowing the towfish to be unaffected by the ship's vertical motion. The system emits acoustic pulses at set intervals that are focused with a defined beam pattern according to the design of the sonar transducer. The range, or imaging distance to either side of the centerline, can also be set, as can other data acquisition parameters. Because the instrument images to both sides, twice the range indicates the effective swath width that represents the width of seafloor that is mapped along track (Figure 4.1). The acoustic sonar pulses are transmitted with a set frequency. Some dual-frequency side-scan sonar

systems exist (*Echo* for example), which enable high and low resolution data to be collected at the same time.

By keeping careful track of the layback, or the horizontal distance behind the ship that the instrument is towed, which is a function of the amount of cable that is spooled out, features on the seabed can be precisely located. The layback represents an offset that can be used to compute the GPS position of features on the seafloor. Acoustic targets stand out on the sonar record as anomalous features. These targets are either natural or man-made features that can be later inspected using visual surveying techniques, as discussed later. Large targets that have vertical relief will have an associated acoustic shadow that is clearly visible on the sonar record. The shadow results from a loss of acoustic information on the seabed because the target is essentially blocking the sonar pulse from reaching points inside the shadow. As with most acoustic data, the interpretation of targets relies on groundtruthing by visual inspection, to determine if the features are natural or manmade. An exception to this is modern shipwreck targets that typically can be recognized solely by their acoustic character. To fully characterize shipwreck targets, visual inspection is still required, however. For more information on side-scan sonar theory and operation, refer to Fish and Carr (1991).

Bathymetric Mapping

The initiation of a terrestrial archaeological survey typically involves examination of topographic maps, aerial photographs, and satellite remote sensing images (Banning, 2002). Marine archaeological surveying must commence with a similar data set. Multibeam (swath) mapping and single-beam (echo sounding) methods are used in reconnaissance surveying to initially interpret the seafloor topography to give a first-order depiction of the submerged landscape. Multibeam bathymetric sonar systems use hull-mounted acoustic transducers and receivers, with signals that sweep through a swath beneath the ship (Figure 4.3). Typically, a hull-mounted multibeam sonar system can resolve features on the seafloor on the order of tens of meters in size, depending on the water depth, acquisition parameters, and characteristics of the transducers. Advances in this technology, particularly with deep-towed and robotic systems, have resulted in much more detailed bathymetric maps, with centimeter-scale spatial resolution (Singh et al., 2000). In addition to collecting new data, pre-existing bathymetric data from

older surveys are useful and there are excellent resources for large data sets, although at much coarser resolution. The NOAA National Geophysical Data Center (NGDC) is an excellent resource for processed bathymetric data sets. Global bathymetric grids based on satellite gravity data exist, but only with a resolution of a few kilometers (Smith and Sandwell, 1997). Higher resolution grids from shipboard surveys exist for most U.S. waters. Once the general bathymetric features are determined, more detailed geophysical work can commence.

Subbottom Profiling

High-frequency seismic reflection methods, also called subbottom profiling (Figure 4.3), typically use lower frequency acoustic signals than side-scan sonar to map features below the seafloor. Very low frequency seismic reflection methods are used to image deep within the earth's sedimentary sequences and crust, but this will not resolve shallow buried features. Oil companies employ this technology for hydrocarbon exploration. *Echo* (Figure 4.2) is equipped with a high-resolution (Chirp) subbottom profiler. Typically these systems are towed behind a survey vessel. A sound pulse is transmitted vertically through the water column, and any density changes within the seafloor sediments produce reflections that are recorded to produce seismic-stratigraphic profiles. High-resolution subbottom profiling data can be used to map anomalous features buried below the modern sedimentary cover and to interpret the recent sedimentary history. Data collected in this manner typically needs to be post-processed to correct for ship and towfish navigational parameters, and to remove artificial noise. The processed data, combined with seafloor mapping data (bathymetry and side-scan sonar), can be used to produce a complete three-dimensional picture of the geological and archaeological landscape. These systems do not have high enough resolution to image sites that are buried in the shallow sediments. However, a recently developed ROV-mounted subbottom profiler has been successfully employed to investigate shipwrecks (Mindell and Bingham, 2001). As with side-scan sonar targets that must be visually verified, seismic data can also be verified by groundtruthing. This typically involves the collection of marine geological samples (usually sediment cores) along a seismic-stratigraphic profile that correlate to the subbottom imagery. For more information on the application of subbottom

profiling to the investigation of submerged archaeological sites refer to Stright (1986). For theory and operational details of high-resolution (Chirp) subbottom profiling, refer to Schock et al. (1989).

A marine magnetometer can be towed in tandem with a side-scan sonar or subbottom profiler (Figure 4.3), or towed by itself. The magnetometer measures the strength of the earth's magnetic field. Magnetic objects on the seafloor will locally disturb the earth's magnetic field and create an anomaly (Figure 4.4). The anomaly is displayed on the shipboard acquisition system, and its location on the seafloor represents a magnetic target, similar to a sonar target. Again, groundtruthing is important for target identification and characterization. For more information on the application of marine magnetometers to shipwreck archaeology, refer to Clausen and Arnold (1976).

Visual Imaging Techniques

Visual imaging of acoustic and magnetic targets on the seafloor is a necessary component of archaeological oceanographic surveys. The visual identification of objects first identified by other means (such as side-scan sonar or magnetometer) determines whether the object is natural or man-made and evaluates its archaeological significance. A number of diverse methods can be used to accomplish this including diver inspection, inspection by remotely operated vehicle (ROV) systems, and inspection by towed video camera systems (Oxley and O'Regan, 2001). In addition, human-operated submersibles can be used for visual imaging. ROVs are particularly useful, especially when deployed from a research vessel equipped with a dynamic positioning (DP) system. This system of thrusters provides enhanced maneuverability and enables the ship to hold to a fixed location above the seafloor while the ROV is driven directly to the target (Figure 4.5). Advances in subsea navigation, lighting, video imaging, and manipulation have improved the quality and general capabilities of ROV systems.

Some ROV systems can be operated in tandem to enhance their lighting and imaging capabilities (Figure 4.5). *Argus* (Figure 4.6), which weighs 6000 lbs., is an imaging towed, lighting platform, and depressor for the ROV, *Little Hercules* (Figure 4.7), which is coupled to the *Argus* via a fiber-optic tether (Coleman et al., 2000). The *Argus-Little Hercules* tandem ROV system was modeled after the *Jason-Medea* ROV system developed by the Deep Submergence Laboratory at Woods Hole Oceanographic Institution (Ballard, 1993). Improvements were made to lighting and videography, and

the equipment was tailored toward the investigation of submerged archaeological sites, not general purpose oceanography (Coleman et al., 2000). Sector-scanning sonar mounted to an ROV is very useful for locating targets on the seafloor. The location from a side-scan sonar survey, for example, can be erroneous by up to several tens of meters due to layback and other navigational errors. In dark water or in areas of poor visibility the sonar device can pick up targets acoustically more than 100 meters away, then that fixed locations are used to help navigate the ROV to the targets. Geophysical instrumentation and oceanographic sensors can be mounted on ROVs, and, in conjunction with precision navigation, used to generate very high-resolution maps and images of the seafloor and archaeological sites such as shipwrecks (Singh et al., 2000; Foley and Mindell, 2002). Geological and archaeological sampling equipment can also be mounted on ROVs to facilitate the collection of seafloor samples and other data that supports the archaeological survey and visual identification.

The subsea tracking and navigation of ROV systems poses an added challenge, but not one that cannot be overcome. An ultra-shore baseline (USBL) system can be employed to track one ROV or multiple ROVs at the same time (Figure 4.8). A specialized transducer is mounted below the hull of the ship that transmits an acoustic signal that gets repeated by a transponder mounted to the ROV. The resulting time delay and compass direction of the repeated signal is received by the ship, and a computer algorithm translates that data into horizontal offsets. These offsets are then used to compute the position of the ROV in plan view relative to the ship. Sophisticated navigational software can be used to plot the ship and ROV positions accurately on a computer screen. Precise subsea navigation is a critical component to conducting visual surveys of submerged archaeological sites.

Human-operated submersibles (Figure 4.9), which have limited capability compared to ROVs because they can only stay on site for short periods of time, can be used for archaeological site investigations, but not typically for reconnaissance surveys. Like ROVs, they can be equipped with scanning sonar, high-quality video cameras, lights, and sophisticated sampling equipment. An advantage to using a submersible is that they can operate independently of the surface ship, which may not be equipped with a dynamical positioning system. The submersible can use sector-scanning sonar to find the target of interest, then drive directly to it and operate with fine precision around the site.

Submersibles can also typically lift heavier objects and carry more equipment and/or samples than ROVs, so for some tasks they have other advantages.

For visual surveys of underwater archaeological sites, it is advantageous to have a number of different systems and to utilize a number of different techniques. Because of the high cost of shipboard operations, archaeological oceanographers need to avoid down time due to equipment malfunctioning and repair. That is another advantage of the tandem ROV system. If one of the vehicles needs repair, the other can be used independently.

Figure 4.1. Use of a side-scan sonar (such as *Echo*, shown in Figure 4.6). Refer to text for explanation.

Figure 4.2. Side-scan sonar towfish, *Echo*, being launched in Lake Huron. This is equipped with a dual-frequency side-scanning sonar, a Chirp subbottom profiler, an altimeter, and CTD sensor.

Figure 4.3. Geophysical surveying and prospecting equipment including multibeam bathymetric mapping, subbottom profiling, and towing a magnetometer. Refer to text for explanation.

Figure 4.4. Magnetic field anomaly measured by a magnetometer, created by a target on the seabed. Refer to text for explanation.

Figure 4.5. Use of remotely operated vehicles (such as the two vehicle system *Argus/Little Hercules*, shown in Figures 4.7 and 4.8). Refer to text for explanation.

Figure 4.6. Optical towsled *Argus* secured to the afterdeck of the R/V Connecticut, weighs 6000 pounds and serves multiple functions. It carries an array of powerful underwater lights and cameras, and acts as the link between the ship and ROV, depressor and heave-compensator.

Figure 4.7. Imaging ROV *Little Hercules* shown being deployed in Lake Huron, is equipped with a high-definition underwater video camera, a sector-scanning sonar, high-wattage underwater lights, and other sensors.

Figure 4.8. Use of precision subsea navigation for tracking an ROV. Refer to text for explanation.

Figure 4.9. Human-operated submersible *PC-8B*. The Bulgarian Academy of Sciences Institute of Oceanology submersible, sitting on the afterdeck of the research vessel *Akademik*, is a 3-person submersible equipped with scanning sonar, lights, still and video cameras, thrusters, and a manipulator.

CHAPTER 5

CASE STUDY I – SOUTHERN NEW ENGLAND CONTINENTAL SHELF OFF BLOCK ISLAND

Introduction

During the Wisconsin glaciation in the late Pleistocene Epoch, about 21,000 years before present (BP), the Laurentide ice sheet reached its southern terminus. South of what is now New England, the ice margin stretched from east to west across Long Island, Block Island, Martha's Vineyard, and Nantucket (Figure 5.1; Uchupi et al., 2001). These islands represent part of the terminal moraine, an enormous deposit of glacial sediment pushed in place by the advancing ice sheet and built upon by outwash sediment (Sirkin, 1996). At this time, sea level was more than 100 meters below the present level and the shoreline was near the edge of the continental shelf. As the glacier retreated, meltwater became trapped landward of the moraine and formed numerous large glacial lakes, which occupied coastal lowlands that presently form the Hudson River valley, Long Island and Block Island Sounds, Narragansett Bay, Cape Cod Bay, Nantucket Sound, and elsewhere. Recent studies indicate that these lakes subsequently underwent catastrophic drainage, primarily through two regions – the Hudson and Block Island valleys (Figure 5.2; Uchupi et al., 2001). These processes were responsible for forming much of the present-day morphology of the continental shelf off southern New England. By 19,000 years BP, enough ice melted to cause rapid retreat of the glacier and by 12,000 years BP, the ice margin was north of the St. Lawrence Seaway (Uchupi et al., 2001). The terrestrial landscape that is observed today throughout this region was sculpted by glacial and post-glacial processes, and few of the features on the submerged outer shelf have changed since that time. One of the most prominent features on the shelf is the Block Island Valley, scoured away by the drainage of glacial lakes Connecticut and Block Island Sound through the Block Island Spillway (Figure 5.2).

Block Island is a small island located about 20 kilometers south of the southern Rhode Island coast and about 20 kilometers east of the eastern tip of Long Island (see box in Figure 5.1). It is situated on top of the aforementioned terminal moraine and is comprised primarily of Pleistocene glacial drift that rests on an unconformity above Late Cretaceous shelf sediment (Sirkin, 1976). Block Island is also situated in the foredeep isostatic zone, a zone of subsidence due to glacial loading that subsequently

rebounded, north of the peripheral bulge, a zone that had been uplifted around the glacier that subsequently subsided (Figure 5.1; Uchupi et al., 2001). Within this zone, subsidence occurred due to the land being depressed by the load of the glacier. After deglaciation, the zone was uplifted. Following the drainage of the glacial lakes through the spillway about 16,000 years BP, sea level rose at a faster rate than the foredeep region was uplifted, resulting in inundation of the terrestrial landscape. Eventually, marine water flooded through the spillway and isolated the landmass containing Block Island.

The first humans to arrive in the New World were the Paleo-Indians. Although the timing and direction of their arrival remains controversial, it is widely believed that they entered northwestern North America across the Bering Strait land bridge between what is now Siberia and Alaska (refer to Chapter 3 for discussion of this and other land bridges). Their migration routes throughout North America, especially along the eastern seaboard, also remain controversial. Nevertheless, the first humans to appear in the Northeast probably arrived about 12,500 years BP. It has been established that Paleo-Indians in the New World settled in near-shore environments to take advantage of exploitable resources - shellfish and waterfowl for subsistence, and waterways for ease of transportation (Snow, 1980; Yesner, 1980). The Paleo-Indian period lasted from this time until about 10,000 years BP, and this represents the very end of the Pleistocene Epoch. During this time period, a wide expanse of the continental shelf off southern New England was exposed. Megafaunal remains on the shelf attest to the fact that this region was inhabitable (Figure 5.3, Snow, 1980), but that does not necessarily mean that it was occupied by humans, and no evidence of human inhabitants on the outer shelf has been discovered or documented (Edwards and Emery, 1977).

Lithic Paleo-Indian artifact finds, especially fluted points, are limited in number but widespread throughout the terrestrial northeastern United States (Figure 5.3, Snow, 1980). Fluted points such as those illustrated in Figure 5.3 are indicative of the Paleo-Indian culture and represent only this particular time period. Whereas lithic Paleo-Indian artifacts have not been found offshore, megafaunal remains have been found, as indicated by fossils that were recovered at depth then brought to the surface (Figure 5.4, Whitmore et al., 1967). These remains, especially teeth from mammoth and mastodon, have been dredged up by modern scallop and sea clam fishermen, and the location of these

finds have been fairly well documented (Figure 5.3, Snow, 1980; Whitmore et al., 1967); however the origin of these remains is somewhat controversial. Uchupi et al. (2001) argue that the teeth and any other associated bones were probably carried there by enormous floods resulting from the catastrophic drainage of large glacial lakes as they spilled across the continental shelf from their original positions behind the terminal moraine. An alternative point of view is that these late Pleistocene faunal remains could exist today at the location where the animal perished, more or less *in situ*, with some slight redistribution due to modern post-depositional processes. Because the teeth do not appear to be heavily reworked, the latter scenario is more likely. Either way, their preservation on the shelf encourages the possibility that other remains (possibly human) or lithic artifacts may also be preserved in offshore environments.

Evidence for human association with Pleistocene fauna and megafauna is sparse for northeastern North America. Elsewhere in the Southeast and especially the Southwest and Great Plains, however, numerous dated finds provide indisputable evidence that indicate Paleo-Indians did hunt, kill, and butcher these animals (Morse et al., 1996). Whether or not people played a role in their extinction, however, remains controversial. A few examples of these finds are given here, all from Florida (Morse, et al., 1996): (1) At Little Salt Spring, Clausen (1979) reported on a giant land tortoise with an embedded wooden stake that clearly had been sharpened; (2) in the Wacissa River (panhandle region), Webb and others (1984) reported on a bison skull with an embedded projectile point; and (3) in several different localities, mastodon and mammoth remains have been recovered showing clear signs of being worked (Dunbar and Webb, 1996). One example from the Northeast also appears authentic and was found underwater in Narragansett Bay, Rhode Island: A Late Paleo-Indian lanceolate point that had been embedded in part of a femur from an immature bovid animal recovered by a shellfisherman (Turnbaugh, 2002, personal communication).

In addition, a number of finds of lithic artifacts from off La Jolla shores, California (Masters, 1983) and, more recently, a flake tool discovered off British Columbia in 53 meters water depth (Fedje and Josenhans, 2000), provide evidence that humans lived on the presently submerged shelf off western North America. Because of the certainty for preservation of faunal remains on the shelf, and the potential for preservation of human remains and artifacts based on known associations, we identified

several offshore areas for exploration and sampling on the shallow submerged shelf off Block Island that had been previously identified as containing preserved relict coastal features (McMaster and Garrison, 1967). The time interval between 10,000 and 8,000 years BP and the location off Block Island were identified as being significant for a number of reasons: (1) There is evidence of early Archaic habitation on Block Island (McBride, 2000, personal communication), so we wanted explore for evidence from an earlier time proximal to where sites are known to exist; (2) McMaster and Garrison (1967) identified a preserved paleoshoreline from this time period south of Block Island; (3) no submerged cultural remains from this time period have been identified anywhere throughout the region, so any discovery would potentially be significant; and (4) off the south coast of Block Island, a region that was exposed during this time interval, is a location where we did not expect to find evidence of heavy bottom-trawling fishing activity that would have disturbed the seabed.

Through close collaboration between the Institute for Exploration (Mystic, CT) and the Mashantucket Pequot Museum and Research Center (Mashantucket, CT), a research program commenced in 1997 to investigate the continental shelf off southern New England for evidence of Paleo-Indian occupation. Phase I of the program took place in 1998, when the U.S. Navy's nuclear research submarine *NR-1* (out of Groton, CT) was used to conduct a series of dives starting in the vicinity of Hudson Canyon and traversing toward the Long Island platform (Uchupi et al., 2001). The location for the transect beginning was chosen to coincide with the intersection of a paleoshoreline, the Fortune Shoreline, with the canyon wall (Uchupi et al., 2001), and near where megafaunal remains have been discovered (Whitmore et al., 1967; Edwards and Emery, 1977). The transect crossed the Fortune Shoreline, and numerous visual observations were made. The paleoshoreline, which follows closely to the 68-meter depth contour, is situated within an undulating topography with sediment waves aligned parallel to the strike of the shelf (Uchupi et al., 2001). Other paleoshorelines were crossed along the transect, including the Franklin and Atlantis Shorelines, and relict features such as oyster shells and glacial erratics were observed (Uchupi et al., 2001). The preservation of these relict shoreline features on the outer shelf with very little sediment overburden, combined with the occasional presence of megafaunal remains, lends credence to the notion that human artifacts could also be preserved in this environmental setting. Phase II of the program, to map the submerged environmental setting off Block

Island, took place in the spring and summer of 2000, and the methods and results from this survey are presented here.

Methodology

In May 2000, a high-resolution geophysical survey of the shallow shelf off Block Island, Rhode Island, was conducted. Following the geophysical survey and data processing, in July of 2000, sediment cores were collected to aid in the paleo-geographic reconstruction of Block Island as it existed between 8,000 and 10,000 years BP. Published relative sea level rise curves for the northeastern United States and maritime Canada were first examined to interpret the position of shorelines during this time period. For nearly all curves, it was determined that the 8,000- to 10,000-year-old shorelines could be found submerged between 18 and 26 meters water depth (Figure 5.5; Stright, 1995). So this was our starting point, and a bathymetric contour map was generated with contours colored to highlight this region of interest (Figure 5.6). Then a different map was created that only showed Block Island inside the 26-meter contour (Figure 5.7). This map essentially illustrates how a “Paleo”-Block Island would have appeared with sea level 26 meters lower than at present. From this map, regions were identified for more detailed surveying, including several promising areas to the west and south of Block Island. To the south, the shelf is shallow, flat, and broad and contains interesting post-glacial landforms, as made evident by the side-scan mosaic (Figure 5.8). To the west, the Block Island Spillway cuts a deep channel that is flanked by what appears to be submerged levees, bars, and spits. The focus for this discussion is only on the region to the south of Block Island.

Using the University of Connecticut’s ship, *R/V Connecticut*, out of the Avery Point Campus in Groton, CT, we surveyed a roughly 15-square-mile region to the south and west of Block Island using a Chirp side-scan sonar/subbottom profiling system (Figure 5.9). We conducted the survey for three days working around the clock. (Refer to Tables 5.1-5.3 for a brief cruise log and sonar and seismic trackline information.) There were several regions where we wanted to survey but could not due to the presence of fishing gear. One area in particular, Southwest Ledge off southwestern Block Island, contained a dense array of lobster traps and gill nets, making it too risky for towing geophysical equipment, so this survey region had to be sacrificed. The primary survey tool was the Datasonics

(Benthos) *SIS-1000* seafloor imaging system. The *SIS-1000* is a 100 KHz side-scan sonar towfish with an integrated Chirp subbottom profiler. A backup Datasonics *Chirp II* system was a secondary survey tool, but this did not collect side-scan imagery, only subbottom profiles. Position information was collected using a differential GPS receiver that was integrated to navigational software. The position and time for each sonar/subbottom ping was also written to the digital data. A Furuno echosounder was used to collect single beam bathymetric information. All navigational and geophysical data was stored and backed up on magneto-optical disks and computer hard drives.

On several occasions during the survey geological sampling was attempted. A gravity corer was used to try to penetrate the sediment and collect a core sample, but these attempts failed because the sandy and rocky seafloor was too hard. On several occasions, a rock dredge was used to collect seafloor samples. This technique proved to work fine, but precision sampling could not be performed, just poorly located dredge hauls of the uppermost sediment along a several-hundred-meter track.

The geophysical data was processed at the U. S. Geological Survey in Woods Hole, MA. The side-scan sonar data was processed on a Unix workstation and displayed using GIS software (Figure 5.8). Multiple tracklines were merged together to create a mosaic of side-scan imagery, resulting in an acoustic picture of the seafloor. Corrections had to be made for slant range, speed variations, and navigational errors. The subbottom profiler data was extracted using the Seismic Unix processing software. Subbottom tracklines were plotted with every 1,000 pings annotated so that similar subbottom features could be correlated between the cross-sections and identified in plan view on the trackline chart (Figure 5.10). Figures 5.11 through 5.14 show the subbottom profiles. These profiles would be better viewed on large-scale plots, but are presented here for illustration purposes. The subbottom profiles were used to interpret the subsurface geology and to identify regions for coring.

During a four-day period in July, 2000, using the *M/V Beavertail* out of Jamestown, RI, we collected nine sediment cores from selected locations identified on the subbottom profiles. Core locations are presented in Table 5.4. These locations were chosen based on a preliminary interpretation of the subbottom profiles. The target was to core in specific paleo-geographic environments, including a possible paleo-river channel and paleo-barrier beach and lagoon. For each core location, a three-point anchor had to be set to secure the vessel, and then a vibracoring system was used to collect the samples

(Figure 5.15). As illustrated in Figure 5.15, after the coring device was deployed and secured, the pneumatic vibracoring head drove the core barrel into the sediment, and then it was slowly pulled out. The core liner could be extracted from the barrel after it was decoupled from the head. Several decent cores were collected, even in regions of coarse cobbles. Poor weather prevented us from collecting more cores, but we did successfully sample several key sites.

The cores were returned to the Mashantucket Pequot Museum and Research Center for analysis, where they were split, described, photographed, sub-sampled, and stored. Photographs from six of the cores are shown in Figures 5.16 through 5.19. Four shells were selected from four different cores for radiocarbon dating (the only cores that contained shell material). The samples were submitted to Beta Laboratories for AMS processing. The dating results are presented in Table 5.5. Finally, the geophysical and sediment sampling data were combined and analyzed to generate an interpretation of the paleo-geographic setting for offshore southern Block Island. This interpretation can be used to identify specific regions for future detailed archaeological investigations.

Results and Interpretation

The side-scan sonar mosaics that were generated by splicing individual tracklines together help to reveal the continuity and spatiality of geologic features on the seafloor. As illustrated in Figure 5.8, diverse patterns can be identified on the seabed indicating different sediment types. The patterns noted by varying shades of gray, mostly either light or dark, correspond to regions of high or low acoustic reflectivity. Darker regions represent sediment on the seabed that are more reflective, indicating the presence of coarser material such as sand, till, or bedrock. Lighter colored regions represent sediment on the seabed that have absorbed more acoustic energy, indicating the presence of finer-grained material such as silt, mud, and clay. Very stiff, dense clay, with low water content, could produce strong reflections, however. The patterns observed in the mosaic presented in Figure 5.8 are also influenced by the seafloor morphology. Large isolated features, such as large boulders, stand out as small reflective targets with an associated acoustic “shadow” that is created when the target blocks the acoustic pulses from returning off the seabed behind the target. Other depressions and prominent features are represented by different sonar patterns. Large sand waves on the seafloor are made evident

in the mosaic by alternating wavy bands of light and dark gray. One significant result from interpreting the sonar data is the lack of evidence for bottom trawling, indicating this region is not heavily fished, and therefore anything remaining on the seafloor has a higher chance for preservation.

The subbottom profiler data (Figures 5.11 – 5.14) reveal a number of diverse relict geomorphologic features buried beneath the seafloor. The Chirp system is relatively high-frequency compared to other subbottom imaging systems. Due to the presence of coarse deposits in the area we mapped, the frequency of this system was for the most part inappropriate – too high for sufficient penetration beneath the uppermost layers. Despite this fact, several prominent features can easily be discerned. Two distinct regions are represented here. The first is a series of east-west trending, contour-parallel profiles collected over a relatively flat portion of the shelf south of Block Island (Figures 5.11 – 5.12). The second is a series of northeast-southwest trending, contour-normal profiles collected over a slightly hummocky portion of the shelf immediately adjacent to the southeast (Figures 5.13 – 5.14).

Figure 5.11 presents all of the lines from the first region at a small scale, but arranged more or less accurately relative to each other so features can be correlated. Three north-south trending lines (lines 18, 19, and 20) run nearly perpendicular to the east-west trending lines (lines 9-17) and are plotted sideways in the upper left portion of the figure. Throughout most of these profiles, prominent subbottom channel-like features can be identified and quantitatively mapped. On the right half of lines 9-15, a meandering channel is observed that at its widest and deepest point along line 11 is about 8 meters deep and 100 meters wide. Its shape, as indicated in this profile, is asymmetrical, typical of what would be expected in a stream meander cross-section. This channel was likely scoured by runoff from the melting glacier during times just following its retreat. The channel probably remained as a low-lying riverbed or dry channel for several millennia following deglaciation, until inundation occurred some time after 8,000 years BP. Just prior to inundation, after the island became isolated, this channel was likely to be a small freshwater tributary that evolved into tidal inlet with rising sea level. Other features can be identified as well, that do not have the same spatial continuity as this channel. Toward the center of line 13 (Figure 5.12), a strong reflector can be identified that could be interpreted as part of an ancient tidal inlet that connects to a lagoon landward of this feature. This possible lagoon feature can be identified in lines 18-20 and on the east-west lines north of line 13. Other small features

could be kettle holes that survived as ponds until they became inundated. All of these features became buried following inundation. The marine transgression submerged the landscape, and modern sediments filled the relict channels.

Figure 5.13 presents all of the lines (lines 21-30) from the second region; plotted so similar features can be correlated, with one northwest-southeast trending line (line 31) that ran perpendicular to the others plotted sideways. For these profiles, coherent subbottom features are difficult to distinguish, but the general surface morphologic features can be correlated. One possible interpretation, based on shape alone, is that this represents a submerged relict barrier beach and lagoon system as originally identified by McMaster and Garrison (1967). This interpretation is also given for line 28 (Figure 5.14). In this figure, the horizontal axis is roughly 3 km long and the vertical axis is roughly 40 m deep, and water depth is about 26 meters. The left side of Figure 5.14 represents the ancient shoreline to the southwest. A weak subbottom reflector exists below the sloping shoreline (barrier beach), and this can be correlated to adjacent profiles. This reflector slopes gently away to the southwest, toward the ocean, and could represent the original glaciated land surface on which the barrier beach was built. Working across the profile from left to right (southwest to northeast), the seafloor slopes back down into an area interpreted as a relict back-barrier lagoon. There are other interpretations possible for this geomorphologic feature, however. It could represent an area that has been scoured by longshore currents, or it could just be a depression into a relict kettle pond. Continuing right, the seafloor then starts to slope back up to what is interpreted as a shoreface behind the lagoon.

Figures 5.16 – 5.19 show photographs of selected cores, including their locations on the side-scan and subbottom imagery. (Refer to Table 5.4 for core locations and Table 5.5 for the results of radiocarbon dating of shells.) Core BV-08 was collected immediately east of the channel (Figure 5.16). It consists primarily of reworked coarse beach sand containing broken shell fragments and rounded beach cobbles. At a depth of about four meters in the core, very coarse glacial till was encountered, probably representing a terrestrial paleo-surface that was scoured by the glacier. Just above this layer, a shell was collected and submitted for radiocarbon dating. This shell dated to 3,980 years BP. Because the shell was disarticulated, it was probably not collected *in situ*, but had been transported there by the reworking and redistribution of sand. Similarly, in core BV-10, which was collected immediately west

of the channel (Figure 5.17), a disarticulated shell fragment from about 4 meters deep in the core dated to 3,320 years BP. This core also contained a thick deposit of reworked coarse beach sand, but no till layer was encountered.

One core was collected from a region not mentioned in detail here, but it is worth noting. Core BV-16 was collected to the west of Block Island in an area that was interpreted in the subbottom profile as possibly containing peat, or sediment deposit with high organic content (Figure 5.18). In this figure, as revealed by the subbottom profile, a layer of no reflections, or high attenuation of the Chirp signal is evident. This could be due to a number of factors, but one that is likely is that it is an organic-rich layer of sediment. The core did not penetrate deep enough to confirm this, but an *in situ* razor clam sampled from 1.4 meters deep in the core gave a date of 5620 radiocarbon years BP. This deposit had not been reworked extensively like the deposits south of Block Island, based on the interpretation of cores BV-08 and BV-10. In addition, based on the radiocarbon date, the rate of sediment deposition is significantly slower in this region compared to the south, resulting in a much thinner layer of Holocene sedimentary overburden.

The next series of cores did not contain any shell material, so no radiocarbon dates were obtained (cores BV-15, BV-03, and BV-18, left to right, Figure 5.19). Core BV-15 was collected from inside the channel, located between but north of cores BV-08 and BV-10, and contains a very thick deposit of reworked beach sand. Unlike the flanking cores, this core contained many more rounded cobbles mixed in with the coarse sand. Also unlike the flanking cores, no glacial till was encountered at the bottom. Cores BV-03 and BV-18 were collected in the second region, to the southeast. Only about 1.25 meters of penetration was achieved in both of these cores (Figure 5.19). Core BV-03 was collected from slightly deeper water from the region that was interpreted in the subbottom profiles as a back-barrier lagoon. Only about one meter of penetration was achieved. Below a thin layer of coarse sand, a thick deposit of dark gray marine clay dominates the rest of the core. Core BV-18 was collected from shallower water from the region interpreted in the subbottom profiles as the terrestrial shoreface landward of the back-barrier lagoon. This core encountered coarse glacial till at only one meter depth. Above the till layer, a tan-colored coarse beach sand layer was found at the top, which graded downward to a dark brown finer-grained, silty sand (Figure 5.19).

An interpretive fence diagram illustrating the relative vertical elevation and relationships among all of the aforementioned cores, except core BV-16, is presented in Figure 5.20. The east-to-west portion of the diagram was chosen to fit between cores BV-10, BV-15, and BV-08, so their actual locations are projected onto this line. Then the diagram hinges to run through cores BV-03 and BV-18. The horizontal scale is arbitrary, but the vertical scale depicts true relative positions of the cores. Three primary litho-stratigraphic units are present: marine clay, coarse reworked sand, and glacial till. Not all cores in the fence diagram contain each unit, but a correlation can still be made, as indicated in the figure. From east to west, the region south of Block Island represents primarily a depositional sequence of coarse reworked beach sand that is redistributed by littoral drift caused by longshore currents. This environment is similar to an environment mapped off Fire Island (central Long Island), complete with paleo-channels and reworked coarse sand (Schwab et al., 1999), although the deposits described here are generally younger. From north to south, and further to the east, the diagram illustrates a different environment. A very thin layer of reworked coarse sand overlies a sequence of marine clay. The clay was deposited in a depression that may represent a relict coastal lagoon, as described above, although no dates were obtained (Figure 5.20). If the thin layer of sand correlates with the thicker sequence to the north (at core BV-18), then it is possible that the clay sequence would lie above the Pleistocene glacial till representing an ancient terrestrial surface, but this sequence is not present in shallower depths. Nevertheless, it can be confirmed that the environment represented here has significantly thinner overburden covering the ancient surfaces.

Two additional cores were collected from inside Great Salt Pond, where New Harbor is located on Block Island, while the vessel was tied alongside the pier (Figure 5.15). One of these cores (BV-GSP-2) was more than five meters long, and revealed some details of the geologic history of the harbor. At the base of the core, we found glacial till, which represents the land surface just after retreat of the glacier. Since this was a low-lying area, it filled with water to form a pond. The next sequence of sediment is very thick varved clays, which represent finely-laminated mud deposited in a pond that froze over seasonally. Then a dramatic change occurred, when sea level rose and infiltrated the harbor. On top of the varved clays is a dark organic-rich marine mud, complete with clam and snail shells, representing a transition from a lacustrine to a marine environment.

Although a limited amount of data was collected, there is enough to formulate a possible interpretation of the paleo-geography and transgression history for the region south of Block Island. This interpretation is presented in Figure 5.21, which illustrates the environmental conditions prior to about 10,000 years ago, with the Holocene sedimentary overburden stripped away, leaving behind the primary geomorphologic features identified in the subbottom profiles. A low-elevation, broad, flat coastal plain existed that contained a number of depressions and channel-like features. These low-lying regions that probably once contained shallow coastal ponds were the first regions to become inundated by rising sea level. A small tidal inlet formed that connected the ponds to the ocean, by cutting through the beach shoreface or barrier, creating a spit and infiltrating the pond with marine water. For these features to be preserved, the shoreline probably stabilized for a time period around the Younger Dryas (some 11,000 years BP; Fairbanks, 1989) when the rate of sea level rise slowed. A transgressive shoreline sequence developed stratigraphically above the inundated landscape. This sequence, which lies above the glaciated land surface and till layer, then retreated inland as sea level rose higher and higher. After sea level reached a point within about 10 meters of the present-day level, about 5,000 years BP, this transgressive shoreline deposit became reworked and redeposited over the shallow shelf, creating the geology that is observed today. The thickness of the reworked deposit varies from place to place, primarily governed by the subsurface morphology.

Discussion and Conclusions

This project represents a first approach to characterizing the paleo-environmental setting of a region south of Block Island, Rhode Island, as it existed approximately between 8,000 and 10,000 years BP. The purpose for this reconstruction is to identify potential geographic settings that may have been favored by Paleo-Indians. The survey and sampling strategy discussed here proved effective for characterizing geomorphologic features for specific regions. High-resolution geophysical data and sediment cores provide the baseline for identifying future sites for more detailed archaeological investigations. At the same time, more information was learned about the sedimentological history and depositional context for this particular shelf region. However, the presence of thick sequences of Holocene sediment creates an overburden burying potential artifacts and other evidence of human

occupation such as shell middens, hearths and living floors, or burial grounds. The preservation of shoreline features such as the ones described here has been investigated by others (Belknap and Kraft, 1981; Hoyt et al., 1990; Josenhans et al., 1995), and the main conclusion is that features on the outer shelf have a much better chance at being well-preserved than features on the inner shelf. This has been confirmed by more recent work (Uchupi et al., 2001), where significant relict features on the outer shelf have been visually identified. Deeper regions on the outer shelf became inundated during a rapid rise in sea level and their existence far offshore has kept them away from the influence of tidal currents and near shore sedimentary processes that could destroy and/or bury them.

Belknap and Kraft (1981) have identified significant variables that influence the preservation of paleo-coastal features. These are subsurface topography, erosion depth and resistance, waves, tides, sediment supply, and relative sea level rise. Near shore Block Island, which is on the inner shelf in a region with large sediment supply and significant wave energy, would not be predicted to have high preservation potential for fragile coastal features, and this does appear to be the case. However, during the early part of the Holocene in this region, sea level rise was comparatively rapid (Belknap and Kraft, 1981), increasing the chance for preservation further offshore. Penland et al. (1988) described the evolution of barrier systems during transgressions and noted that the uppermost sedimentary sequences do not survive transgressions. These features (dunes and beaches) become inundated, eroded, and finally formed into low-relief offshore sandy shoals. If this model is correct, then there would be little chance for survival of archaeological material.

If the coastal features interpreted here (lagoons, inlets, shorelines, and channels) are preserved, then paleo-geographic regions can be accurately identified for future sampling. The interpretation presented in Figure 5.21 reveals features that can be compared to modern-day coastal features for the Rhode Island shoreline. A semi-qualitative comparison between these features and those that exist today along the southern Rhode Island coast is that the size, relief, and depth of the inlets and coastal lagoons are very similar. Boothroyd et al. (1985) presented an overview of the geology of present-day microtidal coastal lagoons in Rhode Island. On average, these lagoons are several kilometers long by a few kilometers wide, with narrow and shallow tidal inlets connecting them to the ocean. These lagoons probably were near-shore kettle holes containing freshwater wetlands that were inundated by rising

marine waters (Boothroyd et al., 1985). The model presented here based on the subbottom profiles is similar. Unfortunately, however, the core data are not complete enough to establish the paleo-environment completely. If fresh and salt water peat deposits had been recovered in the cores, then this would have further supported the paleo-geographic interpretation.

Based on the interpretations presented here, the paleo-environments south of Block Island are not ideally suited for archaeological sampling, although more work needs to be done, particularly in the region that may be the remnant of a back-barrier lagoon. Due to the amount of reworked sediment immediately south of the island (more than four meters in 4,000 years), further investigation or sampling in this area would probably not yield any evidence of Paleo-Indian occupation. The region further to the southeast, however, does have less overburden, and could possibly contain relict coastal features that could have been attractive to humans for hunting and shellfishing. The region of Southwest Ledge, where we were not able to survey or sample, could be promising for future work. To the west of Block Island, where core BV-16 was collected, there appears to be better preservation of older material not very far beneath the surface. This region is close to the Block Island Spillway, which currently is an erosional environment, but with preserved glacial cobbles nearby, indicating very little modern deposition. In addition, the subbottom profiles seem to indicate the potential presence of organic mud and/or peat, so this represents an area identified for future work. Elsewhere, no data were collected north or east of Block Island. Bathymetric contours in these regions are much steeper (Figure 5.6) than to the south and east, however, so these environments did not have a broad coastal plain 10,000 years ago, but they could still be favorable areas to search because the wave energy and sediment redeposition would be reduced.

BRIEF CRUISE LOG – *R/V Connecticut*

Science Party: Dwight Coleman, IFE, co-chief scientist, oceanography
Kevin McBride, MPMRC, co-chief scientist, archaeology
Arne Carr, Doug Levin, and Tim Peterson, AUSS, sonar/seismic technicians
Margaret Van Patten, UConn Sea Grant, data logger

Equipment: Large dredge, small dredge, pipe dredge, gravity corer, box corer
Datasonics SIS-1000– combination CHIRP side-scan sonar/subbottom profiler
Backup systems, Edgetech DF-1000 side scan sonar and CHIRP II subbottom profiler
Furuno deep-water echo sounder
Hypack navigational software, link to ship's DGPS
Sonar/seismic acquisition systems, topside computers, plotters, etc.

OPERATIONS:

Monday, May 15: Left UConn Avery Point pier at 1230 underway to southwest ledge of BI.
First dredge site along eastern bank of BI spillway. Recovered poorly sorted gravel, cobbles and small boulders, all well-rounded. Also, crabs, starfish, clam shells, and a monkfish.
Deployed sonar fish SIS-1000 at 41d 07.8m N, 71d 39.2m W to begin 1st N-S trending trackline. Tweaked the system, then began recording after turn to line 2, at 2217 UTC time. Collected data along lines 2-8, north of SW ledge.
Transited to begin southern survey lines 9-17, SOL 9 at 0440 on 5/16. ran lines throughout evening. Ran 3 north-south lines across 9-17 along channel features.
Recovered sonar fish to attempt coring/dredging along line 18. Coring attempts failed. Dredged from 41d 07.62 N, 71d 36.69 W to 41d 07.38 N, 71d 36.72 W. Three dredge hauls were similar – medium grain size beach sand, some silty sand w/ sand dollars and small surf clam shells.
Transited to southeast survey area – barrier island. Deployed fish and started recording line 21 at 2049. Had cable problem along line 23, fixed and restarted line. Filled in line 22 after line 31.
Switched to CHIRP II at change of watch (0000 5/17 local). 2 survey areas, BI and RV. BI repeated part of southeast sonar lines, RV ran north-south in south survey area.
Transited to spillway, collecting data across SW ledge. Started spillway line 17 at 1748. Ran CH-1,2, 3, and 4 in spillway, recovered CHIRP II.
Deployed SIS-1000 west of spillway levee, in sand wave region. Collected line 32 n-s to western spillway site – Spillway Spit lines 33-37, then ran a few lines in northern spillway channel, 38, 39, 40. Finished line 40 and recovered fish around 1930 local time, then steamed back to UConn pier to arrive around 2200 local time. Finished cruise early, poor weather predicted for Thursday, May 18.

Table 5.1. Brief cruise log and personnel and equipment lists for *R/V Connecticut* Block Island project.

LIST OF SIS-1000 TRACKLINES

<u>Line #</u>	<u>Date</u>	<u>Start Time</u>	<u>End Time</u>	<u>Notes</u>
01	5/15/2000			S-N, Test line, configured system, no data recorded
02	5/15/2000	2217	2307	N-S, west of Block Island, poor navigation
03	5/15/2000	2313	2353	S-N, poor nav
04	5/16/2000	0000	0051	N-S, poor nav
05	5/16/2000	0053	0130	S-N, poor nav
06	5/16/2000	0135	0214	N-S, poor nav
07	5/16/2000	0218	0256	S-N, poor nav
08	5/16/2000	0302	0340	N-S, end poor navigation
09	5/16/2000	0427	0543	W-E, Plus transit line to south of Block Island
10	5/16/2000	0549	0655	E-W
11	5/16/2000	0723	0830	W-E, several channel features, possible organics
12	5/16/2000	0837	0937	E-W, channels
13	5/16/2000	0943	1045	W-E, channels, possible organics, meanders
14	5/16/2000	1050	1138	E-W, channels
15	5/16/2000	1142	1232	W-E, channels
16	5/16/2000	1236	1316	E-W
17	5/16/2000	1321	1341	W-E
18	5/16/2000	1346	1410	N-S, channel
19	5/16/2000	1414	1437	S-N, channel
20	5/16/2000	1440	1500	N-S, channel
21	5/16/2000	2049	2128	SW-NE, Line azimuth 038 deg.; transit toward SE
22	5/17/2000	0310	0329	NE-SW, Out of sequence; switched to Chirp II
23	5/16/2000	2136	2218	NE-SW, Cut short
23A	5/16/2000	2240	2253	NE-SW, Finished line, towfish lowered 3 meters
24	5/16/2000	2259	2332	SW-NE
25	5/16/2000	2335	0007	NE-SW, Next day
26	5/17/2000	0013	0040	SW-NE
27	5/17/2000	0046	0121	NE-SW, Thermals, channel?
28	5/17/2000	0126	0145	SW-NE
29	5/17/2000	0153	0217	NE-SW
30	5/17/2000	0223	0240	SW-NE, Thermals present
31	5/17/2000	0241	0304	SE-NW strike line, some subbottom features
32	5/17/2000	2039	2102	SW-NE, Switched back to SIS-1000; spillway levees

LIST OF SIS-1000 TRACKLINES (continued)

<u>Line #</u>	<u>Date</u>	<u>Start Time</u>	<u>End Time</u>	<u>Notes</u>
33	5/17/2000	2102	2119	SW-NE, change in trend
34	5/17/2000	2125	2146	NE-SW
35	5/17/2000	2148	2207	SW-NE
36	5/17/2000	2211	2231	NE-SW
37	5/17/2000	2237	2309	SW-NE, Channel features
38	5/17/2000	2313	2326	S-N, Stratified layers
39	5/17/2000	2325	2341	N-S
40	5/17/2000	2341	2353	E-W, Nicely stratified layers across channel

Table 5.2. List of SIS-1000 side-scan sonar and subbottom profiler tracklines. Times are GMT.

LIST OF CHIRP II TRACKLINES

<u>Line #</u>	<u>Date</u>	<u>Start Time</u>	<u>End Time</u>	<u>Notes</u>
BI01	5/17/2000	0527	0553	S-N, Barrier island lines, channels and boulder field
BI02	5/17/2000	0604	0639	N-S, poor data
BI03	5/17/2000	0650	0719	Change in sediment type, possible shipwreck
BI04	5/17/2000	0735	0755	Onlapping sediment, two channels
BI05	5/17/2000	0816	0829	Possible barrier beach/lagoon features
BI06	5/17/2000	0849	0922	W-E
RV01	5/17/2000	1011	1037	S-N, strong reflectors, hyperbole
RV02	5/17/2000	1040	1110	N-S, good reflector
RV03	5/17/2000	1112	1136	S-N, channel feature
RV04	5/17/2000	1145	1222	N-S, irregular channel feature
RV05	5/17/2000	1229	1300	S-N
RV06	5/17/2000	1303	1336	N-S
RV07	5/17/2000	1338	1340	Short transit line
RV08	5/17/2000	1341	1408	S-N, two channels
RV09	5/17/2000	1410	1430	N-S
RV10	5/17/2000	1432	1448	S-N
RV11	5/17/2000	1450	1454	E-W
RV12	5/17/2000	1455	1517	N-S, channel and irregular subbottom feature
RV13	5/17/2000	1521	1540	S-N
RV14	5/17/2000	1544	1603	
RV15	5/17/2000	1608	1617	Subbottom feature, channel

LIST OF CHIRP II TRACKLINES (continued)

<u>Line #</u>	<u>Date</u>	<u>Start Time</u>	<u>End Time</u>	<u>Notes</u>
RV15A	5/17/2000	1619	1623	
RV16	5/17/2000	1646	1735	Channel feature
CH01	5/17/2000	1748	1800	Spillway channel lines
CH02	5/17/2000	1810	1839	Southern channel between BI and LI
CH03	5/17/2000	1902	1916	
CH04	5/17/2000	1925	1948	End Chirp II survey

Table 5.3. List of Chirp II subbottom profiler tracklines. Times are GMT.

LIST OF CORE LOCATIONS

<u>Core #</u>	<u>Date</u>	<u>Time</u>	<u>Core Length (m)</u>	<u>Latitude</u>	<u>Longitude</u>	<u>Water Depth (m)</u>
BV-01	7/19/2000	1251	2.59	41° 06.844'	-71° 33.293'	20
BV-15	7/19/2000	1549	4.12	41° 06.725'	-71° 34.994'	23
BV-GSP-1	7/20/2000	1158	3.96	41° 11.079'	-71° 34.929'	06
BV-GSP-2	7/20/2000	1507	5.56	41° 11.079'	-71° 34.929'	06
BV-10	7/21/2000	0745	4.21	41° 06.433'	-71° 35.300'	24
BV-08	7/21/2000	1020	4.06	41° 06.355'	-71° 34.681'	25
BV-03	7/21/2000	1215	1.30	41° 06.277'	-71° 33.857'	28
BV-18	7/21/2000	1518	3.11	41° 07.217'	-71° 33.805'	22
BV-16	7/22/2000	0940	3.54	41° 09.271'	-71° 40.632'	23

Table 5.4. Locations of cores collected off Block Island. Times are local.

RADIOCARBON DATING OF SHELLS

<u>Core #</u>	<u>Depth in Core (cm)</u>	<u>Shell Description</u>	<u>Age</u>
BV-GSP-1	105	<i>Crepidula fornicata</i> , articulated	109
BV-08	405	Small disarticulated clam shell	3980
BV-10	402	Small disarticulated clam shell	3320
BV-16	141	Small articulated razor clam shell	5620

Table 5.5. Results from radiocarbon dating of shells from within selected cores. Age in radiocarbon years before present.

Figure 5.1. Topographic map of southern New England and adjacent continental shelf region to the south, after Uchupi et al., 2001. Southern extent of the Wisconsin glacial lobes is indicated. 21,000 – 20,000 year old shoreline is indicated near the break of the continental shelf. Block Island is also identified. Color scale represents topographic elevations in meters.

Figure 5.3. Distribution of mammoth and mastodon remains on the continental shelf and distribution of Paleo-Indian sites and fluted point finds in eastern New York, northern New Jersey, and southern New England (after Snow, 1980). Positions of the ice front are accurate, but the dates are not. These are based on older data. Refer to Figures 5.1 and 5.2 for more accurate dates.

Figure 5.4. Lithic artifacts and faunal remains from Paleo-Indian times. Upper Left - An example of fluted points, shown in various stages of manufacture, typically produced by Paleo-Indians of eastern North America like those found at sites indicated in Figure 5.3 (after Snow, 1980). Lower Left - artistic depiction of a woolly mammoth. Right - Mammoth (teeth 1, 3, 4) and a partial mastodon molar (tooth 2) found on the continental shelf off New Jersey (after Whitmore et al., 1967) and representative of the finds indicated by the distribution in Figure 5.3.

Figure 5.5. Relative sea level rise curves for the northeastern United States and maritime Canada based on a number of different studies (after Stright, 1995). For nearly all curves, the 8,000-10,000-year-old paleoshoreline would be expected to exist between 18 and 26 meters water depth, barring significant Holocene sedimentary overburden.

Figure 5.6. Bathymetric contour map surrounding Block Island, Rhode Island based on digital gridded soundings from the National Geophysical Data Center Coastal Relief CD-ROMs. Contours between 18 and 26 meters depth are indicated by shades of green and representing the region containing the 8,000-10,000 year old shorelines, as suggested by Figure 5.5.

Figure 5.7. Bathymetric contour map with the entire region within the 26-meter contour shaded to depict a "Paleo"-Block Island. The shape represents the shoreline positions about 10,000 years ago. The lower sea level exposes an island 3-4 times the size of present-day Block Island. Box indicates region depicted in Figure 5.8.

Figure 5.8. Side-scan sonar mosaic for a region south of Block Island (boxed region in Figure 5.7), revealing details of the seafloor between the 8,000- and 10,000-year-old paleoshorelines. Lighter gray regions represent regions of low acoustic reflectivity, such as soft mud and clay. Darker gray regions represent regions of higher reflectivity or higher acoustic absorption, such as coarse sand and cobbles.

Figure 5.9. University of Connecticut research vessel *Connecticut*, which was used for the side-scan and subbottom survey off Block Island. The Benthos (Datasonics) SIS-1000 towfish being deployed through the A-frame of the *Connecticut*. The towfish is a 100 KHz side-scan sonar and CHIRP subbottom profiler.

Figure 5.10. Location of selected side-scan sonar and subbottom profiler tracklines and coring sites south and west of Block Island. Subbottom tracklines are annotated every 1,000 pings, except for Lines 2-8, where poor navigation data was recorded.

Figure 5.11. Series of east-west (and three north-south) trending parallel subbottom profiles from south of Block Island. Location of tracklines indicated by small index map. Refer to text and Figure 5.12 for more detail. Approximate vertical and horizontal scales are given. Profiles have about 20x vertical exaggeration.

Figure 5.12. Subbottom profile section from Line 13 revealing geological features buried beneath the seafloor. For scale, each dotted rectangle represents about 200 meters horizontally and 15 meters vertically. Profile has about 20x vertical exaggeration.

Figure 5.13. Series of northeast-southwest (and one northwest-southeast) trending parallel subbottom profiles from south of Block Island. Location of tracklines indicated. Refer to text and Figure 5.14 for more detail. Approximate vertical and horizontal scales are given. Profiles have about 20x vertical exaggeration.

Figure 5.14. Subbottom profile of Line 28 revealing one interpretation of the seafloor morphology and some subtle geological features buried beneath the seafloor. For scale, each dotted rectangle represents about 200 meters horizontally and 15 meters vertically. Profile has about 20x vertical exaggeration.

Figure 5.15. Vibracoring operation. Sketch of pneumatic vibracoring device. The device is deployed over the rail of the vessel. Compressed air provides the power to the vibrating head, which drives the core barrel down into the sediments. The barrel is then decoupled from the head, and the core tube inside the barrel is extruded.

Figure 5.16. Core BV-08, collected immediately to the east of the meltwater channel indicated in the subbottom profile for Line 11. The core primarily consists of reworked coarse beach sand. Some coarse glacial till was present at four meters below the seafloor. A radiocarbon date from a disarticulated shell just above this till layer is 3980 years BP.

Figure 5.17. Core BV-10, collected immediately west of the same channel indicated in Line 11. The same glacial till layer was encountered at four meters below the seafloor. Another disarticulated shell from just above this layer dated to 3320 years BP.

CORE BV-16
 141cm / 25.3 m water depth
 Small articulated razor clam shell
 5620 years BP

Figure 5.18. Core BV-16, collected west of Block Island. The high attenuation of the acoustic signal indicated in the upper layer just below the surface in the subbottom profile was interpreted to be an organic-rich layer, possibly peat. Core penetration was insufficient to test this theory, but a radiocarbon date from an articulated razor clam shell revealed the deposit was 5620 years old at 140 cm below the surface, indicating the preservation of fragile coastal features by a thin layer of sediment.

Figure 5.19. Photographs of cores BV-15, BV-03, and BV-18. BV-15 was collected from inside the meltwater channel between, but north of BV-08 (Figure 5.14) and BV-10 (Figure 5.15). BV-03 and BV-18 were collected along Line 24, which looks similar to Line 28 (Figure 5.12). Refer to text for interpretation and discussion.

General Lithostratigraphic Units

Figure 5.20. Fence diagram showing general details of five cores collected south of Block Island. Refer to Figure 5.12 for core locations. Cross-section line 1-2-3 indicated in Figure 5.21. Refer to text for discussion.

Figure 5.21. Possible paleo-geographic reconstruction off southern Block Island for the approximate time period between 8,000 and 10,000 years BP based on interpretation of subbottom profiles. Areas shaded blue represent relict geomorphologic features, interpreted here as the remnants of ancient lagoons and river channels. Cross-section line 1-2-3 indicated by blue line.

CHAPTER 6

CASE STUDY II – WESTERN LAKE HURON OFF NORTHEASTERN LOWER MICHIGAN

Introduction

In 2000, the National Oceanic and Atmospheric Administration (NOAA) and the State of Michigan established the Thunder Bay National Marine Sanctuary and Underwater Preserve (TBNMS/UP, Figure 6.1). TBNMS/UP, which is located in northeastern Lower Michigan off Alpena County in western Lake Huron, is the thirteenth designated National Marine Sanctuary in the United States and the first in the Great Lakes. The Sanctuary was established primarily for the protection, preservation, and long-term management of its submerged cultural resources, namely historically significant shipwrecks from the mid-19th century to the mid-20th century. As part of the management plan for TBNMS/UP, NOAA would like to promote the Sanctuary and its cultural resources through public outreach, educational programs, and scientific research. To accomplish this goal, NOAA partnered with the Institute for Exploration (IFE) in Mystic, CT, to start the first phases of research and outreach involving the shipwrecks of Thunder Bay.

The Sanctuary was suspected to contain more than 100 shipwrecks, from wooden schooners and steamers to steel barges and freighters, ranging in size from less than 100 feet long to greater than 500 feet long. Several vessels are of potential national historic significance including the *New Orleans*, *Grecian*, and *Isaac M. Scott* (U.S. Dept. of Commerce, 1999). Of the 30 or so shipwrecks that are known throughout the Sanctuary, about half occur in shallow water (< 15 meters). One vessel, the *Nordmeer*, which ran aground on some shoals northeast of Thunder Bay Island in 1966 (U.S. Dept. of Commerce, 1999), has a rapidly deteriorating hull still partially exposed above water. The remaining shipwrecks found within the deeper parts of the Sanctuary were primarily lost due to collisions in the fog. Many of these known shipwrecks are popular SCUBA diving attractions and contain buoyed markers; some are less popular and poorly located, but occasionally visited by advanced divers. More than 70 other ships are thought to be lost in the same region.

During a 15-day expedition in June 2001, IFE conducted a side-scan sonar survey throughout the deep-water portions of the Sanctuary to determine the extent and character of cultural resources on the

lakebed. The primary goal of this first phase of research was to establish an archaeological baseline for the Sanctuary from which more intensive archaeological survey work could develop. A secondary goal was to explore for shipwrecks that were lost in the vicinity of the Sanctuary, but never found. A tertiary goal was to explore for potential sites of human occupation and artifacts on the lakebed, remnants from when the lake was at a lower level following the last ice age. The goal of the second phase of the project was to augment the acoustic survey with a detailed visual survey. Shipwrecks, side-scan sonar targets, and other features on the lakebed identified during the 2001 survey were inspected and imaged using an advanced remotely operated vehicle (ROV) system during a two-week period in August and September, 2002. In addition, several sediment cores were collected from several deep basins in the region and from one of a large number of sinkholes that were discovered in the northeastern corner of the Sanctuary. To achieve the aforementioned tertiary goal of identifying submerged prehistoric sites, the bathymetry of the Sanctuary was examined to map paleoshorelines according to published land and lake level fluctuation data, which varied considerably following the retreat of the Laurentide ice sheet.

Lake Huron Levels

The elevation of Lake Huron has fluctuated dramatically since the Laurentide ice sheet, which covered all of the Great Lakes 18,000 years ago, retreated (Figure 6.2; Anderson and Lewis, 2002). Lake Huron's elevation history has been well studied (Hough, 1962; Eschman and Karrow, 1985; Lewis and Anderson, 1989; Rea et al., 1994; Anderson and Lewis, 2002), and the lake level rise curve has evolved to the curve portrayed in Figure 6.2 as new data became incorporated. From about 14,000 to 7,000 years BP, the elevation of paleo-Lake Huron fluctuated depending on several factors such as the position of the ice margin, glacial meltwater supply, and post-glacial isostatic rebound. These factors governed the amount of water available to the Great Lakes basin and the route of water flow into and out of the basin. Post-glacial isostatic adjustment raised and lowered flow-restricting horizons such as sills between smaller basins. In general, the amount of isostatic uplift increased from southwest to northeast across the entire Great Lakes basin (Lewis and Anderson, 1989). The Main Algonquin shoreline, which represents an ancient high stand of the lakes causing them all to be interconnected, has been dated to about 11,700 radiocarbon years BP, which converts to about 13,500 calendar years BP

(Figure 6.3(a); Lewis and Anderson, 1989; Lewis et al. 1994). In its present position, the Algonquin paleoshoreline is found at elevations varying from about 164 meters at the Port Huron outlet near the southern tip of Lake Huron to about 450 meters at the North Bay outlet in eastern Lake Nipissing (Lewis and Anderson, 1989). This southwest-to-northeast uplift differential for the Algonquin paleoshoreline is nearly 300 meters across a 450 kilometer span. The magnitude of post-glacial rebound must be accounted for when determining lake-level fluctuations through time.

The chronology of this time period is represented in Figures 6.2 and 6.3, where the history of Lake Huron's elevation is depicted graphically in cross-section view and spatially in map view, respectively. The radiocarbon ages have been converted to calendar years in these figures according to the corrections given by Anderson and Lewis (2002). During the Younger Dryas cold episode, from about 11,000 to 10,000 radiocarbon years before present, the Laurentide ice sheet re-advanced slightly across the Great Lakes basin (Figures 6.3(c) and 6.3(d); Lewis et al., 1994). It has been postulated that this episode was initiated by a re-routing of glacial meltwater runoff from the Mississippi drainage to the St. Lawrence drainage system via the Champlain Sea (Rooth, 1982; Broecker et al., 1989; Lewis et al., 1994; Moore et al., 2000). There is strong supporting evidence to support a theory that this re-routing event increased production of North Atlantic Deep Water (NADW), which then led to a brief climate reversal (Broecker et al., 1989; Moore et al., 2000). The climate change caused Glacial Lake Algonquin to shrink substantially, drawing the levels in the Lake Huron basin down. During the following several thousand years, meltwater continued to discharge to Champlain Sea and differential isostatic uplift, which affected the elevations of outlets, caused lake levels to fluctuate, but the overall long-term trend was lake lowering. This continued until about 8,300 calendar years BP, when the Nipissing transgression commenced and the basins filled again (Figure 6.2; Lewis et al., 1994).

The Lake Stanley unconformity (Figure 6.2), which occurs between layers of sediment in the deep parts of the lake, represents the lowest level of water in the Lake Huron basin (Hough, 1962; Lewis and Anderson, 1989). Glacial Lake Stanley existed when water levels had been drawn down to a minimum, and this occurred basically during three time periods, referred to as Early, Middle, and Late Stanley low stands, with two of these periods represented in Figure 6.3(d) and 6.3(f) (Lewis et al., 1994). In Figure 6.2, the unconformity elevation was corrected for post-glacial rebound (Anderson and Lewis, 2002).

This feature separates deepwater lake clays from stratigraphically lower sands containing shallow-water fossils. The Alpena Sill (Figure 6.2) was one of several sites actively controlling the outflow from the basin during this time period, until levels were either drawn down below the sill depth or raised much higher than the sill flanks (Lewis and Anderson, 1989). In summary, according to the data in Figure 6.2, during the Lake Stanley low stands, much of the lakebed of TBNMS/UP was exposed subaerially, creating a landscape that was probably suitable for human occupation.

Michigan Sinkholes

The underwater sinkholes in the Sanctuary, like those found in Misery Bay, off Middle Island, and in deeper water (Figure 6.4), were of particular interest due to their potential for representing inundated prehistoric sites on the lakebed. The archaeological and paleontological significance of submerged sinkholes off Florida has been well-established (Clausen et al., 1979; Garrison, 1992; Anuskiewicz and Dunbar, 1994), therefore the sinkholes off Michigan described here could be equally significant. Sinkholes and other karst features found throughout northeastern Lower Michigan including Alpena County (the land immediately adjacent to TBNMS/UP) have been described and their distribution has been documented (Warthin and Cooper, 1943; Black, 1983). In this study region, karst formations are associated with dissolution of limestone and evaporite bedrock, causing cavities into which overlying bedrock and surface sediments collapsed (Black, 1984). The surficial geology of TBNMS/UP region is underlain by limestone rocks of the Traverse Group and evaporite rocks of the Detroit River Group, and the latter bedrock type shows evidence of karst formations (Black, 1997). The cavities in the bedrock may be structurally controlled by tectonic faulting, as many of the sinkholes and other karst features occur along a line that follows the faulting trend (Black, 1994). The sinkhole in Misery Bay, which bottoms at about 24 meters water depth, is spring-fed, representing a site of groundwater discharge (Warthin and Cooper, 1943; Black, 1983), and this had been suspected as well in the Middle Island sinkhole. There has never been any mention in the literature of the archaeological significance of Michigan sinkholes, and in general, little research has been done on the geological formation and evolution of northern Michigan sinkholes.

Paleo-Indian and Archaic Occupation

Sometime following the Last Glacial Maximum, humans entered North America. Many researchers believe people crossed into Alaska from Siberia across Beringia, a land bridge that spanned the Bering Strait created by the glacial lowering of sea level (Butzer, 1971; Dikov, 1983). As climate warmed, it was very possible that an ice-free corridor between the Cordilleran and Laurentide ice sheets opened, permitting people to migrate through central Alaska and northwestern Canada, east of the Rocky Mountains, and into the Great Plains region of the central United States (Reeves, 1983). The coastal region from the Aleutian Islands to Puget Sound in the northwestern United States, which was covered by a thick ice sheet that calved into the Pacific Ocean, was probably not a favorable route for human migration (Butzer, 1971). If humans followed the ice-free corridor route and entered the Great Plains region, they would have had little difficulty reaching the Great Lakes region. In fact, the presence of a well-studied site of early Paleo-Indian occupation at the Meadowcroft Rock Shelter in western Pennsylvania, within 200 km of Lake Erie, confirms the existence of people in this part of North America, and is supporting evidence for the ice-free corridor migration theory (Adovasio et al., 1983).

Throughout the Great Lakes region, Paleo-Indian occupation sites are rare. However, several sites have been discovered and dated, indicating the presence of humans who occupied coastal regions surrounding Glacial Lake Algonquin around 12,000 years BP (Cleland, 1992). Several sites have been documented in southern and central Michigan where fluted points were found, some in association with butchered Late Pleistocene faunal remains such as mastodon, caribou, and other big-game species (Mason, 1981). Around 10,600 years BP (12,800 calendar years BP), Glacial Lake Algonquin, which had been held back by the Port Huron outlet (Figure 6.3; Lewis et al., 1994), began to drain. This drainage converted shallow portions of the main lakes into coastal fresh water wetlands and marshes, which would have attracted waterfowl and other game species, establishing habitats attractive to late Paleo-Indians (Mason, 1981). The lithic artifacts left behind by Paleo-Indians, namely fluted points, disappeared by 10,000 years BP, indicating the transition to the Archaic period, when a change in the manufacture of stone tools became evident in the archaeological record (Cleland, 1992). During this time period water levels in the Huron basin approached their lowest elevation, forming the early Stanley

lowstand and the much of the lakebed of present-day Thunder Bay was exposed. A number of early Archaic sites have been discovered in central Lower Michigan and regions of Ontario near the shores of Glacial Lakes Stanley and Hough. Since these low stands persisted intermittently for the next several thousand years until the Nipissing transgression, which inundated much of the Sanctuary lakebed, Archaic human occupation sites undoubtedly exist beneath the present day Great Lakes (Mason, 1981; Halsey, 1991).

Methodology

For the 2001 expedition, the *R/V Lake Guardian*, a 187-foot research vessel operated throughout the Great Lakes by the U.S. Environmental Protection Agency, was used to tow *Echo*, a dual-frequency side-scan sonar (Fig. 6.5). The ship is primarily equipped for chemical analysis of water samples, but for our purposes we used its ample deck space, large A-frame, differential GPS, and CTD sensor. Some specialized equipment was added by IFE, including a winch that was welded to the deck, a large-diameter overboard sheave that was mounted to the A-frame to support our fiber-optic cable and vehicle systems, and a transducer pole mounted to the port side of the vessel. The *R/V Lake Guardian's* main laboratory space was converted to a sonar control room for 24-hour survey operations (Coleman, 2002).

The side-scan sonar survey was designed to cover as much of the lakebed as possible during a 15-day cruise, so an optimal lane spacing, swath width, and towing speed was chosen. For archaeological surveying, this represented a reconnaissance investigation simply designed to locate shipwrecks. The sonar instrument was a dual-frequency deep-towed Chirp side-scan sonar. The high frequency signal centers around 400 kHz and the low frequency signal centers around 100 kHz. Other equipment mounted to the towfish included an acoustic transponder, pressure transducer, altimeter, and a pitch/roll/heading sensor. *Echo*, which is rated to 3,000 meters water depth, has buoyancy that is slightly positive; therefore the towfish is used in tandem with a lead depressor weight. The depressor, which weighs about 650 kg, connects to the towfish using a 30-meter-long neutrally buoyant fiber-optic tether (Fig. 6.5). A steel-armored fiber-optic cable, which mechanically terminates at the depressor weight, supports the load and carries the power to the vehicle and sends the sonar signal and telemetry data back to the surface.

The side-scan sonar data was collected on computers in the control lab, where the sonar signal was demultiplexed, displayed, and logged. Specialized computer software was used that displays and records all channels of the incoming side-scan sonar data. This data, plus navigation, telemetry, and auxiliary sensor data, is written to a single file according to line number, date, and time. One 200-megabyte file equates to about 40 minutes of survey time. A pole-mounted acoustic transponder continuously pinged to the towfish to give the slant-range distance. This data, combined with vehicle depth data from the pressure transducer and the horizontal offset distance from the pole to the GPS antenna, was used to calculate layback, or the horizontal distance between the GPS antenna on the ship and the towfish. This value was then manually entered into the acquisition software and constantly updated as the slant-range changed by winching out more cable. Also, all raw navigation data was logged to files. The raw sonar data was processed to correct for heading and navigation errors, bottom tracking, and speed (ship accelerations). All data was backed-up to CD-Rom in duplicate and stored on large capacity hard drives. As the data was collected, acoustic targets and other interesting features on the lakebed were continuously logged. Shipwrecks stood out as strong sonar reflectors and could easily be identified based on their size, shape, and acoustic character. A large number of sinkholes and other geologic features on the lakebed were also logged. The target database for this survey is given in Table 6.1.

For the 2002 survey, the *R/V Connecticut* was used (Figure 6.5), along with IFE's ROV system *Argus* and *Little Hercules* (Figure 6.6). The *R/V Connecticut* had been recently outfitted with a dynamic positioning system. This system employs computer driven thrusters to stabilize and maneuver the ship with very high precision. The main lab inside the vessel was converted to an ROV operations lab where the video and other signals were displayed on monitors and computers. The pilots and engineers operated the vehicle systems from this space, and a navigator had constant communications with the ship's bridge. The ROV system was successfully utilized to collect high-quality video images of 15 shipwrecks that had been mapped by the 2001 sonar survey. In addition, a number of dives were made in several different sinkholes. All the video imagery was recorded on two different format tapes. DV-Cam tape format, which is relatively inexpensive and can hold more data, was recorded every time the vehicle system was in the water. High-definition format, which is more costly and holds less data

but is much higher quality, was recorded only after a target had been initially located. Lastly, the vehicles' telemetry data, such as depth, altitude, and heading, plus all scanning sonar data were logged on the acquisition computers' hard drives.

Detailed specifications and a discussion of the operation of this two-vehicle system are given in a paper by Coleman et al., 2000, but some details are repeated here. The *Argus* tow sled vehicle was designed with a long, narrow shape determined by the desire to keep cameras and lights as far apart as possible (for high-quality imaging) yet within the vehicle framework for protection from contact with immovable objects. For this expedition *Argus* was equipped with a primary color video camera, a high sensitivity black and white camera for distant viewing, and a 325 kHz forward-looking sector-scanning sonar instrument. The vehicle was also equipped with thrusters at either end to control heading, and a motorized tilt platform, so the lights and cameras could be aimed in any direction below horizontal. The primary ROV high-definition video camera, which was mounted on *Little Hercules* most of the time, could be moved and mounted on *Argus* to capture high-quality images of the ROV working on shipwrecks and other targets. The primary instrument on *Argus* was a 1200-watt light mounted on the tilt platform that provided ample light at depth for the ROV. *Argus*, which weighs 1800 kg in air and was designed to operate at depths up to 3,000 meters, also carried an acoustic altimeter and a high-resolution pressure sensor.

The *Little Hercules* ROV, which weighs 300 kg in air and is also rated to depths up to 3,000 meters, was fitted with a sophisticated high-definition format camera as its primary instrument. There is a large void in the frame and foam pack to allow the camera to tilt between horizontal and vertical orientations. The ROV is propelled by four electric thrusters, providing maneuverability in all directions. It also carries a magnetic compass, a simple heading rate sensor, a precision pressure/depth sensor, an altimeter, two small utility cameras, a 675 kHz sector-scanning sonar, and a pair of 400-watt lights.

In addition to the remotely operated vehicles, *Echo* was also used in 2002 to collect additional acoustic data from the sinkholes and other basins surrounding the Sanctuary. The towfish had been retrofitted with a Chirp subbottom profiler. The Chirp sonar technology, designed in the early 1980's by engineers at the University of Rhode Island, employs high-bandwidth frequency-sweeping acoustic

transmissions that yield high-resolution subbottom images when focused toward the bottom with a narrow-width beam (Mayer et al., 1983). The *Echo* towfish was equipped with a Chirp subbottom profiler that swept through frequencies between 2-7 kHz. The data collected by this instrument was used to identify sediment coring locations and to image the subsurface structure of the sinkholes.

Sediment cores were also collected during the 2002 expedition, using the *R/V Shenehon*, a vessel operated for TBNMS/UP during the summer of 2002 by NOAA's Great Lakes Environmental Research Laboratory. A coring team from the University of Rhode Island Graduate School of Oceanography (GSO) collected a number of 7- to 8-meter-long piston cores from several deep basins within and surrounding the Sanctuary. The deep basin coring sites were chosen by examining the subbottom images to determine where the longest and most complete sedimentary record could be sampled with a 9-meter core, and this was typically where the layers thinned near the basin margins. Two basins, Alpena and Manitoulin, were sampled with several cores collected from each. The deep penetration of these cores allowed a sedimentary sequence to be recovered that spanned the Holocene and very Late Pleistocene Epochs, including the dry periods when the level of Lake Huron was drawn down significantly. These cores are currently being analyzed at GSO and will establish a baseline for more detailed future paleoclimatological research in the Great Lakes basin. In addition to the deep cores, one core was collected from one of the sinkholes. This core was collected last for fear of damaging the core barrel at the bottom of the sinkhole.

Lastly, during the 2002 expedition, the sinkhole off Middle Island (Figure 6.4) was examined using a conductivity-temperature-depth (CTD) sensor from onboard the *R/V Shenehon*. The CTD was lowered toward the bottom while drifting across the sinkhole. The sensor was held at about one meter off the bottom while drifting, then slowly raised back toward the surface. The CTD stores the data internally for later downloading and processing.

Results and Interpretation

During the 2001 shipwreck mapping survey more than 250 square kilometers of lakebed within the Sanctuary was acoustically mapped, representing more than half of the Sanctuary and covering all the deep-water portions greater than 15 meters water depth. In addition, nearly 100 square kilometers of

lakebed north of the Sanctuary boundary was surveyed. More than 50 tracklines of processed side-scan sonar images were combined in a complete mosaic of the Sanctuary lakebed (Figure 6.7). In all, seventeen shipwrecks were precisely located and imaged, most of which were previously known, especially by the technical diving community. In addition two previously unknown shipwrecks were found. Many other sonar targets were also imaged that appear to be man-made objects on the lakebed, not geological features, because they were isolated and not contiguous with the surrounding lakebed geology, or because they reflected a particularly unique-looking echo.

In addition to the shipwrecks a large number of underwater sinkholes and pockmark features were discovered on the lakebed and mapped during the 2001 survey. During the 2002 survey, *Echo*, which had been equipped with a subbottom profiler, imaged several of these sinkholes again, but in more detail with the added channel of data that imaged beneath the lakebed. The data collected from these sinkholes are portrayed in Figures 6.8 – 6.11, which depict both plan views (side-scan) and cross-section views (subbottom). The first profile, line A-B (Figures 6.8 and 6.9), crosses over two sinkholes. The southern sinkhole has a larger diameter and is deeper than the northern sinkhole. The second profile, line C-D (Figures 6.10 and 6.11), crosses over a third sinkhole which is about as deep and wide as the larger of the first two sinkholes imaged. Figure 6.4 reveals the positions of both profiles and the regions within the Sanctuary occupied by karst features. For the most part, sinkholes and other karst features were found only in the northeastern corner of the Sanctuary, except for a few that were isolated. The dimensions of the southern sinkhole along line A-B are about 250 meters long by 150 meters wide by 10 meters deep (Figures 6.8 and 6.9). The dimensions of the northern sinkhole along line A-B are about 50 meters in diameter by 5 meters deep. The dimensions of the third sinkhole are about 100 meters in diameter by 5 meters deep (Figures 6.10 and 6.11). In other sinkholes that were imaged, but not shown here, the dimensions ranged from close to 400 meters in diameter and up to 20 meters deep to less than 25 meters in diameter and only a few meters deep. Some would be better described as pockmarks instead of sinkholes. In addition, some of the sinkholes were nearly perfectly round in shape and others were very elongated, or elliptical in shape. Therefore there was high variability in sinkhole shapes and sizes across the region. Lastly, most were found in water depths between about 80-120 meters. However, if surveying had continued into deeper water along the same

west-northwest to east-southeast trend as the sinkholes, it is quite possible that more would have been discovered.

The interpretation of the subbottom images of the sinkholes and surrounding subsurface geology is given in Figures 6.12 and 6.13. The positions of prominent reflective sedimentary units are interpreted based on details given in Moore et al. (1994) and Rea et al. (1994). These authors identified a number of seismic reflectors in Lake Huron subbottom profiles and correlated them to sediment cores that contained datable horizons. The acoustic character of these reflective units was used to interpret the profiles collected over the sinkholes (Figures 6.9 and 6.11). The top of each unit was assigned a different color, which also represents a different stratigraphic age. This same color scheme was adopted in the sinkhole interpretations (Figures 6.12 and 6.13). A description of the acoustic characteristics between horizons and the radiocarbon date of fossils found just above each horizon is given in Figure 6.14 (Rea et al., 1994). The unique features are the sinkholes. The region of deformation is interpreted on each cross section. These regions of deformation can be represented by a V-shaped "fault" in cross-section (a ring in plan view). These "faults" are actually the boundary within which the sinkholes have formed. Outside this boundary, the sediments have not been deformed and retain their primary depositional character. By carefully examining the uppermost strata adjacent to the sinkholes, it appears these layers are conformably overlying the regions of deformation. Just above the dark green horizon, the "faults" truncate the strata (including the dark green unit). This indicates the sinkholes formed sometime following deposition of the dark green stratigraphic unit. Since the orange stratigraphic unit does not appear to be deposited inside the sinkhole, the sinkhole probably formed after that unit was deposited, but prior to deposition of later stratigraphic units. According to the interpretation by Rea et al. (1994), this would be between the yellow and orange times, around 10,000 years BP. Sediments that have been deposited since their formation have sunk into the sinkhole, but this Holocene sequence is too thin to be resolved by the subbottom profiler.

The 110 meter deep sinkhole depicted in cross-section C-D (Figure 6.13) was explored by the ROV and video imagery was collected. The sediment surrounding the sinkhole was primarily very fine cohesive mud, with scattered cobbles mixed in with the deposit. As the lip of the sinkhole was approached, a large mass of clay could be observed slowly slumping into the sinkhole. This mass of

clay sloped down toward the middle of the depression and in some places was undercut by clay that had already calved off into the sinkhole. The clays deposited within the sinkhole appeared identical to the deposits around its perimeter. Most of the rim of the sinkhole and the deeper middle of the sinkhole was explored to look for any interesting associated features, but nothing noteworthy was found.

Piston core SH02-5 (Figure 6.15) was collected in the third sinkhole (Figure 6.13). This core was 182 cm long and consisted primarily of massive, light gray-colored, non-descript clay. Very fine laminations could be seen throughout the lower portions of the core. The uppermost 17 cm is characterized by a slight change in lithology to a massive, dark gray-colored clay. The sediments represented by this core were probably deposited soon after the sinkhole formation and their lithologic character suggests they may be correlative with varved clay deposits observed in cores elsewhere from around 10,000 years BP, representing a time interval between the yellow and orange reflectors (Mike Lewis, 2003, personal communication). An interesting component of this core was discovered when the split core was being subsampled for paleomagnetic analysis. At a depth of 8 cm from the top of the core, a very dense, 1-cm diameter, spherical, highly-magnetic stone was recovered (John King, 2003, personal communication). Its appearance is anomalous compared with the surrounding fine clay sediment, and does not reflect what would be expected for ice-rafted coarse material. The possibility that the stone is a small meteorite or possibly a human artifact has not been ruled out, but this would require further investigation.

Another sinkhole, referred to here as the isolated sinkhole (Figure 6.16), was explored by the ROV. This sinkhole was several kilometers inshore from the sinkholes that were imaged by the subbottom profiler, in about 93 meters water depth. As the ROV approached this sinkhole a hazy fluid was first noticed that created a layer overlying the entire depression. Near the rim of the sinkhole, several interesting deposits were immediately imaged, including what appears to be a rounded stone containing a hole (Figure 6.17). This is only one interpretation, however. Other large boulders were observed surrounding the sinkhole. As the ROV proceeded in toward the center of the depression, the pilot noticed some buoyancy differences created by the hazy fluid layer. Within the center of the sinkhole, a number of other unique-looking and perplexing deposits were imaged (Figure 6.18). In one place, what appears to be a preserved tree trunk was imaged (upper image). At first the deposit had the appearance

of bone material, but upon closer examination, that was ruled out. If it is a fossil tree, it needs to be determined whether or not it is *in situ*, or was transported and deposited in the sinkhole. Another unique deposit was imaged nearby the first site (middle image). Here, small boulders were found deposited with wood and sediment. At first, the deposit looked like it had been arranged in a particular fashion. The lower images in Figure 6.18 reveal wood debris from within the aforementioned deposits that have the appearance of being cut by a tool, not broken naturally. Of course, all this discourse is speculation at this time, and this sinkhole warrants further investigation and sampling and analysis of the organic material and stone will confirm or refute this interpretation. One observation that was confirmed visually was that in several locations throughout this sinkhole, evidence for spring-fed groundwater venting was obvious. Also, some organic deposits, possibly bacteria, were found around these vents. This venting explains the existence of the hazy fluid layer. As groundwater travels through the subsurface karst formations, it picks up dissolved salts, then gets emitted through the vents as a dense briny fluid that is warmer than the surrounding lake bottom water. This dense, warm fluid layer lies in suspension above the sinkhole, slowly diffusing upward and outward into the surrounding water.

The last sinkhole that was studied during the 2002 expedition was off Middle Island where a CTD cast was made to the bottom of the sinkhole (Figure 6.19). The temperature profile plot shows depth in meters on the left vertical axis and temperature on the right. The horizontal axis represents a distance equating to time as the vessel drifted over the sinkhole. The temperature profile shows a sharp thermocline from about 5 m to 17 m depth where the temperature drops from about 18 to 8 degrees centigrade (Figure 6.19, upper plot). The temperature then gradually lowers to about 6 degrees centigrade about 1 m above the bottom. A thermal anomaly of about 2-3 degrees centigrade exists immediately above the deepest part of the sinkhole. In a similar fashion, the depth/conductivity plot indicates a conductivity increase just above the bottom of the sinkhole that is 4-5 times higher than ambient lake conductivity (Figure 6.19, lower plot). This simultaneous increase in temperature and conductivity is probably associated with an influx of groundwater into the lake through the bottom of the sinkhole.

Discussion and Conclusions

A plot of the elevation uplift of the isolated sinkhole is given in Figure 6.2 that follows the uplift trend of the Alpena Sill given by Lewis and Anderson (1989), but corrected to calendar years according to Anderson and Lewis (2002). This plot indicated that this sinkhole was always below the level of Lake Huron following the last glaciation. If the deposits in the sinkhole prove to be related to an *in situ* tree, or if evidence of human activity is found at the site, then this would be more data to be added that will modify the lake level curve in Figure 6.2. Otherwise, the deposits in the sinkhole could have been transported there. Sampling and analysis of the material in the sinkhole will tell the story, and this is planned for a future expedition.

The presence of submerged karst formations in deep portions of Lake Huron have not been reported previously until this investigation. Moore et al. (1994) reported similar depression features, although not nearly as deep relative to the surrounding lake floor, in results from a side-scan sonar survey in Lake Huron. They described the features as shallow, circular or elliptical depressions on the lake floor, that were common in the side-scan records. Although they did not offer much for an explanation, they did observe that relationship between their occurrence and the near-surface stratigraphy indicated the depressions may not have formed in modern times. Based on the interpretation of subbottom profiler data across several deep sinkholes, a conclusion has been drawn that indicate the sinkholes formed sometime prior to 9,000 years BP, and have been evolving since that time. Modern sediment is being deposited both in and surrounding the sinkholes. Near the rim of the sinkholes, the uppermost surface sediment is slumping in towards the center of the depressions.

If the sinkholes contain evidence of ancient human activity, this could potentially be significant for a number of different reasons. Firstly, the bottom sediments in the sinkholes are probably anoxic, and will therefore preserve any organic material associated with the sites. Secondly, late Paleo-Indian and early Archaic sites are rare throughout the Great Lakes region, and actually throughout eastern North America, so the discovery and investigation of any site could significantly add to the present knowledge of the nature of past human activity and could shed light on some controversial theories about the peopling of the New World. Lastly, no significant prehistoric underwater sites have been documented from mid-continent region lakes in North America, so a new discovery could be very important.

In shallow water, sinkholes near Middle Island and in Misery Bay and even up to the depths of the isolated sinkhole (93 meters), show a relationship with the groundwater hydrologic system, as there is evidence for fluid venting in the bottom of these features. The deeper water sinkholes are probably too far from land to be actively venting groundwater. Future investigations of the shallow sinkholes will attempt to quantify the amount of groundwater influx. Also, the chemistry of the lake water within and surrounding these sinkholes will be analyzed to determine the nature and origin of the venting fluids.

SIDE-SCAN SONAR TARGET DATABASE – R/V Lake Guardian

<u>Target</u>	<u>Type</u>	<u>Latitude</u>	<u>Longitude</u>	<u>Filename</u>	<u>Depth (m)</u>	<u>Ping</u>	<u>Range (m)</u>	<u>Size (m x m)</u>	<u>Comment</u>
1 Top	T	45° 12.005'	83° 01.312'	LINE2_160-	?	5650	Port 222	52 X 3	Layback guess
Bottom		45° 11.973'	83° 01.309'	1324					
2	T	45° 10.431'	83° 01.793'	LINE3_160-	?	6870	Port 157	22 X 13	Ring feature
3	S	45° 10.278'	83° 02.017'	LINE3_160-	?	7396	Star 163	28 X 27	
4 Top	S	45° 10.056'	83° 01.992'	LINE3_160-	?	7984	Star 202	~109 x 30	
Bottom		45° 10.103'	83° 02.050'	1542					
5	S	45° 10.518'	83° 02.794'	LINE4_161-	109	9870	Port 189	> 180 across	Layback guess
6	T	45° 11.311'	83° 02.821'	LINE4_161-	111	12335	Port 199	34 x 8	Layback guess
7	T	44° 54.761'	83° 03.300'	LINE5_162-	50	3287	Port 180	~29 x 12	Original layback was negative
8	T	45° 09.804'	83° 04.790'	LINE7_162-	111	8632	Port 238	20 x 8	Original layback was negative
9	T	45° 06.674'	83° 05.833'	LINE8_163-	42	499	Port 144	29 x 10	Buried wreck?
10	T	45° 12.249'	83° 18.206'	TURN13_165-	38	570	Port 267	60 x 6	Arrowhead-like feature
11 Bow	W	45° 12.760'	83° 17.974'	LINE14_165-	49	76	Port 144	22 x 4	Unknown (Barge?)
Stern		45° 12.755'	83° 17.957'	0508					
12	S	45° 12.701'	83° 06.614'	LINE14_165-	104	6852	Port 62	15 x 9	Ring feature
13 Top	T	45° 13.020'	83° 09.604'	LINE15_165-	79	5503	Star 63	165 x 25	
Bottom		45° 12.964'	83° 09.496'	0846					
14	S	45° 13.264'	83° 04.337'	LINE16_165-	116	1125	Port 87	~20 x ~10	
15	S	45° 13.739'	83° 03.369'	LINE18_165-	126	3445	Star 44	~37 x ~35	Several sinkholes
16 Bow	W	43° 14.058'	83° 16.707'	LINE19_166-	60	7297	Star 44	35 x 11	Defiance
Stern		45° 14.042'	83° 16.680'	0313					
17 Bow	W	45° 19.523'	83° 19.616'	WINDIATE_	57	1871	Star 140	43 x 8	C.B. Windiate
Stern		45° 19.547'	83° 19.621'	166-2140					
18 Bow	W	45° 17.475'	83° 18.951'	CATHERINE	60	183	Star 107	47 x 7	Typo
Stern		45° 17.500'	83° 18.956'	O_166-2224					
19 Bow	W	45° 17.779'	83° 17.043'	TRANSITTOF	61	6312	Port 92	78 x 10	Florida
Stern		45° 17.810'	83° 17.002'	LORIDA_166- 2231					
20	T	45° 11.062'	83° 16.023'	TURN27_167-	41	266	Star 67	~33 x 8	Possible mast feature
21	S	45° 10.720'	83° 09.169'	LINE29_167-	93	1230	Port 151	57 x 44	
22 Bow	W	45° 10.100'	83° 13.049'	NEWORLEA	43	5604	Star 58	92 x 13	New Orleans
Stern		45° 10.053'	83° 13.043'	NSII_167- 1800					
23 Bow	W	45° 04.995'	83° 05.087'	HANNA3_168	42	1614	Star 85	174 x 28	D.R. Hanna
Stern		45° 05.050'	83° 05.193'	-1104					
24	S	45° 09.600'	83° 04.457'	LINE39_168-	107	4958	Star 186	~20 diameter	Other candidates early in file
25	T	45° 07.342'	83° 02.183'	LINE42_168-	74	477	Port 167	~14 x ~7	
26	S	45° 13.049'	82° 57.175'	WRECKHUN	138	1344	Star 85	~300 x 150	
				T_1_168-2358					

SIDE-SCAN SONAR TARGET DATABASE – <i>R/V Lake Guardian</i> (continued)									
Target	Type	Latitude	Longitude	Filename	Depth (m)	Ping	Range (m)	Size (m x m)	Comment
28	T	45° 10.434'	83° 01.815'	WRECKHUN T_1_169-0118	112	10528	Port 110	~20 diameter	
29	S	45° 10.522'	83° 02.366'	WRECKHUN T_1_169-0212	109	4839	Port 66	~39 x ~33	4 smaller sinkhole features nearby
30 Bow Stern	W	45° 03.092'	83° 02.353'	IMSCOTT169 -0513	54	8369	Port 32	158 x 26	<i>I.M. Scott</i>
31 Bow Stern	W	44° 59.496'	83° 02.277'	VIATOR169- 0746	55	8204	Port 109	67 x 11	<i>Viator</i>
		44° 59.492'	83° 02.229'						
32	W	45° 02.716'	83° 09.164'	THEW169- 0152	27	4634	Port 71	43 x 39	<i>W.P. Thew</i>
33	T	44° 59.031'	83° 12.460'	LINE50_170- 0651	31	1339	Port 167	14 x 12	41 m head feature
34	W	44° 58.575'	83° 13.286'	LINE51_170- 1041b	29	9550	Star 108	12 x 4	<i>Carbide Barge</i> (see 37)
35	T	44° 56.620'	83° 14.178'	LINE52_170- 1304	18	2592	Star 55	17 x ?	
36 Bow Stern	W	44° 59.024'	83° 15.999'	MONTANA_1 71-1733	21	2294	Port 63	73 x 16	
		44° 59.047'	83° 16.047'						
37	W	44° 58.587'	83° 13.284'	TRANSIT_CA RBIDEBARG EB170-2225	?	6971	Star 103	20 x 19	<i>Carbide Barge</i> (also 34)
38 Bow Stern	W	44° 58.116'	83° 11.994'	TRANSIT_GR ECIAN_B170- 2253	?	3544	Star 34	118 x ~ 11	<i>Grecian</i>
		44° 58.125'	83° 12.060'						
39 Bow Stern	W	45° 00.984'	83° 09.917'	EBALLEN162 _1751	24	5105	Port 50	45 x 10	<i>E.B. Allen</i>
		45° 00.984'	83° 09.879'						
40 Bow Stern	W	44° 57.908'	83° 06.128'	PEWABIC_2_ 164-1028	52	6582	Port 50	72 x ~10	<i>Pewabic</i>
		44° 57.929'	83° 06.171'						
41 Bow Stern	W	44° 59.013'	82° 55.472'	159_2049	?	685	Port 100	~156 x ~20	<i>Monrovia,</i> <i>Layback guess</i>
		44° 59.048'	82° 55.356'						

Table 6.1. Significant side-scan sonar target database from 2001 Thunder Bay Shipwreck Mapping Survey. For types, W=Wreck, S=Sinkhole, T=Unknown Target.

Figure 6.1. Location map of Thunder Bay National Marine Sanctuary and Underwater Preserve. Contours are given in depth below lake level in meters.

Figure 6.2. Isostatic uplift corrected lake level rise curve for water planes in the Lake Huron Basin (after Lewis and Anderson, 1989; Anderson and Lewis, 2002). Also indicated are the uplift curves for notable features and for the isolated sinkhole, which was projected along the same trend as Alpena.

Figure 6.3. Evolution of the Great Lakes during selected post-glacial times after Lewis et al. (1994). Red lines indicate position of the ice margin, blue arrows indicate flow direction of lake water through outlets. Prior to 9,600 years BP, mid-continent glacial meltwater drained out of Glacial Lake Agassiz to the paleo-Mississippi River and ultimately to the Gulf of Mexico. After 9,600 years BP, the major discharge was to the Champlain Sea and paleo-St. Lawrence River. Ages are in calendar years before present, converted from radiocarbon years (Anderson and Lewis, 2002). Refer to text for details.

Figure 6.4. Regions of karst formations, as known to occur on land (after Black, 1983), in shallow water (Middle Island, Misery Bay), and in deep water - from this investigation. Aerial photograph of the El Cajon Bay, a submerged sinkhole in Misery Bay, is shown (U.S. Dept. of Commerce, 1999).

Figure 6.5. Research platforms for 2001 and 2002 surveys. *R/V Lake Guardian*, upper left, *R/V Connecticut*, lower left, and side-scan sonar towfish, *Echo*, right, with it's depressor weight.

Figure 6.6. Underwater video still image of remotely operated vehicle *Little Hercules* and optical towed *Argus* examining the propeller of a shipwreck in Thunder Bay. These vehicles, which are tethered together and work in tandem, were also deployed from the *R/V Connecticut* to examine the sinkholes (video shot by John Brooks diving on the shipwreck *Montana*, September 2002).

Figure 6.7. Raw mosaic of side-scan sonar trackline coverage, both inside the sanctuary boundary, and further to the north. Shallower regions inside the sanctuary could not be surveyed primarily due to the maneuverability of the ship and towfish. Gaps in the coverage, or "holidays," were filled in after the primary survey was completed.

Figure 6.8. Side-scan sonar track revealing two prominent sinkholes in the port lobe. Image is not geocorrected. Location of subbottom profile in Figure 6.9 is shown. Refer to Figure 6.4 for location.

Figure 6.9. Subbottom profile across the two sinkholes in Figure 6.8. Smaller sinkhole is about 5 meters deep, larger sinkhole is about 10 meters deep. Shown with substantial vertical exaggeration.

Figure 6.10. Side-scan sonar track revealing two prominent sinkholes in the port lobe. Image is not geocorrected. Location of subbottom profile in Figure 6.11 is shown. Refer to Figure 6.4 for location.

Figure 6.11. Subbottom profile across the sinkhole in Figure 6.10. Shown with less vertical exaggeration than in Figure 6.9.

Figure 6.12. Interpretation of seismic stratigraphic sequences in cross-section A-B as in Figures 6.8 and 6.9 (based on Huron seismic stratigraphy given by Moore et al., 1994 and Rea et al., 1994). It appears the sinkholes formed prior to deposition of light green and light blue reflectors. Refer to text for detail.

Figure 6.13. Interpretation of seismic stratigraphic sequences in cross-section C-D as in Figures 6.10 and 6.11 (based on Huron seismic stratigraphy given by Moore et al., 1994 and Rea et al., 1994). Location of Core SH02-5 is shown on the seismic section.

Reflector (color)	Acoustic Character	Age (RYBP)
Surface		
Light Blue		7,600
Light Green	Weak, closely-spaced reflectors	9,000 - 9,800
Yellow		9,900 - 10,050
Orange		10,200
Dark Green	Acoustically transparent unit	11,200
Dark Blue		11,400
Purple	Highly reflective acoustic basement	

Figure 6.14. Radiocarbon dating results for each stratigraphic sequence, after Rea, et al., 1994. Age dates are in radiocarbon years before present (RYBP). No stratigraphic units younger than the orange sequence are observed near the sinkholes.

Figure 6.15. Whole-core photograph of core SH02-5 with description. Core was collected from a sinkhole that was acoustically imaged (Figures 6.10 and 6.13). Note the sharp transition at about 17 cm from massive dark clay to laminated lighter-colored clay. One anomalous stone was recovered from a depth of about 8 cm in the core. The stone was very dense and highly magnetic.

Isolated Sinkhole - 93 m water depth

Figure 6.16. Geo-corrected side-scan sonar image of an isolated sinkhole from 93 m water depth. Refer to Figure 6.5 for location. This was the only significant sinkhole within several hundred meters radius and stood out prominently on the side-scan sonar record. Sinkhole measures about 55 meters long by 35 meters wide and was about 4 meters deep. This image was created by the sonar being towed from west to east north of the sinkhole, resulting in poor reflectance on the northern down-sloping side, and strong reflectance on the southern up-sloping side.

Figure 6.17. Video still image taken by the ROV during a dive in the isolated sinkhole. Scale is approximately 20 cm across the bottom of the image. This particular item appears to be a rounded stone with a hole. This is not confirmed, however, and could represent benthic biology or something that had drifted in to the sinkhole. Future sampling will reveal its nature.

Figure 6.18. More video still images collected from the isolated sinkhole. Scale on the upper two figures is approximately 2 meters across the bottom of the images. In the bottom two figures, the scale is about 20 cm across. The top figure reveals possible remains of a tree trunk with associated roots and branches, which could exist *in situ* and be preserved by the chemical conditions inside the sinkhole. The middle figure reveals a unique deposit of stone and wood material mixed together. Also note the hazy fluid layer that sits above the sinkhole that is caused by the emission of warmer briny water into the bottom of the lake through the sinkhole. The bottom two figures zoom in on features from the above figures and reveal the possibility that the wood had been cut.

Figure 6.19. Temperature (above) and conductivity (below) profiles collected from the sinkhole north of Middle Island (see Figure 6.7 for location). The horizontal scale represents a distance of about 100 meters. The CTD was launched up-current from the sinkhole site for the cast, then lowered down into the sinkhole as the vessel drifted with the current, then brought back up to the surface. Significant thermal and salinity anomalies exist at the bottom of the sinkhole.

CHAPTER 7

CASE STUDY III – WESTERN AND SOUTHERN BLACK SEA OFF BULGARIA AND TURKEY

Introduction

The Black Sea (Figure 7.1) is a unique body of water. It is a large inland sea, about 1,000 km in length along its east-west axis, about 400 km wide on average along its north-south axis, and more than 2 km deep in the central portions of the basin. It is situated along a cultural crossroads between Europe, Asia, and the Middle East, bordered by the Anatolian Mountains and Plateau to the south, the Caucasus Mountains to the east, the Balkans to the west, and by broad alluvial plains to the north that are dominated by large drainage systems including the Danube, Dneister, Dneiper, and Don Rivers. During the early Holocene the waters of the Black Sea were fresh and occupied a large isolated lake (Ross et al., 1970; Ryan et al., 1997). The lake then changed, perhaps catastrophically, to a marine environment as the global rise in sea level caused salt water to breach the sill of the Bosphorus Strait and spill into the Black Sea, which at that time was as much as 155 meters lower in elevation (Ryan and Pitman, 1998).

Another unique feature of the Black Sea is that below an average depth of about 150 meters, the waters are anoxic. The lack of oxygen prohibits nektonic and benthic plants and animals from existing either in the water column or on the seafloor. The bottom waters became anoxic around the same time that they became saline, immediately following the aforementioned marine inundation (Deuser, 1974; Wilkin et al., 1997). An additional unique feature is that the surface currents of the Black Sea circulate in two large cyclonic (counterclockwise-rotating) gyres, one occupying the eastern half of the basin, the other occupying the western half (Oguz et al., 1993). The two gyres meet in the central portion of the basin where the eastern gyre flows northward and the western gyre flows southward. Non-coincidentally, this unique flow regime lies along a suspected ancient north-south trade route that crossed the Black Sea from the Sinop region of northernmost Turkey to the Crimea of southernmost Ukraine (Hiebert, 2001).

All of these unique characteristics of the Black Sea have made this body of water a focus of active research in archaeological oceanography. Since 1998, collaboration among researchers from the

Institute for Exploration of Mystic, CT, the University of Pennsylvania, Florida State University, and the Massachusetts Institute of Technology was initiated and an active program of field work has taken place to investigate the coastal onshore regions, the shallow submerged shelf, and deep Black Sea water for archaeological research throughout the region (Ballard et al., 2001). The primary methodology for most of the research presented here is side-scan sonar mapping, subbottom profiling, and visual surveying using remotely operated vehicle (ROV) systems. The shallow submerged shelf was surveyed to explore for potential sites of human occupation, presently submerged, that were inundated by rising waters in the Black Sea basin. The deep water research primarily involved the investigation of deep sea trade routes, traveled by merchant ships of antiquity, by exploration for well-preserved shipwrecks resting in the anoxic bottom waters. The preservation of archaeological sites, especially organic remains, is greatly enhanced in the deep Black Sea due to the fact that no wood-boring organisms that would otherwise destroy wood can exist.

Holocene Oceanography

There has recently been a considerable amount of renewed interest in the Holocene evolution of the Black Sea region following the 1998 publication of William Ryan and Walter Pitman's book, *Noah's Flood*, in which they proposed that a catastrophic influx of marine waters around 7,150 years BP into the basin flooded about 150,000 square kilometers of the coastal landscape surrounding the "New Euxine Lake." This transition from a lake to a sea was first discovered and documented by geologists in the late 1960s who analyzed a large number of sediment cores collected in the Black Sea (Ross et al., 1970; Degens and Ross, 1972; Ross and Degens, 1974). Several groups of marine geologists have challenged the work of Ryan and Pitman and have suggested that the inundation was much more gradual (Görür et al., 2000), and may have actually progressed in the opposite direction, from the Black Sea into the Sea of Marmara and the Aegean Sea (Aksu et al., 1999). However the discovery of a submerged paleoshoreline off northern Turkey (Ballard et al., 2000), and ancient river channels that flowed across a terrestrial landscape, discovered off southern Russia (Ryan et al., 1997), and off Bulgaria and Romania (this study) confirm that the elevation of the Black Sea was more than 150 meters below the present day elevation around 7,000 years BP.

During a time following the maximum extent of the Würm glaciation, the Black Sea Basin contained an isolated, inland, fresh body of water - the New Euxine Lake (Ross and Degens, 1974; Ryan and Pitman, 1998). It was fed by runoff from the Eurasian ice sheet, until the glacier retreat northward and most of the water became tied up in high-latitude periglacial lakes (Figure 7.2; Ryan and Pitman, 1998). As the ice sheet retreated northward towards Scandinavia, the crustal depression left behind by the weight of the ice caused the northern headwaters of most rivers that currently flow into the Black Sea to flow into the North Sea (Ryan and Pitman, 1998). During this arid time period, from about 14,500 – 7,600 years BP, the elevation of the New Euxine Lake fluctuated, but the overall trend was to contract in size and lower in elevation, as evaporation exceeded precipitation and river input for most of the time. Global sea level, which was rising in response to melting ice sheets, caused the Mediterranean Sea (and hence the Aegean Sea) to rise as well, but it remained below the elevations of the sills in both the Bosphorus and Dardanelles, which are presently -40 m and -70 m, respectively (Aksu et al., 2002). Prior to this time, the fresh water of the New Euxine Lake, which was at an elevation higher than Sakarya Outlet sill but below the plugged Bosphorus sill, spilled into the Aegean Sea via the Sea of Marmara (Figure 7.3, upper panel; Ryan and Pitman, 1998)? Then, around 7,600 years BP, rising Aegean marine waters rose above the Dardanelles sill, inundated the strait, and poured into the ancient Sea of Marmara Lake, changing it to a marine environment (Figure 7.3, middle panel; Ryan and Pitman, 1998). Then, around 7,150 years BP, rising sea level inundated the Bosphorus, broke through a natural dam and eroded the sill to its present depth, and eventually spilled into the New Euxine Lake, either very rapidly (Ryan and Pitman, 1998) or more gradually (Görür et al., 2001). The New Euxine Lake filled nearly to the present level of the Black Sea, and a two-way current system became established through the Bosphorus (Figure 7.3, lower panel; Ryan and Pitman, 1998). This situation persists today.

The Holocene evolution of the Black Sea is illustrated schematically in Figure 7.4, with different models presented by different groups who studied different data sets. The upper panel illustrates the global sea level curve of Milliman and Emery (1968), adapted to the Black Sea region by Degens and Ross (1972). Ross and Degens (1970) published the first western reports on the recent geology of the basin based on the analysis of deep-water sediment cores. In nearly every core, these authors identified

three basic lithologies: a modern uppermost unit of coccolithic ooze (Unit I), or deep-sea mud containing stratified layers of plankton-rich carbonaceous clay, underlain by a thick sequence of sapropelic mud (Unit II) with very high organic content, underlain by a sharp transition to light-colored lacustrine clay (Unit III) that persisted to the base of most cores. This same sedimentary sequence has been reported by a number of other authors who examined different cores throughout the Black Sea (Hay, et al., 1991; Çağatay, 1999). According to Ross and Degens (1970), the marine transition started gradually about 9,000 years BP, prior to deposition of Unit II.

The model first put forth by Ryan et al. (1997; Figure 7.4, lower left) suggested that a catastrophic flood about 7,150 years BP abruptly transitioned the lake to a sea. At this time, just prior to the flood, the lake was about 150 meters lower in elevation than today. Görür et al. (2001) presented new data from a shallow-water survey near the Sakarya River in northern Turkey that suggested BP the marine transition occurred at 7,150 years, but the inflow was more gradual, and the elevation of the lake was much higher than Ryan et al. (1997) reported (Figure 7.4, lower right). Recent work by Major et al. (2003), who analyzed strontium isotopic ratios from Black Sea mollusk shells (a paleo-salinity proxy), also suggests that the inflow was more gradual. Although the curves look different, all of the models presented in Figure 7.4 indicate the New Euxine lake was more than 100 meters lower than the present day level 12,000 years ago. Therefore, despite the rapidity of the influx of marine waters (or glacial meltwater), a major portion of the Black Sea shelf was inundated since that time, and that has significant archaeological implications.

Prehistoric Archaeology

During the peak of the Würm glaciations, the climate of the late Pleistocene was harsh. Nevertheless, humans migrated and spread throughout Europe and its environs (van Andel and Tzedakis, 1996). The dry climate following this last Ice Age would have made the Black Sea basin a freshwater oasis. It is quite conceivable that human populations would have settled in the near shore coastal environments surrounding this oasis. In fact, a large number of prehistoric archaeological sites have been discovered throughout the central and coastal regions of Turkey, Bulgaria, and Romania. The Late Paleolithic, Mesolithic and Early Neolithic periods are represented, but data are sparse. The

only inhabitants of the region during these periods were probably small bands of indigenous hunters and gatherers (Ryan and Pitman, 1998). In Eurasia and the Middle East, by middle to late Neolithic times, human populations began to flourish, small settlements of different bands of people coalesced into larger villages, and stone technology advanced. Two noteworthy sites representative of advanced Neolithic cultures in the region, both exhibiting evidence of agriculture and domestication of animals, are Lepenski Vir (Srejovic, 1972), along the banks of the Danube, and Çatal Hüyük (Mellaart, 1967), in south-central Turkey. Although both of these sites are far from the Black Sea coast, and on opposite sides of the Sea, they provide strong evidence of regional advanced cultures with significant direct parallels represented in painting and sculpture from the sites (Ryan and Pitman, 1998). Along the western and southern Black Sea coasts, agricultural village sites have been discovered that date to at least the seventh millennium BP (Ballard et al., 2001; Hiebert et al., 2002). Following this early time, evidence for ceramic and metal technology appears along these same coasts (Ballard et al., 2001).

In coastal Bulgaria, near Varna, a significant prehistoric archaeological discovery was made – the earliest evidence of gold metallurgy anywhere in the world and perhaps the earliest civilization in Europe dating to 6,600 calendar years BP (Florov and Florov, 2001). This discovery, from a necropolis in the Varna Lakes region of Bulgaria in the present-day Provadiyska River valley, contained a large number of grave sites, some of which contained copper tools along with jewelry and ornaments made from processed gold (Figure 7.5, upper panels). The proto-Bulgarians that occupied the Varna Lakes region probably developed copper and gold metallurgy themselves, independently inventing it in Europe, far from the influence of earlier Near Eastern metallurgists (Renfrew, 1980). Another Bulgarian archaeological site from a similar time period has been excavated at Karanovo. The late Neolithic is represented here, dating to about 8,000 years BP, transitioning to the Copper Age (early Chalcolithic) at about 7,000 years BP (Renfrew, 1980). Bulgaria's central location has made it a connection between a diverse array of Near Eastern, Mediterranean, Russian steppe, and central European cultures, and for this reason the region possesses some of the most significant archaeological resources in all of Europe (Bailey and Panayotov, 1995; Florov and Florov, 2001).

In 1985 divers in a Russian submersible found and recovered a large ceramic plate in about 90 meters water depth off the Bulgarian coast (Figure 7.5, lower panels; Dimitrov, 1999). This artifact was

retrieved from the presently submerged ancient Provadiyska River valley, near the paleoshoreline, about 50 km east of Varna. Although this plate was not found in association with any other artifacts, and its depositional context has not been determined, it could represent a significant relic from a Neolithic coastal Black Sea archaeological site, but this is unsubstantiated. The discovery nevertheless prompted intrigue, and clearly more work needed to be done to interpret its significance.

Elsewhere in the Black Sea region, on the southern tip of the Crimean peninsula in southern Ukraine, late Neolithic archaeological sites were discovered that contain extensive evidence of shellfish gathering, for use as a food resource (Burov, 1995). There is other evidence of whale hunting exhibited in rock carvings, and dolphin bones are present at a few sites. These finds indicate that the early inhabitants of the coastal Black Sea basin following the marine inundation exploited littoral sea resources. This could suggest that earlier hunter-gatherers exploited the coastal regions of the New Euxine Lake for potential food resources. If that is the case, then an expectation to find submerged sites of human occupation on the shallow shelf is not completely unwarranted.

Methodology

Archaeological oceanographic surveys of the Black Sea took place during four field seasons from 1999 to 2002. These surveys, which varied in scale and scope, were successful in mapping the submerged landscape in order to interpret the paleo-geographic environment of coastal lake regions surrounding the ancient Black Sea prior to marine inundation. During the summers of 1999 and 2000, portions of the Turkish Black Sea shelf were surveyed (Figures 7.6 and 7.7). During the summers of 2001 and 2002, portions of the Bulgarian/Romanian Black Sea shelf were surveyed (Figure 7.8). For all surveys, instrumentation varied significantly, but the primary technology and methodology was similar for each location.

During the 1999 survey, a small Turkish fishing vessel (Figure 7.9, upper) was used to conduct a survey of the broad shelf immediately east of Sinop, Turkey (Figure 7.6). A shallow-water side-scan sonar towfish, a small ROV, and a small dredge (Figure 7.9, lower panels) were used to image and sample the seabed in the vicinity of the suspected pre-flood paleoshoreline, represented by the 155-meter depth contour (Figure 7.6). A differential GPS positioning system was used for navigation, with

corrections sent from a stationary land-based receiver. The sonar towfish (Figure 7.9, middle left) was towed behind the fishing vessel at a speed of approximately 3 knots, imaging a swath beneath the instrument about 200 meters wide. The survey tracklines were designed to cross back and forth over the 155-meter depth contour, which had been previously determined by a bathymetric survey using the fishing vessel's echo sounder. The ROV, which was also deployed from the fishing vessel, was used to collect video imagery of the seafloor, to aid in the interpretation of the sonar data (Figure 7.9, lower left). It was equipped with thrusters, a scanning forward-looking sonar, an underwater video camera, and lights. The ROV was launched in the location to image, usually near a pre-determined sonar target, then driven towards the features of interest. Finally, in order to further groundtruth the acoustic and optical imagery, seafloor samples were collected using a small frame dredge (Figure 7.9, lower right). The dredge was towed for several tens of meters along the bottom until it was suspected of being full of sediment, then recovered. The sediment was emptied from the dredge on the deck of the ship and put into storage containers.

During the 2000 survey to the west of Sinop, Turkey (Figure 7.7), a large research vessel was used to deploy several deep-submergence vehicles (Figure 7.10). The *M/V Northern Horizon* (Figure 7.10, upper left) was chartered for the expedition to conduct a side-scan sonar survey and ROV operation. The vessel was equipped with a dynamic positioning system for precision maneuverability while the ROV was carefully working the seafloor below. Equipment had to be added to the afterdeck of the vessel in order for it to support the vehicle systems. This included a large deep-sea winch with a several-thousand-meter-long fiber-optic cable, a large A-frame and overboard sheave, and an articulating deck crane for launching and recovering the ROV and side-scan sonar. Unlike the 1999 survey, all the vehicle systems used in 2000 were capable of working in depths of at least 3,000 meters. Deep waters were explored during this expedition, but a significant amount of time was spent in more shallow regions, near the ancient shoreline. A portion of the wide shelf between the 90 m and 160 m depth contours was surveyed using the *DSL-120* side-scan sonar and bathymetric mapping system (Figure 7.10, upper right). Acoustic targets were inspected using the two-vehicle system, *Argus* and *Little Hercules*, an optical towed and tethered ROV (Figure 7.10, lower panels; Coleman et al., 2000). Archaeological samples were collected by outfitting the ROV with a sample bag or wood-coring device.

The 2001 expedition (Figure 7.8) was in collaboration with the Bulgarian Academy of Sciences Institute of Oceanology (BAS-IO) using their *R/V Akademik* (Figure 7.11, upper left). A new deep-towed vehicle, *Echo*, was the primary survey tool (Figure 7.11, upper right). It is equipped with a dual-frequency side-scan sonar, subbottom profiler, and CTD sensor for measuring salinity, temperature, and depth of water. The primary methodology for *Echo* side-scan operations are given by Coleman (2002). Two general survey regions were chosen: off the Bulgarian coast, along drowned river valleys and ancient shorelines; and off the Romanian coast, along the ancient Danube river valley offshore toward the Vitaez Canyon. For the Bulgarian survey, tracklines were chosen to correspond to regions where the most recent sedimentary layer was the thinnest, thereby allowing any potential archaeological sites to be better exposed and less difficult to image acoustically. To further understand the geology, and to groundtruth the subbottom profiler data, a number of gravity cores were collected (Figure 7.11, middle left). These cores were cut, split, described, photographed, and containerized onboard the ship (Figure 7.11, middle right). The coring locations (Figure 7.8) were chosen to provide details about the depth variation in sediment type, to determine the amount of Holocene sedimentation for a particular site, and to correspond to interesting subbottom features.

During the 2002 survey, again in collaboration with BAS-IO using the *R/V Akademik*, their research submersible, *PC-8B* (Figure 7.11, lower panel), was used to dive on a number of the most interesting acoustic targets identified during the 2001 sonar mapping survey. The 3-person submersible was equipped with a scanning sonar, an underwater video camera, lights, an underwater 35 mm still camera, and a manipulator for collecting samples. About 10 dives were made during a 2-week period. More than 5 days were lost due to poor weather. Without the benefit of a subsea navigation system for tracking the submersible along the bottom as it traveled, we had to rely on the scanning sonar and compass to perform a search for target location. This involved the deployment of an anchor, chain, and float equipped with a sonar reflector. This "marker buoy" then became the hub for a search pattern radially outward from the hub. Navigation was then relative to the buoy's deployed location, which may have been in error due to poor accuracy during buoy deployment. Once a significant sonar target was located, the search was halted until the target was inspected.

Results and Interpretation

During the 1999 survey, an ancient beach was discovered about 155 meters below sea level (Figure 7.12; Ballard et al., 2000). This feature was first interpreted based solely on the side-scan sonar record, which revealed a subtle, but pervasive beach berm formation within what appeared to be a sandy bottom. This berm feature corresponded exactly with the 155 meter depth contour, consistent with the work of Ryan et al. (1997). The acoustic image of the beach was verified visually using the ROV. Video footage was collected that revealed prominent relict shoreline features. The ROV confirmed that the topography across these features gently sloped seaward, and slightly undulated, leading to the beach profile presented in Figure 7.12. Shells, cobblestones, sand, and mud from this beach that were sampled using the dredge, were analyzed and interpreted. The shells proved to be of two varieties – (1) bleached, extinct, freshwater mollusks with a close affinity to species presently living in the freshwater Caspian Sea; and (2) modern marine mollusks, some of which currently thrive only in shallow water (less than 155 meters). Radiocarbon analysis of the shells revealed that the freshwater shells were all older than 7,460 years BP and the saltwater shells were all younger than 6,820 years BP (Ballard et al., 2000; Table 7.1; Figure 7.13). This constrained the marine inundation of the Black Sea to between these two dates. The Black Sea flood date presented by Ryan et al. (1997) was 7,150 years BP, therefore, the work presented here adds further evidence to Ryan and Pitman's hypothesis (Ballard et al., 2000). In addition to the shells, rounded cobbles were collected in the dredge haul (Figure 7.14). The smooth, relatively well-rounded, poorly-sorted nature of the cobbles (Figure 7.14, left) indicate this paleoshoreline was once a high-energy environment, where waves washed and scoured the cobbles (Ballard et al., 2000). Several cobbles were flattened, and contained a ring of very fine sediment (Figure 7.14, right) representing the remnants of a concreting pavement that formed part of the relict shoreline above the waterline (Ballard et al., 2000). The fact that all of these fragile beach features were well-preserved suggests that the flooding event was rapid, adding supporting evidence to the Ryan and Pitman flood hypothesis (Ballard et al., 2000). Otherwise, a slow marine transgression would tend to destroy fragile features as the water slowly rose and waves continued to erode the shore.

During the 2000 expedition, a number of potentially significant archaeological discoveries were made. The submerged coastal landscape was mapped (Figure 7.15; Ballard et al., 2001) to reveal a flat,

but slightly undulating terrestrial landscape that became inundated. Several ancient stream channels were imaged by sonar. These features are interpreted to represent a weak drainage system that flowed across the shelf during the arid times prior to the flood of marine waters. One particularly interesting sonar target was discovered that was examined in more detail. "Site 82" represents an isolated, highly reflective sonar target that sits on the crest of a low hill, much like an archaeological "tell" (Figure 7.16). Subsequent dives on the site with the ROV revealed more details about the nature of the site. A number of stone blocks that have the appearance of being manipulated by human hands were found scattered around the site (Figure 7.17; Ballard et al., 2001). The randomness of the arrangement of blocks suggests that it is non-natural. Natural geologic jointing of bedrock would typically result in a more regular arrangement. Interspersed with the stone blocks are a number of what appear to be wooden supports of a collapsed structure. The wood, which varies in length and diameter, has a fresh-looking appearance, and has a definite characteristic of being hand-hewn, not randomly broken or eroded. Matrix sediment samples collected from the site support the possibility that humans occupied this location prior to its inundation. The sediment contained fragments of charcoal, seeds, and possible bone material. In addition, the chemical composition consisted of elevated concentrations of phosphorus and magnesium compared to a control sample collected far from the site (Hiebert et al., 2002). Radiocarbon dating of two wooden "artifacts" collected from the site were quite young, indicating contamination of the site by modern driftwood. Although these results are inconclusive, they do suggest the site was occupied by humans, but further sampling and analysis will need to be done in order to confirm. The amount of wood present at this site, and at the locations of three shipwrecks found at about 100 meters depth, suggest the anoxic layer in the Black Sea fluctuates (Figure 7.18; Ballard et al., 2001). The fluctuating boundary creates an intermediate "mixed" layer where anoxic waters can infiltrate from below. One shipwreck found in deep water (320 meters) was nearly perfectly preserved in the anoxic bottom waters.

For several reasons, the submerged shelf off northern Turkey is probably not the best place in the Black Sea to search for ancient sites of human habitation. Here the continental shelf drops off quickly to deep water, so the submerged "pre-flood" terrain is steep. There are also not as many major drainage systems as elsewhere in the Black Sea. Finally, the Anatolian Fault, a major tectonic plate boundary,

runs through northern Turkey. When earthquakes occur along this fault, the result is slumping and sliding of sediments on the continental shelf and slope, which can easily bury any potential archaeological sites. High sedimentation rates have been documented for this region (Ross and Degens, 1974). Therefore, for the 2001 Expedition, a region that is much more promising for locating sites of human habitation was explored – the broad Bulgarian/Romanian shelf. The side-scan sonar data revealed numerous potentially man-made targets (Table 7.2) in addition to geologic structures. The subbottom profiler data revealed detailed geologic structures related to the ancient shoreline, in addition to the locations of small mud volcanoes and gas pockets. Within the cores that were collected (Table 7.3), freshwater and saltwater shells were found that will enhance our understanding of the flood as they were discovered in their original positions near the ancient shoreline. In all, five subregions were surveyed, covering more than 700 miles of linear tracklines. More than 100 acoustic targets were discovered, all being around the size and dimensions of potential man-made structures, ancient dwellings or shipwrecks. The subbottom profiler on *Echo* was used to follow ancient river channels until they intercepted the ancient shoreline. An ancient delta region was mapped where the paleo-river Provadiyska met the ancient shoreline off Varna, Bulgaria (Figure 7.19), near where the ceramic plate was recovered (Dimitrov, 1999). Two subbottom profiles were collected across this region, one roughly perpendicular to the shoreline (Figure 7.19 - Line 19), the other parallel (Figure 7.19 - Line 13). The subbottom profile across Line 13 (Figure 7.20) reveals a slight undulating topography underlain by a thick sequence of Pleistocene sediments. Within the upper layers of sediment is a large quantity of free gas, as indicated by the diffractions in the acoustic signal and by the reflections off gas bubbles in the water column above small faults in the strata - features that are characteristic of a deltaic environment. Line 19 (Figure 7.21) reveals the unconformity that corresponds to the pre-flood surface of the Black Sea shelf, where the reflector pinches-out at the seafloor. A core collected seaward of the paleoshoreline reveals the abrupt transition from lacustrine to marine sediment.

During the 2002 expedition, the Bulgarian submersible was used to dive a number of important targets (Table 7.4). One dive near the Provadiyska paleoshoreline, revealed relict features – *in situ* ancient mussel shells that once thrived in a shallow water environment (Figure 7.22). This is further evidence to support that this location is an ancient shoreline along a freshwater lake. Future dives using

a submersible or ROV will reveal the nature of some of the Romanian acoustic targets collected during the 2001 survey. These could not be imaged using the submersible in 2002 for logistical reasons. One of the targets (Figure 7.23) had a very non-natural appearance including a large circular feature on the seafloor surrounded by smaller objects. This target was also isolated and not part of any larger geologic structure.

Discussion and Conclusions

A significant result from the last four years of archaeological oceanographic surveying in the Black Sea is a delineation of the submerged paleoshoreline off the coast of north-central Turkey and off the coasts of Bulgaria and Romania. In addition, landward of this paleoshoreline, the inundated landscape was mapped, characterized, and sampled. A number of submerged river channels leading to the ancient lake shore were also delineated. With solid evidence from this research for the consistent existence of this paleoshoreline, a conclusion can be drawn that during Neolithic times, the Black Sea was about 150 meters lower in elevation than today and was an isolated freshwater lake. It must have existed for a significant amount of time at this elevation in order to form persistent shoreline features. Once the marine transgression through the Aegean and Marmara Seas breached the Bosphorus sill, the entire Black Sea lake's coastal plain became inundated. Whether or not the inundation was catastrophic, rapid, or more gradual does not alter the fact that many coastal archaeological sites now lie submerged, shallowly buried on the drowned Black Sea shelf.

The discovery of Site 82 in 95 meters water depth about 20 km off the coast of northern Turkey in 2000 stimulated discussions by archaeologists that deepwater terrestrial sites could be preserved and found on the Black Sea shelf. The results are inconclusive to establish this discovery as an authentic site of human occupation. Clearly more work needs to be done on this site and elsewhere on the submerged shelf to gain more conclusive results. With support from the National Science Foundation, we are returning to Site 82 during the summer of 2003 to conduct a more detailed mapping and sampling survey of the region. Pieces of wood will be mapped, measured, and collected for radiocarbon dating. Sediment box cores will be collected to analyze the near-surface stratigraphy. Stone and other debris will be mapped and collected to analyze more details about the site. This will all

be performed using a sophisticated ROV system developed for deep sea archaeological mapping and excavation.

Results from the submersible survey off Bulgaria in 2002 include the investigation of eight side-scan sonar targets that were mapped during the 2001 survey. Four of the eight targets were shipwrecks, including one Hellenistic period shipwreck that carried amphora containing fish bones that dated to around 2,400 years BP (Coleman et al., 2003). No suspected sites of human occupation were discovered, but only a limited number of submersible dives were made due to poor weather conditions during the expedition, so many potentially significant sonar targets have yet to be visually inspected. Unlike off northern Turkey, every acoustic target that was found was man-made. The lack of rocky outcrops on the Bulgarian shelf helps the preliminary identification of targets, and future archaeological oceanographic survey work will undoubtedly result in the discovery of new man-made objects on the seafloor.

RADIOCARBON DATING RESULTS

<u>NOSAMS Accession #</u>	<u>Species of Mollusk</u>	<u>Type</u>	<u>Age (years BP)</u>	<u>Age error (+/- years)</u>
OS-21644	<i>Papillicardium papillosum</i>	S	3200	70
OS-21645	<i>Modiolula phaseoline</i>	S	2810	40
OS-21646	<i>Dreissena rostriformis var. distincta</i>	F	15550	120
OS-21647	<i>Dreissena rostriformis var. distincta</i>	F	10800	75
OS-21648	<i>Dreissena rostriformis var. distincta</i>	F	10450	70
OS-21649	<i>Dreissena rostriformis var. distincta</i>	F	10450	70
OS-21650	<i>Dreissena rostriformis var. distincta</i>	F	10400	70
OS-21651	<i>Dreissena rostriformis var. distincta</i>	F	10500	70
OS-21652	<i>Trophonopsis breviata</i>	S	2800	45
OS-21653	<i>Bittium reticulatum</i>	S	3860	50
OS-21654	<i>Abra albra</i>	S	4130	45
OS-21655	<i>Mytilus galloprovincialis</i>	S	6820	55
OS-21656	<i>Parvicardium exiguum</i>	S	3190	50
OS-21657	<i>Turricaspia caspia lincta</i>	F	12100	85
OS-21658	<i>Turricaspia caspia lincta</i>	F	9310	65
OS-21659	<i>Turricaspia caspia lincta</i>	F	7460	55
OS-21660	<i>Turricaspia caspia lincta</i>	F	7590	55
OS-21661	<i>Turricaspia caspia lincta</i>	F	7480	55
OS-22454	<i>Mytilus galloprovincialis</i>	S	4830	45
OS-22455	<i>Mytilus galloprovincialis</i>	S	6470	45
OS-22456	<i>Mytilus galloprovincialis</i>	S	6020	45
OS-22457	<i>Mytilus galloprovincialis</i>	S	4000	45

Table 7.1. Taxonomy and radiocarbon dating results of mollusks collected on the Sinop paleoshoreline reported by the National Ocean Sciences Accelerator Mass Spectrometer (NOSAMS) facility in Woods Hole, MA (after Ballard et al., 2000). Results are reported in radiocarbon years before present. Refer to Figure 7.5 for an age distribution plot. For the type column, F=freshwater, S=saltwater.

SIDE-SCAN SONAR TARGET DATABASE – R/V Akademik

<u>Target</u>	<u>Latitude</u>	<u>Longitude</u>	<u>Depth (m)</u>	<u>File Name</u>	<u>Ping</u>	<u>Range (m)</u>
1	43° 03' 53.38"	28° 35' 33.63"	?	TRANSIT_2_229_1457	11593	S 91
2	42° 54' 11.57"	28° 29' 19.39"	151	LINE1_229_1835	3866	S 212
3	43° 03' 52.35"	28° 35' 30.87"	109	LINE4_230_0335	8481	P 123
4	43° 02' 33.29"	28° 33' 52.76"	110	LINE5_230_0711	2405	S 108
5	42° 59' 22.02"	28° 31' 20.69"	?	LINE7_230_1442	3344	P 150
6	42° 58' 43.43"	28° 32' 58.74"	?	LINE7_230_1442	8530	P 187
7	43° 00' 18.25"	28° 31' 21.71"	?	LINE9_230_1625	3100	P 104
8	42° 59' 52.17"	28° 34' 00.09"	170	TURN9B_230_1801	1003	P 138
9	42° 59' 11.16"	28° 33' 03.41"	146	LINE12_230_2021	6390	S 150
10	42° 57' 01.71"	28° 32' 41.51"	177	LINE13_230_2106	5781	P 130
11	42° 56' 16.85"	28° 32' 04.95"	165	LINE13_230_2106	8893	P 124
12	42° 56' 12.54"	28° 31' 52.50"	185	LINE13_230_2106	9636	S / P
13	42° 46' 55.18"	28° 27' 08.63"	180	LINE17_231_0042	2814	P 136
14	42° 48' 59.89"	28° 27' 52.43"	165	LINE17_231_0042	10871	S 185
15	42° 49' 47.68"	28° 27' 54.19"	184	LINE17_231_0136	1734	P 168
16	42° 52' 40.00"	28° 28' 43.47"	151	LINE18_231_0240	387	S Many
17	42° 51' 18.87"	28° 28' 14.91"	172	LINE18_231_0240	4852	P 118
18	42° 46' 40.23"	28° 26' 59.90"	181	LINE18_231_0335	8668	P 137
19	42° 49' 13.32"	28° 27' 15.63"	164	LINE19_231_0427	11752	P 117
20	42° 50' 07.45"	28° 27' 41.76"	168	LINE19_231_0428	2830	S 152
21	42° 50' 24.28"	28° 27' 39.75"	166	LINE19_231_0428	4112	P 104
22	42° 52' 17.05"	28° 28' 03.35"	146	LINE19_231_0428	11740	P 160
23	42° 48' 21.66"	28° 26' 56.91"	149	LINE20_231_0631	2655	P 153
24	43° 23' 35.11"	28° 44' 52.07"	75	TRANSIT_233_1507	8731	S 117
	43° 23' 34.45"	28° 44' 50.75"		STEAMSHIP2_233_1613	6301	P 92
25	43° 23' 33.46"	28° 44' 41.57"	75	LINE22_233_1645	476	P 200
26	43° 22' 22.48"	28° 45' 23.54"	75	LINE22_233_1645	4130	P 233
27	43° 14' 57.64"	28° 38' 53.60"	83	LINE26_234_0433	7309	P 190
28	43° 13' 14.37"	28° 39' 52.83"	84	LINE29_234_1108	3378	P 186
28B	43° 12' 32.65"	28° 37' 31.48"	83	LINE27_234_0730	1468	S 83
29	42° 35' 01.32"	28° 19' 18.75"	93	LINE1_239_1257	11442	P 280
30	42° 25' 07.88"	28° 20' 05.87"	123	LINE2_239_1853	3811	S 227
31	42° 25' 03.35"	28° 20' 25.56"	125	LINE3_239_2212	12045	S 280
32	42° 26' 06.41"	28° 21' 11.89"	118	LINE4_240_0240	3765	P 268
33	42° 28' 06.35"	28° 21' 57.17"	116	LINE5_240_0428	4547	S 204
34	42° 22' 20.90"	28° 21' 58.51"	133	LINE5_240_0429	7047	S 142
35	42° 19' 49.73"	28° 25' 56.47"	160	TURN11_241_0117	1271	S 150
36	42° 20' 55.15"	28° 26' 04.61"	163	LINE12_241_0135	3037	P 83

Table 7.2. Primary sonar targets from 2001 side-scan sonar survey (Bulgarian regions only). In the range column, P=port and S=starboard lobes (channels) of the sonar record.

GRAVITY CORE STATIONS – R/V Akademik

<u>Core</u>	<u>Date</u>	<u>Latitude</u>	<u>Longitude</u>	<u>Depth (m)</u>	<u>Length (cm)</u>	<u>Notes</u>
AB1	8/16/01	43°04.2000'N	028°49.2200'E	1111	110	CTD station to 500m
AB2	8/18/01	42°59.7700'N	028°29.7500'E	84	30	Sediment underlain by rock pavement
AB3	8/18/01	42°59.5400'N	028°33.0700'E	145	133	
AB4	8/19/01	42°52.1000'N	028°29.6000'E	115	153	Echo crashed
AB5	8/22/01	43°06.2600'N	028°39.8900'E	500	130	CTD station to 500 m
AB6	8/22/01	43°05.0636'N	028°41.1673'E	570	162	
AB7	8/22/01	43°06.5900'N	028°39.3600'E	140	160	End of Provadiyska polygon
AB8	8/25/01	44°04.6472'N	030°07.7733'E	90	33	Begin Vitaez Canyon polygon
AB9	8/25/01	44°04.3733'N	030°07.3609'E	85	80	CTD station
AB10	8/25/01	44°02.5900'N	030°12.1206'E	140	74	CTD station
AB11	8/25/01	44°02.0320'N	030°11.6894'E	120	45	CTD station
AB12	8/25/01	44°02.8300'N	030°12.5800'E	115	32	CTD station
AB13	8/25/01	44°00.0987'N	030°16.1837'E	350	350	CTD station
AB14	8/25/01	43°53.2900'N	030°26.4200'E	784	355	Diatomaceous ooze CTD station
AB15	8/26/01	43°51.5329'N	030°20.9826'E	117	240	End of Vitaez Canyon polygon
AB16	8/27/01	43°00.8700'N	029°08.6700'E	1629	235	Begin Cape Emine polygon
AB17	8/27/01	42°40.3513'N	028°20.9182'E	120	270	
AB18	8/27/01	42°40.3596'N	028°19.1361'E	90	100	End of Cape Emine polygon

Table 7.3. Gravity core locations and details from the 2001 Bulgaria/Romania survey.

SUBMERSIBLE DIVE SITES

<u>Dive</u>	<u>Target</u>	<u>Date</u>	<u>Latitude</u>	<u>Longitude</u>	<u>Depth (m)</u>	<u>Identification</u>
1	33	7/29/02	42°28'07.52"	28°21'58.55"	116	Dredge spoil dump site, trawl marks, no primary target found
2	19	7/29/02	42°49'14.06"	28°27'14.70"	164	Trawl marks, ancient mussel shells, no primary target found
3	22	7/30/02	42°52'17.89"	28°28'02.34"	146	Lots of trash found: 2 oil drums, a wire, large plastic garbage bag
4	11	7/30/02	42°56'20.77"	28°32'03.49"	165	Intact shipwreck near anoxic zone
5	3	7/31/02	43°03'53.74"	28°35'30.12"	109	Large fishing net filled with debris
6	28B	8/1/02	43°12'35.01"	28°37'33.36"	83	Large two-masted wooden shipwreck, (possibly Ottoman)
7	28	8/1/02	43°13'17.64"	28°39'53.90"	84	Amphorae pile from ancient shipwreck
8	4	8/2/02	43°02'33.63"	28°33'49.01"	110	Possible wreck covered with fishing net

Table 7.4. Submersible dive locations and target identifications from the 2002 expedition.

Figure 7.1. Map of the Black Sea region. General locations of 1999, 2000, 2001, and 2002 study areas are indicated by black boxes. Outline of the 155 meter isobath is indicated, representing the approximate location of the pre-flood shoreline.

Figure 7.2. Position of the Eurasian Ice Sheet at about 14,500 years BP, relative to the New Euxine Lake, referring to the ancient Black Sea when it was an inland freshwater lake during this time period. Arrows indicate general flow of glacial meltwater and outflow from the lake (Ryan and Pitman, 1998).

Figure 7.3. Ryan and Pitman's (1998) model for the inflow and outflow of the Black Sea and Sea of Marmara prior to and following their proposed flood. Around 14,500 years BP, the New Euxine Lake was at a higher elevation than the Sea of Marmara and Aegean Sea and flowed out only, but through an outlet well east of the present day Bosporus (upper panel). From that time until about 7,600 years BP, the Lake dried up and lowered in elevation, without outflow to the Sea of Marmara (middle panel). The Aegean level rose and inundated the Sea of Marmara during this time, breaching the Bosporus sill. Following the proposed flood, and until the present day, two-way flow persists between all three bodies of water (lower panel).

Figure 7.4. Models representing sea level rise histories for the Black Sea basin. Upper figure after Ross and Degens, 1974. The global sea level rise curve for the last 35,000 years, after Milliman and Emery (1968), shows that once sea level dropped below the sill depth of the Bosphorus, the Black Sea became isolated and its waters freshened. The lake remained isolated until the first marine spillover, about 9,000 years BP, followed by deposition of the marine sapropel unit, and followed most recently by deposition of the coccolithic ooze layer. Lower left figure after Ryan et al. (1997) model proposes a catastrophic flood of the basin around 7,150 years BP that would have rapidly changed the lake into a sea, compared to the gradual inflow model. The Ryan model is also depicted in the adjacent figure, presented as a sea level rise curve. Lower right figure shows a competing model from Görür et al. (2001). Their sea level rise curve (middle) suggests the marine invasion of the Black Sea was more gradual.

Figure 7.5. Archaeological finds from the Varna region of Bulgaria. A large distribution of sites exists surrounding Varna and the Provadiyska River, including the Varna I necropolis (upper figure, Varna Archaeological Museum). This necropolis, from the Varna Lakes region, contained nearly 300 graves, 4 of which contained more than 2,000 gold objects (Renfrew, 1980), many of which have been excavated and put on display in the Varna Museum - Archaeological Institute of the Bulgarian Academy of Sciences (middle left). The gold jewelry recovered from the grave proved to be the oldest processed gold in the world dating to 6800 BP (middle right, Renfrew, 1980). This and other copper tools found in the grave indicated an advanced culture thrived along the shores of the Black Sea in early Chalcolithic times. In addition to these finds, a sample of pottery was found offshore Varna (lower photographs) in the drowned paleo-river valley and recovered using a submersible (P. Dimitrov, 2001, personal communication).

Figure 7.6. Survey region in 1999, off Sinop, Turkey in the southern Black Sea. Refer to Figure 7.1 for location. The 155-meter depth contour represents approximate position of the suspected paleoshoreline, with the observed location highlighted. Side-scan sonar survey tracklines are also depicted.

Figure 7.7. Side-scan sonar tracklines (blue) from the 2000 expedition west of the Sinop peninsula. See Figure 7.1 for location. The region surveyed was between the 90 meter and 160 meter depth contours, on a relatively flat portion of the submerged shelf. Some tracklines explored deeper water. Black box indicates region mapped in Figure 7.10.

Figure 7.8. Survey regions in 2001, off Bulgaria and Romania. Using the *R/V Akademik* out of Varna, Bulgaria, five survey regions (three off Bulgaria and two off Romania) were chosen near where paleo-rivers met the paleoshorelines. Survey regions were also chosen where the Holocene sediment cover was thin. Side-scan sonar and subbottom profiler survey tracklines are depicted in red. Locations of gravity cores are also displayed, chosen where subbottom profiler data had been collected. Small black box indicates location of Figure 7.19.

Figure 7.9. Research tools used during the 1999 expedition to map the paleoshoreline east of Sinop, Turkey. Turkish fishing vessel *Güven* (upper photograph), used to deploy the *DF-1000* side-scan sonar (middle left) and the *Searover* remotely operated vehicle (lower left). Modified bottom dredge used to collect seafloor sediment samples, including cobbles and shells, from the paleoshoreline (lower right).

Figure 7.10. Research tools used during the 2000 expedition to investigate near shore and deep-sea archaeological sites off the coast of Northern Turkey in the southern Black Sea. Research vessel *Northern Horizon* (upper left), which was equipped with a dynamic positioning system for precision navigation and maneuverability during ROV operations, was outfitted with specialized handling equipment (winch, A-frame, and articulating crane). The *DSL-120* deep-towed side-scan sonar and swath bathymetric mapping towfish (upper right) was used to acoustically map and image the seafloor both landward of the paleoshoreline and into the deep anoxic waters. The optical imaging towed, *Argus* (lower left) and ROV *Little Hercules* (lower right) were used to investigate, image, and survey the acoustic targets mapped by the sonar system. Refer to Coleman et al. (2000) and Ballard et al. (2001) for more descriptions.

Figure 7.11. Research tools used during the 2001 and 2002 expeditions to explore the portions of the Bulgarian/Romanian continental shelf in the western Black Sea. The Bulgarian Academy of Sciences Institute of Oceanology research vessel *Akademik* (upper left) was used in 2001 to deploy the side-scan sonar system, *Echo* (upper right), and a gravity corer (middle left). The sediment cores were extracted, split, and described in the ship's lab (middle right). The Bulgarian research submersible *PC-8B* (lower photograph), which was also deployed using the *Akademik*, was used during the 2002 expedition to visually verify acoustic targets on the seafloor.

Figure 7.12. Region identified as “beach location” in Figure 7.2. Lower section is a side-scan sonar image collected across 155-meter depth contour, traveling south to north about 30 km east of Sinop, Turkey. Upper section of figure is vertical section across the paleoshoreline from A – A’ revealing a “typical” beach profile (after Ballard et al., 2000). Dredge locations for cobble and shell samples are depicted in the following figures.

Figure 7.13. Age range (in radiocarbon years BP) of selected mollusk shells collected in a dredge haul along the strike of the Sinop paleoshoreline, seaward of 155-meter depth contour. Total mollusk age ranges from the data in Table 7.1 is represented by the length of each black bar. Freshwater mollusks plot older than 7,460 BP, saltwater mollusks plot younger than 6,820 BP (Ballard et al., 2000).

Figure 7.14. Rounded, poorly-sorted cobbles collected in a dredge haul near the Sinop paleoshoreline, landward of the 155-meter depth contour near the beach berm, as indicated in Figure 7.12 (left). Subset of these cobbles (right) that show a concreting ring around the flat circumference of each indicating they were once welded together (Ballard et al., 2000).

Figure 7.15. Bathymetric contour map for the region indicated in Figure 7.3. The undersea topography represents a slightly undulating landscape cut by lower-elevation paleo-river valleys, representing drainages to the ancient lakeshore. Location of side-scan sonar target #82 is indicated in lower left region near the confluence of two valleys (see Figure 7.17 for more detail). A portion of cross section A-A', as shown in Figure 7.18, is indicated.

Figure 7.16. High-resolution bathymetric contour map for the region immediately surrounding Site 82. The site sits on a topographic high, in approximately 93 meters water depth, and about 5 meters more shallow than the surrounding seafloor. Image processed from the *DSL-120* swath mapping sonar towfish, which was used during the 2000 expedition.

Figure 7.17. Site sketch map of Site 82 revealing the spatial distribution of objects and features that comprise the site, including large amounts of hewn wood, stone blocks that have a worked appearance, and possible subsurface man-made structures. The original unique side-scan sonar target is pictured (with reversed video making strong reflections light-colored). Approximate dimensions of the site are 10 meters by 15 meters. A photograph collected looking vertically down on the site by an underwater electronic still camera is shown revealing some of the wood and stone features on the site.

Figure 7.18. Cross section A-A', location shown in Figure 7.15, from south to north off the Turkish Black Sea coast. The location of "Site 82" is indicated, as well as the projected locations of several shipwrecks that were discovered that revealed variable degrees of preservation. The presence of copious amounts of wood at Site 82 and associated with shipwrecks A, B, and C, indicate varying amounts of preservation due to a temporally fluctuating mixed layer beneath the well-oxygenated surface layer. Shipwreck D was found very well preserved in about 320 meters water depth, where there is no oxygen. The approximate depths of the chemoclines and the positions of modern sea level and ancient lake level are also indicated.

Figure 7.19. Interpretive sketch of the paleo-river Provadiyska where it crossed the shelf and met the paleoshoreline of the Black Sea, about 35 km east of Varna, Bulgaria, where the river presently flows. The location of subbottom profiles for Lines 13 and 19 are shown.

Figure 7.20. Subbottom profile of Line 13 collected parallel to and seaward of the Varna paleoshoreline, roughly perpendicular to the strike of the paleo-river Provadiyska. Individual strata are revealed across the length of the profile, which depicts the hummocky deltaic topography that is presently submerged beneath about 150 meters of water. The strong reflections in the water column and the diffractive lenses within the strata indicate the presence of a large amount of gas deposited beneath the surface and being expelled into the water. Location of the profile is given in Figure 7.19.

Figure 7.21. Subbottom profile of Line 19 and sediment core from the Bulgarian paleoshoreline. Core location indicated in Figure 7.7. The subbottom reflector that represents the pre-flood unconformity pinches out where it meets the present-day seafloor. Horizontal line is noise from an acoustic reflection off the air-sea interface above. The approximate location of Core AB-6 is indicated. A sharp interface between the lacustrine clay below and marine sapropelic mud above is revealed, indicated an abrupt transition from fresh to salt water. Location of the subbottom profile is given in Figure 7.19.

Survey, Site Prediction, and Ocean Exploration

As mentioned earlier, the high costs associated with conducting shipboard oceanography require modification to established archaeological survey guidelines. A significant component of archaeological oceanography is to design a survey that will satisfy at least the minimum archaeological requirements for conducting a complete survey. This will involve doing a great deal of background research prior to the design of the survey in order to optimize the time onboard the survey vessel. This background research must involve predictive archaeology for pre-determining high-probability locations for the discovery of sites. For example, for shipwreck archaeology, the specific locations of trade routes should be understood to the best of one's ability. However, as mentioned previously, during the survey phase, sites outside of the known trade routes should also be searched to prove the non-existence of sites and to more-precisely delineate the trade routes. Also, for prehistoric archaeology, predictive methods and modeling could be used to better constrain the survey parameters. For example, by analyzing bathymetric and other previously collected geophysical data, researchers can interpret where the most likely locations are to explore for inundated prehistoric sites.

The National Oceanic and Atmospheric Administration (NOAA) recently established the new Office of Ocean Exploration. One of the primary scientific objectives is to map previously unexplored regions of the ocean floor to search for new archaeological sites (U.S. Department of Commerce, 2001). With this, the federal government of the United States has invested a great deal into the new field of archaeological oceanography. We can therefore justify a modification of the established archaeological survey methodologies in order to optimize expensive time on scientific research vessels, most of which are funded by the U. S. government, so this is also in the best interest of the funding agencies.

The modification of established archaeological survey guidelines should be determined at a high level by an international organization, with input from both the commercial and academic communities. For example, for exploratory reconnaissance surveys using towed geophysical equipment, coarse trackline spacing may be required in order to cover specific regions in the allotted amount of time. Higher survey speeds may also be required. Both of these modifications can degrade the potential quality of the data that is collected. However, an optimal middle-ground can be established for acquiring the best possible data in the shortest amount of time.

Legal and Ethical Considerations

Many of the state, federal, and international laws pertaining to the protection and management of submerged cultural resources are focused toward shipwrecks (the Abandoned Shipwreck Act of 1987, for example). If the submerged cultural resource is a prehistoric site of human occupation, then the resource should be viewed in a much different manner than if the submerged cultural resource is a shipwreck. The obvious reason for this is that a shipwreck is a single, isolated, semi-contained resource (if the debris field is small), whereas an inundated dwelling that may appear as a single, isolated resource could be, and probably is, adjacent to other similar sites. Therefore this resource would require a more extensive site survey and management plan. The National Historic Preservation Act contains provisions for the protection of submerged cultural resources, particularly for the safeguarding of resources on the outer continental shelf from hydrocarbon and mineral exploitation. However, with the deep sea now made accessible by advances in oceanographic technology, underwater archaeology can be conducted outside of exclusive economic zones and sovereign boundaries of nations. This opens up a new suite of legal and ethical issues for underwater archaeology of the deep sea.

Archaeological oceanography, being a legitimate scientific discipline, should operate under a scientific code of ethics for the proper protection, preservation, and possible excavation of submerged cultural resources. Archaeological sites that exist today under water may or may not be naturally protected and preserved. If the sites are in a poor state of preservation and a consensus is reached that the resource should be protected, then this could justify site excavation. If the sites are in a high state of preservation, then perhaps they are best left that way. However, in order to properly manage the resource, the sites need to be investigated, and this may require the use of intrusive techniques.

Oceanographic technology can be made accessible to salvagers, who often have the financial resources to acquire the tools necessary for the recovery of objects in the ocean. This raises more legal and ethical issues, and it is unclear whether or not newly accepted international laws (such as those put forward by the UNESCO convention on the protection of underwater cultural heritage) will help to protect underwater archaeological sites (Mather and Watts, 2002).

For the future of archaeological oceanography to be successful, a solid plan for the protection and preservation of submerged cultural resources must be developed. Once sites have been discovered and documented, professional archaeologists and oceanographers can decide the best course of action. If it is determined that a site will only be further degraded by natural processes, or that the site is at risk of being damaged by looters, then this may involve the material excavation of the site, with an appropriate conservation and management plan for the artifacts. Otherwise, the best course of action may be the *in situ* preservation of the site. After all, ancient sites have been situated in their current location for up to many thousands of years, and can certainly survive longer, within limits of course.

The Future

Advances in oceanographic technology during the past several decades have led to enormous advances in our capability for conducting research in the deep sea. Given this rate of advancement, it is conceivable that deep-sea archaeological sites could be properly and completely excavated in the future, to rigid archaeological standards. It is also conceivable that advances in acoustic technology could one day permit very high-resolution imaging of buried sites. Advances in medical technology surpass advances in oceanographic technology. High-resolution acoustic, magnetic, and visual imaging techniques developed for medical industries could one day be applied to underwater archaeology, and sites could one day be documented and excavated by relying on the advanced technology in the same manner that surgeons rely on advanced technologies during complicated surgical procedures.

Given this, it could be argued that deep-sea archaeological sites should not be disturbed until significant technological and methodological advancements are made. These future advancements could help future researchers in the field of archaeological oceanography conduct better science. Until then, researchers need to focus on unobtrusive surveys and detailed investigations of submerged archaeological sites, with a very limited amount of destructive subsurface sampling to better understand and document sites.

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