COMPUTERS AND NAUTICAL ARCHAEOLOGY:

CHARACTERIZATION OF THE C. S. S. GEORGIA WRECK SITE

A Thesis
by
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ABSTRACT

Computers and Nautical Archaeology: Characterization of the C.S.S. Georgia Wreck Site. (December 1982)

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In December 1979, Texas A&M University began a series of investigations for the U.S. Army Corps of Engineers, Savannah District, to investigate, characterize, and make recommendations regarding the wreck site of a Civil War period Confederate ironclad vessel, the C.S.S. GEORGIA. The survey proved to be difficult, since visibility in the Savannah River around the sunken vessel is zero. In addition, the wreckage extending above the sediments is comprised of bent and twisted railroad rails and rusted pieces of casemate which once formed her iron shell. A nine-foot tide fall, coupled with a current velocity up to 5.1 feet per second, makes diving on the tangled wreckage dangerous and difficult. Thus, only during high and low slack tides can divers grope over the parts of the ship which protude from the river sediments. Even this is practicable for less than two hours per day.
A study of the history of the C.S.S. GEORGIA left many questions unanswered, such as her length and breadth. In order to provide accurate information and a meaningful site assessment, a series of remote-sensing surveys of the shipwreck and the surrounding area was initiated. Among the techniques employed were side-scan sonar, magnetometry, and bathymetry. During the course of this work, thousands of readings were taken. Records of these data required processing and graphic presentation in order to offer meaningful insights into the nature of the wreck site. Subsequently, a decision was made assigning computers a major role in this work. The development and use of computer-graphic techniques served to image large data bases in formats more easily understood.

A review of the literature relevant to computers, computer graphics, and computers in terrestrial, and nautical archaeology revealed that programs did exist to do this type of work, but they would require modification to suit our purposes.
DEDICATION

This thesis is dedicated to Sant Ajaib Singh, the desert mystic. He teaches by example the knowledge of the ages. His has been the greatest impact upon my life, making this work and all I might do possible.
ACKNOWLEDGEMENTS

The GEORGIA Project has been the responsibility of Dr. Ervan G. Garrison. As Principal Investigator for the Corps of Engineers, Savannah District, he has been responsible for the development of a site characterization. It was at his suggestion that computer-graphics techniques were employed. Dr. Garrison has provided support and encouragement during this work. His guidance and counsel coupled with his intellectual curiosity have made this project as educational as it was challenging.

From the moment Dr. Garrison assigned to me responsibility for the computer work on the GEORGIA Project, a number of people assisted my efforts. Dr. John Demel directed me to Dr. Douglas Green of Texas A&M's Electrical Engineering department. Dr. Green and his students, Steve Hyde and Larry Chrisman, produced the first three-dimensional graphics for this project. Dr. Sid Theis of TAMU's Remote Sensing department adapted and developed the programs to produce the first contour maps of the GEORGIA data. Mr. Wally Snell, also of Remote Sensing, provided facilities for doing much of the hand drafting. Dr. Tom Parker and his student in Environmental Design, Greg Houston, produced the first grey tone contour maps.

Personnel of the TAMU Data Processing Center have been particularly helpful and patient. With their aid, this neophyte found his way
through a maze of computers and computer graphics. Special acknowledgments must be made to Roger Sorrells, who has led me out of many dead ends. The mysteries of SCRIPT and of SYSPUB, the text editing systems used to format this thesis, were passed to me by Dr. Michael Quick and Blair Brenner. Dr. Quick also taught me how to use the Versatec plotter, which was used to produce most of the graphics in this document. Thomas Reid should be mentioned for his thorough understanding of the graphics programs supported by the Data Processing Center. Terry Humphreys enlivened the wee hours with his wit and provided answers insuring that the dawn would bring with it the desired computer graphic. Without his kindness many an all night session would have ended as an exercise in futility.

Those who participated on the GEORGIA Project helped to produce the data base used in this thesis. They include Jim Tribble, Ed Baxter, Jim Duff, Jody Simmons, Jay Rosloff, Michala Perreault, Dr. Lee Lowery Jr., Dr. Harry Jones, Dr. Charles Giammona, Dale Greenwell, Shelley Ruby Lang, Robert Holcombe, Thomas Yourke, Alan May, and Dr. Ervan Garrison.

Dr. Roy Hann, Head of the Environmental Engineering Division of Civil Engineering, and Dr. Donald McDonald, Civil Engineering Department Head, have provided a working environment which encourages productive research and have thereby facilitated the work on the GEORGIA Project. Alan Montgomery, formerly with Environmental Engineering, also added his computer expertise and assistance.
The U.S. Army Corps of Engineers, Savannah District, contracted the research on the wreck site of the GEORGIA, and a number of Corps personnel deserve mention. Chief among these is Colonel Tilford C. Creel, who through his commitment to the preservation of the C.S.S. GEORGIA has been a fine example of a public servant protecting his charge for the public weal today and tomorrow. Richard J. Anuskiewicz, Corps Archaeologist, has assisted in every way he could and participated fully in gathering data in the field and in interpreting the results. Particular thanks must go to Captain Bill Sikes of the survey vessel CARLSON and to Dick Bell, who operates the onboard computerized survey system. Their kindness and knowledge insured that the bathymetric data base was reliable.

Mr. J. Richard Steffy has graciously given of his time in going over the idea of such a project and encouraging me to pursue it. Dr. Frederick H. van Doorninck, Jr., my committee chairman, has borne the duties of that office well, offering constructive criticism which improved the quality of this thesis. Dr. Doug Green's innovative and creative program in computer graphics within the Electrical Engineering Department inspired and aided this work.

Ray Leighman's editorial efforts resulted in a major restructuring of the text that greatly improved the format. His generous labors are appreciated. Jess Simmons edited the manuscript and proof read it, but any errors or omissions are mine alone.

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The one person who has been the greatest help, without whom I would not have been able to produce this thesis, is my beloved wife, Bobbe. She has been a companion, helper, critic, encourager, and contributor. Her sacrifices have been great and are deeply appreciated.
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CHAPTER I
INTRODUCTION

Background -- The C.S.S. GEORGIA Project

Beginning in the 1960's, legislation was passed in this country requiring that America's archaeological and historic sites and monuments be protected and treated as valuable resources by federal agencies and managers, whose decisions often determined the future of those sites (McGimsey and Davis 1977:8-24; Advisory Council on Historic Preservation 1980:5-15). These locales have come to be regarded as cultural resources. Before major land modification projects can be undertaken, planners must evaluate the sites likely to be impacted and take steps to preserve, avoid, or excavate them (McGimsey and Davis 1977:46-48). The assessment of the cultural resources of an area requires a survey of the zone where the work is to be done. On land, this can be a fairly simple procedure involving walking over the terrain in a systematic fashion and recording the sites and historic features encountered.

However, for sites lying under the water, the archaeologist's problems can be considerable. He has all the difficulties of site location encountered by surveyors of forested regions; in addition, he has the much greater difficulty of determining the nature and extent of the

This thesis follows the style and format of American Antiquity.
archaeological site underwater.

Location of a sunken ship forms only part of the process. Archival research both precedes and follows the survey as the archaeologists seek to identify the wreck and evaluate its importance. Diving often will reveal important evidence regarding the age of the ship, her cargo, national origin, or architecture. Sometimes the water is clear enough to allow a visual inspection of the site, but more often visibility in rivers is poor. Currents and bad visibility combine to make diving dangerous and visual survey impossible.

Despite such difficulties, preliminary surveys and site characterizations are essential parts of the archaeological process. Muckelroy (1980:16) has put it well:

Once an archaeologist has identified a site and decided to study it, his first task is to undertake a pre-disturbance survey. His aim is to make an exact record of the surface appearance of the site before removing anything. This should reveal the extent and significance of the remains and help the archaeologist to decide how best to tackle them.

Throughout history, indeed even in prehistory, commerce (as well as water) flowed in the rivers of the United States. Today hundreds of wrecks are testimony to the courage and enterprise of early navigators. These wrecks are each a capsule of the era from which they date. Some are pivotal pieces of the story of how America was settled and grew.

Each year the U.S. Army Corps of Engineers oversees the dredging of thousands of miles of waterways. In order to avoid the accidental destruction of shipwreck remains, the Corps commissions surveys to be
made of areas they are about to dredge. These surveys serve two functions: the location of the cultural resource, and the prevention of a collision between the dredge head and a submerged vessel.

Prior to the passage of legislation requiring such surveys, a Civil War ironclad wreck was struck by a dredge operating under contract with the Corps of Engineers in the Savannah River. The dredge head was severely damaged by the vessel's iron casemate and railroad rail cladding. Studies of the ironclad were initiated under the Corps' supervision and sponsorship. The exact position of the vessel was to be determined, and a pre-disturbance site survey and characterization was to be carried out. The vessel was identified as the C.S.S. GEORGIA.

Construction of the Ironclad

Among the more important wrecks to be found in the North American waters are those from the period of the War Between the States. Few sea battles have lead to a complete change in naval strategy, but no warship constructed after the meeting of the MONITOR and the VIRGINIA at Hampton Roads was unaffected by the outcome; the ironclad VIRGINIA devastated the wooden ships in the Union fleet. Naval authorities in the Confederacy made a major commitment to the construction of ironclad vessels as their only hope of overcoming the superiority of the United States Navy. Their strategy consisted of two considerations which were well expressed by Stephen R. Mallory, Confederate Secretary of the Navy. He wrote to President Davis in August of 1862 (ORN Series II, Vol.II:152):
The judgements of naval men and of other experts in naval construction have ... been consulted and ... it is believed that (our policy) will enable us, with a small number of vessels comparatively, to keep our waters free from the enemy and ultimately to contest with them the possession of his own.

The responsibility for financing the ships which were to defend the rivers and harbors of the South often rested with the seaport or the state to be defended.

Hastily constructed, these vessels often are poorly documented even though they were built well within the period of written history. War has a way of cutting short the recording process and of destroying the extant records. Consequently, one of the most dynamic and innovative periods of American shipbuilding is the source of many unanswered questions. Some of the Union vessels are well known from photographs, drawings, and designer's plans. Southern vessels often lack such documentation. Such was the case with the Confederate States' Steamer GEORGIA. (There was another C.S.S. GEORGIA, a cruiser similar to the ALABAMA. In this thesis C.S.S. GEORGIA will refer to the ironclad.)

Little is known about architectural details of the C.S.S. GEORGIA, for no plans, no photographs, nor any models of her have been found. However, from contemporary accounts and drawings (Nordoff 1863), a general picture of her construction can be sketched. She was built in the city of Savannah, with funds raised by the Ladies Gunboat Association and monies appropriated by the Georgia state government. Work began on the vessel early in 1862, or possibly late 1861, and was completed by mid-1862 (Wells 1971:103).
The overall shape of the VIRGINIA was followed for the ironclad's upper structure. Below the waterline she was more flat bottomed and reputed to lack a keel. At some point during her construction, a decision was made to make her into a floating battery rather than a ram. The reason stems from the inability of her engines to provide sufficient propulsion to such a mass of heavy timbering and iron in a strong tidal river like the Savannah. Figure 1 shows an artist's conception of the way the GEORGIA might have looked.

The South's iron industry lacked the capacity to produce and transport armor plate on the scale required by the shipbuilding program. However, facilities did exist to turn out railroad rails. Rebel ingenuity and a great need led to the use of rails as the armor cladding for the GEORGIA. These rails ran from top to bottom down her sloping sides, perpendicular to the waterline. They were made to fit tightly by setting every other one upside-down, so that the thick head of the second rail lodged snugly under the heads of the first and third rails. This interlocking pattern of rails was then fixed to the siding with long iron spikes. Where rails were not used, iron casemate provided the necessary protection. Such an arrangement was not unique; even the Union gunboat CAIRO, recovered from the Yazoo river in the 1960's, utilized railroad rails to supplement her casemate (McGrath and Ashley 1981:39).

Wood samples recently raised from the GEORGIA are a variety of southern pine (Garrison et al. 1980:106). It is possible that other woods were used, but records surviving from the period offer no clue.
Figure 1. Artist's conception of the C.S.S. GEORGIA.
References to the vessel's dimensions are contradictory. Her length is reported as 150 (Scott 1862, Turner 1862), 250 (Shomette 1973:282) and 260 feet (Still 1971:87; Melton 1968:178). Reported widths vary from a width of 50 feet to a width of 60 feet. Many details of her construction must await her excavation.

Area of Operation

Following her launching, the GEORGIA operated in the area from the mouth of the Savannah River to the Savannah city harbor. Much of her life was spent moored opposite Fort Jackson, just downstream from the city. Figure 2 shows these locations. Her underpowered engines prevented her from taking part in coastal action, but her large size made her an adequate floating battery protecting the approaches from the sea to the city of Savannah. She served as a meeting place for the commanders of the other vessels in the Savannah Defense Squadron. Her position became so permanent that the cannon were removed from one side and placed in Fort Jackson. Sitting just above Elba Island, she served as a barrier to the Union penetration of Savannah. So, while the GEORGIA could not move up and down river rapidly and could not prevent the Union control of the mouth, at least she prevented the enemy from moving up the river to threaten Savannah.

Her Demise

The GEORGIA's insufficient engines did not prevent her from being useful during the defense of the city of Savannah from seaborne attack.
Figure 2. Vicinity and locality maps of the C.S.S. GEORGIA wreck site.
However, her inability to maneuver ultimately mandated the vessel's destruction at the hands of her own crew.

In December of 1864, Sherman's troops had completed their march to the sea and had turned north to block General Lee's southern flank. Savannah came under siege. The GEORGIA steamed upstream to provide support for the army in and around Savannah. Her underpowered engines struggled against the current, but her slow rate of travel made it apparent that she could neither aid in the defense of the city of Savannah nor escape past the Union gunboats waiting downstream. On December 20, 1864, she had moved to a spot in the center of the river in front of Fort Jackson. There her officers and crew, numbering 122 men, scuttled her at anchor to prevent the Union from capturing the huge vessel and her guns (See site map, Figure 3). A few days later, General Sherman sent President Lincoln news of Savannah's capitulation. As a Christmas present to Lincoln, the city was spared the torch which so many other southern cities had felt as Sherman passed through them.

History Since the Civil War

After the close of the war, efforts were made to remove the remnants of the GEORGIA. The superstructure was blasted with dynamite. Of her original 500 to 700 tons of iron, about 80 tons were salvaged (Report of the Chief of Engineers 1872:655-659). Then, for some unknown reason, salvage was abandoned. Her whereabouts was forgotten until a dredge struck her in 1968. U.S. Navy divers investigated and reported that the superstructure was collapsed but the hull was still largely intact.
Figure 3. Wreck site of the C.S.S. GEORGIA.
During the years between 1968 and 1978 the wreck was damaged by dredging. The vessel lies along the northern edge of the dredged channel. A dredged branch off the main shipping channel was cut over the upstream end of the wreck. Portions of the wreck abutting this dredging activity were damaged.

Systematic study of the vessel began when U.S. Army Corps of Engineers' archaeologist Richard J. Auneskiewicz and Corps' marine biologist Tom Yourke dived on the site. They presented their findings at the 1979 Conference on Underwater Archaeology. Alan Albright and Ralph Wilbanks of the University of South Carolina examined the structure in 1978 and recorded what they could on underwater video.

Protected as it is by a mantle of silts, the GEORGIA might well be left to archaeologists in the future. However, nearby dredging and plans for the expansion of Savannah harbor bring with them threats to the stability of the environment surrounding the wreck. The exact nature of those threats and the degree of the GEORGIA's preservation had to be determined to assist in planning for development of the harbor.

"Why bother with such a wreck?" is a question asked by many. The answer lies in the fact that here we have a vessel which promises to contain a well-preserved cross-section of life in the Confederate States' Navy. Artifacts and wood raised from the site show no evidence of a fire, which is mentioned by some writers (Melton 1968:178) as the primary means used for her destruction. In the haste of battle there was little time to remove personal belongings, tools, provisions, and weapons. Commander Hunter directed that her guns be spiked and she be
scuttled if Savannah should fall (ORN Series I, Vol.XVI:482). When her crew left they would have to be travelling light in order to avoid the Union forces which were present in the area. Although we have not located an account of her sinking, it is possible to extrapolate from the accounts of the SAVANNAH's crew. "Nothing was saved except what was carried about the person, and no transportation could be obtained from the army except a wagon to carry the sick, who could not march." (ORN Series I, Vol.XVI:484)

Diver survey indicates the GEORGIA was not burned. Early salvage attempts recovered only a small portion of her iron. These attempts blasted part of the wreck but such blasts are attenuated under water and would not have effected much of the surrounding material and structure. Dredging has impacted the upstream end of the wreck, perhaps as much as 50 feet of the vessel's length has received some damage. As we shall see later, despite such assaults, significant portions of her structure remain.

This may well be one of a very few fairly intact hulls of Southern ironclads to have survived. The NUESE and the JACKSON were raised during the 1960's. No controlled excavation of them occured. The unhappy result was that little was learned about shipboard life. Such ironclad vessels represent experiments in naval architecture which sped the change from wooden-hulled sailing ships to the steam-driven, steel-hulled warship. Despite the relative closeness of their time to ours, many Southern ironclads are ill-understood, and little is known of the details of their construction. Thus, the C.S.S. GEORGIA may provide
scholars and the public with a window through which to view a poorly recorded page of our past.

Circumstances have arisen which may well provide a funding base and the necessity to excavate and remove the GEORGIA. Should harbor widening be undertaken, an opportunity will present itself to apply the lessons learned from the CAIRO, JACKSON, NEUSE, and from the rapidly evolving field of nautical archaeology, to the careful and controlled study of the GEORGIA. As part of planning for expansion of Savannah's harbor, the United States Corps of Engineers initiated a series of studies to delineate the wreck site of the C.S.S. GEORGIA and to characterize the environment surrounding it. In 1979, Texas A&M University's Cultural Resource Laboratory contracted with the Corps of Engineers to perform this characterization.

Conditions at the Wreck Site

The environment of the wreck is determined by the Savannah river. The sediment load is so heavy that visibility is zero only a few feet under the water's surface. At the wreck site, there is no light penetration. Divers feel their way over the wreckage as if they were totally blind. This poor visibility, combined with problems caused by the currents and tides, required that remote sensing play a large role in the site survey.

A ten foot tide fall combines with the current to produce velocities in excess of five feet per second. Such currents make it impossible for a diver to move freely and restrict diving to periods of slack
tide. The dive windows of slack tide allow only a hour or two of work per day. A large buoy marks the site, and its chain provides divers a route to the site below. Lines were connected to the buoy's concrete anchor and used to construct a grid over the site and to encompass its perimeter.

Further complicating diving is the fact that the GEORGIA was clad with railroad rails and iron casemate. Today, after early salvage attempts and hits by dredges, the site resembles a junk yard with jagged twisted metal projecting above the bottom silt. Such debris threatens to entangle the unwary diver and make it impossible to visit the site safely once the current begins to move rapidly.

Even during the short times of slack tide, diving is not without problems. An average of 15 to 20 vessels move up the Savannah ship channel each day. These produce waves up to 5.2 feet high with a period of four seconds. This ship traffic disrupts diving activity and poses the danger of collision for support vessels.

**Dredge Activities:** In order to maintain the ship channel, periodic dredging is performed in the river. This dredging has impacted the wreck site of the GEORGIA along its south side and western end. In fact, the GEORGIA now protrudes from the north side of the channel and lies on the eastern side of the intersection of the Back River channel and the main Savannah River channel. The Back River channel at one time cut over the upstream end of the ship, but dredging of this channel now has been redirected to run west of the wreck to avoid further damage. The old and the current channel locations are seen in Figure 3 (p. 10).
Site Dynamics: Currents, tides, ship traffic, dredging, and the sedimentation all combine to make the site a dynamic and changing environment. Removal of sediments from the south side by dredging, combined with the scouring effects of the currents, has undercut the wreckage along the channel. How the remains of the vessel were being effected by site dynamics was poorly understood.

Survey Techniques

Diver Survey: Survey of the site by traditional underwater techniques is impossible. These techniques were evolved during work in the much clearer waters of the Mediterranean. Such techniques as photogrammetry cannot be employed at all. Even simple methods requiring a tape measure are useless when one cannot read the tape. The heavy sediment load of the river results in rapid deposition of silts that can quickly bury base lines. Divers can do little more than swim over the wreck and feel their way about, making mental notes of features as they encounter them.

It was possible, however, to establish a rough perimeter of the site by having divers feel their way around the site and send up buoys at intervals. These buoys were then shot in from transits located atop monuments on the river banks, and their locations were plotted on a map.

This method had a number of drawbacks. Only the wreckage which lay above the bottom could be located. The divers were placed in danger, operating at a depth of 30 to 40 feet in total blackness, unable to
even read their gauges; contact with diving partners had to be by touch. Because of currents, the buoys might not be directly over the divers, Buoys were released as divers encountered intact superstructure and other significant features. Surveyors using transits located the buoys for later mapping, causing points on the wreck to be inaccurately located on the map.

Artifacts belonging to the Georgia were recovered from the channel area outside the hull. It is thought that dredge damage to the upstream end of the ship may have caused the displacement of these artifacts, which included glass bottles, a pair of shackles, an adze, and a number of projectiles. Two pieces of ceramics were found on the wreck. The locations of artifacts were recorded by shore-based transits sighting to diver released buoys, as the perimeter and features had been surveyed. Collection of artifacts was strictly limited because of the impossibility of obtaining accurate provenience and the difficulty of conserving a larger sample of artifacts.

Probe Survey: Because of the difficulties detailed above, it was recommended that the site be enclosed within a sheet-pile cofferdam. This would still the currents and tides, improve visibility, and allow divers to work in a safer environment. Water would be left in the dam, and water levels would be kept nearly the same, inside and outside the structure, by a series of openings in the walls. In an effort to determine that the wreck lay within the area proposed to be impounded by a cofferdam, a series of probes was made along the perimeter of the proposed cofferdam. Buoys were set at the four corners of the proposed
area by triangulation from shore stations. A 60-foot length of one-inch diameter pipe, with air jetting through it, served as a probe. A barge was used as a platform for the probing. The pipe was raised and lowered manually with the aid of a pulley mounted on the barge's A-frame. The initial part of the survey was during slack tide, but as the survey progressed the current picked up. It finally bent the probe as the last side of the proposed cofferdam perimeter was being probed.

While the surveys described above yielded much valuable information about the site, they did not provide an integrated site characterization. The descriptions by divers were similar to those of the blind men describing the elephant. More extensive diving operations were not possible due to the expense and danger involved. Another way had to be found to complete the site characterization. Remote-sensing technology offered a way to overcome these problems. A variety of sensing surveys utilizing a variety of instruments were used to provide information about the site.

**Side-scan Sonar Survey:** A side-scan sonar survey was conducted over the site, in 1979. Dr. Jim Henry, of the University of Georgia's Skidaway Institute in Savannah, conducted a survey using an EG&G 100 kilohertz side-scan system. One of the sonargraphs from that survey is particularly striking. The sonar image is a view as it would appear looking southward from the South Carolina side. The dredged channel of the Back River enters from right; the main channel lies beyond the wreck. Downstream is to the left. On the original, the high relief appears dark and the shadows are light. By reversing the shades, an
image is obtained which looks more familiar, with shadows dark and the higher relief light. Figure 4 is an example of a negative printing of the sonargraph.

**Bathymetric Survey:** The strong currents and the large size of the area to be covered precluded the possibility that a thorough survey of the bottom terrain could be affected by probing. The lack of visibility required that some way be found to understand the bottom topography and to monitor its change through time. Five bathymetric surveys were conducted over a span of three years in an attempt to learn more about the bottom terrain and processes at the wreck site.

**Magnetometer Survey:** Proton magnetometers have proven to be effective devices for the locating of historic shipwrecks (Breiner and MacNaughton 1965; Clausen 1966; Hall 1966; Green, Hall, and Katzev 1967; Green 1970; Breiner 1973; Arnold 1974; Arnold and Clausen 1975a and b; Breiner 1975; Arnold 1976; Lenihan 1974; Clausen and Arnold 1976; Garrison and Lowery 1980; Murphy 1980). Magnetometer survey, whereby ferrous materials on wreck sites are detected, constituted another form of remote-sensing survey utilized in the work on the GEORGIA. Two surveys were conducted — an initial survey of a somewhat limited scope and a follow-up survey of a more extensive and definitive scope. These surveys also produced an array of digital data requiring display in a fashion which communicated the information contained within the data base.

With so much data from such a variety of sources, it was decided that there was a need to set up the project so that computers would
Figure 4. Side-scan sonar image of C.S.S. GEORGIA wreck site.
play a major role in the storage, processing, and imaging of the information. This effort represented an expanded use of computer technology in nautical archaeology. Computer graphics have been applied to the imaging of magnetometer data (Breiner and Coe 1972; Arnold 1974; Weymouth 1976; Weymouth and Nickel 1977; Frankel 1980); however, the systematic use of computers in all aspects of the project was unique at that time. A review of the application of computer technology to archaeology will be helpful in understanding the tremendous advantages and applicability of this tool.

Background — Computers and Archaeology

Recent years have seen a dramatic increase of the use of computers in archaeology, because new advances in technology have made small, powerful computers available and affordable. As archaeology moves toward becoming a more quantitative discipline, computer work offers a way to deal with masses of numbers. All facets of our society are embracing computer technology as a tool for solving problems.

W. W. Taylor (1948) gave a stimulus to the development of new methodologies in archaeology. He recommended that mathematical quantification be employed to bring more objectivity into the field and to move the discipline in a more scientific direction. His admonitions were taken seriously by A. C. Spaulding, who devoted much of his career to developing the applications of statistics in archaeology. It is notable that in his 1953 article, "Statistical Techniques for the Discovery of Artifact Types," Spaulding makes no mention of the computer as a
possible aid to perform the complex manipulations he was recommending. Computers were still in their infancy, requiring an extensive knowledge of machine language unavailable to the average archaeologist. In fact, a review of the literature relevant to computers in archaeology reveals that archaeologists did not utilize the first generation of computers to any significant degree.

Computers are said to pass through successive generations, each new generation being considerably advanced over the previous one. With the arrival of the second generation, 1950-65, came simpler languages, easier access to the machines, cheaper computer time, and clearer applications.

An inspection of Doran and Hodson's bibliography from Mathematics and Computers in Archaeology (1975:349-370) reveals some interesting details. Of the publications listed in that bibliography, fewer than thirty of those written before 1965, judging by their titles, involved the use of computers. This number doubles for those written between 1965 and 1970; and for those written between 1970 and 1975, there are twice the number of computer-related articles there were between 1965-1970. This indicates that although computers were beginning to become available during their second generation, usage of them by archaeologists was restricted to a few experimental efforts. By the third generation of computers, statistical methods were finding acceptance in the discipline of archaeology.

The complex computations required by such techniques were easily handled by the more powerful machines. Costs had continued to go down
and prepackaged programs like the Statistical Packages for the Social Sciences, SPSS (Nie et al. 1975) relieved the archaeologist from the need of also having to be a statistician and a computer programmer. Those prepackaged routines could be called up, the data plugged in, and the results analyzed.

By the second generation, few major universities were without computers, and by the third, none were without them. Quantification had become the next best thing to publication for the attainment of academic kudos. Early applications had been fairly straightforward and included such techniques as chronological ordering of artifacts, matrix analysis, and taxonomic considerations, as well as basic statistical applications such as chi square and others advocated by Spaulding.

During the third generation, 1965 to 1970, the computing machine became a standard research tool in the tool kits of many archaeologists (Chenall 1967; Cowgill 1967, 1968a, 1968b; Tugby 1965, 1969; Doran 1969; Rogers 1969). Many regarded it as an all purpose tool, good for everything from seriation studies, multivariate analysis, classification, factor analysis, correlation studies, and model testing to simulation, and even, perhaps, buttering one's toast. Conferences on computers in archaeology were held and books were written dealing with this subject (Gardin 1969). Binford and others actively employed quantitative techniques, finding the calculating machine to be well suited to their needs (Binford and Binford 1968). The first articles on potential abuses of computerized statistical methods appeared (Brothwell 1969).
By 1970, statistics had become firmly established as a part of the methodology of anthropological inquiry (Pelto 1970), and computers were often the tool chosen to assist in the statistical work. The computer continued its incredible development, and the use of it in our field increased as the fourth generation of computer technology burst upon the world.

Particular areas of archaeology are quite suited to the use of this tool. Cataloging of artifacts (Hodson 1969; Doran 1971; Hodson et al. 1971; Whallon 1971), graphic portrayal of data (Arnold and Clausen 1975a; Arnold 1974 and 1982; Kaplan and Coe 1976; Frankel 1980; Upham 1979), and statistical manipulation of numerical information (Cowgill 1967, 1968a, 1968b; Binford and Binford 1968; Pelto 1970; Hodson et al. 1971) are just a few of the operations which can be carried out with relative ease.

A stroll through the halls of academia today will produce more views of earnest scholars plying keyboards and staring into computer terminals than vistas of ivory towers. A tiny chip, which few of us have seen, and even fewer of us understand, has delivered the promises made for machine intelligence to the doorstep of anyone who really wants to use such artificial brain power. The computer has arrived. The applications to archaeology have broadened considerably. From the first pioneering efforts to take the computer into the field (Gaines 1971, 1973, 1974; Wilson 1975:213), we are to a place where mapping and recording of artifacts are done on a microprocessor located on a barge moored over the wreck of Henry VIII's flagship, the MARY ROSE (Margaret
Rule 1981, personal communication). Field notes are recorded on Apple computers, along with the financial records, artifact inventories, materials and supplies inventories, records of photographs taken, schedules, and even video games to entertain during off hours. Text editing systems, such as the one used to compile this report (University of Waterloo 1979, 1980), have taken some of the drudgery out of the rewriting process. Gaines and Gaines (1980) have provided an excellent summary of the potentials and problems offered by computer technology today and tomorrow.

The literature now abounds with computer-related articles. Increasingly, sophisticated statistical routines are applied as the cost of time for processing millions of numbers has continued to decline. Cluster analysis, numerical taxonomy, distance and similarity measurements, sampling and reliability tests, and a myriad of more opaque techniques are discussed, employed, and abused (Thomas 1976 and 1978). The potential of the mass memory is being used to create data banks which allow instantaneous access to a wealth of information (Scholtz and Chenhall 1976). In England, a semi-standardized artifact recording form has been developed and is in use in many of the excavations there (Wilcock 1981:100-122). This standard form is also used at the excavations of the MARY ROSE, although it has been modified to suit the needs of a shipwreck, as opposed to a land-site, excavation. Le Blanc (1976) has discussed some of the considerations needed to make recording and classification systems computer compatible. These include the use of only those symbols found on a standard keyboard, thus assuring that ar-
tifact and feature labels can be inputted into the computer in a form identical to that in which they are recorded on the artifact or in field notes.

With the advent of microcomputers and minicomputers, it has become practicable to input data for the artifacts and to create the artifact file while in the field and store that record on cassette tape or on floppy disks (Gaines 1971, 1973, 1974, 1981:80-90). In nautical archaeology, most artifacts begin a long route through the conservation process after excavation. The computer offers an excellent way to track the path of artifacts through this process. At the MARY ROSE excavation, this information was maintained in a series of interrelating notebooks, but plans were being made to record all data relating to the processing and conservation of finds onto computer files. In anticipation of this, computer-compatible cards were used in all documentation. A similar system was proposed to the Corps of Engineers, Savannah District for use in the GEORGIA.

Increasingly, the recording method used in nautical archaeological surveys and in hydrographic surveys involves using a shipboard minicomputer to integrate the data produced by a suite of instruments (Arnold 1975; Murphy 1980). The computer synchronously records readings from a magnetometer, a fathometer, and a position fixing system such as Loran-C or a microwave positioning system. The minicomputer records the data on cassette tape for later processing at the main computer facility. It also produces printed copy as a back-up and to allow assessment of the data as the survey is being run. Some shipboard systems have enough me-
mory capacity to process and plot data as they are collected aboard the survey vessel.

Computer graphics produce quality maps and illustrations which are reliable, replicable, verifiable, and cost much less than similar products produced by artists (Kaplan and Coe 1976).

Computer-graphic techniques offer visual display of data for ease of interpretation (Upham 1979). In recent years a number of three-dimensional plotting routines have been developed and are now generally available (Nagy 1971; Laboratory for Computer Graphics and Spatial Analysis 1971; Hartig 1973; Smith and Pao 1973; Hanson 1980; Reid 1980; SAS Institute 1981). Along with the development of the basic mapping packages have come routines to label and provide legends for the graphics (Laboratory for Computer Graphics 1971; Smith and Pao 1973; Versatec 1978; Hanson 1980; Reid 1980; SAS Institute 1981). Computer technology has so much new to offer; it is not surprising that the archaeologists' applications of these innovations lag far behind the potential.

After reviewing the literature pertinent to the GEORGIA and to computer applications in archaeology, two things were clear. First, there were many unanswered questions regarding the vessel and her environment that would have to be answered. Second, although some of the techniques and methodologies necessary to obtain such information did exist, others would have to be designed and developed. Even those technologies which existed would have to be adapted to the needs of the GEORGIA Project and to the facilities available at Texas A&M University.
The literature on quantification and computers in archaeology provided a basis for the further development of computer-assisted quantitative methodologies. The literature on nautical survey pointed the way to proceed, which was clearly to involve applications of computers and computer graphics as a tool to image information gathered by divers and instruments in a hostile environment.

Illustrating the possible applications of computers to the field of archaeology, particularly nautical archaeology, will be the purpose of the remainder of this paper. A specific project, the GEORGIA Project, is used as a case study. Computers have already played an important part in the initial studies and hold promise to solve many problems which will be faced in the future (Garrison and Lowery 1980; Baker et al. 1981). The following pages describe the ways in which computer technology and nautical survey were integrated to meet the needs of a specific project.

Purpose and Objectives

Based upon the preliminary studies and the literature review, a number of objectives for the GEORGIA Project were established. These were as follows:

1. To characterize the C.S.S. GEORGIA wreck site, describing its dimensions, orientation, and condition.

2. To discover how the physical processes of siltation, erosion, and undercutting were effecting the site.

3. To discover how dredging was effecting the site.
4. To provide baseline data needed by engineers and planners for use in designing a system to permit the study of, and possibly the excavation and removal of, the wreck.

5. To develop computer applications capable of facilitating the aforementioned objectives.

6. To develop computer applications and computer-graphic programs which would have a broader utility in the field of archaeology and, particularly, in the techniques of nautical archaeological survey.

Scope

The remainder of this report discusses the ways in which remote sensing, diver survey, computerized data processing, and computer graphics were employed to accomplish the site analysis objectives listed above. The methods of accomplishing those goals are delineated. The results are presented and discussed. Examples of the computer-generated graphics are included in the figures to illustrate the results of the project. Problems which were encountered are mentioned, and recommendations for similar projects are offered. Finally, applications of these methodologies in the field of archaeology are indicated, and the potential for further applications is discussed.
CHAPTER II
METHODS AND MEANS

The problems faced by the GEORGIA Project personnel and the growing use of computers in archaeology led to the development of a methodology which utilized all available techniques as a means for site characterization. Because of the nature of the underwater environment, no reliable map of the site could be made based on diver inspection alone. The extent and nature of the debris on the bottom could only be guessed, and it was not possible to monitor the wreck site to assess the changing environment. There was also no way to observe the wreck to see if dredges were, in fact, avoiding it. It was determined that this goal could best be accomplished through the use of remote-sensing technology: side-scan sonar, magnetometric survey, bathymetric survey, and underwater video. Diver survey was also a facet of the research and included the laying of a mapping baseline over the site, as well as the collection of samples of the iron cladding, timbers, and some artifacts. Samples of the riverbottom sediments were collected by piston coring.

The bathymetric survey was fully computerized, resulting in the collection of a large data base. Automated data collection produced more information than could be assimilated without extremely laborious work. To overcome this problem, computerized data management was em-
ployed to assist in the creation of a wreck site characterization.
This was accomplished through the use of a variety of programs adapted
to process the data from bathymetric and magnetometer surveys. The com-
puter was employed in a variety of other jobs as well.

C.S.S. GEORGIA and Computers

Computer technology consists of two aspects -- hardware and soft-
ware. Hardware is the physical machinery which constitutes the system.
Software comprises the languages, programs, and conventions which the
user employs to manipulate the machinery. Hardware concerns the ar-
chaeologist only to the degree he is considering the purchase of termi-
nals, computers, or printers. Software must be mastered to a degree.
Programming languages used in the GEORGIA Project were FORTRAN, SAS,
and BASIC. Other applications of computers in archaeology will find
other languages to be more useful. However, since most microcomputers
are using BASIC, that may be the language for field operations in the
future.

During the early phases of the GEORGIA Project, the use of compu-
ters was quite limited. A bibliography of sources relevant to the pro-
ject was compiled using the WYLBUR text manipulating system developed
by Stanford and supported at Texas A&M University. To do this, an ACT-V
cathode ray tube (CRT) terminal was used as the input device. The ter-

minal was connected to the Texas A&M University Amdahl computer. The
Cultural Resources Laboratory actually compiled a comprehensive bibli-
ography of the sources used in the various projects of the lab. The
GEORGIA bibliography was part of that larger file.
Texas A&M also supports more specialized text editing systems which were developed at the University of Waterloo. Included in these systems are SCRIPT, SYSPUB, and SYSPAPER (University of Waterloo 1979, 1980; Texas A&M University 1981). SCRIPT is the most complex of the three, and thus offers the most versatility. SYSPUB and SYSPAPER are much easier to use than SCRIPT, because many of the formatting options which must be specified in SCRIPT are provided in SYSPUB and SYSPAPER as part of the packaged program. SCRIPT commands may be employed in the other two systems to attain variations in the prepackaged format. For example, this thesis was written using the THESIS format option of the SYSPUB package.

A variety of output devices are available for printing the compiled text. These include high-speed printers, Versatec printer-plotters, Xerox printers, and Diablo typewriters which print on standard or legal-sized paper. The high-speed printers print only upper case letters and print onto standard, multicolored, lined paper. This type of output is very useful for editing rough drafts and for obtaining hard copy of the material stored on disks in the Data Processing Center. The Versatec printer-plotter prints onto roll paper which must be cut apart and then photocopied. The advantage of this machine is that any symbol or special image can be produced.

Perhaps the most attractive output device for texts is the Xerox 9700 laser printer. The product of this new device is quite clean and legible, and resembles typeset copy. The Diablo printer also produces very fine finished copy. All these devices, except the high-speed prin-
ter, have a variety of type faces and font sizes available. This thesis, for example, was printed by the Xerox printer.

Data and text compiled onto the computer need not be printed except as desired for editing or study. It is possible to maintain a running catalog of work in progress. A file was maintained on the C.S.S. GEORGIA which contained listings of all maps produced during the project. Another file was planned for artifacts; however, few artifacts were recovered, and a more traditional notebook file sufficed for keeping an record of them.

In the event of an excavation of the wreck, thousands of artifacts would be recovered. A computer file would be used to allow for constant updating and modification of the records. A similar file is planned to track the artifacts through conservation. Such files would be stored on disk and could be easily accessed and modified using the WYLBUR system. These files would not replace written documentation; instead, they would supplement it, providing a means for easy storage and modification of the data. They should periodically be copied onto magnetic tape to provide a security backup for the data sets in the event of a system crash or an accident that damages the original. To effect this computerized storage of archaeological data, some thought must be given to the printed forms used to record artifacts, features, samples, and conservation procedures.

The grist of the computer is numerical information. The ways in which data are collected, transmitted, processed, and imaged influence the final product. To understand the end result, it is useful to under-
stand the methods of data treatment. One of the major factors effect-
ing the final product is the method by which the information is gath-
ered.

Data Collection

In marine surveys, the trend is toward sophisticated, integrated
systems which combine computerized instrumentation with synchronous
data recording. The location of certain wrecks is clearly known or
knowable from archival research. Many others must be located using
side-scan sonar and magnetometers. The output of these instruments
must be tied to known coordinates to allow for relocation of the sites.
One solution is to sight the survey vessel from shore based transits.

This method, using surveyor's transits, was employed for the probe
surveys of the GEORGIA site. The transits were set up on known coordi-
nates and, by triangulation, it was possible to record the position of
the survey vessel as it moved through the water.

A series of air-jet probes were made to assure that the proposed
cofferdam location would not cut through parts of the wreck. For this
survey, a 60-foot long mild steel pipe was connected by flexible hose
to a compressor. Air shot out the end of the pipe, causing the pipe to
penetrate the riverbed. For the cofferdam perimeter probe, the four
corners were established based upon the bottom relief shown on compu-
ter-generated maps of bathymetric data. These maps were evaluated to-
gether with the magnetometer data. Once the X-Y coordinates of the cof-
ferdam had been established, the calculations were performed to
determine the angles which the shore-based transits would sight to find those X-Y coordinates on the Savannah River. As a motor boat passed over those locations, buoys were dropped to mark the four corners of the proposed cofferdam. Next, the Corps of Engineers' barge ran the perimeter between the four buoys, and the air-jet probe was dropped every 25 feet. As the probe was dropped, the transit operators were instructed by radio to take a reading. These readings, like the sightings for the artifacts and features, consisted of a series of angles shot from two of the shore stations to a point aboard the vessel doing the survey.

The magnetometer surveys were conducted in a similar fashion, with sightings being made to the vessel which was towing the fish. During the survey the magnetometer sensor was towed 25 feet behind an aluminium boat.

There are problems with this method of surveying. First, the time required by the surveyors to take each successive reading limits the data density to the facility and speed of the surveyor. Second, if a large area is to be surveyed, the transits must be reset frequently. Third, it requires that personnel man the shore transit stations. Further limitations are those of human endurance and patience. After a few hours of recording, inadvertent errors creep into the data. The data collected from transit surveys must then be entered into computer files, a laborious and boring job. Although the transit surveying method requires more time and people, it is not so susceptible to mechanical breakdown as are the more automated systems. For certain applications it is totally satisfactory.
A more technologically complex, and perhaps more satisfactory, method of recording data is required for large surveys which generate much more data. Fortunately, for the bathymetric surveys of the GEORGIA, the U.S. Army Corps of Engineers' survey boat CARLSON, equipped with a microwave positioning system, was used. The microwave system consisted of a shipboard transponder and main distance measuring unit and two remote transponders. The remote transponders were taken to two large radio towers and mounted on these towers prior to the survey. The X and Y coordinates of these towers in the Lambert or State Plane coordinate system were known by prior survey. The Corps uses these towers routinely in their hydrographic surveys on the Savannah River.

The system works quite simply. The main transponder aboard the survey vessel periodically emits a microwave signal. The two remotes receive this signal and are triggered to emit a responding microwave signal. When the main shipboard unit receives their response, the distance measuring unit records the time lapses for the entire operation. It converts the time lapses into distance measurements from the vessel to either of the remote transponders. Prior to each survey the system was calibrated by docking the boat at a point of known range from either of the towers and adjusting the measuring unit to give exactly those ranges.

The time interval between successive measurements could be varied. A short time interval would give a larger data base by providing more closely spaced readings. Time between measurements had to be great enough to allow for the interrogation and response and for the record-
ing of the data. A one- to two-second sampling interval for depth soundings was used and proved satisfactory. The positions for the depth readings were obtained by having the depth data print off simultaneously with the distance data from the microwave positioning system. The computer stored these data on magnetic tape and, on demand, punched the data onto paper tape.

A graphic plotter maps every other reading by printing the depth value onto a scale map. Hand contouring of the map produced by the shipboard graphic plotter allows a real time check and feedback of the data being collected.

These surveys provided the data base for later computer-generated graphics. A considerable amount of data was produced, and the need to have a consistent format for the production of graphic imagery led to the decision to employ computer graphics for this purpose. The typical bathymetric survey conducted over the GEORGIA produced 50,000 readings, giving time, position, and depth information. This information could be gathered in a two- to three-hour survey. It was recorded onto printed paper which could then be manually entered into the computer.

With the advent of minicomputers and microcomputers has come the option of integrating nautical survey instrumentation and recording data from a suite of sensors on magnetic tape. These ideal systems are currently in use by industry leaders in the field of hydrographic survey. In such a system, a minicomputer (which programs in FORTRAN) or a microcomputer (which programs in BASIC) is used to collate data coming from the positioning system, the magnetometer, and the fathometer. All
these data go straight onto magnetic tape, and it is also written out as hard copy on a printer so that there is backup if something should happen to the tape. Portable graphics printers now make it practical to produce finished graphics, such as contour maps, in the field. Decca's Autocarta instrumentation is an example of such an integrated system.

The interface of all this machinery can present problems and requires some expertise in both electronics and data processing. For example, we are currently interfacing a Del Norte/Decca microwave positioning system, a Geometrics magnetometer, and a Hewlett Packard 85 microcomputer. The output from the magnetometer is in a form known as RS232C; the output from the positioning system is in a form called Binary Coded Decimal (BCD). Each of these requires special connectors and programs to be received and recorded onto magnetic tape by the Hewlett Packard computer. However, the initial efforts of setting up such a system can be well justified if one is doing a number of surveys. Such an integrated system can save hours of drudgery at a computer terminal inputting data recorded on printed output or by hand in the field.

A final important consideration of data collection is format. The data collector should be familiar enough to know the format into which the data must be organized for processing. Careful design of collection forms and collecting formats can save much time and confusion. The ideal situation occurs when the data can be collected in the same format required for processing.
Data Transmittal

For most surveys, data transmittal is an important consideration. Once the data are recorded, a variety of options are open to get it to the computer for further processing. On the GEORGIA Project the two main methods of data transmittal were from two different eras. When transit sightings were used to establish positioning data, the angles were recorded in field notebooks. These field notes were later manually entered into the computer using the WYLBUR system, and a simple FORTRAN program was written to convert the angles into X and Y coordinates in the State Plane grid system.

When the CARLSON was used, the data were punched onto paper tape. This paper tape was backed up by a simultaneously produced printed copy of the data. The paper tape was brought back to Texas A&M University, read onto magnetic tape, entered into a WYLBUR file, and stored on disk at the Data Processing Center.

A third, and more innovative, method of data transmittal occurred when it was necessary to obtain a copy of the program used by the Savannah Corps of Engineers Office to convert the microwave measurements to X-Y coordinates in the State Plane system. The program was transmitted via standard telephone line from the Corps' computer to Texas A&M's computer. This rapid method saved days of waiting for mail and offers a way for field personnel to access the memory and capacity of main frame computers even though many miles may separate the computer from the field team. Recently, a number of other alternatives have become available. At Texas A&M, the WYLBUR system is available and may be accessed
over the telephone lines. By simply dialing the Data Processing Center's dedicated numbers, one can utilize the main frame computer from any telephone. Programs can be run and data processed. The finished graphics can be sent back over the line to a graphics terminal on the archaeological site, in a motel room, or at the dock.

We have already described the punched paper tape used to transmit the bathymetric data from the GEORGIA surveys. Today these paper tapes are being replaced with magnetic tapes, either reel-to-reel or cassette. Magnetic tapes are easier to handle, are less easily damaged than paper tape, are able to hold more data in a smaller space, and are driving paper tapes from the market place. There is another method of data transmittal gaining in popularity, the so-called "floppy disks." Many mini- and microcomputers utilize this method of data storage and transmittal. No mention has been made of the once common computer card. The card was similar to the punched tape in that it carried information as a series of punched holes in a card which could be read optically by a card-reading machine. These have nearly been replaced by magnetic tapes in the modern computer center. The advent of more powerful mini- and microcomputers may reduce the importance of data transmittal since these small computers will be able to do much of the graphics work on in-field portable graphics printers.
Data Processing

Once the information has been collected, recorded, and transmitted, it requires editing, correcting, and processing. Data processing refers to operations performed on the data by the computer machine. This may be a repetitive mathematical function such as averaging. It may be a transformation, such as the conversion of the transit's angles into X-Y coordinates. To perform these tasks, the machine requires a set of directions called a program. These directions must be in a computer language the machine can understand.

Computerized data processing offers a way to reduce the time and energy required to analyze the data. Rarely are the rough data collected during field work suitable for publication. Inevitably it must be reduced, modified, charted, graphed, mapped, manipulated, corrected, checked, recorrected, collated, synthesized, and made ready for publication. Some of these labors can be assisted by the computer.

The data processing was quite the same for the probe, bathymetric, and magnetometer surveys on the GEORGIA wreck site. First, the angles would be entered in a regular format into a WYLBUR file. Next, a program to perform the trigonometry was written which would solve for the X-Y coordinates of the sightings in terms of the State Plane grid. The program would write the answers to a third WYLBUR file for storage. Finally, a mapping program would be modified to access the stored coordinates and plot the locations of the sightings.

As stated previously, two magnetometer surveys were executed over the site. Both relied on transit sightings for locational information.
Locational data was processed in the same manner as the data for the probes surveyed, the artifacts recovered, and the features located. In this case, however, the final listing of data contained not only the X and Y coordinates, but also the magnetometer reading which had been taken at that particular location. A problem arises in that the magnetometer, being towed behind the vessel, is not actually recording the magnetic field where the boat is located; instead, it is recording an area which is behind the boat by the length between the magnetometer sensor fish and the pole aboard the ship which is being sighted by the transit teams. If all surveying is run in one direction, upstream, then one can compensate for this offset fairly easily by simply moving the features and data downstream a distance equal to the distance from the sighting pole or stadia rod to the tow fish. This works well on straight stretches of river, if the successive passes are fairly parallel and the distance from tow fish to stadia rod is constant.

A greater problem arises when passes are made running both upstream and downstream. Staggered offsets are produced, with the actual location of the magnetometer readings being offset upstream on one pass and offset downstream on the next. Every other pass must be shifted in the same direction, with data from those passes between being moved the opposite way. For example, if you make ten passes over a wreck site, moving in opposite directions each successive pass, and if you make passes 1, 3, 5, 7, and 9 moving upstream, your positioning will place the magnetometer readings too far upstream. Similarly, the magnetometer readings for passes 2, 4, 6, 8, and 10, which you ran downstream, must
be moved upstream the distance from the fish to the point sighted on the survey vessel. Running downstream also results in the readings being spaced more widely, because the current is carrying the vessel along more rapidly. In order to simplify data processing and provide a more consistent data base, all lines on a magnetometer survey should be run moving upstream.

Unfortunately, the magnetometer surveys for the GEORGIA were conducted with the vessel moving both upstream and downstream. Correcting the data base required much hand plotting and calculating. In this case, small errors were quite tolerable, because the mass of iron from such a large, ironclad vessel produced an enormous magnetic anomaly.

In the appendices are examples of the FORTRAN language programs used to process the different types of data collected on the GEORGIA field work. The programs to convert the angles read during the magnetometer survey, the perimeter probing, and the artifact collection were basically the same and employed trigonometric formulas to solve for an X coordinate and a Y coordinate, which could then be plotted by the graphics terminal. However, the magnetometer survey data required additional processing before contour maps could be produced.

CONREC (the contouring program used in this thesis) and SRFACE (the three-dimensional plotting program used) require that the data be gridded; that is to say, the mapping routines require that the data be in a uniform matrix, like a piece of graph paper. Each intersection of lines on the graph paper must have a value, and all the values must be evenly spaced. This procedure is so central to the processing of survey data that it should be more fully discussed.
Gridding Data

Data are gridded by a program called GRIDIT (Appendix B), which accesses the file containing the readings taken in the field. Appendix A is a sample part of such a data file. The GRIDIT program performs the mathematical functions on each reading and writes the resolved values into a new file (see appendix C for a sample of the gridded data file). This new file contains values for each intersection of a grid which will be used by the mapping programs (Appendix D is such a mapping program) as the basis for map production. As noted before, both magnetometer and fathometer data required gridding, although the particulars of the programs vary because the phenomenological natures of the data are not the same.

The computer-generated graphics in this thesis are the byproducts of a series of steps which reduce the data gathered by surveyors in the field to a form usable by the computer. Gridding automatically involves two other techniques—smoothing and weighing. Understanding and controlling these factors are critical to the data processing, for if the data are not gridded in a consistent, logical fashion, the final maps can be misleading and their value as interpretive tools vastly reduced.

Magnetometer surveys and bathymetric surveys require two different gridding programs. The reason for this lies in the nature of the phenomena being described. Bottom terrain tends to change gradually and, except where dredging has occurred, the terrain can be said to trend arithmetically. Thus, suppose you have two points a and b, separated by
distance \( d \), and you wish to find the depth value for point \( c \) located one quarter of the way from \( a \) to \( b \). It is logical to add the depths \( a \) and \( b \), and divide by 2 to obtain depth at point \( e \) midway from \( a \) and \( b \). The depth \( a \) may be added to depth \( e \) and the sum divided by 2 to arrive at an approximate value for the depth at point \( c \).

The process becomes more complex when there are five points of known value and you wish to know the value for a point in the middle of those five. To determine the value in this case, the factor of the relative closeness or distance of each known point from the unknown point plays an important role. Still, it is no great problem to weigh closer points more heavily and distant points less heavily as a simple function of their relative distance from the location of the point whose depth value is unknown.

For bathymetric survey, arithmetic averaging works quite well. In our case, the points whose depth is not known will always be the points at the intersections of the grid. As previously stated, the contouring and three-dimensional mapping routines depend upon regularly-spaced data to generate the maps. An arithmetic extrapolation works satisfactorily to describe most cases of bottom topography. Thus, if two points are separated by ten meters, and point \( a \) is 20 meters deep and point \( b \) 40 meters deep, then the value for point \( c \) midway between them will be 30 meters. Similarly, if point \( d \) is separated from \( e \) by 40 meters, and point \( d = 20 \) meters and point \( e = 40 \) meters, the value for point \( f \) midway between them also will be 30. This is so even though the distance between the first set of points and the distance between the sec-
ond set of points is different. Were this magnetometer data, such a
system of averaging and weighing the relative values as direct arith-
metic functions of distance would not be appropriate.

A second consideration, called the "window of influence," affects
the gridding process. How far from the grid intersection do you want
the program to reach when it calculates the value for the grid inter-
section? A large window of influence will cause the program to utilize
many data points when extrapolating the value of the grid points. Sharp
features will become smoothed or reduced because of their being aver-
aged with so many other data points. The effect of having a small win-
dow of influence may be to make it so small that there are not enough
known points within the window to obtain a reliable average for the
unknown datum point. It may even be so small that there are no values
within it. Generally, the window of influence should be large enough to
include a minimum of 3 known points.

Figures 5 and 6 illustrate a problem which occurs when too small a
window of influence is utilized. These maps are of a magnetometer sur-
vey of the lower reaches of the Mississippi River. For this survey a
lane spacing of 50 meters was used. "Lane spacing" refers to the dis-
tance between successive passes of the survey vessel and tow fish over
the survey area. If the window of influence is too small, the data do
not average across the lanes, and we end up with strips of contours
which coincide with the lanes run when the data were collected (see
Figure 6). Thus, the important factors to remember in determining the
window of influence to be used in your gridding program are data densi-
Magnetometer Survey of Southwest Pass

50 Gamma Contour Interval

Scale in Meters

by: James Graham Baker

Figure 5. Computer generated magnetic contour map.
Magnetometer Survey of Southwest Pass

50 Gamma Contour Interval

Scale in Meters

by: James Graham Baker

Figure 6. Magnetic contour map based on poorly gridded data.
ty and the desired results. If your desired result is a continuous contour map, such as Figure 5, then the data must be collected densely enough so that a reasonable window of influence can be used. A one mile window of influence would fill in for a very sparse data base, but for archaeological survey, the results would be quite meaningless.

For magnetometer surveys, a 45 meter lane spacing has been recommended (Arnold and Clausen 1975a:361). A 30-meter window of influence should in this case provide some overlap. For bathymetric data from surveys of a specific wreck site, such a large window of influence would cause excessive smoothing of the data. Again, the window would depend upon your density of data; hopefully, the window would be much smaller, say 5 meters.

Just as considerations for windows of influence vary from bathymetric to magnetometer surveys, so too do weighing-factor considerations. Magnetic variation and the nature of magnetic anomalies require a different set of parameters than does topographic mapping. The reason for this is that magnetic impulse drops off with the cube of the distance as you move away from the object causing the anomaly. This is expressed in the formula:

\[
\Delta F \text{ (anomaly strength)} = 0.2 \times \frac{M}{d^3} \]

Thus, if \( M = 1000 \text{ gauss cu. cm.} \), then if:

\[
\begin{align*}
d & = 1 \text{ meter}, \quad F = 200 \text{ gammas}, \\
d & = 2 \text{ meters}, \quad F = 25 \text{ gammas}, \\
d & = 3 \text{ meters}, \quad F = 7 \text{ gammas}. \\
\end{align*}
\]
Thus, at a point midway between one and three meters, the magnetism is shown not to trend arithmetically. This differs radically from the arithmetic trending of bottom terrain and illustrates why a different weighing function must be used to model the two types of data (Breiner 1975:7-9).

Three factors are used in the GRIDIT program to produce gridded values from randomly-spaced data. These are the window of influence, the shape function, and the scale dimension. The scale factor serves a dual function. First, it establishes the distance between the regularly-spaced points of the matrix. Second, the scale works in conjunction with the window of influence and the shape factor to determine the distance which will be covered in the window of influence and to determine how values falling within that window will be weighed. The window of influence (called IB) is set in the equation

\[ IB = \# \]

The number on the right of the equation is variable and refers to the number of rows and columns of the matrix which are to be included in the window of influence. Therefore, if IB = 1, then the program would use only the data values in the adjacent matrix cells to determine the value for a particular matrix intersection. If IB = 2, then the two adjacent cells would be used in the mathematical calculations of each matrix value. It is not hard to see how this functions in conjunction with the scale to determine how large an area of the actual survey will be included in the averaging operations to determine the matrix values. A larger scale factor will include more area; a smaller one will in-
clude less area. A larger IB will include more area; a smaller IB, less. The IB and scale factors should be adjusted to include a minimum of two to four of the randomly-spaced data points to insure a degree of accuracy in the determination of the values of the matrix.

The final factor to be considered is the shape or weighing function. This is set in the program by the equation

$$AK = \#.$$ 

In this equation, the higher the value is set for AK, the more equally all data points are weighed; that is, the more nearly equal the influence of all randomly-spaced data points will be when converting them into a regularly-spaced matrix. If all are weighed equally, you have the effect of simple averaging. As the value for AK approaches 0, randomly-spaced data values (which are located closest to the matrix point being solved for) are weighed more heavily. In the GRIDIT program

$$WT = EXP (-DD/\text{AK}) .$$

Where:

$$WT = \text{Weight}$$

$$\text{EXP} = \text{Inverse of the natural logarithm}$$

$$DD = \text{Distance from the grid intersection to the random data points}$$

$$AK = \text{Shape factor}.$$  

The effect of a high value for AK is to mask or pull down aberrant values found in the randomly-spaced raw survey data. The averaging is arithmetic and can be said to trend in a fashion similar to undisturbed
bottom terrain. As the AK value approaches zero, less and less averaging occurs, and data spikes show up more clearly. This occurs because in solving for the unknown values of the matrix points, the program weighs the known data points closest to the matrix points more heavily than it weighs more distant ones. Points further away from the intersections of the grid are weighed more lightly. This weighing preserves greater influence for very anomalous readings and is more appropriate for modelling magnetometer data than are high values for AK.

The source for this gridding technique is the Barnes Exponential Gridding Technique (Barnes 1973; Theis 1979). The technique was developed for meteorology. There are other techniques used to derive gridded values from randomly-spaced data, but they will not be discussed here. There are also some newer programs which have the capacity to map randomly-spaced data, allowing one to dispense with gridding routines altogether.

In nautical surveys, two different gridding programs may have utility. For one the AK value would be set low. Magnetometer surveys would be appropriately gridded using such a program. The low shape factor would prevent the masking of locally intense readings caused by highly anomalous metallic concentrations. This should also have a fairly low value for IB to prevent the smoothing of anomalous readings. Since anomalies are what are being sought in magnetometer surveys, it is critical to preserve the anomaly through the gridding process so it will appear on the final graphic. A low value for IB will also prevent the masking of small anomalies which can occur when they are averaged with surrounding nonanomalous values. This is particularly a danger
when what is being sought is an early shipwreck without large quantities of iron aboard.

The second type of gridding program would be for bathymetric survey. In that case, surface trends tend to be more arithmetic in nature, and averaging is a more satisfactory way to fill in data gaps. For these, a higher value would be used for both AK and IB.

Problems can arise if the scale and IB factors are set too small. This will create cells in the matrix which have no value (have no randomly-spaced data). The mapping routines will leave these areas blank. The result will be strips of contours following the survey vessel's path. For example, if the lane spacing during survey was 50 meters and the scale in the GRIDIT program is set to 10 meters and the IB=1, then values will be produced for only a 20 meter swath, and no connections will be drawn between the lanes. While this may reflect the reality of the survey, it does not model the information in a manner which can be interpreted easily by the layperson.

If the IB is changed to 3, then the reach of the window of influence is extended to provide some overlap between the successive lanes, and lines will be drawn to connect them. Another way to accomplish this is to change the scale while leaving the IB constant. As mentioned before, the IB and scale should work together to include two to four of the randomly-spaced points within the window of influence. No more than 7 points are ever needed within the window. It should be noted that reducing the scale (making the grid smaller) does not increase resolution unless there is sufficient data density to justify the reduction
and keep 2-4 data points in the window of influence. Large grid scales and large IB values will have the effect of smoothing the data. From the above, we can see that gridding is an important consideration in the graphic imaging of randomly-spaced survey data.

It should be stressed that the data being processed were considerable. The average survey had thousands of depth readings correlated to lane counts. Thus, computerized data processing offered the only efficient way to deal with the huge body of information. The next step after the data have been put into a suitable form is to actually create the maps.

Data Imaging

Initially, all graphics were produced by hand drawing the images. For magnetometer surveys, the magnetometer readings were written on the map and the contours interpolated in an arbitrary manner. In this case, where there were such a small number of readings, this method is probably satisfactory. If there were thousands of readings, however, it would be a different matter. Another consideration for these images is that the values also had to be moved to the north of where they were recorded by a distance equal to one third of the depth of the wreck below the magnetometer sensor fish (Weymouth 1976:6).

Hand mapping was also done for bathymetric data. The Corps of Engineers translated the results of their hydrosurveys into navigation maps showing the bottom depths. These data were initially recorded in one of two ways. Either the data were printed onto strip charts or it was printed on large sheets of paper from a graphic terminal.
Data recorded on strip charts takes the form of a line representing the bottom. This line follows the bottom relief. Draftsmen take information on depth from these strip charts and record the depths in lines which follow the lines run by the survey vessel. It is a fairly simple matter to draw the contour lines between the different depths. For maps of a broad geophysical nature, such a technique may be adequate, provided the data base is fairly sparse.

The CARLSON carried a more advanced graphics recorder. This actually inked in the depths measured by the fathometer as the vessel was surveying. Later, a draftsperson inked in the contour lines to produce a map of the bottom features. The first maps of the GEORGIA wreck site were made by this method. There were problems when the system was not as versatile as a larger computer system can be, where all aspects of the mapping can be performed by the graphics terminal.

Among the features which can be provided by a fully computerized mapping system are the ability to easily change the size to the maps produced, the freedom to decide what type of annotations are to appear and where, the ability to place features such as buoys and cofferdams onto the map, the option to overlay a grid of a desired type to allow for the accurate determination of positioning information, and the ability to image the data base in two-dimensional contour maps or in three-dimensional isometric displays. The latter option can also provide stereo pairs for stereoscopic viewing of the bottom relief.

Of course, two major considerations are cost and scientific replicability. In both categories, computer graphics can offer a superior
solution. While the initial program development may be expensive and time consuming, later re-use of the programs quickly catches up and overcomes the initial development costs. Also, as automated data input systems are developed, the cost of inputting large amounts of data drops dramatically. From a methodological point of view, computer graphics offer replicability and precision, as well as the possibility for misuse. Science requires that results of experimentation be repeatable, and the mathematical calculations and plotting packages available fulfill that criterion. However, that is not to say there are no problems, as we shall see later.

CONREC: A Contouring Program

At the Texas A&M Data Processing Center the major contouring and mapping program supported in 1980 was CONREC, a program obtained from the National Center for Atmospheric Research (NCAR). CONREC has been adapted to suit the requirements of A&M's mainframe computer and plotting devices (Reid 1980). By writing a FORTRAN program consisting of a series of calls to subroutines, the user can produce plots which are of a high quality and reasonably inexpensive. This system is moderately complex and takes some time to master. It has the advantage of offering a high degree of flexibility and control over the final product. For example, the user has the option to have titles wherever he pleases, and to have those titles whatever size and darkness he requires. Scaling, orientation, contour intervals, labelling of contours, types of lines drawn, and a wide variety of other options can be set by the user.
Computer graphics have been employed in nautical archaeology for some time. Arnold (1979:1-16) has discussed some of the applications of computer graphics in nautical and terrestrial archaeology. For the GEORGIA, contour maps and three-dimensional isometric displays were created of both magnetometer and fathometer generated data.

SRFACE: A Three-Dimensional Imaging Program

SRFACE is a subroutine developed by T. Wright of the National Center for Atmospheric Research (NCAR) to image three-dimensional surfaces as isometric graphics (Reid 1980:viii, 125). The utility of such a program lies in the ability of the human eye to grasp and assimilate visual data quickly, especially when the data are displayed as a three-dimensional projection. A contour map of the bottom relief may easily communicate to one familiar with and adept at interpreting such maps, but three-dimensional images allow for easy interpretation by divers and archaeologists, as well as by the layman, whose interest is perhaps only casual. As a tool to "see" through thick sediments in waterways with zero visibility, such graphics offer the best alternative.

Like the contour maps, this type of image can be assigned titles, scale, legends, and textual accompaniment. The user has the option of assigning any viewpoint he chooses, which allows him to view the site from any position. This can produce the effect of swimming around the site. Relief in the foreground will obscure relief behind it, and the program has the option not to image these hidden lines. Also, stereo pairs that may be viewed with a stereoscopic viewer can be produced quite easily.
The final production of computer graphics relies upon mapping programs and upon the graphics printer. We have already discussed the two programs used for the GEORGIA graphics. Others are available, as Arnold (1979:2, 1982) points out. There are also a variety of choices of printers, from electrostatic printers, to pen plotters, to Xerox laser printers. All of the graphics contained herein were produced by a Versatec electrostatic printer. It has the advantage of speed over the pen plotters, but the disadvantage of being limited to one color. The lines on the Versatec printer are composed of segments of straight lines, giving curves a somewhat jagged appearance in contrast to the smooth curves of the pen plotters. The wave of the immediate future seems to be the Xerox laser printers, which eliminate the jagged lines, while retaining the speed and economy of the electrostatic plotters.

Data imaging of the two magnetometer surveys differed. The first survey was contoured and mapped by hand and is shown in Figure 7. By the time the second survey was conducted in the summer of 1980, we had begun to develop our mapping capability. The adjusted data were entered into a WYLBUR file and contoured using modifications of the GRIDIT and CONREC programs used to map the bathymetric data. Figure 8 is the computer-drawn contour map of the magnetism present at the wreck site.

The bathymetric surveys were by far the most computerized of all the surveys conducted during work on the GEORGIA. Five surveys were made -- one in December of 1979, one in February of 1980, one in March of 1980, one in August of 1981, and a final one in May of 1981. Each successive survey was more thorough than the previous one, covering a
Figure 7. June 1978, Magnetic contour map of the C.S.S. GEORGIA wreck site.
Figure 8. August 1980, Magnetic contour map of C.S.S. GEORGIA wreck site, computer-generated.
larger area, obtaining more readings per unit of area, and allowing for ever-increasing resolution and detail. The first one was processed by the Corps of Engineers, which simply hand contoured the plotter output. The plotter output consisted of a State Plane reference grid with the depths written at approximately the correct locations. It was produced by a pen plotter, which printed only every second reading, because it could not keep up with the computer's recording of the information coming from the fathometer.

The Corps also produced a contour map of the data from the February 1980 survey. Upon close examination, it was discovered that the grid overlay for the two maps, December 1979 and February 1980, was inconsistent. A decision was made to produce the maps at Texas A & M, and all subsequent maps were produced on the computers located on the Texas A&M campus. Maps from the February 1980 survey were subsequently redone. Figures 9, 10, 11, and 12 are contour maps of the different months' surveys. Figure 12 shows the locations of the air-jet probes relative to the bottom relief and proposed cofferdam. All maps have the Lambert State Plane grid and are scaled in feet. The contour interval for the series is one foot.

The time involved in hand plotting and contouring thousands of depth positions made the computer the logical choice for data management and imaging. In addition, the potential for three-dimensional imaging of the site offered an option nearly impossible to achieve by traditional drafting methods.
Figure 9. February 1980, Bathymetric contour map of C.S.S. GEORGIA wreck site, computer-generated.
Figure 10. March 1980, Bathymetric contour map of C.S.S. GEORGIA wreck site, computer-generated.
Figure 11. August 1980, Bathymetric contour map of C.S.S. GEORGIA wreck site, computer-generated.
In order to meet the objectives and provide graphics easily understood by non-specialists, both contour maps and three-dimensional isometric plots of the bathymetric and magnetometer surveys were needed. At first these were made by the members of other departments; later, all were produced by the author. The bathymetric survey data were copied from the paper tape to magnetic tape and entered into a WYLBUR data set. The goal was to develop a variety of versatile computer- graphic systems to display the data. Part of this process involved the changing of positioning data from range-range distances into X-Y coordinates in the State Plane system. Range-range data simply gives the distance from the vessel to either of two microwave towers. These distances are first converted to State Plane coordinates, and then the data are gridded to prepare for mapping. For this to be done, it was necessary to process the data and to change it from a form which was randomly-spaced to a form where there was an average value obtained for each row and column in a regularly-spaced spaced matrix. The reason for this is that the contour mapping programs supported at Texas A&M University require that the data be in a gridded form prior to mapping. On land surveys, it is fairly easy to take readings at such regular intervals. On the water, this is usually impossible due to currents, tides, waves, vessel speed, and drift.

Once the data have been gridded, they can be mapped. This process involves six basic steps: 1) collecting the readings from the fathometer and the microwave positioning system, 2) recording those readings on punched paper tape, 3) bringing that paper tape to the A&M tape
reader, 4) reading the information onto a magnetic tape, 5) reading
the magnetic tape onto a WYLBUR file, and 6) checking the file for any
problems or errors in the data processing to this point. Now the data
are ready to be gridded. The gridding program reads the values from the
file and constructs a matrix of values. Finally, the matrix of values
is plotted as a contour map. Actually the process is slightly more com-
plicated, but these are the basic steps in data processing.

A variety of isometric, three-dimensional graphics depicting the
survey data as three-dimensional images were produced. Once again the
data had to be put into a gridded format before graphics could be pro-
duced. Figures 13.a. and b. are examples of the three-dimensional im-
ages produced.

Figure 13.a. was produced by the Electrical Engineering department
under the direction of Dr. Doug Green. Both a. and b. confirm the site
configuration depicted in the side-scan sonar, Figure 4 (p. 19). The
site can be seen to consist of two mounds, a smaller one downstream and
a larger one upstream to the west. Figure 13.b. was produced by the
author and is derived from the May 1981 bathymetric survey. It is in-
teresting to note the continuity of the main features of the wreck
which appear as two mounds in the center of the images. Also, the imag-
es exemplify two of the options available in many of the three-dimen-
sional plotting routines. Figure 13.a. has a skirt, giving the relief
the effect of standing on a pedestal. On the other hand, Figure 13.b.
(p. 67) shows the dredged channel on the left side as it rises toward
the wreck. The figures differ in the amount of terrain covered; Figure
Figure 13. February 1980 and May 1981, Isometric plots of C.S.S. GEORGIA, looking south.
11.b. reflects the much larger area encompassed in the later survey. The scales are also different. Figure 13.b. has a five foot grid; Figure 13.a., a six foot grid. Figure 13's images were produced by interpolating the values for each intersection in a regular grid and then connecting all lines in the grid in three-dimensional space. These images have a drawback because the Z axis, the vertical dimension, is scaled arbitrarily by the program to fill the space available on the plotter paper. Distortion of the real relationship of the three dimensions occurs as a result. They do serve to indicate quite clearly the relative values of features on the Z axis. It is also possible to control the scaling of the Z axis to make it comparable to the X and Y axes. Similarly, it is possible to exaggerate the vertical axis to bring out subtle features. For the three-dimensional graphics presented here, the vertical axis has been exaggerated to show more clearly the features of the site.

Figures 13 through 16 illustrate the ability of the computer to rotate a three-dimensional image to produce the effect of viewing the site from different sides. This rotation is accomplished by the programmer specifying two points in space. The first is the point from which the viewer is viewing the image. The second is the point at which one is looking. These two points are specified in terms of their X, Y, and Z coordinates in the grid system used for the plotting. By changing the coordinates of the viewer's eye, it becomes possible to view the image from any side.
Figure 14. May 1981, Isometric plot of the C.S.S. GEORGIA wreck site, looking east.
Figure 15. May 1981, Isometric plot of C.S.S. GEORGIA wreck site, looking north.
Figure 16. February 1980 and the May 1981, Isometric plots of C.S.S. GEORGIA wreck site, looking northwest.
Figure 14 demonstrates the use of the skirt option again. The viewpoint has shifted 90 degrees from that of Figure 13 (p. 67), moving in a counterclockwise direction. This image -- like Figures 13.b., 15, and 16 -- has a contour line every 2 feet of relief. Figure 13.a. lacks the contour line and is comprised of lines running north-south or east-west. The addition of the contour line feature helps to provide a feel of scale to the Z axis and may be done by using a simple command. Figure 14 is unique in the series in that a command was given to print it using a double line weight; for that reason, it is noticeably darker than any except Figure 13.a. Figure 13.a. was produced on a printer at Electrical Engineering which had a nib pattern twice as thick as the Versatec plotter at the Data Processing Center. Figures 14-16 all have a 5-foot grid scale.

In Figure 14, the dredged main ship channel occupies the right half of the image. In the center, the low mounds of the wreckage are seen to rise out of the north side of the ship channel. The Back River channel is seen entering the image in the left foreground. From here we move counterclockwise another 90 degrees to view the wreck from the Georgia side in Figure 15.

Figure 16.a. and b. move us another 45 degrees toward the east. As was the case in Figure 13, the February 1980 and the May 1981 bathymetric surveys provided the data bases for the images. The two are presented together to show the utility of this technique, as it shows the effects of the suspension of dredging activity in the area of the wreck for the Back River channel. In Figure 16.a., February 1980, the dredged
channel has a sharp, steep wall that enters the graphic from the upper back corner to the northwest. By May of 1981, the suspension of dredging has permitted the degradation of the channel wall, and it is no longer discernible as a distinct feature. The terrain in the area of the channel wall now slopes gradually up to the river-bottom level of the undredged area north of the wreck.

Figure 17 represents still another option of three-dimensional plotting. The two images shown in Figure 17 may be viewed with a stereoscopic viewer, producing a stereoscopic image in three dimensions. The X, Y, and Z coordinates of the viewpoint for the two images has been separated by six degrees, the amount required by the human eye to perceive an image in stereo. To produce such an image is a relatively simple task requiring only a slight modification to the three-dimensional plotting program.

Just as the same data base may be imaged as a contour map or three-dimensional display, it can also be used to produce a map on which differences in depth are imaged as in shades of grey textures. To obtain gridded data, we simply overlaid the contour map with a grid and manually assigned values to the grid intersections. This proved to be quite time-consuming, not worth the time and effort in terms of the additional information gained. Programs are available, such as the SAS/GRAF package, which can access the disk-stored data base used for the other types of graphics. This capability makes the greytone contour map a more attractive option. Our greytone map was informative. The deep parts of the dredged channel show as black, while higher
Figure 17. February 1980, Stereoscopic pair, Isometric plots of C.S.S. GEORGIA wreck site, looking northeast.
relief of the wreck are imaged as lighter tones of grey (Figure 18). Lightest tones represent superstructure standing above the sediments. The Back River channel comes in from the northwest, upper left, and appears as a darker area. A 1.5-foot shade interval was used.

After an initial period of dependence upon others for the production of such images, a number of problems arose which lead to the decision to master these various mapping processes and to produce all the graphics myself. The turnover of students in the other departments meant that we were continually losing the people who were familiar with the work. In addition, it was difficult to coordinate the activities of such a widely diverse group whose class schedules and deadlines occasionally conflicted with our own. After a time, I was able to become proficient in the use of the Versatec plotter and to modify existing programs to suit our specialized needs.

Contour maps can serve as the basis for models of the wreck site. Figure 19 is a photograph of such a model. The contour lines were traced onto 1/8 inch art board. These tracings were then cut out and stacked to approximate the bottom terrain. Engineers used this model as an aid in determining the location and size of the coffer dam which may one day impound the site. A copy of the model will also go to the Museum at Fort Jackson near the wreck site to assist in interpretation for tourists. The model was based on the August 1980 bathymetric survey.
CHAPTER III

RESULTS

A leading nautical archaeologist once asked what was the value of such sophisticated technology. What did it reveal that could not be learned by simple probing? This chapter addresses this concern. Probing of the site was attempted, but swift currents made the 60-foot length of pipe bend like spaghetti. The only way to obtain an accurate picture of the wreck site was to combine all possible methods of observation. While computer-generated graphic imaging was not the only technique employed, it was an important one.

Verifying History

Archival materials reporting the size of the GEORGIA do no agree either on her length or width. By a careful study of the contour and 3-D maps it was possible to determine that the vessel had to be at least 200 feet long for it to produce the mound-like structure seen in the graphics. Historic versions range from 150 to 250 feet for the vessel's length.

How much of the ship remains? Modern writers tell of the ship having been burned, but Garrison (personnel communication) feels that the sea cocks were pulled. Other than Commander Hunter's order that she be scuttled if the Union took Savannah (ORN Series I, Vol.XVI:482), no
contemporary descriptions of the sinking have been located. In this case, the amount of structure revealed in the graphics correlated data from the side-scan sonar and diver investigation. Information collected during the project established that the vessel had not been burned. No charred wood was recovered by divers, who report encountering large pieces of intact superstructure with the railroad rail cladding still in place. These observations by divers in zero visibility waters are confirmed by side-scan sonar which shows two large pieces of intact superstructure (Figure 4, p. 19). Contour maps and three-dimensional images verify and confirm this picture. In the graphics, one sees there are two mounds at the north edge of the dredged ship channel. The west mound is much larger than the eastern mound. Archival records indicate that in the late 1860's the wreck was dynamited in an attempt to clear the wreckage from the channel (Report of the Chief of Engineers 1872:655-659). About 80 tons of iron were salvaged before efforts were abandoned. The depression in the mound between its east and west sections may be the section which was dynamited and salvaged. If, in fact, the ship was not burned then we should have a substantial percent of her in quite good condition. The dredging damage seems to be confined to her upstream end. The dynamite damage to an area downstream of midship. The computer graphics show structure extending 175 to 200 feet in length along the northern margin of the channel.

Another important fact provided by the computer graphics was the orientation of the site. Diver surveys had approximately located and orientated the site, but from the contour maps it was possible to see that the ship lies almost parallel to the dredged channel.
The Physical Environment

For planning purposes, understanding the physical environment of the wreck site was as important as understanding the wreck itself. A study of the side-scan sonar image in Figure 4 (p. 19), the contour maps in Figures 9 through 12 (pp. 61-64), and the three-dimensional maps in Figures 13 through 16 (pp. 67 and 69-71) tells us much about the general nature of the site. The sonar graph is the product of a fortuitous pass directly along the longitudinal axis of the wreck. Thus, what appears as a horizon line in the image is, in fact, a longitudinal cross section of the relief of the site. Also visible directly below the horizon line are two large pieces of broken superstructure. From the wreck area the broad flat plane of the river bottom stretches toward the South Carolina shore. It is interesting to compare Figures 4 and 13 (pp. 19 and 67) for, although they represent two different types of images, they both record the two mounds in an amazingly consistent manner.

The contour maps show the same two pieces of superstructure, but they are much more informative about the surrounding terrain. The mental picture derived from the contour maps, combined with the information from the three-dimensional isometric images, makes it possible to understand the way in which dredging has determined the bottom topography. The wreck lies at the junction of two dredged channels, one being the main dredged channel of the Savannah River and the other being the dredged channel for the Back River. The latter channel can be seen running diagonally from the northwest into the main channel near the center of the map. Dredging for this channel has impacted the wreck.
The main dredged channel has a depth of 40 feet. The South Carolina side gradually deepens to a depth of 30 feet at the edge of the channel. The drop into the channel is quite rapid along the main channel. The drop into the Back River channel is more stepped and irregular. The understanding of these bottom features was essential for the engineering studies involved in the design of the cofferdam, where the bearing and loading of these currents and sediments dictated the strength requirements of the coffer dam.

The Cofferdam

Part of the responsibility of the GEORGIA Project was to investigate possible courses of action open to the Corps of Engineers in dealing with the site should widening and deepening of the Savannah harbor channel be initiated, or should the site become endangered due to undercutting or other causes. Test excavations were recommended to determine the condition of the remains. To carry out these tests, it would be necessary to construct a cofferdam to still the currents and tides and permit divers to excavate safely. Engineering studies (United States Army Corps of Engineers 1982) determined that a driven sheet-pile cofferdam would serve the purpose well. These studies depended upon the computer-generated graphics to help determine stresses and burial depths of the pilings. The location of the dam was determined from the contour map, and coordinates were assigned to the four corners by having the computer draw the dam onto the map. Figure 12 (p. 64) shows the position of the recommended cofferdam and also has * symbols
placed at the locations of air-jet probes made in an attempt to insure that none of the wreck lay in the path of the dam.

Thus, the computer graphics played a determining role in both the design and location of the proposed cofferdam. In black water environments, this technology can greatly facilitate the planning phase of archaeological work, allowing the development of alternative plans and providing vital information for the planning process.

Monitoring the Site
Because the project extended over a number of years, it was possible for us to produce a series of maps representing the wreck site and vicinity as it changed over a three-year period. Maps based on data from four different months -- February 1980, March 1980, August 1980, and May 1981 -- are included herein as Figures 9, 10, 11, and 12 (pp. 61-64), respectively. What we find is a dynamic bottom terrain.

Dredging activities along the Back River have damaged the upstream end of GEORGIA and knocked debris into the main river channel at the point of juncture for the two channels. Artifactual materials recovered from this area suggest the hull may have been breached by this damage. This mound of debris is seen most clearly in the 3-D display, Figure 14. When it became known that this damage was occurring, the Back River channel was realigned to enter above the wreck. Once dredging was suspended, the old edge of the Back River channel began to erode and become less angular. This action is clearly visible in Figure 16, a. and b (p. 71).
It was in the mound of debris formed by dredging impact that divers encountered Dahlgren and Brooke's Rifle projectiles. The location of these projectiles and other debris was made precise by the subsequently produced computer graphics.

Shoaling, Deposition, Undercutting, and Erosion

As mentioned above, computer graphics allow the monitoring of the site. The contour maps provide the Corps of Engineers with a method to determine if shoaling and excessive sedimentary deposition is occurring. This is especially important at the upstream end of the site where the two dredged channels come together. Since the path of dredging activity at the mouth of the Back River channel has been changed to avoid the wreck, there is some concern by the Corps that the channel not be allowed to silt closed.

From the point of view of the archaeologist and historic preservationist, undercutting and erosion are the processes most important to monitor. Divers report that, along the channel side of the wreck, undercutting has already occurred. Should overdredging occur near the undercut parts of the superstructure, it might break loose and tumble into the channel. Such a shift would be noticeable on the contour maps. By providing a means of observing the site through time, computer graphics may alert archaeologists to the need for salvage excavations, should changing conditions threaten the wreck. The GEORGIA Project was involved in the monitoring of the site for only three years, but the technology which was developed could be applied to provide regular annual observations of the site and its surroundings.
Predicting the Future

Information gained from the studies gives a fairly reliable indication of what the future holds for the GEORGIA. Past dredging in the area damaged the upstream end of the wreck, tumbling pieces of structure and artifacts into the channel. The side of the wreck along the channel has been exposed by the dual actions of dredging and currents. If the main channel is deepened, the channel walls in the area of the GEORGIA will tend to retreat toward the South Carolina shore, with the wreck forming a pedestal in the channel. Eventually, the process of undercutting which we already see in progress will cause the collapse of the remaining intact structure. In that event, many of the delicate items which have been preserved by virtue of their stable environment will decay as they are exposed to the agents of water, current, tide, and oxygen. The protective mantle of silts is part of what makes the GEORGIA historically important.

We are also able to predict that if the site is not clearly marked damage will occur by dredges actually hitting the wreckage. We can see that this has happened in the past, prior to the placement of the wreck marker buoy. If sedimentation begins to block the Back River channel and dredging is resumed along the path used in the period prior to 1970, the destruction of the upstream end of the site will continue.

Now that we have seen some of the ways in which computers and computer graphics were used in the GEORGIA Project, we will turn to a description of the efforts and problems involved in the production of graphic images using a computer. An attempt shall be made to identify
the processes involved and to identify certain pitfalls, which we learned to avoid by falling into them.
CHAPTER IV
DISCUSSION

Problems and Recommendations

During the course of the GEORGIA Project, we ran into a number of problems which may be instructive. Each time transits were set up we found that if they were set up on the same side of the river and the survey was run in the area between them, this simplified later programming. If they were set up first with both on the east bank, then one on each bank, and then both on the west bank, this required three different programs to do the different trigonometry required by the changes. Careful attention had to be paid to see that each different set of data received the correct processing. It is best to keep the data collection as consistent and simple as possible.

A second problem stemmed from the fact that the data processing was separated from the data acquisition. The Corps of Engineers field personnel conducted the bathymetric surveys and provided us with the finished paper tapes. It was found that on maps produced from two different months' survey data the State Plane Coordinate grid did not match. On the final survey of May, 1981, I was able to personally conduct the survey. It was only then that the cause of the grid slippage was discovered. The microwave positioning system had been changed, but no one had thought to inform us. This change in microwave systems re-
quired a change in the constant value use to mathematically convert the microwave lane counts into X-Y coordinates. This illustrates why it is valuable to have the person doing the data processing present at the time of data collection. His input can save much time later on.

During the May, 1981 survey, I was able to collect a much denser and broader data base. This resulted in a more reliable and extensive picture of the riverbed. The ship repeatedly passed over the wreck site until all areas were well covered. It was possible to follow the survey vessel's track on the graphic plotter.

Another embarrassing problem arose out of this same lack of continuity between data collection and data processing. The original contouring program was written by someone else. In it he limited the relief to be contoured to between -28 and -40 feet below mean low water level. When the August, 1980 data came in, there was an erroneous pair of readings at the downstream end of the wreck site. These readings recorded an elevation of 2000 feet above mean low water and a nearby hole of -500 feet depth. Somehow these "gliches" were not caught, and they were mapped onto the contour map. There they appeared as a -28 feet high feature right next to a -40 feet deep hole. Limiting the contouring to a -28 to -40 feet range effectively masked the erroneous data readings by chopping off the bottoms and tops. Occurring as they did at the downstream end of the wreck, they looked like nothing so much as a direct hit by the dredge. What else could have caused 12 feet of nearly vertical relief? Fortunately, the three-dimensional mapping program had no such limits on what it imaged, so that when the three-di-
dimensional graphics were run for the August data base, a towering mountain showed up right beside a very deep sinkhole. The error was corrected, but not before a good deal of verbage was spilled. Had there been continuity of personnel from data collection through production of the finished graphics, this error might have been avoided. At any rate, it points out the danger of arbitrarily limiting the range to be contoured, the danger being that when noise spikes do occur they will be truncated and masked. Once masked they may appear to be within the range of normal features.

Another problem which creeps up on the computer user is the lack of adequate documentation of data sets and programs. It is important to take the time to insert descriptive and explanatory notes in programs and datasets. In six months or a year, those notes may be critically important reminders of the way a data set was derived or of the reason a particular part of a program is written as it is. Also, if something should happen to the person in charge of the computer work, it is nearly impossible for his successor to sort out and understand undocumented files. The importance of such documentation can not be overemphasized.

Care should be taken to have the files backed by making copies of them on a periodic schedule. If this is done every two weeks or every month, should the active disk or tapes then be destroyed, the damage will be to only a week's or month's work, and not to the work of a year or more. As texts become stored on disk and tapes, this becomes critical. Imagine the tragedy of losing a site report text because it was not backed up by a second copy.
A final caution concerns the interpretation of the computer graphics and processed data. Such output is not reality; it is a model of reality. To understand what is depicted requires some explanation. There is a tendency on the part of the uninitiated to regard such computerized, mathematical models with awe, to feel that they are the thing they represent. As Jermann and Dunnell (1979:32) have pointed out:

Because of its immediate sensory impact there is a tendency to regard a map as the map. Viewed in this manner, a map becomes a piece of data, a phenomenon, rather than an analytical model. . . . Any map is only one of an infinite series of possible maps that can be drawn from the same data.

As seen from the discussion on gridding, these models are the product of mathematical manipulations which are based on assumptions not always applicable to nautical archaeology. For example, we know from diver reports that the GEORGIA has exposed timbers, iron rails, and casemate protuding in a tangled mass from the upstream end of the wreck site. This condition is not reflected in the computer graphics. Why is this so?

The programs used for mapping have been adapted for use in archaeology, but they were written for other disciplines -- cartography and meteorology. The terrain studied in those disciplines trends more gradually than it does in a ship wreck. By the same token, the sensors used to gather the data come to archaeology by way of geophysics, oceanography, and navigation, where the same caveat applies.

Does this mean such tools cannot be applied in nautical archaeology? No. It means we must beware of the computer graphic, aware of how
it is generated, how the data are collected, and how the graphics are printed. If we have such awareness, then computer graphics can be accepted for what they are -- mathematical models of reality. Like all models they may be of use if they are good ones. If they are not of use then there is no need to create them merely as an exercise in modern technology.

The data should be collected in a computer-compatible fashion. For example, it is popular to use Greek letters for artifact labelling. However, computer keyboards do not have Greek letters, and if the artifact catalogue is going to be compiled on a computer (as the Mary Rose Trust is doing), then all the artifact numbers must be changed. For this reason the Trust has set up numbering systems which can be entered without altering the preliminary assignment number.

The data should also be program compatible. If the program is expecting a matrix which begins in the lower left-hand corner as the 0, 0 coordinate, then it simplifies things to collect the data using the same system. Unfortunately, not all mapping routines have the same origin. Harvard's programs -- SYMAP, SYMVU (Laboratory for Computer Graphics and Spatial Analysis 1979 and 1971), and ASPEX (Hanson 1980) -- have their origin point in the upper left corner. Those at Texas A&M University -- CONREC, SRFACE (Reid 1980), CALCOMP, and COMPLOT (Smith and Pao 1973) -- origin at the lower left corner. It is not impossible to alter a matrix to be compatible with a new origin, but it is a bother.
We have already discussed the value of having the same person collect and process the data and produce the final graphics. This is most often not possible. Care should be taken to see that the information coming out of the field is as clear as possible. If field personnel are unsure of a reading, they must make the decision. The data processor is in no position to choose between a number of alternative readings for the same point on a grid of a magnetometer survey.

Other problems will occur. Equipment will fail as surely as the sun will rise. Always check out electronic equipment before leaving home base and before starting field work. Bring spares for all circuit boards and be ready to trouble-shoot. Have tools to work on electronics aboard. Trouble may not occur, but it is best to be ready for it.

With so many problems, one might wonder if it is all worth it. The rule of thumb should be to keep it simple. If the work you have to do does not require sophisticated equipment, then nothing is to be gained by having it along. And yet, if your job is of such a size that factors necessitate computerized technology, there is no substitute. Computers can increase efficiency and quality. Remote-sensing technology allows us to characterize our environment in ways not possible with our unaided senses.

**Significance: Contributions to Archaeology**

The techniques used on the GEORGIA Project have contributed to the development of a survey methodology for the survey of large areas where visibility is poor. For example, the Corps of Engineers is currently
planning to deepen the dredged channel of the Mississippi River from the mouth to Baton Rouge. This great waterway has been the lifeway of commerce into America's heartland for hundreds of years. Remote-sensing technology is the best method currently available to locate shipwrecks in the path of this dredging activity. Combined with archival research, it is hoped that vessels of historic import can be located before dredging damages them. The surveys currently underway employ refinements of the computer-graphic capabilities developed during the work for this thesis. Figures 5 and 20 (pp. 46 and 93) depict a survey area in the Southwest Pass of the Mississippi River. At least two shipwrecks are clearly seen as magnetic anomalies on the contour map. The relative intensities of anomalies can be gauged from the 3-D display in Figure 20. Smaller anomalies may also represent wreck sites. Hopefully, archival research will shed light on these features. An integrated system consisting of microwave positioning, magnetometer, and side-scan sonar is being used in the survey. The data from the magnetometer and the microwave positioning system are printed onto paper tape and are later hand entered into the Texas A&M University computer. Programs are run and plotting is done at the College Station facility.

Figure 20 was produced by a simplified plotting routine available through the SAS Institute and supported at the Data Processing Center at TAMU. SAS/GRAPH greatly facilitates the plotting of a wide variety of types of data sets on computer-graphic devices (SAS Institute Inc. 1981). This "user friendly" system is easier to learn and use than the NCAR packages, CONREC and SRFACE, but it lacks their versatility.
Magnetometer Survey of Southwest Pass

25 Meter Grid

by: James Graham Baker

to Gulf

WRECK

to New Orleans

WRECK

Figure 20. 3-D Isometric plot of anomalies in the Southwest Pass of the Mississippi River.
Development is currently underway to integrate the magnetometer and microwave systems with a Hewlett Packard 85 microcomputer which will record the data onto cassette tapes. These tapes can then be read directly into the WYLBUR computer system, thereby eliminating weeks of data entry labor. On a large project, such as the Mississippi survey, the savings in labor and time of computerized data processing and imaging can be in the tens of thousands of dollars.

As was mentioned in the Introduction, offshore, nearshore, river, and lake surveys are required by the Federal Government to protect the material remains of our history. Pipelines, oil well drilling, dredging, and channelization all require prior archaeological surveys. These surveys provide a dual benefit. First, the archaeologist is able to locate and study the objects of his interest. Second, the contractors and sponsoring agents are forewarned about what lies in the path of their construction activity. When a dredge hits a wreck it can destroy a cutter head. The consequent time delays and replacement expenses cost many times what the archaeological survey which could have prevented the disaster would have cost.

During the summer and fall of 1980, such a survey was carried out in Florida's Apalachicola River. Positioning was obtained by shore-based transits. Recording was done by the transit operators. The data were brought to Texas A&M University and entered manually into the computer. The magnetometer data were imaged as printed values placed on the plot in the correct relation to the shore stations by the computer. The values were then contoured by hand. The programs modified for this work were some of those developed during the GEORGIA Project work.
In the summer of 1981, Dr. Ervan Garrison conducted a magnetometer survey of a 100 by 100 meter area of St. Catherines Island, off the Georgia coast. Dr. David Thomas, of the American Museum of Natural History, was seeking to relocate the site of a Spanish outpost and mission, Santa Catalina de Guale, which had been forcibly taken by the British in the 1680's (Thomas et al. 1978).

I mapped the data from this survey using programs developed for the GEORGIA project. The data, consisting of 2601 magnetometer readings, were ordered into a matrix. Readings had been taken every 2 meters. Because the data were already in a regularly-spaced gridded format, no gridding program was needed. The CONREC program was modified and used to produce contour maps of the magnetic features of the area. The background magnetism of the earth's field was subtracted from each reading. The differences were the values subsequently mapped. Thus, if the magnetometer read 50,175 gammas and the calibrated value of the background magnetism was 50,170, then the difference of 5 gammas was the value contoured, since it represented the part of the total reading which had been induced by man's settlement of the area. The background magnetism was determined by taking periodic readings at a locale determined to have a representative non-anomalous magnetism.

Figures 21 and 22 depict the first area surveyed, Quadrangle IV. Figure 21 is a contour map of the area, and Figure 22 is a three-dimensional isometric projection of the same area. On the contour map, the broken lines represent areas where the magnetism is less than the ambient magnetism of the earth in that general area. Such areas are said
Santa Catalina de Guale

Magnetometer Survey of Quad IV
Scale in Meters

by: James Graham Baker

Figure 21. Magnetic contour map of Quad IV, Santa Catalina de Guale.
Figure 22. Isometric plot of Quad IV, Santa Catalina de Guale.
to be negatively anomalous. Some of these areas of less-than-ambient magnetism have been excavated and have turned out to be ancient manmade shell middens (Dr. David Thomas 1982, personal communication). Shell, being less magnetic than the surrounding soil, has caused a decrease in the magnetism of areas where it is concentrated.

The solid contour lines represent areas of higher-than-ambient magnetism. Metal objects are the most common cause of such areas, but fire pits, brick, buried walls, and other cultural debris can cause a rise in magnetism. The isometric projection shown in Figure 22 is a three-dimensional rendering of the same data base seen in Figure 21. The relative size of anomalies can be quickly assessed by a quick study of such three-dimensional images. For the St. Catherines project, two isometric maps were produced for each quadrangle. One imaged the positive anomalies as elevations or mounds of magnetism. The second map imaged negatively anomalous features as mounds and the positive anomalies as depressions. By reversing the negative and positive axes it was possible to assess the relative strength of the negative anomalies which would otherwise have been masked, since they lay below the plane of ambient magnetism.

The magnetometer survey produced dramatic results. As soon as the survey was completed, obvious magnetic features were investigated. A water well and a 16th century church were quickly located (Dr. David Thomas 1982, personal communication). Later, the magnetic contour map provided the archaeologist with an extremely cost effective way to plan his excavations. The initial survey at St. Catherines was so successful
that the Museum acquired its own magnetometer and surveyed a total of nine 100 by 100 meter quadrangles. Contour maps and three-dimensional maps of the magnetometer readings for all nine quadrangles were produced on the computer. Over 25,000 magnetometer readings were included in the data. Figure 23 is the final site map of all nine quadrangles. This map and the information it contains will provide essential information for the years of excavation to come and will provide a basis for planning excavation strategy. There is little sense in digging the areas that are blank, for man's actions leave their mark on an area's magnetism, and where there are no anomalies, there is not likely to have been much activity by the earlier inhabitants.

From the above, it is clear that remote-sensing techniques and computer-graphic imaging of data offer much to the field of archaeology. In areas where poor visibility, currents, depths, or ship traffic prevent diver inspection, they provide a safe means to learn more about an area. By aiding the planning stage of an excavation, such techniques offer a cost effective way to characterize wrecks and archaeological sites on land.
Santa Catalina de Guale
American Museum of Natural History
Magnetometer Survey of Quads I, II, III, IV, VI, VII, XX, XXI, and XXII

Legend

- Positive Anomaly
- Water & Unsurveyed Areas
- Negative Anomaly
- Excavations

Scale in Meters

by: James Graham Baker

Figure 23. Magnetic contour map of Santa Catalina de Guale.
CHAPTER V
CONCLUSION

The development of a body of laws requiring management of cultural resources has led to a need to locate and characterize shipwrecks within the authority of the United States. These wreck sites lay beneath the often murky inland waterways and estuaries of our nation. Surveys relying on fathometers and magnetometers have proven effective to locate such wrecks. More detailed characterisation of such sites has rarely been attempted, and those have generally relied upon divers to provide more information concerning to the wreck sites.

Because many of our waterways have fast currents and poor visibility, diver location and characterization are not always safe or possible. In an attempt to devise a methodology to better describe the nature of such sites, computerized graphic techniques were applied to the imaging of data gathered during remote-sensing surveys of the wreck site of the C.S.S. GEORGIA. These techniques were useful in facilitating the mapping of the site. Information revealing the extent of the site, orientation of the ship's wreckage, condition of the remains, and the physical environment surrounding the site was gained by the production and interpretation of computer-graphic images based on magnetometer and bathymetric data. Also, information came to light regarding changes occurring at the site through time. Shoaling and undercut-
ting were discovered to be active processes in the wreckage. The effects of dredging could be dramatically seen; the upstream end of the wreck has been impacted and has partially collapsed into the main channel, where it appears as an extension of higher relief within the main channel. The portion of the wreck exposed by dredging activity along the northern side of the main channel has been shown to be in danger of further undercutting and collapse if channel deepening is carried out.

Diver survey, coupled with the maps and graphics produced by the programs included in the appendices, have been responsible for formulating a rather full idea of the wreck site and its environs. This picture now forms the basis for further planning to protect or possibly excavate the GEORGIA. Engineering plans for the construction of a cofferdam around the site have been drawn up using the graphics to better understand the terrain. In general, the maps and three-dimensional images have proven an effective tool to communicate a variety of information to archaeologists, planners, engineers, historians, and laypersons.

Computers proved to be an effective tool in solving the problems created by a need to process large quantities of data in a consistent, replicable, and economic manner. Microwave lane counts, sightings from transits, or readings from distance measuring units were reduced to X-Y coordinates within acceptable mapping systems (either State Plane or Universal Transverse Mercator systems). Positional information was then correlated to magnetometer and fathometer data. An grid overlaid on the graphics provided positional information that locates features
and allows later investigators to relocate both the wreck and its features.

The graphics package is flexible and allows the later addition of features, such as the cofferdam, onto the graphic image. Artifacts and structure can also be added as they are located. Such graphics can be both two-dimensional contour maps and three-dimensional. The three-dimensional images can be expanded to include the cofferdam or the structural artifacts.

Computer-graphic software is in a state of rapid development. Recent advances are nothing short of incredible. The use of computer technology by archaeology has traditionally lagged far behind the frontiers of computer applications. In nautical archaeology, Arnold (1974, 1979) has been one of the most active in applying computer-graphic technology.

We have seen how computer technology was useful in solving a particular set of problems in the GEORGIA Project and how it assisted in the management and presentation of large amount of data. We looked at some of the problems encountered and how those can be dealt with to reduce their impact. The ways in which those techniques have been useful to other nautical projects and to terrestrial archaeology have been touched upon. Now we will look at applications currently being developed, applications which will be in use in the immediate future.

The MARY ROSE Project, currently underway in Portsmouth, England, has pioneered new applications of computers in underwater work. Probably no other nautical project has had such an ambitious program of
integrating computers into the day to day activities of the excavators, conservators, managers, and curators. Britain has begun to institute an information retrieval system in her museums. Archaeologists in England have utilized computers on land excavations. The MARY ROSE Trust has built upon this foundation, expanding computer applications to the seabed. Artifacts are cataloged on computer-compatible cards, a modification of a card used by museums for automatic information retrieval. Wilcox (1981:100-122) illustrates one of these museum cards and discusses the state of computer applications in British archaeology. The data from these cards are entered into a computer file and later form the artifact catalogue. On the cards the locations where the artifacts were found are noted in three dimensions. Since the X, Y, and Z coordinates of each feature are recorded, it will be possible to create a three-dimensional drawing of the ship and to replace each item into that drawing. This can be done using computer graphics. It will be quite an easy matter to sort the artifacts and to map each category to better study the distribution of such things as fine ceramics, jewelry, and other categories of personal belongings. The computer can quickly generate graphic images for the archaeologist to study. It is also possible for the architecture of the ship to be rendered in computer graphics. Various interpretations can be drawn and more easily modified than with hand-drawn ship's lines. This is an area which will continue to become more practical as finer, more precise, and more easily operated graphics devices become available.
Business and industry are perfecting the machinery and software which will cause a revolution in drafting. That revolution goes by the acronym CAD/CAM, computer aided design and computer aided manufacturing. The technology being developed in these fields will soon break upon the public in much the same way calculators, video games, and home computers have. When that revolution is over, it will have changed much of the way we do archaeology. Most affected will be the post-excavation data analysis and mapping phase.

The graphics produced for the GEORGIA fit nominally under the umbrella of computer aided design, CAD. As such they represent a primitive application of that technique. CAD work stations were quite expensive ($100,000 to $150,000) but are becoming less so each year. They were somewhat complex to operate but increasingly are becoming "user friendly." They typically consist of a keyboard, a data tablet or digitizer, a graphic display such as a cathode ray tube, a computer, a storage media (tape or disk drives), and a plotter (which makes the drawing).

The digitizer allows the draftsman to enter the drawing into the computer by automatically converting the drawing to digital form. The cathode ray tube (CRT) allows him to view what he is drawing. Industry has embraced this technique because it is cost effective. The advantages include the easy alteration of drawings to accommodate additional information. Also, an almost unlimited palette of colors is available on certain CAD systems.
For archaeology, various reconstructions can be tried out with ease to determine the most satisfactory explanation of the recovered artifacts and features. It is no problem to image all of a certain type of artifact from a site to study its distribution -- say, all the coarse-tempered ceramics, or blue glass, or weapons. Once the information is entered, the possibilities are limited only by the imagination of the operator.

Since these systems are quite able to image objects in three dimensions, there is no reason why timbers could not be documented and reassembled on the CRT. Once imaged, the timbers may be assembled and the entire assemblage rotated, allowing inspection of the reconstruction from any angle. These are not fantasies. Similar applications of CAD systems are being employed daily in science and industry. Although some people fear the loss of human values and judgements, the computer exists only as a tool to facilitate the making of human judgements and the upholding of human values.

Increasingly, the positioning and mapping of excavations will also be computerized. The resulting reduction in precious bottom time will provide a strong stimulus for the further development of these techniques. Kelland (1973:163-176 and 1976:17-32) has pointed the way to the development of an underwater sonar system for mapping of objects and submerged features. The technology exists today to assemble a system linked to a shipboard computer. Such a system would consist of a mobile transducer and a number of submerged transducers fixed at known coordinates. The mobile unit would be moved to the point to be mapped and
triggered. A sound pulse would travel to the transducers and back to the mobile unit, where the time elapsed would be measured and sent up a wire to the topside computer. The entire system would function like the digitizers of a CAD system. The time-consuming mapping and measuring of artifacts and features would be facilitated for situations where visibility is poor and photogrammetry is impossible.

This thesis has discussed the use of computer processing and computer graphics to characterize the wreck site of the C.S.S. GEORGIA and the processes effecting that site. Baseline data were developed allowing engineers and planners to plan for the future. Based upon this information, a cofferdam has been designed. If constructed, this dam would still the waters of the Savannah River, improving visibility and creating a safe working environment for nautical archaeologists. Test excavations could then proceed in a safe and scientific manner. Planners in the Corps of Engineers have been provided with information necessary to comply with legislation protecting such historic sites. Should harbor widening be undertaken they will have a plan to preserve the GEORGIA. Finally, computer-graphic techniques have been developed, and these have already been applied in a number of other archaeological projects. The success of these techniques has been repeated for other environments -- the Mississippi and Apalachicola Rivers. The American Museum of Natural History has had the author modify these programs for use on land magnetometer surveys. We have seen that the opportunities for the successful applications of computers in the field of nautical archaeology is by no means limited to graphics. Cataloging, text edit-
ing, recording, statistical operations and a myriad of other jobs can be facilitated by the computer. Finally, we have indulged in a bit of reasoned speculation about the future and the great opportunities for computer technology to aid the archaeologist.

No pretense is intended that all the applications of computers or even computer graphics have been touched upon. The potential is so vast that archaeologists will be exploring all the options for years. I have attempted to touch upon some of the areas likely to bear fruit abundantly if we will but till the ground.
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APPENDIX A: RAW BATHYMETRIC DATA

The following list of data is an example of the data which came from the survey vessel CARLSON during the bathymetric surveys conducted over the GEORGIA wreck site. It was read into the A&M computer from a punched paper tape produced during survey. The data are randomly-spaced as a function of wind, tides and currents. In order to be mapped by a contouring program, the data must be processed using a program such as one in Appendix B.

Time   Depth Range1 Range2
1018435 00398 011376 026186
1018446 00396 011370 026185
1018457 00399 011364 026184
1018470 00399 011357 026183
1018482 00398 011351 026182
1018496 00411 011344 026182
1018508 00398 011338 026181
1018523 00402 011330 026180
1018539 00400 011322 026179
1018550 00408 011317 026178
1018564 00409 011310 026177
1018582 00415 011303 026175
1018599 00411 011296 026174
<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
</table>
| 1019013 | 00415 | 011289 | 026173 |(10,88),(794,257)
| 1019025 | 00419 | 011283 | 026172 | 1019040 | 00422 | 011275 | 026172 |
| 1019054 | 00430 | 011268 | 026171 | 1019065 | 00425 | 011263 | 026171 |
| 1019080 | 00424 | 011255 | 026172 | 1019094 | 00297 | 011249 | 026171 |
| 1019106 | 00291 | 011243 | 026171 | 1304067 | 00311 | 011179 | 026392 |
APPENDIX B: GRIDDING PROGRAMS

The following is a program which processes randomly-spaced data from bathymetric or magnetometric surveys. It provides values for intersections of a regular grid based on mathematical interpolation of the randomly spaced data base. It writes these new values to a file to be used by the CONREC program for contouring or by the SRFACE program for production of three-dimensional isometric images.

Two examples of the gridding program are included in this appendix. The first one is the program used to grid the data base for Figure 6 (p. 47). In this program the value for IB is set too small and the result was the aising seen in the Figure 6 (p. 47). It differs from the second program also in the values set for AK, having the lower value more appropriate for magnetic contouring.

Southwest Pass Gridding Program

//GRIDITSW JOB (R269,3D,1,1,JB), 'JIM BAKER'

/*LEVEL 1

// EXEC WATFIV,REGION=512K

//FT08F001 DD DSN=USR.R269.JB.SWPASS,DISP=SHR

//FT09F001 DD DSN=USR.R269.JB.BADSW,DISP=SHR

//SYSIN DD DATA

//SOPTIONS

C PRECEEDING LINES ARE JOB CONTROL LANGUAGE WITH INSTRUCTIONS
FOR THE MACHINE OPERATOR, IDENTIFYING THE ACCOUNT TO BE BILLED,
DIRECTING FINISHED OUTPUT, TELLING WHERE RAW DATA FILES ARE,
AND SPECIFYING AMOUNT OF MEMORY REQUIRED TO RUN THE PROGRAM.

THIS PROGRAM GRIDS X-Y COORDS WHICH HAVE BEEN OBTAINED
IN UNIVERSAL TRANSVERSE MERCATOR UNITS. THIS ISSUES
RESULTS USEABLE BY CONREC. IT IS PARTICULARLY USEFUL IN
THE MAPPING OF MAGNETOMETER DATA. NXMAX AND NYMAX NEED TO BE
RESET AS THE DIMENSIONS OF THE ARRAY CHANGE.
TO CHANGE THE SCALE, ALTERATIONS SHOULD BE MADE TO THE
EQUATIONS IN WHICH THE VALUES FOR X AND Y ARE DERIVED.
IF THE DIVISOR IS MADE LARGER, THE MATRIX WILL COVER A
LARGER AREA. IF THE DIVISOR IS MADE SMALLER, THE MATRIX WILL
COVER A SMALLER AREA.

REAL A(71,51,2), B(51,71)

REAL A AND B DEFINE TWO MATRICES TO BE FILLED BY THE PROGRAM,
ONE OF THESE IS FOR THE WRITING TO A FILE AND THE OTHER IS TO
BE PRINTED OFF ON THE PRINTER TO ALLOW THE PROGRAMMER TO CHECK
THE NUMBERS TO SEE IF THEY ARE REASONABLE. IN THIS CASE THE
MATRICES SIZES ARE 71 BY 51 CELLS AND 51 BY 71.
NYMAX AND NXMAX ARE THEN DEFINED.

NYMAX=71
NXMAX=51

DO 7 I=1,NYMAX

DO 7 J=1,NXMAX

DO 7 K=1,2
7 A(I,J,K)=0.0
C THE ABOVE 4 LINES CREATE THE MATRIX OF CELLS AND SET ALL
C VALUES EQUAL TO ZERO.
IB=1
C AS STATED THE IB FACTOR GOVERS THE WINDOW OF INFLUENCE.
C IF A LARGE VALUES IS ASSIGNED TO IB, THE WINDOW OF INFLUENCE
C WILL COVER A LARGER AREA THAN IF A SMALLER NUMBER IS ASSIGNED.
C THIS ASSIGNMENT DECIDES HOW MANY ADJACENT CELLS OF THE MATRIX
C WILL BE USED IN THE INTERPOLATION OF CELL VALUES.
AK=.25
C THE AK VALUE DETERMINES HOW DATA POINTS ARE TO BE WEIGHED
C RELATIVE TO EACH OTHER. THE WEIGHING IS A FUNCTION OF
C DISTANCE FROM THE DATUM POINT TO THE GRID POINT BEING
C DERIVED. POINTS FURTHER AWAY WILL CONTRIBUTE LESS TO
C DETERMINING THE VALUES OF THE GRID POINTS THAN WILL POINTS
C CLOSE TO THE GRID POINTS. THE HIGHER THE VALUE FOR AK, THE
C CLOSER YOU APPROACH A WEIGHING OF 1, WHERE ALL DATA POINTS
C HAVE THE SAME WEIGHT WITHIN THE WINDOW OF INFLUENCE. YOU
C BEGIN TO HAVE THE EFFECT OF AVERAGING. THIS AVERAGING WILL
C PULL DOWN OR MASK ANOMALIES AND IS NOT A DESIREABLE FEATURE
C FOR MAGNETOMETER SURVEYS. AS AK VALUES APPROACH ZERO, LESS
C LESS AVERAGING OCCURS, DATA SPIKES SHOW UP MORE CLEARLY IN
C THE GRIDDED OUTPUT. THE EFFECT IS TO PRESERVE GREATER
C INFLUENCE FOR ANOMALOUS READINGS.
4 READ(8,19,END=99) VAL,X,Y
C THE READ STATEMENT TELLS THE COMPUTER WHERE THE DATA IS STORED
AND HOW THE READINGS ARE ORDERED, THE MAGNETOMETER VALUE
(VAL), THE X COORDINATE, AND Y COORDINATE. A FORMAT STATEMENT
INFORMS THE COMPUTER OF THE NUMBER OF DIGITS OCCUPIED BY
EACH NUMBER. IN THIS CASE THE MAGNETOMETER READING WILL BE
SEVEN DIGITS LONG WITH ONE OF THOSE BEING TO THE RIGHT OF THE
DECIMAL POINT. X-Y VALUES ARE TO BE 10 DIGITS LONG, WITH
TWO OF THOSE TO THE RIGHT OF THE DECIMAL POINT.

19 FORMAT(F7.1,2F10.2)

THE NEXT THREE LINES CONTAIN A CORRECTION FACTOR TO ADJUST
THE X AND Y VALUES TO ALLOW FOR THE DISTANCE FROM THE
TOWED MAGNETOMETER FISH TO THE TRANSPONDER ON THE SURVEY
VESSEL WHICH IS RECORDING POSITIONING DATA.

THE FIRST VALUE IN "ANG" IS THE ANGLE OFF AN E-W LINE
THAT THE VESSEL WAS TRAVELLING. FOR THIS FACTOR TO WORK IT IS
IMPORTANT THAT THE VESSEL'S DIRECTION BE ALWAYS UPRIVER AND
AT THE SAME ANGLE TO THE EAST-WEST LINE, AND AS STRAIGHT AS
POSSIBLE IN THE LAST TWO LINES, THE DISTANCE FROM THE FISH
TO THE TRANSPONDER, IS SUBTRACTED FROM THE X-Y COORDS
RECORDED BY THE SENSOR.

ANG=(68. *3.14159)/180.0
X=(((X-25.*COS(ANG))-278500)/25.
Y=(((Y-25.*SIN(ANG))-3220750)/25.

THE PREVIOUS TWO LINES SET THE X AND Y ORIGINS OF THE GRID,
AND 25 IS SET AS THE GRID SPACING, THE CELL SIZE OF THE MATRIX.
IXF=IFIX(X+0.49)-18

IFIX CONVERTS REAL NUMBERS INTO INTEGER NUMBERS BY REACHING
OUT TO THE NEAREST X VALUE -IB AND ADDS .49 SO THAT VALUES
ABOVE .51 BECOME 1 AND VALUES BELOW .49 BECOME 0.

IF(IXF.GT.(NXMAX-1)) GO TO 4

THIS IS A COUNTER THAT KEEPS THE ROUTINE FROM DERIVING
VALUES WHICH FALL OUTSIDE THE MATRIX GRID.

IF(IXF.LT.0) IXF=0

THE PREVIOUS LINE PREVENTS THE DERIVATION OF VALUES IN THE
NEGATIVE X QUADRANT.

IXL=IFIX(X+0.49)+IB

IFIX CONVERTS REAL NUMBERS INTO INTEGER NUMBERS BY REACHING
OUT TO THE NEAREST X VALUE +IB AND ADDS .49 SO THAT VALUES
ABOVE .51 BECOME 1 AND VALUES BELOW .49 BECOME 0.

IF(IYL.LT.0) GO TO 4

THE ABOVE IS A ROUTINE TO PREVENT THE DERIVATION OF VALUES
IN THE -X DIRECTION.

IF(IYL.GT.(NYMAX-1)) IYL=(NYMAX-1)

THIS ADJUSTS THE VALUE OF THE NEAREST NEIGHBOR TO THE
MAXIMUM X DIRECTION VALUE TO PREVENT THE DERIVATION OF
VALUES GREATER THAN THE MATRIX SIZE.

IYF=IFIX(Y+0.49)-IB

IF(IYF.GT.(NYMAX-1)) GO TO 4

IF(IYF.LT.0) IYF=0

IYL=IFIX(Y+0.49)+IB

IF(IYL.LT.0) GO TO 4

IF(IYL.GT.(NYMAX-1)) IYL=(NYMAX-1)
THE PRECEEDING 6 LINES DO THE SAME STEPS FOR THE Y VALUES

THAT WAS DONE IN THE 6 LINE OF CODE PRECEEDING THEM DID

TO VALUES IN THE X DIRECTION.

THE FOLLOWING 4 LINES ARE COUNTERS TO MOVE THE CALCULATIONS.

\[ \text{IXF} = \text{IXF} + 1 \]

\[ \text{IXL} = \text{IXL} + 1 \]

\[ \text{IYF} = \text{IYF} + 1 \]

\[ \text{IYL} = \text{IYL} + 1 \]

THE NEXT TWO LINES OBTAIN VALUES FOR IIX AND IYY

DO 1 IIX = IXF, IXL

DO 1 IYY = IYF, IYL

THE FOLLOWING TWO LINES CALCULATE THE DISTANCE FROM THE

KNOWN DATA POINTS TO THE GRID POINTS WHOSE VALUE IS TO BE

DERIVED.

\[ \text{DD} = ((\text{FLOAT(IIX-1)} - X) \times (\text{FLOAT(IIX-1)} - X)) \]

\[ 1 / ((\text{FLOAT(IYY-1)} - Y) \times (\text{FLOAT(IYY-1)} - Y)) \]

THE NEXT LINE CALCULATES THE WEIGHTING FACTOR.

\[ \text{WT} = \exp(-\text{DD/AK}) \]

THE FOLLOWING TWO LINES DERIVE VALUES FOR THE GRID

INTERSECTIONS.

\[ A(IYY, IIX, 1) = A(IYY, IIX, 1) + WT \times VAL \]

\[ A(IYY, IIX, 2) = A(IYY, IIX, 2) + WT \]

THE CONTINUE AND GO STATEMENTS CYCLE THE PROGRAM SO IT REPEATS

THE CALCULATIONS UNTIL ALL GRID POINTS ARE DERIVED.

THE NEXT 18 LINES OF CODE ARE FILLING THE TWO MATRICES
C WHICH WERE CREATED TO HOLD THE DATA.

1 CONTINUE
   GO TO 4

99 CONTINUE
   DO 2 I=1,NYMAX
   DO 2 J=1,NXMAX
   IF(A(I,J,2).GT.0.0) GO TO 11
   A(I,J,1)=-99.
   GO TO 2

11 CONTINUE
   A(I,J,1)=A(I,J,1)/A(I,J,2)

2 CONTINUE
   II=NYMAX+1
   DO 33 I=1,NYMAX
   II=II-1
   JJ=NXMAX+1
   DO 33 J=1,NXMAX
   JJ=JJ-1

33 B(J,1)=A(I,J,1)
C THE FOLLOWING THREE LINES ARE INSTRUCTING THE PROGRAM TO
C WRITE ALL THE DATA POINTS SOLVED TO A TAPE FILE FOR STORAGE.
C
C WRITE(9,88) B

88 FORMAT(10F8.1)
   DO 10 I=1,NXMAX
C THE NEXT 5 STATEMENTS ARE WRITING THE DATA TO THE HARDCOPY
C PRINTER AND FORMATTING THAT OUTPUT. THE FINAL LINES ARE
C TERMINATING THE PROGRAM.

WRITE(6,66) (A(J,1,1),J=1,NYMAX)

WRITE(6,65)

65 FORMAT(///)

66 FORMAT(15F7.1)

10 CONTINUE

STOP

END

C THE //SDATA STATEMENT INDICATES THAT THE DATA TO BE PROCESSED
C WILL FOLLOW IMMEDIATELY.

//SDATA

GEORGIA Bathymetric Data Gridding Program.

This and similar programs were used for the production of the
gridded data which were later mapped using CONREC and SRFACE programs.
This program has an IB and an AK value suitable for bathymetric data
and for the density of data collection of the GEORGIA bathymetric sur-
veys.

//GRIDIT JOB (R277,03D,1,1,JB), 'JIM BAKER'

/*JOBPARM R=256

// EXEC WATFIV,REGION=256K

//FT08F001 DD DSN=WYL.ST.RHZ.MAY,DISP=SHR

//FT09F001 DD DSN=WYL.ST.RHZ.MAYGRD60,DISP=SHR

//SYSIN DD DATA

//SOPTIONS
DOUBLE PRECISION V,H4,X1,X2,Y1,Y2,XJ,XK,XL,XK1,XK2,XM,XN,
1P,S,XAT,YAT,D SQRT

REAL A(61,81,2),B(81,61)

DO 7 I=1,61
DO 7 J=1,81
DO 7 K=1,2
7 A(I,J,K)=0.0

IB=3

AK=1.0

C THE MAJOR DIFFERENCE BETWEEN THIS PROGRAM WHICH WAS USED TO
C GRID THE GEORGIA BATHYMETRIC DATA AND THE PREVIOUS ONE, USED
C TO GRID MAGNETOMETER DATA IS TO BE FOUND IN THE NEXT 22 LINES
C OF STATEMENTS. THESE LINES COMPRIS E A SUBROUTINE TO DERIVE
C X-Y COORDINATES FROM THE RANGE-RANGE DATA OF THE MICROWAVE
C POSITIONING SYSTEM. THIS SUBROUTINE TAKES THE PLACE OF THE
C SUBROUTINE WHICH COMPENSATED FOR THE SENSOR-TRANSDUCER
C OFFSET USED IN THE PREVIOUS PROGRAM. OTHER THAN THIS DIFFERENCE
C THE TWO PROGRAMS ARE FUNCTIONALLY SIMILAR.

V=147.879*2*3325.4

H4=3325.40

X1=842260.10

Y1=774640.67

X2=882687.71

Y2=780229.39

XJ=DSQRT((X2-X1)**2+(Y2-Y1)**2)

XK=(X2-X1)/XJ
XL = (Y2 - Y1) / XJ

XK1 = \sqrt{V / 200.} / H4

XK2 = XJ * XJ

4 READ(8,19,END=99) VAL, R, G

19 FORMAT(8X,F5.1,2F7.0)

XM = (XK1*R)**2

XMM = XK1*R

XN = (XK1*G)**2

P = (XM - XN + XK2) / (2. * XJ)

CHK = XM - P**P

IF (CHK .LT. 0.0) GO TO 4

S = DSQRT(XM - P**P)

XAT = P*XM + S*XL + X1

YAT = P*XL - S*XK + Y1

X = (XAT - 849350.) / 5.

Y = (YAT - 759550.) / 5.0

IXF = IFIX(X + 0.49) - IB

IF (IXF .GT. 80) GO TO 4

IF (IXF .LT. 0) IXF = 0

IXL = IFIX(X + 0.49) + IB

IF (IXL .LT. 0) GO TO 4

IF (IXL .GT. 80) IXL = 80

IYF = IFIX(Y + 0.49) - IB

IF (IYF .GT. 60) GO TO 4

IF (IYF .LT. 0) IYF = 0

IYL = IFIX(Y + 0.49) + IB
IF(IYL.LT.0) GO TO 4
IF(IYL.GT.60) IYL=60
IXF=IXF+1
IXL=IXL+1
IYF=IYF+1
IYL=IYL+1
DO 1 IIX=IXF,IXL
   DO 1 IYY=IYF,IYL
      DD=((FLOAT(IIX-1)-X)*(FLOAT(IIX-1)-X))
      1((FLOAT(IYY-1)-Y)*(FLOAT(IYY-1)-Y))
      WT=EXP(-DD/AK)
      A(IYY,IIX,1)=A(IYY,IIX,1)+WT*VAL
      A(IYY,IIX,2)=A(IYY,IIX,2)+WT
   1 CONTINUE
   GO TO 4
99 CONTINUE
   DO 2 I=1,61
   DO 2 J=1,81
      IF(A(I,J,2).GT.0.0) GO TO 11.
      A(I,J,1)=-99.
   2 CONTINUE
5 CONTINUE
   A(I,J,1)=A(I,J,1)/A(I,J,2)
2 CONTINUE
   II=62
   DO 33 I=1,61
II=II-1
JJ=82
DO 33 J=1,81
JJ=JJ-1

33 B(J,I)=A(I,J,1)
WRITE(9,88) B

88 FORMAT(10F8.3)

DO 10 I=1,81
WRITE(6,66) (A(J,I,1),J=1,31)

66 FORMAT(//,2X,31F4.1)

10 CONTINUE
STOP
END

//SDATA
APPENDIX C: GRIDDED DATA

The following numbers were derived by processing Appendix A using the program in Appendix B. These numbers are the regularly-spaced depth values which are required by the contouring program in Appendix D. The "-99.000" value is used to indicate a data void. All numbers are depths below mean low water level in the Savannah River.

\[
\begin{array}{ccccccccccc}
40.906 & 41.177 & 42.012 & 42.091 & 42.032 & 42.013 & 42.058 & 41.880 \\
42.246 & 42.305 & 42.350 & 42.466 & 42.321 & 42.297 & 42.268 & 41.918 \\
41.615 & 41.504 & 41.500 & 41.622 & 41.762 & 41.753 & 41.911 & 42.062 \\
40.726 & 40.707 & 40.685 & 40.800 & 41.224 & 41.745 & 41.886 & 41.913 \\
41.137 & 41.087 & 41.078 & 41.196 & 41.195 & 41.196 & 41.165 & 40.962 \\
40.900 & 40.400 & 40.400 & 40.400 & 40.400 & 40.400 & 40.400 & -99.000 \\
40.900 & 40.906 & 42.352 & 42.387 & 42.363 & 42.290 & 42.163 & 42.058 \\
42.282 & 42.307 & 42.216 & 42.033 & 41.903 & 42.185 & 42.345 & 42.296 \\
41.176 & 41.004 & 41.407 & 41.499 & 42.038 & 42.044 & 41.978 & 41.928 \\
40.952 & 40.883 & 40.806 & 40.756 & 40.945 & 40.932 & 41.159 & 41.690 \\
41.512 & 41.280 & 41.320 & 41.389 & 41.266 & 41.068 & 41.089 & 41.012 \\
40.900 & 40.892 & 40.400 & 40.400 & 40.400 & 40.400 & 40.400 & 40.400 \\
\end{array}
\]
APPENDIX D: A CONTOURING PROGRAM

The following program is the plotting routine which takes the regularly spaced and gridded data from Appendix C and produces the final contour map. Within the program are subroutines which draw the dredged channel and the coffer dam in the appropriate locations. Also the air-jet probes are located by calls to PSYM which specify the coordinates of each probe. The probe location is then symbolized with an asterisk. Figure 12 (p. 64) was produced using this program. It is a variety of CONREC (Reid 1980).

A CONREC Contouring Program Example.

//MAY60 JOB (R269,3D,1,10,JB), 'JIM BAKER'

//*LEVEL 0

//PROCLIB DD DSN=WYL.PC.RPO.PROCLIB, DISP=SHR

// EXEC TXRGSP, REGION=256K

//GO.PLOTPARM DD *

&PLOT MSGLVL=1 XMAX=25.0 SCALE=.5 &END

//GO.SOURCE DD *

C   THE PRECEEDING LINES ARE JOB CONTROL LANGUAGE AND SPECIFY
C   WHICH ACCOUNT WILL BE CHARGED, WHEN THE PROGRAM WILL BE RUN
C   AND A VARIETY OF OTHER PARAMETERS.

REAL A(81,61)

C   "REAL A" IS A REAL ARRAY CONSISTING OF 81 CELL OF LENGTH AND
61 CELLS OF WIDTH.

COMMON/CONRE1/SIZEL,SIZEM,SIZEP,NLA,NLM,XLT,YBT,SIDE,NREP,NCRT,
1ILAB,NULBL,IOFFD,EXT,IOFFP,SPVAL,IOFFM,ISOLID,IHILO

THE PREVIOUS TWO LINES ARE A CALL TO ALLOW THE COMPUTER TO
ACCESS PROGRAMS STORED IN THE COMMON CONREC BLOCK. THERE IS A
LIST OF THE OPTIONS INCLUDED IN THAT BLOCK WHICH THE USER MAY
CHOOSE TO USE. IF A PARTICULAR OPTION IS CHOSEN THE VALUE OF IT
IS SET, AS VALUES ARE SET FOR SIZEM, IOFFP, SPVAL, AND IHILO
IN THE FOLLOWING LINES.

SIZEM=1.5

SIZEM DEFINES THE CHARACTER SIZE USED TO LABEL THE CONTOURS.

IOFFP=1

IOFFP IS USED TO TELL THE COMPUTER A SPECIAL VALUE WILL BE
USED, IN THIS CASE 1 SPECIAL VALUE WILL BE USED.

SPVAL=-99.

SPVAL IS USED TO ASSIGN A NUMERICAL VALUE TO THE SPECIAL VALUE
FEATURE. BY ASSIGNING A VALUE OF -99 TO THE SPVAL WE ARE ABLE
TO INSERT -99 INTO OUR DATA BASE WHERE DATA VOIDS APPEAR. THE
CONREC PROGRAM WILL THEN KNOW NOT TO CONTOUR IN THOSE AREAS.

IHILO=0

IHILO CAN BE SET TO HAVE HIGHS AND LOWS ON THE MAP LABELED,
OR ONLY HIGHS LABELED, OR ONLY LOWS, OR NEITHER.

READ(8,88) A

THE READ STATEMENT TELL THE COMPUTER WHERE TO GET THE DATA TO
BE CONTOURED. IN THIS CASE IT IS ON UNIT 8, AND WILL BE IN THE
FORMAT DESCRIBED IN THE FOLLOWING LINE, IN THE FORM
OF AN ARRAY.

88 FORMAT(10F8.3)

THE FORMAT STATEMENT TELLS THE COMPUTER HOW TO READ THE DATA.

CALL PLOTS(0,0,0)

THE CALL TO PLOTS INITIALIZES THE PLOTTING AND INDICATES THAT
A PLOT IS TO BE PRODUCED.

CALL SYMBOL(1.0,1.0,.2,'X',0.0,1)

THE CALL TO SYMBOL IN THIS CASE WILL PRINT AN "X" AT THE LOWER
LEFT HAND CORNER OF THE MAP, AT THE ORIGIN THAT IS.

CALL SET(1.0,17.0,1.0,13.0,849350.0,849750.0,759550.0,
1759850.0,1)

THE CALL TO SET ESTABLISHES THE RELATIONSHIP THAT WILL PREVAIL
BETWEEN THE MACHINE SPACE AND THE GRID SYSTEM YOU WILL USE ON
THE FINISHED MAP. THE PLOTTER HAS ITS OWN GRID WHICH MUST BE
MADE TO RELATE TO THE DESIRED MAP'S GRID.

THE FOLLOWING CALLS TO PSYM ARE PLOTTING THE PROBE LOCATIONS
AND BUOYS' LOCATIONS. THE FIRST SET OF COORDINATES ARE THE
LOCATION OF EACH POINT TO BE PLOTTED, THE OTHER NUMBERS
SPECIFY THE SYMBOL TO BE USED AND THE SIZE OF THE SYMBOL.

CALL PSYM(849466.30,759531.50,11,1,0,1)

CALL PSYM(849564.20,759589.10,11,1,0,1)

CALL PSYM(849584.30,759624.10,11,1,0,1)

CALL PSYM(849600.50,759641.40,11,1,0,1)

CALL PSYM(849620.50,759670.10,11,1,0,1)

CALL PSYM(849640.80,759670.10,11,1,0,1)

CALL PSYM(849579.00,759718.80,11,1,0,1)
CALL PSYM(849641.00,759619.90,11,1,0,1)
CALL PSYM(849665.20,759683.60,11,1,0,1)
CALL PSYM(849649.90,759838.10,11,1,0,1)
CALL PSYM(849536.60,759819.00,11,1,0,1)
CALL PSYM(849509.40,759791.50,11,1,0,1)
CALL PSYM(849476.00,759790.20,11,1,0,1)
CALL PSYM(849465.00,759759.30,11,1,0,1)
CALL PSYM(849416.50,759756.20,11,1,0,1)
CALL PSYM(849427.30,759715.00,11,1,0,1)
CALL PSYM(849398.80,759699.10,11,1,0,1)
CALL PSYM(849396.50,759669.80,11,1,0,1)
CALL PSYM(849641.50,759828.30,11,1,0,1)
CALL PSYM(849581.20,759815.90,11,1,0,1)
CALL PSYM(849625.50,759811.70,11,1,0,1)
CALL PSYM(849646.30,759748.60,11,1,0,1)
CALL PSYM(849672.80,759695.00,11,1,0,1)
CALL PSYM(849663.20,759750.80,11,1,0,1)
CALL PSYM(849430.30,759557.00,11,1,0,1)
CALL PSYM(849413.50,759601.40,11,1,0,1)
CALL PSYM(849418.50,759605.30,11,1,0,1)
CALL PSYM(849410.60,759647.60,11,1,0,1)
CALL PSYM(849352.90,759651.50,11,1,0,1)
CALL PSYM(849350.00,759550.00,9,1,0,1)
CALL PSYM(849350.00,759850.00,9,1,0,1)
CALL PSYM(849750.00,759550.00,9,1,0,1)
CALL PSYM(849750.00,759850.00,9,1,0,1)
CALL PSYM(849542.00, 759671.00, 10, 1, 0, 1)
CALL PSYM(849523.00, 759647.00, 10, 1, 0, 1)
CALL NEWPEN(3)

C A CALL TO NEWPEN IS USED TO CHANGE THE LINE WEIGHT, ON
C ON COLOR PLOTTERS, THIS CALL IS USED TO CHANGE COLORS. HIGHER
C NUMBERS PRODUCE THICKER LINES ON BLACK AND WHITE PLOTTERS.
C THE NEXT THREE LINES ARE INSTRUCTIONS FOR DRAWING LINES
C TO INDICATE THE LIMITS OF THE DREDGED RIVER CHANNELS.
C A CALL TO FIRST POINT TELL THE PLOTTER WHERE TO BEGIN,
C THE FOLLOWING TWO CALLS DIRECT THE PLOTTER TO DRAW A LINE TO
C THE POINTS SPECIFIED IN THOSE CALLS.
CALL FRSTPT(849350.0, 759664.0)
CALL VECTOR(849475.0, 759600.0)
CALL VECTOR(849750.0, 759722.0)
CALL NEWPEN(4)

C AGAIN NEWPEN IS USED TO DARKEN THE LINE WEIGHT FOR DRAWING
C THE COFFERDAM. THE FOLLOWING LINES DIRECT THE DRAWING OF THE
C DAM'S PERIMETER.
CALL FRSTPT(849748.5, 759712.0)
CALL VECTOR(849471.0, 759586.0)
CALL VECTOR(849406.5, 759722.5)
CALL VECTOR(849683.0, 759848.0)
CALL VECTOR(849748.5, 759712.0)
CALL NEWPEN(1)

C THIS NEWPEN CALL RESETS THE LINE WEIGHT. THE CALL TO LABMOD
C FOLLOWING SETS LABEL SIZES, TYPE FACE, AND ORIENTATION.
THE CALL TO GRIDAL ESTABLISHES THE TYPE AND SIZE OF GRID TO
BE EMPLOYED. THE SECOND CALL TO SET IS USED TO ESTABLISH THE
RELATIONSHIP BETWEEN THE PLOTTER'S GRID AND THE MATRIX
IN WHICH THE DATA IS STORED.

CALL LABMOD(6H(F5.0),6H(F4.0),0,0,0,0,1,1,0)
CALL GRIDAL(8,1,6,1,2,1,2,0)
CALL SET(1.0,17.0,1.0,13.0,1.0,81.0,1.0,61.0,1)
CALL CONREC(A(1,1),81,81,61,27.,40.,1.,1)
CALL PLOT(0.,0.,999)

THIS CALL TO PLOT IS AN INDICATOR TO THE PLOTTER THAT ALL
PLOTTING IS TERMINATED. THE STOP AND END STATEMENTS STOP AND
END THE PROGRAM. TWO FINAL LINES OF JOB CONTROL LANGUAGE
GIVE THE ADDRESS OF THE DATA FILE CONTAINING THE VALUES TO
BE CONTOURED.

STOP
END

//GO.FT08F001 DD DSN=WYL.JB.RHR.MAYGRD60,DISP=SHR
//GO.SYSIN DD *
VITA

James Graham Baker was born on November 18, 1946, the son of Douglas Dunlop Baker and Penelope Irene Elizabeth Baker. His father's occupation, construction management, demanded the family travel widely. During his teens, the family lived in Utah, where he developed his interest in archaeology.

While studying for a B.A. in Anthropology from Southern Methodist University, he did field work in Texas, New Mexico, Venezuela, and Guatemala. Following graduation in 1972, he worked in a wide variety of fields. In 1973 and 1974, he studied mesoamerican prehistory at Mexico's University of the Americas.

He returned to Texas in 1974 to marry Bobbe Jean Clinton, an artist and professional photographer. They returned to graduate school in 1979. While studying nautical archaeology at Texas A&M, he worked as a Research Assistant for the Cultural Resource Laboratory and later as a Research Associate for the Environmental Engineering Division and the Data Processing Center of the Texas Engineering Experiment Station. He served as data manager and developed computer-graphic programs for the investigations of the C.S.S. GEORGIA. His work in computer-graphic applications in archaeology includes map production for and participation in the MARY ROSE Project in southern England, the American Museum of Natural History's Santa Catalina de Guale Project, the National Park Service's Point Reyes Peninsula Survey, and a survey in the lower reaches of the Mississippi.

His home is at 1119 Ashburn, College Station, Texas 77840.