OCS Study
MMS 89-0024

Historic Shipwrecks and Magnetic Anomalies of the Northern Gulf of Mexico

Reevaluation of Archaeological Resource Management Zone 1

Volume II: Technical Narrative

U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

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ABSTRACT

As a result of Minerals Management Service (MMS) remote sensing surveys, numerous unidentified magnetic anomalies and side-scan sonar contacts which could represent historic shipwrecks have been recorded in the Gulf of Mexico (GOM). The objectives of this study are divided into two tasks. Task I provides a collection, evaluation, and synthesis of archaeological, environmental, and geographic data to evaluate and redefine the Cultural Resource Management Zone 1 (CRMZ1) in the Gulf. The CRMZ1 is an area considered to have a high probability for the occurrence of historic shipwrecks.

Task II was designed to establish an interpretive framework that would help identify the nature of magnetic anomalies and side-scan sonar contacts within the CRMZ1. Field studies were conducted to determine the relationship between linespacing of magnetometer and side-scan surveys and the percentage of objects detected on the seafloor. These data were then analyzed to investigate whether remote sensing data gathered during a cultural resource survey could discriminate between a cultural resource and recent debris.

The results from Task I indicate: (1) an increased distribution of shipwrecks in the eastern Gulf beyond the present CRMZ1 boundary but a low preservation potential at these wreck sites, and (2) a higher potential of finding shipwrecks around historic port areas in the central and western Gulf because of higher preservation potential.

Recommendations to relocate the CRMZ1 based upon both the distribution of reported shipwreck locations and their preservation potential are made. It is proposed that the CRMZ1 be moved to within 10 km of the Gulf coast and that specific higher probability zones be delineated outside the CRMZ1 that reflect the increased frequency of wrecks in the vicinity of ports and certain hazards.

The results of Task II indicate: (1) magnetic anomalies increase in direct proportion to area surveyed, i.e. the 150 m line interval detects one-third of the anomalies compared to a 50 m line interval survey, (2) survey areas with oil and gas structures have higher numbers of magnetic anomalies than undeveloped survey areas, and (3) the present survey methods used for cultural resource surveys are not sensitive enough to differentiate between modern debris and a potential cultural resource.

Other methods can more confidently differentiate between modern debris and shipwrecks. One method forms the basis of our recommendations on Task II which suggest using 50 m lane spacing for survey areas having a high potential for shipwrecks. The recommendations in both Task I and II combine to reduce the general survey area on the Outer Continental Shelf (OCS) but increase the effectiveness of the surveys in areas that have a high probability of both shipwreck density and preservation potential.

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Task I An Evaluation of Cultural Resource Management Zone 1

1.0 INTRODUCTION

For more than 11 years, the Federal Government has required oil and gas lessees to conduct remote sensing surveys for the detection of significant historic and prehistoric archaeological resources prior to development of their leases on the Outer Continental Shelf (OCS). The authority for this requirement is based primarily on the National Historic Preservation Act of 1966, as amended, which states in effect that any Federal Agency, prior to approving federally permitted or federally funded undertakings, must take into consideration the effect of that undertaking on any National Register or National Register eligible property. Also stated in Section 110 of this legislation and in Executive Order 111593 is that an effort must be made to locate such properties prior to development of an area. The OCS Lands Act Amendments of 1978 specifically states in Section 206(g)(3) that "such exploration (oil and gas) will not . . . disturb any site, structure, or object of historical or archaeological significance." The National Environmental Policy Act of 1969, as amended, states in Section 101(b)(4) that the Federal Government has a continuing responsibility to ". . . preserve important historic, cultural, and natural aspects of our national heritage . . ."

In 1977, a baseline study, *Cultural Resources Evaluation of the Northern Gulf of Mexico Continental Shelf*, 3 vols., Coastal Environments, Inc., was conducted in order to better determine where significant properties may occur in the Gulf of Mexico (GOM). This study generated models for predicting the locations of historic and prehistoric archaeological sites on the OCS. (These reports are available from the National Technical Information Service (NTIS) with the following order numbers: *Vol. I, Prehistoric Cultural Resource Potential*, PB-276773/AS; *Vol. II, Historical Cultural Resources*, PB-276774/AS; and *Vol. III, Maps*, PB-286-874/AS.) *The Minerals Management Service (MMS) Manual for Archaeological Resource Protection* requires that these archaeological baseline studies, which are the basis for MMS decisions on where to invoke the archaeological survey requirement, be updated as new data become available.

As a result of MMS required lease block remote sensing surveys, numerous unidentified magnetic anomalies and side-scan sonar contacts which could represent historic shipwrecks have been recorded in the GOM. These surveys also recorded numerous examples of relict late Wisconsin landforms (fluvial channels with evidence of terraces and point bars, bays, lagoons, barrier islands, natural levee ridges, salt diapirs, and sinkholes) where there is a high probability for associated prehistoric sites.

Avoidance or further investigation of archaeologically sensitive areas is usually required prior to approval of lease permits; however, because industry has generally chosen avoidance rather than further investigation of these areas, little data have been collected which would help in building an interpretive framework for the evaluation of unidentified magnetic anomalies and side-scan sonar contacts, or in evaluating the predictive model for prehistoric site occurrence.

1.1 Objectives

The objectives of this study are:

a. To reevaluate and make recommendations to change, if necessary, the location of Cultural Resource Management Zone 1 in the GOM.

b. To determine the relationship between linespacing of magnetometer readings and side-scan sonar and the detection of objects at or below the seafloor.

c. To investigate whether remote sensing data gathered during a cultural resource survey in the GOM can be analyzed to discriminate between a cultural resource and recent debris.

1.2 Scope of Work

This study was divided into two major tasks: Task I, Evaluation of Cultural Resource Management Zone 1 and Task II, Establishing an interpretive framework to characterize unidentified magnetic anomalies and side-scan sonar contacts.

Task I. The evaluation of cultural resource management zone 1 provided for collection, evaluation, and synthesis of archaeological, environmental, and geographic data to evaluate and redefine MMS's Cultural Resource Management Zone 1, if appropriate. Cultural Resource Management Zone 1 is an area considered to have a high probability for the occurrence of historic shipwrecks. Industry is required to perform magnetometer and side-scan sonar surveys in Zone 1 prior to commencing exploration, development, or pipeline projects. The boundary of Cultural Resource Management Zone 1 is depicted on Environmental Impact Statement Visual No. 11, Gulf of Mexico, 1983 (Figure II-1). The Zone 1 boundary depicted in the CEI study, Volume 3 is identical to that in Visual No. 11. This phase of the study required the following two efforts: (1) information collection; and (2) information analysis and synthesis.

The following data sources were analyzed as part of Task I and synthesized into this report:

a. *The Cultural Resources Baseline Study (of the Northern Gulf of Mexico Continental Shelf*, Volumes I, II, and III) by CEI, 1977.

b. Historic maps and other literature sources--These were reviewed to establish the locations of historic ports, harbors, and other navigable waters where shipwrecks are likely to be concentrated.

c. Historic shipping routes as shown by CEI (1977)--The possible influence of factors such as mean wind and current directions on modifying actual sailing routes were evaluated.

d. Information on historic hurricane paths--In combination with literature and archival information on ships lost during hurricanes, this information was used to determine the relative importance of hurricanes on historic ship losses. Available information on the intensities of different hurricanes is also included. The goal of this work was to determine if hurricane paths could be used to predict shipwreck concentrations for various time periods.

e. The locations of shipwrecks discovered since the completion of the CEI baseline study--These shipwrecks were added to CEI's list. The locations of known shipwrecks, why the locations are known, and how these locations can be used to predict the location of other historic shipwrecks are discussed.

f. Available information on the historic locations of shoals, reefs, sand bars, and barrier islands--This information was evaluated as a predictive factor in shipwreck location.

g. Factors such as bottom sediment types, depth of unconsolidated sediments and GOM wave and current energy zones--The effect of these factors on the state of preservation and integrity of shipwreck sites was evaluated.

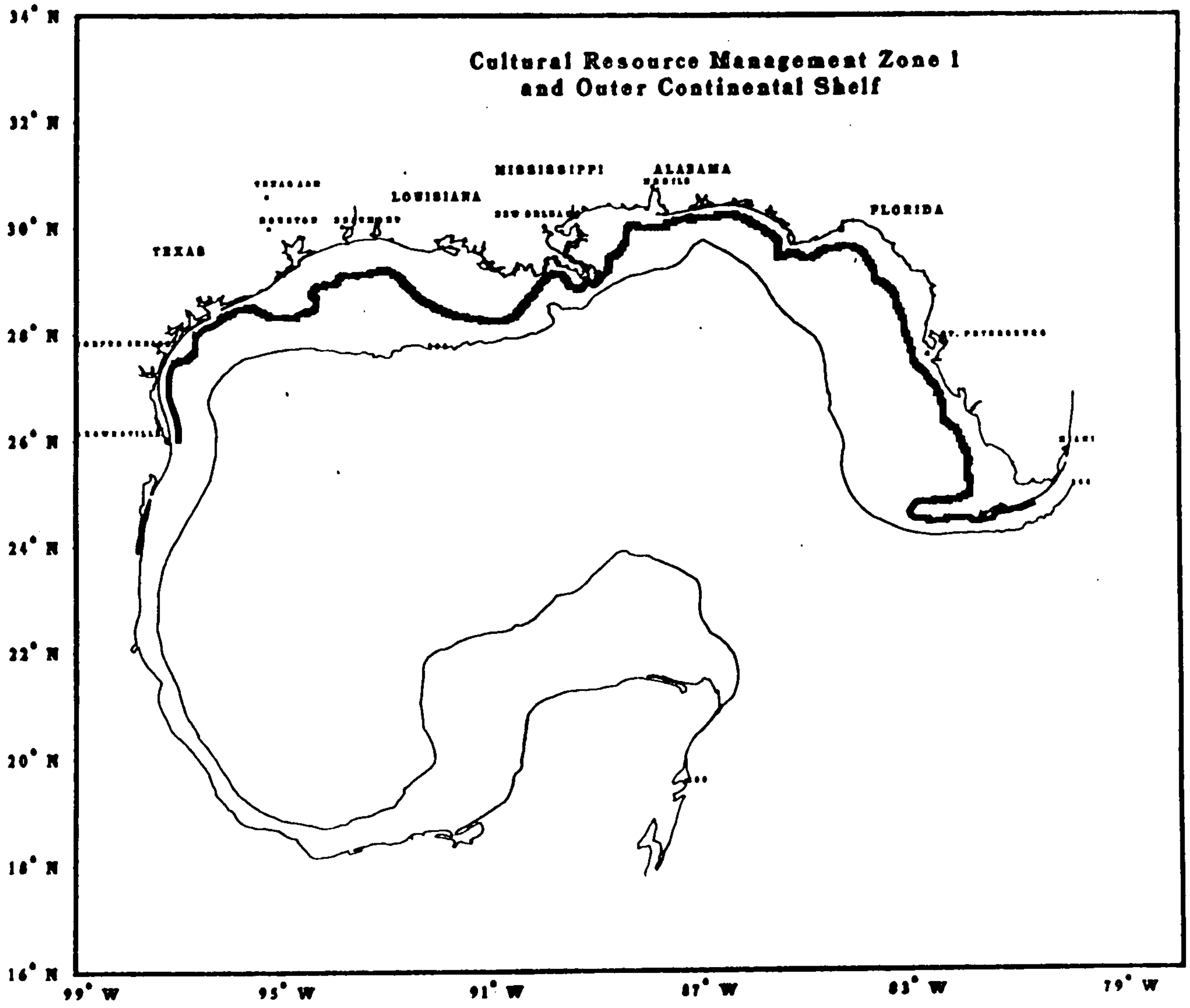

FIGURE II-1. Cultural Resources Management Zone I and the Outer Continental Shelf, Gulf of Mexico.

1.3 Previous Studies

The CEI study considered the occurrence of shipwrecks and related artifacts as the basis for determining the probability of the existence of cultural resources. The CEI researchers confined their study area northward of 26 degrees latitude (CEI 1977; Figure II-2). Their study used a methodology based on:

a. spatial bounding north of 26 degrees latitude;
b. temporal bounding of four periods ranging from 1500-1945;
c. collection of shipwreck data within (a) and (b);
d. evaluation of shipwreck locations, their frequency, and preservation factors (sediments, energy zones, etc.);
e. evaluation of factors causally related to the observed shipwreck frequency, both spatially and temporally; and
f. evaluation of discovery or exploration techniques for locating shipwrecks.

Their study relied on library documentary sources for the bulk of the data utilized in the analyses and interpretations. CEI's study included the prehistoric millennia for the northern Gulf of Mexico as well (Vol. I). This aspect is outside our consideration so this review focuses only on the last two volumes of that study .

Since the CEI study, similar studies have been conducted using similar document-based methods (Bourque 1979; Science Applications, Inc. (1981). These later studies are multi-volume evaluations of cultural resources of the OCS from the Bay of Fundy to Cape Hatteras (Bourque 1979) and Cape Hatteras to Key West (SAI 1981). The methodology used in this study considers all the factors involved in the occurrence and preservation of historic cultural resources on the OCS.

Every study concentrates on specific factors over others. This is done because of a) investigator expertise, b) specific hypotheses to be evaluated, or c) available data. The CEI study is biased to the prehistoric archaeology of the northern Gulf of Mexico. In particular, it develops an explanatory model for the occurrence of drowned sites of the OCS. CEI recently published the results of the study which focuses on the occurrence and potential preservation of prehistoric archaeological sites on the OCS (Pearson, et. al. 1986).

The Bay of Fundy Cape Hatteras study (Bourque 1979) develops a predictive model based on historic patterns of shipping to evaluate shipwreck locations. The Cape Hatteras-Key West study (SAI 1981) applied an inductive modeling approach to shipwreck distribution. These studies attempted to define management zones for both prehistoric and historic cultural resources on the OCS. Each must be viewed as approximations of the cultural resources located on the vast coastal plains that now form the drowned shelf.

CEI (1977) and other initial surveys are attempts to indirectly define archaeological phenomena over broad areas of the continental margin. All authors involved in these studies have pointed out the general nature of the research and the inadequacy of the available databases. These attempts have conceptual merit but little predictive or hindcast power in the delineation of the archaeology of the OCS. They are "educated guesses" made after consideration of the available data. Smith (1978) presents a comprehensive treatment of the data relating to New World shipwrecks. The present study cannot redress this lack of primary, direct archaeological observations which are necessary to construct a realistic picture of historic cultural resources on the northern Gulf OCS.

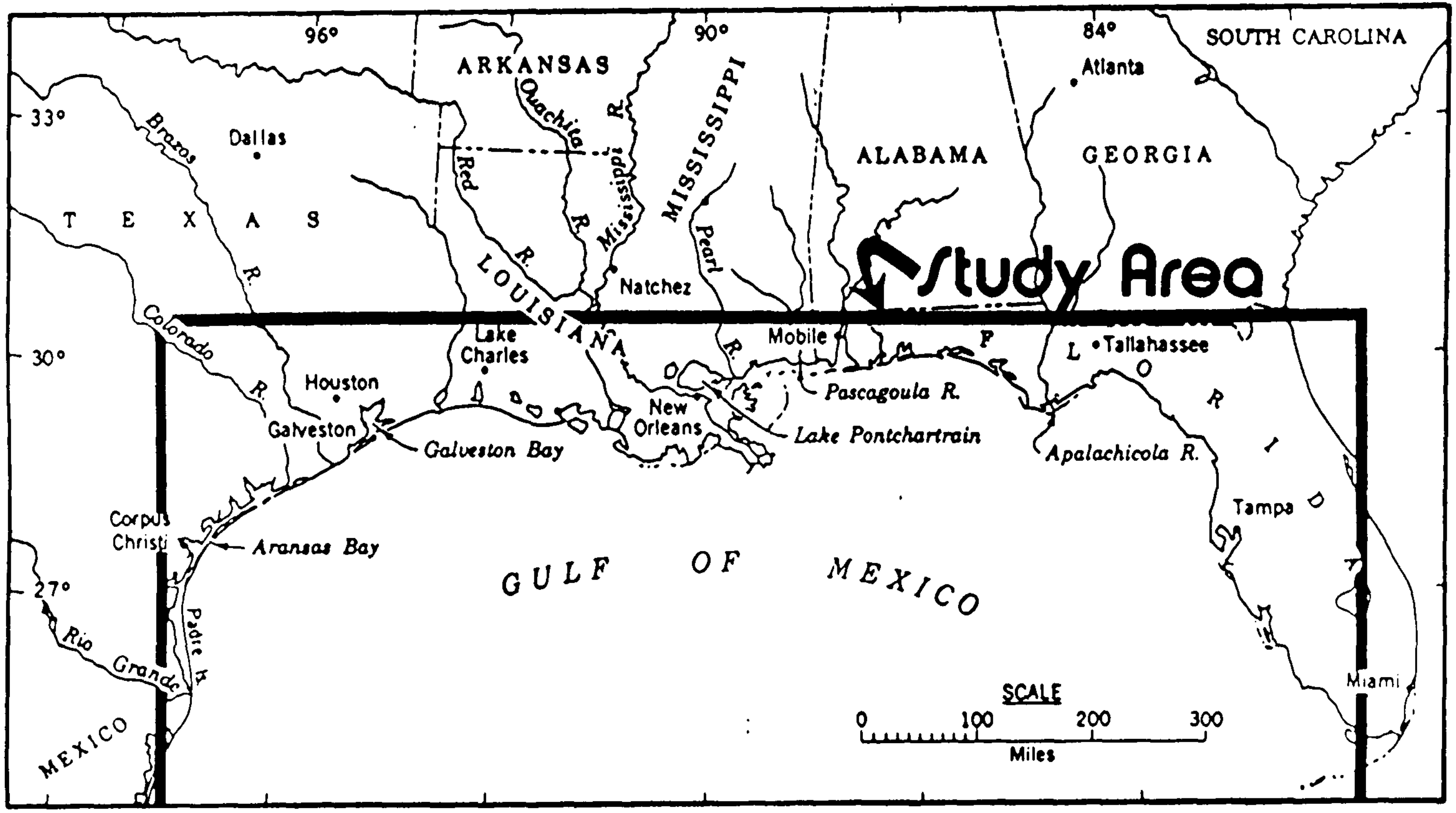

FIGURE II-2. Study area, CEI 1977.

With these caveats in mind, this report updates and expands CEI's original data to consider historical, archaeological, geological and geophysical research that has been done since 1977. Historical and archaeological syntheses since 1977 include the previously mentioned Padre Island shipwreck study (Arnold and Weddle 1979) as well as Weddle's recent excellent works, *Spanish Sea* (1985) and *La Salle, the Mississippi, and the Gulf* (1987). Secondary sources such as Surrey's study of commerce of French Louisiana (1916) and Chaunu and Chaunu's (1955) monumental study of Spanish commerce from 1504-1650 have been examined. By building on such scholarly works and incorporating CEI's framework into our study, some new insights are gained into the causes and distribution of shipwrecks on the northern Gulf Continental Shelf.

The few archaeological studies on the OCS include the excellent work on the 1554 ship wrecks off Texas (Weddle and Arnold 1979) and the EL NUEVO CONSTANTE (Pearson, et. al. 1981) as principal examples. Other reports, published or not, are of variable quality and include Hole's (1974) report on the blockade runner ARCADIA, Arnold and Hudson's (1981) paper on the USS HATTERAS, and Garrison's (1986) ITM proceedings report on the blockade runner, WILL O'THE WISP, and reports by treasure hunters such as the recent flamboyant discovery of the ATOCHA (Mathewson 1986).

Advantage was taken of a source unavailable to CEI - computer-based data files. Some of these files are *The Hangs and Obstructions File* by the Hydrographic Office (HO), *The Automated Wreck Obstruction Information Service file* (AWOIS) of the National Ocean Survey, *The Historic Shipwreck File of Texas Antiquities Committee* (TAC) and *The Florida Shipwreck File of the Division of Archives and History, State of Florida.* While relying on secondary materials as their main sources, these compilations represent professional efforts at systemizing shipwreck information by use of the retrieval speed and storage capability of the computer.

The shipwreck data in this study were organized in a similar manner to that of the AWOIS file. The data from primary and secondary materials collected at the various archives were merged and a master file of historic shipwrecks of the northern Gulf of Mexico was created. This file, with over 4,000 entries, represents the largest such data base for the Gulf.

The data used in this study are plotted as accurately as possible. The location of historic shipwrecks and the resulting distributions as a function of historic and natural factors are examined. Covariance between specific factors and shipwreck patterns was then examined for causality versus random occurrence.

The methods and sources used for data collection are detailed in the following sections.

2.0 METHODS - GENERAL

The CMRZ1 is defined as a high probability zone for the occurrence of historic shipwrecks. The observed distribution for historic shipwrecks is a product of historical and natural factors. Historic factors include cultural, economic, and technological change and natural phenomena include storms, currents, winds, shoals and reefs.

This study evaluates some of these factors over a period ranging from the 16th to the 20th centuries. Such a study is termed diachronic since it examines relationships in interacting variables (factors) over time. It is assumed that these factors differentially influenced the location and density of shipwrecks in the northern Gulf of Mexico. Numerical methods are utilized where quantification in variables allows such analyses.

Again, the CEI study was our point of departure. New research expanded state files on shipwrecks, in particular, those of Florida and Texas (Arnold 1980). Newly acquired microtexts, such as the Colonial Archive records for the French administration of the Louisiana territory, were located at Tulane University. Newly published cultural resources studies were used for historic Gulf ports such as Mobile, Alabama; Pascagoula, Mississippi; Biloxi, Mississippi; Pensacola, Florida; Gulfport, Mississippi; and Brownsville, Texas.

Updated holdings were found at the P.K. Younge Library at the University of Florida, Mariners Museum in Newport News, Virginia, the Howard Tilton Library at Tulane University and the DeZavala and University of Texas Libraries in Austin, Texas. The Sterling C. Evans Library of Texas A&M University has become a repository of secondary sources owing in large part to its affiliation with the Institute of Nautical Archaeology (INA). New guides to the extensive holdings of major Spanish archives such as Archivo General de las Indies (AGI), Seville and Archivo General de la Nacion (AGN), Mexico City have been published or otherwise made accessible for use in this study.

2.1 Chronological Considerations

In order to better isolate and evaluate data relating to Gulf shipwrecks it is necessary to impose a chronological order on the data that approximates major historic or technological periods for that region. CEI defined four periods: (1) 1519-1699; (2) 1700-1819; (3) 1820-1899; and (4) 1900-1945. Our major periods are:

A. New Spain Period, 1500-1699 (16th/17th centuries);
B. Colonial Period, 1700-1803 (18th century);
C. American Period, 1803-1865 (19th century, early);
D. Victorian Period, 1866-1899 (19th century, late); and
E. 20th Century, 1900-present.

"Period" is used in the sense of a time interval whose beginning and ending dates are well established (Willey and Phillips 1958). Correlation of the earlier CEI classification with this study can be made because the CEI time periods are the same as ours for consistency.

Period A, the New Spain Period, is that of the early explorers such as Ponce de Leon and Hernando Cortes. It is highlighted by the exploration, conquest and exploitation of New Spain which led to further Spanish expansion into the northern Gulf region. This period also includes the French entry into the northern Gulf. The terminal date reflects the establishment of the French as a major colonial presence (Wood 1979, Weddle 1985, Webb 1952, Sauer 1968 and 1980, Bolton 1915, Dunn 1971).

Spain, France and Britain played significant roles in the northern Gulf area during Period B, the Colonial Period (Dunn 1971, Rea and Service 1982, Charlevoix 1763, 1766). This period is further divided into the effective end of French involvement in the northern Gulf (1700-1763), the establishment of British control of Louisiana and West Florida as a result of victory in the Seven Years War (1763-1781) and the last period of Spanish control beginning with Galvez's capture of Pensacola (1781-1803).

Period C, the American Period, is the period from the cession of Louisiana to the United States by Napoleon up to the fall of the Confederate States of America and the end of the American Civil War. It is the beginning of American control of the northern Gulf and its increased shipping activities. New ports, such as Galveston (1821), Freeport (1830), Brownsville (1849), Cedar Key (1866), Key West (1828), and Tampa (1855), make the northern Gulf an American sea after three centuries of Spanish domination.

Period D, the Victorian Period, reflected post-war and later increased maritime activity. The war period of 1861-1865 resulted in few shipwrecks as a result of direct action by either the Confederacy or the Union. Confederate Blockade runners such as the ACADIA and the WILL O' THE WISP were run to ground by Union blockades and the U.S.S. HATTERAS ran afoul of the famous Confederate cruiser, ALABAMA, becoming perhaps the most notable shipwreck of this era on the OCS. Ports continued to grow and thrive along the Gulf from Texas to Key West.

Period E, the 20th Century, covers the period of transition from an agrarian based economy to today's emphasis on manufacturing and petrochemicals. Additional shipwrecks occurred in the northern Gulf during World War II as German submarines or U-Boats attacked commercial shipping. Two of these submarines, the U-157 and the U-166, rest in the northern Gulf (Röhwer 1983) (Appendix A).

These periods were used to organize the shipwreck data for discussion purposes. Our distribution maps combine various periods so shipwreck patterns and trends can be plotted in the Gulf over time.

2.2 Geographical Considerations

The original CEI study encompassed an area of the northern Gulf of Mexico above 24°N and west of 80°30'W. The same area was used in our study but we extended the east boundary to 80°W.

2.2.1 The Determination of Latitude-Longitude Points of Shipwrecks

The methods used to assign coordinates to the data are discussed in the next two sections. The sources of information for this report were in various forms including manuscript listings, magnetic tapes, computer discs, and literature. The formats of these sources also varied. A modified AWOIS format has been used in the final database. This format includes ship name, approximate date of loss, abbreviated source name, and latitude and longitude of the approximate location (Appendices G and H). Other files are available which include the descriptive location of the ship loss. This database, which contains approximately 4,000 entries, is the largest computerized shipwreck file ever assembled for the Gulf of Mexico. Computerization allows the file to be continually updated as well as manipulated for different uses.

Some of the sources did not provide exact latitudes and longitudes of the ship wrecks; however, descriptive locations were provided.[1] Latitudes and longitudes for the shipwrecks were obtained by using these descriptions, large scale charts, and a Numonics 2400 digitizer. Descriptions such as "off the coast of ---" were assumed to be at the site in question. In addition, those points described as "X miles off the coast of ---" were assumed

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[1] An early example is the Spanish reference to Matacumbe. This name was applied to the entire keys area with the exception of the Maraquesas (Smith 1976).

to be perpendicular from that coastline. A list detailing assumptions for each site is available as an appendix (Appendices G-I) to this report.

The data were verified by rechecking a random sample using the digitizer. When the exact latitude and longitude were provided, duplicate listings of the wrecks from other sources provided another means of verification.

The sources were examined to determine the most reliable one. Primary sources were considered more reliable than secondary ones. When duplicate ship entries occurred, all but the most reliable were deleted. In instances where the name and date were identical but the location varied within one-tenth of a decimal degree, the information from the most reliable source was retained.

2.2.2 Accuracy, Precision, and Assigned Shipwreck Positions

The accuracy of shipwreck positions assigned in this study is primarily a function of: (1) geographic coordinates given for the shipwreck and (2) level of precision in the particular analysis. The first factor, geographic coordinates given to the shipwreck, is dependent on the reporting period of the loss. Geographic coordinates were infrequently used to report early shipwrecks. Before the 20th century and up to the present day, shipwrecks were located utilizing some shore landmark as a reference. This is far less common today where electronic navigation is the rule.

The second factor, level of precision, is directly related to that precision required of the particular spatial analysis being used in this study. For instance, the highest locational precision used in this study is the lease block. The accuracy of the shipwreck positions is 0.16 for an assigned lease block whose original report gave no quantitative position.[2] However, the spatial analyses of this study did not require high precision for shipwrecks in lease blocks, and we typically used larger quadrats that increased the chance for the position reported or assigned to be within the quadrat.

While we carefully and systematically assigned the accuracy of shipwreck positions to our charts, we were concerned with overall distribution patterns that required less accurate relative position locations (Appendix H briefly describes the methods used to determine shipwreck positions on distribution charts in this report). For instance, travel routes to the Carrera de las Indies of the 16th to 18th centuries could vary over 2 degrees in position (120 miles) depending on the trade winds and currents. To correlate a scatter of shipwrecks with such a broad traffic pattern does not require a locational precision much smaller than the variability in that of the independent factor (e.g. traffic routes).

The same is true for hurricane paths. Their occurrence within the Gulf of Mexico reflects statistical uncertainty. Areas of greater or lesser probability for these storms along the northern coast produce large areal sectors. To correlate a pattern or density of shipwrecks of a similar scale does not require a positional accuracy that is below that seen for the hurricanes themselves.

AWOIS or TAC databases give more precise accuracies. AWOIS, for instance, gives a circle of error for the reported position of one mile, three miles, or greater than three miles. TAC utilizes a margin of error based on a reasonable probability that a shipwreck will be within a six lease-block cluster of the given position.

2.3 Data Sources

Hanable (1983) identified four major sources of shipwreck information: (1) databanks; (2) documents; (3) directories; and (4) descriptions. To this classification we should add (5)

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[2] Probability based on the possible shipwreck location being within an area of six lease blocks or 54 square miles. This follows techniques used by the Texas Antiquities Committee and Borque (1979).

other secondary literary sources. Data banks are organized, comprehensive collections of detailed data which have been stored and are accessible for rapid retrieval. Directories are lists of the names of vessels and usually include dates and locations of casualties. Documents are unpublished materials that provide substantive data about shipwrecks. Descriptions are acccounts of individual shipwrecks. Secondary literary sources are described below.

2.3.1 Shipwreck Data Banks

Four major shipwreck data banks exist at the federal and state level for shipwrecks in the northern Gulf of Mexico. These files are:

a. the *Texas Antiquities Committee Shipwreck File* (TAC), Austin, Texas;
b. the *Shipwreck File,* the Bureau of Archaeological Research, Tallahassee, Florida (BAR);
c. the *Automated Wreck and Obstruction Information Service* file (AWOIS), National Ocean Service, Rockville, Maryland; and
d. the *Hangs and Obstructions* file (HO), Hydrographic Office.

The TAC shipwreck file is a Dbase, MS-DOS type file with over 1800 entries. Most of these entries are from secondary sources but many have been added based on data obtained from the TACs Historic Map Project conducted in 1979[3]. File categories include: name, year lost, position (descriptive, geographic, latitude/longitude), block number (refers to oil and gas lease block number, Texas state lands), and vessel type.

The Florida shipwreck file has been created by the Bureau of Archaeological Research, Division of Historical Resources. It is an MS-DOS file existing in Dbase II and III formats. For the Gulf portion of the file there are well over 700 entries.[4] File categories include: wreck number; tonnage; name; year built; vessel number; where built; nationality; date lost; home port; nature; vessel type; position (descriptive and geographic); notes; and comments.

Another data bank for shipwreck research is the Automated Wreck and Obstruction Information Service file (AWOIS), maintained by the National Oceanic and Atmospheric Administration. Developed within the past five years, this data bank is an ASCII file containing 3,100 records of items the National Ocean Survey considers obstructions to navigation. Individual files for each vessel or obstruction entered in this data bank include four types of records. These are: name records, history records, description records and survey requirement records. Name records have, among other data, vessel, name registry numbers, and latitudes and longitudes of location. History records have information relative to the original and revised presentations of information about the wreck or obstruction on nautical charts. Description records have a reference source (by numerical designation) and specific descriptive information such as vessel dimensions, age, construction type, date sunk and other miscellaneous information which may include last recorded owner, present wreck condition, if the wreck is a local diving or fishing attraction, etc.

The Hydrographic Office's Hangs and Obstruction (HO) file is another easily obtained data source for shipwreck information. It is a recently developed ASCII file like AWOIS. Specific categories in the file are: wreck number; position evaluation; name; source of position; nationality (two letter code); position (latitude/longitude); type of wreck; depth over wreck; flag of sinking agent; date of sinking agent; type of sinking agent; and date of information.

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[3] J. Barto Arnold 1987, personal communication.

[4] James Miller 1987, personal communication.

Each of these databases may duplicate information within another database. In the case of the HO and AWOIS files, this duplication allows a cross check on the reports for each wreck. The TAC and Florida files have evolved as strictly shipwreck databases. They extend further into the historic record, but rely on secondary sources for most of their information. Specific advantages and disadvantages of the four databases are listed in Table II-1.

2.3.2 Documents

Documents, as defined above, are unpublished materials that provide substantive data about shipwrecks. Sources for shipwreck information consist of newspaper or magazine articles, maritime historical accounts and official records. Official records are the most reliable source but are varied in information content. Maritime countries such as Spain, France, and Britain maintained shipping lists (records of returns, etc.) and logs for commercial and naval craft. Such documents, kept in archives throughout the world, vary in their systematic recording and filing practices. The ability to relocate a wreck site was not a criterion in most accounts of maritime disasters until the 20th century.

2.3.2.a Record Groups, Federal

Record groups (RG) are in the National Archives and in regional federal archives and record centers. The following groups contain information pertinent to shipwrecks in the Gulf.

The Records of the Steamboat Inspection Service (RG41), established in 1854, continue into the 20th century. RG26, Records of U.S. Coast Guard and RG35, Records of U.S. Custom Service are government documents of wrecks after 1874. In that year Congress required masters or owners of American vessels to report any casualty to the vessel to the Collector of Customs at the port at which the vessel was documented. A casualty could be an incident involving loss of life, serious injury to any person, material loss of property, or damage to a vessel affecting seaworthiness. The Collector of Customs forwarded one copy of a casualty report to the General Superintendent of the United States Life-Saving Service and kept one copy, usually copied into volumes containing blank wreck reports. The volumes are among the Records of the U.S. Customs Service (Record Group 36). Customs wreck reports from 1913 to 1939 are available on National Archives Microfile T925. National Archives Microfile T926 is an "Index to U.S. Coast Guard Casualty and Wreck Reports." Also among Coast Guard records are bound volumes of abstracts of wreck reports received from Collectors of Customs from 1874 to 1975 and original reports from 1908 to 1913 (RG26).

Table II-1.

AUTOMATED SHIPWRECK DATA BASES - SOME ADVANTAGES AND DISADVANTAGES.

AWOIS

Advantages:
1. automated
2. continually updated
3. good location with an evaluation of accuracy
4. record of wreck condition
5. ground-truth data

Disadvantages:
1. limited to the 20th century
2. wreck data is death report filed with National Ocean Service
3. records before 1945 sketchy
4. vessel descriptions rare
5. bias toward near-shore wrecks due to agency mission

HD

Advantages:
1. automated
2. locational accuracy good
3. vessel type specified where known
4. less bias toward near shore wrecks
5. updated regularly

Disadvantages:
1. primarily limited to 20th century
2. few soundings
3. no condition of wreck given

TAC

Advantages:
1. automated
2. locations assigned systematically where exact geographic position not known
3. excellent time range, 16th-20th centuries
4. large file (over 1700 entries)
5. updated

Disadvantages:
1. based primarily on secondary sources
2. few locations with high accuracy

Florida (BAR)

Advantages:
1. automated
2. vessel description and documentation of loss
3. excellent time range, 16th-20th centuries

Table II-1
(continued).

4. updated

Disadvantages:

1. based primarily on secondary sources
2. no condition given for wreck
3. limited accuracy in reported positions

Reports of the U.S. Life-Saving Service are another source of shipwreck information. This service began in the Revenue Marine Division of the Treasury Department in 1871 and eight years later came under a general superintendent who reported directly to the Secretary of the Treasury. Regulations required Keepers of Life-Saving Stations to report assistance rendered by their stations to any vessel, crew, or person and sent the originals to the General Superintendent of the service. The stations retained a copy of the reports. Annual reports of the Life-Saving Service contain narrative reports of services and tables of casualties occurring near life-saving stations. A microfilm copy of these tables is available for the period 1876 to 1914.

An act of January 28, 1915 established the U.S. Coast Guard by consolidating the Department of the Treasury's Revenue-Cutter and Life-Saving Services. Perhaps for this reason, Coast Guard records include copies of Life-Saving Service assistance-rendered reports for the period 1901 to 1915. These are arranged by fiscal year by Life-Saving Service district. Also with the Coast Guard records are microfilmed copies of assistance-rendered reports for the period 1916-1940. These are arranged by date of casualty in two groups: reports of assistance rendered and reports of miscellaneous services rendered. These 1916 to 1940 reports are available on National Archives Microfilm T-920 and, like the customs wreck reports, are indexed on National Archives Microfilm T-926.

Other federal records also have shipwreck or associated maritime information. Some shipwreck data can be found in records of the Lighthouse Service (Records Group 26).

2.3.2.b Document Sources, State and Private

Significant and diverse document holdings ranging across all the historic periods of the northern Gulf were found at: Old Spanish Missions Historical Research Library Collection (OSMHRL), Our Lady of the Lake College (San Antonio, Texas); University of Florida, P.K. Younge Library of Florida History (Gainesville); Texas Antiquities Committee Shipwreck and Map files (Austin, Texas); Mariners Museum Research Library (Newport News, Virginia); LBJ Library and Archives (Austin, Texas); De Zavala State Library (Austin, Texas); University of Texas Library (Austin, Texas); Sterling C. Evans Library, Texas A&M University (College Station, Texas); and Howard-Tilton Library, Tulane University (New Orleans, Louisiana).

2.3.2.c Document Sources, Foreign

The primary source for information on the Spanish period in the New World is the Archivo General de Indies (AGI) in Seville, Spain. It is known to the English speaking world as the Archive of the Indies. It is divided into sixteen major sections. Within each section, each *legajo* or bundle is assigned a number. Loose papers used to be left in whatever order the most recent user had adopted, but since the mid 1960's the staff of the Archive systematically organized them according to date and sequential *numeros*. The numeration of documents within the *legajos* has made it possible to cite a document by its individual number.

The Archivo General de la Nacion (AGN) is the national archive for Mexico located in Mexico City. It contains both AGI and AGN documents. Many relating to New Spain have been reproduced and appear in repositories such as the P.K. Younge Library and at the Spanish Colonial Research Center, University of New Mexico, Albuquerque. The major secondary study cited in this report, *Seville et l'Atlantique* is based almost exclusively on AGI documents (Chaunu and Chaunu 1955). In France, the main sources of French maritime information are located at the Archives Nationales, Paris in the Archives des Colonies.

The Archives des Colonies in the Archives Nationales consist of a number of series of varying importance for the history of New France and Louisiana. The outgoing communications, including the orders, memoranda, and instructions of the king and the dispatches of the ministers, make up series B. The incoming communications, series C11A, "Canada et Dependances, Acadie, Ile Saint Jean et Ile Royale, Correspondence Generale," is composed of the original documents received from the governors, intendants, officers, and other officials of New France.

The corresponding file for Louisiana, series C13A, "Louisiane, Correspondence Generale," consists of correspondence received from officials in Louisiana and is similar to series C11A in content. Series C13A is also the main repository of documents relating to French activities connected with Texas, particularly the expeditions of Louis Juchereau de St. Denis, and contains much relating to Florida. The Archives des Colonies are essential for the history of the administration of the American domain, for its political, military, Indian, and church affairs, and for legal, social, and economic history.

Surrey (1916) used these documents as the principal sources in her study of commerce in Louisiana which gives some significant data on shipwrecks during this period. These archives have been duplicated on microfilm by the U.S. National Archives and a set was found at the Howard-Tilton Library, Tulane University. For British shipwreck records, the Public Record Office (PROKew), is a repository of admiralty and foreign office documents such as dispatches and logs. Information on shipwrecks is available but not as extensive as that found at Guildhall Library, London. Other repositories include the Board of Trade, London and the Admiralty Library, Naval Historical Branch. Most records of shipwrecks have been abstracted into directory form such as *Lloyd's Registers*, Wreck Returns (Board of Trade), Admiralty Progress Books and Navy Lists (PROKew), and the Maritime Museum Wreck Registers (Greenwich).

A lesser-known abstraction of British records for the north Gulf is found in Rowland (1911): *Mississippi Provincial Archives, English Dominion, 1763-1781* (1911). This collection of transcripts was made by the Mississippi Department of Archives and History. Additional data on the French period is found in three other volumes of the *Mississippi Provincial Archives* (Rowland and Sanders 1928, 1929 and 1932). The shipwreck data from the British sources were found mainly in the Mariners Museum Research Library collection with the exception of the Wreck Returns of the Board of Trade. No complete set of these returns is known for any data on wrecks in the United States.

2.3.3 Directories

A principal directory is *Merchant Vessels of the United States*, published by various government agencies since 1867 and currently published by the U.S. Coast Guard. These annuals contain vessel names under type of vessel (sailing, steam, unrigged, yachts, etc.), with details on rig, tonnage, dimension, when and where built, home port, and owner. There is also information on abandoned or lost vessels, those sold outside the United States, and on government vessels and shipyards. Complementary or similar directories include the *American Bureau of Shipping Records, General List of Merchant Shipping, Lloyd's Register,* and *Registre Veritas.* These give name of vessel, date built, builder, owner, size, tonnage, machinery on-board, flag of registry, and -- in later years -- official number and signal letters.

The principal foreign directories are Lloyd's List 1740-1970, Lloyd's Weekly Shipping Index 1880-1917, and Lloyd's Missing Vessel Books 1873-1954. Lloyd's List published all vessel movements and casualties reported to Lloyd's with customs house entries and much other information. There is a microfilm index to the list for 1838 to 1926. From 1927 there is a card for each vessel on which all movements and casualties are reported. *Lloyd's Weekly Shipping Index* published voyage, engaged date of sailing and latest report for ocean going steamers and sailing vessels. The index also reproduced all casualty reports published during the previous week. *Lloyd's Missing Vessel Books 1873-1954* are manuscript records of all vessels posted missing by the Committee of Lloyd's giving details of vessels, masters, crews, voyage, and cargo. For the more recent past, *Lloyd's Marine Loss Records 1939-1970* give details of all vessels lost with full reports as received at Lloyds. Many of these citations are found at the Mariners Museum, Newport News, Virginia.

Lytle and Holdcamper (1975) published a directory of ship losses abstracted for government documents contained in the U.S. National Archive and as enrollments, casualty reports, life-saving station reports, etc. This directory supplements the *List of Merchant Vessels of the United States* by covering the early period 1790-1868.

2.3.4 Descriptions

These are published accounts of individual shipwrecks. They are found in almost all repositories. Important, but difficult to systematically examine, they represent the most labor intensive aspect of shipwreck research as they are so scattered and uneven in detail. These are typically news accounts which may be the least biased of all shipwreck accounts (Bourque 1979).

Lochhead (1951, 1954, 1958) abstracted several accounts from New York and Boston shipping lists as well as news accounts of losses. While more like a directory, these listings allow one to access the individual reports. These abstracts were found at the Mariners Museum Research Library.

2.3.5 Secondary Literature

Data for historic shipwrecks developed principally from secondary sources has limited value due to lack of validity. The most valid reports on shipwrecks are primary sources - news accounts, official reports, logs, or other direct observations of the specific shipwreck. To adequately research all primary source data for historic shipwrecks is beyond the resources of this study as it was for the CEI study. We examined collections of primary sources or facsimiles of these materials in a number of archives and libraries. We further restricted the study to only those archives in the United States, with the exception of the National Archives of Mexico (AGN) and Spain (AGI).

For Spanish shipwrecks excellent secondary sources were found in studies by researchers of the National Library of France (Bibliotheque Nationale, Paris) (Chaunu and Chaunu 1955), research done on the 1554 shipwrecks located in the Old Spanish Mission Research collection at Our Lady of the Lake College, San Antonio, and records of the Spanish Colonial Research Center, University of New Mexico, as well as newly printed catalogues of the holdings of AGN (Mexico City).

For the French shipwrecks of the colonial period we used the facsimile microfilm of the correspondence found in Archives Nationale, Colonies, Series 13, located at the Howard-Tilton Library, Tulane University. British losses were found in similar facsimile data of the London Board of Trade, Lloyds. Admiralty and Foreign Office reports were located principally at the research library of the Mariners Museum, Newport News, Virginia. American shipwreck data were found in a variety of sources at the U.S. National Archives and its branches, as well as copies located at Mariner's Research Library, the DeZavala State Library (Austin, Texas), the University of Texas Library (Austin), and the Sterling C. Evans Library of Texas A&M University. Sources in these repositories include the *Reports of the Steamboat Inspection Service, Reports of the U.S. Live Saving Service* (later U.S.

Coast Guard), *Official Records of the War of the Rebellion, Union and Confederate Navies* (ORN), and the *List of Merchant Vessels of the United States* (MVUS).

3.0 HISTORIC SHIPPING ROUTES

Shipping routes have been correlated with shipwrecks in studies including CEI (1977), SAI (1981), Bourgue (1979) and Pierson (1987). Fundamental in the correlation of shipwrecks with trade routes is the notion of economics and politics. European and later New World colonial ships sailed the Gulf for economic gain. Trade centers, termed "nodes," formed at principal river mouths and embayments such as the Mississippi River, Mobile Bay, Pensacola, Tampa, Biloxi, and Galveston.

Seaborne trade also existed in the Gulf before Columbus. Evidence in Pre-Columbian records suggest that civilizations practiced thriving coastal trade along the coasts of Mesoamerica. This commerce was conducted for hundreds of years using large seagoing canoes capable of navigating the shallow coasts of Mesoamerica. Travel between Mesoamerican and Gulf islands, later called the "Indies" by the Europeans, is evidenced by shared cultural traits and reports of Indian craft using sails and oars (Diaz del Castillo 1955).

The first European to sail the Gulf of Mexico was Sebastian de Ocampo in 1508 (Weddle 1985). The first navigator to transverse the "hidden seas" northern shore was Alonzo Alvarez de Pineda in 1519 (Weddle 1985). The first circumnavigation of the northern Gulf was in 1686 (Weddle 1987). During this period of over a century and a half Spain increased its commercial exploitation of the Gulf.

The Gulf of Mexico was a "Spanish Sea" for almost two centuries. The Gulf provided a sheltered sea route for Spain's economic exploitation of its "Nueva España" (New Spain) until the French colonization of the Louisiana Territory in 1699. From Vera Cruz to Havana commerce was developed that carried the wealth and resources of the "New World" back to Iberia (Hoffman 1980).

The summer southeasterly tradewinds and the Loop Current created a natural marine route for the Spanish. American treasure was the first trade good to traverse the Gulf (Figure II-3). It came principally from Mexico and Peru after the discovery of the fabulous Aztec and Inca mines. Its economic impact on the European world precipitated a price revolution (Hamilton 1934).

Spain's 16th century expansion and the effect of New World gold and silver on the European world system was closely linked to the reduction of costs and hazards of long distance voyages (Davis 1973; Mendelssohn 1976). Before this expansion trade over such long distances was restricted to low bulk, high value items (McGovern 1986). By the mid-16th century merchant vessels began to sail in fleets convoyed by warships (Hamilton 1934). Costs were borne from proceeds of the "averia," a special convoy tax levied on goods carried to and from the Indies (Veitia Lenaje 1681). The larger ships that were introduced at this time in response to the increasing volume of trade meant gradual abandonment of old routes. With the conquest of New Spain and Tierra Firme (Panama), vessels sailed from these new territories through the Straits of Florida and home to the continent. After 1519 and the successful voyage through the Straits of Florida by Ponce de Leon and Alaminos , Spanish fleets increasingly traversed the central Gulf on their way to Havana and then Spain (Weddle 1985, MacLeisch 1989). This route, documented by Chaunu and Chaunu (1955), is corroborated by original ship records.

Between 1519 and 1699, Spanish flotas crossed the Gulf from Vera Cruz to Havana (Figures II-3 and II-4a). For reasons of expediency (favorable currents and winds) and later necessity (protection from pirates) the Gulf route became fixed through the Florida Straits. It was only when the French entered the Gulf, first with the failed La Salle Colony (1685) and then with Iberville's successful enterprise (1699), that new routes developed.

France developed new routes to her Gulf ports of Biloxi, Mobile and New Orleans fulfilling La Salle's dream to plant a French colony and exploit the strategic importance of the Mississippi River (Weddle 1986, 1987). The French routes ran first to the colonies on the Windward Islands and then to the Gulf coast (Figure II-4a). Their return was a mirror of their outward

Figure II-3 1722 De l'Islés map of Gulf of Mexico showing Flotas route journey (Surrey 1916). By this mechanism, goods were shipped to and from markets in the islands, New France and the continent.

Like the Spanish, little if any variation occurred during the main French period (1699-1763) in the Gulf of Mexico. What variations did appear were the result of French attempts to develop trade with New Spain and Cuba. However, Spanish authorities resisted this commerce over the first half of the 18th century. Only the French in Mobile and their Spanish counterparts in nearby Pensacola proved an exception (Surrey 1916).

The principal ports of Mobile, New Orleans and Pensacola persisted throughout the turmoil of the late colonial period up to the beginning of 19th century. Coastal trade increased while the British and Spanish supplanted the French along the northern Gulf. A new cargo, negro slaves, was added to the American commerce of newly acquired Louisiana (1803) and Florida (1819).

Along these coasts and that of the Texas Republic (1836-1845) more ports arose to draw lumber, grain, and cotton commerce. The period between 1830-1850 has been termed the "golden era" of the merchant marine of the United States. Due principally to the demand of the east coast and Europe for Gulf coast cotton, new lines developed to form a shipping triangle connecting the Gulf ports to New York and Europe (Figure II-4b). During this period New York came to dominate the shipping of the Gulf coast and this control did not cease until the Civil War began in 1861 (Laing 1974).

Normal commerce in the Gulf ceased when the Civil War began. This was due to 1) a naval blockade imposed on Southern ports by the Federal navy and 2) the huge profits to be earned by a successful running of this blockade. Coastal trade disappeared and was replaced by swift, low-silhouetted sail and steam vessels making direct dashes from ports such as Havana, Bermuda and Nassau. Their destinations were Brownsville, Galveston, New Orleans and Mobile (Coggins 1962). This anomalous pattern of shipping traffic persisted through the war period and then vanished.

After a reconstruction period, maritime commerce revived along the Gulf coast with traffic moving on coastal and direct routes to South American, European, Caribbean, and eastern U.S. markets. The southern U.S. ports established direct links to these extra-Gulf destinations breaking with the past reliance on New York's control of the commerce (Laing 1974). Coastal traffic was restricted by law to U.S. vessels for the latter part of the 19th century but the American merchant marine never recovered its pre-Civil War prominence. The effects of Confederate raiders, lost markets, and increased costs (insurance, crews, and ship building) combined to allow a greater share of the trans-Gulf vessels to become foreign. Norwegian, British, Danish, Dutch, German, Italian and Columbian vessels called at southern ports defining new traffic patterns to new places like Tampa (1885) and Port Arthur (1897). Minerals such as phosphate (Tampa) and oil (Port Arthur) joined lumber, grain and cotton as exports from Gulf ports through the Yucatan and Bahama Channels (Table II-2). Tampa became a major Gulf port after the arrival of the south Florida railroad in 1885 with the concomitant entry of the Plant Steamship Line (Smyth 1898).

New economic vessel designs such as schooners and propellor driven steamers plied the Gulf at the turn of the 19th century. Commercial traffic on these routes continued throughout the first half of the 20th century with little change until the outbreak of World War II. From 1942-1943, German submarines preyed on traffic from Gulf ports moving east through the Florida Straits (Röhwer 1983). This traffic stayed principally coastal, with vessels leap-frogging along the rim of the Gulf to stay in the shallow waters and away from submarines (Victory at Sea 1952). With the end of the war, shipping patterns returned to normal and even more traffic entered secondary ports as well as those used in the 19th century. The goods carried changed over the century with oil-derived cargo supplementing agrarian exports in the western Gulf and grains or manufactured goods performing the same role at central and eastern Gulf ports (Center for Wetland Studies 1972, Sibley 1968). The principal axis of traffic shifted westward from the east-central Gulf to the west-central reversing the 19th to early 20th century pattern (Table II-3). A large factor was the opening of the Panama Canal in 1914, giving easier routes to west coast and Asian markets (Figure II-5).

One thing common to all these routes over the long period of more than four and a half centuries of commerce was the loss of vessels because of natural and historic factors. It is ironic that as better technology in vessel design replaced older designs, losses continue consistently to the present day.

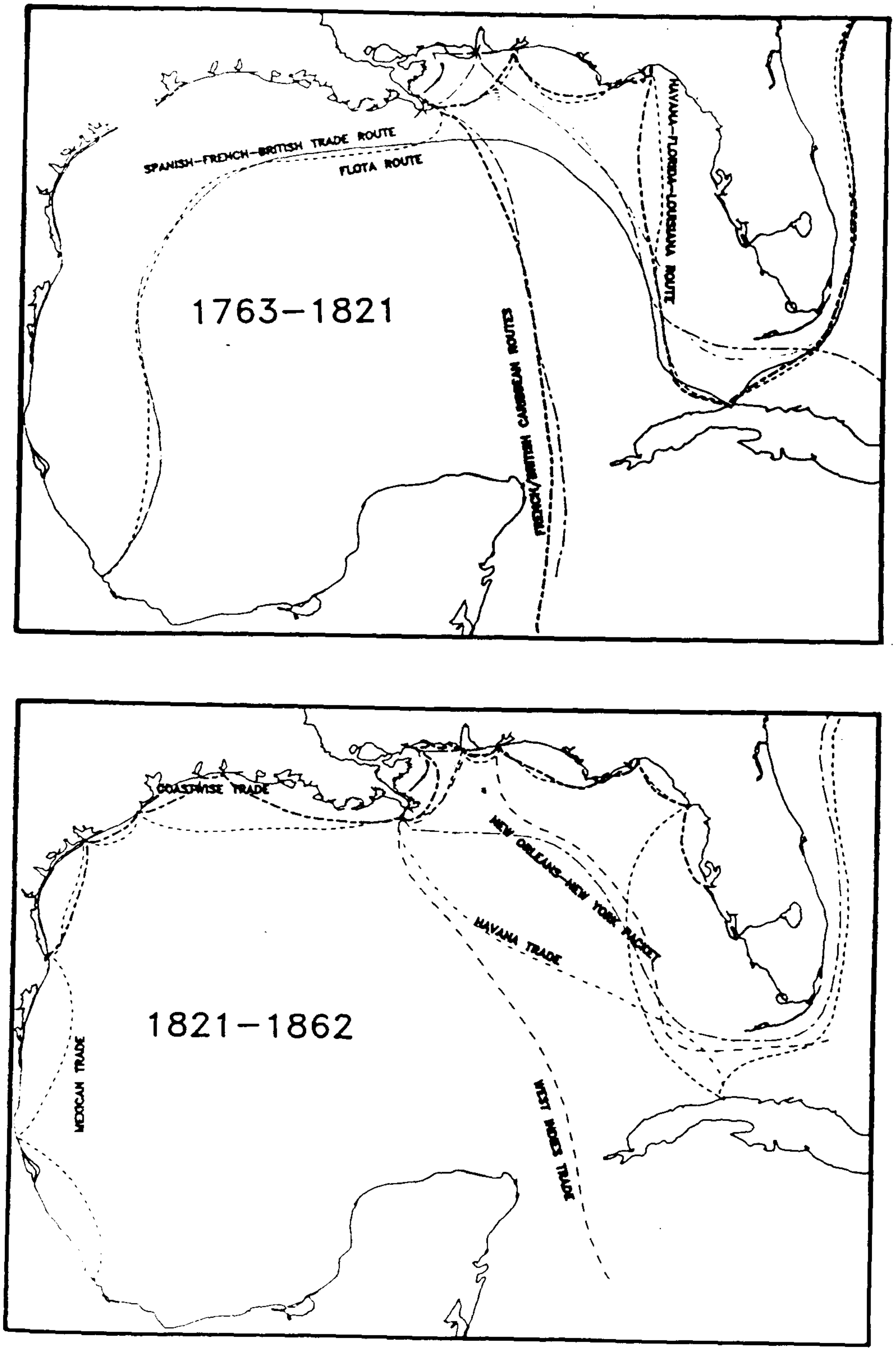


FIGURE II-4. (a) Shipping routes, 1763-1821
(b) Shipping routes, 1821-1862.

Table II-2.

SHIPWRECK CARGOES OF THE LATE 19TH - EARLY 20TH CENTURIES (SOURCE: LLOYD'S).

Years	Cargoes	Origin/Destination	Registry
1891	ballast	Havana-->Pensacola	USA
1891	logwood	Jamaica-->Falmouth	Norway
1891	ballast	Rio-->Ship Island	Germany
1891	ballast	Rio-->Mobile	Norway
1891	-	Swansea-->New Orleans	UK
1890	-	Cienfuegos-->New Orleans	Spain
1891	-	La Plata-->Appalachicola	UK
1891	coal	Pensacola-->Galveston	-
1891	-	Point a Pitre-->Appalachicola	USA
1893	logwood	Kingston (Ja.)-->Hamburg	Norway
1893	-	Santos-->?	Austria
1893	ballast	Progresso-->Pensacola	-
1894	logwood	Belize-->LaHavre	UK
1894	-	Pascagoula-->Liverpool	-
1894	ballast	Marseilles-->Pensacola	Norway
1894	wine	Barcelona-->Havana	Spain
1895	bananas	Ruatan-->Mobile	Colombia
1895	timber	Pensacola-->Rio	Norway
1895	-	Chiltepec-->? (off Corpus)	-
1895	-	Mobile-->Santa Domingo	Colombia
1896	lumber	Pensacola-->Rio	Colombia
1896	lumber	Mobile-->Montevideo	Norway
1896	-	St. Paul de Loanda-->Pensacola	Austria
1897	lumber	Sabine Pass-->Schiedam	Holland
1898	crushed stone	New York-->Key West	USA
1898	-	Pensacola-->Messina	Italy
1898	pitch pine	Pensacola-->Cardiff	Norway
1898	lumber	Moss Pt. (MS)-->N.Y.	USA
1898	ballast	Barbados-->Ship Island	Colombia
1899	-	Charleston-->Pensacola	USA
1899	coal	Baltimore-->Galveston	USA
1899	-	Appalachicola-->Boston	USA
1900	coal	Baltimore-->Galveston	USA
1900	mahogany	Santa Ana-->Channel	UK
1900	-	Dacquiri-->Ship Island	USA
1900	-	Cuba-->New York	Denmark
1901	ballast	Cay Francis-->Mobile	USA
1901	ballast	Porto Plata-->Ship Island	USA
1902	ballast	Matanzas-->Pascagoula	Colombia
1904	ballast	Newport-->Pensacola	Italy
1904	pitch pine	Mobile-->Cienfuegos	Colombia
1904	ballast	Kingston-->Pascagoula	USA
1905	ballast	Buenos Aires-->Ship Island	Italy
1906	-	Pensacola-->?	Germany
1906	wood	Pensacola-->Buenos Aires	Italy
1906	-	Mobile-->?	Italy
1906	-	Horn Island<-->?	?

Table II-2
(continued).

1906	lumber	Pensacola-->?	Norway
1906	lumber	Mobile-->Buenos Aires	Norway
1906	lumber	Ship Island-->?	Norway
1906	lumber	Ship Island-->Buenos Aires	Norway
1907	lumber	Pensacola-->Montevideo	Norway
1907	ballast	Sandefjord-->Gulfport	Norway
1909	ballast	Buenos Aires-->Pensacola	Italy
1909	ballast	Ft. De France-->Gulfport	Italy
1909	ballast	Puerto Rico-->Mobile	USA
1910	-	Havana-->Pensacola	-
1911	lumber	Pensacola-->San Juan (P.R.)	USA
1912	ballast	San Juan-->Mobile	USA
1913	general; rice	Vigo-->Havana	UK
1914	phosphate	Tampa-->New Orleans	USA
1914	ballast	Havana-->Gulfport	USA
1915	phosphate	Tampa-->New Orleans	USA
1915	sisal grass	Progreso-->Mobile	USA
1915	lumber	Sabine Pass-->Boston	USA
1915	asphalt	Trinidad-->Gulfport (MS)	USA
1915	-	Gulfport-->Mobile	USA
1916	molasses	San Juan-->New Orleans	USA
1917	-	Santa Domingo-->Pascagoula	Colombia
1917	phosphate	Port Tampa-->Matanzas (Cu)	USA
1918(?)	lumber	Gulfport-->Puerto Rico	USA
1919	pitch pine; lumber	Gulfport-->Genoa (Italy)	USA
1919	-	Mobile-->Genoa	USA
1919	-	Mobile-->Ponce (P.R.)	USA
1919	-	Punta Rasa-->Tampa	USA
1919	staves/iron	Mobile-->Lisbon	USA
1920	oil	Port Arthur, TX-->Mobile	USA
1920	lumber	Tampa-->Cuba	USA
1920	mahogany	Belize-->New Orleans	USA
1920	ballast	Havana-->Charleston	USA
1921	-	Mobile-->Havana	USA
1921	oil	Port Arthur, TX-->Miami	USA
1921	ballast	Santa Domingo-->Mobile	Colombia
1921	ballast	Mobile-->Santiago	USA
1922	general	New Orleans-->Houston	USA
1923	lumber	Gulfport-->Havana	USA
1924	-	Jamaica-->N.Y.	USA
1924	-	New Orleans-->Sabine River	USA
1924	lumber/resin	St. Andrews, FL-->?	Italy
1925	lumber	Tampa-->Boston	USA
1925	lumber	Gulfport-->Puerto Rico	USA
1925	lumber	Mobile-->Havana	USA
1925	lumber	Pascagoula-->Trinidad	Colombia
1926	ballast	Miami-->Pensacola	USA
1926	ballast	Gulfport-->Mobile	USA
1927	-	Tampa-->Baracoa	Honduras
1928	liquor	Belize-->(Louisiana)	Canada
1930	-	Port Arthur-->Pensacola	USA

Table II-3

TRAFFIC OF GULF PORTS (1983-86)

	PORTS	TRAFFIC (no. of vessels)
1.	Galveston/Houston/Texas City, Tex.	11,710
2.	Mouth of Mississippi/New Orleans/ Baton Rouge, La.	3,906
3.	Tampa/St. Petersberg, Fla.	1,656
4.	Beaumont/Port Arthur, Tex.	1,181
5.	Mobile, Ala.	964
6.	Corpus Christi, Tex.	861
7.	Lake Charles, LA.; Freeport, Tex.	582
8.	Gulfport, Miss.	339
	Pascagoula, Miss.	312
9.	Boca Grande, Fla. (Charlotte)	134
	Pensacola, Fla.	
	Brownsville, Tex.	114
10.	Carrabelle, Fla.	
	Key West, Fla.	46

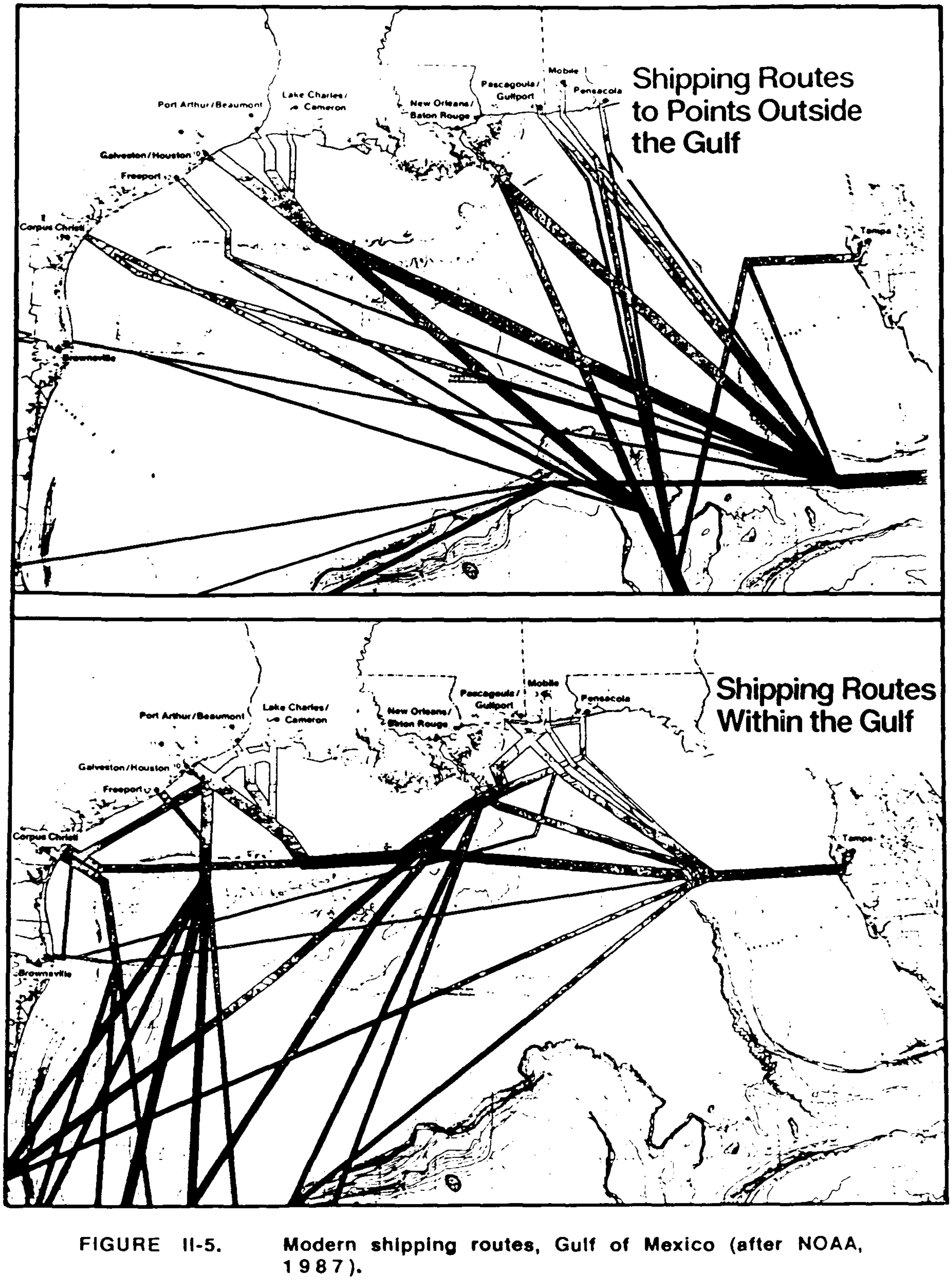


FIGURE II-5. Modern shipping routes, Gulf of Mexico (after NOAA, 1987).

4.0 HISTORIC PORTS, HARBORS AND NAVIGABLE WATERS

This study reviewed the establishment of historic ports, harbors, and navigable waters where shipwrecks are likely to be concentrated utilizing historic maps and literature sources listed in Appendix B. It is difficult to consider these factors independently from shipping routes. As discussed in the preceding section, ports act as nodes along trade routes. Maritime transport networks cannot exist without ports. Their variability is derived from specific economic and geographic relationships in the transport network. Simply illustrated, the early Spanish Gulf trade route included the ports of Vera Cruz, Havana and Cadiz. As the colonial period continued, ports developed along the Gulf rim and the trade networks became more complex. A hierarchy of trade centers developed as coastal traffic increased. The size of the ports were largely a function of the size of port facilities and the navigability of its harbor.

The ultimate determining factor for the location of a port is its position relative to the specific economic goods such as natural resources, manufactured items and services. In the early period of the post-Columbian era, posts such as Vera Cruz, and its San Juan de Ulua harbor, developed as distribution centers for the plunder looted by Conquistadores (Figure II-6). Later, Vera Cruz became the principal port for gold and silver extracted from the mines of central Mexico. Havana developed as a port along the treasure route through the Straits of Florida and became the principal assembly point for the New Spain and Terra Firme fleets.

As French interests increased, Gulf ports developed in natural harbors with clear channels at: (1) Biloxi 1699, (2) Mobile Bay, 1701 and (3) Dauphin Island 1699 (Hamilton 1910). By 1717, New Orleans was established at the Balise on East Pass. The Spanish developed Pensacola in 1698 after La Salle's failed colonization attempt (Figures II-7 and II-8). British and American control of these ports began in the early 19th century. New ports followed settlers into Texas and Florida. Familiar names such as Galveston (1821), Tampa (1831), Key West (1822), Brownsville (1849), Corpus Christi (1848), Pascagoula (1870s), Gulfport (1887), Port Arthur (1897), Lake Charles (1803), and Velasco (1831) appeared along the Gulf. Other ports arose and faltered: Indianola (1844-1886); Cedar Key (1860's-1880s); and Grand Chenier (1870-1920s) (Table II-4).

The major problems in accessing these ports was in their shallowness. The Mississippi River, with its birdfoot delta and numerous passes, posed a particular problem for mariners. It was only with Iberville's ascent of the river in 1700 that its navigable nature was ascertained. The Spanish had always associated the Rio Espiritu Santo (their name for the Mississippi) with a non-existent bay. This misconception was finally corrected after the circumnavigation of the Gulf by Iriarte and Enriquez in 1686 during their search for La Salle's failed colony. Their voyage defined the true nature of the river's deltaic complex (Weddle 1987). Even with this knowledge, the Spanish never grasped the economic and strategic importance of the Mississippi River to the control of the northern Gulf of Mexico. This is particularly ironic since De Soto's men retreated down the river to the Gulf in 1541 but did not appreciate what they had done. The river's importance was realized by Rene-Robert Cavalier Sieur de La Salle in his determined efforts (1681, 1685) to exploit the great river for the development of vast areas of New France.

The commerce that flowed from these northern Gulf ports began slowly. The French, and later the British, recognized the importance of trade with the Spanish (Rowland 1911) throughout the 18th century. As local political and economic revolutions impacted the Gulf coast of Mexico (1816), the United States (1776-1789), and Texas (1836), so did the geopolitics of the Old World. The War of 1812 arose as a consequence of the Napoleonic wars. Piracy increased in the Caribbean markets of American ports as well as in the Gulf (Lafitte 1810-1821). Over 800 American ships were seized by the French using courts, privateer and warships when the U.S. defaulted on its first international treaty (Roberts 1974).

An American naval presence emerged in the Gulf with the eviction of Lafitte from Campeachy (Galveston Island) in 1821, the clearance of the Bahamian Channel pirates in 1825, the support of Seminole Wars in Florida and the Mexican War (1845-46). Strong fortifications were built at northern ports to guard harbor entrances and channels. By the Civil War these forts and harbors became the target of powerful fleets. If the port could not be taken it was blockaded. The Gulf shore is dotted with shipwrecks which failed in running the blockades (Appendices C and D).

The commerce of war gave way to a return to export/import activities that drew larger and larger vessels to these ports. "Deep water" became the rallying cry for the competing ports of the coastal states. Dredging began with William Eads at Southwest Pass, and the Corps of Engineers continued at ports along with the Gulf (Gould 1889). Passes were modified, new ones cut, and old ones allowed to fill as man and his engineering skills altered the natural harbors and channels to meet the changing demands of maritime commerce and technology. This has meant a greater occurrence of historic shipwrecks in waters further from the Gulf shore. The larger vessels required by the growing ports became more restricted to specific entrance channels and less natural navigable water was open to them along the shallow coast. Ships that strayed too far from open fairways or dredged channels were often wrecked.

In summary, accessibility to Gulf ports determined the size and number of vessels as much as the kind of goods shipped at these ports. Transport costs decreased as vessel size increased which influenced the change in vessel types, active ports and shipping routes with time. This is reflected in the historical evolution of ports and vessels in the Gulf where galleons replaced naos and caravelles, schooners replaced brigs and barques, and steam or oil carriers replaced sailing vessels (Appendix E).

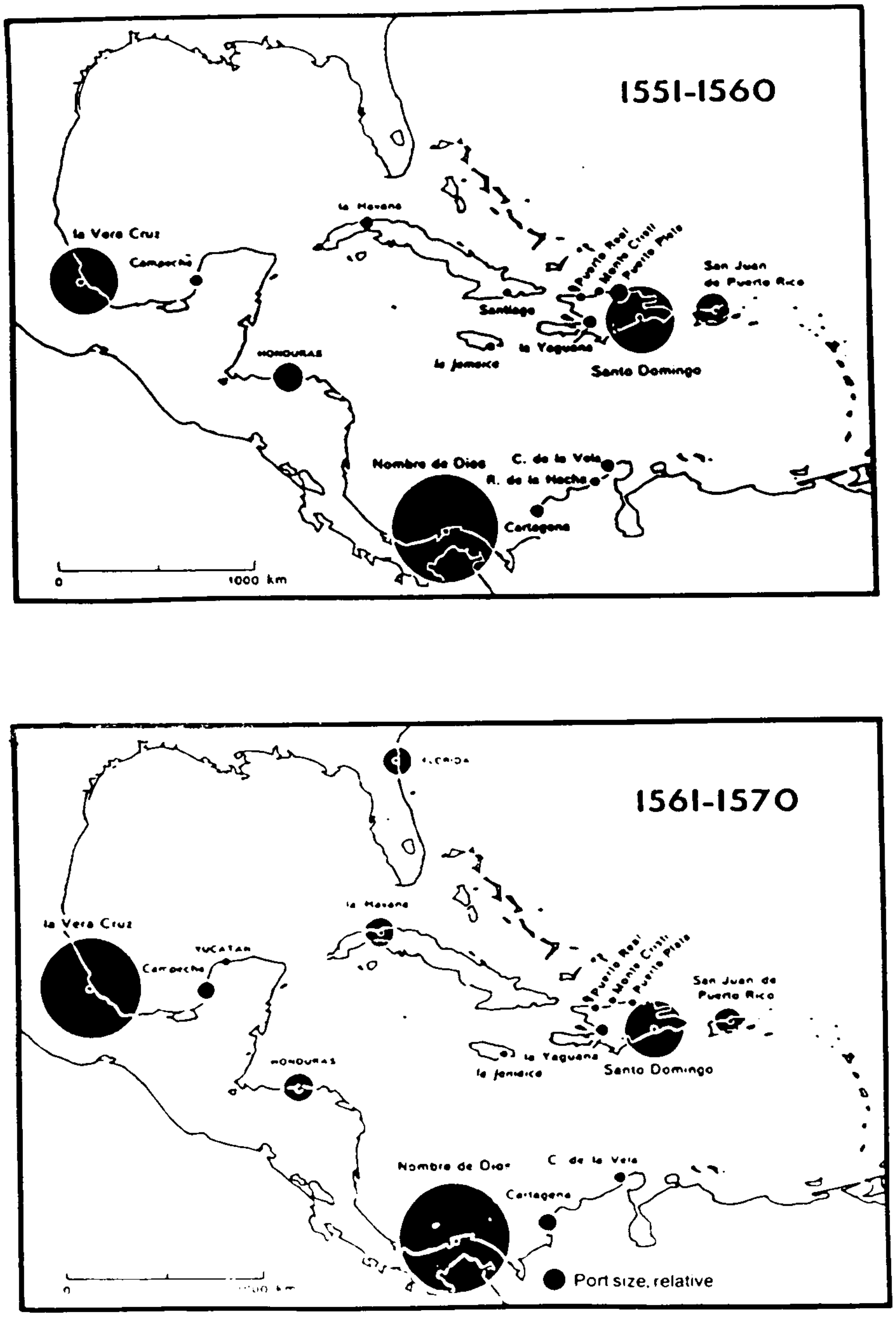


FIGURE II-6. Spanish port development, 16th century.

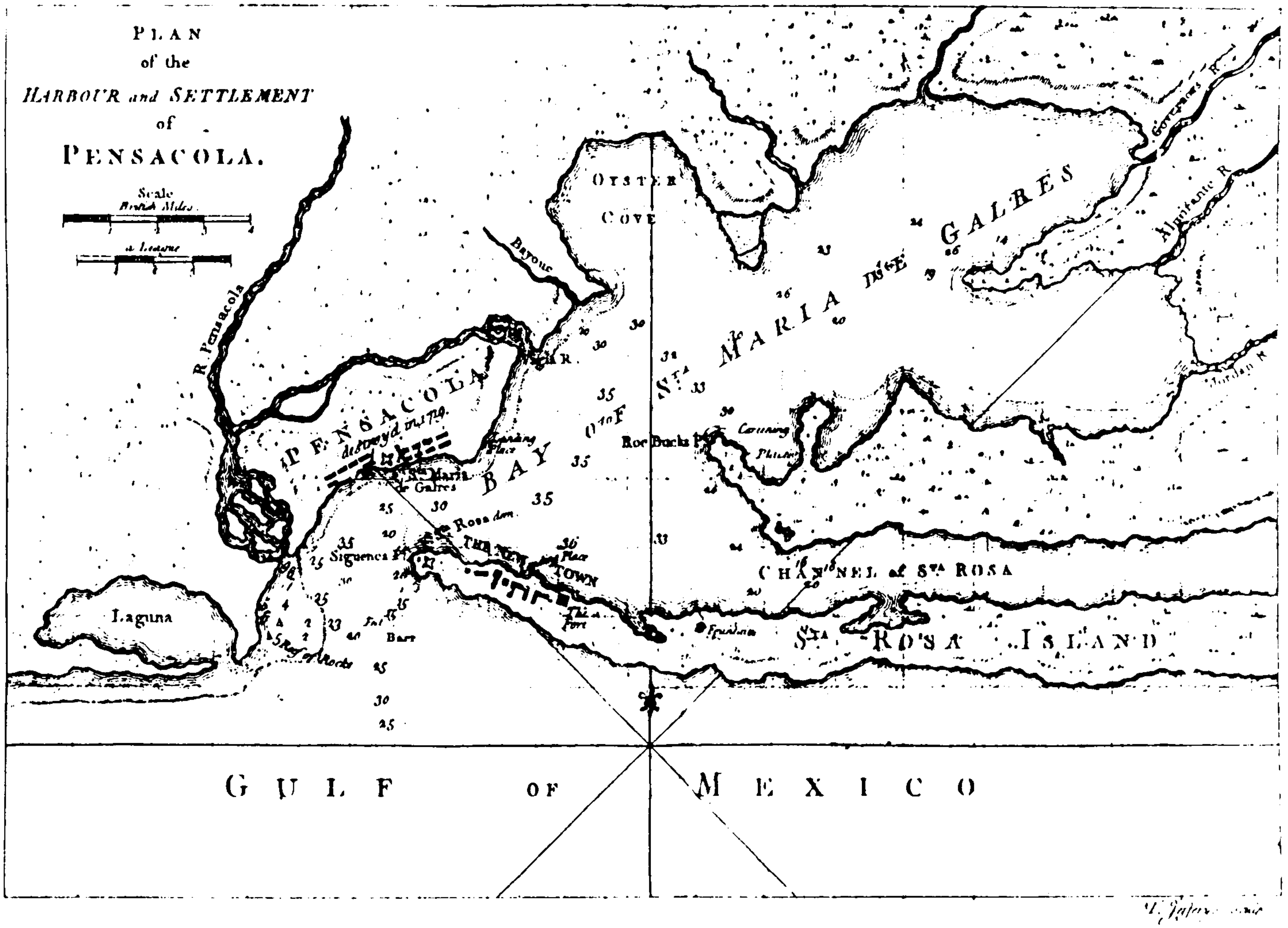


FIGURE II-7 Plan of the harbour and settlement of Pensacola, late 18th century

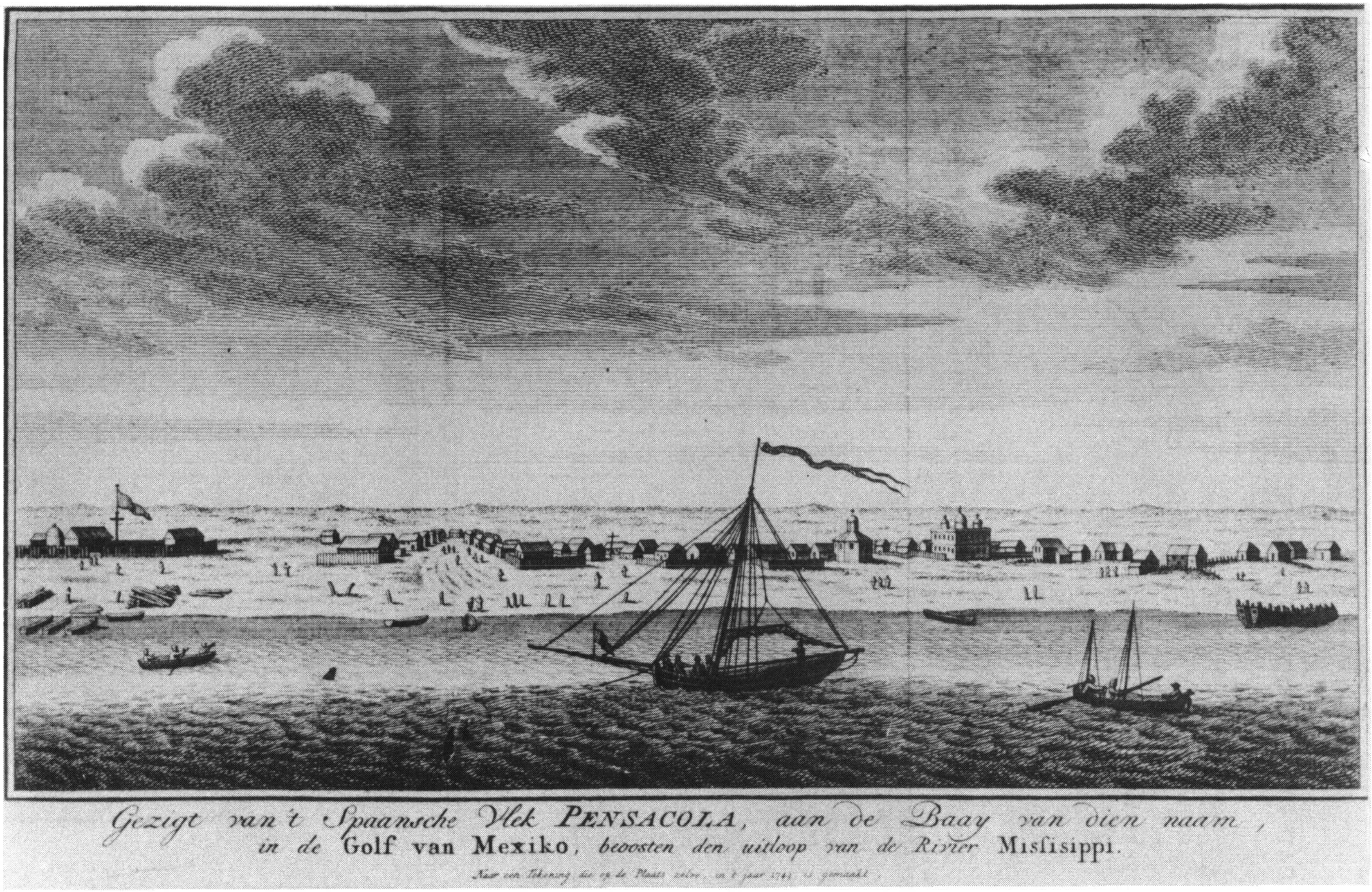


Figure II-8 Pensacola, 1743

Table II-4.

DATES OF FOUNDING OF HISTORIC PORTS OF THE NORTHERN GULF OF MEXICO (AFTER CEI, 1977).

Texas Ports

- Galveston (1816/21)
- Houston (1836)
- Freeport/Velasco (1830's)
- Indianola (1844-1886)
- Sabine (1840)
- Port Isabel/Brownsville (1840's)
- Port Aransas (1820/1839)
- Corpus Christi (1845)
- Port Arthur (1897)
- Port Lavaca (1900's)

Louisiana Ports

- Balise/New Orleans (1718)
- Grand Terre (1810-21)
- Lake Charles (1803)
- Morgan City (1850)
- Grand Chenier (1870-1920's)

Mississippi Ports

- Biloxi (1699)
- Pascagoula (1870's)
- GulfPort (1887)

Alabama Ports

- Dauphin Island/Mobile (1699/1710)

Florida

- Penscacola (1699)
- Key West (1822)
- Cedar Key (1830-1890's)
- Tampa (1831)
- San Marcos-Apalachee (1631)
- Apalachicola (1821-1865)

5.0 BARRIERS, SHOALS, BARS, AND REEFS

5.1 Historical Perspective

The early Spanish observers thought the coast line of the northern Gulf of Mexico was a continuous peninsula with a large river flowing behind it. As late as 1686, the Spanish continued to misjudge the nature of the coast and persisted in assuming the extenuated body of water inside the sand beaches (barriers) to be a river paralleling the coast from the Rio Maupate to the Sabine (Weddle 1987). Even when French cartographers such as Claude and Guillaume De l'Isle began showing barrier islands in the 18th century, Spanish maps continued to represent a solid, unbroken coastline (MacLeisch 1989; Weddle 1987).

This is understandable, for the Spanish made little effort to settle this northern coast until the French incursion beginning with La Salle (1685) and Iberville (1699). Their knowledge improved markedly after the 1686 voyage of Rivas and Iriarte who entered all "bays, bars, and river mouths" in their circumnavigation of the Gulf (Weddle 1987). While searching for the La Salle colony of Matagorda Bay, Texas, the Spanish completed the exploration of the Gulf begun by de Leon and de Soto in the 16th century. The Spanish had always understood the nature of the reef chain along the northern aspect of the Straits of Florida. Their vessels had braved these hazards on the return to Spain since the 16th century (Chaunu and Chaunu 1955; McDonald and Arnold 1979) and Alaminos successfully charted the route through the straits in 1519.

To the French observer of the early 18th century, the whole Louisiana coast was skirted by a beach of little sand banks forming a double coast (Chaville 1903). The coast from the Rio Grande to the Florida Keys was "so flat that it can hardly be seen at a distance of two leagues and it is not easy to get up to it" (Raynal 1915). These early French observers correctly describe the shoreline and coastal waters of the northern Gulf, particularly those east of the mouth of the Mississippi River. In 1700, the French observed the overall shallowness of the coastal waters and many sand bars, particularly those at the mouths of the Mississippi . They further noted the "little depth of water" in "the constantly changing" river mouths (passes) which had not more than three meters of water (Raynal 1915). They encountered the same problem at Biloxi Bay where only shallops of less than a hundred tons could enter (Surrey 1916). By the 18th century, navigators were aware of the hazards of the coastal Gulf.

5.2 General

Formed by the interaction of sea level, waves, winds, currents and sediments, natural shoals and barriers make it difficult to navigate the deep channels between them. These coastal features are dynamic. This is not to imply that barrier islands, river inlet bars, sand shoals, and coral reefs migrate about the shore to impede shipping. In fact, Shepard (1960) observes that barrier islands have been relatively stable along the western Gulf on charts from about 1780 to 1880. In the Mississippi delta area, some islands disappeared to the advancing deltaic fronts and others, such as the Southern Chandeleur islands, disappear and reappear but these natural incidents are more the exception than the rule in terms of shoreline change. More changes have been noted in the barrier features of the Texas Gulf coast due to man-made activities such as dredging and jetties (McGowen, et. al. 1977).

Natural factors such as storms modify the barriers. The migration of headlands and bars alter channels while inlets can be completely closed after storms. An example of this latter case is the old Corpus Christi Pass (Morton and McGowen 1980). These natural features present a hazard to ships and are locations for historic shipwrecks as determined during this study. Even when the bias from increased reporting frequency for shallow coastal shipwrecks compared with that of wrecks in deeper open water is eliminated, the natural hazards of the coasts are clearly the most important factor in explanation of shipwreck density. This is particularly so where maritime traffic patterns extend near hazardous shoals or reefs. Again, examining shipwreck location data from a chronological perspective, we see the convergence of historic shipwreck density with these maritime hazards.

In this study, we examine the nature of these natural hazards, relying on the work of others in the area of sediment and coastal geology. Historic maps, charts, and documents were used to discuss particular features and their importance to the location of historic shipwrecks. Historical changes in the shoreline were examined and related to the occurrence of shipwrecks (Appendix B).

The processes underlying this scenario of change are discussed. Specific topics include the Mississippi delta complex, changing channels between barriers, bars and mudflats, headlands and shoals, and, reefs of the Straits of Florida. These 307 km of natural navigation hazards became a principal cause of wrecks in the Gulf.

5.3 Shoals and Bars

Shoals and bars are prominent all along the northern Gulf coast. Shipwrecks in the Gulf occurred when vessels approached too close to these features and became stranded. These features are formed by the dynamic relationship between shoreline orientation, wave direction, and longshore sediment transport (McGovern, Garner and Wilkinson 1977). Channel bars and shoals form where rivers discharge into the Gulf such as at the entrance to Mobile Bay (Otvos 1982). These features vary according to the available sand budget and currents. These geographic forms are especially hazardous to mariners because of their ephemeral nature (Figure II-9).

Four major shoal complexes are: (1) the "Quicksands" and the Marquesas; (2) the shoals of Cape San Blas; (3) the entrances of the Mississippi River; and (4) the submarine delta of Mobile Bay.

(1) Dry Tortugas/Marquesas - Located southwest of the Florida keys, this area has the largest number of shipwrecks in the Gulf (Bearss 1971). Described by Hutchins (1784) and Romans (1775) these shoals were recognized as hazards very early in the history of the Gulf. Vaughn (1914) describes the Tortugas having a lagoon only 3 m deep. The Marquesas lie west of the Rebecca Channel and the Tortugas west of the Boca Grande Channel. Of the two areas, the Marquesas have less coral and more shoals interspersed with carbonate detrius. The two complexes are crescent-shaped formed by the west flowing counter current (Figure II-10).

(2) Cape San Blas - Shown in Figure II-11, Cape San Blas is a cuspate foreland (Shepard 1960). Southward of the Cape extends a large shoal area. The Cape formed a natural danger for coastal traffic from east of the Mississippi to Tampa or Key West. The data from this study indicates it was less a hazard than the southern Florida shoal areas. The difference is in the opportunity for seaward movement by vessels in rounding the headland without interference by currents such as seen in the Straits. Vessels still sank at or off the Cape in such numbers as to single it out as a hazard area and therefore a moderate-high probability zone for historic shipwrecks.

(3) Mississippi River Delta - (Figure II-12) The whole deltaic area could be termed a large shoal or bar protruding across the shelf onto the slope and beyond. Coupled with the shoals and changing condition of the various passes, the delta presented serious problems to all historic navigators. Charlevoix (1766) attributes the origin of the passes to the river bar located at Head of Passes. The modern delta has advanced and distributaries such as Southeast Pass have dried up since early Gulf exploration (Scruton 1960).

With the founding of New Orleans in 1718 (Otvos 1982, Charlevoix 1766), the delta and its passes evolved to the commercial route we see today. Ships have stranded on the mudflats and shoals near shore or in the large shallow bays flanking its principal distributaries. Seaward of these entrances are deep unobstructed waters. This abrupt transition from the shallow coast to the deeper Gulf presented open water dangers to unwary craft during storms. Vessels rounding

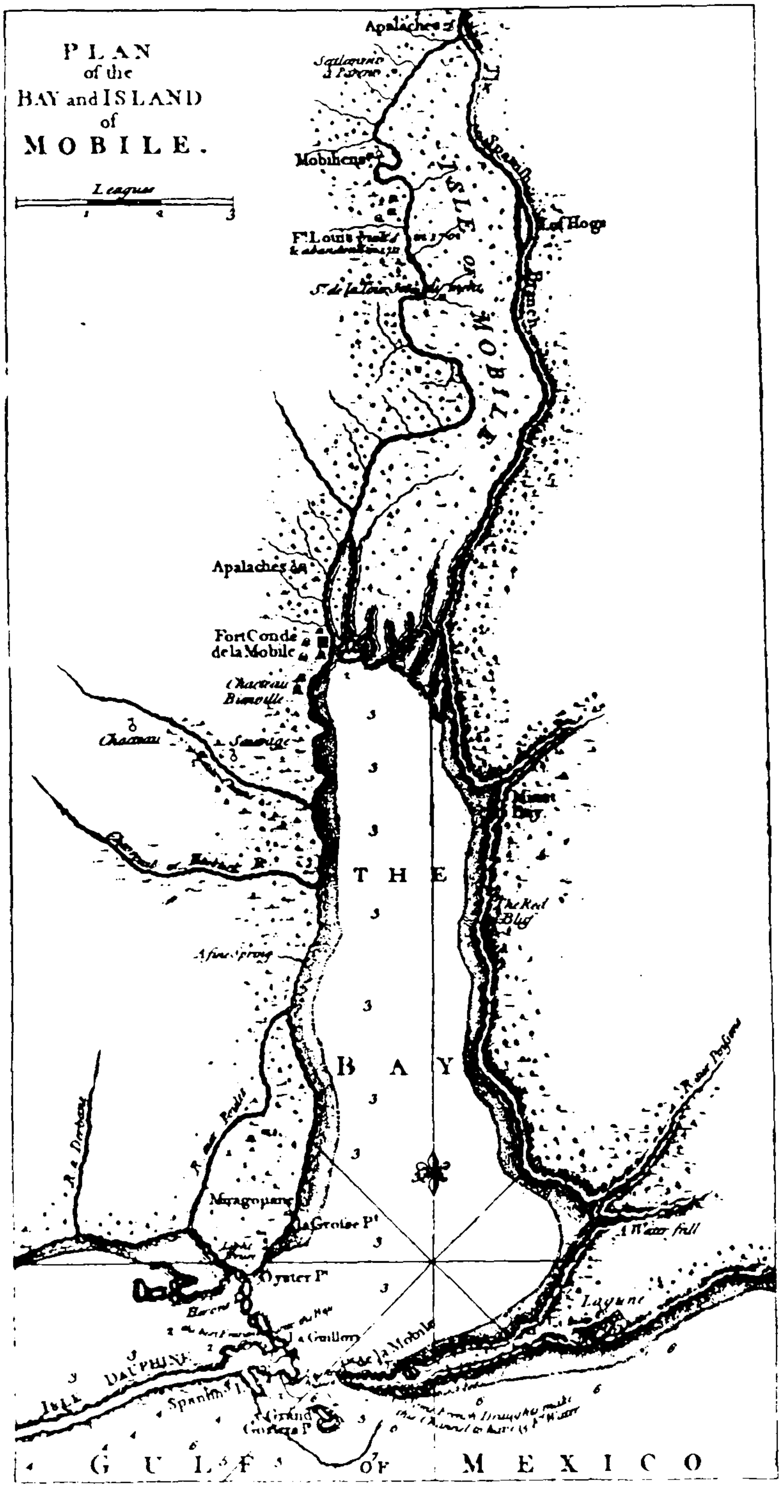


FIGURE II-9. Mobile Bay, 18th century map.

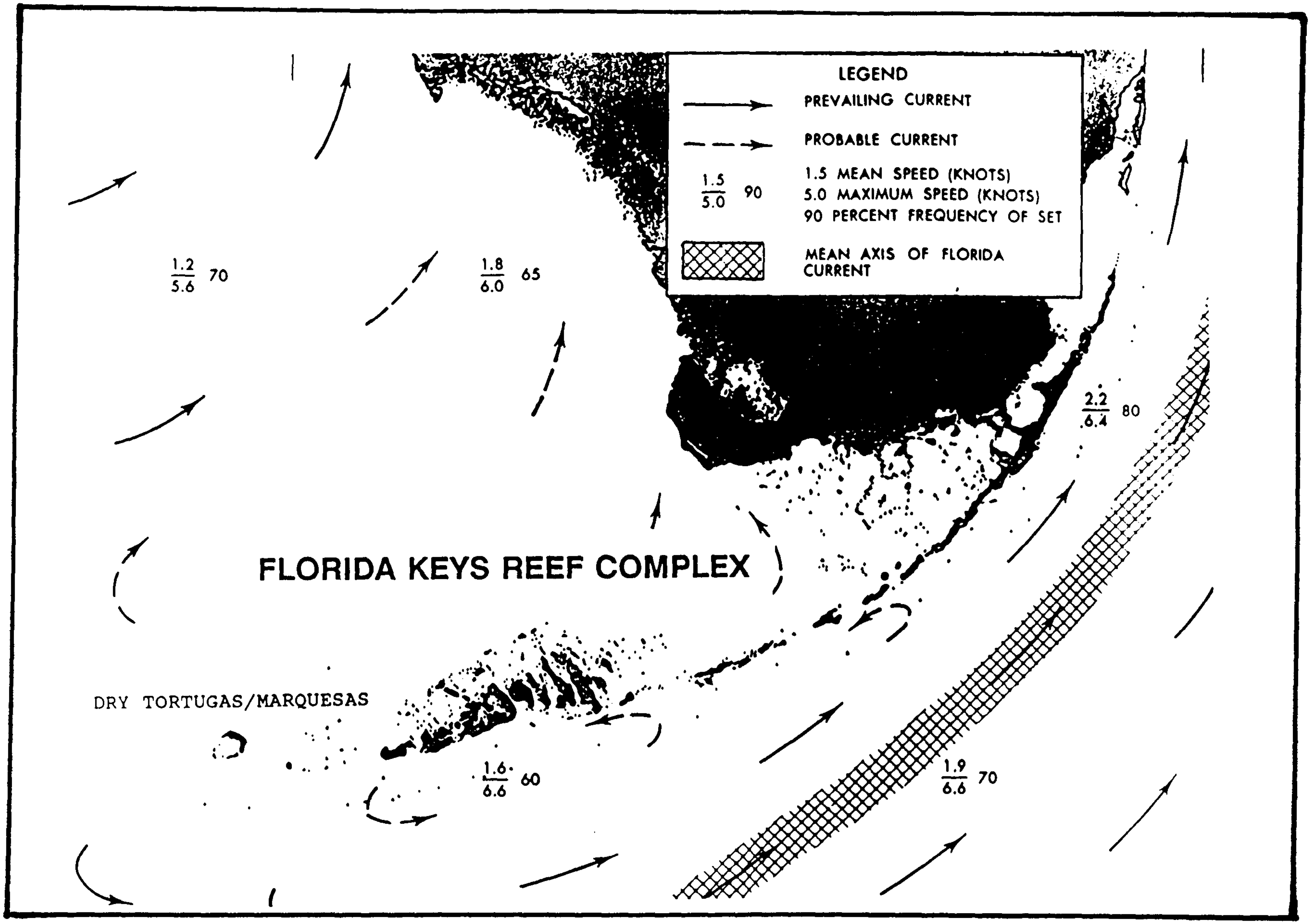


FIGURE II-10. Florida Reef Complex, Dry Tortugas and Marquesas.

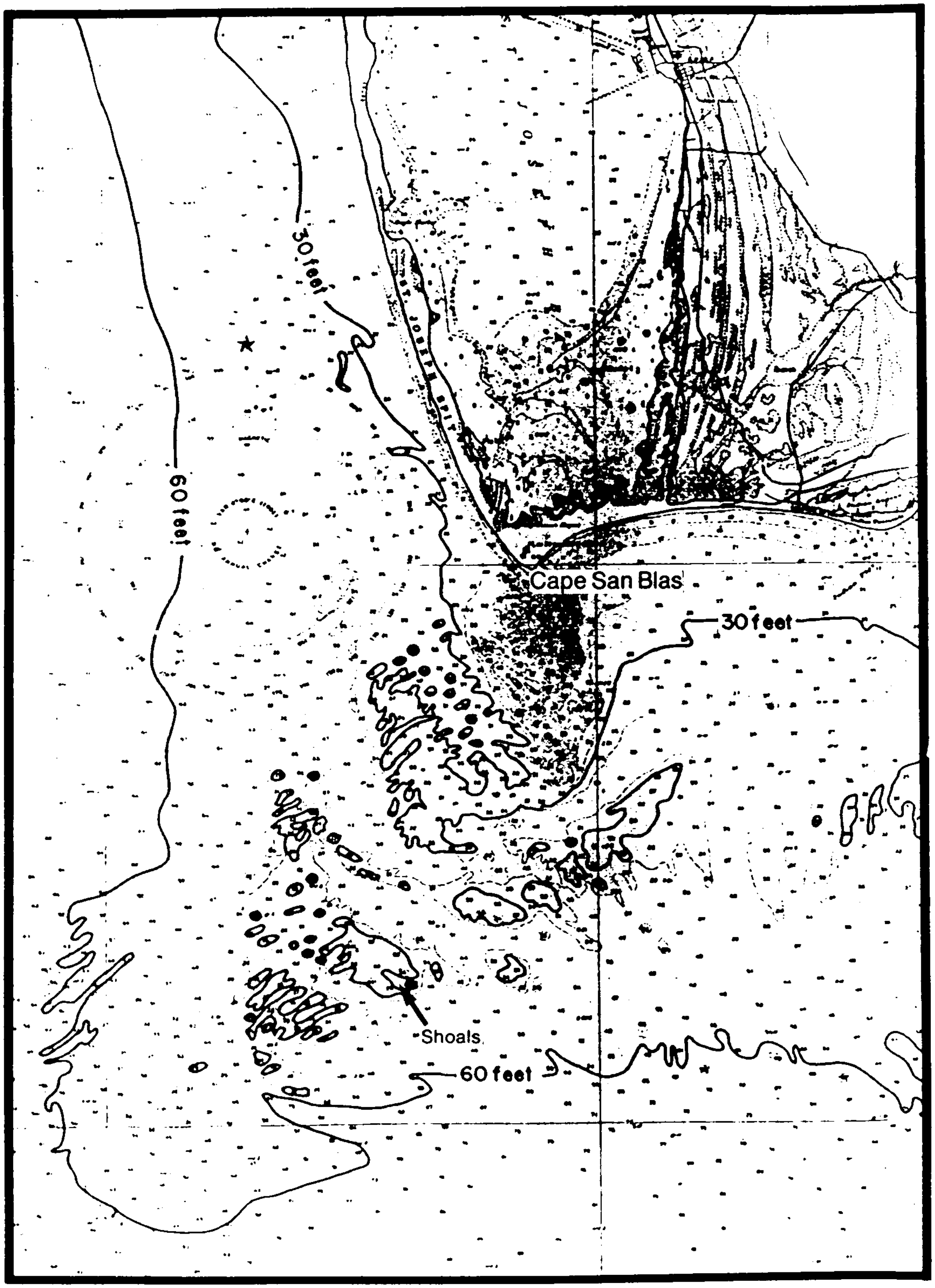


FIGURE II-11. Cape San Blas (Florida).

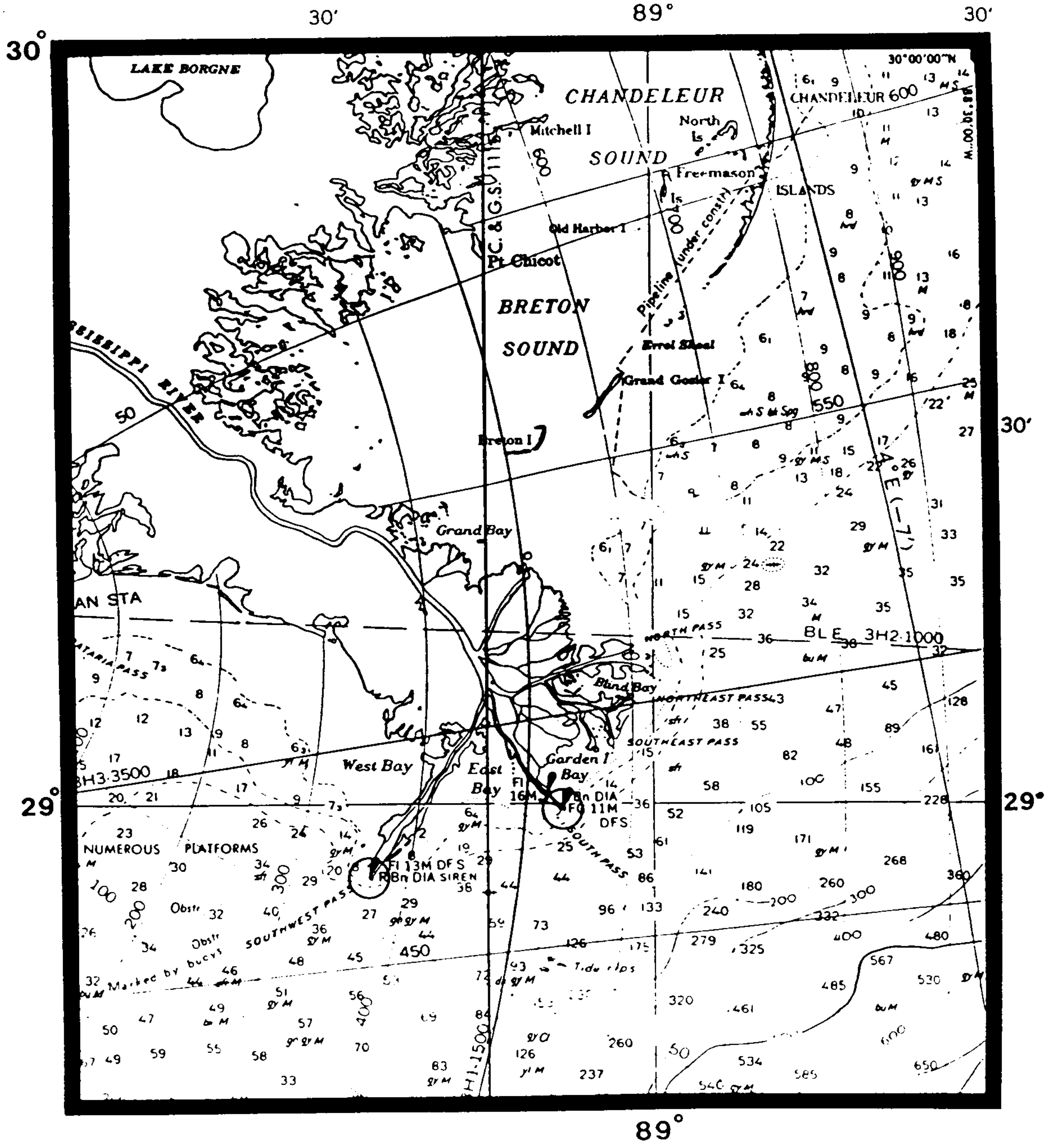


FIGURE II-12. Mississippi River Delta.

the delta could encounter rough seas with only the shallow waters and numerous mudflats or shoals as a lee shore.

The data shows a pattern of loss to either side of the deltaic tip. The pattern suggests strandings as the principal type of wrecking process rather than open water foundering. The heavy modern traffic pattern developed slowly from the 18th century with losses distributed to the east of the Balise (Northeast Pass) and along the Chandeleurs as would be expected for the French Colonial era. Only after the development of Louisiana ports and ports west of Sabine in the 19th century did shipwreck density begin to approach that of eastward waters.

(4) Mobile Bay Delta - (Figure II-9) Mobile Bay discharges roughly 85 percent of its outflow into the Gulf of Mexico forming a 10 kilometer wide delta seaward of Dauphine Island (Otvos 1982). The delta has numerous shoals and islands that change shape, disappear and reappear, much like the Chandeleurs, depending on conditions. Storms, in the past, completely closed the entrance channel to ships drawing more than three meters (Summersell 1949).

5.4 Barrier Islands

Shepard (1960) divides the barriers of the north coast into (1) long, straight, or smoothly curved (Texas); (2) segmented with wide passes (Louisiana, Alabama and Mississippi); cuspate headland or spit (Cape San Blas, Cape St. George); or lobate/cresentic (Southwest Florida). These barriers are generally sand facies lying between two mud facies. Their overall position between 1870-present changed little although locally they have fluctuated in length, growing westward, eroding eastward particularly in the northwest Gulf.

Otvos (1982) modifies Shepard's theory on sand sources for the barrier islands by including the sediment discharge of Mobile Bay as a key element for barrier nourishment east of the Mississippi. Otvos echoes Shepard in the assessment of a relatively stable barrier coast, although he places more emphasis on the processes of segmentation and emergence/submergence. He speculates that the permanent separation between Petit Bois and Dauphin Islands occurred during a storm, possibly in 1740. The H.M.S. MENTOR cruise in 1780 used a 1744 map that still showed Petit Bois and Dauphin Island as one island (Gauld

Agassiz (1852) described the reefs as a "series submarine elongate hillocks rising above sea level in the form of islands in places." These reefs have changed over time. One example is Looe Key, 12 km southwest of Big Pine Key. Exposed in the 19th century, it has disappeared (Wheaton and Jaap 1988). This key has taken its name from the 1744 wreck of the HMS LOOE, a 44-gun British Frigate, one of many wrecks along the reef complex.

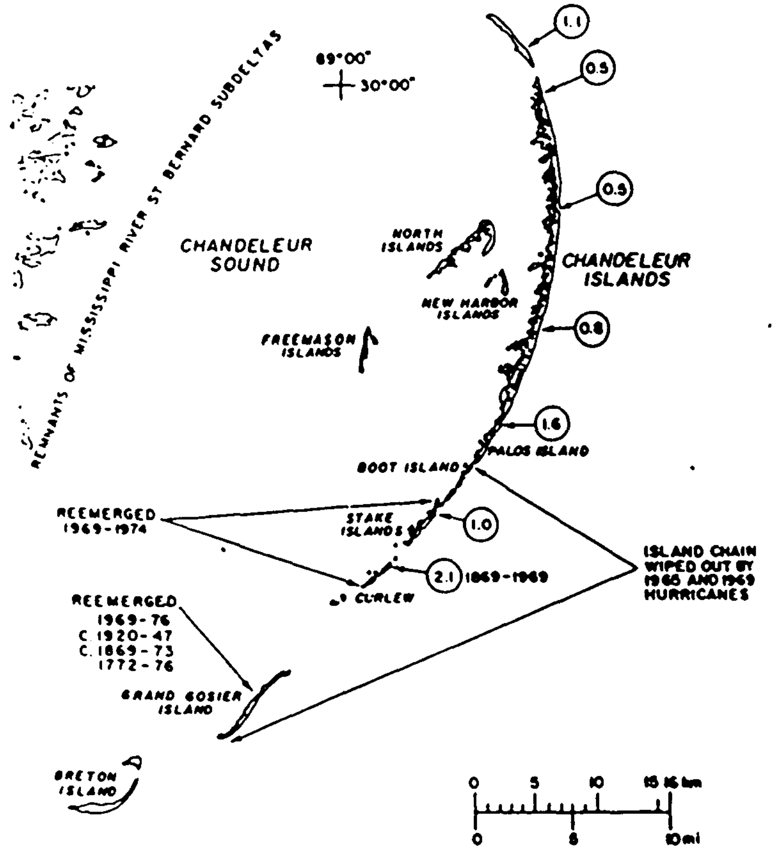


FIGURE II-13. Chandeleur Islands.

6.0 WINDS, CURRENTS, AND WAVE ENERGY ZONES

This chapter discusses factors significant to the cause of shipwrecks as well as to their preservation within the marine environment. Historic sailing vessels either sailed into unfavorable winds or rode favorable seas. Wind strength, direction, and the subsequent current shears were determinant factors in a vessel's final track across the northern Gulf. Longshore currents can run either parallel or contrary to swells depending on prevailing winds. Mariners balanced these natural forces with a cruise track which provided both economy and safety for their ships. When they failed, a shipwreck occurred.

Once the vessel sinks, it is subject to shallow water physical processes such as wave height which in turn depends on wind velocity. One can examine illustrations such as Figure II-14 where wave and storm wave heights indicate statistical patterns for the Gulf. Where these wave related water movements are frequent and strong we can assume rapid deterioration of a shipwreck.

6.1 Historic Perspective

Gauld (1796) cites Lorimer (1769) for an early description of the Gulf of Mexico wherein the Gulf is considered as "one great whirlpool." Here the Gulf Stream is termed "the stream of the Gulf of Florida". This early description, while somewhat simplistic, characterizes the Loop Current as a river of water flowing through ambient Gulf of Mexico water (Molinari, et. al. 1975).

The technology of ships and navigational equipment available to sailing vessels required that natural wind patterns and current be used whenever possible (Hoffman 1980). No ships of the early 16th to 18th centuries could point very well. De Camp (1963) observes that early sailing vessels could sail one point (11°) into the wind if the ship had a deep keel to keep it from sliding sideways. Modern square rigs can make two points, while fore-and-aft rigs can make three points (33°). Even by 1815, square rigged vessels such as brigs could not sail a course in the Gulf of Mexico as easy as a fore-and-aft rigged schooner (Faye 1940).

Navigational instruments of the 16th and 17th centuries could determine latitude but longitude was problematic until the development of accurate chronometers in the 18th century (Sea Technology 1986). Logs and lead lines were used for speed measurement and depth soundings. Compasses were a primary aid. So to reach the Florida Straits and exit the Gulf, sailors had to reach across the tradewinds in vessels that varied greatly in sailing qualities. Ships traveling east to west in the Gulf could take advantage of the prevailing winds but then had to deal with the Loop Current. Winds, currents, and the weather patterns of the Gulf to a large degree determined the pattern of commerce (Hoffman 1980). Hurricane season limited west to east sailings to late spring or early summer (March to June), while winter fronts restricted activity from November through February. Late August to late November was used, but October was known as a period where hurricanes could readily spawn (Chaunu and Chaunu 1955). As for winter, in 1564, the Spanish Admiral, Don Garcia de Toledo wrote: "It is a fact clearly established that all sea expeditions in winter are a complete waste of money..." (Flanagan 1987).

6.2 Winds and Currents

Circulation in the Gulf is complex, especially involving the interaction of the Loop Current and associated eddies (U.S. Department of Interior 1983). The Loop Current exits the Gulf through the Straits of Florida and its associated reef complex (Figure II-15 and Figure II-16).

The Gulf is characterized by an "offshore" or open Gulf and an "inshore" or shelf area energy regime. The open Gulf is influenced by the Loop Current, eddies, a semi-permanent gyre in the

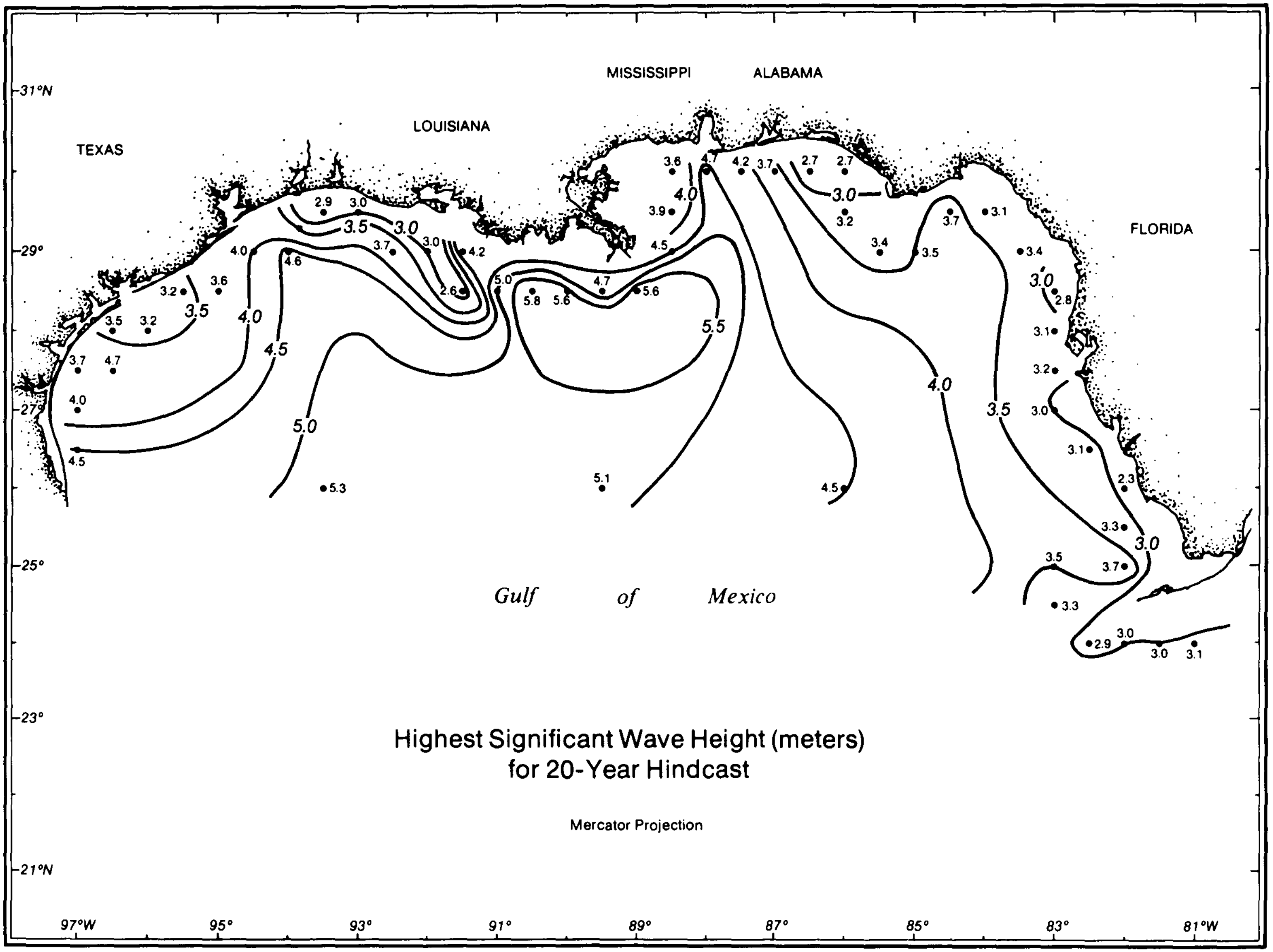
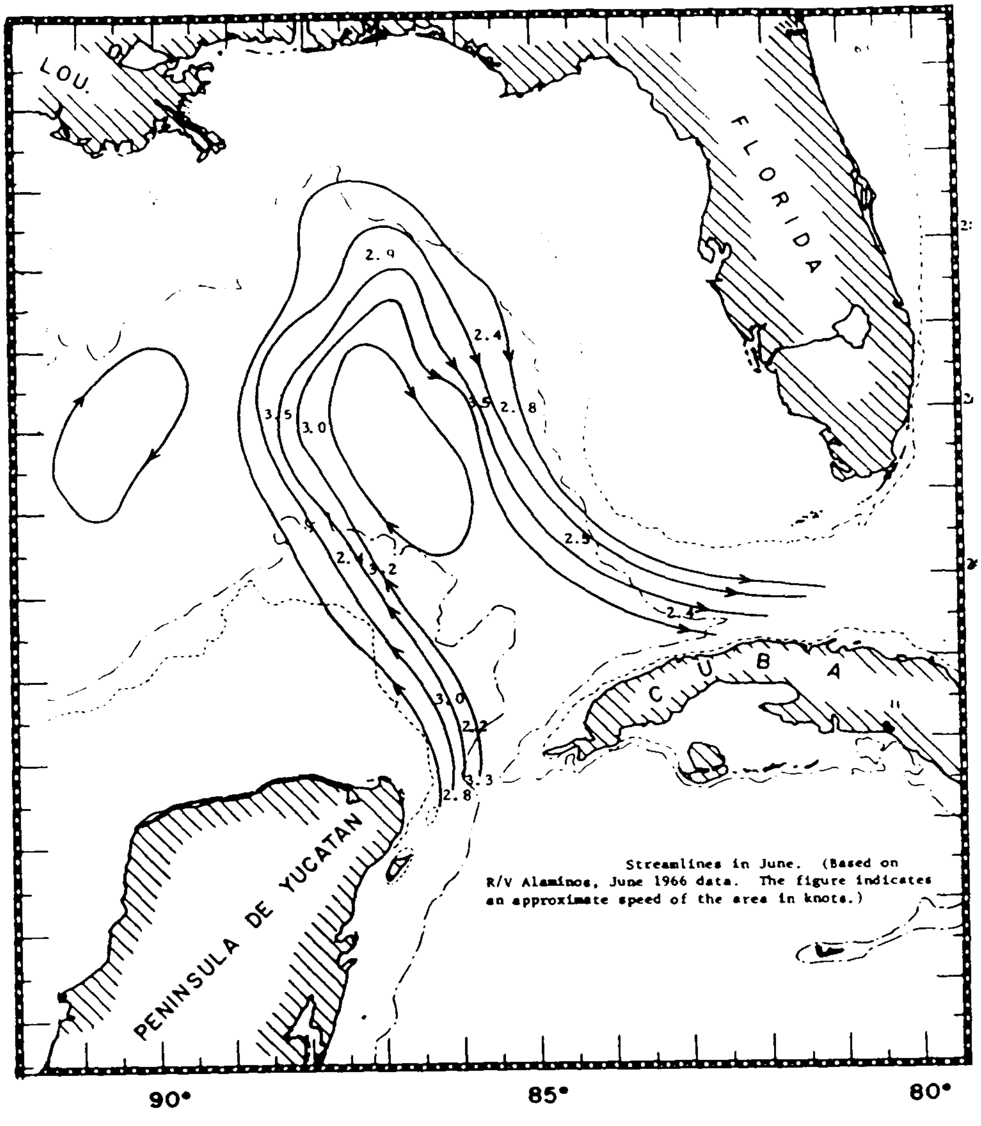


Figure II-14. Highest Significant Wave Height (meters) for 20-Year Hindcast.



Streamlines in June. (Based on R/V Alaminos, June 1966 data. The figure indicates an approximate speed of the area in knots.)

Figure II-15. The Loop Current (from Ichiye et al. 1973).

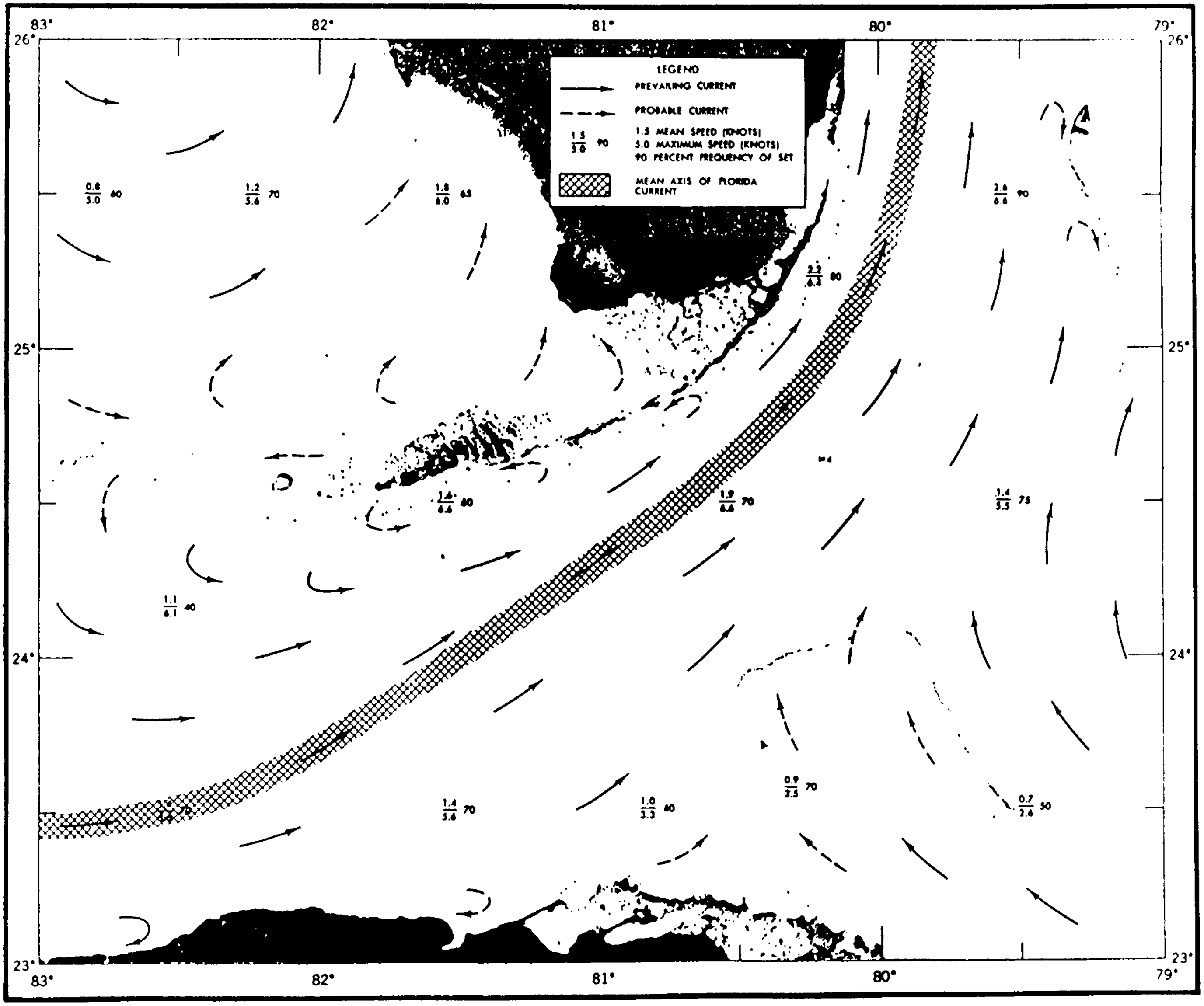


FIGURE II-16. Surface currents, Straits of Florida.

western Gulf, winds, waves, and water column density. The shelf circulation, particularly in the northwestern Gulf, shows strong influence from secondary flows of the Loop Current. Surface circulation is affected more by tides, winds, and freshwater inflow than by the open Gulf circulation features. The mean seasonal circulation is better known for the Texas-Louisiana shelf than for the eastern Gulf. Figure F-4 shows streamlines of the mean flow on the Texas shelf, computed from historical data (Cochrane and Kelly, 1986). The spacing between the streamlines is proportional to the magnitude of the mean surface currents. In months other than June, July and August, an elongated region of counter clockwise circulation dominates the shelf. On the inner shelf side, flow towards Mexico prevails, which is driven by the mean wind field that has an easterly component during months other than June, July and August. The coastal flow carries the discharge from the Mississippi and Atchafalaya Rivers and a large load of suspended sediments far down the Texas coast. Along the outer shelf and shelf-break there is a counter flow towards the east.

Historic sailing routes suggest that navigators became aware of the predominantly easterly flow along the outer shelf and took advantage of it when sailing from Veracruz to the eastern Gulf, as they could pick up at least 25 cm/s (0.5 knots) of speed. During the summer months, the coastal currents reverse, flowing northward along the lower Texas coast and eastward along the upper Texas and Louisiana coasts to Calcasieu Pass, Louisiana. Eastward flow on the outer shelf is weaker during the summer. The flow offshore of the Florida shelf is dominated by the southward flowing side of the Loop Current. It is so strong (102.8 to 154.2 cm/s) that it was immediately noted by the first explorers.

Blumberg and Mellor (1981) describe the typical wind field for the Gulf of Mexico. The northwestern Gulf is dominated by the easterly trades which vary from a southwesterly flow in summer to a northeasterly direction in winter. Major perturbations in this wind regime occur during winter with the passage of rapidly moving cold fronts termed "northers" (McGrail and Carnes 1983). DiMego, et.al (1976) analyzed all frontal passages into the Gulf for the period 1965 to 1972 and computed statistics of frequency and duration of frontal systems. Table F-2 shows the results for the middle of the Texas-Louisiana shelf as interpolated from their maps. The transition from the low frequency regime of summer to the high frequency regime of winter occurs between September and October.

Waves associated with the winds of the Gulf are generally only 1-1.5 m in height with 5-6 second periods over much of the year. Winds associated with cold fronts frequently produce three to four meter wave heights, while midwinter fronts can raise waves to seven meters (McGrail and Carnes 1983). These rare waves represent a low percentage of the general distribution for the Gulf as seen in Figure II-14. That they occur and can wreck large sailing vessels such as the SAN MIGUEL suggests an important role for storm related waves in the cause of historic shipwrecks. Figures F-5a and II-14 show the mean significant wave height and highest significant wave height, respectively, for northern Gulf waters based on hindcasts of 20 years of wave statistics (Hubertz, et.al. 1988). Tropical storm and hurricane conditions were specifically excluded from the wind fields used for the hindcast. Significant wave height is the average of the wave heights of the highest one-third of the waves in a wave record. Significant wave height is statistically related to other wave height estimates. The average of the highest ten percent of the waves in a record is equal to 1.27 times the significant wave height, and the average of the highest one percent of the waves is equal to 1.67 times the significant wave height. Figure F-5 suggests that mean significant wave heights are slightly higher east of Cape San Blas, over DeSoto Canyon, and along the south Texas coast. The latter may be a result of wave and current interaction between southward flowing coastal currents and northwestward moving waves that are driven by the mean winds. Figure II-14 suggests that the region west of the tip of the Mississippi Delta is a high energy zone under storm conditions. In general, for offshore Gulf waters, storm waves exceeding 6 m can be generated by storms.

Andrews (1978) describes the effects of the wind and current system in the Caribbean and the Gulf of Mexico. Westward tradewinds blow steadily for most of the year. The powerful, east-flowing currents that form the Gulf Stream add to the natural forces affecting sailing or navigation from the 16th to 20th centuries. Favorable conditions made for swift east-west voyages from Spain and across the Caribbean. An example in the 16th century was a 20 day cruise that covered 2400 km from Dominica to Cape San Antonio (Andrews 1978). Above the Florida Straits more favorable voyages could be made for west to east trips in concert with the Loop Current (Hoffman 1980).

"Northers" as a wind-related factor in shipwrecks, are second in importance only to hurricanes. "Nortes" are mentioned due to their impact on Spanish fleets as early as 1566 where Captain General Pedrode de las Roelas gives an account of his ships requiring 55 days to reach Havana from San Juan de Ulua after being dispersed by a norther on April 5 (Chaunu and Chaunu 1955)

The influence of these fronts is seen where storms caused the loss of three galleons of a Spanish treasure fleet in 1551. Struck by "storms" in March, the fleet was dispersed and one galleon, the SAN MIGUEL, was extensively damaged. When attempting to reach Havana, it was blown into the Straits of Florida by a south-southwest wind and forced to enter the Bahama Channel without landing in Cuba. With a "wind contrary for La Habana (Havana) and good for Spain", the galleon began her run for Spain. No sooner had she begun when the wind turned into the east again and the vessel found itself dangerously near the "Los Martires" (Florida Keys). Winds turned so sharply south to east that the galleon was battered for three days and nights until it was demasted, became rudderless and ran aground on 29 April (Chamberlain 1988).

Tropical storm and hurricane winds create the most extreme wave and current conditions in the Gulf that not only cause shipwrecks but also affect the remains of shipwrecks. Abel (1988) hindcast wave statistics for 20 years. Although 20 years is a relatively small sample, their computed results for 20 year and 50 year external waves (Figure F-6) for 56 locations around the Gulf (Figure F-7) are useful in assessing factors such as energy zones and preservation. As with normal wave conditions, the regions of the lower Texas coast and the Mississippi Delta are relatively high energy zones.

7.0 HURRICANE PATHS

7.1 Historic Perspective

Shipwreck locations are determined by, but not caused by, sailing routes and ports. On the other hand, seasonal hurricanes do cause maritime losses. Hurricane, derived from the Caribe Indian word "ouragan," entered English as "hurricane" (Millás 1968). The pre-Columbian Indians knew the destructive power of these storms. Early navigators learned by experience. Columbus experienced hurricanes as early as his second voyage on June 16, 1494 (Henry, et.al. 1975). The Spanish learned to schedule their fleet sailings around the peak season. Large fleets that sailed against these storms were lost in the Keys and Bahama Channels during 1622, 1633, 1715, and 1722.

The French and British were aware of the force of hurricanes from reports of destruction along the northern Gulf (McWilliams 1981; Ware 1982). The effects of these storms fell equally upon them all with only the number of maritime losses being mitigated by the differences in the number of vessels of the respective colonial powers at any one time. Spanish shipping, the most numerous in the early centuries, sustained the greatest number of losses. With ports along the entire northern shore of the Gulf by the mid-19th century, there were few areas where maritime commerce could not be impacted.

7.2 Storm Paths and Shipwrecks

Fortunately for mariners, the natural frequency of hurricanes is statistically low. Approximately 7.5 storms form per year mostly during August, September and October. Sixty-three years of hurricane data indicate an average occurrence of one hurricane per year for the area of 25-30° latitude which includes the Gulf of Mexico (Hayes 1967). One hundred years of data for Texas supports this estimate of frequency (Henry et.al. 1975; Tannehill 1956).

Modern forecasting terminology refers to "strike probability" as the most likely point for a hurricane's landfall. This study considered historic hurricane tracks and correlations with shipwrecks. Estimates of severe storm occurrence can be made for segments of the Gulf coast, but it is difficult to determine the tracks of hurricanes (Dewald 1980). The reasons for this are: (1) lack of extensive historical data on storm tracks before the modern era of weather aircraft and satellites; and (2) inherent randomness in individual storm tracks. Appendix F shows the variability of individual hurricanes. The only observable tendency is for the greater storms to move erratically westward for many days before recurving in parabolas of varying pitch (Mason 1972). This observation may be only an artifact for the data acquired the last 50 years.

Millás (1968), in his extensive study of historical hurricanes between 1492-1800, underscores the importance of shipwrecks related to tropical storms. The most important elements in the relationship of hurricanes, shipwrecks, and the natural or historical factors are: (1) reported shipwreck frequency; (2) seasonality; (3) historic period; and (4) development of ports and trade routes. When there was relatively low shipping, shipwrecks are rarely observed in the historical literature. As the frequency of shipping grew and routes dispersed over the circum-Gulf area, the interplay of a normal storm frequency guaranteed a higher incidence of vessel losses. Variation enters into this scheme due to stochastic variations in storm frequency.

A composite representation of tropical storm tracks shown in Appendix F does not show any patterns. The 755 storm paths cover the Gulf of Mexico (Gleick 1987). A general trend shows paths that follow the tradewind belts but there is little predictable behavior beyond this observation (Dewald 1980).

It is difficult to examine the complete path of a historic hurricane and the incidence of shipwrecks along it. Where such data are available, it is primarily post 1830 (BLM Visual No.

2; Tannehill 1956). While it gives insight into modern losses from storms, the extrapolation to historic storms seems tenuous. As good as the data presented by Millás (1968) on storms of the Spanish period are, historic paths can only be speculated.

Recognizing these methodological problems, we analyzed documented cases such as the 1722, 1733, 1778, and 1780 storms in the Colonial era, selected storms from 1916-1981 and a suite of recent data from 1945-1977. The results are shown in Tables II-5 and II-15. Hurricane Juan, a relatively weak, late season Gulf hurricane, is presented due to the extraordinary data obtained by the R/V PELICAN trapped in the storm's path for several days in 1985 (Figure II-17) and compared to that of SOLANO'S FLEET in 1780 (Appendix F; SAI 1985; Millás 1968; Tannehill 1956).

This is not an exhaustive accounting of the losses caused by storms over the historic and modern eras. It is a sample of the data that exists from diverse sources. The data does support the expectation that given the incidence of a major tropical storm in the northern Gulf, we can assume an increased frequency of shipwrecks for any one year. With an overall frequency of one hurricane per year for the Gulf region, any intersection of that storm with principal shipping routes or ports may result in an increased number of vessels lost. If it is a large hurricane, then the probability of vessels being lost is almost certain. The pattern of shipwrecks will then be expected to follow shipping routes rather than some general trend of historic hurricane paths. Given the random pattern for storm tracks, their chance intersection with fixed shipping routes is important in the explanation of observed shipwreck patterns.

Tables II-5, II-6, II-7, II-8 and II-9 present reported vessel losses correlated with specific storm paths. The hurricanes selected are documented in various historic and modern sources and allow a qualitative correlation between path and number of vessels lost. The years selected show a marked increase in percentage of vessels lost per year to hurricanes compared to the observed average for the 21 year MVUS sample. For example, the MVUS sample for 1961 shows a 16 percent loss while our calculated data indicates a 35 percent loss due to storms (Table II-5). Table II-10 compares large hurricanes and shipwreck occurrence. The expected relationship between "super" storms and shipwrecks is mitigated by the observed frequency of losses in the areas of zero probability for these storms. (Table II-10a). Central and eastern ports of the northern Gulf where the frequency of great hurricanes is low, show a relatively even density of shipwrecks similar to the central and western areas (Table II-10b). Given the few number of major ports in the eastern Gulf this frequency can be largely explained by the location of Gulf shipping lanes and the continued impact of lesser size storms than great ones. Table II-11 presents basic data for hurricane frequency by state, and Table II-12 shows calculations of shipwreck frequency in Gulf areas.

Table II-13 compares tropical storm probability and shipwreck occurrence. A strong correlation between hurricanes and shipwrecks is not supported by the data presented in these tables. Storms, hurricanes, northers or squalls did increase the frequency of shipwrecks but not to a degree that one can point to an area of increased storm frequency and observe a corresponding increase in shipwrecks. Storms act only in concert with other variables such as port location and shipping routes. When these factors converge, an increased frequency can be seen. This observation is supported by analyses presented later in this report.

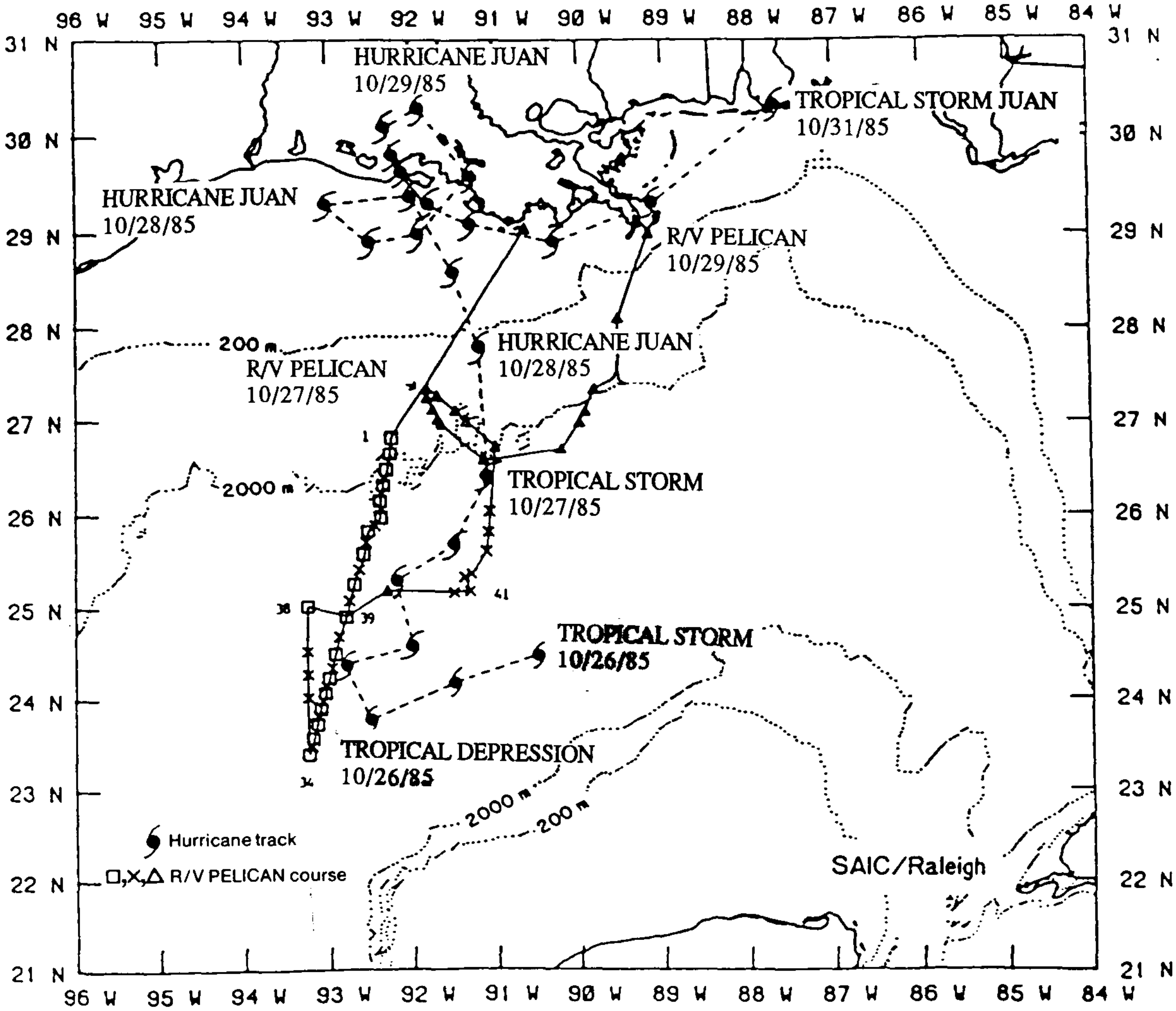


Figure II-17. Cruise track of R/V PELICAN and path of Hurricane Juan, Oct. 1985 (from SAIC 1988).

Table II-5

HURRICANE AND NORTHER-RELATED LOSSES FOR SELECTED YEARS, MVUS DATA

Year	Total Losses	Total Reported as Hurricane Losses	Total Reported as Other Losses
1945	1	0	0
1946,1947*	7	0	0
1947,1948*	2	0	0
1957	1	1	0
1958	2	0	0
1959	2	0	1
1960	23	5	2
1961,1962*	28	10	0
1962	-	-	-
1964	2	0	0
1965	4	2	0
1966	6	0	0
1967	23	6	1
1968,1969*	21	1	0
1969	31	8	2
1970	10	1	1
1971	19	0	1
1972,1973*	33	5	1
1973,1974*	21	0	0
1974	77	1	0
1975,1976*	28	2	0
1976,1977*	77	0	0
	286(100%)	47(16%)	9(3%)

*Several reporting periods (MVUS) included in single volume year

Table II-6.

HISTORICAL REPORTS OF GULF HURRICANES; SPANISH DATA.

YEAR	LOCATION	VESSEL LOSSES	SOURCE
1551 (Nov)	S.E. Gulf; Straits of Florida	at least 4 lost (1 urca)	Spain, Documents de Ultramar, 1864, Serie I, V Millás, 1968
1551	S.E. Gulf Straits of Florida	none mentioned	Anales de la Academia de Ciencas de la Habana, Vol VII, p. 330; Millás 1968
1554	S. Coast of Florida	3 (stranded on coast)	Spain 1864, Documentos de Ultramar, Serie II, XIV, 25 Millás, 1968
1559	Pensacola Bay	7 vessels destroyed	Priestly, 1971
1568	Florida	none lost	Richard Hakluyt, Spanish Documents concerning English voyages to the Caribbean Sea, 1527-1568. Document Nos: 26, 27, and 28, Millás, 1968
1622	Florida Straits	La Margarita (Galleon) at Matacumbe Key: Nuestra Senora de Atocha Rosario at Tortuga; a Frigate and 3 ships	Pezuela, Jacob de 1842 Ensayo historico sobre le Isla de Cuba. New York, Millás, 1968
1623 (Sept/	Florida Straits	Flagship (almiranta) and the galleon Espiritu Santo	Documentos Ineditos de Indias Spain, 1864, II 14, 43, Duro, 1895, iv, Millás, 1968

Table II-6
(continued).

1634 (Sept)	Straits of Florida	flagship and 2 other ships on keys of Matacumbe	Duro, 1895, iv, 451 Millás, 1968
1641 (Sept)	Straits of Florida	none in Gulf	Duro, 1895, iv, 449, Millás, 1968
1644	Straits of Florida	10 English vessels, Keys	Lopez de Cugolludo, 1688, Millás 1968
1692 (Oct 24)	Florida	none	Millás, 1968
1695	Florida Keys	Winchester 4th rate near Key Largo (not Gulf of Mexico)	Millás, 1968
1715	Straits of Florida in Bahama Channel	10 vessels lost Millas, 1968	Duro, 1900, vi, 121, 489
1724	Gulf of Mexico	Navios de azoque Guadalupe and Tolosa lost with all hands	Duro 1900, vi, 489, Millás 1968
1720	Straits of Florida	2 vessels in Keys	Duro, 1900, vi, 489, Millás 1968
1733	Straits of Florida	La Florida at Matacumbe Key; flagships and 6 ships at Viboras Key, 2 in Key Largo; 2 in Matacumbe Key; 2 in the small key of Matanzas; 1 in key vaca, 2 in Los Mártires	Duro, 1960, 489 Millás, 1968
1766	Pensacola	Fleet wrecked; Le Constance lost on Chandeleurs	Tannehill, 1956; Pearson 1981
1780	Straits of Florida S.E. Gulf of Mexico to Miss. River (N.E. half of Gulf of Mexico (formed in Gulf)) Oct 20: 100 miles SSE of Miss. R. delta	19 ships lost * near 25°27N 91°7W, 26°42N 86°11W	Admiral Jose Solano marqués del Socorro Millás, 1968; Tannehill 1956

* locations coincide with similiar storm Oct 21

Table II-7

HISTORICAL REPORTS ON GULF HURRICANES; FRENCH DATA

YEAR	LOCATION	VESSEL LOSSES	SOURCE
1722	la Louisiane	several small craft (chaloupes)	A.N., C., Sér C^{13}, vol. vi, fol. 340
1732 (Aug)	la Louisiane	Spanish frigate at Chandeleurs; Vigilante	A.N., C., Sér. C^{13}, vol. xvi, fols. 7 (Feb. 5, 1733)
1734	Mobile (New Orleans-Mobile)	none-severe storm in April 1 ship off Island (many others destroyed)	A.N., C., Sér C^{13}, vol xvii, fols 53-54
1735	off Havana; S.E. Gulf of Mexico	2 vessels (French) before the end of the year...hurricane	A.B.N. Fr., vol. 10769, fol. 88
1738	la Louisiane	4 ships wrecked by storms (hurricanes) 202-203, 221	A.N.,C., Sér. C^{13} vol xxii fols. 221
1740 (Sept)	la Louisiane Mobile-New Orleans	large bateau lost, boats of all kinds	A.N.,C., Sér. C^{13}. vol xxvi, fols. 127-130
1750	la Louisiane	large storm at harvest (29 Sept 1750)	A.N., C., Sér. C^{13} xxxiv, fol. 347
1752	la Louisiane	numerous storms and hurricanes - in fall harvests	A.N.,C., Sér. C^{13} vol. xxxvi, fols 228, 271
1755	mouth of Miss. River	1 vessel destroyed by storm (hurricane)	A.N.,C., Sér. C^{13} vol. xxxix, fol.

Table II-8.

CORRELATION OF HURRICANE DATA FROM SPANISH AND FRENCH SOURCES.

YEAR	SPANISH	FRENCH	COMMENTS
1722	Sept 8/9, Jamaica Grand Cayman	lower Louisiana Coast, New Orleans, "everything in port lost"	storm moved WNW Jamaica over Caymans and probably over Yucatan Channel into the Gulf of Mexico (Millás 1968: 178)
1732	no record	Chandeleur Islands, Mobile	Storm probably formed in Gulf of Mexico due to lack of reports from Spanish, sources in West Indies (A.N.,C., Sér. C^{13}A, vol. xvi, fol. 7)
1734	no record	April; Mobile	
1734	Sept 12, Jamaica	fall(?)	Storm came from south-eastern Caribbean Sea, Moving WNW after crossing Jamaica (Millás, 1968: 19)
1735	no record	2 vessels between Cuba and Louisiana, before the end of the year	Gulf hurricane? Reference: A.B. N.,Fr. vol. 10769, fol. 88
1738	(2) Aug 30, Puerto Rico South Hispanola (2) Sept 12, Guadeloupe, St. Thomas, Puerto Rica, Santa Domingo	Louisiana no date	(Mobile-Storm (1) moved due west after striking New Orleans) southern part of Hispanola (2) changed directions several times originating in

Table II-8
(continued).

			Atlantic east of Guadeloupe Caribbean, moved N.W. passed south of Virgin Islands thence WSW-W crossing south coasts of Puerto Rica and Hispanola
1740	Sept. 11/12, Puerto Rico	9/11/18; Mobile New Orleans Pensacola	moved S.E.; normal to weak intensity
1750	no storms reported	Sept. 29, Louisiana (Mobile-New Orleans)	Gulf hurricane "large storm" A.N.,C., Sér.C^{13}, vol xxxiv, fol. 547
1752	no storms reported	Louisiana "harvest (fall ?)"	Gulf tropical storms or hurricanes? Two storms in September Tannehill 1956 A.N.,C., Sér C^{13}, fols. 220,271
1755	November, Cuba (3)	mouth of Miss. River date unknown	Gulf origin
1766 *	Oct 8, Puerto Rico	Pensacola, Oct 22	Perhaps-there is too much separation in dates to be same hurricane. Hurricane at Pensacola may have had a Gulf origin and minimal strength Ref. Gauld in Ware 1982:78, Still this may be the same

Table II-8
(continued).

			hurricane as at Puerto Rico.
1780 *	Oct. 20/21 Gulf of Mexico, approx, 26 N Latitude, 86 W Longitude. Landfall west Florida (Pensacola)	a) Aug 24, 1780 (4) landfall at Miss. River delta-Pensacola b) no association	Storms of Gulf origin (Millás, 1968: 260-2 Tannehill, 1956 reports four October hurricanes.

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* After 1763, French possessions ceded to Britain in settlement of Seven Years War. Data for 1766 from British sources.

Table II-9.

HURRICANE-RELATED LOSSES FOR SELECTED HISTORIC STORM PATHS.

YEAR	PATH OF HURRICANE	LOSSES	SOURCES
1722	Jamaica, Grand Cayman, W. Cuba Yucatan Strait to Mississippi Sound	several "chalaupes"	Millás; A.N.,C., Sér. C[13]
1733	S.E. Gulf, Florida Strait, Bahama Channel	19 vessels	Millás; Florida (Bureau of Archaeological Research)
1766	Gulf?, Pensacola	"Spanish fleet wrecked"	Tannehill (1956: 245)
1778	Jamaica, Yucatan Strait, to Pensacola	17 vessels	Florida (Bureau of Archaeological Research)
1780	26°42'N, 86°11'W to 25°27N, 91°7'W to Matagorda Bay, TX	19 vessels	Millás (1968)
1846	Caribbean, Havana, Key West, Apalachicola area	20 vessels	Tannehill (1956)
1893	Caribbean, Yucatan, Delta, Mobile	"fishing fleets destroyed"	Mistovich, Knight and Solis (1983)
1916	Yucatan Strait/W. Cuba(?) to Pensacola	16 vessels; "30-40 boat's destroyed in Biloxi-Gulfport region"	MVUS (1916); Mistovich (1987)
1919	18°N, 63°W; Puerto Rico, Tortugas, S. Texas	10 vessels	Tannehill (1956)
1960	Old Bahama Channel, Straits of Florida, Cape Sable	5 vessels	MVUS; Visual No. 2
1961	Caribbean, Yucatan Channel West Gulf, Matagorda Bay	10 vessels	MVUS; Visual No. 2
1967	Yucatan, Bay of Campeche, Rio Grande	6 vessels	MVUS; Visual No. 2
1969	Caribbean, W. Cuba, S.E. Gulf Mississippi Sound	8 vessels	MVUS; Visual No. 2

Table II-9 (continued).

1972	Yucatan Channel, E. Central Gulf; Cape San Blas	5 vessels	MVUS; Visual No. 2
1981	Origin of Frederic's Track, E. Central Gulf, Dauphin Island - Gulf Shores, AL.	11 vessels	MVUS

Table II-10a.

SHIPWRECK VERSUS "GREAT" HURRICANE PROBABILITY IN THE STUDY AREA.

Coastal Sectors of Zero Probability for Great Hurricanes*	Shipwrecks per 1° of Latitude-Longitude centered on Coastal Sectors of Zero Probability **
9	141
10	211
14	143
15	84
16	75
17	72
18	30
19	3
20	96

* After Simpson and Lawrence 1971; cf. Figure 3. That study.

** Data, this study

Table II-10b.

INCIDENCE OF MODERN "GREAT" HURRICANES IN GULF (AFTER TANNEHILL, 1956).

1886	Apalachicola, Florida (June)
1886	Indianola, Texas (August)
1900	Galveston, Texas (September)
1906	Alabama (September)
1910	Key West (October)
1915	Galveston, Texas (September)
1916	Corpus Christi/Brownsville, Texas (August)
1916	Mobile/Pensacola (July)
1919	Key West/Corpus Christi (September)
1929	Panama City, Florida (September)
1933	Brownsville, Texas (September)
1947	New Orleans, Louisiana (September)
1957	Calcasieu Parish, Louisiana (June)
1961	Port O'Conner, Texas (September)
1969	Biloxi, Mississippi (August)

Table II-11

HURRICANE FREQUENCY BY STATE, 1879-1943 (AFTER MITCHELL, 1924 AND TANNEHILL, 1956)

State	Frequency per 100 miles of Coastline
Texas	9.5
Louisiana	4.5
Mississippi	15.4
Alabama	13.2
Florida	4.4

Table II-12

VALUES USED TO CALCULATE SHIPWRECK DENSITY

Lat./Long.	Gulf Areas	Area(mi.^{2})	n	n/A
24-26°/97-96°	Rio Grande	3600	154	0.04
26-28°/97-96°	Western	7200	590	0.082
28-29°/93-96°	Central	14,950	1308	0.088
27°30'-30°/93-89°	Central La.	28,400	728	0.026
30°-27°30'/89-88°	Miss./Ala.	10,800	284	0.026
30°-28°/88°-85°	West Florida	14,400	210	0.015
30°-28°/86-83°	Big Bend	14,400	278	0.019
29-27°/84-82°	Middle Ground	7,200	271	0.038
27-25°/84-81°	SW Florida	18,000	175	0.01
24-25°/83-80°	Tortugas	10,800	818	0.076
	Total	129,750	4816*	0.0371

* number includes duplicate entries

Table II-13.

SHIPWRECK VERSUS HURRICANE FREQUENCY IN THE STUDY AREA.

Tropical Storm Probability/ 50 Mile Sector*	Historic Shipwreck Frequency/ 1° Latitude-Longitude**
4%	97
5%	26
6%	114
7%	176
8%	126
9%	270
12%	335
13%	84
14%	52

* Data from Simpson and Lawrence 1971; cf. Fig. 3. That report.

**Data from Shipwreck File, this report.

8.0 SEDIMENTS, ENERGY ZONES AND OTHER PRESERVATION FACTORS

> "In general, given similar bottom conditions, it appears that the breakdown and deterioration of vessels of wooden and composite construction lost in reasonably calm areas on a bottom composed of silts, sand, or a combination of these materials will be similar whether the water is 10 m or 100 m deep and the wreck 20 or 2,000 years old (CEI 1977)."

This quote, offered as a summary statement in the 1977 report by CEI, while presenting a generally broad treatment of the relationship of historic shipwreck preservation, sediments and energy zones, is more correctly, a hypothesis concerning these variables. It provides little predictive value regarding shipwreck materials, nor are the relationships of these factors discussed. The preservation of shipwreck materials in the marine environment includes the interaction of shipwreck material, sediment type, sediment depth, energy, water depth, water temperature, water column chemistry, and biological activity.

A recent example of the acceptance of untested assumptions concerning historic shipwreck preservation is that of the RMS TITANIC. The discovery of the lost superliner by a joint French-American expedition in 1985 was one of the most dramatic events in the past decade. One observation was repeated with a tone of disbelief: the total absence of preserved wood on the wreck. It was assumed that the preservation of organic materials, such as wood, was enhanced in deep, cold marine waters (Marx 1971). The principal reason for this expectation was assumed low levels of biological activity by organisms such as marine borers whose range did not include the deep ocean. This observation about the shipworm *Teredo*, common to warm ocean waters, was correct. Not taken into account was the presence of other marine boring organisms. Further, expectations about metal preservation, particularly iron, were also in error. Marine bacteria have reduced the great ship to a rust hulk. Only the great mass of the wreck prevented more complete destruction of the hull and superstructure. Expected redox rates due to low temperatures did not prevent the deterioration of ferrous materials by biological and chemical factors. Some of the more general expectations concerning preservation in deep water shipwreck archaeology were changed by discoveries made on the TITANIC. This being the case with the dark, relatively static abyssal zone of ocean we should expect less for the shallow, more dynamic continental shelf and slope of the northern Gulf of Mexico.

Brown (1987) reported on controlled *in situ* experiments utilizing timbers and ferrous materials of historic shipwrecks where differential deterioration processes were measured relative to marine biological and chemical processes. Shipwrecks occurring in shallow coastal waters of the Gulf can act as artificial reef structures where recruitment and colonialization of the wreck fabric is immediate and thorough. While encrustation occurs on the wreck exterior, destruction internally proceeds as *Teredo* worms infest the wreck. In a short time, a timber is deteriorated from the inside although it seems preserved in the sediments. The key element in estimating preservation of wooden shipwreck material is the identification of the burial sediment, its depth, and the inherent biological communities associated with such conditions.

The survival of shipwreck materials has been discussed by Clausen 1965; Gluckman 1967; Mathewson 1975, 1977; Muckelroy 1978; Burgess and Clausen 1976; Dethlefsen 1978; Marx 1985; Watts 1985; SAI 1981; Keith, et. al. 1985; Smith 1985; and Keith and Simmons 1986. Wrecks range from 16th century caravel vessels to the Civil War ship, USS MONITOR. The principal cause for the wreck of most vessels was shallow reef or sandy shoal areas. The exception is the MONITOR which lies in water over 70 m. The MONITOR is a metal vessel and the others are wooden sailing craft. With the exception of the MONITOR, none of the vessels were found intact.

The destruction of the wooden hulls by grounding in a high energy wave zone together with subsequent deterioration over time have combined to preserve little of the ship's fabric in many of the case studies. A few ship frames, floors or fragments of scantlings leave mainly a scatter of differentially preserved artifacts about a ballast feature. The vessel reaches an equilibrium with environmental factors. Depth appears to be a factor but only in relation to water chemistry. Wave related destruction is ameliorated or retarded by either protection from exposed features such as ballast or by simply being reduced to such a configuration as to preclude further erosion. Where wave or currents of any magnitude cannot act strongly on a hull such as the MONITOR, or an extreme case, such as the TITANIC, the vessel survives as a more or less recognizable reflection of the original ship. This observation is corroborated by observations such as those made on the BREADALBANE (MacInnis 1985) where depth and cold have preserved this wooden vessel, and with the USS HATTERAS (Arnold and Hudson 1981) of the Civil War period.

The relationship of sediments to the preservation of a historic shipwreck site appears related to physical protection from erosional forces. Muckelroy (1977, 1978) suggests that waves and currents break up and carry away more of a ship than biological or chemical destruction.

The best guarantee for preservation of all types of material in either shallow or deep water is for everything to be buried by sediments, especially if the sediments are low in oxygen, e.g. a chemically reducing environment. The process of burial is generally more rapid in nearshore waters where sediments are transported by longshore and storm currents. The nearshore sediments of the northern Gulf are typically coarse with silt and clay muds farther offshore or on the slope of the shelf proper (Figure II-18).

The importance of sediment transport and subsequent burial probably explains the good preservation of wrecks including the SAN JOSE, EL LERRI (Smith 1978) and the Molasses Reef Wreck (Keith and Simmons 1985). Vessels in dynamic, biologically active areas like the shoals and reefs of the northern Florida Straits and Bahama Channel that remain preserved seem to have fallen into natural lacunae where sediments buried their remaining fabric.

Where sediments cannot quickly bury the wreck, ballast seems to be the only means for preservation of any hull or cargo remains in the nearshore environment. Preservation in the open sea must rely on factors other than burial as sedimentation rates (ca. 0.012 m/year) are very low. Those elements buried in the muds shared the greatest chance of survival as evidenced by the remains of the EL NUEVO CONSTANTE (Pearson, et. al. 1981). Bascom (1971) and Muckelroy (1978) speculated on factors operating in the deeper water that could aid in preservation such as lower temperatures and oxygen, and slow corrosion rates, especially of ferric metals. Currents promote erosion by mechanical or chemical means. Recent research results on the deepest of known shipwrecks, the RMS TITANIC, show extensive destruction of wooden materials by organisms (Ryan 1987). While *Toredo* and *Limnoria* do not live below 100 m, other organisms such as *Xylophaga* and *Xyloredo* (Ryan 1987) do.

8.1 Sediments of the Gulf of Mexico--General Background

Berg (1986) characterized the Holocene sediment distribution of the northern Gulf of Mexico continental shelf as follows:

Litoral (beach)	longshore sands, silts, clays
Neritic (shelf)	alternating muds, sands overlying Pleistocene clays
Bathyl (slope)	sand and shell banks, muds, clays
Deltas	foreset beds of sands, silts, muds organics

This general surface sediment distribution for the northern Gulf of Mexico is shown in Figure II-18. Berryhill and Trippet (1981) state the Holocene sediments of 96°W longitude range from 4 to 43 m in thickness. These sediments begin thinning east of 96°W longitude. From 96° to 93°W a veneer or lack of Holocene sediments is seen (Brashier, Beckert and Rouse

1983). Those sediments east of this general area are known to have up to 15 m of sandy sediments (Nelson and Bray 1970; Kolb and Van Lopik 1958).

East and north of the Mississippi delta, sand and shell make up most of the surface sediments (Scruton 1960). The shelf sediments east of the delta to DeSoto Canyon are dominated by the MAFLA sand sheet (Berg 1986; Alexander 1978). Terrigenous sediment, containing varying amounts of silt and clay occur off Mississippi and Alabama (Rezak, et. al. 1985). Southeast of the Apalachee Bay is a karstic shelf of thin or no sediments on the outer shelf. (Berg 1986; Alexander 1978). Sands occur shoreward and give rise to headlands like Cape San Blas and shoal areas like the Marquesas and Tortugas. Slope sediments on the eastern shelf are generally thin (≤1 m) overlying the karstic Florida platform. Muds are seen to be thicker in the Desoto Canyon portion of the slope. These latter observations were made on the 1985 cruises of the OREGON II and JOHNSON SEALINK. Overall sediment thickness deposited during the last 10,000 years averages about 23 m and yields a low sedimentation rate of 0.012 m/yr. Major sediment sources for the northern Gulf shelf are the Mississippi and Rio Grande rivers (van Andel 1960).

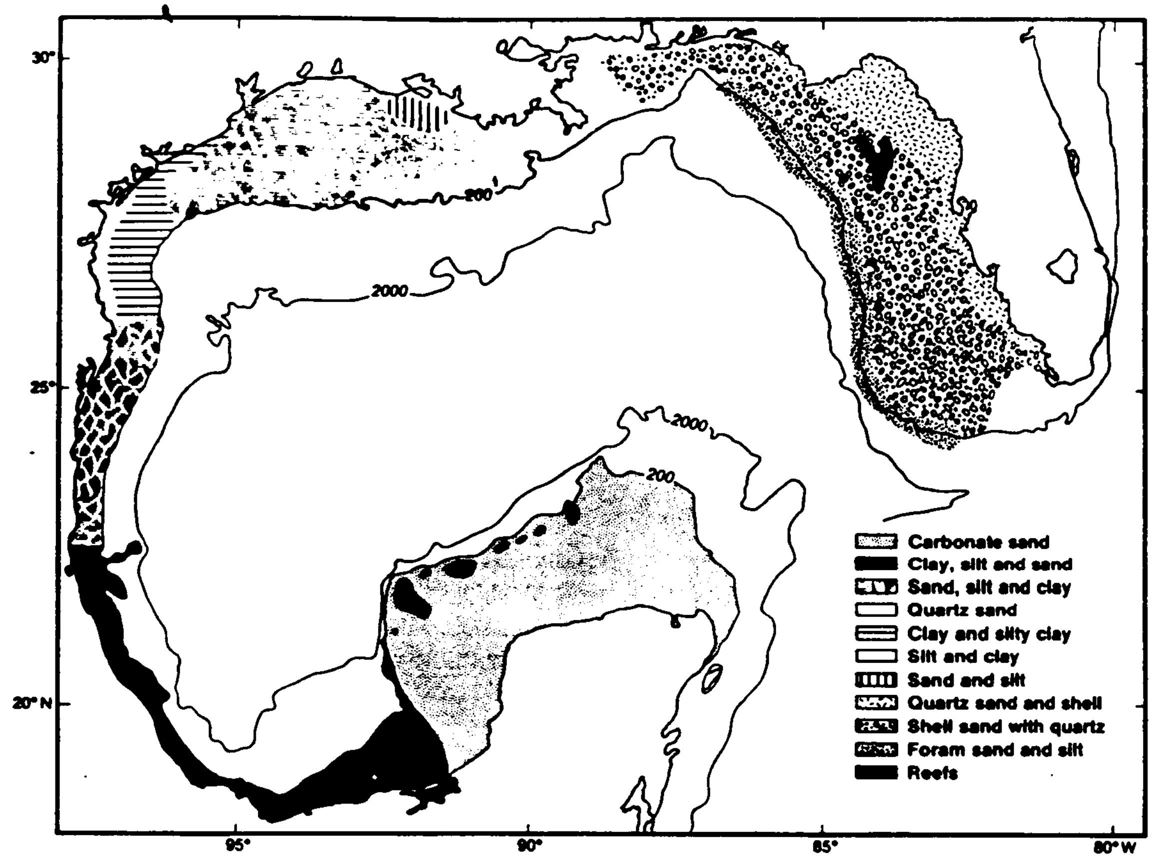


FIGURE II-18. **Sediment distribution, Gulf of Mexico Outer Continental Shelf (from Rezak *et* al., 1985).**

8.1.1 Energy Zones

The energy zones measured by wave height and current velocity follow the wind flow of the Gulf (Blumberg and Mellor 1981). Westerly winds dominate the surface circulation and create a moderate-high energy zone along the central-lower Texas coast. The upper Texas to western Louisiana coast grades to a low energy zone (average wave height < l m). Eastward of the Mississippi delta, the Mississippi-Alabama-Florida shore is a moderate-low energy zone. The peninsular coastline of Florida progrades with mangrove swamps and convex barrier islands indicative of a low energy regime (Curray 1960; Tanner 1985) (Figure II-19).

Surf zone energy levels range from zero (< 4 cm) to moderate. The best example of the zero energy coast in Florida is the "Big Bend" coast between Tallahassee and Tampa (Tanner 1985). The zero to low energy coast condition occurs because: (a) prevailing winds blow from land to sea; (b) coastline concavity provides divergence of wave orthogonals and reduces wave energy to the coast; (c) the offshore coast is shallow and wide so deep water wave energy is dissipated in frictional processes crossing the shelf; and (d) the Gulf does not produce the upper parts of the typical ocean spectrum of periods and heights (Tanner 1985).

The western Louisiana and eastern Texas coast are concave with a broad shallow shelf that creates a low energy coastline (Kwon 1969). Moderate to high energy coasts occur in conjunction with barrier islands along Mississippi, Alabama, and Louisiana.

8.1.2 Biological and Chemical Factors

The wrecking process and decomposition rates involved in shipwreck preservation have not been extensively studied and are poorly understood. Factors such as energy zones, biology, and chemistry interact dynamically and vary with the environment. This section reviews known factors in shipwreck decomposition. The effects of biological organisms that attack organic materials during and after the mechanical breakup of a ship are examined. These organisms are chiefly bacteria and shipworms. We also examine the decomposition of metallic materials as a result of electrochemical activity and relate the deterioration of materials to sediments and energy zones.

8.1.2.1 Borers and Bacteria

The recent rediscovery of the RMS TITANIC provided new insights into the breakdown of a large shipwreck by marine organisms (Ryan 1986; Ryan 1987). Lying more than three kilometers in the cold north Atlantic where low temperature and associated biological activity were assumed to aid in the preservation of shipwreck materials, particularly organics (Livingstone 1975), such was not the case. The wood-boring mollusc, *Xyloredo ingolfia*, a deep water relative of the warm water *Teredo*, was reported in large numbers on the ship.

The biology of the *Teredo* shipworm is well documented (Nair and Saraswathy 1971). Weiss (1948) observed the actual preservation of wood from *Teredo* attack by barnacles that fouled wooden surface areas. *Teredo* represents only one genera of shipworms. Two others are *Bankia* and *Martesia* (Hunt and Garrat 1967). The shipworms are found in most coastal waters and frequently attack exposed surfaces at or near the mud line.

Crustaceans also affect woods. *Limnoria, Sphaeroma,* and *Chelura* are found in American waters. *Limnoria* and *Sphaeroma* belong to the order Isopoda while *Chelura* is an *Amplipodea* (Hunt and Garrat 1967). *Limnoria* is the most destructive in the Gulf and invade the same timbers as shipworms.

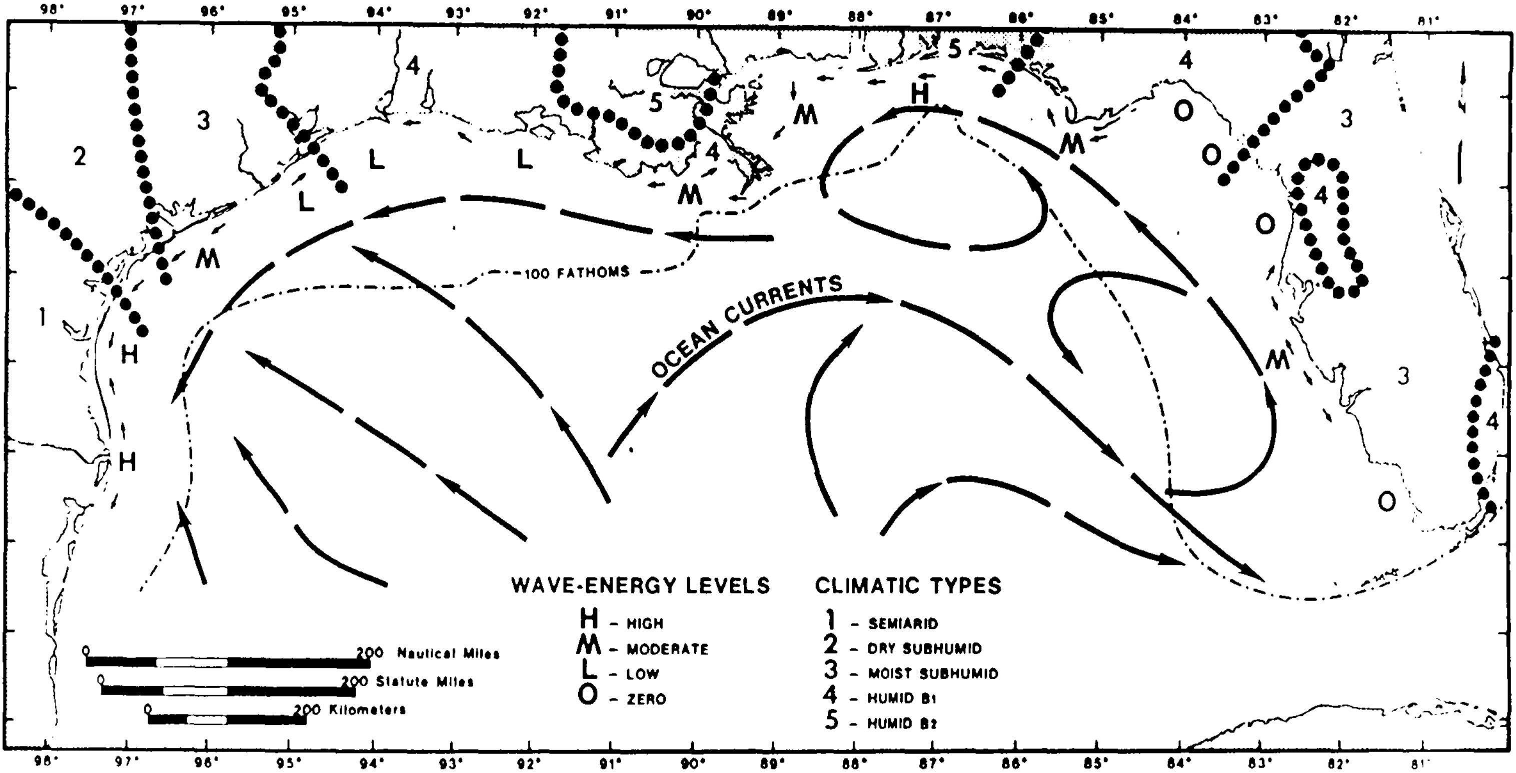


FIGURE II-19. Some major process parameters of the northern Gulf of Mexico (after Kwon 1969).

No woods are known to be naturally immune to destruction by marine borers. Heartwoods of certain kinds have been found to offer resistance to attack. The most resistant woods are foreign woods such as jarrah, totora, turpentine wood, azobe, manbarklak, angelique, and greenheart (Hunt and Garrat 1967). Native woods such as pine, fir and oak are soon destroyed unless some form of artificial protection is provided such as impregnation, coatings, or sheathing.

Coupled with other benthic organisms and aerobic bacteria, the organic remains of shipwrecks are metabolized in sediments. Low dissolved oxygen promotes the growth of sulfide bacteria typically associated with muds (Evans 1963; Pearson 1972; Richards 1957). The impact of sulfide reducing bacteria is principally on metals rather than organic materials (Hamilton 1976). These organisms are the suspected cause of the extensive corrosion seen on TITANIC (Ryan 1987).

8.1.2.2 Electrochemical and Biological Corrosion

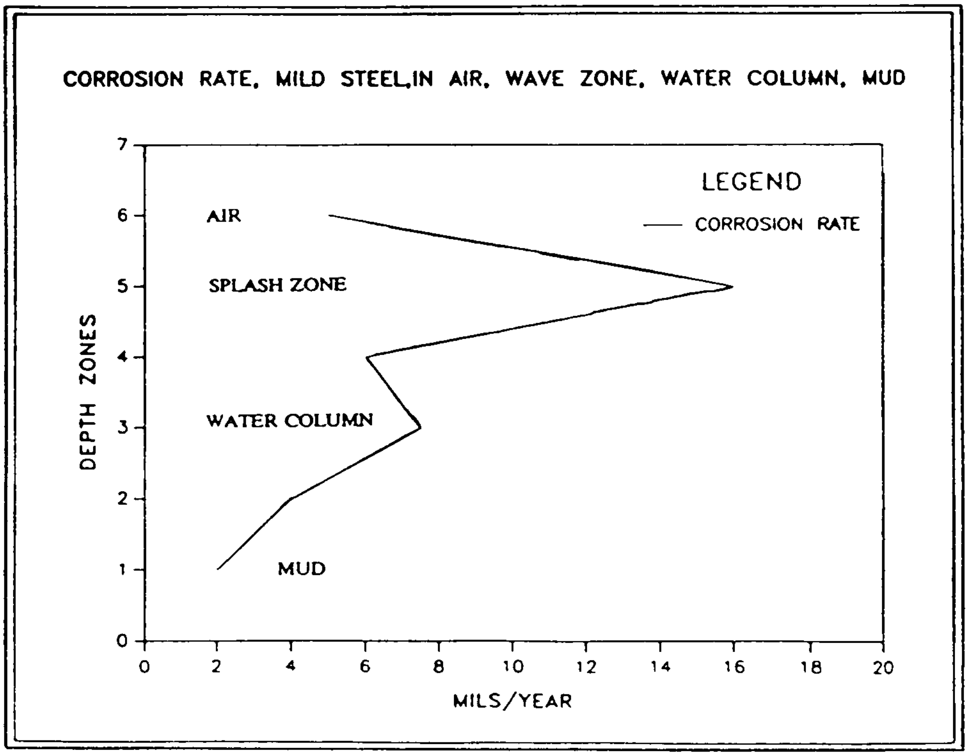
Electrochemical activity is the longest lasting and most detrimental portion of the decomposition cycle for a shipwreck site. Sediment overburden can reduce the corrosion rate but will not stop until the metal reaches electrochemical equilibrium (Brown 1987). In the electrochemical process iron goes into solution as iron hydroxide which is oxidized into hydrated ferric oxide (rust). The corrosion rate of the metals drops off significantly in clean mud (Warren 1980)(Figure II-20a).

Cornet (1970) states that iron corrodes ten times faster in sea water than in air and five times less in soil. In comparing steel to wrought iron used in many 19th century vessels, there is no direct technical evidence that wrought iron rusts more slowly than steel in the sea (Warren 1980). Sulfate bacteria are responsible for as much as 60 percent of corrosion in salt water. These are typically strains of *Sporovibrio desulphuricans* (Pearson 1972) and *Desulphovibirio desulphuricans* (Farrer 1953). Hamilton (1976) attributes this to continued bacterial oxidation after electrochemical equilibrium has been reached (Figure II-20b).

Other metals susceptible to corrosion and encountered in shipwrecks are tin and brass. Brass is susceptible because it contains zinc. When zinc dissolves it leaves a spongy mass of copper (Warren 1980). Tin oxidizes to tin oxide (Warren 1980). The noble metals (of which copper is one) are resistant to corrosion while silver is susceptible to sulfide formation (Hamilton 1976).

8.1.2.3 Dissolved Oxygen (DO)

A correlation between organic content of the sediments and dissolved oxygen content of water was suggested by Richards (1957). In the western Gulf, an oxygen minimum layer can seasonally impinge on the bottom because of the relatively high organic content in the surface sediments. Since corrosion decreases as DO decreases, there may be a higher chance of finding metallic artifacts in sediments with a high organic content (Chandler 1973). Large areas of hypoxia (i.e., concentrations of dissolved oxygen lower than 2 mg/l) regularly develop off Louisiana west of the Delta (Pokryfki and Randall 1987). Dennis (1984), Rabalais (1985) and Renaud (1985) also produced extensive bibliographies on hypoxia. Hypoxia occurs in Texas coastal waters, but less frequently. Pokryfki and Randall (1987) measured the spatial extent of hypoxia in coastal waters from Galveston, Texas to Cameron, La. in July 1974. Their results for concentrations of dissolved oxygen on the bottom are shown in Figure F-8. They note that the hypoxic mass of bottom water lay entirely inshore of the 20 m isobath and was not an extension of the oxygen minimum layer that impinges on the outer shelf from the deep Gulf.



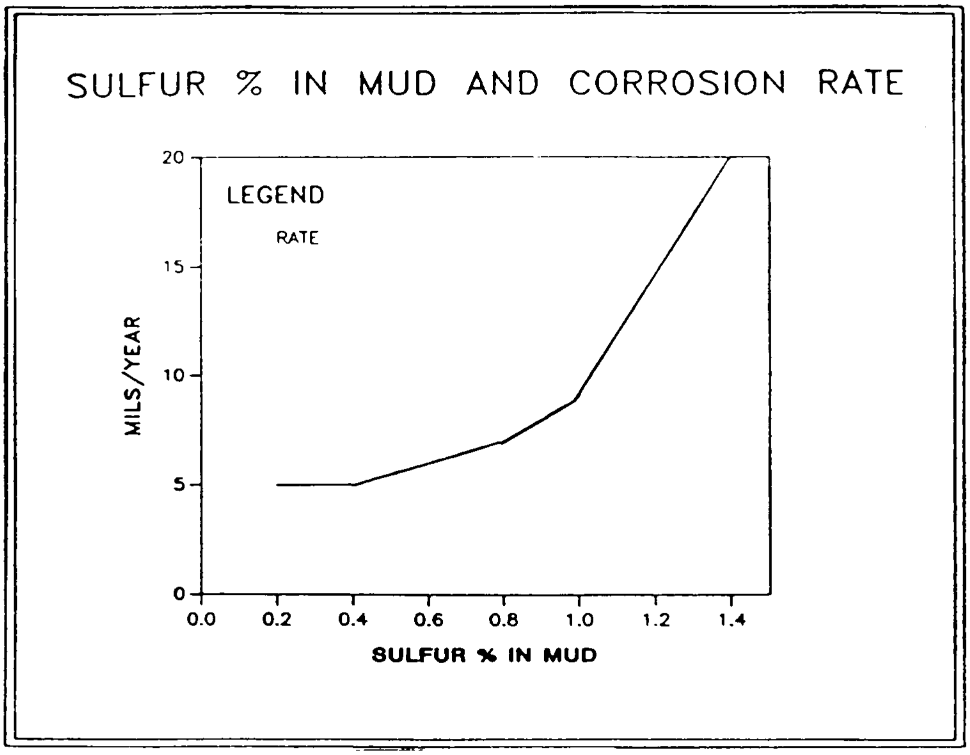


FIGURE II-20. (a) Corrosion rates in sea water, air and mud
(b) Corrosion rates versus sulphur content in mud.

8.1.2.4 Currents and Corrosion Rates

The impact of currents on shipwrecks depends on other factors. In the initial wrecking phase, the currents, in association with shallow water wave action, break apart, erode and scatter wreckage (Muckelroy 1978). At the same time scour around shipwreck debris can bury parts of the wreckage depending on sediment transport. Low sediment deposition in deeper water tends to preclude burial other than lower hull elements.

Current velocities influence corrosion rates of metals, notably iron. A water flow of ~0.5 m/s (1 knot) encourages rusting of steel. At 1 m/s the rate is three times higher (Warren 1980). The rate rises to eight times that of static water at 6 m/s. The rate also varies with temperature, doubling every 10° C rise in temperature up to about 80° C and decreasing as oxygen decreases (Chandler 1974). Miller (1985) considers the USS MONITOR highly corrosive due to the relatively high temperature, oxygen content, and current velocity at the site.

8.1.3 Environmental Factors in Shipwreck Preservation

We can define a range of environments in which shipwrecks occur with the range being: (1) static and hypoxic, and (2) dynamic and aerobic. The static-hypoxic environment is considered conducive to preservation (Chandler 1974). This type of site would be characterized by a mud/silt environment in a low DO area e.g. Louisiana or Texas. However, preservation is still affected by the interaction of other chemical factors. Pollutants can accelerate metal corrosion rates. Composites such as wood-iron structural joinery can continue to corrode or rot due to the interaction of certain woods and iron. Oak will accelerate iron corrosion due to the tannic acid in the wood (Warren 1980). Hamilton (1976) cites bacterial corrosion in anoxic conditions even inside encrustations.

The other type of environment, dynamic-aerobic, would have sands or detrial sediments in a zone of strong bottom currents, e.g. the upper Texas or west Florida shelf. Here, temperature, current velocity and oxygen content would promote abrasive erosion of exposed surfaces, biological attack and accelerated corrosion of metallic materials.

Figure II-21 summarizes environmental factors in shipwreck preservation. The postulated relationships are shown in a schematic using a rank scale of low to high for the variables. The coarse sediment deposits with high current velocity, biological activity, DO, and corrosion rates would be characteristic of a dynamic-aerobic environment with poor overall preservation. The converse, would define the static-anaerobic environment with a higher probability of overall preservation of shipwreck materials.

Muckelroy (1978), following Hiscock (1974) and King (1972), evaluated 11 environmental attributes potentially affecting the preservation of shipwrecks. Of these, three relate to sediments: (a) topography; (b) the coarsest material in deposits; and (c) the finest material in deposits. Water movement (e.g. energy zones) plays a minor role in preservation.

We examined five out of eleven of Muckelroy's original factors affecting shipwreck preservation because some of Muckelroy's variables were not truly independent. For example, current velocity and dissolved oxygen are directly related in almost all situations (Figure II-21). We propose, as did Muckelroy, that the main determining factor in the survival of archaeological remains is sediment type and distribution. We examined a series of shipwrecks representing five classes of sites as defined by Muckelroy (1978) to test this hypothesis. These classes are:

Class 1	Extensive structural remains, many organic remains and other objects in a coherent distribution
Classes 2 & 3	Elements and fragments of the hull some to many organic and other objects in a scattered distribution
Classes 4 & 5	No structure few to no remains in a scattered, disordered distribution

We approached the relationships involved in shipwreck preservation by examining sediment type and burial depth on known wrecks. The data are drawn from sources not available to CEI and present a clearer understanding for preservation relative to specific sediment facies and shelf characteristics. The study draws heavily on earlier, comprehensive studies of shelf sediments such as Curray (1960; 1965); Nelson and Bray (1970); Van Andel (1960); Scruton (1960); Bouma (1972), Rezak, et. al. (1985); and Berg (1986) and integrating with unpublished shipwreck survey data (Smith 1978).

To do this in a systematic matter, a conceptual model of the continental shelf was used where sediment facies were organized across a matrix of the Inner, Middle, and Outer Neritic Zone within the western, central, and eastern provinces of the northern Gulf. Longshore facies and delta areas were treated separately for their preservation potential.

The analysis includes an archaeological inventory of known shipwrecks from various shelf regions. The study identifies the differential preservation of shipwreck materials (hull, superstructure, cargo) the spatial aspects of the shipwreck sites; and how factors, such as bottom sediment type, and thickness of unconsolidated sediments, interact with other factors, such as associated biological activity or waves and energy zones. Correlations with biological activity, sediment facies and burial depth are observed. Other associations occur with surface waves and coastal energy zones.

Eighteen wreck sites in the Gulf, Atlantic and Caribbean are examined in Table II-14. The distribution of the remains of structural and organic elements and other objects are used to measure the proposed relationship between sediments and preservation. We deviated from Muckelroy's methodology by necessity as the environments of British wrecks differ somewhat from those in American waters.

Figure II-22 illustrates the location, type and relative amount of structural remains typically found at each site. The schematic view lists only major decks and does not show any standing rigging. It does allow a conceptualization of the preserved remains of an early historic shipwreck such as those discussed for Molasses Reef (Keith and Simmons 1985; Smith and Keith 1986; Oertling 1986); Highborn Kay (Smith 1985); *SAN ESTEBAN*; *ESPRITU SANTU* (Arnold 1978; Arnold and Weddle 1978); and, to lesser degree, later Spanish wrecks of 17th and 18th centuries such as SAN JOSE (Smith 1978).

Table II-14 does not yield a definitive picture of the relationship of preservation to environment but some conclusions can be drawn:

a. Structural remains are poorly preserved in nine cases where the vessels were sunk in dynamic, coarse sediment environments. The ESPIRIT SANTO had no structural remains;
b. Organic remains were not preserved or poorly so in 11 cases. All of these cases involve dynamic, coarse sediment environments. The MARY is an exception;
c. Preservation of other objects vary widely across the sample with little observed correlation with the specific environmental variables selected in this example;
d. Discontinuous wreck sites occur only in dynamic, coarse sediment environments; and
e. 19th century wrecks, are more preserved than earlier 16-18th century wrecks.

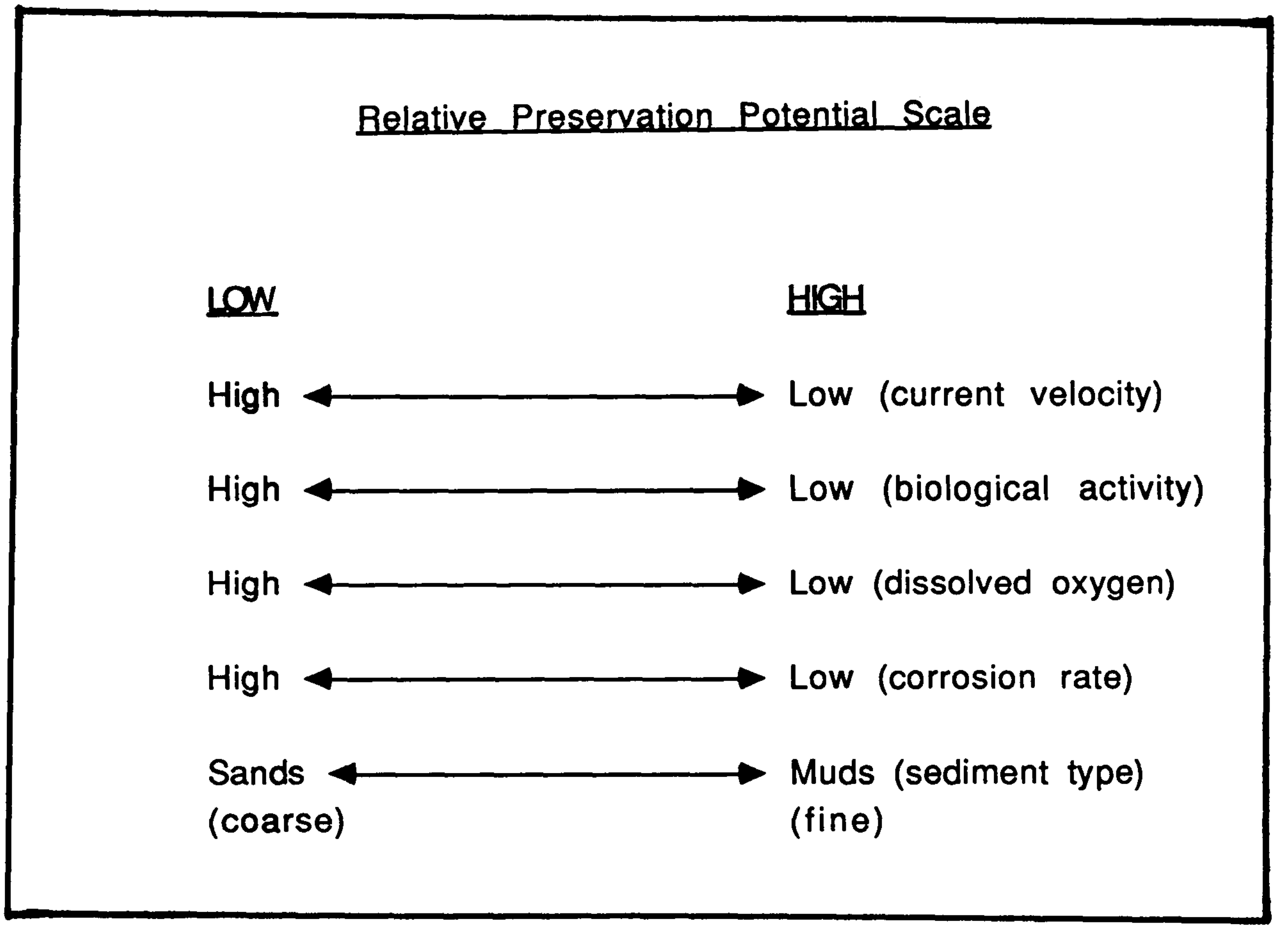


FIGURE II-21. **Hypothesized relationships of sediments, energy, chemical, biological factors and preservation of shipwreck materials.**

Table II-14.

SPECIFIC SHIPWRECK CASES: THEIR PRESERVATION AND ENVIRONMENTAL FACTORS.

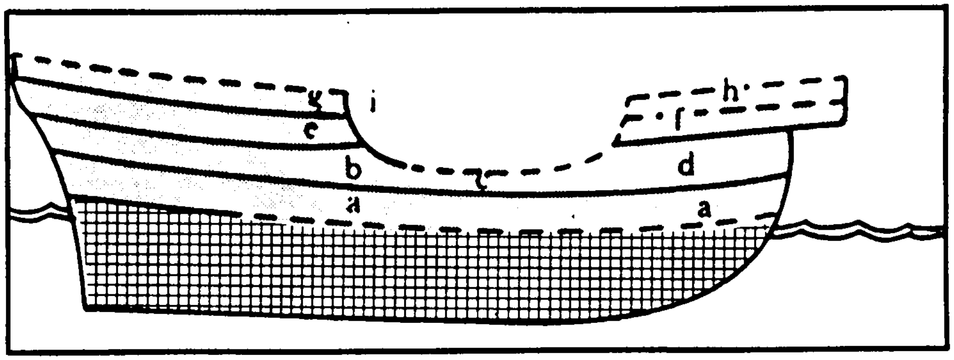
Site Name	Period (century)	Structural Remains	Organic Remains	Other Objects	Distri-bution	Current Velocity	Biological Activity	Dissolved Oxygen	Corrosion Rate	Sediment Type
Molasses Reef Wreck(1)	16th	≤ a	0	FEW	CONT.	HIGH	HIGH	HIGH	HIGH	CORAL SAND
Highborn Key Wreck(2)	16th	≤ a	FEW	FEW	CONT.	HIGH	HIGH	HIGH	HIGH	CORAL SAND
San Esteban (3)	16th	keel fragment	0	MANY	DISCONT.	HIGH	HIGH	HIGH	HIGH	SAND SHELL
Espirutu Santo (4)	16th	0	0	MANY*	DISCONT.	HIGH	HIGH	HIGH	HIGH	SAND SHELL
New Ground Reef Wreck(5)	16th	≤ a	FEW	MANY	CONT.	MOD	HIGH	HIGH	HIGH	CORAL
Nuestra Senora de Atocha(6)	17th	≤ a	FEW	MANY	DISCONT.	HIGH	HIGH	HIGH	HIGH	SAND
El Capitan(7)	18th	≤ a	FEW	MANY	CONT.	MOD	HIGH	HIGH	HIGH	CORAL
El Lerri(7)	18th	≥ a	FEW	UNK.	CONT.	MOD	HIGH	HIGH	HIGH	SAND CORAL
San Jose(7)	18th	a, b	FEW**	MANY	CONT.	HIGH	HIGH	HIGH	HIGH	MUD SAND GRASS
Augustias(7)	18th	≤ a	0	FEW	CONT.	HIGH	HIGH	HIGH	HIGH	ROCK
El Nuevo Constante(8)	18th	≤ a	MANY	MANY	CONT.	LOW	LOW	LOW	LOW	SILT CLAY
Will O' The Wisp(9)	19th	a-b	UNK.	UNK.	CONT.	HIGH	HIGH	HIGH	HIGH	SAND
USS Hatteras(10)	19th	a-d	UNK.	UNK.	CONT.	LOW	MOD	MOD	MOD	SILT MUD
Hillsboro Beach Wreck(11)	19th	≥ a	FEW	MANY	CONT.	HIGH	HIGH	HIGH	HIGH	SAND
Mary(12)	19th	≥ a	MANY***	UNK.	CONT.	HIGH	HIGH	HIGH	HIGH	SAND
USS Monitor(13)	19th	90-100%	UNK.	MANY	CONT.	HIGH	MOD-HIGH	HIGH	HIGH	SILT SAND
Acadia(14)	19th	≥ a	UNK.	MANY	CONT.	HIGH	HIGH	HIGH	HIGH	SAND

Table II-14
(continued).

(1) Keith and Simmons, 1985; (2) Smith, et al, 1985; (3) Arnold 1978; Arnold and Weddle 1979; (4) ibid (5) Parrent 1985; (6) Mathewson 1977; 1986 (7) Smith1978; (8) Pearson 1981; (9) Larry R. Martin, personal communication, 1988; (10) Melancon 1976; (11) Woolsey, ORN, Ser I, Vol 22; (12) Corpus Christi Caller-Times, 1987; (13) Miller 1985; (14) Hole 1974

Notes:

* No provenance on finds (see Arnold and Weddle 1978: 25-27)
** Partial human skull, first ever found on New World' s shipwreck
*** Burlap detected in 1987 during inspection by remote-operated vehicle (ROV)



▦ **Portion of vessel most likely to be preserved**

□ **Portion of vessel most likely not to be preserved**

(a) The overlop, or nether overlop, or upper lop.
(b) The somercastle, or nether deck, or barbican.
(c) The waist.
(d) The nether deck in the forecastle.
(b) (c) and (d) together are occasionally called the upper overlop.
(b) and (c) together are frequently called the nether deck.
(i) The breast of the ship.
second deck.
(f) The middle deck in the forecastle, or the upper forecastle.
(g) The highmost or highest deck, or the upper deck, or the deck; or (probably when shortened to a poop) the small deck.
(h) The upper deck in the forecastle (not in small ships).

FIGURE II-22. Structural preservation, 16-18th century vessel.

Based on this review, preservation is enhanced in fine-grained sediment and low energy environments (ex. EL NUEVO CONSTANTE; USS HATTERAS) and reduced in coarse grained sediment and dynamic environments (ex. ESPIRITU SANTO; USS. MONITOR). Further, preservation of structural fabric in early shipwrecks appears to be reduced where salvage efforts were conducted. This seems most prevalent in Spanish examples (SAN ESTABAN, ESPIRITU SANTO, EL CAPITAN, EL LERRI, SAN JOSE) where salvaged vessels in the lower energy, finer-grained sediment environments are better preserved. In coarser-grained sediments, where energy levels are high, such as nearshore and barrier-spit environments, rapid burial clearly reduces the deterioration due to biological activity.

In deeper water, but with coarse-grained bottom sediments, preservation can be enhanced by low oxygen levels in pore water due to turbidity. Such conditions exist on the northwestern Gulf of Mexico shelf in the summer months (Rezak, et. al. 1985). Indeed the nephloid layer may act as an agent in the reduction of organisms or chemical reactions at certain periods in large areas of the northwestern Gulf.

This survey considered a small sample of shipwrecks in the Gulf or nearby waters which have had a degree of archaeological expertise applied to the study of their remains. Shipwreck archaeology with scientific site surveys and excavation of Gulf shipwrecks is recent and incomplete. We summarize our survey's results in the following chart of sediment environments postulating an expected probability, low to high, for preservation of historic shipwrecks. Using this model, preservation of historic shipwrecks is expected to be highest on the northwest Gulf of Mexico continental shelf west of the Mississippi River delta and low on most of the eastern Gulf's shelf areas (Figures II-23 and II-24).

SEDIMENTS AND PRESERVATION POTENTIAL

● SANDS	LOW
● SANDY/SILT	LOW–MODERATE
● SILTS	MODERATE
● SILTY/CLAY	MODERATE–HIGH
● CLAY	HIGH

FIGURE II-23. **Expected preservation potential and sediment distribution, northern Gulf of Mexico.**

GULF SEDIMENT AREAS AND EXPECTED PRESERVATION POTENTIAL

RIO GRANDE AREA	HIGH
WESTERN AREA	HIGH–MODERATE
CENTRAL AREA	MODERATE–LOW
CENTRAL LOUISANA AREA	HIGH–MODERATE
MISS/ALABAMA AREA	LOW–MODERATE
WEST FLORIDA AREA	LOW–MODERATE
BIG BEND AREA	LOW
MIDDLE GROUND	LOW
SOUTHWEST FLORIDA AREA	LOW
DRY TORTUGAS AREA	LOW

FIGURE II-24. **Gulf sediment areas and expected preservation potential.**

9.0 INTERPRETATION OF SHIPWRECK DISTRIBUTION PATTERNS

9.1 Introduction

Patterns exist in man's social milieu. Behavioral variations combine with natural factors to produce specific patterns. The explanation of shipwreck distribution patterns is the same as for the spatial distribution of sites of other artifacts. Shipwrecks of the northern Gulf of Mexico are the product of historical and natural factors. Ships played a key role in long distance transport of goods, people and ideas. The patterns of the shipwrecks of the northern Gulf of Mexico mark the important routes of the economic and political past while their density give indications of the perils along those routes.

9.1.1 Methods of Shipwreck Pattern Analyses - Other Studies

This study has benefited from earlier studies of shipwreck patterning conducted by other authors (CEI 1977; Bourque 1979; SAI 1981; and Pierson 1987). The CEI (1977) investigators compiled an encyclopedia listing of shipwrecks and drew conclusions based on these data. Their conclusions should be cast as hypotheses on the temporal and spatial distribution of shipwrecks. They estimated the number of shipwrecks in the Gulf of Mexico to be between 2,500 to 3,000. Further they projected that 80 to 90 percent of these wrecks are located within 10 km of the present coastline. They expected concentrations of shipwreck sites to be associated with areas of marine traffic such as at the approaches to seaports, mouths of navigable rivers, straits, shoals and reefs. They recognized that certain areas in deeper water, where shipping lanes have crossed for centuries had numerous shipwrecks, but felt expected higher incidence for wrecks in these areas did not warrant special treatment. Finally, they predicted the shipwreck population to fall into a bell-shaped distribution with a peak in the period of 1800 to 1910.

Bourque (1979) in the cultural resources baseline study for the Atlantic OCS measured shipwreck densities with specific depth ranges over time. He did not directly use the complete set of shipwreck locational data in his analysis. His method of evaluation concentrated on shipping data. Like CEI, he projected a peak for vessel losses in the period of 1800-1880. The locations of shipwrecks were assigned positions within an area of six or fewer lease blocks or simply classified as "6X" (general location known, but not within 6 lease blocks). The result of these analyses produced a model that predicted shipwreck density within shipping zones.

SAI (1981) followed the generalistic approach of CEI. An exhaustive list of shipwrecks was compiled for the OCS from Cape Hatteras to Key West. The effort derived a general correlation of shipwreck density with specific areas and factors. The investigator identifies "clusters" of shipwrecks in time and space. The approach is fundamentally inductive and non-numerical. The author does examine sample bias in a broad sense and speculates on its affect on the recognition of true patterns. Factors responsible for these concentrations of shipwrecks are identified as increased commerce, warfare and natural hazards such as the Florida reef tract.

Pearson (1987) generated a computerized shipwreck data file. From this database the authors developed a model using "prediction factors" such as port or anchorage, hazard, shipping route and number of reported sites. These factors weighted the data in specific locales and were used to isolate sensitive areas for the occurrence of shipwrecks. These factors are deterministic and random site occurrences are projected for areas outside zones near seaports, islands, hazards, and traffic lanes. No measures of dispersion were given for the characterization of randomness so the nature of the Pearson study is not statistical.

Other studies of shipwrecks exist for areas along the northern Gulf of Mexico. These reports are generally cultural resource studies of specific ports or entrance channels such as Galveston (NOAA 1988, Hudson 1979), Pensacola (Tesar 1973), Mobile (Mistovich and Knight 1983), Gulfport (Mistovich 1987), Pascagoula (Mistovich, Knight and Solis 1983), Freeport (Bond 1981), and Brownsville (Espey, Huston & Assoc. 1981). None of these studies produce more than an inventory of shipwrecks within their given project area. No higher level syntheses are attempted although the compilation of data is impressive. Typically the reports locate known or suspected shipwreck sites and correlate these locations with historical and instrumental survey data.

9.1.2 Methods of Shipwreck Pattern Analyses - This Study

We have compiled shipwreck data from a number of sources and created a computerized data base. This follows Pearson (1987) more than the CEI, SAI, and Bourque efforts. The frequency of shipwrecks was examined over 50 year periods or every 20 years after the 20th century. The distribution of shipwrecks was examined using simple numerical techniques after the data were placed in quadrants of 0.5 and 1.0 degrees, or roughly 2304 and 9216 sq km, respectively. The data were also sorted according to MMS lease block areas (23 sq km).

We followed over a decade of investigators in the formal analysis of spatial data (Clarke 1977, Hodder and Orton 1976, Orton 1982, Hietala 1984, Johnson 1984, and Neft 1966). The data were examined using factor analysis (Cooley and Lohnes 1962, Rowlett and Pollnac 1970) and distribution analysis (Hodder 1977).

Figures II-25 through II-36 show the distribution and frequency of shipwrecks from 1500 to the present. These plots show shipwrecks within OCS lease blocks, with the exception of those for 1500-1599. Plots with shipwrecks exclusively within state lands are shown in Appendix H. The geographic (x-y) coordinates assigned to the vessels allow us to apply spatial techniques with the scatter plots that this sequence of maps represent. The trend is in the increased frequency for shipwrecks over time. A bias for the underreporting of losses exists in the early periods, but this recognition must also consider that fewer vessels sailed the Gulf waters during those times. The method used to assign coordinates to these data are discussed below before continuing with other data analyses.

9.1.3 Chronological Trends: 16th-20th Centuries - Summary

The frequency of shipwrecks from 1500 to 1986 are tabulated in Table II-15. Chronological trends in the shipwreck patterns correlate with general historic factors such as Flota cycles, colonization, commerce, and shipping routes. The data are divided into 50 year periods from 1500-1899 and 20 year increments thereafter (Table II-16).

The chronological trend reflects the increase in shipwrecks with time. The increase coincides with settlement of the northern Gulf coast after 1700. Before this time losses were sporadic and concentrated at the Straits of Florida.

Another factor in this trend is the reporting of losses. In the early periods vessels with no survivors were simply "lost" with little in the way of accurate reports of their fate. The numbers for these periods are conservative by an unknown amount.

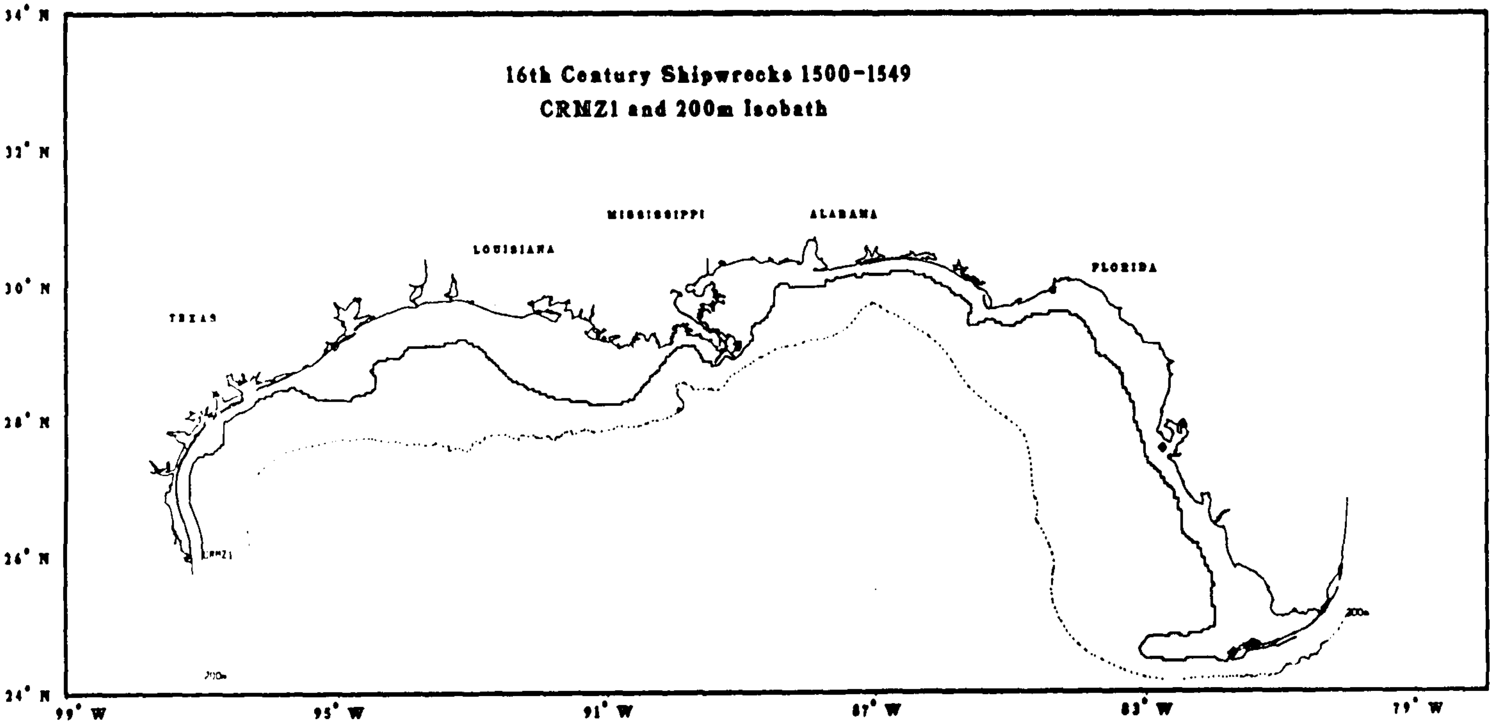


FIGURE II-25. Shipwreck positions, 1500-1549.

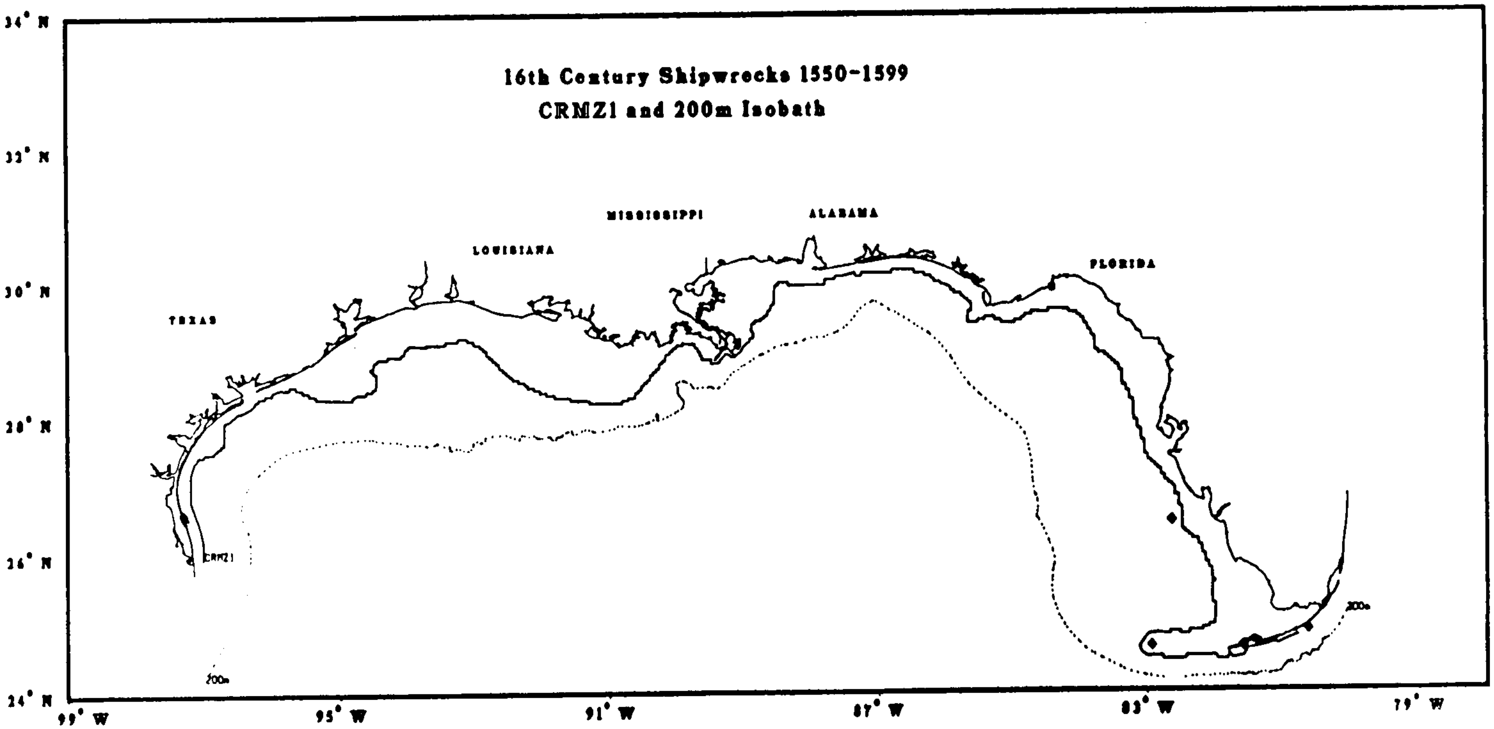


FIGURE II-26. Shipwreck positions, 1550-1599.

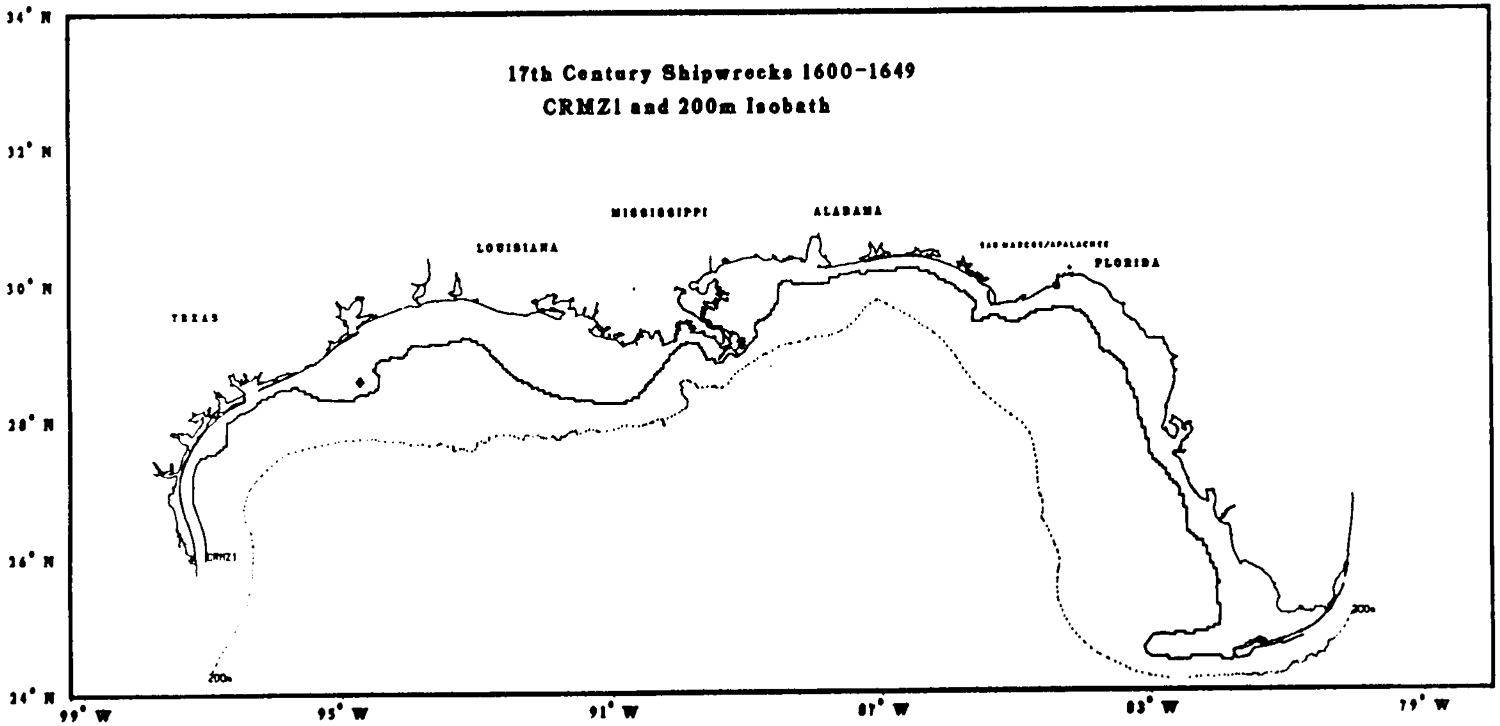


FIGURE II-27. Shipwreck positions, 1600-1649.

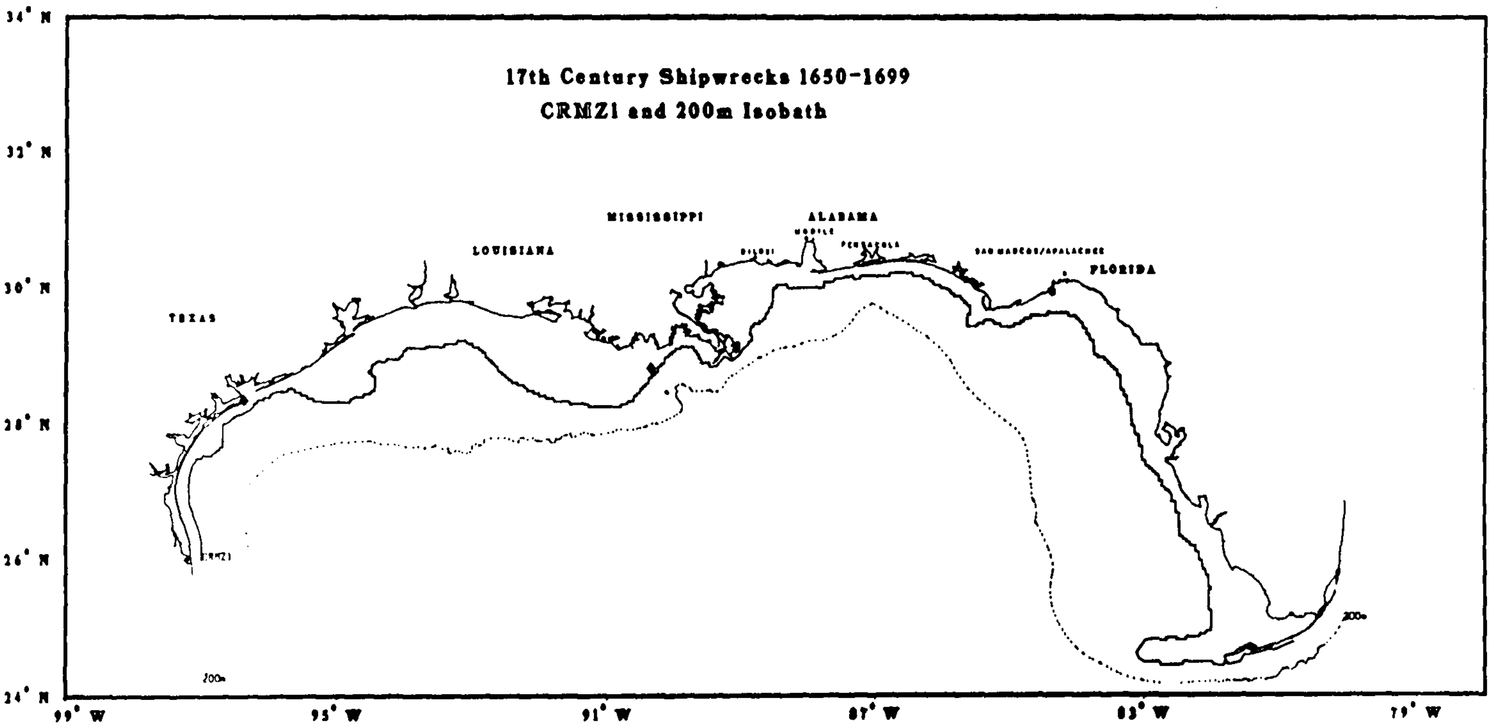


FIGURE II-28. Shipwreck positions, 1650-1699.

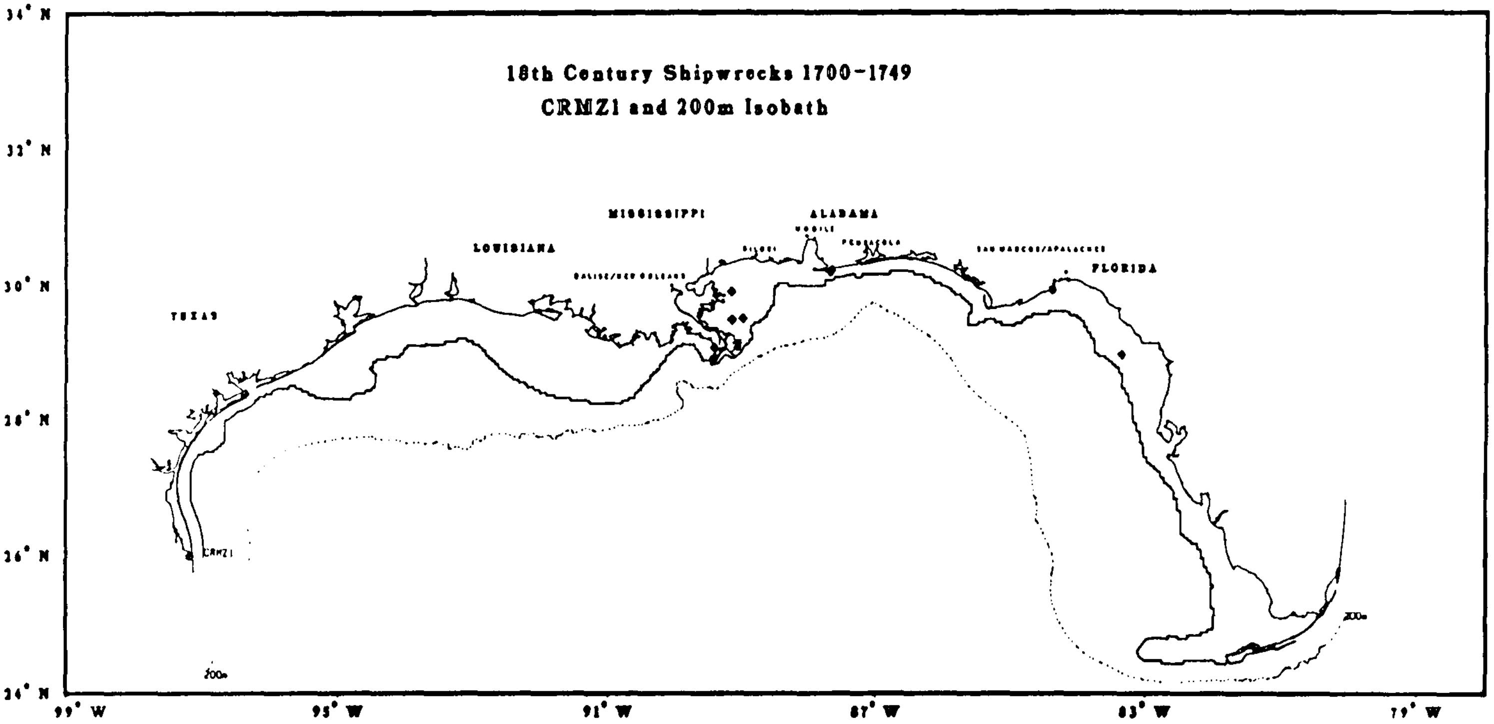


FIGURE II-29. Shipwreck positions, 1700-1749.

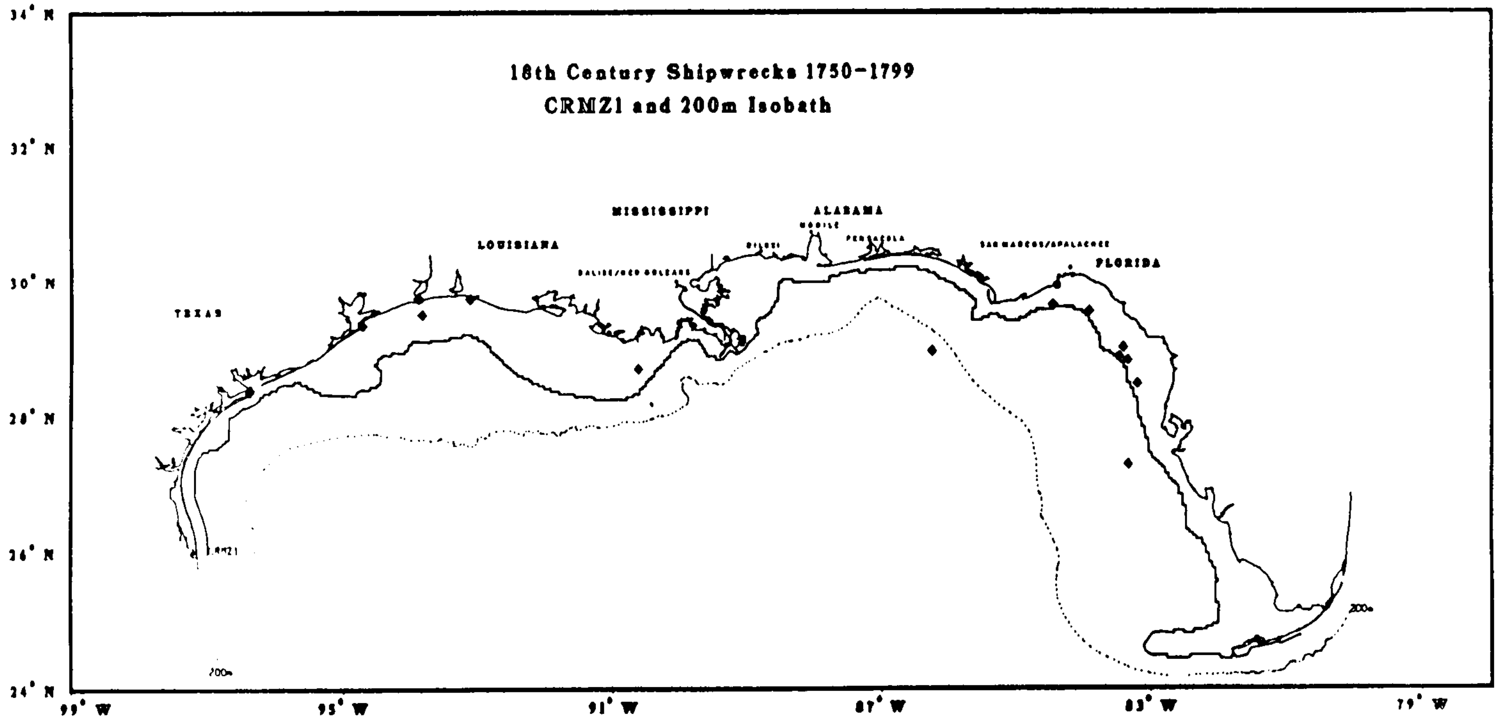


FIGURE II-30. Shipwreck positions, 1750-1799.

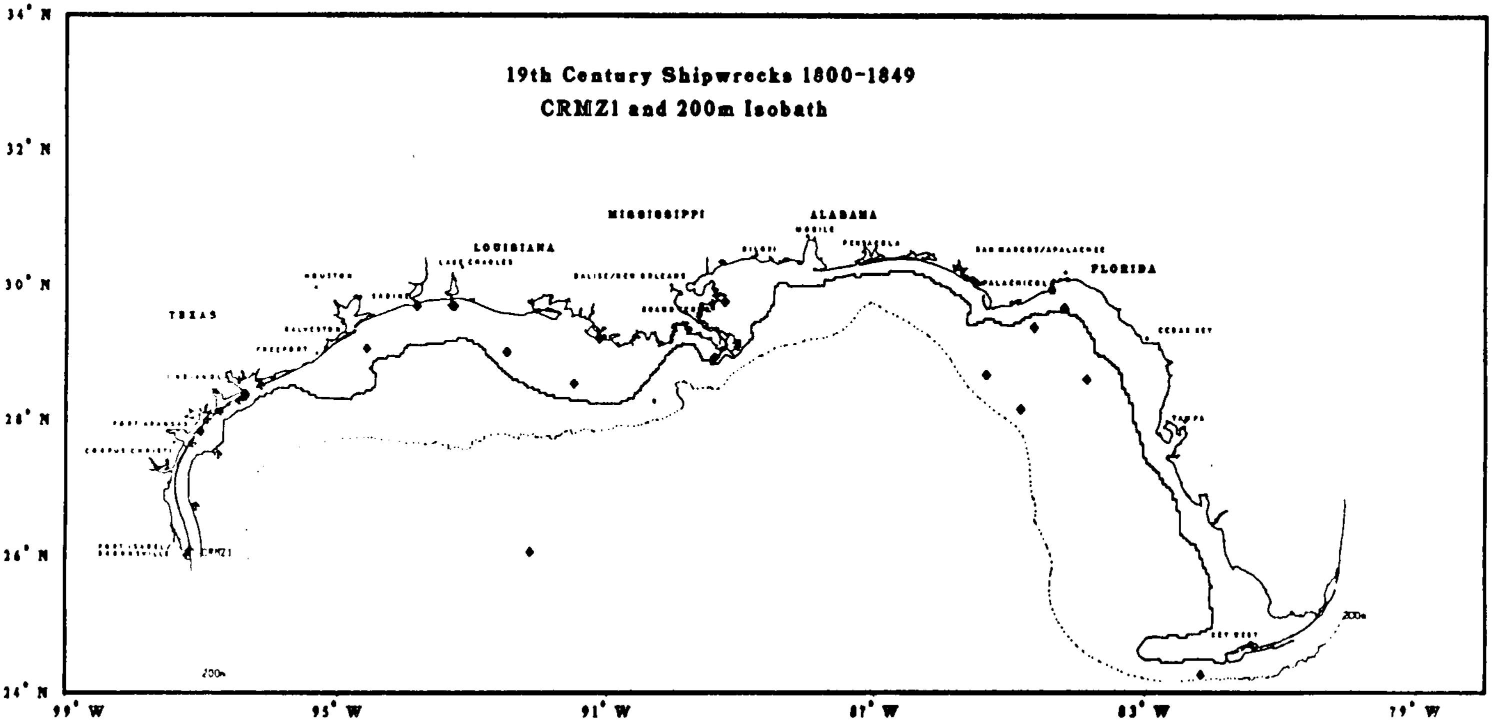


FIGURE II-31. Shipwreck positions, 1800-1849.

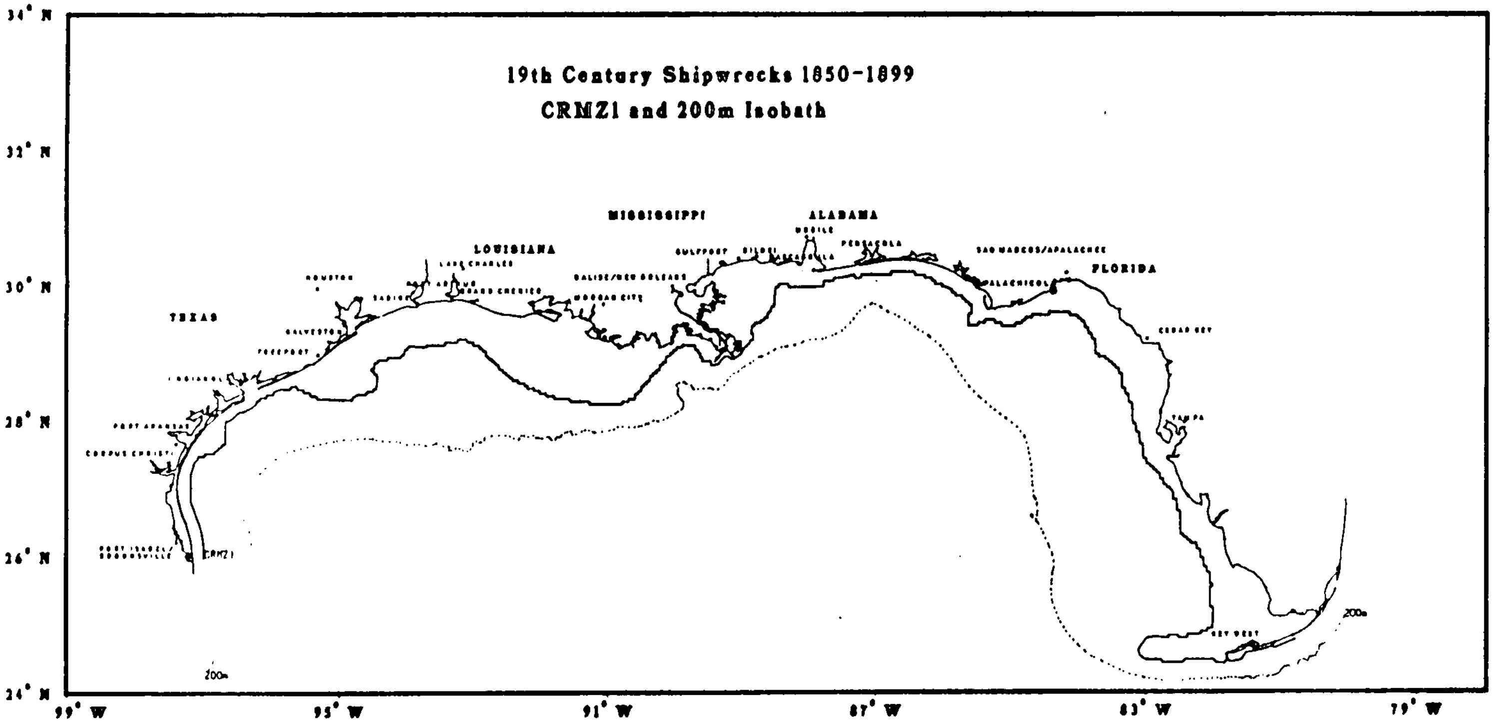


FIGURE II-32. Shipwreck positions, 1850-1899.

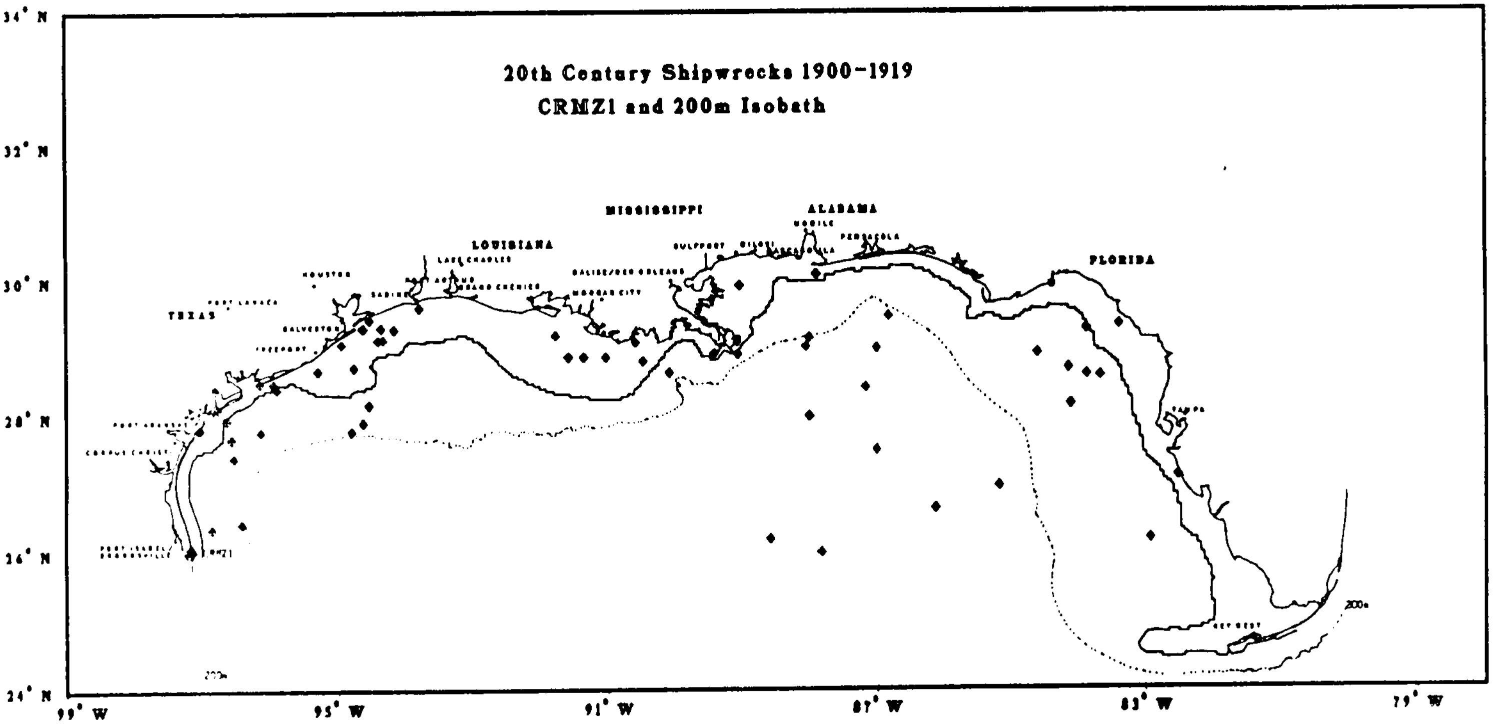


FIGURE II-33. Shipwreck positions, 1900-1919.

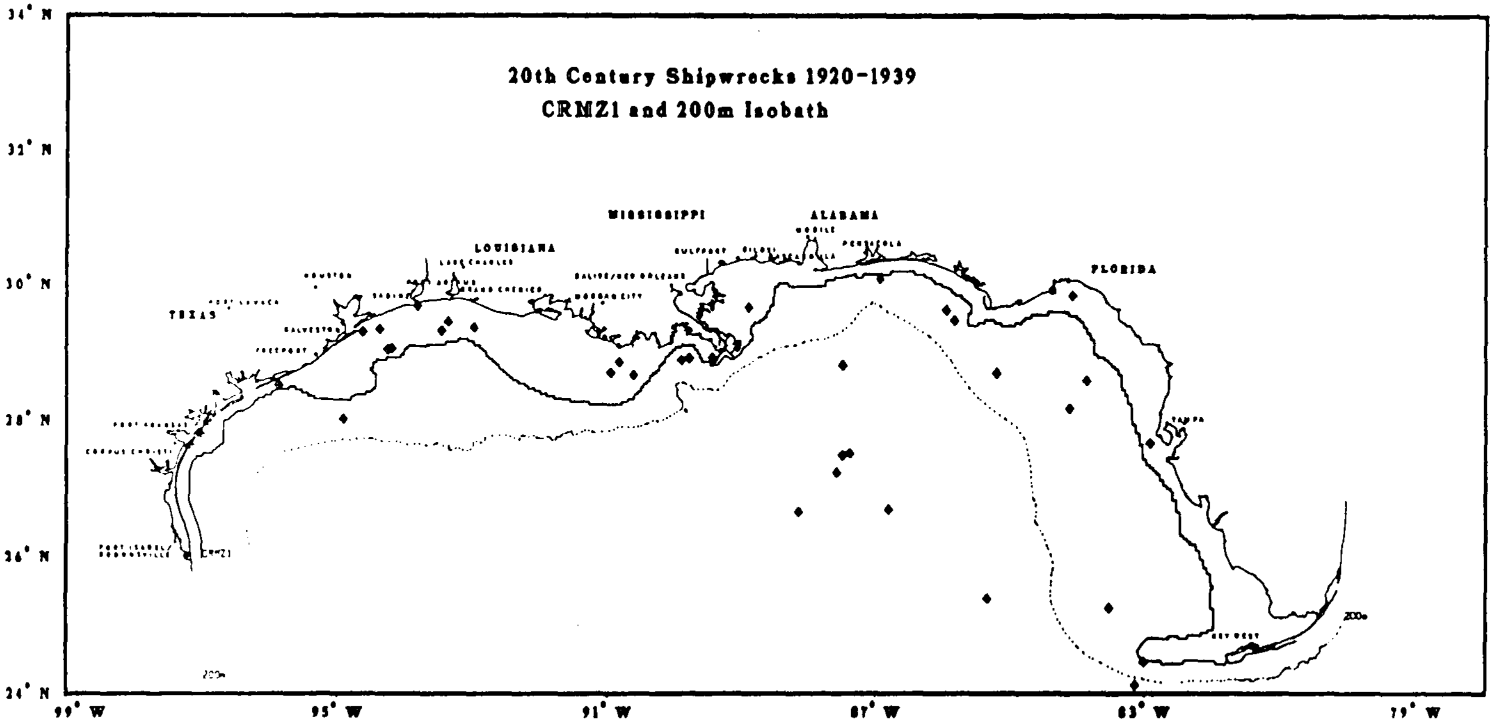


FIGURE II-34. Shipwreck positions, 1920-1939.

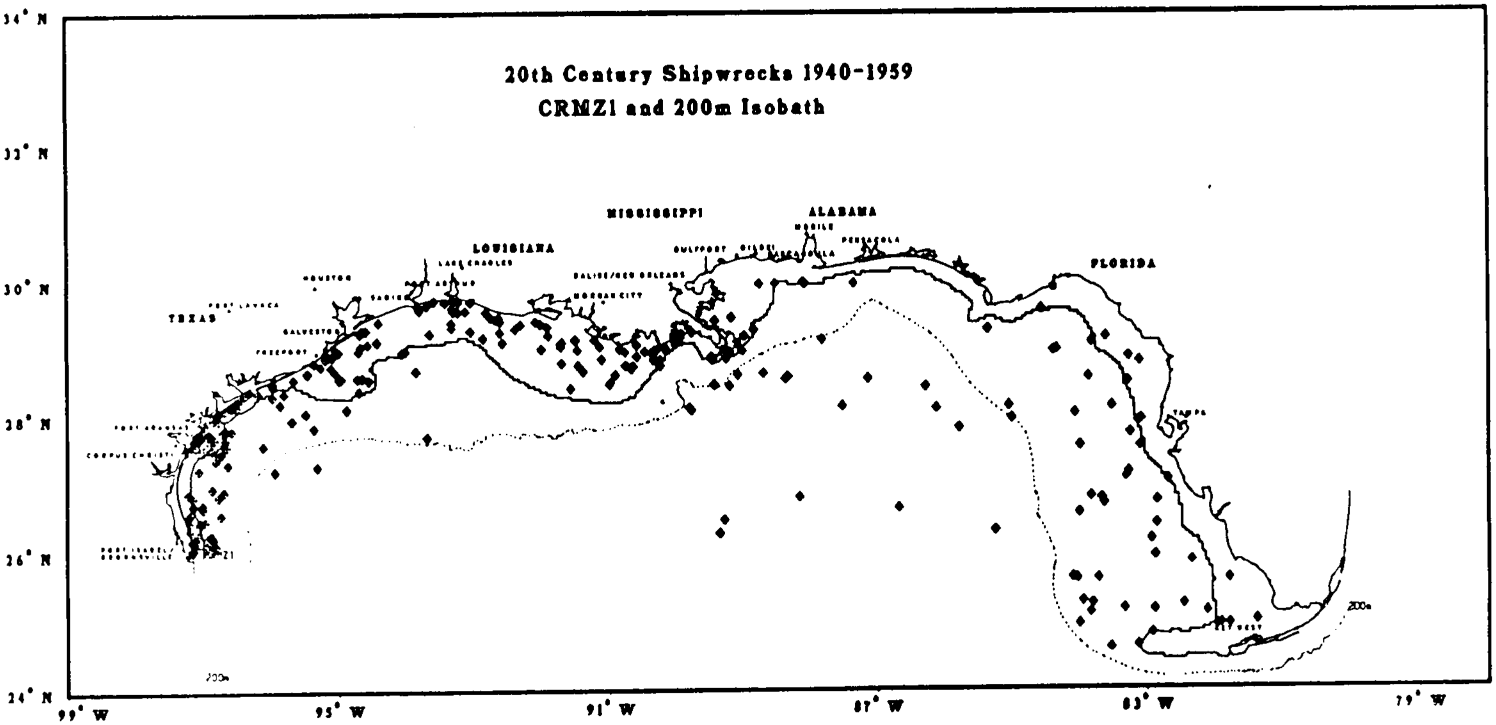


FIGURE II-35. Shipwreck positions, 1940-1959.

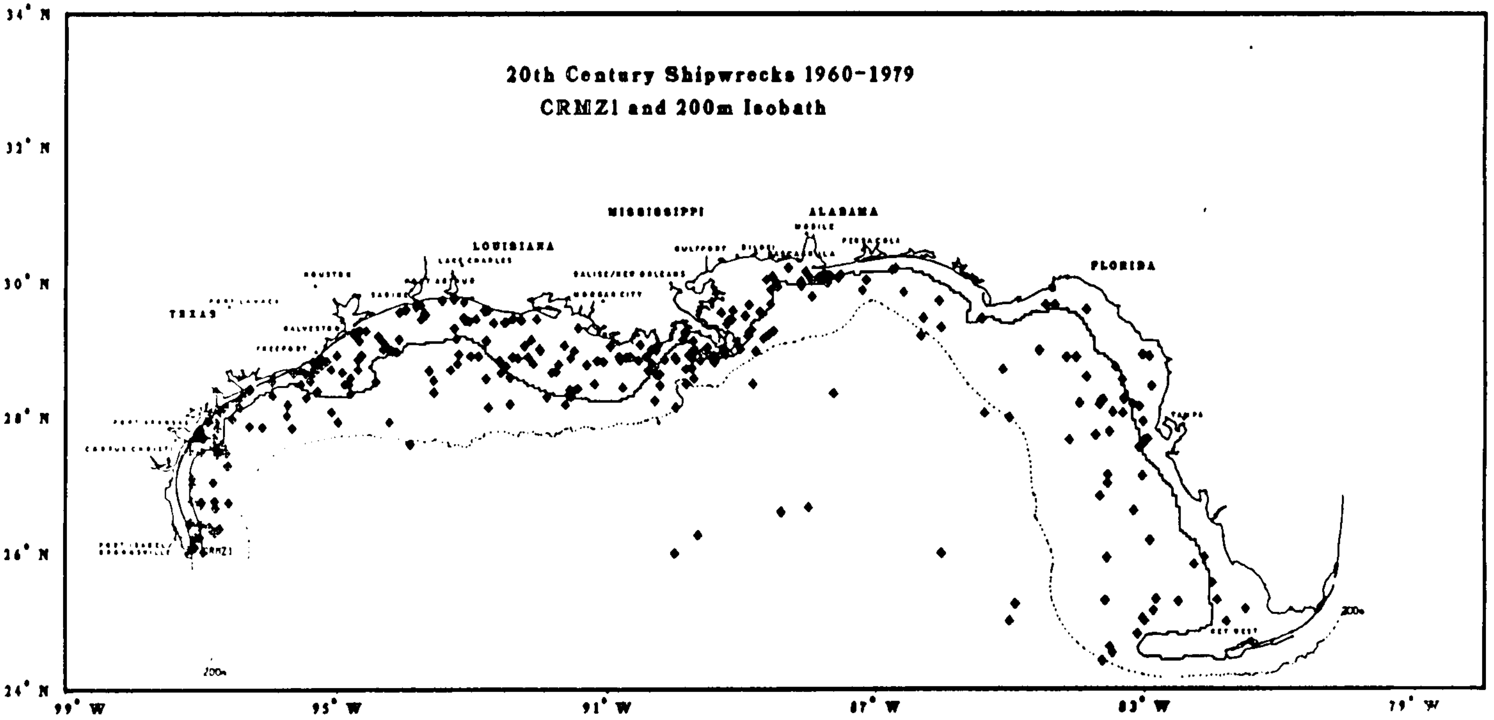


FIGURE II-36. Shipwreck positions, 1960-1979.

Table II-15.

SHIPWRECK FREQUENCY OVER TIME BY DECADE, 1500-1986.

Decade	Shipwrecks
1500-1509	0
1510-1519	0
1520-1529	7
1530-1539	0
1540-1549	4
1550-1559	10
1560-1569	1
1570-1579	3
1580-1589	0
1590-1599	4
1600-1609	2
1610-1619	2
1620-1629	13
1630-1639	3
1640-1649	3
1650-1659	0
1660-1669	0
1670-1679	2
1680-1689	10
1690-1699	2
1700-1709	9
1710-1719	4
1720-1729	2
1730-1739	40
1740-1749	10
1750-1759	11
1760-1769	20
1770-1779	17
1780-1789	9
1790-1799	10
1800-1809	20
1810-1819	38
1820-1829	41
1830-1839	85
1840-1849	196
1850-1859	89
1860-1869	186
1870-1879	149
1880-1889	178
1890-1899	126
1900-1909	240
1910-1919	367
1920-1929	259
1930-1939	76
1940-1949	267
1950-1959	541
1960-1969	678
1970-1979	367
1980-1986	53

Table II-16.

CHRONOLOGICAL TRENDS IN GULF SHIPWRECK DISTRIBUTIONS BY 50 YEAR PERIODS.

1500-1549: Losses reflect period of Spanish exploration of northern Gulf of Mexico
1550-1599: Distribution begins to show pattern of losses determined by flota routes. Losses off Texas are flota vessels wrecked by storm while on this route. Losses of Florida are likewise. The Straits area begin to take their toll.
1600-1649: The principal losses are still Spanish flota vessels. The 1622 hurricane losses in the keys are a significant portion of the shipwreck pattern for this period.
1650-1699: The pattern reflects the first French losses in the Gulf at Matagorda Bay in 1685. The remainder are Spanish losses.
1700-1749: The distribution shows the first major change in northern Gulf's shipwreck pattern. This is due to the French colonization of Louisiana and the increase in a similiar interest by the Spanish in Pensacola to balance the French.
1750-1799: The pattern of shipwrecks in the north-eastern Gulf is the result of two basic processes: colonization and commerce. The French and Spanish have reached the height of their maritime activity in the Northern Gulf of Mexico. The flotas end in the last quarter of this century.
1800-1849: The shipwreck distribution shows the extension of the colonization process to the north-western Gulf of area. Texas and Louisiana west of the Delta has port development at a significant level after the 1830's with Galveston, Brownsville, Freeport rising to importance.
1850-1899: The continued shift westward in the shipwreck distribution is offset by the principal ports of New Orleans and Mobile in the North-central Gulf area. The observed pattern is skewed by the extent of the Texas data for the period. Losses in the Straits continue as it is the major egress channel for inter-Gulf commerce. Eastern Gulf losses in the Civil War are under-represented in the Panhandle region. e.g. Apalachicola and Cedar Key.

SHIPWRECK DISTRIBUTIONS BY 20 YEAR PERIODS, 1900-1979

1900-1919: The pattern is fully modern with intra and inter-Gulf commerce developed between all major ports. The eastern area has Tampa growing as a port and major fisheries off the Panhandle and Florida Keys. The distribution of open-Gulf shipwrecks reflects the major commercial sea route to the Mississippi River and New Orleans.
1919-1939: The pattern for modern era is the result 20th century Gulf commerce in commodity goods e.g. oil and agricultural exports.
1940-1959: Two principal factors increase the number of shipwrecks off southwest Florida: fisheries and Tampa trade. For the northwestern Gulf it is singularly petroleum production in the offshore that cause Intra-Gulf routes to shift westward to Houston (cf. Figure I-16).
1960-1979: The major intra-Gulf, inter-Gulf routes axis are still (Present) east-west reflecting bulk cargoes movement from central/north-west Gulf ports. Losses increase in the north-western area exploration/production movement to the outer shelf.

9.1.4 Spatial Analysis -Arithmetic Mean Centers (AMC)

A trend in the scatter plots is the aggregation of shipwrecks within the northern Gulf with time. The arithmetic mean centers (AMC) were calculated for the shipwrecks within quadrants of 0.5 and one degrees. No attempt has been made to examine the variations in the aggregation of AMCs over time. The objective is to examine the presence or absence of aggregation at the most general level. Tables II-17 and II-18 summarize the data (Appendix I) (Figures II-37, II-38, II-39, and II-40).

9.1.5 Spatial Analysis - Contour Plots and Cluster Analyses

Figure II-41 is a contour plot of the one degree quadrant data using the graphic contouring package, DISSPLA (ISSCO 1976).

The value for each quadrant is treated as a point determination of shipwreck density. The general shape and size of areal concentrations is seen in this visual presentation.

Data from the shipwreck file were arranged into a matrix of lease block codes and numbers of shipwrecks. A cluster analysis with a flexible sorting strategy (Pimentel 1979) was used to construct the dendrograms in Figures II-42 and II-43. The Bray-Curtis index (Bray and Curtis 1957) was used as a measure of distance between shipwreck dates and lease blocks.

The main purpose of cluster analysis is to sort a previously unpartitioned heterogeneous collection of objects into a series of sets; e.g. one wishes to identify sets and allocate objects to those sets. A number of different clustering schemes are available. For this study, the clustering algorithm chosen was sequential and agglomerative. A sequential clustering process forms clusters in a regular stepwise manner and is much faster than "simultaneous" formation of clusters. Agglomerative clustering procedures begin with pairs of objects (e.g. ships, dates, etc.) and build up clusters. Divisive methods begin with the entire data set and divide it into subsets (Rohlf 1970).

The dendrogram of date similarity shows four distinct groups (Figure II-42). All of the 1900s and the 1850-1899 dates are grouped in one cluster while the remaining groups are not clustered together. This dendrogram groups together dates with the greatest similarity in number of shipwrecks within the same lease block location.

The matrix transpose (Figure II-43) separates into nine distinct groups. This dendrogram groups lease blocks with similar numbers of shipwrecks. These lease block groups were plotted to examine their spatial distribution (Figure II-44).

Three dimensional plots of latitude and longitude by date increment were generated for the nine groups derived from the cluster analysis of dates (variables) and lease blocks (observations) (Figure II-44). These figures provide a visual representation of the cluster analysis results.

These figures represent a view from about Brownsville, Texas in the southwestern Gulf of Mexico looking toward the northeast at an approximate viewing angle of 70 degrees above the vertical axis. Each cylinder symbol represents one or more shipwrecks within a specific lease block for a given date interval. Summary information is included below each plot which describes each group's characteristics. With the spatial data, the primary cause of dissimilarity between groups two, three, four, five, six and groups one, seven, eight and nine, is the number of ships in a lease block (high and low repectively). Additionally, the mean shipwreck date separates groups one, two, three, four, and nine from groups five, six, seven, and eight (early and recent respectively).

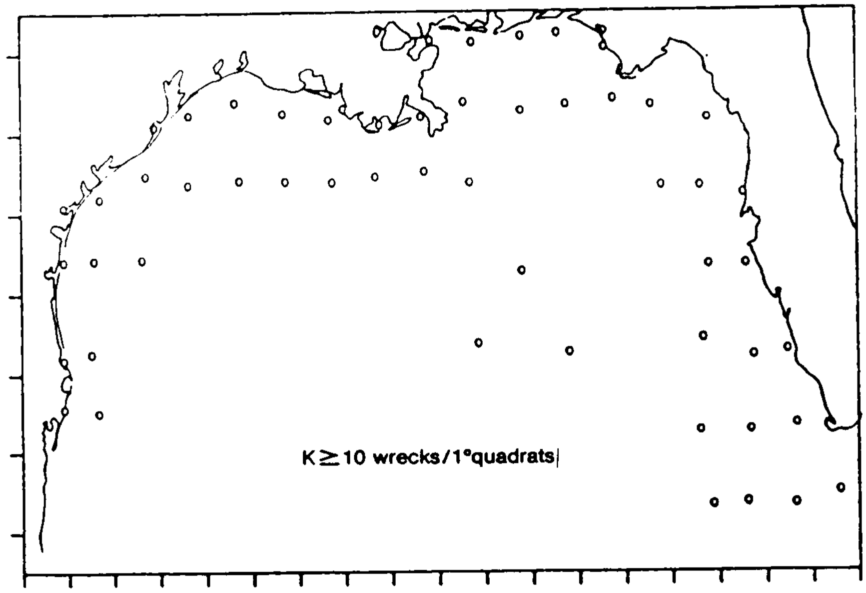


FIGURE II-37. AMC for K≥10, one degree quadrats.

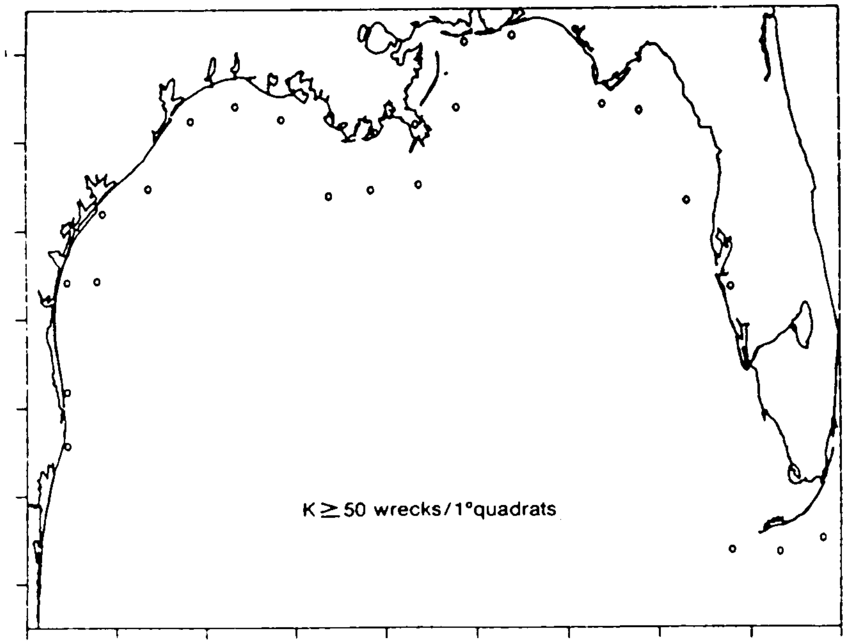


FIGURE II-38. AMC for K≥50, one degree quadrats.

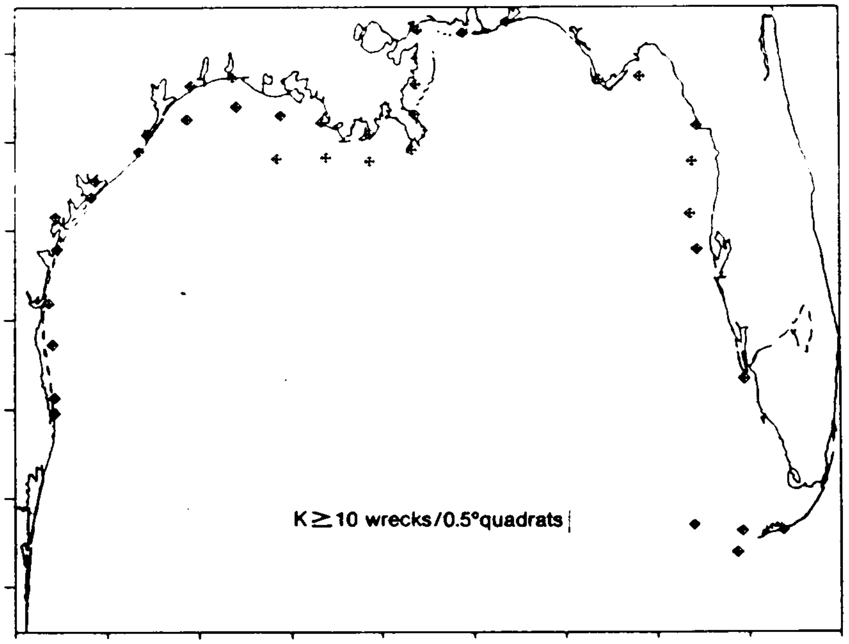


FIGURE II-39. AMC for K≥10, 0.5 degree quadrats.

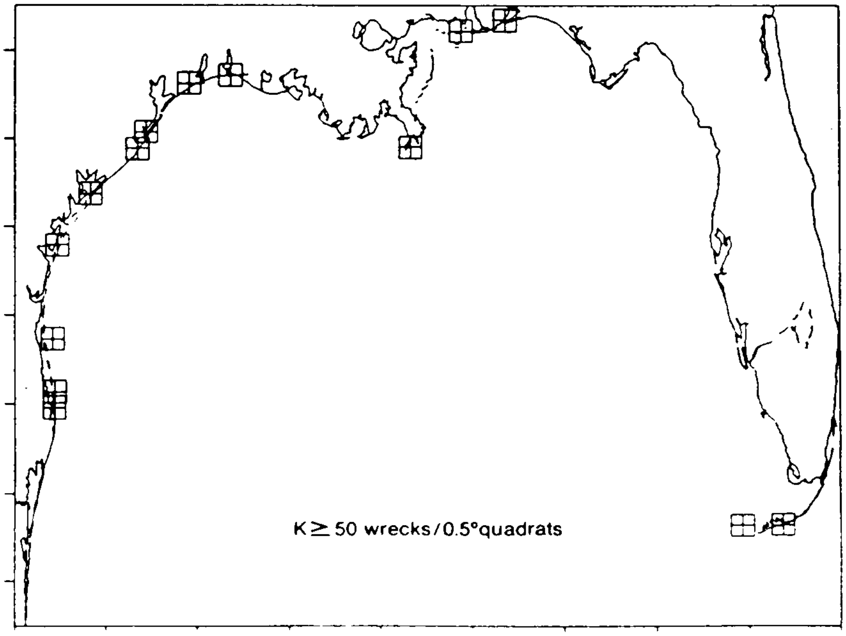


FIGURE II-40. AMC for K≥50, 0.5 degree quadrats.

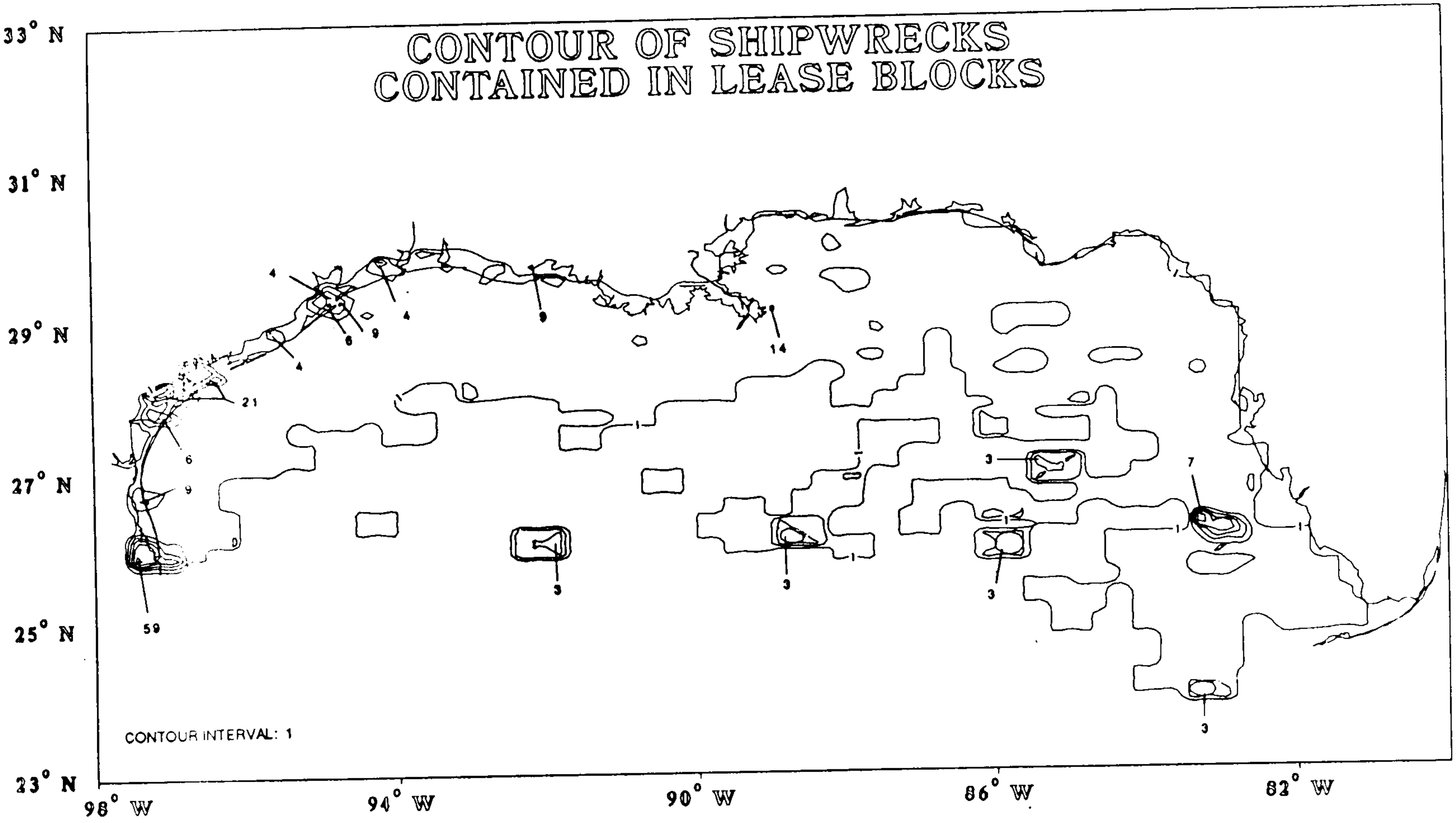


FIGURE II-41. **Contour plot of shipwrecks contained in lease blocks.**

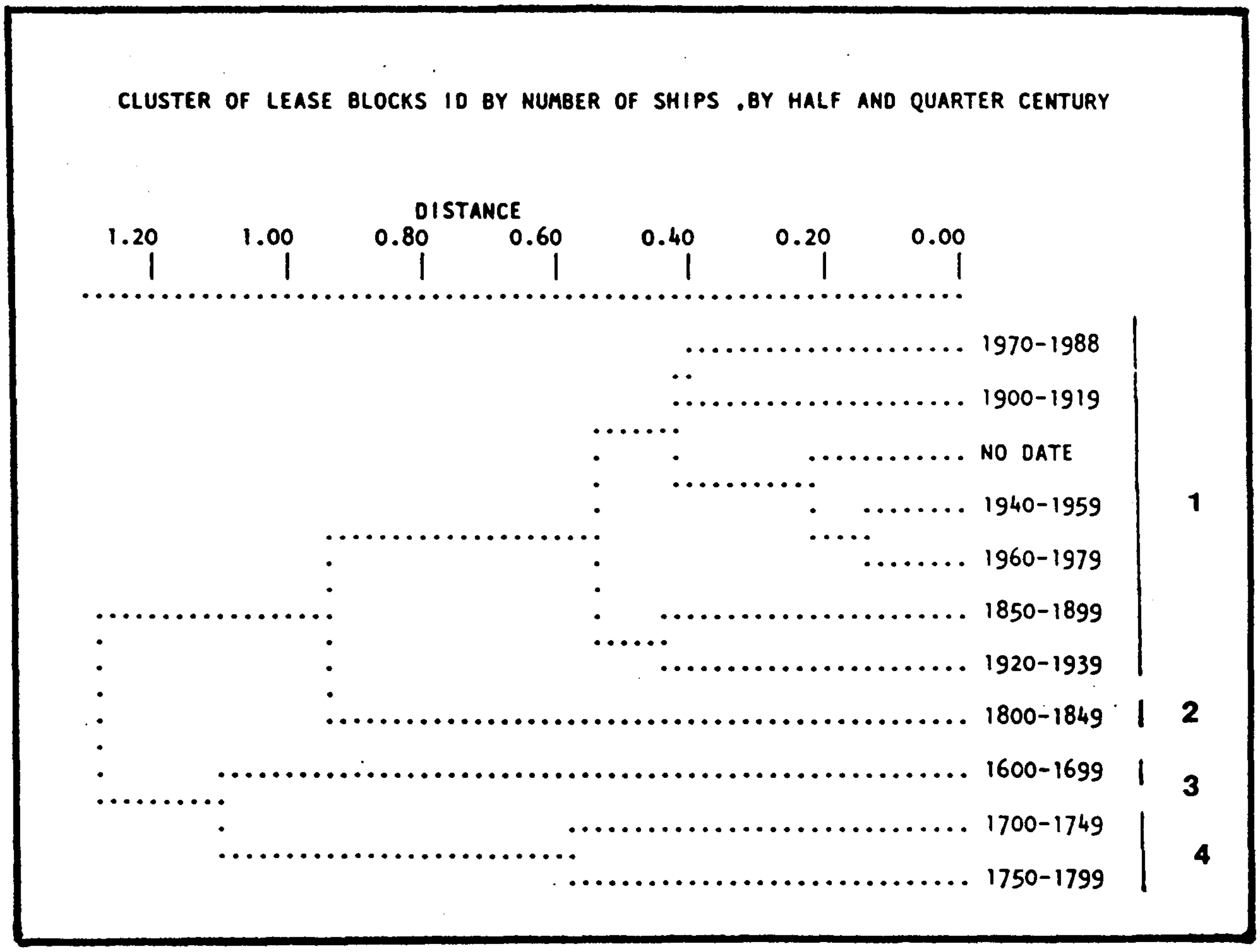


FIGURE II-42. Dendrogram of 50 and 20 year intervals.

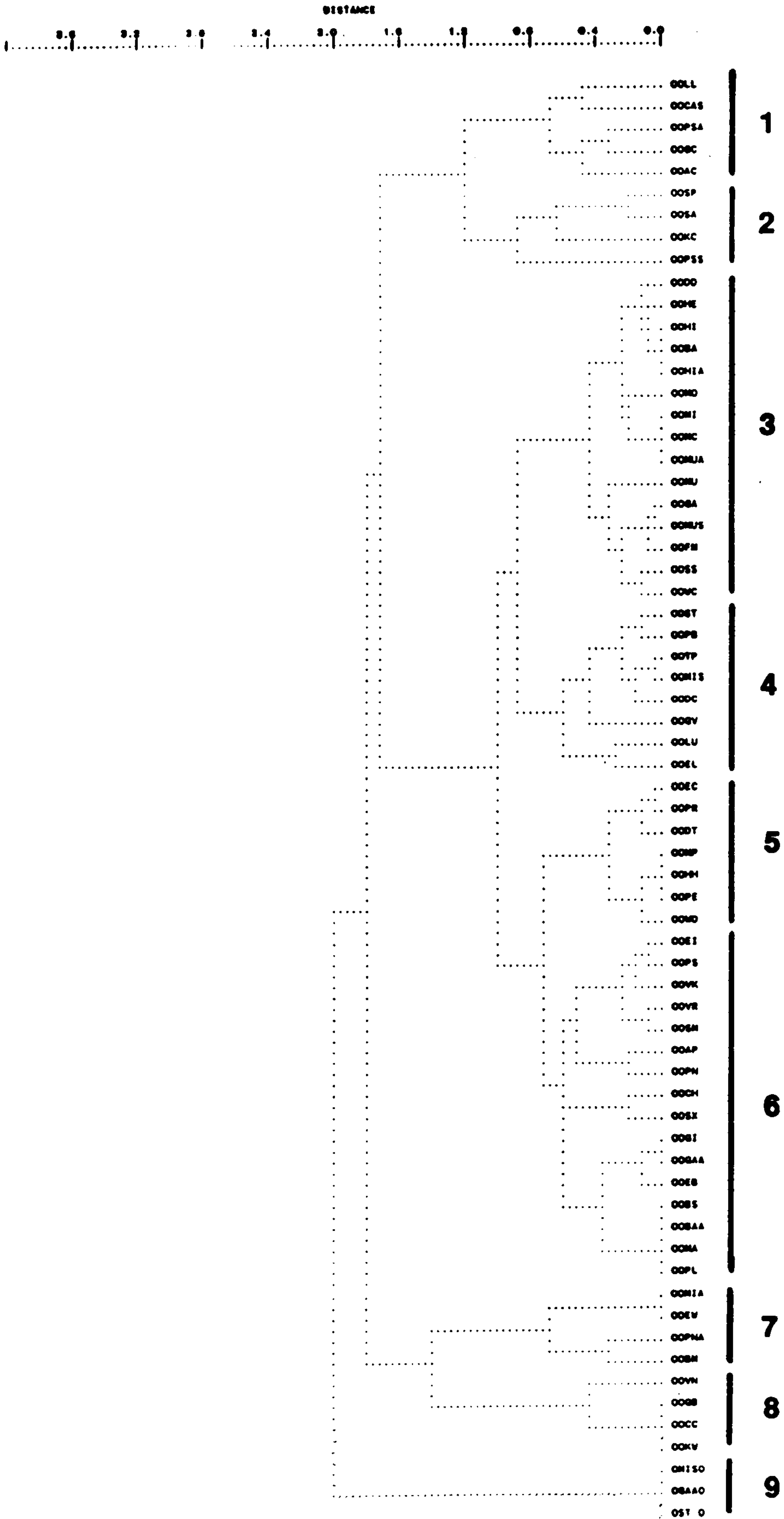


Figure II-43. Dendrogram of lease blocks.

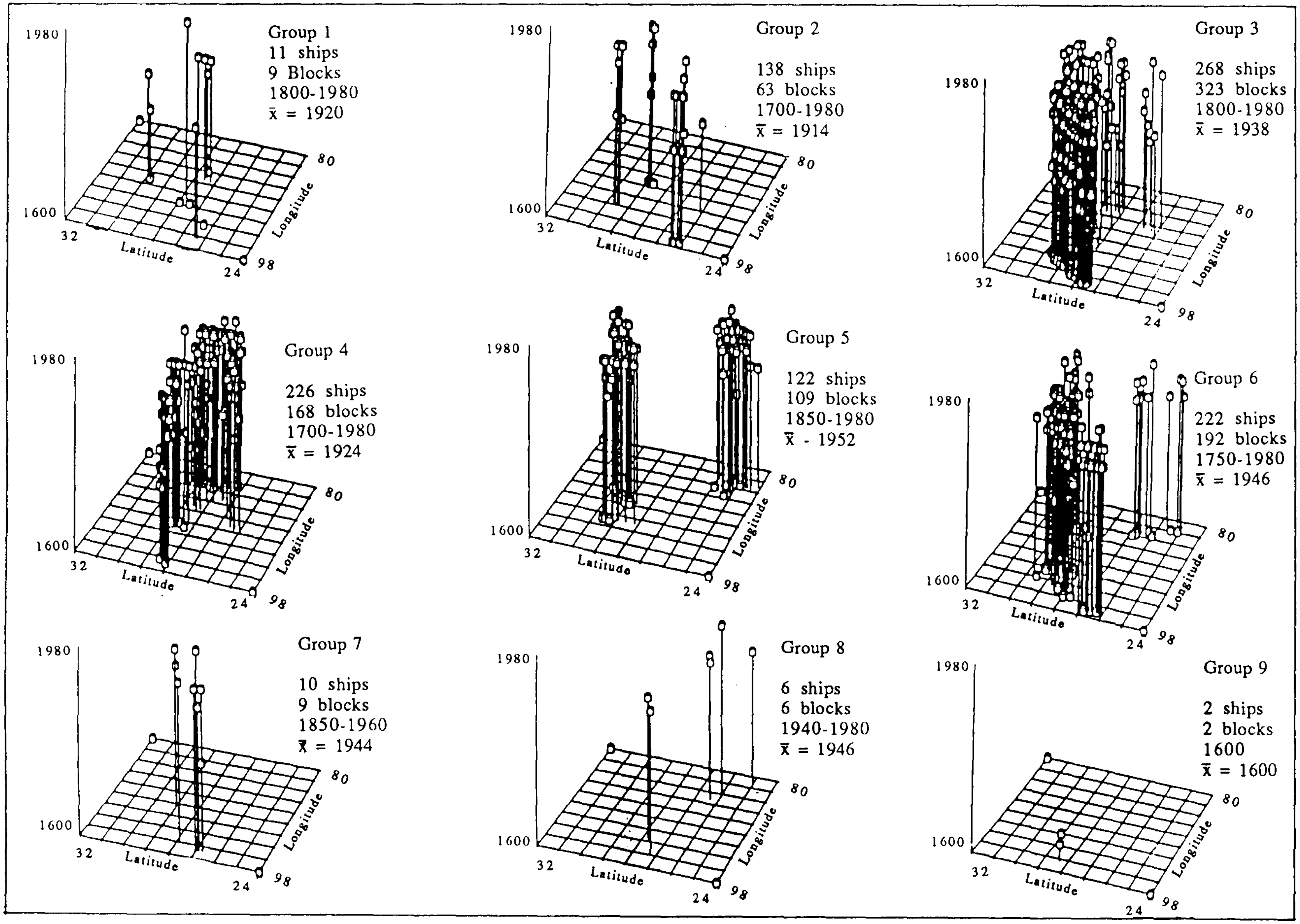


Figure II-44. Three-way plot of dendrogram lease block groups.

Table II-17.

AMC ANALYSIS: 1° (DEGREE) QUADRATS.

a)	V = 1:	This result simply shows quadrats with reported shipwrecks. Little in the way of locational or spatial trends were seen and no plot is presented.
b)	K ≥10:	Here the criterium for assigning an AMC is that the quadrat must have ≥ 10 shipwrecks. What is interesting is a two-level spatial distribution of AMC's (Figure II-37). The inner row of points correspond to nearshore shipwrecks while the second, more seaward distribution, are deeper water shipwrecks. This distribution collapses with the increases of (n) as seen in the next step.
c)	K ≥ 50:	The distribution of AMC's follows that of the nearshore shipwrecks with little representation of the less numerous offshore losses (Figure II-38). This distribution closely approximates CRMZ1 as currently defined (MMS Visual No. 11).

Table II-18

AMC ANALYSIS: 0.5° (DEGREE) QUADRATS

a) K > 10: The distribution (Figure II-34) differs significantly from the one degree quadrat results. This reflects the effect of area analysis. That is larger size better reflects broad-scale pattern as smaller quadrats are sensitive to finer-scale patterning. What is interesting is the way the pattern more closely approximates one degree quadrat results of N≥50. The trend is shoreward off Texas, but more seaward of Western Louisiana.

b) K > 50: Here the distribution (Figure II-40) collapses onto all the major port locations of the northern Gulf with the exception of Tampa, which may be an artifact of an under representation of data for the given area.

Group nine is the simplest projection of the dendrogram data as it is composed exclusively of 16th century shipwrecks. Group five as well as group six show a partitioning of shipwrecks into two sectors of the Gulf--The Keys and the west-central areas. Groups three and four contain shipwrecks of the central and east Gulf areas. Groups one, two, seven, and eight are best characterized as open Gulf losses.

9.2 Specific Factors and Shipwreck Patterns

In this study we examined five principal factors affecting shipwreck locations and patterns. These are: (1) historic shipping routes; (2) port location; (3) shoals, reefs, sandbars, and barrier islands; (4) ocean currents and winds; and (5) historic hurricane routes.

These factors do not account for all the shipwreck locations in the northern Gulf but reflect the most important elements in understanding the distribution of shipwrecks and developing explanatory models for shipwreck patterns.

The comparison of this data with the various distributional plots of the shipwreck data allows comparisons such as seen in Figure II-45 where similar patterns for shipwrecks and offshore oil development (Figure II-46) for the Louisiana and upper Texas coasts are observed.

9.2.1 Intercorrelation of Study Factors Affecting Shipwreck Location - Factor Analysis

Two separate factor analyses were conducted for shipwrecks and variables that relate to their distribution across various Gulf areas. The first analysis evaluates these variables versus sectors of the Gulf coastline as defined by DeWald (1980). The data are broken down chronologically so that temporal trends or correlations may be detected in the analysis. The second analysis used a matrix of fewer cases, based on larger Gulf areas, and variables less sensitive to chronological variation but perhaps sensitive to the other associations in the data.

9.2.1.1 Analysis 1: Chronological Factors

This matrix is composed of seven variables (four time periods, age of ports, ports, storms) and 26 observations (Gulf areas) for each variable (Appendix J; Table II-19). A principal component factor extraction method was utilized. The factors were evaluated for independence and variance. The program used was STATVIEW (Abacus Concepts 1986).

Five variables were used which measure shipwreck frequency in six periods. Data for the 16th century were merged with that of the 17th century because of the low number of shipwrecks known for these periods. Further, it is assumed that the processes underlying the patterns were similar for both periods.

The data for the 19th century was partitioned because processes responsible for shipwreck patterns changed more rapidly and the data were scaled accordingly. The results of the factor analysis appear in Appendix J and our interpretation of these results are:

1. Three factors were defined (Table II-19);
2. These factors are largely independent of one another; (1.454 vs 1.468);
3. The variance is equally divided between these three factors (0.43, 0.31, 0.26);
4. Factor 1 is characterized as an association of 16th, 17th, and 18th versus 19th and 20th century wreck locations. It represents a demographic factor;
5. Factor 2 is characterized by a moderate association of variables representing 19th century shipwrecks and port development; and
6. Factor 3 associates port and storms. The linkage is not compelling. Ports seem to be more strongly associated with wreck frequency than with the number of

years the port existed. The proportion of the variance explained by this factor is low.

9.2.1.2 Analysis 2: Areal Factors

This matrix is composed of six variables (hurricanes, ports, routes, hazards, energy, wrecks) and 10 cases (periods) per variable (Table II-20)(Appendix I). The methodology differs from the previous analysis. Larger scale areas of the Gulf are compared with the presence of hurricanes, ports, traffic routes, hazards, and energy zones in relation to shipwreck frequency. Table II-20 shows the data used in the analysis along with additional tables and associations. Table II-12 illustrates the values used to calculate the shipwreck frequency for the areas. The hurricane frequency is taken from Tannehill (1956) with little alteration. The variable "routes" represents the number of periods with major inter or intra-Gulf routes present; "hazards" represents major reef, shoal, or other hazards. The results of the factor study are as follows:

1. Two factors were identified. This was seen when restricting the program to this number of factors and allowing the program to determine the number of factors independently;
2. The factors are not strongly intercorrelated although the same cannot be said of the variables. The matrix sampling efficiency (MSA) is low (0.498) reflecting the number of composite or interrelated variables. Elimination or redefinition of some of these variables could raise the MSA although the value is not significantly below 0.50 which is the value commonly used to evaluate the sampling adequacy;
3. The orthogonal solution seems a good approximation when compared to the unrotated or oblique solution. Following the oblique solution (varimax), we see a proportionate accounting of the variance 0.63 for Factor 1 and 0.37 for Factor 2;
4. Factor 1 is interpreted as depicting a strong association of shipwrecks to routes and hazards (0.698; 0.672); and
5. Factor 2 associates shipwrecks and ports. Our first inclination is to call this the "ports" factor.

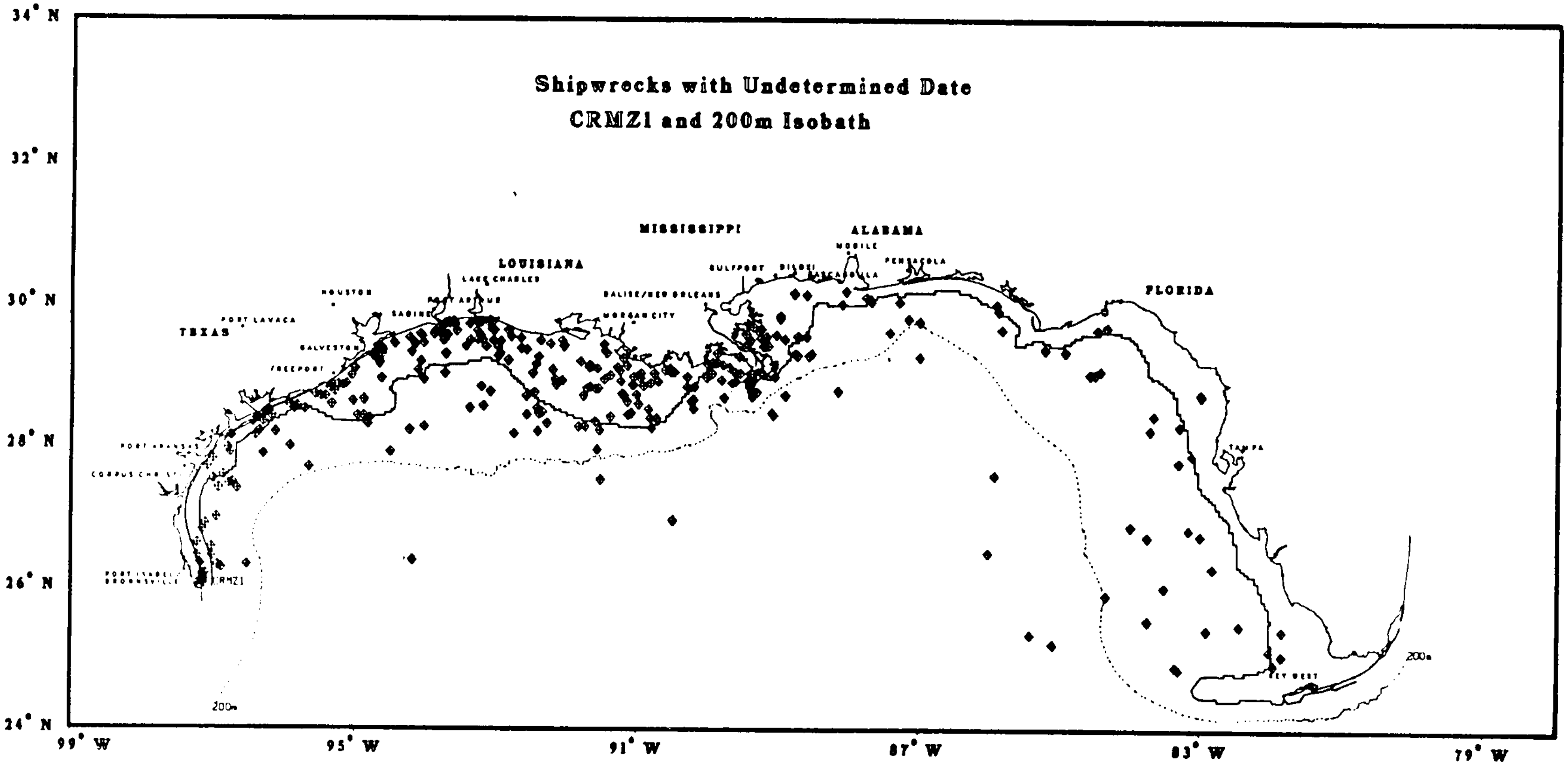


FIGURE II-45. Shipwreck positions, year unknown.

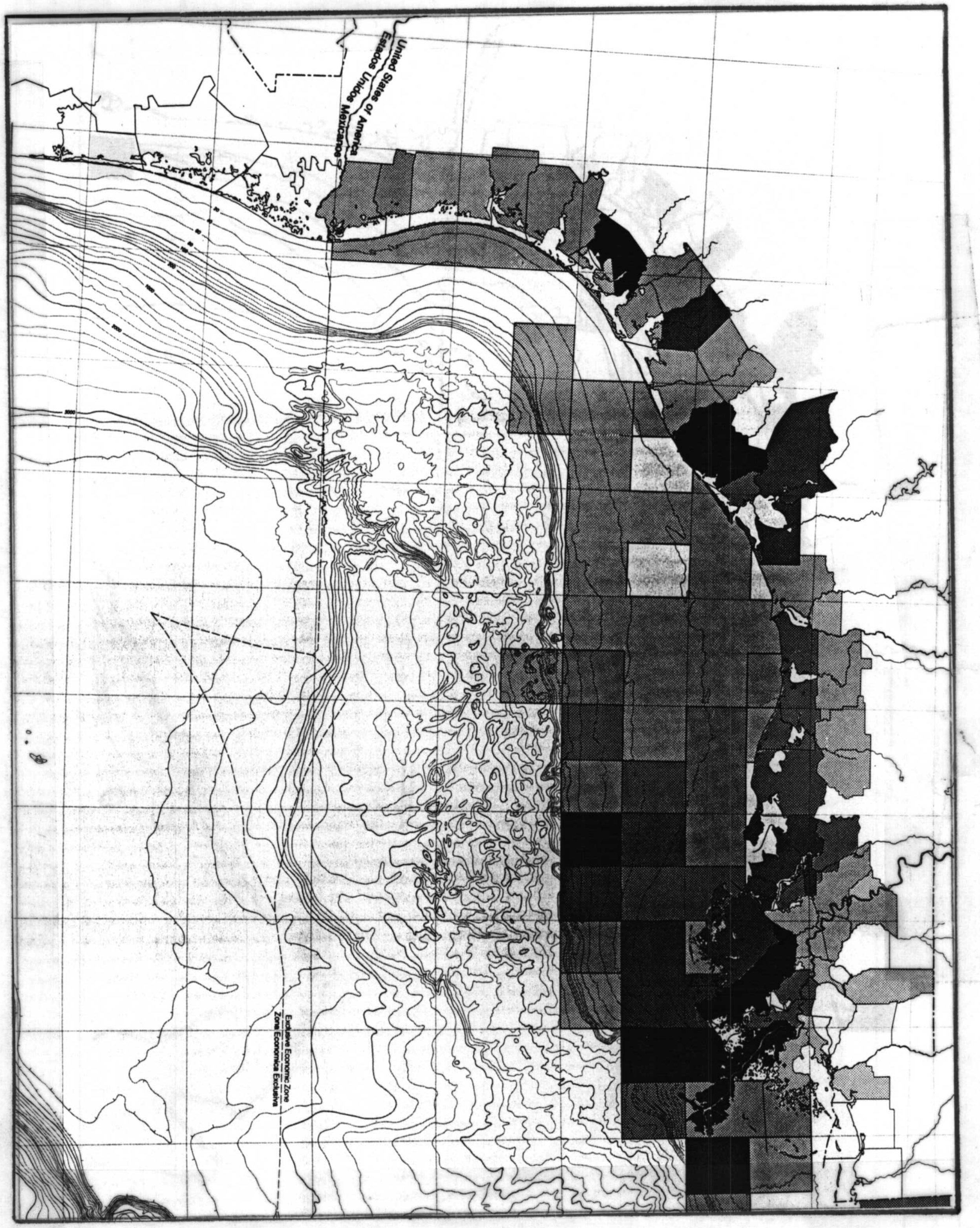


FIGURE II-46. Areas of oil and gas activity.

Table II-19.

FACTOR ANALYSIS - CHRONOLOGICAL FACTORS.

a. Chronological Variables

	Wrecks 20th C.	Wrecks 19th C.	Wrecks 18th C.	Wrecks 17-18th C.	Age Oldest Port	Ports,Major	Major Storms	Column 8
1	13	38	0	0	149	1	13	•
2	10	57	0	4	88	1	8	•
3	11	42	0	0	142	1	15	•
4	47	69	0	2	144	1	10	•
5	61	64	0	0	153	1	9	•
6	102	117	0	0	167	1	12	•
7	30	29	0	0	148	1	9	•
8	0	0	0	0	0	0	9	•
9	0	0	0	0	0	0	12	•
10	24	0	0	0	138	1	7	•
11	126	0	0	0	270	1	26	•
12	21	12	0	0	270	1	26	•
13	57	42	0	0	118	3	9	•
14	39	23	12	0	288	1	21	•
15	30	0	0	0	168	1	3	•
16	0	0	0	0	0	0	12	•
17	15	11	0	0	34	1	9	•
18	0	0	0	0	0	0	8	•
19	0	0	0	0	0	0	14	•
20	0	0	0	0	0	0	13	•
21	53	0	0	0	113	1	21	•
22	0	0	0	0	0	0	18	•
23	10	0	0	0	148	2	7	•
24	11	0	0	0	0	0	6	•
25	22	14	43	15	166	1	12	•
26	156	57	87	29	0	0	15	•

b. Chronological Factors

Oblique Solution Reference Structure-Orthotran/Varimax

	Factor 1	Factor 2	Factor 3
Wrecks 20th...	.716	.511	.414
Wrecks 19th...	.387	.777	-.084
Wrecks 18th...	.955	-.001	.089
Wrecks 17-...	.956	.023	.016
Age Oldest P...	-.07	.617	.71
Ports,Major	-.162	.797	.206
Major Storms	.188	-.001	.938

Table II-20.

FACTOR ANALYSIS - AREAL FACTORS.

a. Areal Variables

	Hurricanes	Ports	Routes	Hazards	Energy	Wrecks
1	10	1	2	0	3	3
2	10	2	2	0	3	12
3	10	6	2	0	1	27
4	5	2	3	3	2	15
5	15	4	3	2	2	6
6	13	1	3	2	3	4
7	4	0	3	0	0	6
8	4	2	3	0	2	6
9	4	1	4	5	0	4
10	4	0	4	5	0	17
11	•	•	•	•	•	•
12	•	•	•	•	•	•
13	•	•	•	•	•	•
14	•	•	•	•	•	•
15	•	•	•	•	•	•

b. Areal Factors

Oblique Solution Reference Structure-Orthotran/Varimax

	Factor 1	Factor 2
Hurricanes	-.675	-.067
Ports	-.097	.707
Routes	.698	-.152
Hazards	.672	.001
Energy	-.892	-.39
Wrecks	.468	.94

10.0 SUMMARY AND CONCLUSIONS - TASK I

Determining spatial patterns of shipwrecks in the Gulf of Mexico does not explain the causes for these patterns. These factors are not always independent. For example, increased frequency of shipwrecks along trade routes does not explain why the vessels were lost, only why they were there in the first place. Factors such as poor seamanship, poor navigation, scuttling, explosions, and fire cause shipwrecks. The maritime insurance system can also be a causal factor in intentionally wrecking vessels, but it probably claims only a relatively small percentage of Gulf ships (James Parrent 1986, personal communication). These lessser factors and the principal ones detailed in this study determine a vessel's safe journey or unfortunate loss.

An interesting aspect of the analyses conducted on the data in this study shows an increase in the number of losses over time. This contradicts conclusions in the CEI study (1977) where the peak for shipwreck losses was expected to lie between 1880 and 1910. New data suggests that shipwreck loss continues to increase through the 20th century. This fact is somewhat surprising if one assumes, like the CEI investigators, that improvements in the technology of ship design, the use of diesel engines, and better navigational tools would reduce the number of ships lost over time. However, the rate of shipwrecks actually increases because of improved technology. Improved technology may allow more vessels to be exposed to risks that early mariners would avoid because of recognized shortcomings in their ships or navigational aids.

Important natural factors that influenced the distribution of shipwrecks are storms, historic hurricanes, and the weather fronts called "northers." At the outset of the CEI study northers were considered under the larger category of winds, currents and energy zones. The normal wind patterns were not representative of seasonal storms. Sailing ships used the prevailing winds in their travels. These winds influence nearshore currents whereas the Loop Current and its eddies dominated the central Gulf and Straits of Florida. Storms broke these normal patterns and drove vessels into nearshore hazards or caused them to founder in the open sea. Examples given in this report (SAN MIGUEL (1551), L'ADOUR (1722), EL NUEVO CONSTANTE (1766), Solano's fleet (1780)) are representative of the direct casual nature of seasonal storms in the loss of ships in the northern Gulf.

Over 16 percent of vessels involved in the Spanish Carrera fleet suffered loss due to storms (Chaunu and Chaunu 1955). As that landmark study evaluated over 11,000 sailings this percentage for the first century and half in the Gulf's maritime history is reliable. Our own correlation of historic hurricane data with the MVUS and BAR shipwreck files show a percentage of storm related losses to be 16 and 9.1 percent respectively.

There is a correlation between large hurricanes and shipwrecks for the specific years of 1622, 1733, 1780, 1886, 1900, 1915, 1919, 1928, 1944, 1947, and 1961. For eight reporting periods (31 years) in the MVUS data (1945-1976) we found that 16 percent of losses could be associated with tropical storms. For 14 historic hurricanes ranging from 1722-1981, we found a total of 146 verifiable ship losses or an average of 10 per storm. The correlation of individual storm paths and vessel losses is difficult because reporting practices do not list the hurricane as a cause, but report the ship as "foundered," "stranded," etc. Many of the vessels assigned to various storms were made on the basis of the simultaneity of location for storm and vessel on a given date. A general association is seen between storm frequency and the occurrence of shipwrecks, although the highest hurricane frequency areas do not have the highest occurrence of shipwrecks.

Another factor in the distribution of Gulf shipwrecks is the 307 km reef and shoal complex of the Florida Keys, Marquesas, and the Dry Tortugas. The convergence of winds, current, reefs, and storms make the Straits of Florida the most hazardous area for ships that exit or enter the Gulf. Charlevoix (1734, 1766) recognized that if a sailing vessel sailing east deviated half of a degree north or south, it was at the mercy of counter currents and the west-blowing trades (Figure II-16).

Westbound vessels ran the hazard of either the northern shore of Cuba or the reefs if they made for the countercurrents that ran close to these areas (Figure II-19). The advent of steam made the journey more timely and predictable, but the distribution of late 19th and 20th century shipwrecks still underscores the high probability for wrecks in these regions.

The Chandeleur Islands east of the Mississippi have claimed a large portion of maritime traffic. This is associated with the development of coastal traffic from the early 1700s to the present day. It underscores the importance of New Orleans as the major historic port of the northern Gulf since the 18th century.

Winds and currents during the 16th through the 19th centuries made westward journeys easy but necessitated tacking or sailing off the wind in eastward crossings of the Gulf. The pattern for the winds varies from easterly in winter to south southeast for summer. To take advantage of the summer wind regime meant the sailing vessels from New Spain, Terra Firme or the Caribbean sailed northeasterly courses for much of their journeys before turning southeastward to the Florida Straits. As a result, vessels ascribed to routes which allowed them to take advantage of easterly flowing currents. With the coming of steam powered vessels and other changes such as colonization of the northern shore, this pattern was significantly modified.

Coastal traffic took advantage of the coastal currents in the southeast and northwest Gulf and winds in the central and north Gulf. The vessels risked the hazards of the shallow coasts when they traded the safety of deeper water for faster voyages by following coastal currents.

In summary, the patterns for Gulf shipwrecks are the result of economic decisions involving maritime commerce. The mariners used the winds and currents in the Gulf to chart the sailing routes we observe in historic records. This is seen in the change from the earlier period pattern of shipwrecks when compared to later periods. The Spanish lost ships principally at the Straits, not because of a poor reading of currents or winds, but to anomalies of weather (e.g. northers or hurricanes). Less frequently they made errors in navigation that resulted in a shipwreck. As a determining cause in shipwreck patterns, winds and currents must be viewed as secondary.

The probability for shipwrecks along the Gulf increased with the development of commerce. Commerce followed the colonization of Florida, Louisiana and Texas. After the turn of the 18th century, this development proceeded with France, Spain and Britain exchanging roles as their global fortunes changed. With the Anglo-American settlement of the northwest Gulf coast in the mid-19 century the picture was complete for maritime commerce. The entrances to harbors became high probability zones developed for shipwrecks .

Changes in the late 19th and 20th century shipping routes increased the observed frequency of shipwrecks in the open waters of the eastern Gulf (Figure II-47). The patterns for this later period are distinctly different for the west and east portions of the northern Gulf. The western Gulf has higher probability zones along and near shore, while the eastern Gulf has an incidence of shipwrecks in the open sea that is more than double that of the West (2.5 versus 5.4).[5] The reasons for this increased frequency are not completely understood. Traffic patterns are the most likely reason for the increased frequency of vessels exposed to the risks of storms and stranding. What is also of interest is the validity of hindcasting the same probability for vessel losses throughout earlier periods where sailing commerce was known to concentrate in this part of the Gulf. The question is an open one, but historical similarities in traffic pattern and frequency are not supported by the results of our factor analysis studies.

While the correlation of shipwreck sites to sailing routes is difficult, we have observed in our factor analysis that the association in the distribution of shipwrecks and the location of sailing routes for a given period are linked. Sailing routes were important in both a navigational and strategic sense. During the Spanish era of exploration these routes were

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[5] Calculated using shipwreck frequencies per 1° quadrats, see Appendix I.

PERIODS	PORTS	OPEN SEA	CHANNELS	COASTAL
16th/17th	0	.1	.5	.34
18th	.03	.16	.65	.17
19th	.48	.16	.25	.16
MOD	.32	.24	.19	.25

FIGURE II-47. Matrix of shipwreck probability.

defined by trial and error. The early Spanish navigator was restricted to a few principal routes determined by the Westerlies outbound to the New World and the tack against them using the Gulf Loop Current to reach the Gulf Stream. Exits from the Caribbean existed at either the Mona Passage (between Hispanola and Puerto Rico) or the Windward Passage (between Hispanola and Cuba). For the Gulf, Tierra Firme ships sailed the Yucutan Channel and the Straits of Florida, or a great arc for New Spain fleets from Vera Cruz, to near the mouth of the Mississippi River and southeast to the Straits. It is this later route that has the greatest significance for all periods in the Gulf during this age of sail.

We see a peak value for the occurrence of shipwrecks associated with ports in the 19th century (Figure II-47). For the 16th and 17th centuries losses are high given the lack of navigational aids, vulnerability to storms, and known piracy and warfare. This frequency increases for the 18th century for most of the same reasons as well as with the increase in ports (Figure II-49). In the 19th and 20th centuries, with improvements in navigational aids, ship design, and losses at ports, shipwrecks continue to be higher than in other areas, except the Straits of Florida (Figures II-48 and II-49). An explanation of the frequency of shipwrecks may be the direct result of a ship coming to port where an entrance bar lies. Such a pattern is seen at major port entrances.

Other longshore bars or off headlands may explain the occurrence of wrecks in shallow waters. Strandings are the result of encountering these hazards. A marked example of a treacherous shoal area is that off Cape San Blas (Figure II-19). This shoal area has claimed a proportion of shipwrecks over that seen for the Gulf as a whole and is demonstrated in the distributional plots and the plot of the AMC's (Figures II-37 through II-40).

10.1 Pattern and Distribution of Shipwrecks

The number of ships lost in the open sea versus those lost nearshore were discussed by Muckelroy (1978), Bascom (1976), CEI (1977), and Marx (1971). Marx estimated that approximately 98 percent of all shipping losses in the western hemisphere prior to 1825 occurred in less than 10 m of water. CEI's authors follow this proposition when developing the CRMZ1. Muckelroy suggested that the 10 m boundary probably underestimated the potential for deep-water archaeology. Bascom concluded from a study of 19th century losses at Lloyds of London that about 20 percent of all sinkings occur away from the coast. This figure probably better approximates the correct order of magnitude for all sinkings in the open sea at any period. The data in this study support Bascom. An inspection of our shipwreck distribution plots shows that 75 percent of shipwrecks occur in nearshore waters and the remainder in the open sea (Figure II-47).

Knowing shipwreck locations can sometimes increase the reliability of predicting other shipwreck locations. While recognizing that under reporting of losses in earlier periods exists, recognizing patterns must also include some understanding of historical processes that underlie patterns. Alfred Kroeber (1948) defined pattern recognition as "a rough plan of convenience for the preliminary ordering of facts awaiting description or interpretation. Interpretation requires a move to process those factors which operate either toward stabilization and preservation, or toward growth and change."

Kroeber, as an anthropologist, was speaking principally of cultural patterns and their stability, but it is clear such processes that operate on shipwreck patterns are the result of changes in the cultures of a particular time. Following Kroeber, we observe that shipwreck patterns persevere or change through time and space as a result of underlying cultural processes. We must conclude that processes underlying shipwreck patterns for the northern Gulf have changed over time. If processes, for a particular period are stable, then the pattern for shipwrecks shouldbe consistent for that era if our first assumption concerning under reporting is valid. To attempt to predict shipwreck locations between periods such as those of the Colonial times (17th - 18th centuries) using 19th century distributions seems unwise given the results of our factor analyses.

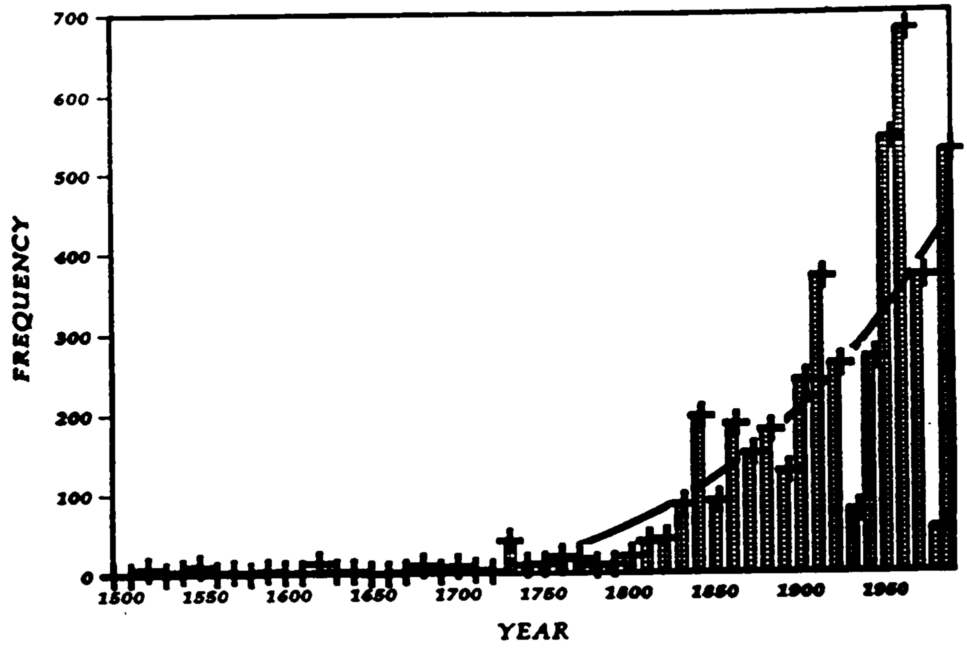


FIGURE II-48. Shipwreck frequency by decade.

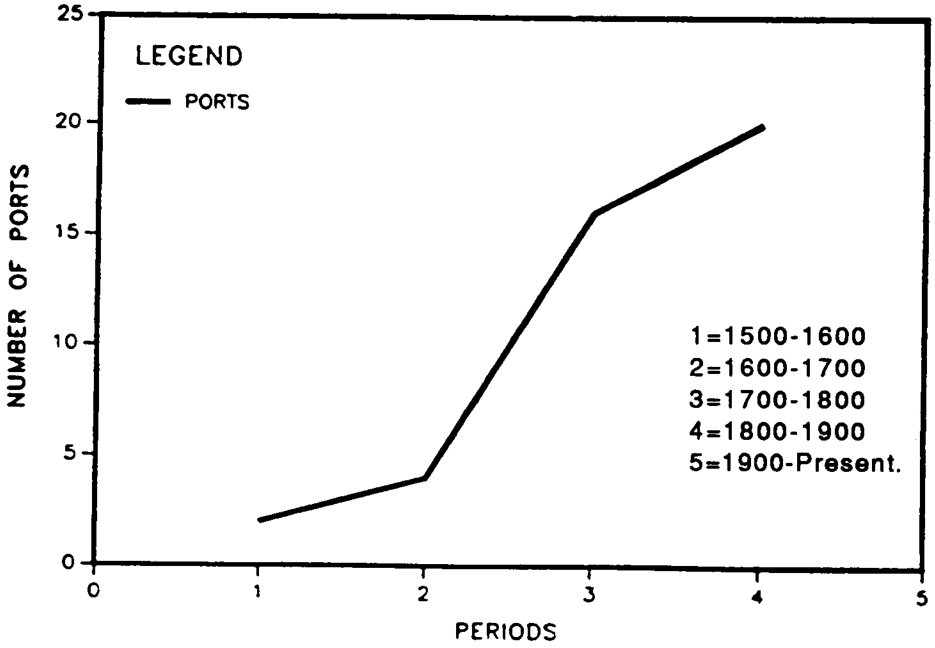


FIGURE II-49. Port development - northern Gulf of Mexico.

10.2 Point patterns, probability distributions, and processes

Settlement studies, such as one by Hudson (1969), considered a spatial process that led to clusters. His theory was that patterns were produced in three stages: (1) an initial stage of colonization by individual settlements or small groups of settlements; (2) a second stage of spread outward from these initial centers; and (3) a final stage moving toward a regularity in spacing and overall density. Such a model describes the Gulf's shipwreck data although distinctions must be made in the specific type of spatial diffusion.

Hudson's model and other models derived from biological analogues (Pielou 1969) ignore historical factors common in cultural processes. Outward diffusion from an initial settlement may be uniform to the point that it is constrained only by environmental factors such as availability of food, water and space. Pattern development for ports in the Gulf of Mexico is different.

Here the placement of ports is constrained by environmental factors (depth of water, winds, currents) as well as historical ones (communication, political and economic motives). A classic example of factors underlying the spread and placement of ports is early 18th century Pensacola. It was "refounded" as a direct response to the French placement of Mobile. The French, in turn, founded New Orleans in order to establish direct communication with her northern territories and to exert pressure on Spanish Texas (Weddle 1987).

The number of shipwrecks follows the number of ports founded. Their location follows that of routes between the ports. In French Louisiana, shipwrecks increased to a level reflecting the economic commerce the colony could support. After Louisiana became an American possession, the population increased along with the number and size of ports. Consequently, shipwreck frequency increased. Larger centers, such as Houston and New Orleans, have shifted patterns toward those portions of the Gulf where traffic to and from these ports is heaviest (Table II-3).

10.3 Preservation and Shipwrecks

The potential for shipwreck site preservation is another important consideration in the overall analysis of the CRMZ1. If an area with a high potential for historic shipwrecks lacks the potential for preservation, that area may not need to be included within the boundary of the CRMZ1. An example of an area with negative environmental factors for site preservation is the region at the mouth of the Mississippi River. By historic accounts, it was an area of high ship concentration. The tremendous sediment deposits off the Mississippi Delta militate against finding a shipwreck in that area due to sediment dynamics. If, by chance, a site survived these natural forces, it would be covered by sediments of a depth that would insulate it from discovery.

Examples of information derived from shipwreck preservation studies on the OCS CRMZ1 are: Clausen and Arnold (1975); Arnold and Weddle (1978); Hole (1974); Arnold and Hudson (1981); and Pearson, et. al. (1981). From this we derived a measure of the relative probability for shipwreck preservation in various areas of the northern Gulf of Mexico (Figure II-50). Ships falling on areas of moderate to high sediment depths, hypoxic burial conditions, and low current regimes have good preservation potential.

These conditions characterize much of the western and the west-central areas of the northern Gulf. It cannot be stated unequivocally that vessels sinking in sediment-starved areas of the shelf, such as that of the eastern Gulf area, cannot be preserved, but based on results of this inquiry the probability seems low. In an area where burial or protection by fouling organisms exist, biofouling must be rapid in order to preserve vessel fabric or cargo. Due to the small amount of data for the eastern Gulf area, we cannot draw such conclusions. Until such data is available our expectation is that much of the eastern Gulf area will be characterized by poor preservation of historic shipwrecks.

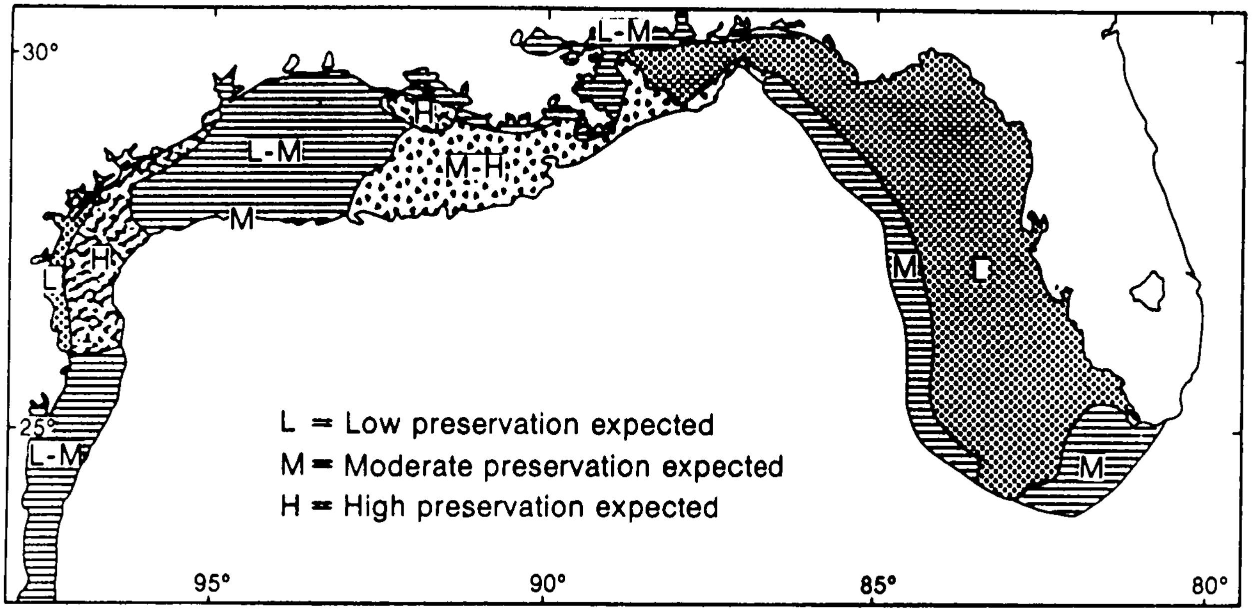


FIGURE II-50. **Expected preservation potential and sediment distribution, northern Gulf of Mexico.**

Exceptions are the cases of vessels sinking near to shore in the lee of headlands where sediment transport and current eddies provide a sand blanket to retard deterioration of ship remains.

10.4 A Reevaluation of Cultural Resource Management Zone 1

Cultural Resource Management Zone 1 (CRMZ1) as originally drawn (Plate 11, CEI 1975; Figure I-1) was assumed to contain 80 percent or more of the northern Gulf of Mexico shipwrecks. This assumption of shipwreck probability is conservative in comparison to other writers such as Marx (1971a) who cite values as high as 98 percent. As Muckelroy citing Bascom points out, the data supports the lower figure (Muckelroy 1978). The authors estimated that two-thirds of the total number of shipwrecks in the northern Gulf are within 1.5 km of the coast while the remainder lie between 1.5 and 10 km (CEI 1977). They conclude that wrecks are associated with the approaches to seaports, straits, shoals, reefs, and along the maritime routes. As we have seen in this study, the foregoing assumptions are largely supported by the data, but the authors deviate from their assumptions in the actual drawing of CRMZ1.

Generally, the CRMZ1 is far beyond 10 km off the coast. There are no reasons given for this. When we examine the total distribution of known shipwrecks developed by our study, the CRMZ1 boundary encompasses much of this overall density particularly west of the Mississippi delta. The eastern area of the northern Gulf departs sharply from this coincidence as deeper shipwrecks occur there. The results of multivariate analyses indicate a strong partitioning of shipwrecks chronologically which allows us to relate shipwreck patterns to historic changes in the northern Gulf of Mexico. Further, the AMC studies, a rough form of trend surface analysis, clearly illustrate that the pattern of shipwrecks coincide with factors such as port development, routes and hazards even when chronological considerations are waived. Four major groups, by chronological periods, were isolated by cluster analysis (Figure II-42) and nine groups by areas (Figure II-44). Using these results we can more confidently evaluate shipwreck potential across the northern Gulf of Mexico.

Tables II-21 and II-22 summarize our expectations for the potential of shipwrecks across the northern Gulf. We merged the observed frequency for shipwrecks in specific areas with our assumptions concerning preservation in those areas to derive a rank-order scale of this potential. Again, this classification is more of an extended hypothesis than a comprehensive recapitulation of the actual situation for the vast sweep and variability of the OCS.

Where we have assigned "low" values to an area or subarea we are simply stating that the preservation and/or density of shipwrecks is generally lower than that expected for other areas. Drawing on our statistical analyses (Figure II-44) we define our shipwreck density values as follows: low $\leq$ 175 shipwrecks per area; moderate = 175-500 shipwrecks per area; high $\geq$ 500 shipwrecks per area. Exceptions such as the New Ground Reef wreck and the SAN JOSE both lie in low preservation potential areas based on the general picture seen for shipwrecks in the Keys-Tortugas area. Here the redeposition of the coarse-grained sediments preserved significant portions of these historic wrecks. Further out on the Florida platform we do not expect to see this movement of sediments and we expect low preservation in this area.

The conclusions we offer are derived from our present understanding of the shipwreck archaeology in the northern Gulf of Mexico. Our study results indicate:

1. Increased distribution of shipwrecks in the eastern Gulf area beyond the present CRMZ1 boundary but a lower preservation potential relative to the central and western Gulf;

2. Previous underestimations of early shipwrecks in the central and eastern Gulf areas; and

3. Increased potential of unreported shipwrecks in high density areas, e.g. a higher probability of finding wrecks in these zones because of higher preservation potential.

Recommendations for revisions of the CRMZ1 include:

1. Move the current CRMZ1 to within 10 km of the Gulf coast based upon the distribution of reported shipwreck locations and their probability of preservation.

2. Delineation of specific higher probability zones to reflect the increased frequency of shipwrecks in the vicinity of ports and certain hazards. They should have guidelines at least equal to those for the CRMZ1 and include:

   a. Brazos Santiago-South Padre Island (TEXAS);
   b. Corpus Christi-Mustang Island (TEXAS);
   c. Freeport-Matagorda Island (TEXAS);
   d. Galveston-High Island (TEXAS);
   e. Sabine River (TEXAS);
   f. Calcasieu (LOUISIANA);
   g. Barataria Bay/Grand Isle (LOUISIANA);
   h. West Bay-Mississippi Delta (LOUISIANA);
   i. East Bay-Chandeleur Islands (LOUISIANA);
   j. Mississippi-Alabama Barrier Complex (Cat, Ship, Horn, Petit Bois, Dauphin Island) (MISSISSIPPI-ALABAMA);
   k. Pensacola-Santa Rosa Island (FLORIDA);
   l. Apalachicola-Cape San Blas (FLORIDA);
   m. Cedar Key (FLORIDA);
   n. Tampa-St. Petersburg (FLORIDA);
   o. Cape Sable (FLORIDA) ; and
   p. Dry Tortugas-Marquesas (FLORIDA).

3. Recognize individual blocks outside high probability zones and CRMZ1 proper according to the occurrence of specific historic shipwrecks. These blocks and immediately adjacent blocks should be considered as localized high probability areas such that surveys should consider the specific block and the eight contiguous blocks.

Surveys conducted within these newly defined zones should utilize the survey methods recommended based on the results of the second part of this study.

Table II-21.

PRESERVED SHIPWRECK PROBABILITY FOR GENERAL AREAS.

Areas	Shipwreck Potential	Preservation Potential	Overall Potential
RIO	LOW	HIGH	MODERATE
WES	HIGH	HIGH	HIGH
CEN	HIGH	MOD-HIGH	HIGH-MOD
CENLA	HIGH	HIGH	HIGH
MSAL	MOD	MOD	MOD
WFL	MOD	MOD	MOD
BB	MOD	LOW	LOW-MOD
MG	MOD	LOW	LOW
SWFL	LOW	LOW	LOW
KEYTO	HIGH	LOW	MOD

Table II-22.

PRESERVED SHIPWRECK PROBABILITY FOR GENERAL AREAS & SUB-AREAS.[7]

Areas & Sub-areas	Shipwreck Potential	Preservation Potential	Overall Potential
RIO	LOW	HIGH	MODERATE
South Padre	HIGH	HIGH	HIGH
South Padre East	LOW	HIGH	MOD
WESTERN(WES)			
South Padre	HIGH	HIGH-MOD	HIGH
North Padre	MOD	MOD-HIGH	MOD
Mustang Is.	HIGH	MOD-HIGH	HIGH
Matagorda Is.	MOD	MOD-HIGH	MOD
S.P. East	LOW	HIGH	MOD
N.P. East	LOW	HIGH	MOD
M. Is. East	LOW	HIGH	MOD
Mat. I. East	LOW	HIGH	MOD
CENTRAL (CEN)	HIGH	MOD-HIGH	MOD-HIGH
Matagorda Is.	HIGH	HIGH	HIGH
Brazos	HIGH	HIGH	HIGH
Galveston	HIGH	MOD-HIGH	HIGH
High Is.	HIGH	MOD	MOD-HIGH
Sabine Pass	HIGH	MOD-HIGH	HIGH
West Cameron	LOW	MOD-HIGH	MOD
Brazos So.	LOW	MOD-HIGH	MOD
Gal. So.	LOW	HIGH	MOD
H. Is. So.	LOW	HIGH	MOD
H. Is. East	LOW	MOD	LOW-MOD
H. Is. East So.	LOW	MOD	LOW-MOD
W.C. West	LOW	MOD-HIGH	MOD
W.C. South	LOW	MOD-HIGH	MOD
CENLA	HIGH	MOD	MOD
East Cameron	MOD-HIGH	HIGH	MOD
Vermilion	MOD-HIGH	HIGH	MOD
South Marsh Is. N.	MOD-HIGH	HIGH	MOD
Eugene Is.	MOD	HIGH	MOD
Ship Shoal	MOD	HIGH	MOD
South Pelto	MOD-HIGH	HIGH	MOD
Grand Isle	HIGH	HIGH	HIGH
West Delta	HIGH	HIGH	HIGH
South Pass	HIGH	HIGH	HIGH
E.C. So.	MOD	HIGH	MOD
S.M. IS.	MOD	HIGH	MOD
S.M. Is. So.	LOW-MOD	HIGH	MOD
E. Is. So.	LOW-MOD	HIGH	MOD
S.S. So.	LOW-MOD	HIGH	MOD

Table II-22
(continued).

South Timbalier	MOD	HIGH	MOD
S.T. S.	MOD	HIGH	MOD
Ewing Bank	LOW	HIGH	MOD
G. Is. So.	LOW-MOD	HIGH	MOD
W.D. So.	MOD	MOD	MOD
S.P. So.	MOD	LOW	LOW-MOD
MSAL	MOD	MOD	MOD
Breton Sound	HIGH	MOD	MOD
Main Pass	HIGH	MOD	MOD-HIGH
Chandeluer	HIGH	MOD-HIGH	MOD-HIGH
Mobile	HIGH	MOD	MOD-HIGH
S.P. East	MOD	LOW-MOD	LOW-MOD
Ch. East	MOD	HIGH	MOD-HIGH
M.P. So. & East	LOW	LOW-MOD	LOW
Viosca Knoll	LOW	MOD-HIGH	LOW
Mobile So.	LOW	HIGH	MOD
WFL	MOD	MOD	MOD
Pensacola	MOD	MOD	MOD
Pen. So. 1	LOW	HIGH	MOD
Pen. So. 2	LOW	HIGH	MOD
BB	MOD	LOW	LOW-MOD
Apalachicola	MOD	LOW	LOW
Ap. So.	LOW	LOW-MOD	LOW
MG	MOD	LOW	LOW
Gainesville	LOW	LOW	LOW
Tarpon Sp.	MOD	LOW	LOW
SW FL	LOW	LOW	LOW
Tampa	LOW	LOW	LOW
T.W.	LOW	LOW	LOW
St. Petersburg	LOW	LOW	LOW
Charlotte Harbor	LOW	LOW	LOW
KEYTO	HIGH	LOW	MOD
Pulley Ridge	LOW	LOW	LOW
Miami	LOW-MOD	LOW	LOW
Dry Tortugas	HIGH	MOD	MOD

[7] Sub-areas identified by use of MMS lease area additions e.g. West Cameron; Appalachicola South, etc. (cf. MMS Visual No. 4, 1986)

Task II Establishing an Interpretive Framework to Characterize Unidentified Magnetic Anomalies and Side-Scan Sonar Contacts

11.0 INTRODUCTION

The Minerals Management Service (MMS) established the boundaries of Cultural Resource Management Zones 1 and 2 based on the results of the 1977 baseline study, *Cultural Resource Evaluation of the Northern Gulf of Mexico Continental Shelf.* Cultural Resource Management Zone 1 (CRMZ1 or Zone 1) was defined based on the higher probability of historic shipwreck sites. Zone 2's definition was based primarily on the occurrence of prehistoric cultural resources.

All the blocks within Cultural Resource Management Zone 1 (Figure II-51), also lie within the area of high industry interest including 69 of the 90 tracts (77 percent) in the central Gulf planning area (Figure II-52) (Brashier, Beckert and Rouse 1983).

About 39 percent (1,770) of the 4,592 blocks within the central area are in Zone 1. MMS estimates that of the 278 blocks leased in the central Gulf, approximately 108 blocks (39 percent) occur within Zone 1.

The two principal instruments for shipwreck detection are the magnetometer and the side-scan sonar. At 150 m linespacing the magnetometer gives about 25-30 percent coverage of the sea floor, which constitutes only a sampling survey (Clausen and Arnold 1975). However, at this linespacing, side-scan sonar can cover over 100 percent of the sea floor with good resolution.

Conducting surveys at 150 m linespacing is based on the premise that detection of all unidentified magnetic anomalies and side-scan contacts recorded within a survey area will result in the avoidance, and therefore, the protection of historically significant shipwrecks. This assumes that either all parts of a shipwreck are ferromagnetic and would be recorded by the magnetometer, or that all nonferromagnetic parts of a wreck would be evident on the side-scan records. Neither is necessarily the case.

In areas with a relatively hard bottom or in areas with only a thin sediment layer, it is probable that there would be some evidence on the side-scan sonar records of any shipwreck within a survey area. However, over large portions of the OCS, particularly the central and western planning areas, the thickness of unconsolidated sediments is sufficient to conceal debris from most pre-20th century wrecks of wooden or composite construction (Clausen and Arnold 1975). According to the results of studies conducted by various marine archaeologists in their work with shipwrecks (Clausen and Arnold 1975; Watts 1980; Arnold 1982a, and Saltus 1982) at 150 m linespacing, it is possible to pass by an historically significant shipwreck with no indication on the magnetometer record.

In practice, archaeologists preparing cultural resource reports for lease block surveys consider anomalies over five nanoteslas (nT) with a period of three or more counts as a possible target. From a magnetic contour map of a 16th century Spanish shipwreck site (Figure II-53) present methodology cannot detect anomalies on more than two lines (Arnold and Clausen 1975). To illustrate this point, a 150 m grid was superimposed on the magnetic contour of the Spanish wreck as shown. The "A" pattern detects the site on only two lines with three separate anomalies that have magnetic amplitude no greater than five nanoteslas. Moving the entire survey grid to the right 50 m produces the "B" pattern, which detects three anomalies with a magnetic amplitude of 40 nT and two of five nT intensity, and is only observed on one line. The "C" pattern is achieved by moving the grid 50 m farther to the right and shows one anomaly at 30 nT amplitude with two peaks. The "D" pattern, which occurs when the grid is shifted approximately 45 degrees, detects no anomalies.

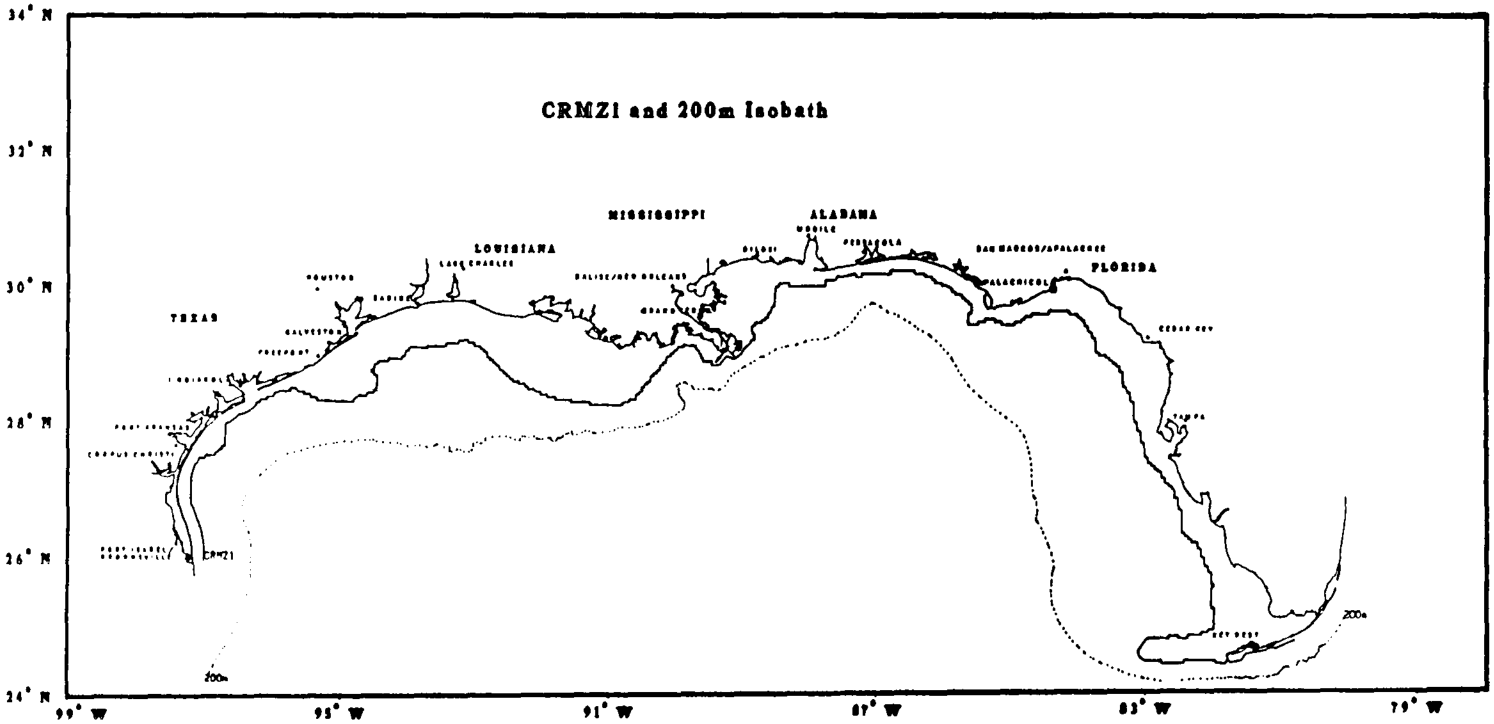


FIGURE II-51. Cultural Resource Management Zone 1 and the Outer Continental Shelf, Gulf of Mexico.

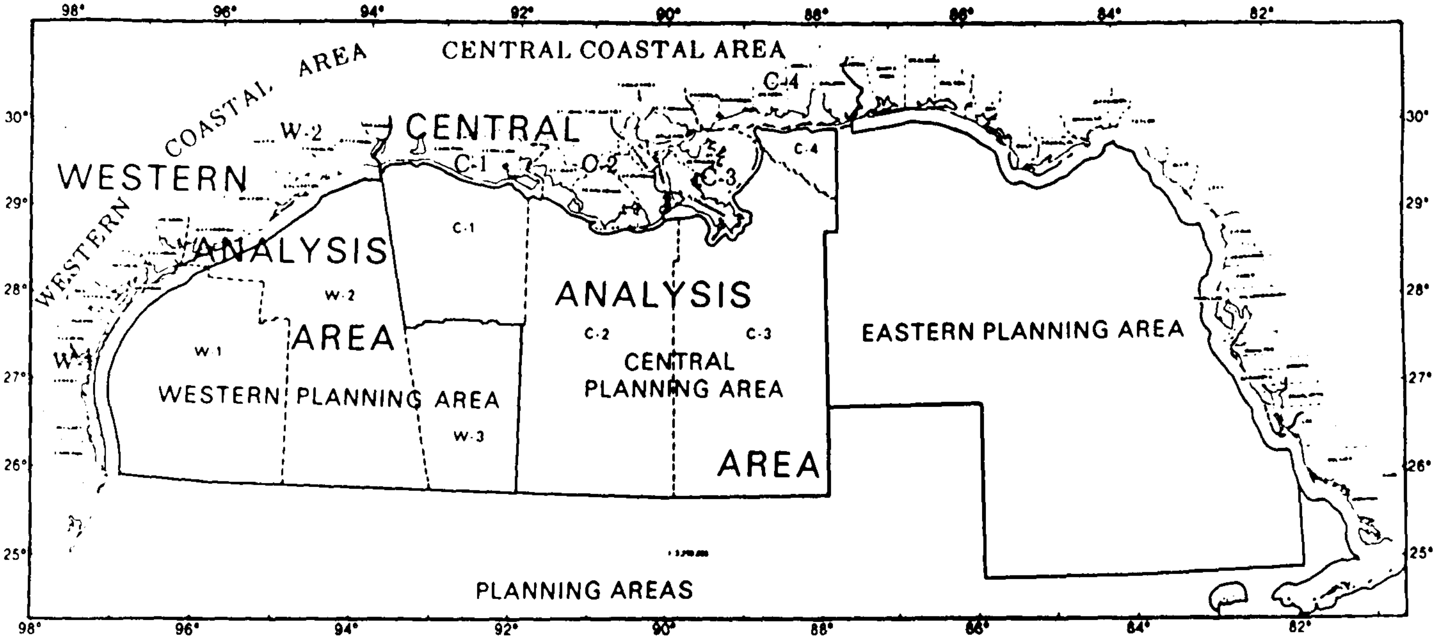


FIGURE II-52. **Northern Gulf planning areas.**

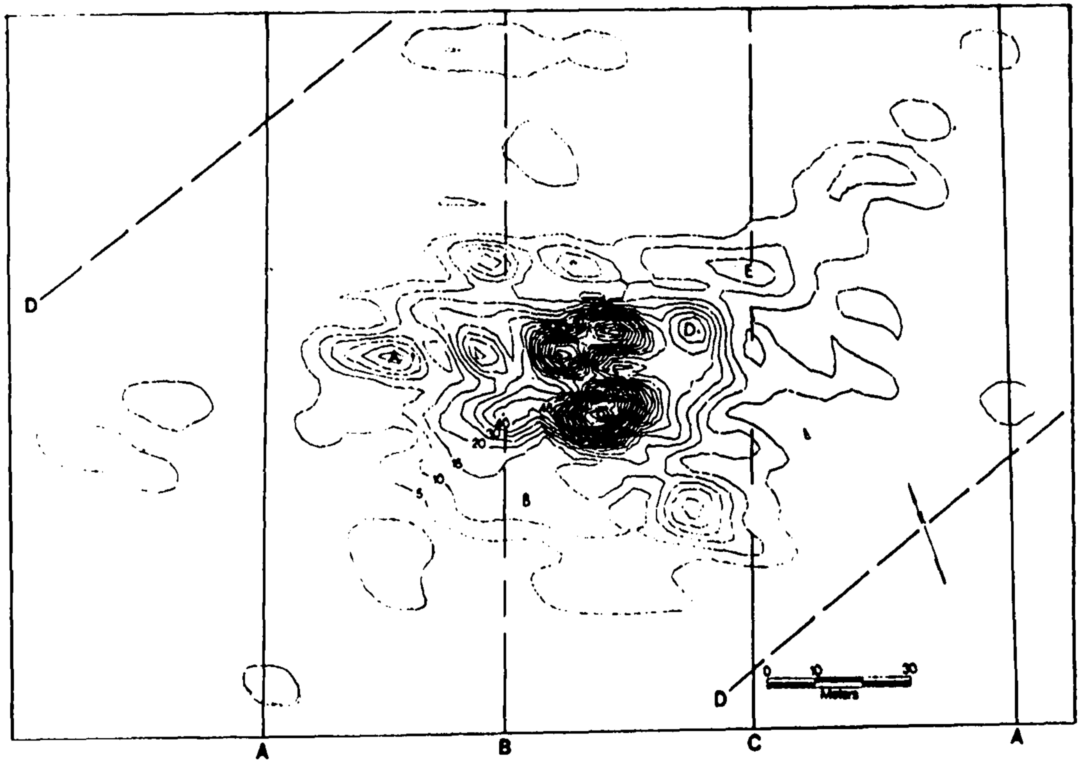


FIGURE II-53. Magnetic plot of 16th century shipwreck.

Adding to the linespacing problem are single objects lost or disposed of, such as shrimp net boards, lengths of chain, cable, pipe, steel drums, ordnance and seismic gear, which yield low amplitude anomalies. It has been observed that small, near surface faulting also produces a 5-6 nT anomaly for a period of five to seven counts. A geological phenomenon is usually observed as a small anomaly of two to five nT recorded over a long duration whereas cultural material are characterized by larger amplitude anomalies and shorter duration (CEI 1977).

After 1977, concerns about the detection and characterization of anomalies in cultural resources surveys continued to surface in the literature. Arnold (1980) compared the results of underwater remote sensing surveys done for research purposes with the results of those done for cultural resources management. He concluded that the empirical data emphasizes the inadequacy of the 150 m linespacing for the detection, much less the characterization, of anomalies. Arnold (1982) makes a strong case for the use of groundtruthing to identify and characterize anomalies.

In 1986, MMS continued the dialogue on this issue and hosted a session at the Seventh Annual Information Transfer Meeting (ITM) entitled, "Marine Archaeology: A Problematic Approach to Resolution of Unidentified magnetic Anomalies" (MMS 1986). Arnold reiterated his criticism of survey methodology based on the 150 m linespacing saying pattern recognition and anomaly characterization based on such patterning could not be reliably done using this methodology. Garrison presented his results of a study of the 19th century shipwreck (WILL O' THE WISP) using 25 m linespacing. He concluded that of three factors commonly used to characterize underwater magnetic anomalies--amplitude (intensity), signature (shape), and duration (period)--only duration was significant at over 100 m distant from an anomaly. Saltus contended that only groundtruthing could determine the cause and significance of magnetic features. Bevan suggested new instrumental approaches to the problem of anomaly characterization while Weymouth counseled the translation of the factor of time (in seconds) to distance so it could more readily be used in equations and nomograms for the estimation of the size and nature of the magnetic source. Following this tack of the simple application first principles, he urged the use of the full width, half maximum (FWHM) number for estimation of depth or distance of anomalies (MMS 1986).

The question of how best to identify anomalies centers on issues of methodology. The characterization of anomalies is inhibited by the lack of data. Current cultural resource remote sensing surveys cannot provide a level of data adequate to reasonably evaluate anomalies. Groundtruthing of anomalies is viewed as a logical and common step in most remote sensing. It has been wholly lacking in cultural resource remote sensing surveys carried out on the Gulf of Mexico OCS due to a policy of avoidance adopted by industry.

11.1 Objectives

As a result of MMS required lease block remote sensing surveys, numerous unidentified magnetic anomalies and side-scan sonar contacts which could represent historic shipwrecks have been recorded in the Gulf of Mexico OCS. These Gulf of Mexico surveys have also recorded numerous examples of relict late Wisconsin landforms (fluvial channels with evidence of terraces and point bars, bays, lagoons, barrier islands, natural levee ridges, salt diapirs, and sinkholes) which have a high probability for associated prehistoric sites to occur.

Avoidance or further investigation of archaeologically sensitive areas is usually required prior to approval of lease permits; however, because industry has generally chosen avoidance rather than further investigation of these areas, little to no data have been collected which would help in building an interpretive framework for the evaluation of unidentified magnetic anomalies and side-scan sonar contacts, or in evaluating the predictive model for prehistoric site occurrence.

Based on Task I, we have indicated areas on the GOM OCS that have high, moderate, and low probabilities for the occurrence of historic shipwrecks. Task II of this study was designed to establish an interpretive framework to characterize unidentified magnetic anomalies and side-scan sonar contacts within the CRMZ1. It has the following two efforts: (1) Information collection; and 2) information analysis and synthesis. Two previously surveyed lease blocks (one that was not subsequently developed, and one that has been developed) were resurveyed for magnetometer and side-scan sonar data with survey linespacing at 50 m, and navigation system accuracy at ±5 m. These data and the data from the original lease block survey were analyzed to determine the following:

1. The percentage of anomalies recorded during the survey at 50 and 100 m linespacings that was recorded during the original lease block survey at a 150 m linespacing;
2. The correlation in anomaly locations, amplitude, duration, and signature (dipolar/monopolar) between the original and new surveys; and
3. The number of new magnetic anomalies and/or side-scan contacts that were recorded within the developed lease block, and the location of these anomalies relative to oil and gas structures.

Sites within lease blocks were selected for groundtruthing and signature characterization of unidentified magnetic anomalies without associated side-scan sonar contacts, unidentified side-scan sonar contacts without associated magnetic anomalies, and unidentified magnetic anomalies with associated side-scan sonar contacts. Anomalies were chosen from the resurvey sites as discussed above.

Groundtruthing and signature characterization included the following:

1. Relocating the anomaly or contact and collecting magnetometer and/or side-scan sonar data at a linespacing of 50 m or less.
2. Constructing a three-dimensional magnetic contour map of the unidentified magnetic anomalies, and magnetic anomalies with associated side-scan sonar contacts.
3. Identifying the source of the anomalous contact through diver inspection, using a hand held magnetometer.
4. Photographing any marine debris and historic shipwrecks where observable at the seafloor.

The results of the resurvey and groundtruth efforts include:

1. Post-plot maps that show the track of the survey vessel and navigational fix points at a 1:1200 scale and compare the findings of the original lease block survey with the resurvey data.
2. Contour maps with a two gamma contour spacing of each magnetic anomaly that was investigated, and a catalogue of magnetic signatures for each object.
   (a) The survey and groundtruthing methods, and the instrumentation used is described and survey and diving findings are discussed.
   (b) All the data collected during the field surveys were analyzed to determine the relationship between survey linespacing and anomaly detection, the influence of oil and gas structures on magnetic anomaly distribution and to characterize the changes at different distances and orientations to the magnetic sensors. The goal of the pattern recognition analysis of magnetic and side-scan sonar signatures is to develop a method that differentiates resources, and that can be used by MMS cultural resource analysts in the cultural resource survey review process.

12.0 METHODS

12.1 Data Collection - Resurveys of Lease Blocks

12.1.1 Selection Criteria

A search of MMS files was conducted to determine candidate blocks for the Task II study. Criteria used in our selection included:

1. Block within Cultural Resource Management Zone 1;
2. High data quality;
3. Block development (yes or no);
4. Sensor tow depth known or could be determined; and
5. Freeport/Galveston area location.

The list of potential blocks were examined using these criteria are seen in Table II-23. Item 5 was considered from a logistical standpoint because this location allowed access to large portions of the Texas aspect of CRMZ 1. Consideration was given to using study blocks off western Louisiana as the study team was equally familiar with these waters having carried out oceanographic studies in the Cameron area for over four years (Gittings, et. al. 1982; DeRouen, et.al. 1982, 1983; Hann, et. al.1984).

An additional factor in the selection of the area was the available information concerning known shipwrecks in those areas. The Texas data was more extensive than for any other state. Further, hydrocarbon exploration and development has been extensive on the OCS off Galveston. A final factor in the selection of blocks to be resurveyed was water depth. While it is possible to work near the edge of the OCS with SCUBA: (a) the CRMZ 1 typically does not extend this far; and (b) the more time the divers can reasonably spend at a depth without exceeding decompression limits provided a key safety factor for groundtruthing activities.

With these criteria in mind, three blocks were selected for resurvey from the Galveston Lease Area--GA 324, GA 313, and GA 332 (Figures II-54 and II-55).

12.1.2 Sampling Considerations

Obtaining a valid sample from 4000 potential lease blocks within CRMZ 1 exceeded the economic limits of this study. Recognizing this, we attempted to maximize our sampling of variability within a sample population of three blocks. We selected to resurvey two halves (GA 324 and GA 332) of the undeveloped block and one whole developed block. The use of a half block approach in GA 332 was to maximize comparability between the original survey and our resurvey of it.

12.1.3 Analysis of Resurvey Data - Objectives

These resurvey data and the data from the original lease block survey were analyzed to determine the following:

a. The percentage of anomalies recorded during the survey at 50 and 100 m linespacings that was recorded during the original lease block survey at a 150 m linespacing;
b. The correlation in anomaly locations, amplitude, duration, and signature between the original and new surveys; and
c. The number of new magnetic anomalies and/or side-scan contacts that were recorded within the developed lease block, and the location of these anomalies relative to oil and gas structures.

Table II-23.

LIST OF POTENTIAL LEASE BLOCKS FOR TASK II STUDY[3].

Developed Blocks & Lease

GAL 385 (#8132)
GAL 210 (#7236)
BR 397 (#6060)
BR A-50 (#7229)
GAL 361 (#6111)
BR 494 (#6071)
GAL 345 (#6107)
GAL 313 (#6098)
GAL 300 (#6097)
BR 550 (#6080)
GAL 271 (#6096)
BR 608 (#6083)
GAL 211 (#6094)
N PADRE 969 (#5953)
N PADRE 976 (#5954)
MAT 673 (#8104)

Undeveloped Blocks & Lease #

GAL 379 (#8129)
GAL 380 (#8130)
BR A-27 (#8121)
GAL 386 (#8133)
GAL 359 (#8551)
GAL 346 (#7248)
GAL 347 (#7249)
MAT 688 (#8548)
GAL 191-F (#7235)
BR 476 (#6066)
BR 491 (#6069)
GAL 332 (#6103)
GAL 344 (#6106)
BR 512 (#6075)
BR 534 (#6077)
BR 615 (#6084)
BR A-67 (#7232)
GAL 347 (#7249)
GAL A-99 (#7258)
MAT 680 (#8547)
GAL 460 (#8134)
GAL A-74 (#8137)
GAL 324 (#8127)

TOTAL = 39

The following list of potential lease blocks were selected for further study from which to determine the sample to be surveyed with the 50-meter line spacing methodology:

Developed Blocks & Lease #

GAL 313 (#6098)
GAL 271 (#6096) (partial block)
GAL 210 (#7236)
GAL 385 (#8132) (partial block)
GAL 211 (# 6094) (partial block)

Undeveloped Blocks & Lease #

GAL 460 (#8134)
GAL 191-F (#7235) (partial block)
GAL 359 (#8551) (partial block)
GAL 386 (#8133)
GAL 346 (#7248) (partial block)
GAL 347 (#7249) (partial block)
GAL 324 (#8127)
GAL 332 (#6103) (partial block)

TOTAL = 13

[3] Source: MMS Lease Edit/Update Program

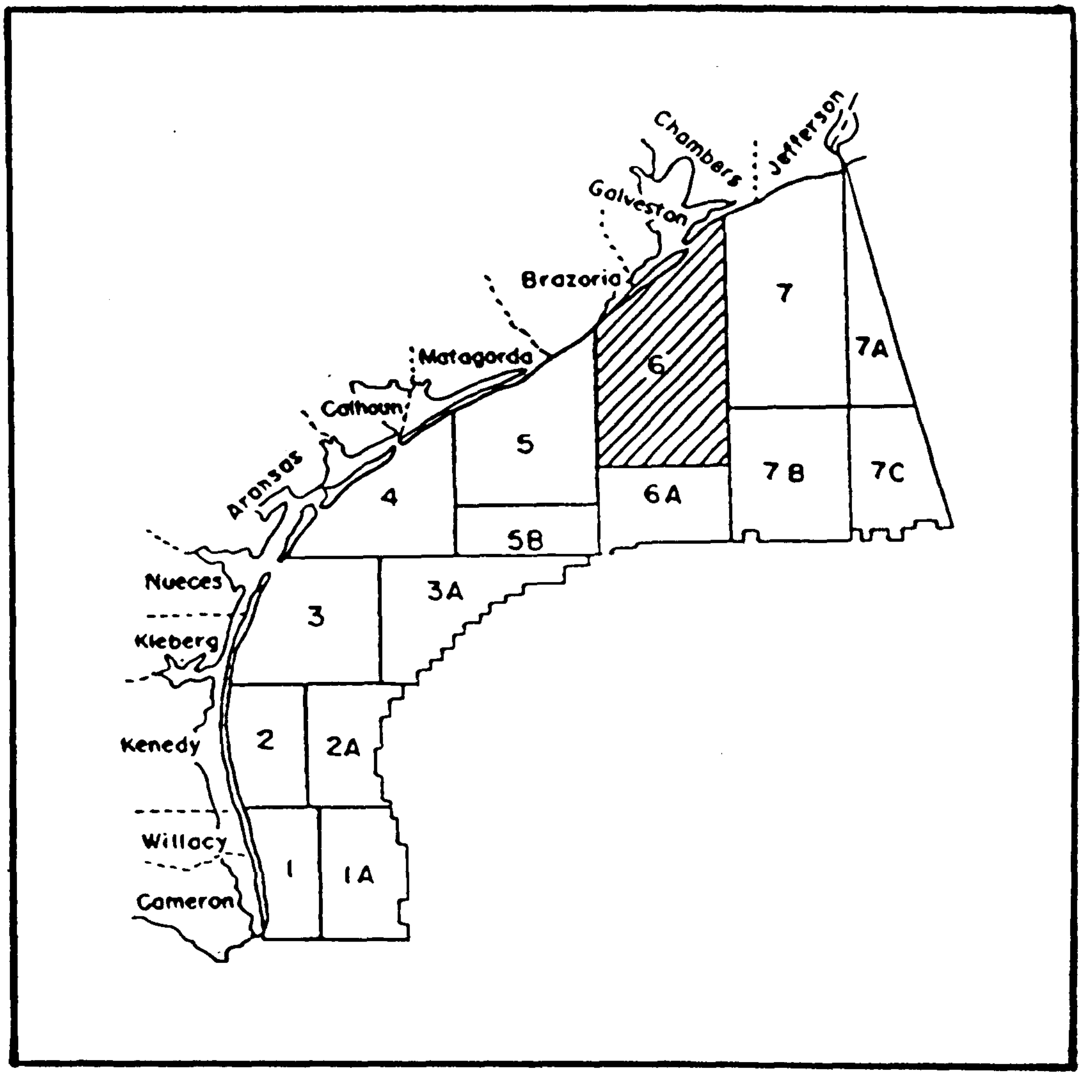


FIGURE II-54. Galveston lease area.

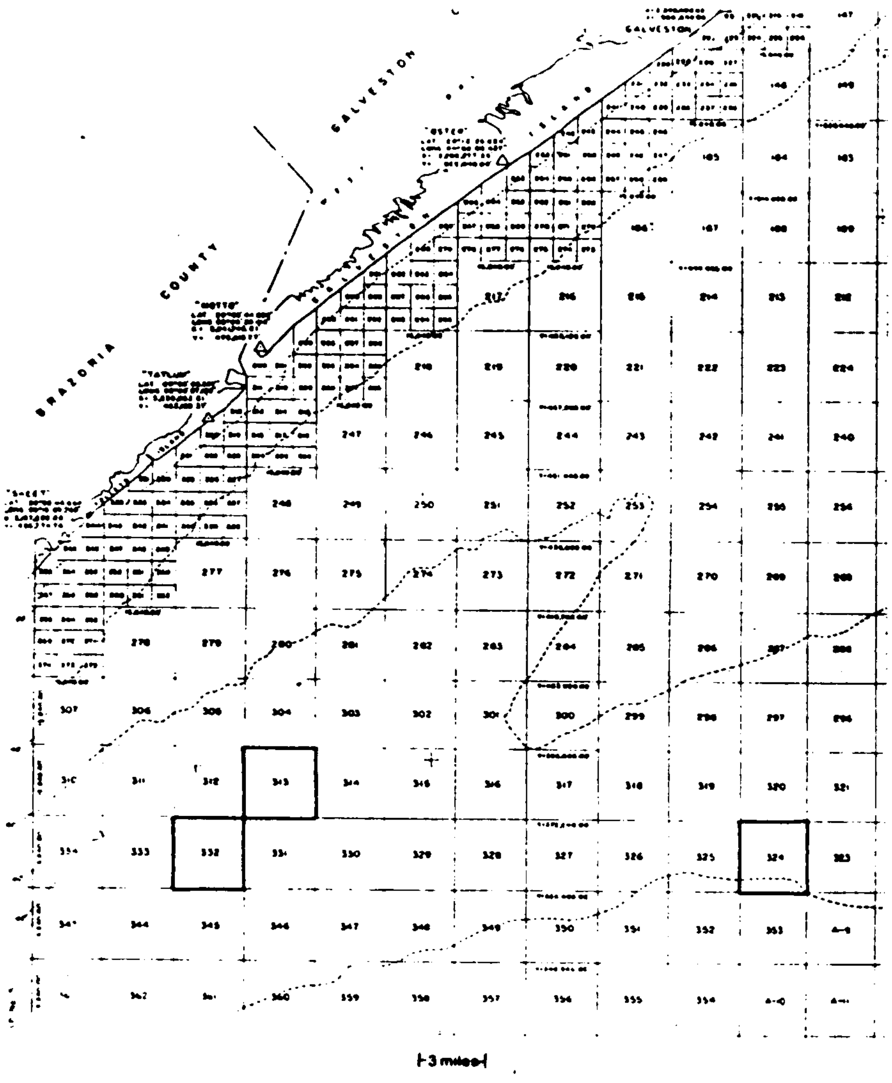


FIGURE II-55. Study blocks - Galveston area.

These analytical steps were defined by MMS in order to determine the relationship between linespacing of a magnetometer and side-scan sonar and the detection of objects at or below the sea floor. Further, the magnetometer data were subjected to various digital filtering, spectral analysis techniques, and algorithms useful in digital signal processing. The intent of this processing was to examine more clearly magnetometer parameters such as amplitude, duration and signature shape.

12.2 Data Collection - Groundtruthing Studies

12.2.1 Sample Size Consideration in Groundtruthing Studies

A sufficiently large population of anomalies was selected so that pattern recognition and associated statistical analyses could be performed. A sample size from the three classes: (1) unidentified magnetic anomalies without side-scan sonar contacts; (2) unidentified side-scan sonar contacts without associated magnetic anomalies; and (3) unidentified magnetic anomalies with side-scan sonar contacts was selected using standard statistical methods. Each class was split into cultural resource or recent debris (i.e., p or q). It is difficult to justify an exact number for the sample size in this study. Laserwitz (1968), uses the fact that the numerator in the formula for the variance of a sample proportion reaches its maximum value when the proportion is 0.5, when p and q are not known. A conservative estimate for sample size is simply

$$n = 1/k^2$$

Where k is the desired interval about 0.5 at the 95 percent confidence level.

This interval is an estimate of precision such that the confidence limits vary by a fixed percent about the value 0.5. Taylor (1961) set confidence limits and precision to estimate the sample size by similar methods (Craddock 1969).

Using Lazerwitz's method and requiring a precision of 0.1 (i.e. a limit of ±20 percent about p), our n = 100; using a value of 0.2 we obtained a sample size of 25. In terms of confidence limits, assuming a normally distributed population, such a small sample is less reliable than a value calculated from a larger sample. Because the sample size is small the use of the t-distribution is necessary to set confidence limits. Here the degrees of freedom, n-1, are such that the sample mean may differ more than 2 degrees from that of the population selected. Still the value of our mean will be a standard deviation approaching ± 40 percent. This number then is primarily justified in terms of utilizing available study time and funds. In the actual study, 27 sites were examined during groundtruthing cruises.

12.2.2 Groundtruthing Procedures - Characterization Objectives

Groundtruthing and signature characterization included the following:

1. Relocating the anomaly or contact and collecting magnetometer and/or side-scan sonar data at a linespacing of 50 m or less;
2. Constructing a SYNVIEW magnetic contour map and magnetic profile map of the unidentified magnetic anomalies, and magnetic anomalies with associated side-scan sonar contacts;

3. Identifying the source of the anomalous contact through diver inspection, using hand held magnetometer and/or metal detectors and sediment probing devices as necessary; and
4. Photographing any marine debris and historic shipwrecks where observable at the sea floor.

The objective of this procedure was to compile a sample inventory that would reflect a real population of shipwrecks or modern debris in the survey areas and, to a large degree, the Gulf of Mexico.

13.0 FIELD STUDIES

13.1 Resurvey - Lease Blocks

13.1.1 GA 324 - Location and Description

Galveston area lease block 324 is 46 km east-southeast of Surfside, Texas (Figures II-54 and II-55), in water depths of 22 to 25 m. The sea floor slopes evenly southward at a mean gradient of 1:2,000 (0.03) in the northwest quadrant changing to a southwest-southward slope around the toe of Heald Bank with a gradient of 1:3,000 (0.02) (Figure II-56). The sea floor is smooth and featureless with some small scale local relief in the southwest corner. Bottom sediments consist of Colorado and Brazos River lower delta slope and prodelta mud transitional eastward to sandier Heald Bank deposits (Curray 1960; CEI 1977). The original geophysical and archaeological assessment was done in 1985 by Gardline Surveys, Inc. for Kerr-McGee Corporation.

13.1.2 GA 313 - Location and Description

Galveston area lease block 313 is 22.5 km south-southeast of Surfside, Texas, in water depths of 20 to 21 m. The sea floor slopes in the southwest corner at a gradient of 1:3,000 (Figures II-55 and II-56). The sea floor is smooth and featureless with no relief. The bottom sediments are silty sand overlying clay deposits. The Pleistocene horizon (Beaumont Clay Formation) is believed to be between 21 to 24 m below the present sea floor (McClelland Engineers 1979). The original geophysical and archaeological assessment work was done in 1984 by John E. Chance and Associates, Inc. for Superior Oil Company.

13.1.3 GA 332 - Location and Description

Galveston area lease block 332 is 24 km south of Surfside, Texas (Figures II-55 and II-56), in water depths of 20 to 27 m. The sea floor is smooth and featureless. The sea floor slope is less than 1:3,000. Bottom sediments are unconsolidated sandy silts. These overlie deeper (21 m) Pleistocene clays (McClelland Engineers 1979). The original geophysical and archaeological assessment was done in 1983 by John E. Chance and Associates, Inc. for Shell Offshore, Inc.

13.1.4 Instrumentation and Techniques of Resurvey

13.1.4.1 Magnetometer

The instrument used in the resurveys was a Geometrics G-866 proton precision magnetometer. Three different cable lengths were utilized--76 m, 106 m, and 182 m as required by survey conditions. The G-866 has a BCD character serial output which was interfaced with a microcomputer for digital logging of all data. The resolution was typically 0.2 nT at 1.5 sec sample intervals.

This sample interval was necessitated by firmware parameters of the PROMs used by Geometrics on this model. A factory modification allowed shorter intervals to be used but these were not utilized until groundtruthing surveys.

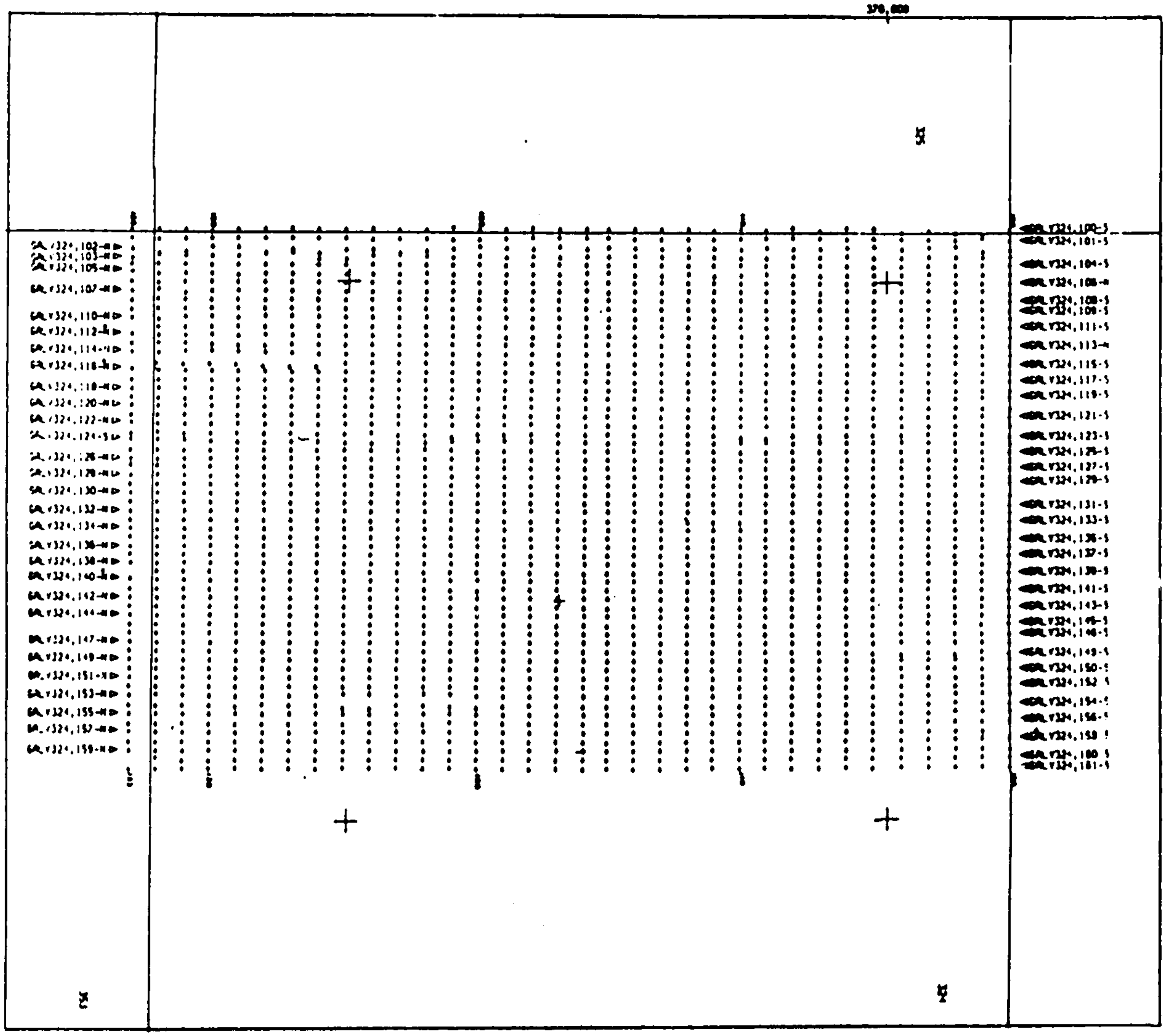


FIGURE II-56. Block GA 324 cruise tracks.

Typical Settings:
Sample Interval: 1.5 sec
Scale: 100/1,000 nT
Averaging: 0 to 3 point
Event Mark: 150 m

13.1.4.2 Side-scan Sonar

Two different instruments were used in separate resurveys. The EG&G Mark 1B system consisting of a model 259-4 recorder and model 259, 100 kHz tow vehicle was used in the resurvey of Galveston Area block 324 (GA 324). For the resurvey of blocks GA 313 and GA 332, a digital model, the EG&G 260 side-scan sonar became available. This later instrument allowed faster more efficient survey due to its microprocessor controlled processing of that corrected for slant range and vessel speed. By comparison, to avoid excessive distortion in the noncorrected images taken with the Mark 1B, we towed at 4-4.5 knots. The Model 260 could be towed at 8 knots but typically averaged 5 knots.

All data were recorded on analog chart paper. Both instruments were interfaced to the navigation system for correlation of all timing fixes. Settings used were as follows:

EG&G Mark 1 B
Range: 50 m
Frequency: 100 kHz
Event Mark: 20 sec

EG&G Model 260
Range: 75 m
Frequency: 100 or 500 kHz
Event Mark: 20 sec

13.1.4.3 Depth Sensor

The instrument used to constantly monitor the tow depth of the magnetometer sensor was a Teledyne Model 28951. The depth sensor was mounted on the cable ahead of the magnetometer sensor and the output depth read on a digital display. The update rate was 1.0 second and the accuracy was 0.3 m depth.

13.1.4.4 Depth Sounder

A Si-Tex depth recorder printer was operated with a 200 kHz hull mount transducer for maximum detail in the shallow water depths typical of the blocks chosen for resurvey. The instrument was adequate for high resolution bathymetry of the rather featureless sea floor in the three blocks. Combined with the side-scan sonar it enhanced our ability to relocate underwater contacts.

13.1.4.5 Navigation Systems - Medium and Short-range Systems

STARFIX - This satellite system was utilized in the resurvey of GA 324 due to the need for a precision navigation system with medium range (80 km) capability. This system operates in the microwave frequency band of four to six GHz (gigahertz). Accuracies are within 5 m of a position.

Navigation was accomplished by use of a Hewlett Packard Model 1000 minicomputer which converted range data from the STARFIX receiver into latitude and longitude coordinates. These in turn were used to steer preset course lines of desired lengths and offsets. Figure II-6 illustrates the precision in course lines using this system.

Del Norte Trisponder - This system is classified as short range (≤80 km) and was used in the resurvey of GA 313 and GA 332. The system operates at 9.3 GHz and has an accuracy of 1-3 m of a position.

Navigation was accomplished using internal firmware steering and conversion programs of the Del Norte Model 542 distance measuring unit (DMU). The positional data was output from a serial port on the DMU to an interface with a Hewlett Packard Model 97 microcomputer using software which logged this data and simultaneous magnetometer readings to diskettes. Figure II-56 illustrates the course lines steered with this system.

13.1.5 Techniques of Resurvey

Utilizing the methodology required by the scope of services, the resurveys were conducted using 50 m offsets of survey lines in each of the three blocks chosen for restudy. Preplot navigation charts were prepared for each block as shown in the example for GA 313 and GA 332 (Figure II-57). These preplots were used in resurvey navigational programs.

In GA 324, 61 lines were resurveyed; GA 313, 102 lines were resurveyed; and GA 332 55 lines were resurveyed (Figures II-58 and II-59). This represents over half of GA 324, one-half of GA 332, and all of GA 313 for a total of two complete blocks resurveyed.

The control points established and used for the resurvey of GA 313 and GA 332 are shown in Table II-24. These were established by Dr. Robert Bruner of the survey division, Department of Civil Engineering, Texas A&M University. For GA 324 the resurvey utilized the STARFIX system so no controls were necessary other than those maintained by STARFIX to calibrate their satellite constellation.

As described in this section, all survey instrumentation and procedures comply with MMS Notice to Leasees 75-3 (NTL 75-3), Revision Number 1 with the exception that the survey linespacing was 50 m and navigation accuracy was 5 m of position. Typically, most surveys done under NTL 75-3 guidelines utilize such precision in navigation but do not exceed the 150 m in linespacing required by that directive. Specific techniques used in each block are described below.

13.1.5.1 GA 324

a. Magnetometer - A weighted, 76 m tow cable and sensor array was deployed astern of the R/V EXCELLENCE II. This vessel is 20 m in length so the minimum distance for the sensor was never closer than 58 m to the vessel. This follows the general rule of thumb for towing distance of not less than twice the ship's length (Milne 1980).

b. Side-scan sonar - The 100 kHz EG&G Mark 1B towfish was deployed just astern of the survey vessel (12 m). Range was set at 50 providing 25 overlap for adjacent survey lines.

13.1.5.2 GA 313 and GA 332

a. Magnetometer - A 106 m tow cable and sensor was deployed in the resurvey of these blocks. The length allowed the reduction of depresser weight on the cable used with the 72 m cable.

b. Side-scan sonar - The 100/500 kHz EG&G 260 side-scan sonar was used in the standard configuration astern the vessel during survey but used in what is termed a "bow deployment" during anomaly relocations. The dual frequency vehicle was towed directly under the vessel. This allowed the simultaneous correlation of sonar contact and geographic position as the tow fish was at the same point as the navigation system's antenna.

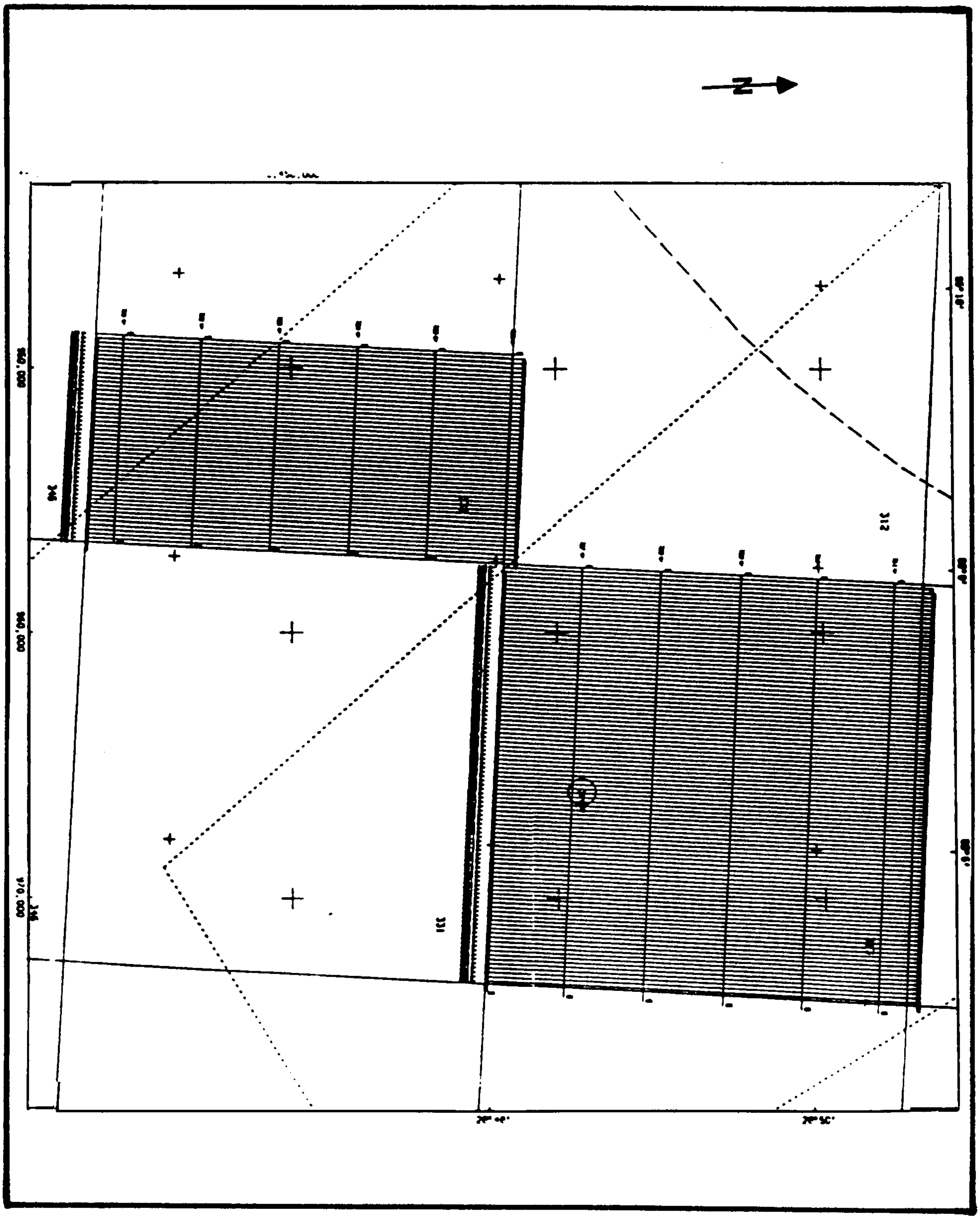


FIGURE II-57. Preplotted cruise tracks, GA 313 and GA 332.

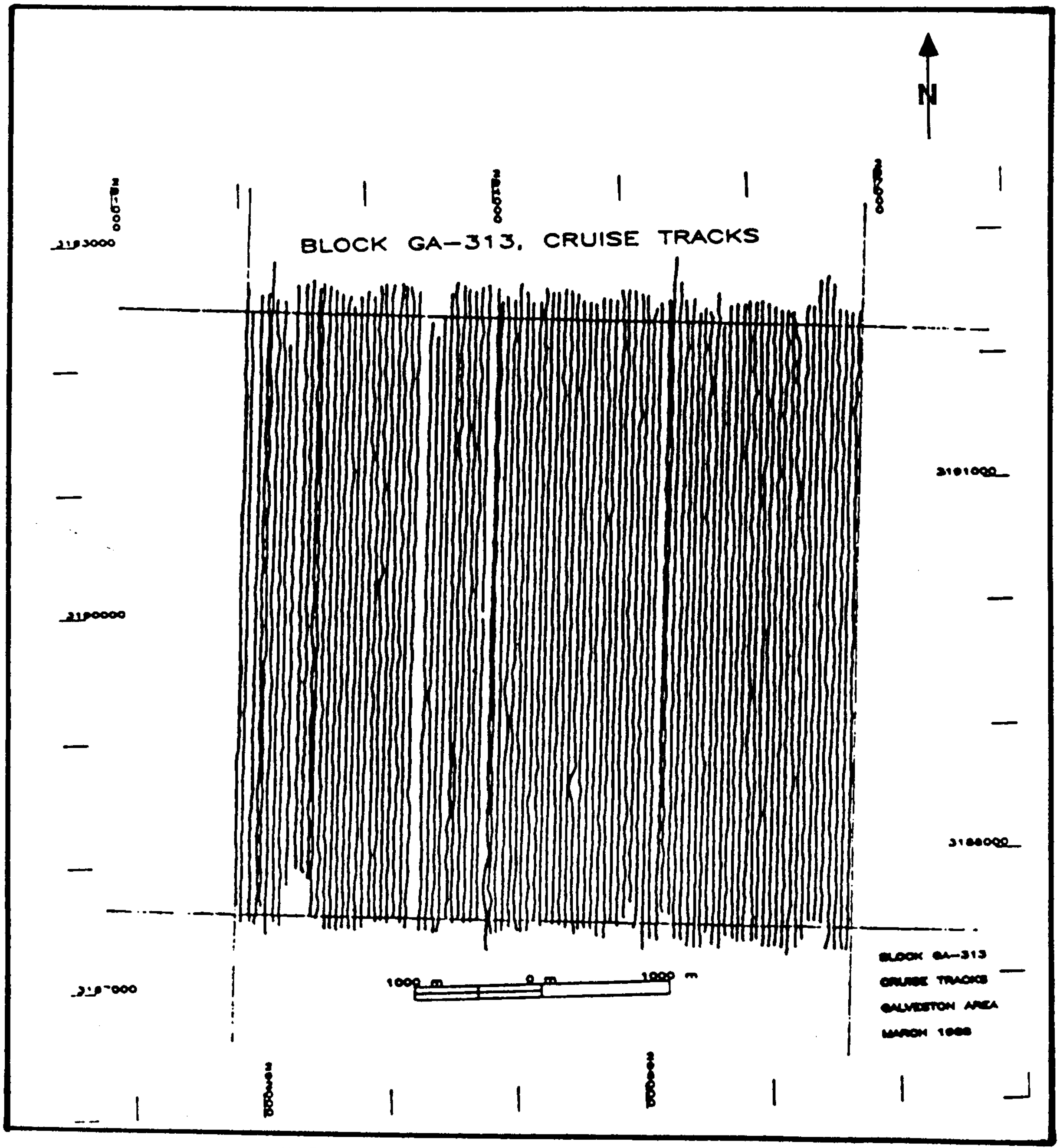


FIGURE II-58. Block GA 313 cruise tracks.

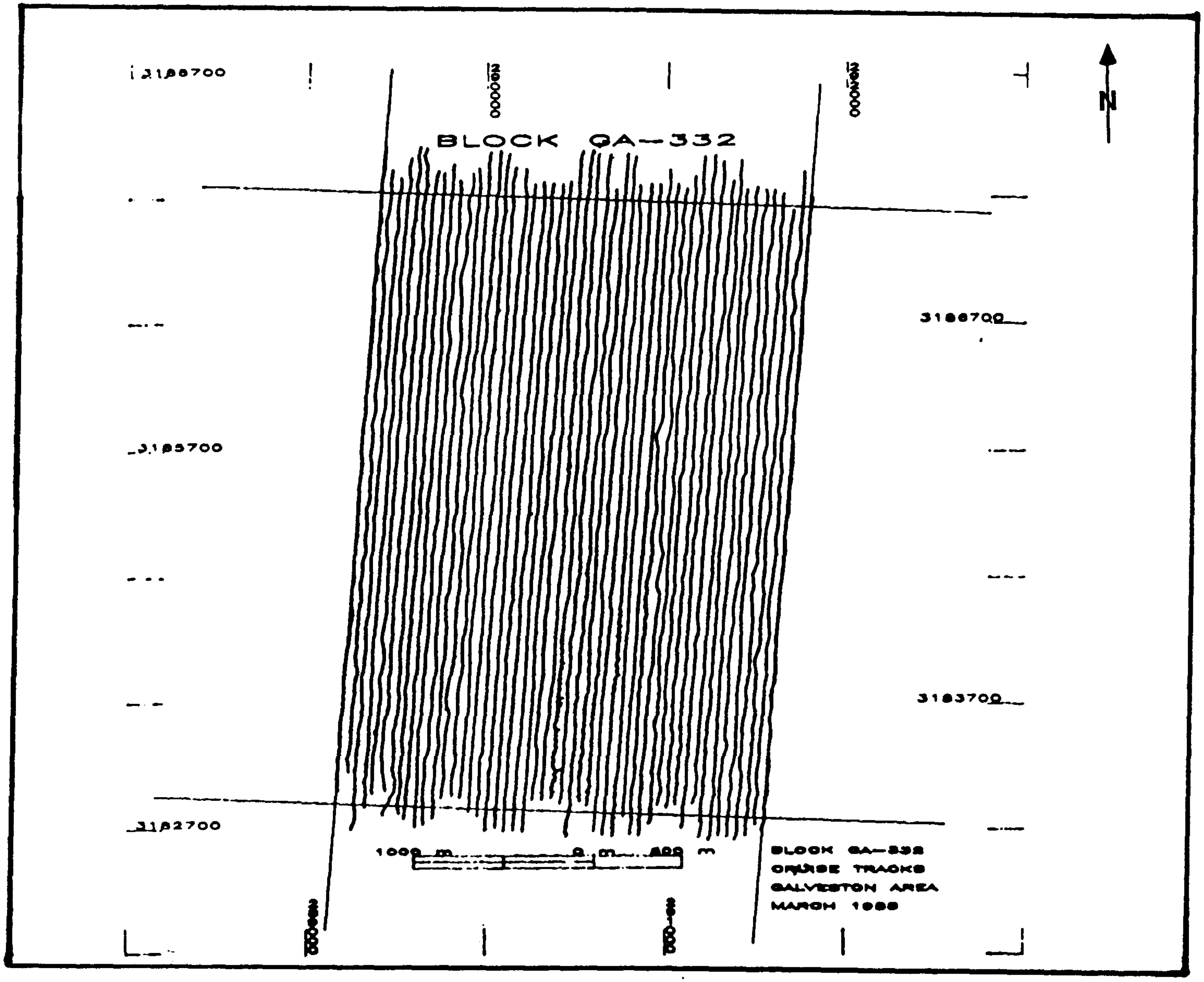


FIGURE II-59. Block GA 332 cruise tracks.

Table II-24.

SUMMARY OF GEOGRAPHIC CONTROL DATA.

a. CONTROL POINTS USED FOR RESURVEY OF BLOCKS 313 & 332

Station	Location	Geographic Coordinates	UTM Coordinates (meters) x=E	UTM Coordinates (meters) y=N	State Plane Coordinates (feet) x=E	State Plane Coordinates (feet) y=N
TR 724	SFX 310L	ø = 28°50' 26.143" x = 95°14' 22.683"	281491.71	3192210.59	3203652.5	385586.3
TR 764	LORAC	ø = 28°58' 22.395" x = 95°15' 58.692"	279169.52	3206922.22	3193583.6	433386.5
TR 744	COAST G.	ø = 28°56' 27.407" x = 95°18' 02.962"	275736.09	3203447.04	3182919.4	421428.6
E TOWER	LORAC	ø = 28°58' 22.401" x = 95°15' 58.704"	279169.19	3206922.41	3193582.5	433387.1
C.E. FH2	COAST G.	ø = 28°56' 28.016"	275622.16	3203467.23	3182673.87	421482.36

b. LOCATIONS ENTERED FOR THE MICROWAVE REMOTES

Remote	Easting	Northing	
724	281491.7	3192210.6	(meters)
744	275736.1	3203447.0	
764	279169.5	3206922.2	

c. CALIBRATION FACTORS ENTERED FOR EACH REMOTE

Remote	Calibration Factors	Height Meters	Reference-x Reference-y
724	755	5	281491.7 192210.6
744	800	5	275736.1 203447.0
764	800	13	279169.5 206922.2

13.2 Groundtruthing Activities

13.2.1 Techniques of Relocation and Recording

13.2.1.1 GA 324

The instrumentation utilized in the resurvey of this lease block was redeployed for relocation and groundtruthing with the exception of the side-scan sonar. This latter instrumentation was not used because none of the sites selected for groundtruthing were side-scan sonar contacts or contacts associated with magnetic anomalies.

The position of the site was relocated and a marker buoy dropped. Typically, the position marker was deployed after the location was refined instrumentally. The anomaly sites selected for groundtruthing in GA 324 were difficult to relocate instrumentally so the position determined from the lease block resurvey was relied on for deployment of the marker buoy.

Navigation and magnetic data were acquired on three transects of the site. One line was run directly over the location with two offsets of 15 to either side of the feature. Once logged, all tow cables were recovered and divers deployed.

Divers established a temporary datum at the marker buoy anchor. From this station, an area of over 50 m diameter was examined by swimming a circular search pattern increasing the diameter with each complete rotation. Typically, an increment of 3-5 m was used as visibility at the bottom rarely met or exceeded this limit. Divers used the underwater metal detector during the circle search.

Any source for an anomaly or side-scan sonar contact was located, measured, and video documented if visibility conditions allowed. Divers used standard surveyor tapes or pre-measured lines to gauge their progress. For video work, a JVC portable VCR, VHS-C format was used. Video was selected routinely over still photographic techniques because of poor visibility due to the nephloid layer so prevalent in this part of the Gulf (McGrail and Carnes 1983).

13.2.1.2 GA 313 and GA 332

Most of the Task II groundtruthing activity took place in these blocks. In these blocks the side-scan sonar was utilized extensively.

As with GA 324, the site chosen to be groundtruthed was relocated using the same navigation system used for resurvey. A marker buoy was dropped after data for signature characterization analyses was taken. In some instances, data was taken and the site not examined by divers. Such a decision was made after analysis of the instrumental data. Typically, only magnetic anomalies were the subject of such re-examination. The reason for this was an economic one--only about 20 sites could be effectively examined in the field study period so only sites with a reasonable chance of being identified by divers were groundtruthed. By experience, we found that anomalies without an associated side-scan sonar contact were buried and had a less than 30 percent chance of identification by divers. Once the divers were deployed, the techniques used were similar to those used at GA 324.

13.3 Results and Resurveys

13.3.1 Anomaly Comparisons - Original Survey and Resurvey Results

13.3.1.1 GA 313 Results

The resurvey of GA 313 provided comparative data for the category of a developed lease block. Completely resurveyed, a total of 70 lines (exclusive of 27 lines) at the 50 linespacing interval produced 85 magnetic anomalies, compared to the original survey result of 17 anomalies. (Table II-25) (Figure II-60a). This number is conservative due to the reduction of our sample from 97 to 70 due to excessive noise or other problems (such as complete loss of one line due to a formatting error on a diskette). Inspection of Table II-25 shows the spatial relationship of "bad" or noisy lines to those used in our analyses. In one instance lines 178 and 179 the linespacing is reduced to 150 m and only in one other case, lines 186-189, does the elimination of data leave a gap of 200 m between contiguous lines. This leaves nearly 75 percent of the block surveyed at the 50 m interval and nearly 90 percent at the 100 m interval. Similarly, the 100 linespacing produced 65 magnetic anomalies. An interesting result is the increase in anomalies seen for the 50 m linespacing interval data of the resurvey (59) as compared to the original survey (17). This was assumed to relate to oil and gas development in GA 313 since the original survey.

Table II-25.

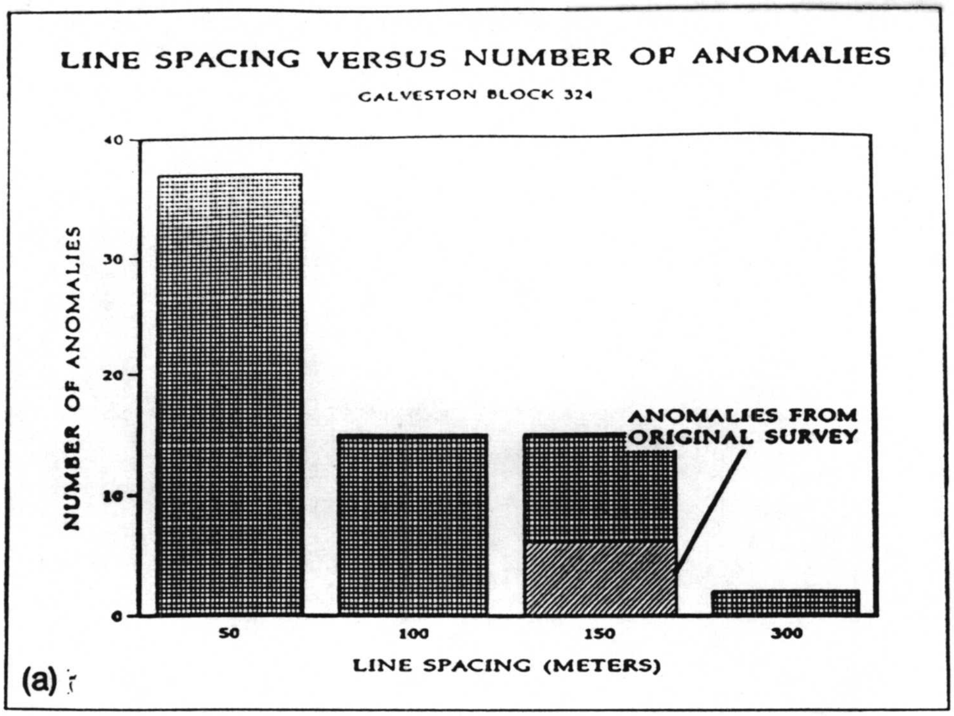
GA 313: PERCENTAGE OF ANOMALIES AT VARIOUS LINE SPACINGS; 50 AND 100 METERS.

Line	50 Meters	100 meters
148	2	-
149	-	-
150	1	-
151	0	0
152	2	-
153	-	-
154	0	-
155	0	0
156	4	-
157	2	2
158	0	-
159	0	0
160	1	-
161	1	1
162	1	-
163	0	0
164	3	-
165	5	5
166	1	-
167	3	3
168	3	-
169	0	0
170	-	-
171	4	4
172	3	-
173	-	-
174	3	-
175	5	5
176	2	-
177	0	0
178	-	-
179	-	-
180	4	-
181	4	4
182	-	-
183	1	1
184	3	-
185	3	3
186	-	-
187	-	-
188	-	-
189	2	2
190	2	-
191	2	2
192	0	-
193	0	0
194	1	-

Table II-25
(continued).

195	-	-
196	2	-
197	5	5
198	4	-
199	6	6
200	7	-
201	4	4
202	1	-
203	5	5
204	-	-
205	3	3
206	-	-
207	-	-
208	-	-
209	2	2
210	0	-
211	-	-
212	-	-
213	-	-
214	-	-
215	4	4
216	-	-
217	-	-
218	-	-
219	3	3
220	3	-
221	1	1
222	4	-
223	4	4
224	-	-
225	-	-
226	-	-
227	4	4
228	5	-
229	1	1
230	1	-
231	2	2
232	2	-
233	2	2
234	2	-
235	3	3
236	1	-
237	1	1
238	2	-
239	1	1
240	-	-
241	3	3
242	2	-
243	1	1
244	-	-

Σn @ 50 meters: 116 minus 31 duplications = 85 anomalies
Σn @ 100 meters: 85 minus 20 duplications = 65 anomalies
Original Survey n=17



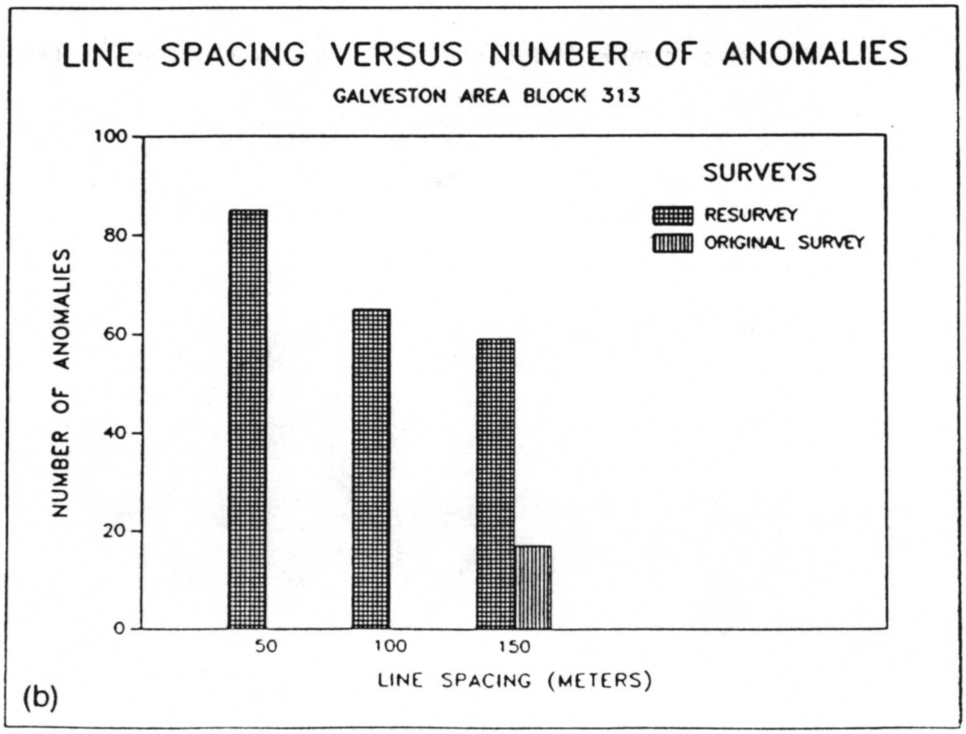


FIGURE II-60. (a) Linespacing versus number of anomalies, GA 324
(b) Linespacing versus number of anomalies, GA 313

13.3.1.2 GA 324 results

The resurvey of GA 324 provided much of the data for the undeveloped lease block. Of the 61 survey lines, a total of 40 were used for this analysis. Lines 100-109 and 151-161 were of marginal quality because of a high signal-noise ratio. All lines left in the sample were contiguous and allowed a complete evaluation of one-half the block at the required linespacings. The data utilized were high quality and represented a coverage area of the original survey where six of the eight original anomalies were found.

Thirty-nine (39) anomalies were detected during resurvey at the 50 linespacing interval (Table II-26) (Figure II-60b). Twenty-three (23) were located at the 100 linespacing interval. No anomalies were detected on adjacent survey lines.

13.3.1.3 GA 332 results

This undeveloped block was originally surveyed along diagonal tracks that covered only that portion outside the active shipping fairway. Resurvey covered that portion within the fairway along north-south survey tracks (Figure II-57). Intercomparison suffers somewhat although no anomalies were detected in the original survey. Resurvey covered about 25 percent of the original survey tracks in the southwest portion of the block.

Resurvey of the eastern half of GA 332 detected 57 anomalies at a 50 linespacing interval and 36 at a 100 m linespacing interval (Table II-27). Most of this area is an active shipping fairway.

13.3.2 Correlation of anomaly locations, amplitude, duration, and signature between the original and new surveys.

13.3.2.1 GA 313 results

Anomaly locations - Six possible relocations of seventeen originally reported anomalies were made during resurvey. Possible reasons for this discrepancy are discussed in Section 14.2. Correlations of between our position and the original survey were difficult because grid coordinates in a Lambert projection were used on the original survey and geographic coordinates (Lambert) and grid coordinates (Universal Transverse Mercator, UTM) were used in the resurvey.

Original Survey	Resurvey
line 1 S, Fix Pt. 8.2	line 149 N, Fix Pt. 155
line 8 N, Fix Pt. 8.2	line 172 S, Fix Pt. 108
line 11 S, Fix Pt. 3.9	line 181 S, Fix Pt. 111.2*
line 16 N, Fix Pt. 5.7	line 193 N, Fix Pt. 160
line 35 E, Fix Pt. 25.1	line 181 S, Fix Pt. 141
line 38 W, Fix Pt. 21.1	line 196 S, Fix Pt. 141
line 40 W, Fix Pt. 17.8	line 204 N, Fix Pt. 100*

*same anomaly

Table II-26.

GA 324: PERCENTAGE OF ANOMALIES AT VARIOUS LINE SPACINGS; 50 AND 100 METERS.

Line	50 Meters	100 Meters
110	1	-
111	0	0
112	1	-
113	2	2
114	0	-
115	0	0
116	2	-
117	2	2
118	0	-
119	1	1
120	0	-
121	1	1
122	0	-
123	1	1
124	0	-
125	0	0
126	3	-
127	2	2
128	0	-
129	4	4
130	1	-
131	0	0
132	0	-
133	1	1
134	0	-
135	0	0
136	0	-
137	1	1
138	0	-
139	2	2
140	0	-
141	1	1
142	0	-
143	2	2
144	1	-
145	0	0
146	1	-
147	0	0
148	4	-
149	3	3
150	3	-

Σn @ 50 meters = 39 (no anomalies on adjacent lines)
Σn @ 100 meters = 23 (no anomalies on adjacent lines)

Original Survey n=8 (lines 100-161, n=6)

Table II-27.

GA332: Percentage of anomalies at various line spacings; 50 and 100 meters.

Line	50 meters	100 meters
100	0	-
101	-	0
102	0	-
103	0	0
104	0	-
105	0	0
106	2	-
107	-	-
108	3	-
109	0	0
110	0	-
111	1	1
112	0	-
113	1	1
114	1	-
115	0	0
116	0	-
117	0	0
118	-	-
119	-	-
120	4	-
121	3	3
122	0	-
123	-	-
124	0	0
125	0	-
126	0	0
127	0	-
128	1	1
129	2	-
130	3	3
131	3	-
132	2	2
133	-	-
134	2	2
135	-	-
136	-	-
137	3	-
138	4	4
139	-	-
140	4	4
141	3	-
142	3	3
143	-	-
144	5	5
145	-	-

Table II-27
(continued)

146	-	-
147	2	-
148	2	2

∑n @ 50 meters = 90 minus 13 duplications = 77 anomalies
∑n @ 100 meters = 36 minus 6 duplications = 30 anomalies
Previous survey = 0 anomalies

Amplitude - For these possible correlations the maximum amplitude for the anomalies were (in nanoteslas):

Original Survey	Resurvey
line 1 S, 26 nT	line 149 N, 21 nT
line 8 N, 65 nT	line 172 S, 34 nT
line 11 S, 7 nT	line 181 S, 12 nT
line 16 N, 40 nT	line 193 N, 12 nT
line 35 E, 10 nT	line 181 S, 12 nT
line 38 W,145 nT	line 196 S, 28 nT
line 40 W, 12 nT	

Duration - The duration of the anomalies is compared in signature widths.

Original Survey	Resurvey
line 1 S, 23 m	line 149 N, 3 sec, 8 m
line 8 N, 15 m	line 172 S, 1.5 sec, 4 m
line 11 S, 30 m	line 181 S, 4.5 sec, 12 m
line 16 N, 23 m	line 193 N, 3 sec, 8 m
line 35 E, 15 m	line 181 S, 4.5 sec., 12 m
line 38 W, 8 m	line 196 S, 15 sec., 38 m
line 40 W, 15 m	

Signature - The original survey report gives no indication as to the signature--dipolar, monopolar, etc.--of the reported anomalies. The resurvey signature descriptions are:

Anomaly	Signature
line 149 N	monopole, negative
line 172 S	monopole, positive
line 181 S	multipole, positive/negative
line 193 N	monopole, negative
line 196 S	monopole, negative (very broad)

13.3.2.2 GA 324 results

Anomaly locations - Three possible relocations of six originally reported anomalies were made. The associations between these anomalies of the two surveys are:

Original Survey	Resurvey
line 39 N, Fix Pt. 120.35	line 119 S, Fix Pt. 111.5
line 42 N, Fix Pt. 110.80	line 129 S, Fix Pt. 120.8
line 47 N, Fix Pt. 105.40	line 144 N, Fix Pt. 127.9
line 146 S, Fix Pt. 127.4	

Amplitude - For these possible correlations the maximum amplitude for the anomalies were (in nanoteslas):

Original Survey	Resurvey
line 39 N, 6 nT	line 119 S, 18 nT
line 42 N, 4 nT	line 129 S, 7 nT
line 47 N, 5 nT	lines 144, 146, 7 nT, 11 nT

Duration - The duration of the anomalies are difficult to compare with the original survey. It is assumed fix point intervals on the original survey were 1500 m Interpolation based on this assumption yields the linear duration. Duration time is difficult to estimate without a good estimate of vessel speed. Resurvey anomaly durations are given in meters and seconds as vessel speed was constantly monitored.

Original Survey	Resurvey
line 39 N, .30 (45 m)	line 119 S, 6 sec; (15 m)
line 42 N, .20 (30 m)	line 129 S, 6 sec; (15 m)
line 47 N, .30 (45 m)	line 144 N, 4 sec; (10 m)
line 146 S, 14 sec; 116 ft.(35 m)	

Signature - The original survey report gives no indication as to the signature--dipolar, monopolar, etc.--of the reported anomalies. The resurvey signature descriptions are:

Anomaly	Signature
line 119 S	monopole, positive
line 129 S	monopole, positive
line 144 N	monopole, negative
line 146 S	multipole, positive/negative

Comments - Of the six anomalies, five appear to be verified. The anomalies reported in the original survey, line 11 S and line 35 E, are very close in position. Given the close proximity, we treated this as one anomaly, line 181 S (our survey). To reduce possible error in intercorrelation of positions between surveys we examined adjacent lines (e.g. for the anomaly on 181 S we looked at data from lines 180 and 182).

13.3.2.3 GA 332 results

No intercorrelation between surveys possible due to absence of anomalies on original survey.

13.3.3 Number of new magnetic anomalies and/or side-scan sonar contacts recorded within the developed lease block, GA 313, and the location of these anomalies relative to oil and gas structures.

The resurvey of block GA 313 produced 68 new anomalies at a 50 m linespacing. The distribution of anomalies before noise filtering or removal of adjacent survey line data is seen in Figure II-61. The central portion of the block has the greatest concentration of anomalies with the highest density seen near the production well now in the block. The well itself is the principal anomaly but all the groundtruthed side-scan targets were within 1,000 m of the platform. Only magnetic anomalies were seen and groundtruthed outside the 100 m diameter. The results tend to support the notion of a "toss zone" but the debris seen within this area may not directly result from oil and gas activities. The objects found near the well site could have come from commercial and sport fishing activities. The refrigerator found on line 202 could have fallen from a trawler while the barrels seen on lines 207 and 205 could have fallen from supply boats or from fishing craft. A pipe found on line 229 is clearly related to oil and gas activities.

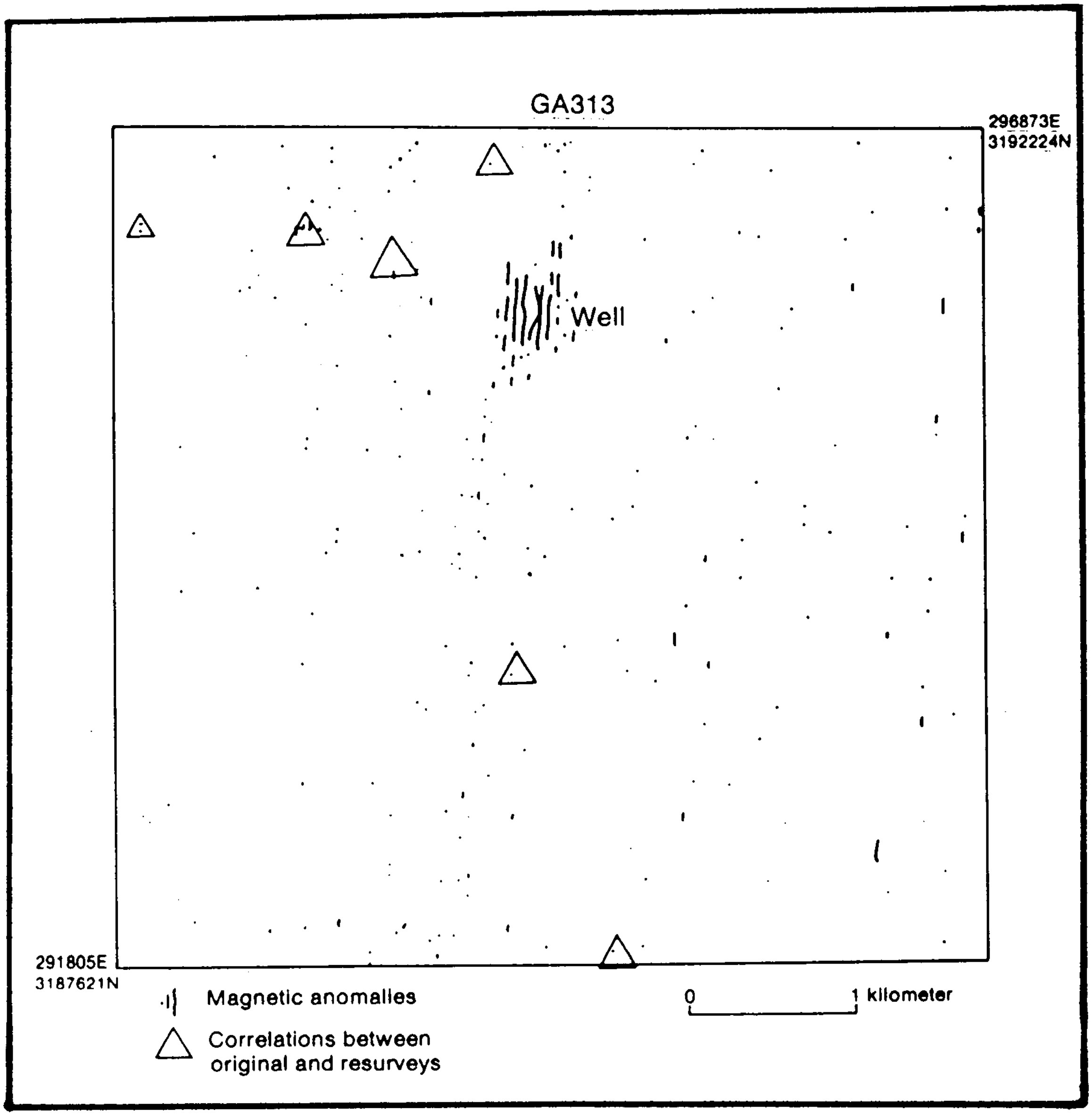


FIGURE II-61. Increase of anomalies in GA 313, unfiltered data.

Whether oil and gas activities directly generate this marine debris is not clear from this survey. What is clear are the following:

a. an increased number of anomalies after block development;
b. all observed side-scan sonar targets are post-development; and
c. the anomalies and side-scan sonar targets concentrate near the oil and gas structure.

13.4 Groundtruthing Characterization of Side-Scan Sonar Contacts and/or Magnetic Anomalies - Instrumental and Observational Data

13.4.1 Magnetometer and/or side-scan sonar data collected at linespacing of 50 m or less

Summary data on the results of relocation and groundtruthing efforts are given in Table II-28. Characterizations of individual side-scan sonar and/or magnetic anomaly sites appear later in this report and in Appendix K. We followed formats originally used by Arnold (1980) Clausen and Arnold 1975; Arnold 1979, 1982; Clark 1986; Scollar, et. al. 1986; and Gearhart 1988. The attempt is to present empirical data which demonstrates specific causes for a variety of anomaly types - shipwrecks to modern debris. Arnold (1980) makes no attempt at any data synthesis as it correlates among theoretical expectations, anomaly characteristics and their sources. It is, however, one of the first expositions of the value of groundtruthing in evaluating anomalies.

Arnold (1980) discusses a problem in the use of earlier magnetometers which involves the non-detection of rapid scale shifts. When a strip chart recorder was used to record magnetometer data, only the trace, corresponding to scale ranges was often printed. When the analog record shifted with a large anomaly reading, the chances were good that one would not detect the shift.

Recent improvements in analog recorders, such as that used on the present survey avoid this problem by overprinting the actual magnetic reading on the record simultaneously with the profile trace (Table II-28). Our methodology has taken this one step further by the extra capability of recording the digitized data to magnetic tape via a serial BCD interface to a microcomputer. This eliminates the non-detection of sudden scale shifts in high gradients as well as provides the opportunity to record ancillary survey data such as time and position with the magnetometer readings. The full utility of this method can be seen in the computer based manipulation and processing of survey and groundtruthing data for visual display and analysis.

Table II-28.

SUMMARY DATA - RELOCATION AND GROUNDTRUTHING STUDIES.

Sites Resurveyed	Sites Relocated*	Anomalies and/or Targets Logged for Data
101 (GA332)	101 (GA332)	101 (GA332)
106 (GA332)	104 (GA332)	107 (GA332)
107 (GA332)	110 (GA324)	110 (GA324)
108 (GA332)	116 (GA332)	116 (GA332)
109 (GA332)	125 (GA332)	125A (GA332)
110 (GA324)	137 (GA332)	125B (GA332)
116 (GA332)	148 (GA332)	125C (GA332)
125 (GA332)	152 (GA332)	125D (GA332)
137 (GA332)	163 (GA332)	137 (GA332)
148 (GA332)	164 (GA332)	148 (GA332)
149 (GA313)	175 (GA313)	152 (GA313)
150 (GA313)	185 (GA313)	164 (GA313)
152 (GA313)	202 (GA313)	175 (GA313)
163 (GA313)	203 (GA313)	185A (GA313)
164 (GA313)	205 (GA313)	185B (GA313)
175 (GA313)	229 (GA313)	185C (GA313)
185 (GA313)	305 (GA332)	202 (GA313)
192 (GA313)		205A (GA313)
194 (GA313)		205B (GA313)
197 (GA313)		207 (GA313)
202 (GA313)		229 (GA313)
203 (GA313)		305 (GA332)
205 (GA313)		
207 (GA313)		
229 (GA313)		
231 (GA313)		
305 (GA332)		

*Only sites that could be relocated on more than one resurvey line are listed. Some features, particularly magnetic anomalies, could be found on a northward or southward resurvey line but not on the opposite line direction. The objects were there but could not provide adequate detail for mapping requirements. A few features could not be relocated at all.

ANOMALIES/SIDE SCAN TARGETS GROUND-TRUTHED

101 (GA332)
107 (GA332)
125A (GA332)
125B (GA332)
125C (GA332)
125D (GA332)
152 (GA313)
163 (GA313)
164 (GA313)
175 (GA313)
185A (GA313)

Table II-28
(continued).

185B (GA313)
185C (GA313)
202 (GA313)
205A (GA313)
205B (GA313)
229 (GA313)
305 (GA 332)
110 (GA324)

ANOMALIES/SIDE SCAN TARGETS IDENTIFIED
152 (GA332)
163 (GA313)
164 (GA313)
175 (GA313)
202 (GA313)
205A (GA313)
205B (GA313)
229 (GA313)
305 (GA332)
107 (GA332) Tentative

14.0 SUMMARY AND CONCLUSIONS - TASK II

14.1 Magnetic Anomaly Characterization - general parameters

All sites evaluated by groundtruthing were modern marine debris. The results directly aid in evaluating the instrumental signatures obtained in the resurveys.

14.1.1. Pattern Recognition in Instrumental Signatures and the Correlation with Shipwrecks and/or Modern Marine Debris.

Two major areas of concern for anomaly characterization are: (1) "masking" of shipwrecks by the proliferation of modern marine debris, associated with oil and gas development; and (2) the modeling of single or multiple component magnetic signatures to allow the development of an interpretative framework to help discriminate between remote sensing data representative of modern marine debris and the remains of historic shipwrecks.

Current survey methodology and subsequent characterizations lack spatially adjacent magnetic data such that contour plots can be prepared. Currently, only single line profiles of anomalies can be evaluated as to the strength and duration of the signature or signatures. Linington (1966) suggested an approach to the analysis of such profile data by deducing anomaly shapes using a simplified series of approximations based on magnetic theory. Few analyses followed this early effort in the presentation of magnetic data in graphical form.

The effectiveness of a particular survey intensity as a discovery technique greatly depends on the size and visibility of the things being sought (Doelle 1977). Shipwrecks are discrete sites but in relation to single artifacts or small assemblages they are "large anomalies." This largeness must be viewed relative to the survey area itself. Nominally, the range of vessel size, by area, is from a few square meters to in excess of 2,000. This is small given the size of the Gulf of Mexico or even a lease block (27.8 km). Thus, it is difficult to expect any magnetic intensity detected on one line to be detected at any strength on an adjacent line space 150 m away. This follows from the simple physical relation of magnetic strength to distance given by the equation:

$$\overset{>}{T}_x = \frac{\overset{>}{M}_f}{d^3} \qquad \text{(Eq. 1)}$$

Where T = the anomaly magnetic strength
M = the dipole moment in cgs units and that of a localized field
d = the distance from the sensor to the anomaly in centimeters

As the distance increases from the object the intensity of the magnetism decreases with the cube of the distance. This phenomenon alone allows detection of only the largest magnetic features (five tons of iron) on two adjacent lines at 150 m offset. A further complicating factor is the direction of the earth's magnetic field and its vectorial relation with that of the object. By simple physics, these components increase or decrease the magnetic strength of the signal depending on orientation of the object and local field. The use of side-scan sonar in concert with the magnetometer is considered a form of redundancy to mediate the loss of magnetic strength by a broader acoustical scan of the bottom.

Figure II-62 illustrates the best case for either detection system. It is the liberty ship B.F. SHAW sunk as an artificial reef off Freeport, Texas. Unfortunately, this example is the

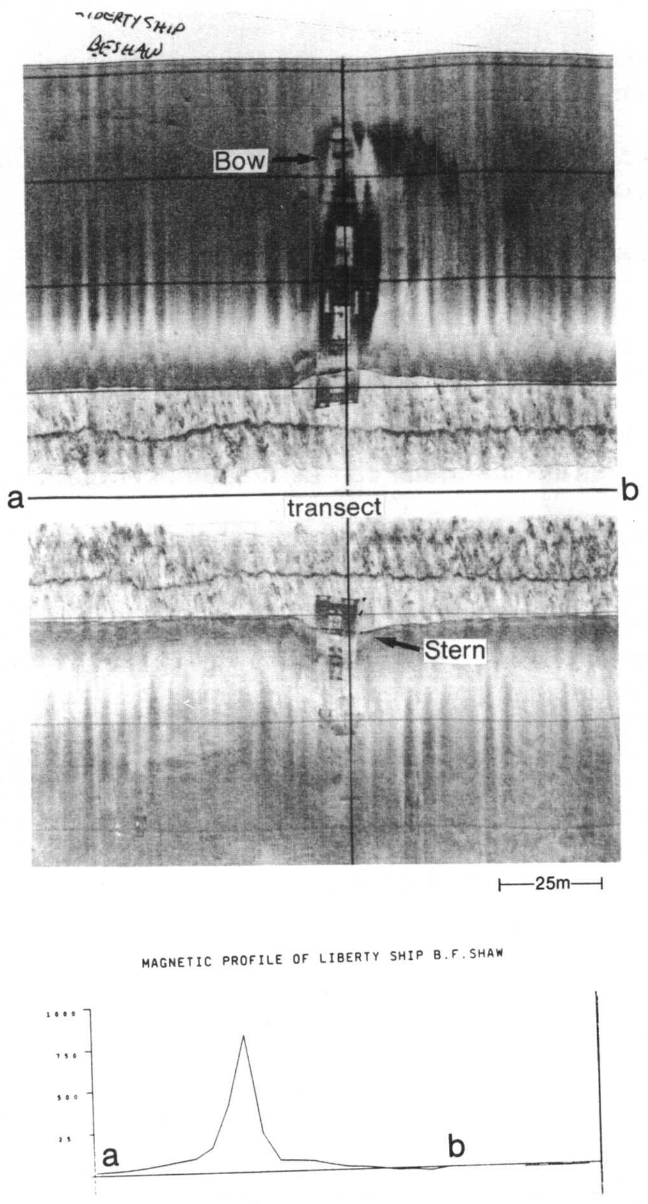


Figure II-62 Sonogram and magnetic profile of the Liberty Ship B.F. SHAW exception rather than the rule. We cannot expect such a concentration of metallic mass, size, and preservation from earlier vessels. The liberty ship is over 100 m long and all metal. Such an object falls in the 50 m overlap zone for adjacent tracks on a 150 m linespacing. However, if the vessel was less than 50 m in length, as was common for sailing ships, it would not be detected by the side-scan sonar at the 100 m scale. An increase of instrumental scan range to 200 m would only loose the resolution of smaller features.

A particular problem with the intercorrelation of acoustical and magnetic data on anomalies is related to range. It is believed that fine grained and short-ranged sweeps by the sonar will provide greater resolution of the anomalies by reducing scale size on the sonographs. The percentage of anomalies can be determined and compared for specific types of anomalies that partition into modern debris, modern shipwrecks or historic shipwrecks. Arnold (1976, 1977, 1978, 1979, and 1980) showed that on 47 significant magnetic anomalies in Texas waters, only 13 percent, or six cases, showed debris above the bottom and hence detectable with side-scan sonar. As one study of block GA 313, 10 side-scan targets proved to produce eight anomalies upon groundtruthing. Two of these targets were bottom disturbance due to anchoring or mooring activities and produced no detectable anomalies. The rest of anomalies examined in GA 313 had no associated side-scan sonar targets.

The search for indicator variables or patterns of magnetic data can only raise present predictive confidence. Variables in the magnetic data for analysis include but are not limited to:

a. duration;
b. amplitude;
c. shape;
d. sign; and
e. frequency.

The characteristics of magnetic data were treated by authors such as Aitken (1974), Tite (1972) and Breiner (1973). In sum, magnetic data has two principal aspects, a spatial aspect and a spectral aspect. An early presentation of the spatial character of magnetic data is shown in Figure II-63. In succeeding years computer graphics techniques have been applied for the visual, qualitative display of this data.

While informative, these graphical presentations have not led to reliable methods of determining the nature of the anomalies detected by magnetic survey (Baker 1982). These two- and three-dimensional presentations of magnetic data have collapsed several parameters of dimensions into a visual representation analogous to a diversity index. These indices, by their nature, are dimension-less and reduce masses of numbers into a single parameter (Green 1979). Information may be lost in the spatial image. Variables such as amplitude, frequency, wavelength, and shape may be more meaningfully evaluated by such composite approaches (Green 1979) than by considering them as separate index measures.

As pointed out in our introductory remarks, current methodology used in lease block surveys for anomaly analysis is inhibited by the lack of original data in leasee reports. This original data can be called for by agency professionals reviewing the leasee reports and has become common practice. No comparative body of data have emerged from the many surveys done where the lease stipulation was invoked.

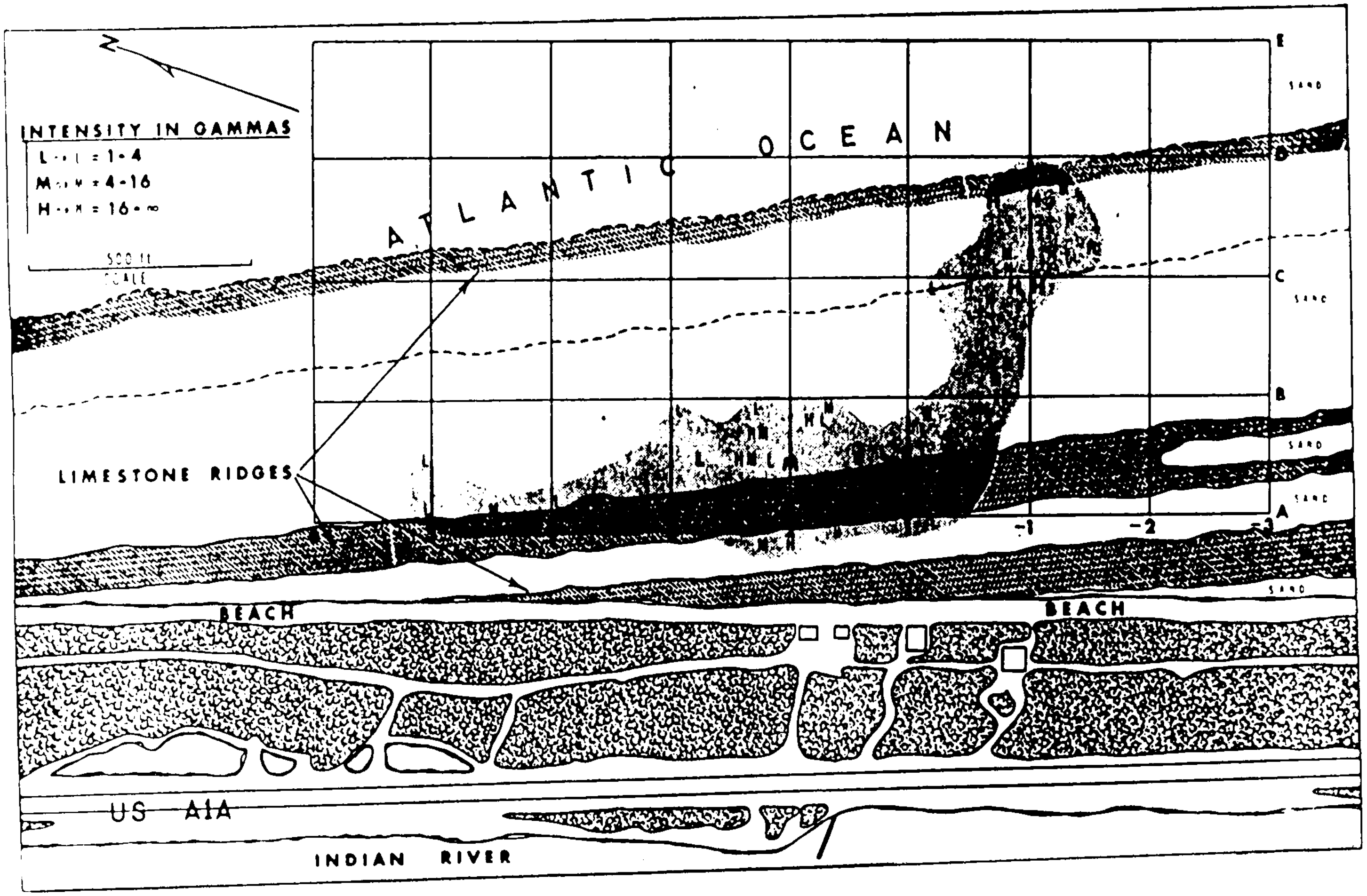


FIGURE II-63. Two-dimensional graphical presentation of magnetic data for a 1715 shipwreck.

14.1.1.1 Duration

Duration is more properly called anomaly width but has also been described as the wavelength (Breiner 1973). If we treat the wavelength as the total observed perturbation created by a magnetic feature, then the duration can be measured in temporal units. In some instances it is reported in spatial units. In Figure II-64, the duration *t* of the anomaly would be the time necessary for the wavelength to reach a maximum, a minimum and return to ambient field strength. Typically, dipolar anomalies exhibit such behavior where a maxima and minima are seen before the ambient level is finally reached.

In the case of monopolar anomalies, the anomaly may not exhibit a minima, showing only an inflection about the maximum. Here the duration is simply read as the time, *t*, from the anomaly's departure from ambient field, t_1, to its return, t_2.

The expression of duration as a distance has not been regularly done in lease survey reports. Duration reported as time does not allow the utilization of the width of the wavelength to determine even the depth of buried anomalies by the "full width-half maximum" (FWHM) rule of thumb (Weymouth 1986; Breiner 1973). Utilizing the maximum value of the anomaly, and assuming a simple shaped source (sphere, etc.), a depth estimate within 10-50 percent can be obtained (Breiner 1973). In large portions of the Gulf's continental shelf, most historic materials are not too deeply buried (2 m) and this empirical formula can be roughly used to estimate distance to the source. Even this simple technique cannot always be used when some reports cite duration as a function of time only.

The importance of duration as a quantitative descriptive parameter is illustrated by Table II-29 taken from Garrison (1986) where within 100 m of a shipwreck the anomaly duration is constant.

TABLE II-29

WILL O'THE WISP Study: Anomaly Duration Related To Distance From The Source

Line #	Time (sec)	Distance (m)
1	130	0
2	140	50
3	150	75
4	160	100
5	70	125
6	40	150

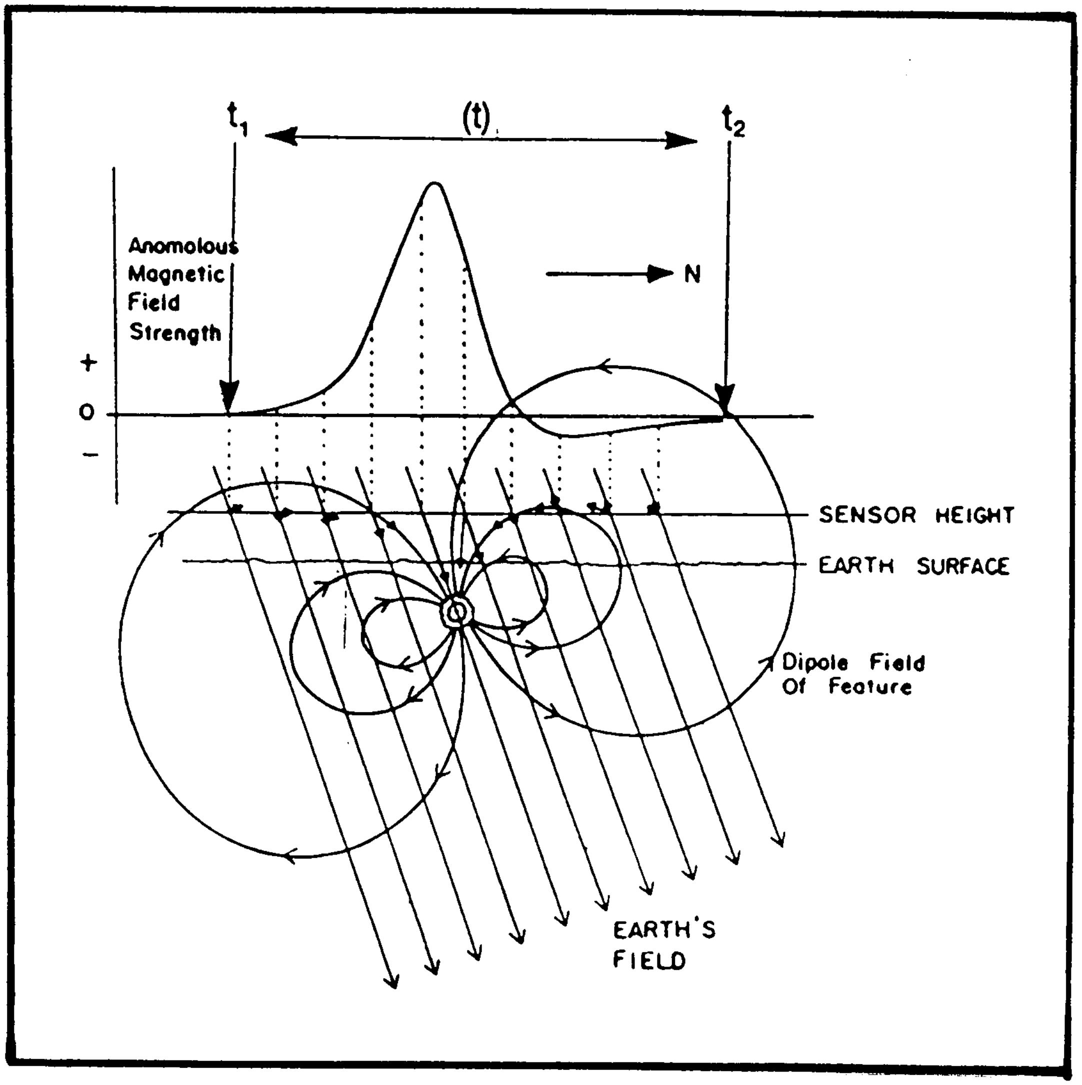


FIGURE II-64. Schematic representation of the relationship of anomaly amplitude, shape, duration and field orientation.

14.1.1.2 Amplitude

The basic expression for estimating the maximum amplitude of any anomaly is the general form of Equation 1 or:

$$\vec{T} \;.= \frac{\vec{M}}{d^n}$$

(Eq. 2)

Where T, M, and d = the same as Equation 1

The falloff rate, d, as a function of n, distance, is expressed more generally as n. Typically n equals 3 for dipoles and n equals 2 for monopoles.

The relative amplitude of an anomaly is a function of the earth's field direction, the configuration of the source, and any remnant magnetism (Breiner 1973, 1975). The maximum amplitude is largely a function of burial depth and magnetic contrast. Magnetic contrast is the result of the magnetization of the object sometimes described as remnant magnetism. This permanent magnetism is a property of the material together with its thermal and mechanical history. In metallic iron the oxides haematite (Fe_2O_3), magnetite (Fe_3O_4) and maghaemite (Fe_2O_3) are responsible for the permanent magnetism (Tite 1972). Magnetic contrast is a direct function of the amount of these oxides distributed in materials such as soils, structures and artifacts. The concentration of iron oxide in soil depends on its geological strata while structures and artifacts are manufactured with materials containing these oxides. In the case of clay and metal materials the thermal history can determine their magnetism by heating past a temperature termed the Curie Point. The magnetic domains within the materials align with the magnetic field of the earth at this temperature producing an induced magnetism of greater strength than before firing. When the object is moved at a later date, it retains this magnetic alignment and its enhanced magnetism. This capacity of field strength and direction retention forms the basis for magnetic dating techniques.

For the detection of magnetic anomalies in the Gulf of Mexico, amplitude will be directly related to the magnetic properties of the object or source, its alignment in the local magnetic field, and its distance from the sensor. Another factor which is related to the alignment is the direction of the earth's field. Because the earth behaves as a dipole magnet with magnetic lines of force, the direction of these lines of equal intensity or magnetic flux determine field strength. The field is strongest at the poles, weakest in the equatorial plane (Figure II-65). This directional aspect of magnetic fields ultimately means that amplitude of an anomaly is a vectorial sum of the earth's field and the weaker local field of the anomaly source:

$$\vec{T} = \vec{T}_e + \Delta \vec{T}_e + \Delta \vec{T}_p$$

(Eq. 3)

Where T = the total field value
T_e = the earth or external field
ΔT_e = that part of the earth's field along T_e
ΔT_p = that portion perpendicular to T_e

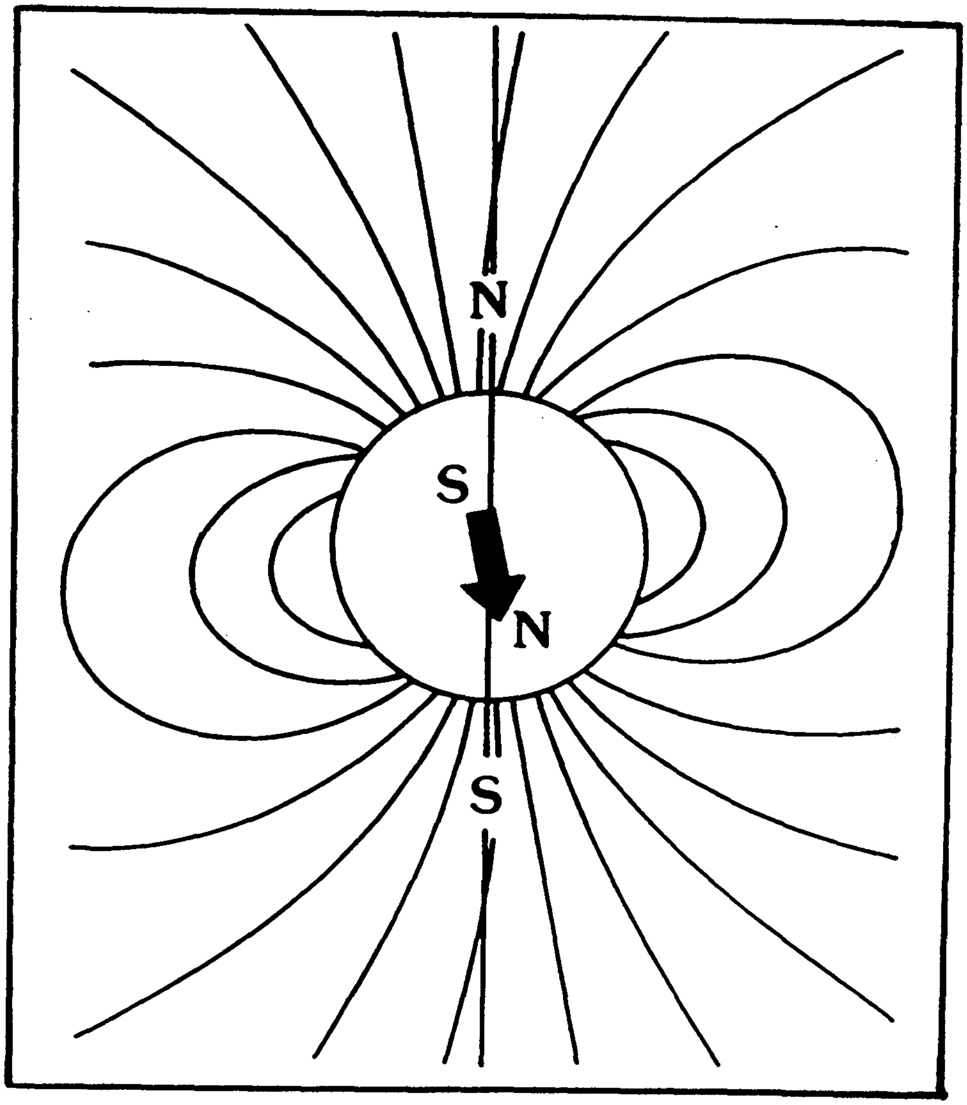


FIGURE II-65. Dipole field of Earth.

Because the sum of $T_e + \Delta T_e$ is roughly a million times or six orders of magnitude larger than T_p, the approximation becomes:

$$\vec{T} = \vec{T}_e + \Delta \vec{T}_e \qquad \text{(Eq. 4)}$$

The amplitude of the anomaly varies with the component T_e and its orientation relative to T_e. If it is parallel and in the same direction, it will simply result in Equation 2.

Any angular variation in T_e will reduce M by some constant k or,

$$\vec{T} = \frac{kM}{d^n} \qquad \text{(Eq. 5)}$$

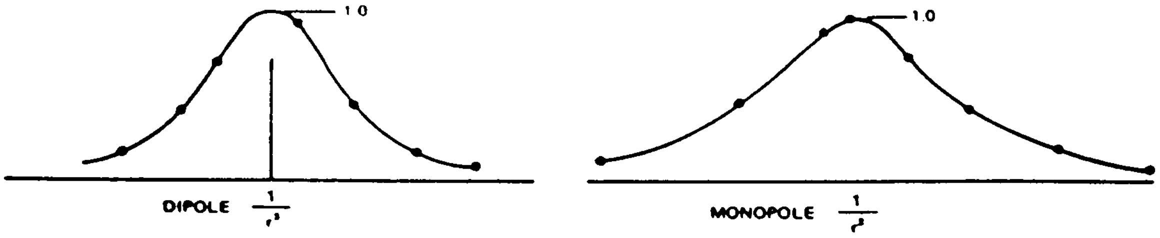
A special case of this general equation is at the magnetic poles or above 60°N latitude where M becomes 2M. Orientation of the anomaly source within the earth's external field largely determines the observed amplitude. This accounts for the variation seen in Gulf lease survey data for reported anomalies. Typically, the anomaly is detected on one line of direction and detected again on an adjacent line of opposite direction. The anomaly amplitude will vary with d and T_e. Current survey methodology using opposite adjacent line directions make it difficult to assess the fall off factor, d^n and thus, any estimate of anomaly size or distance particularly at the 150 m linespacing. Utilizing the 50 m survey methodology improved on this by having adjacent line directions at 100 m intervals. Groundtruthing surveys using 10 m offsets allowed for more rigorous application of evaluation techniques based on the formulae discussed in this section.

14.1.1.3 Shape

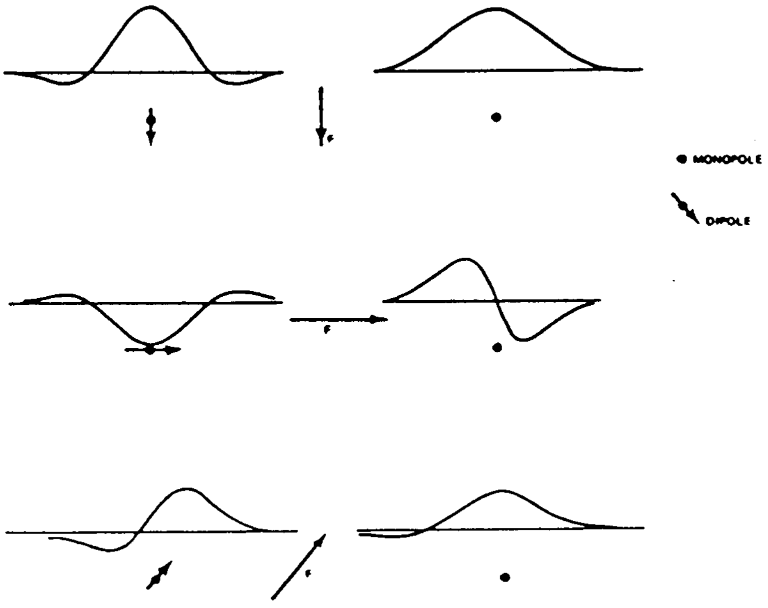
The shape of a magnetic anomaly along a survey line is a result of the same factors that influence the amplitude. Most authors refer to shape as dipolar or monopolar. The fall off of the strength of the anomaly is expressed in the slope of the profile. Typically, the steeper slope values are associated with dipolar anomalies while monopolar anomalies have broader, less steep profiles (Figure II-66 a, b).

Ideally, anomalies in the Gulf of Mexico follow these rules (after Tite 1972):

a. The maximum of the anomaly lies to the south of the feature, the displacement being approximately equal to one-third of the depth to the center of the feature;
b. The separation between two points, in a straight line traverse, at which the anomaly has half its maximum value is approximately equal to the depth or width of the feature, whichever is greater (the full width-half max rule, FWHM); and
c. A reverse anomaly (i.e., decrease in magnetic field intensity) may occur to the north of the feature at a distance equal to the depth; the reverse anomaly does not exceed 10 percent of the maximum normal value of the anomaly except in the case of metallic iron.



a. Fall-off Rate



b. Shapes

FIGURE II-66. (a) Fall off rate for dipole and monopole
(b) Anomaly shape relative to field orientation.

Breiner (1973) notes that anomalies are usually interpreted as though induced magnetization were the total source of the anomalous effects. Shape is therefore a combination of field and anomaly source orientation. This generally produces the asymmetry shown in Figure II-66 a, b.

Anomalies produced by shipwrecks or modern debris are variable in symmetry and reflect the kind of source materials. Von Frese (1978; 1984) suggested a technique termed "reduction to the pole" which aids in the recognition of remanent magnetized features. This technique moves the anomaly profile directly over its source and removes induced effects thus presenting the investigator with a profile representative of the nature of the feature. To date, this procedure has not been utilized on submerged anomalies and may be a tool for evaluating profile shape in a less qualitative manner than current methodology. Since almost all anomalies detected in the Gulf result from remnant magnetization in iron or steel materials, a technique which more accurately characterizes this parameter may prove analytically useful.

14.1.1.4 Sign

This parameter is related to shape, but is treated here as it applies to practices in lease survey reports. The reported values for anomaly amplitude are given in terms of the range or "peak-to-peak" values. Sign, in terms of an anomaly, is considered positive (+) when the observed amplitude exceeds the ambient external field, T_e, and is negative (-) when it falls below this value. It is a relative value dependent on the observed value for the external field.

Reporting the amplitude as a range ignores this property of anomaly behavior. One cannot correctly characterize the anomaly strength with a range value as it ignores the physical behavior of magnetic features. The magnitude of the reverse anomaly allows for a truer characterization of the anomaly as dipolar or not. However, using the reverse anomaly to calculate amplitude will not yield a value that agrees with a numerical result of a variation of Equation 1. The proper utilization of the amplitude of the anomaly and that of the reverse anomaly seems an important point to consider in the characterization of marine survey data.

14.1.1.5 Frequency

The term used here is more commonly a synonym for the complexity of magnetic anomalies. Frequency relates to the parameter of noise from natural background variations. In marine surveys such background variation is usually the result of speed or fluctuation in sensor distance from the bottom. Local geology can introduce background noise as well.

Scollar (1979) has observed that noise amplitudes can be the same order of magnitude as those associated with archaeological anomalies. Weymouth (1986) stresses the importance of distinguishing the nature and magnitude of noise separate from the signal if possible. In addition, he classifies noise by its frequency of occurrence. It can be random and non-repeatable or very regular. It can be long or short range occurring over several readings or just one or two. The importance of noise is that it sets a lower limit to the size of identifiable anomalies. In lease surveys the acceptable noise is three nanoteslas allowing for the detection of at least five nanotesla anomalies.

Noise can be removed by mathematical filtering techniques. Anomalies commonly have dimensions differing from that of noise and as such can be emphasized to the exclusion or reduction of noise. An approach called threshold median filtering or interquartile difference filtering removes noise by comparing values observed with a median value in a moving window (Scollar 1984). Where the value exceeds the interquartile difference, it is replaced by the median. A variation used in the analysis of the resurvey data is shown in Figure II-67. Here the noise has been filtered by using a moving comparison to a median and the frequency pattern observed for the long range noise (Kaplan and Coe 1976). The data displayed in Figure II-67 represents an entire three mile survey line. Such presentation introduces another parameter of magnetic survey data - trend or gradient. Trend analysis is a well established set of procedures that utilizes mathematics to remove trends (Davis 1970). In this analysis we have used what Davis terms convolution filtering. By using two-dimensional moving averages each data point is replaced by a weighted average of neighboring values inside a given radius.

Displays of this nature are possible when data is logged digitally and processed through algorithms that can image complete survey lines, line segments with anomalies shown, individually or together, as to frequency and complexity.

14.1.2 Anomaly Characterization and Pattern Recognition of Resurvey and Groundtruthing Data

The data used for the following analyses are those of the resurvey of blocks GA 313, GA 324, and GA 332. Various techniques of magnetic data display were used on various portions of this data base to characterize anomalies and recognize any patterns associated with these data. The groundtruthing data is appended to this report and cited in appropriate examples.

14.1.2.1 Graphical Display of Resurvey Data - Single and Multiple Profile Techniques.

The first data were collected in GA 324. The analog magnetic data and digital navigation data were merged in the post plot process. This is the familiar technique utilized by leasees fulfilling survey requirements under NTL-75-3.

These data were plotted using DISSPLA graphics package which provided the perspective plot of magnetic anomaly profiles for GA 324 (Figure II-68). This method is informative as it allows for an easy assessment of the distribution of anomalies within the surveyed area. Individual detail for the anomalies can be obtained by relaxing the scale of the anomaly relative to the overall length of the survey line. Where anomalies are broadly dispersed, this linear scale exaggeration is conveninent. In the case where anomalies are more clustered together or more dense overall, it may be less appropriate. Figure II-69 illustrates this point where a plot of GA 313 data is shown. The large anomaly of a well is seen but the scale has not been manipulated due to the density of adjacent anomalies. No detail of smaller anomalies can be seen at this scale.

Line profiles can be displayed individually for the further analysis of anomalies. The z-axis, which denotes amplitude, has been scaled such that low level noise is exaggerated. Smoothing produces an image like that for GA 324 (Figure II-68).

Figure II-70 for line 230 (GA 313) illustrates (a) raw data showing the gradient over the three mile survey line and (b) detrended, filtered data. The compression of the x-y scale accentuates the z-axis (amplitude). The well feature anomaly is clearly seen as in Figure II-69.

Multiline or adjacent line comparison is facilitated by the use of digitized data. In Figure II-71 (a), adjacent lines of GA 313 are shown where the same anomaly is seen on both lines near the right hand end of the tracks. Figure II-71 (b) illustrates this format using four lines adjacent to each other. No anomalies are seen in common.

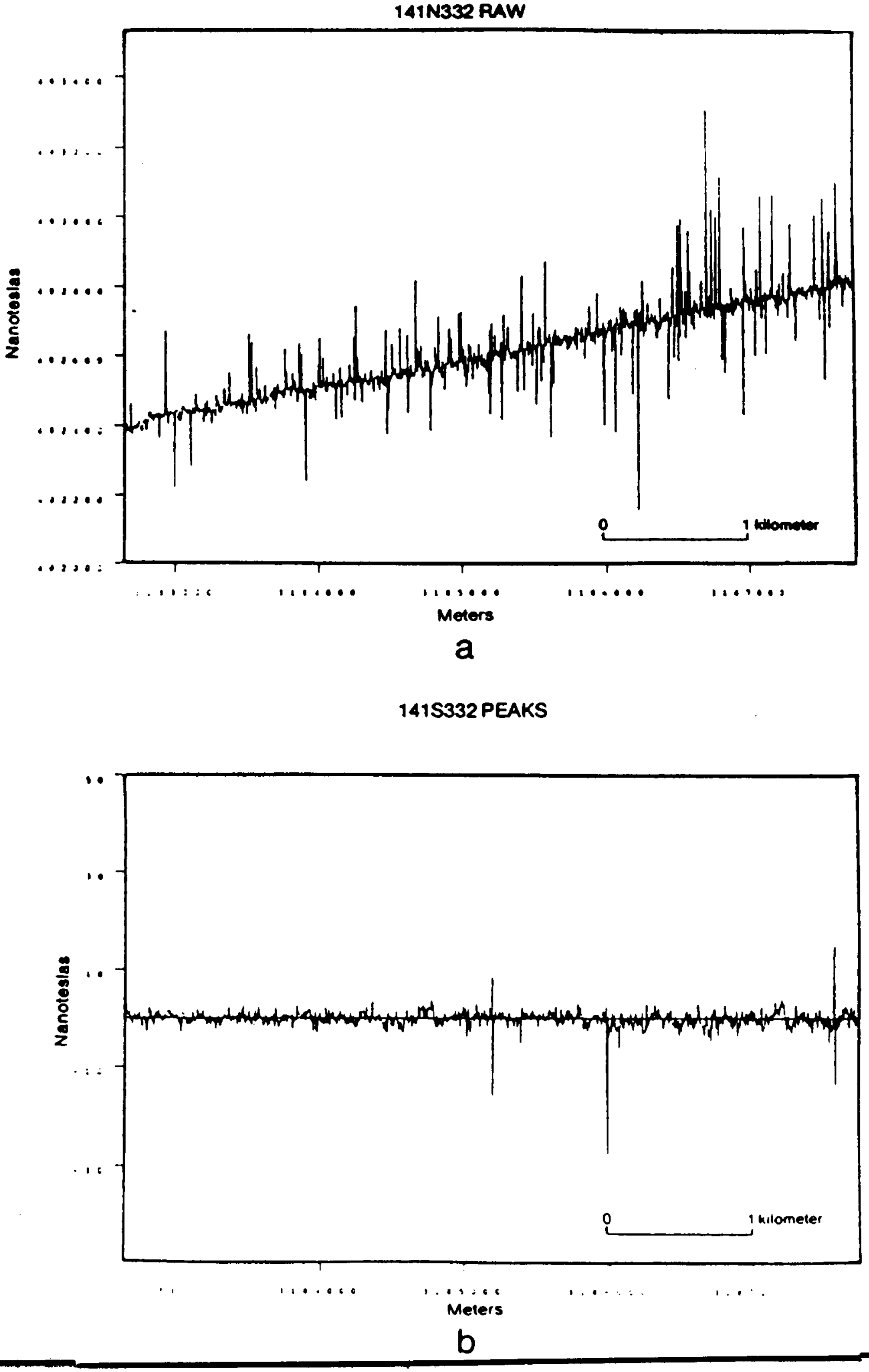


FIGURE II-67. Noise filtering, line 141 GA 332.

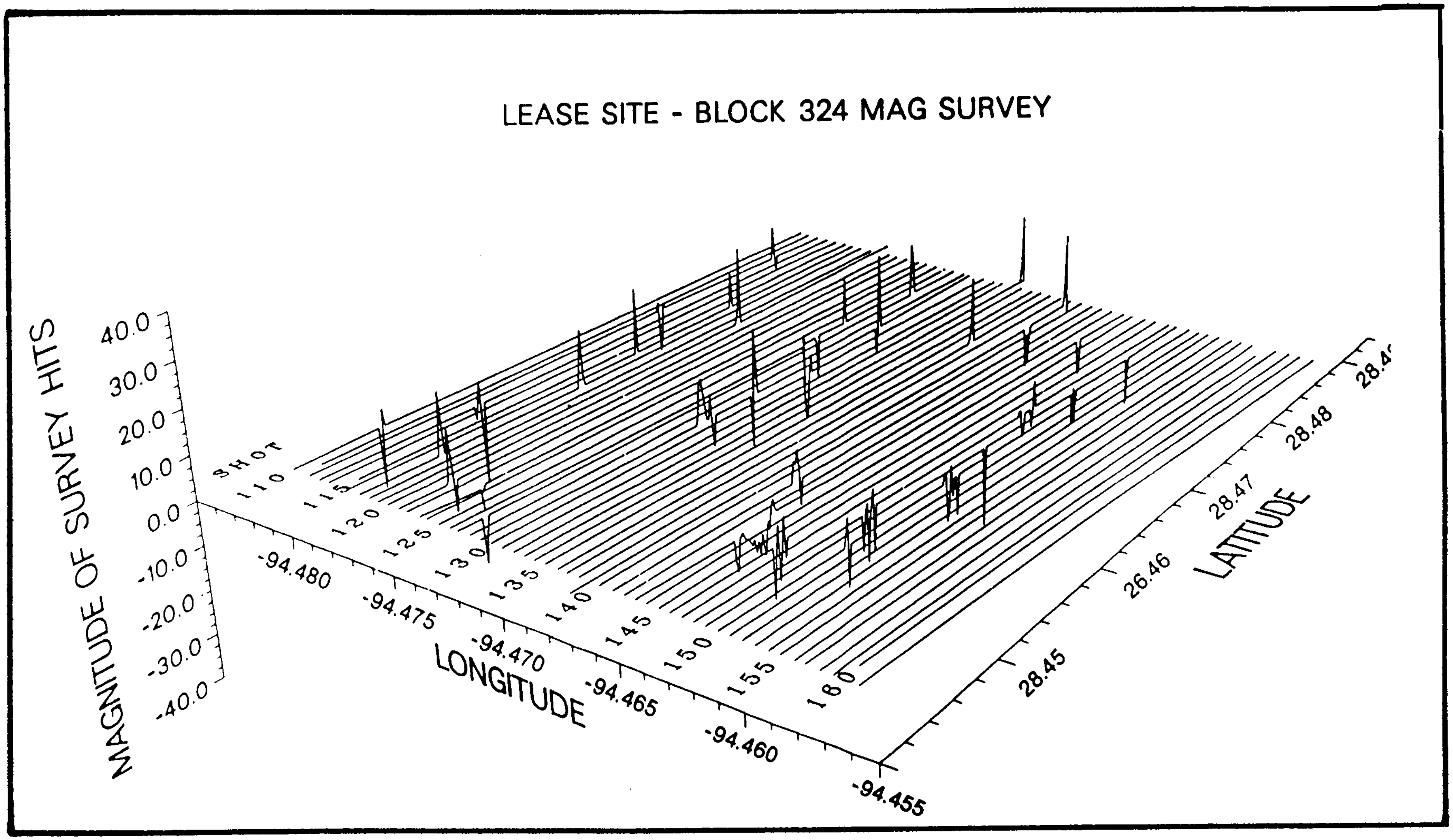


FIGURE II-68. Magnetic profiles, GA 324, DISSPLA graphics.

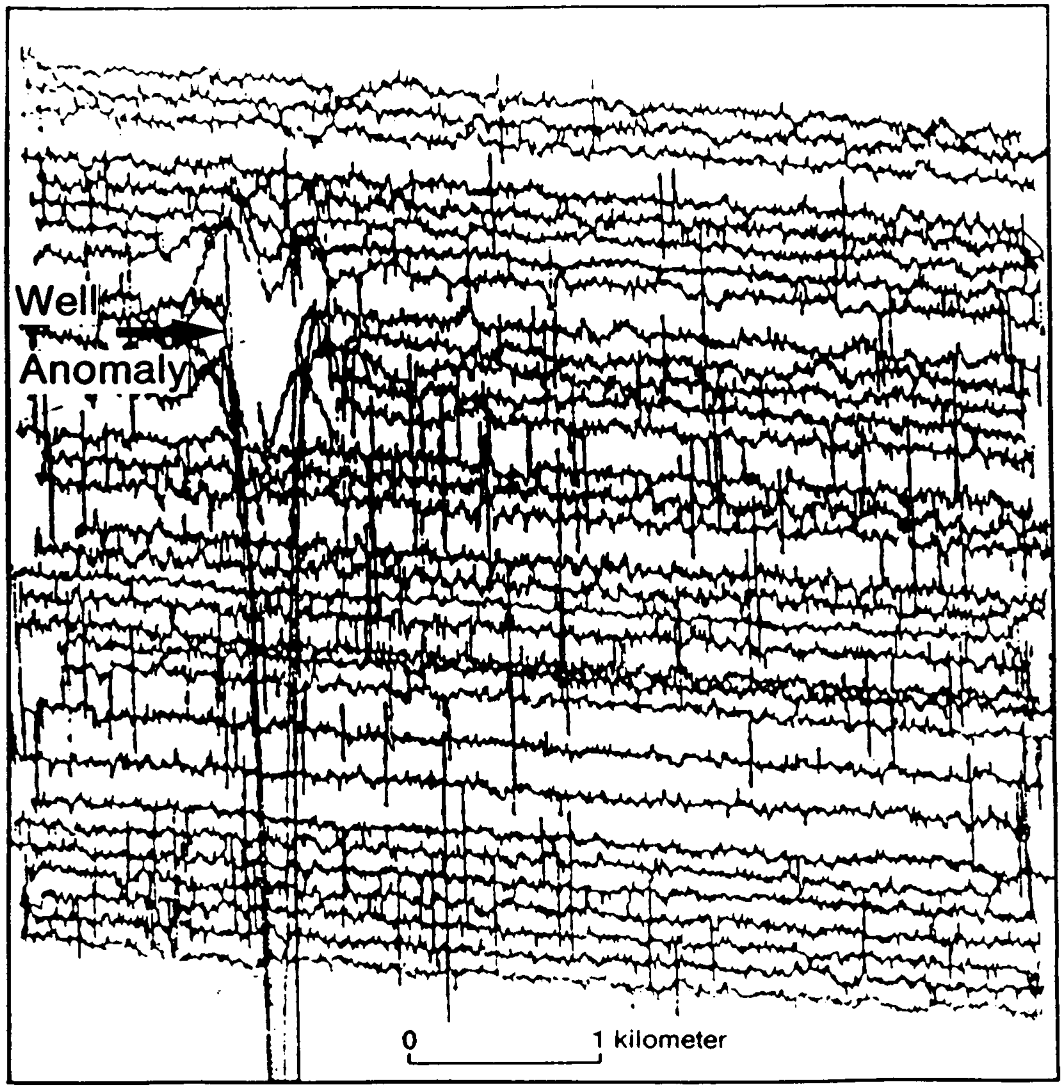


FIGURE II-69. Magnetic profiles, GA 313.

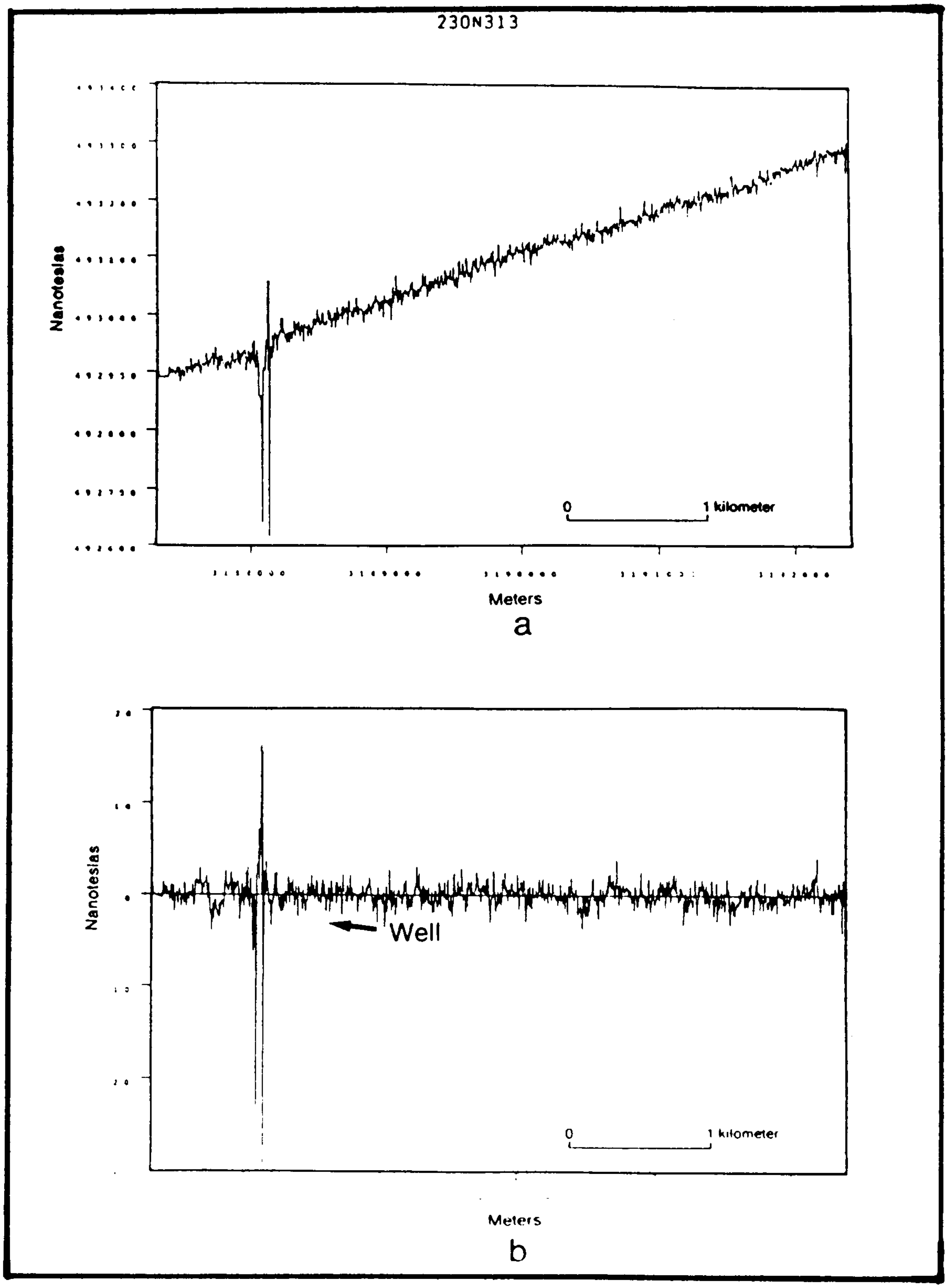


FIGURE II-70. Single line magnetic profile, (a) raw data (b) gradient removed, filtered.

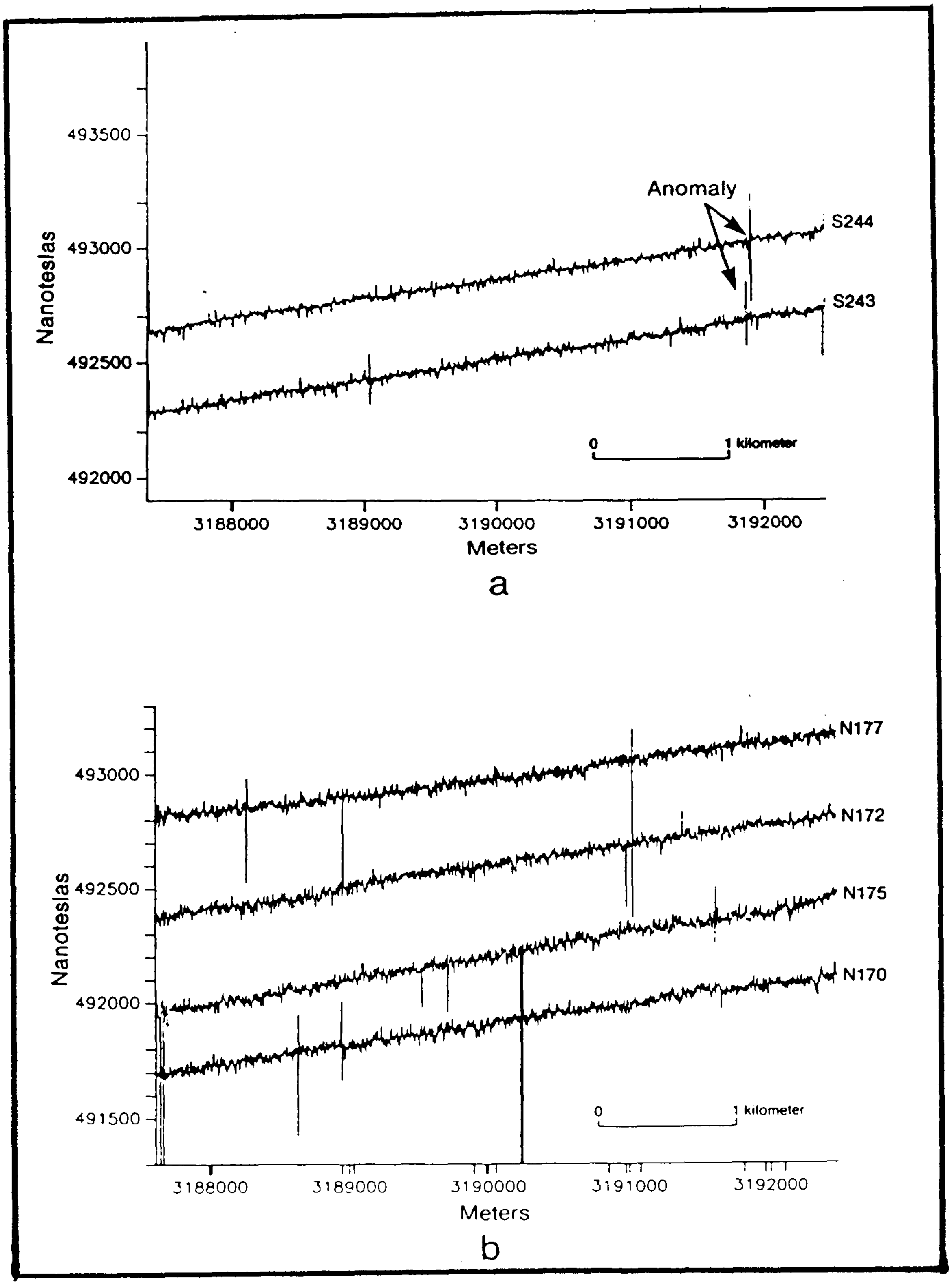


FIGURE II-71. Multi-profile display of data.

14.1.2.2 Graphical Display of Resurvey Data - Contour and Isometric Formats.

Within many graphics packages, such as DISSPLA, are routines that create contour and isometric presentations of x-y-z data. The data base for GA 324 was utilized using DISSPLA. Similar results can be obtained using DI 3000, a graphics package by Precision Visuals. Figure II-72 shows a contour map of the anomalies shown in the profile data of Figure II-68. As the data is sparse and contains no adjacent anomalies, the spatial extent is exaggerated and arbitrary. The visual presentation does allow the easy discrimination of monopolar and dipolar anomalies. The example of an isometric perspective of the same data (Figure II-73) is less informative as to the sign and amplitude of the anomalies. The distributional aspect is well depicted and if there were any anomalies with some complexity and/or spatial extent this format would be more useful. None of the above examples are called for under this study's scope of services and are presented as alternative methods in the graphical presentation of broad scale anomaly trends in lease blocks.

14.1.3 Graphical Display and Analysis of Groundtruthing Data - Individual Anomalies

The complete set of groundtruthing data is located in Appendix III-A. The suite presented in this analysis are those which have the most complete set of observations instrumentally as well as a reliable determination of their source. The aim is to examine and characterize the changes in magnetic signatures resulting from different sources, source orientations, and distances. Side-scan sonar data, where available, help establish a characterization of the anomalies or anomaly patterns.

14.1.4 Individual Sites

14.1.4.1 Site 2, Line 107 GA 332-SP106

The sharp gradient magnetic anomaly detected during resurvey (Appendix K, Figure K-2a) was not replicated during groundtruthing relocation. A dipolar anomaly (Appendix K, Figure K-2b) was found during these efforts with an adjacent anomaly 10 m away. Divers obtained localized readings on the metal detector but were unable to physically locate the source due to burial in the mud.

Figure II-74 shows a 2 nT contour plot of the anomaly and an isometric view (Figure II-7; Figure II-87). In this latter case, the source was verified, by groundtruthing, as a cable. The source of this anomaly is thought to be the same.

14.1.4.2 Site 7, Line 125 GA 332-SP156

This anomaly is a cluster of small anomalies scattered over a 50-75 m diameter area. The anomalies are small with largest being 27 nanotaslas (Appendix K, Figure 7b). The anomalies were of short duration (5 sec) rarely over 12 m.

The contour and isometric views (Figures II-76 and II-77) enhance the discrimination of the spatial amplitude of this scatter of sources. Groundtruthing provided no identification of the anomalies due to burial depth.

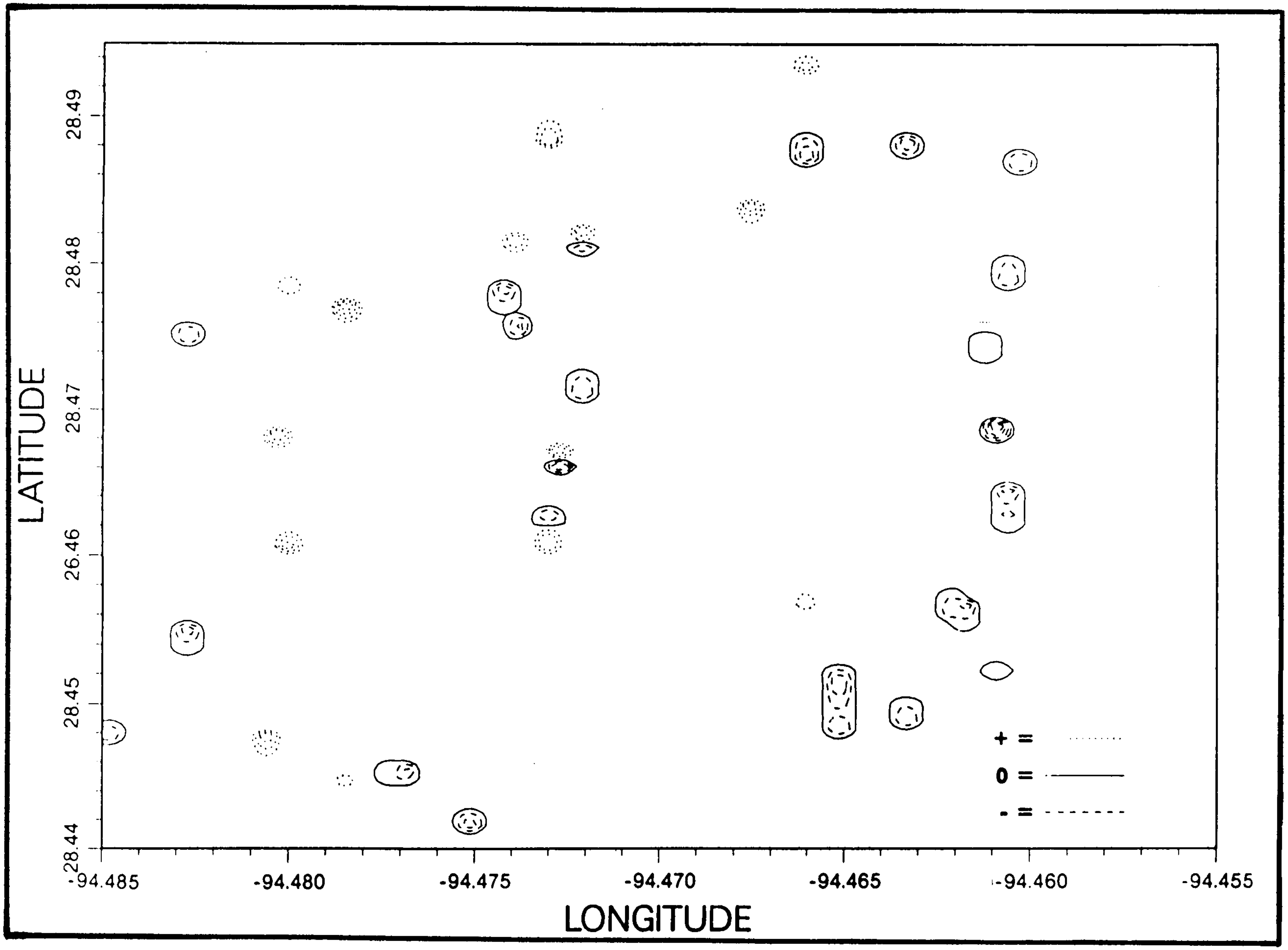
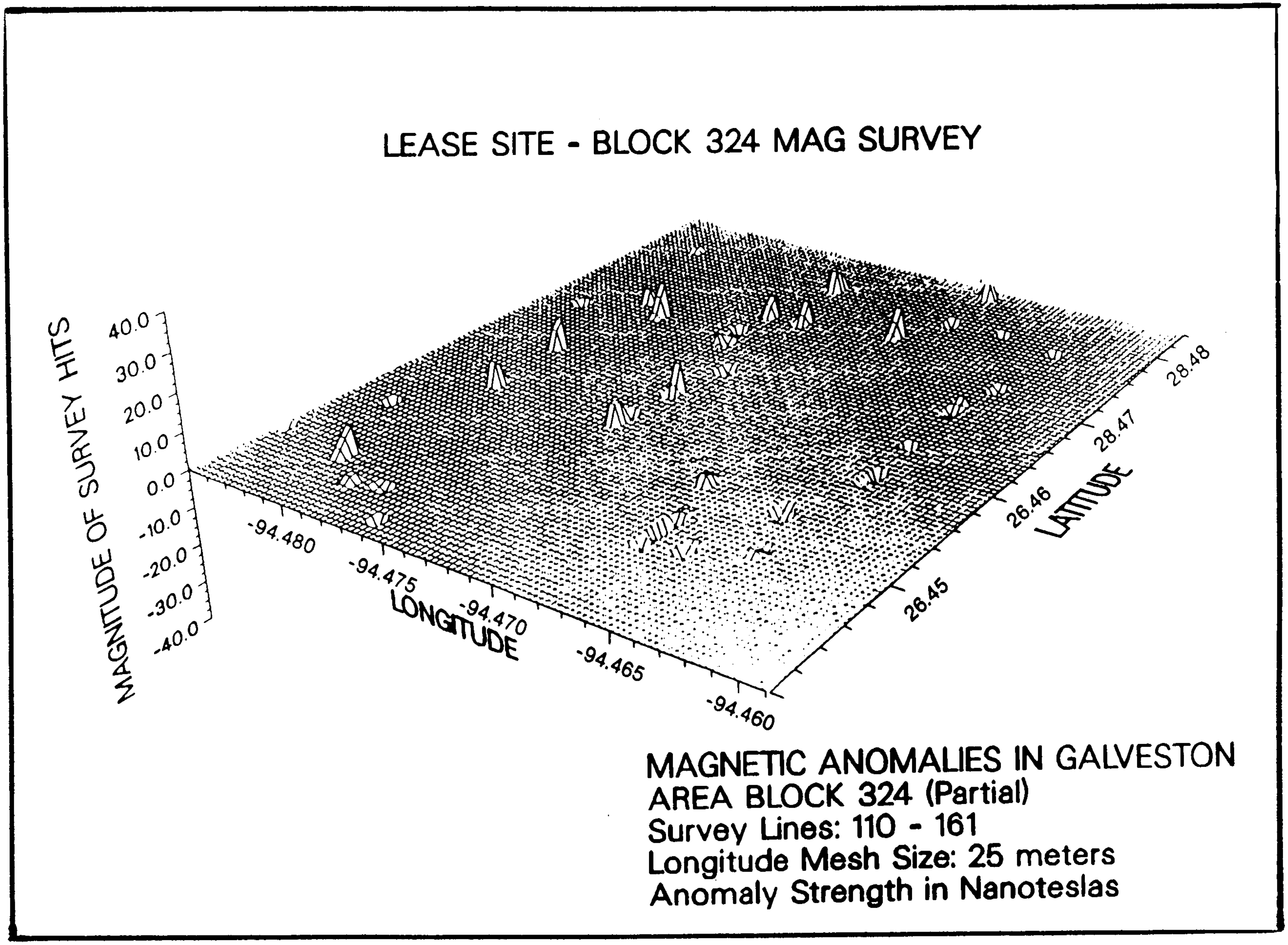


FIGURE II-72. Magnetic contour map, GA 324.


LEASE SITE - BLOCK 324 MAG SURVEY

MAGNETIC ANOMALIES IN GALVESTON AREA BLOCK 324 (Partial)
Survey Lines: 110 - 161
Longitude Mesh Size: 25 meters
Anomaly Strength in Nanoteslas

FIGURE II-73. Isometric view of magnetic data, GA 324.

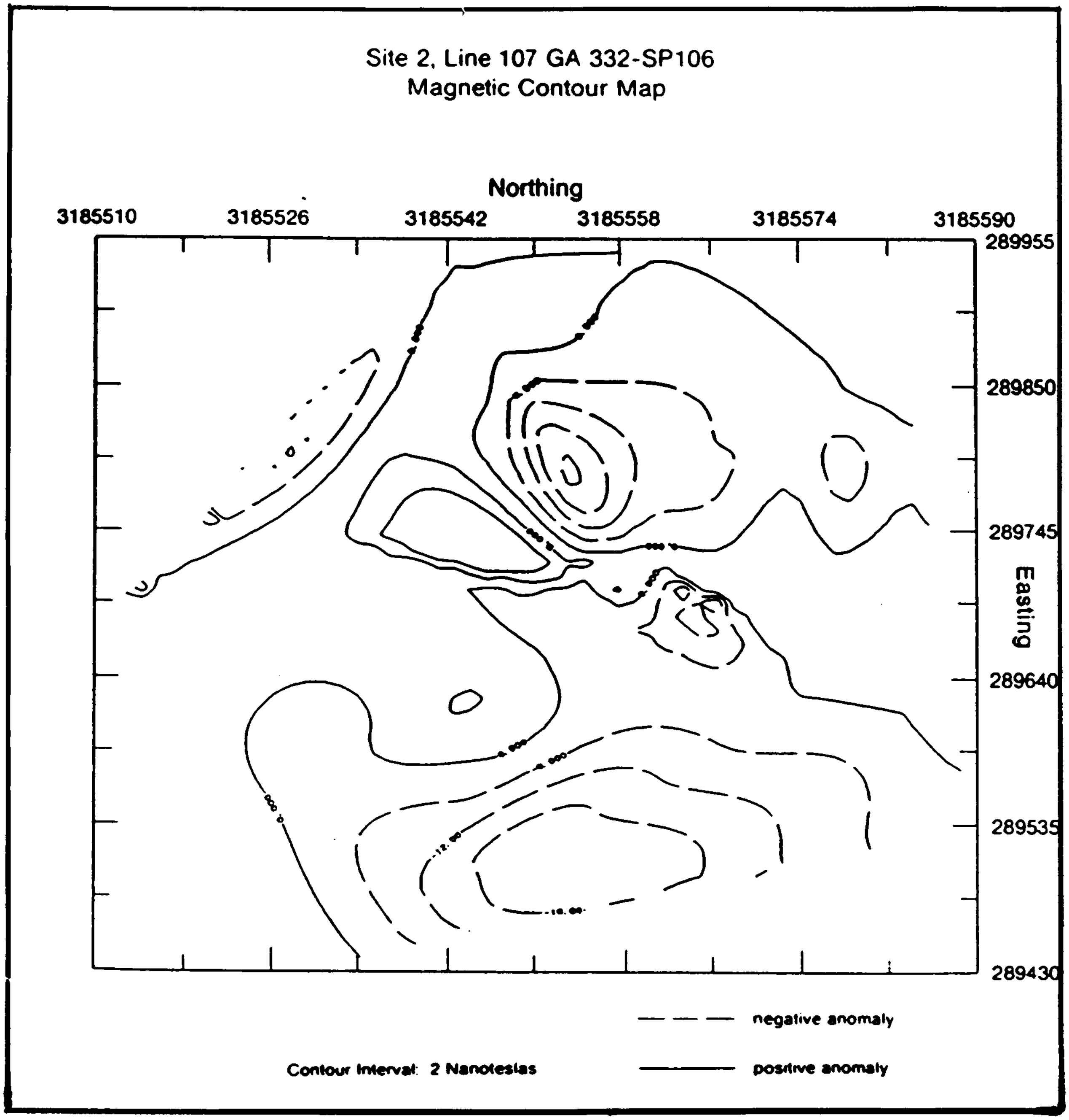


FIGURE II-74. Contour plot of site 2, 207 GA 332.

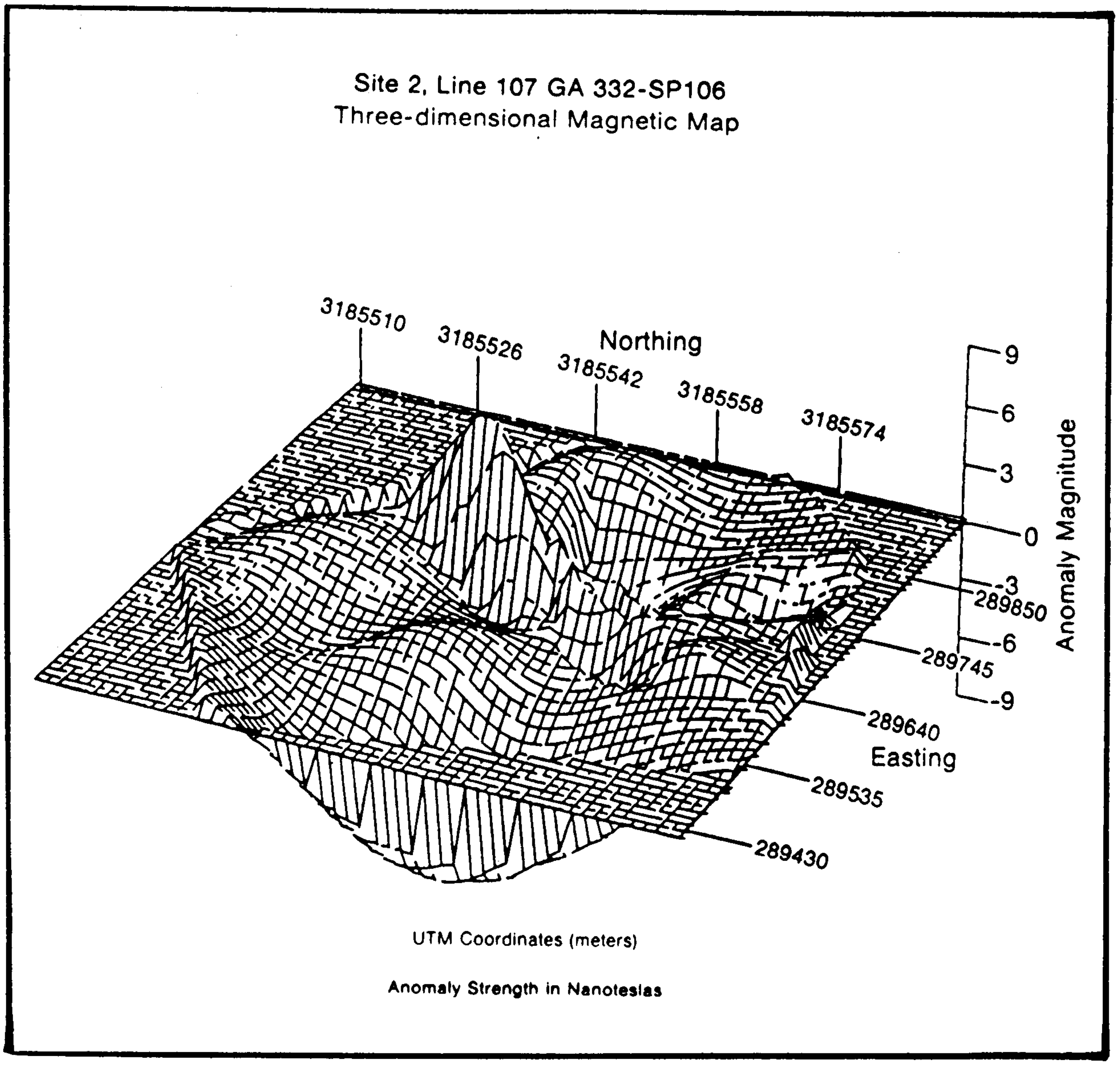


FIGURE II-75 Three dimensional plot of site 2, 107 GA 332.

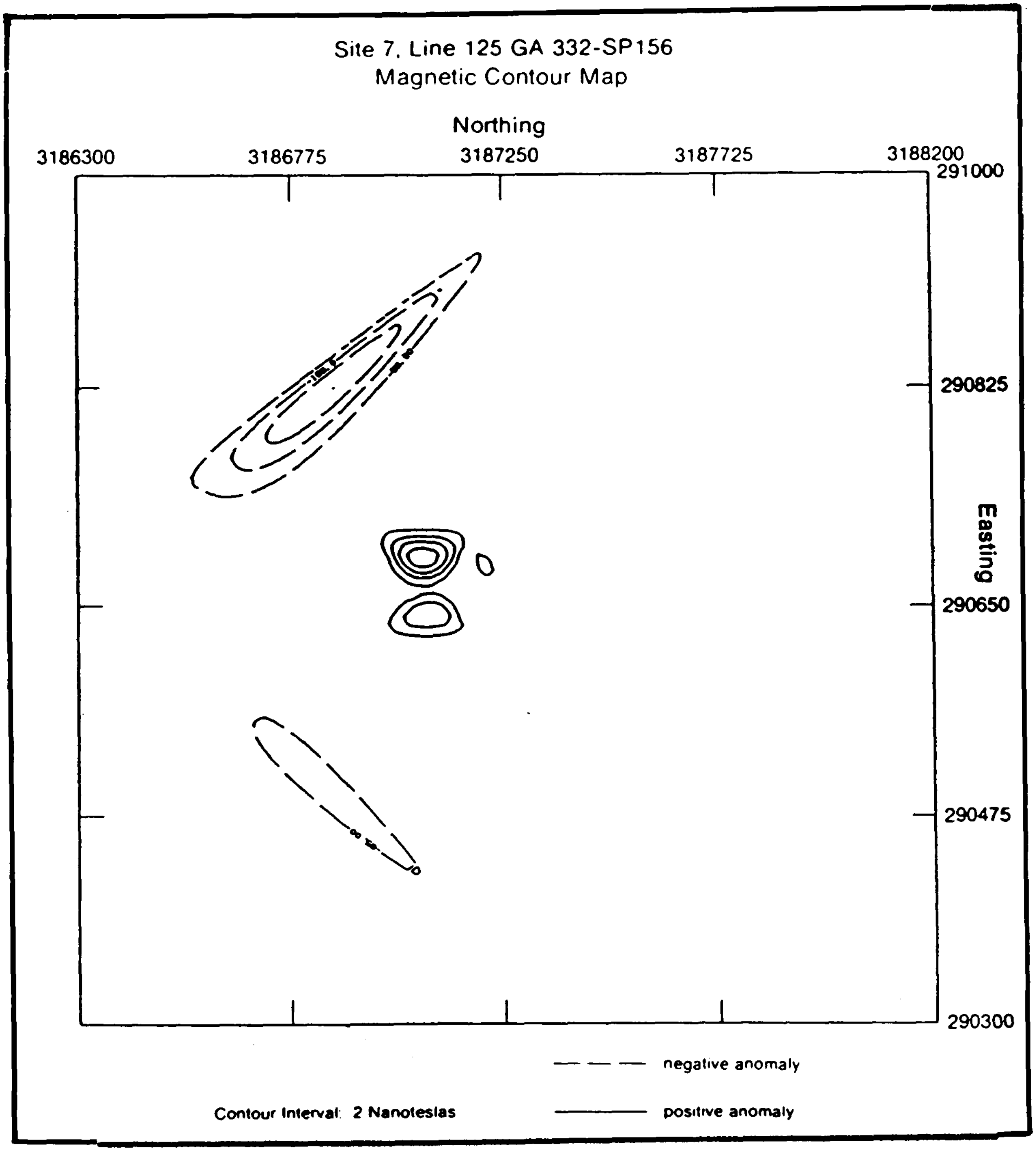


FIGURE II-76. Contour plot of site 7, 125 GA 332.

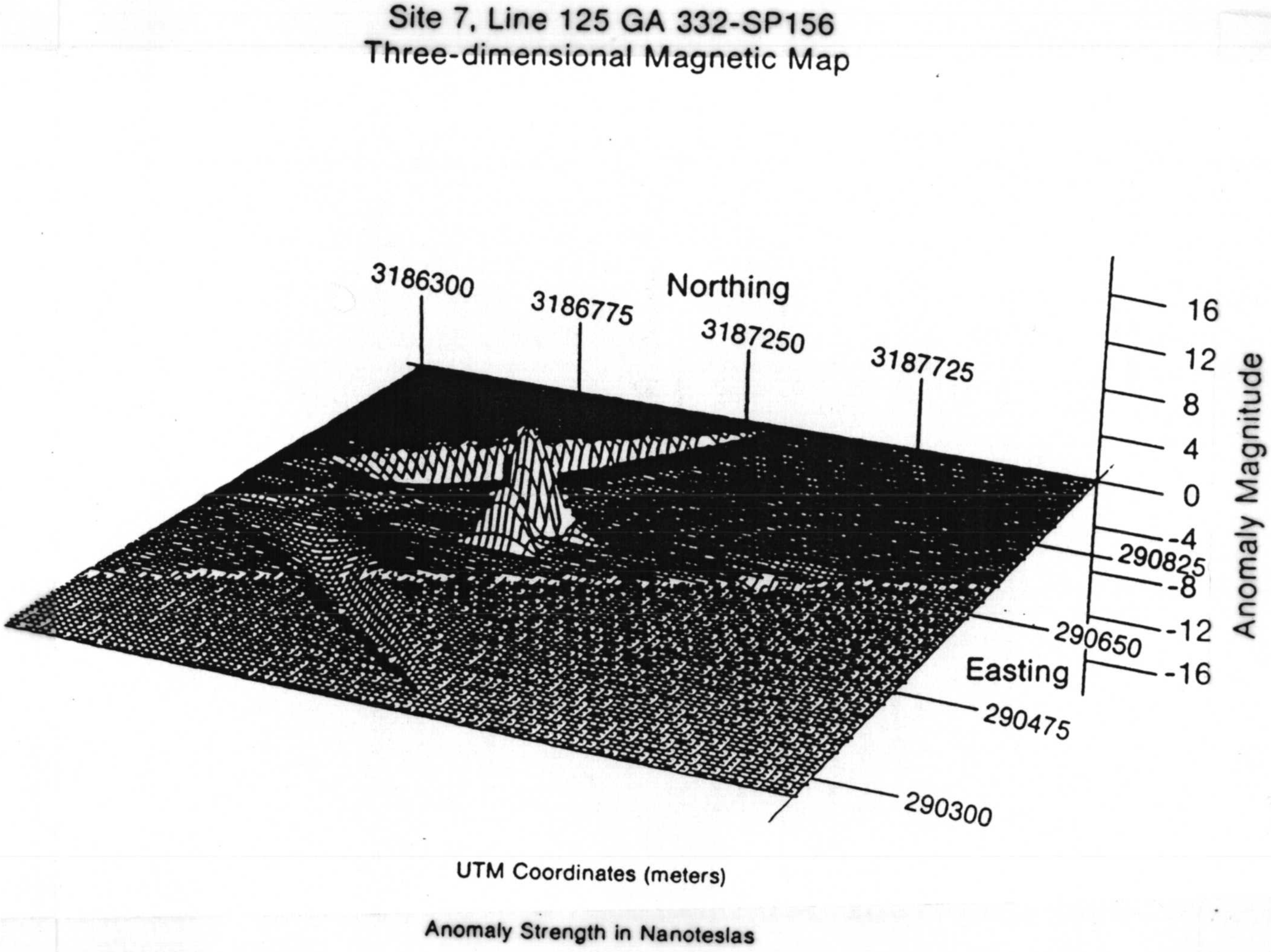


FIGURE II-77. Three dimensional plot of site 7, 125 GA 332.

14.1.4.3 Site 8, Line 137 GA 332-SP144

The anomaly found during resurvey was relocated during groundtruthing as a moderate magnetic feature (Appendix K, Figures 8b, and 8c). The small spatial extent and duration (2-3 m) together with a lack of complexity is shown in Figures II-78 and II-79. No dives were made on this site and it was classified as marine debris in an anchorage area.

14.1.4.4 Site 9, Line 148 GA 332-SP106

The 94 nT anomaly found on resurvey was more clearly defined upon groundtruthing relocation activities. The duration was significant, approaching 34 m (13.5 sec). The amplitude could not be duplicated, with 13 nT the maximum value recorded during relocation (Appendix K, Figure K-9b).

Our contour and isometric displays show a broad, localized anomaly centered over a buried source (Figure II-80 and II-81). Groundtruth dives were planned but could not be carried out due to poor weather on the last day of the field work. The signature resembles that of remnantly magnetic cable or chain. The anomaly shows no distinct orientation affects which would be associated with a liner source such as pipe.

14.1.4.5 Site 11, Line 152 GA 313-SP114

This feature was originally classified as a side-scan sonar target without any associated magnetic anomaly (Figure II-82 and II-83). Upon relocation during groundtruthing activities, a low amplitude anomaly was detected.

Divers located the scar marks of a large jack up drilling rig. These depressions were up to 1.5 m in depth (Appendix K, Figures K-11a and K-11b). Metal detector survey of two depressions proved negative.

14.1.4.6 Site 12, Line 164 GA 313-SP162

This side-scan sonar target (Appendix K) had no large magnetic features. The anomaly shown (Figures II-84 and II-85) is not believed to be associated with the long anchor drag scar. This identification is made based on the characteristics of the sonar image notably the chain pattern at the end of the drag. Divers confirmed the identification of the feature during an easy relocation.

14.1.4.7 Site 13, Line 175 GA 313-SP126

This broad anomaly (6 sec, 15 m) has a monopolar character when detected on a single line (Appendix K, Figure K-13a). This is true for adjacent lines with the sign of the anomaly changing with line direction (Appendix K, Figure K-13b, c). Maximum amplitude is 29 nT(Appendix K, Figure K-13b).

Graphical display of the relocation magnetic data shows a different spatial character to the anomaly. In the data we see three separate monopoles (Figures II-86 and II-87). These are shown in other perspectives such as the contour and isometric grid displays. Groundtruthing by divers located a cable whose spatial extent clearly shows why the magnetic pattern is as it is, e.g., a large loop that individual lines represent a single monopolar anomalies.

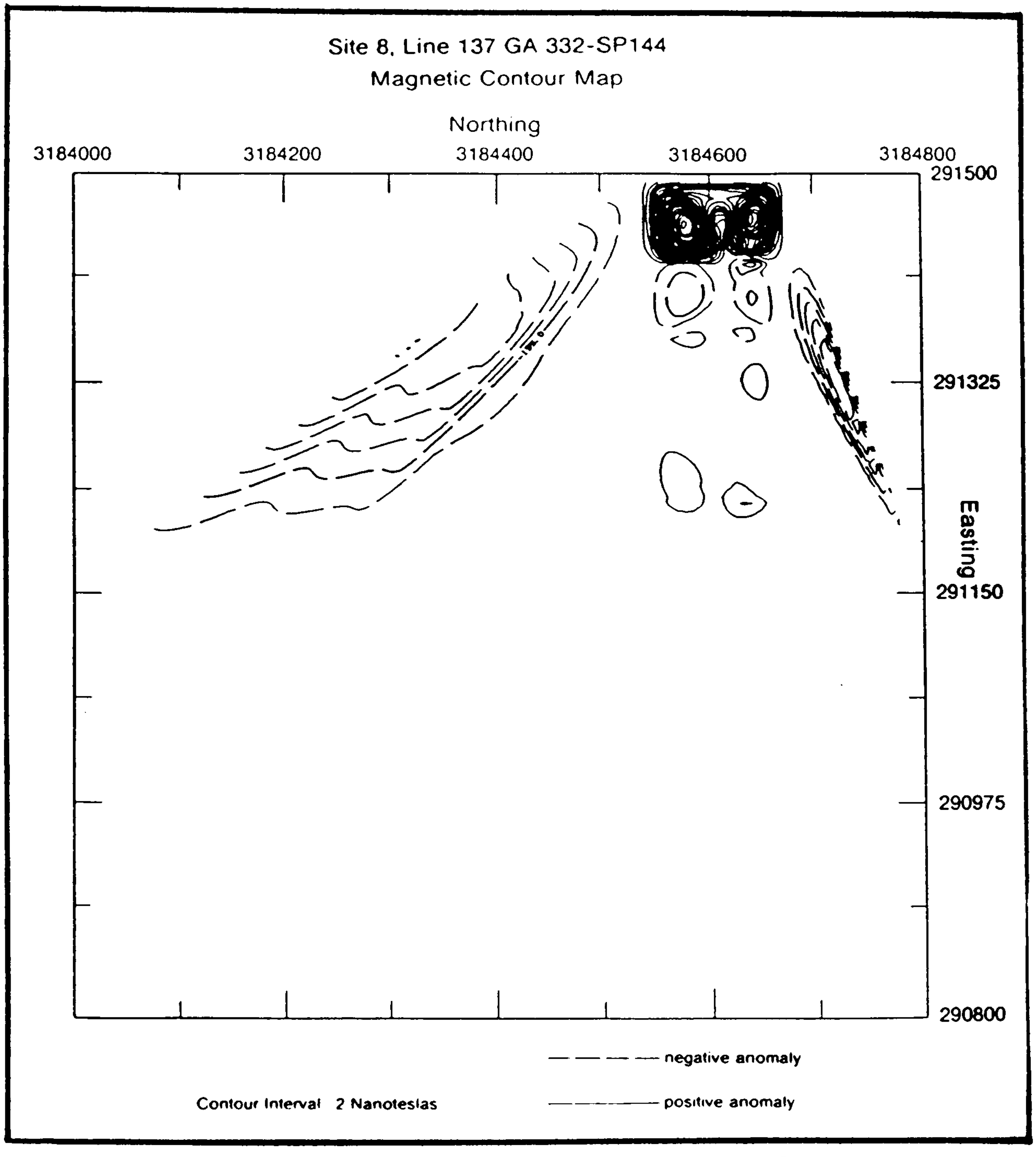


FIGURE II-78. Contour plot of site 8, 137 GA 332.

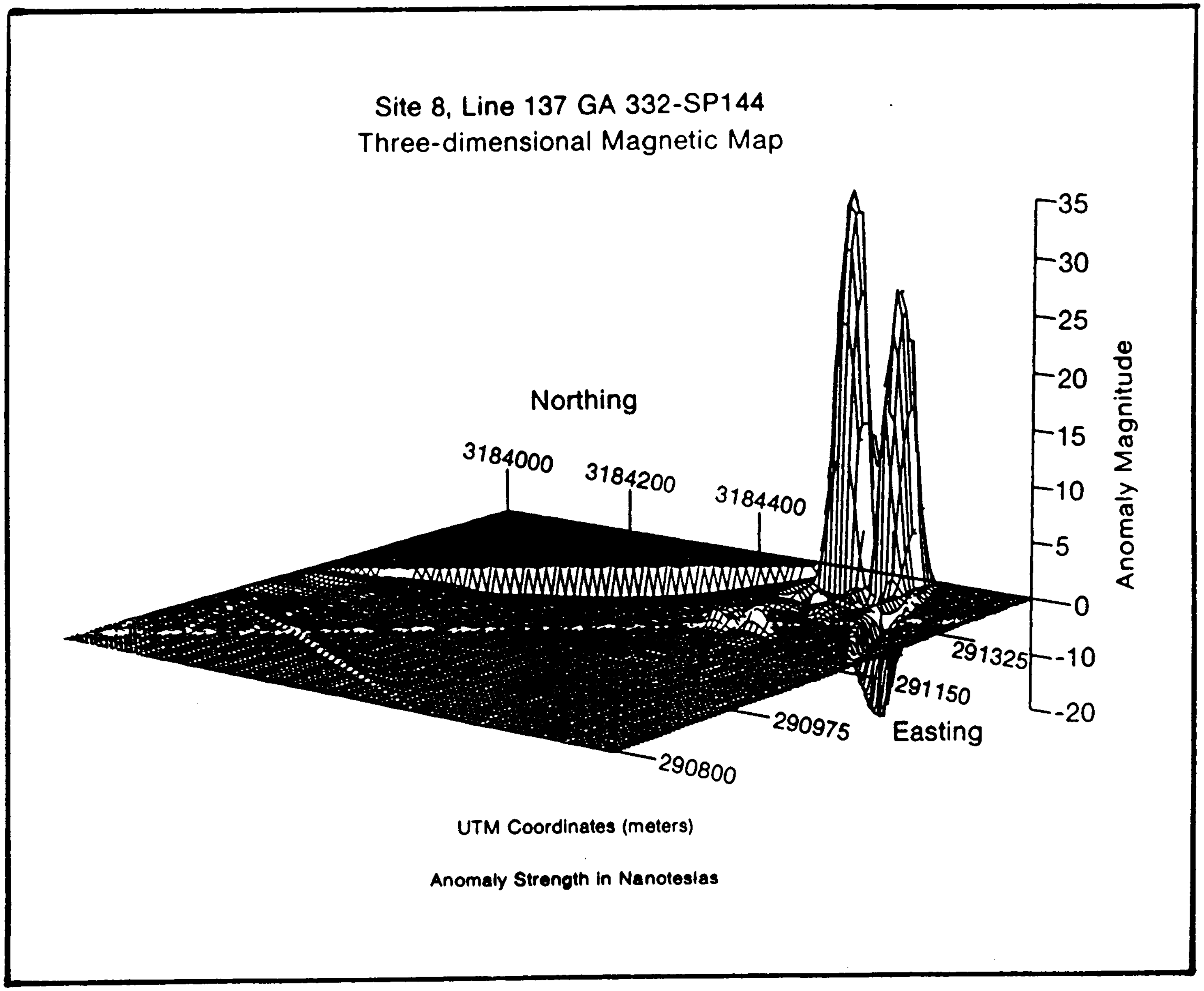


FIGURE II-79. Three dimensional plot of site 8, 148 GA 332.

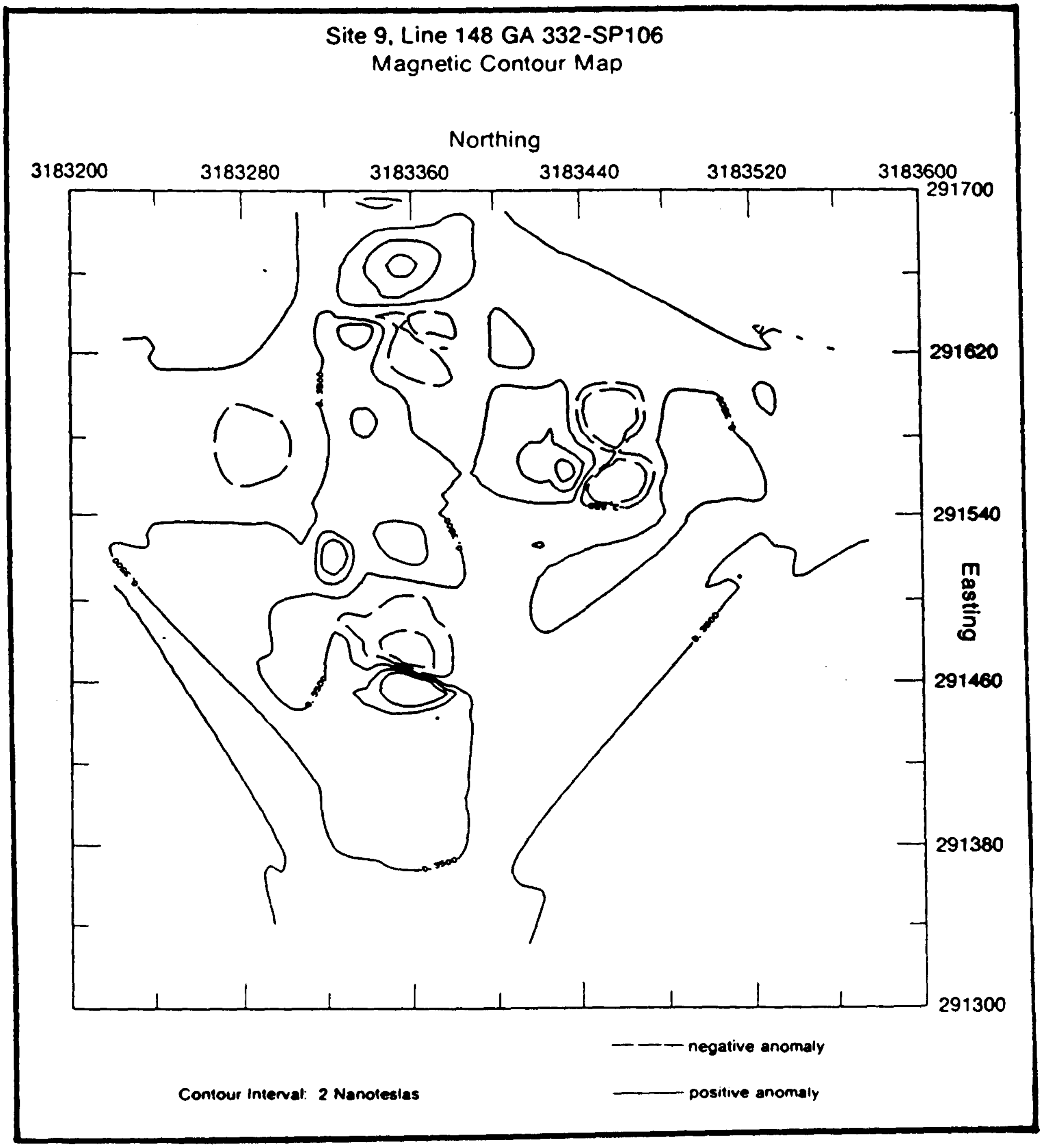


FIGURE II-80. Contour plot of site 9, 148 GA 332.

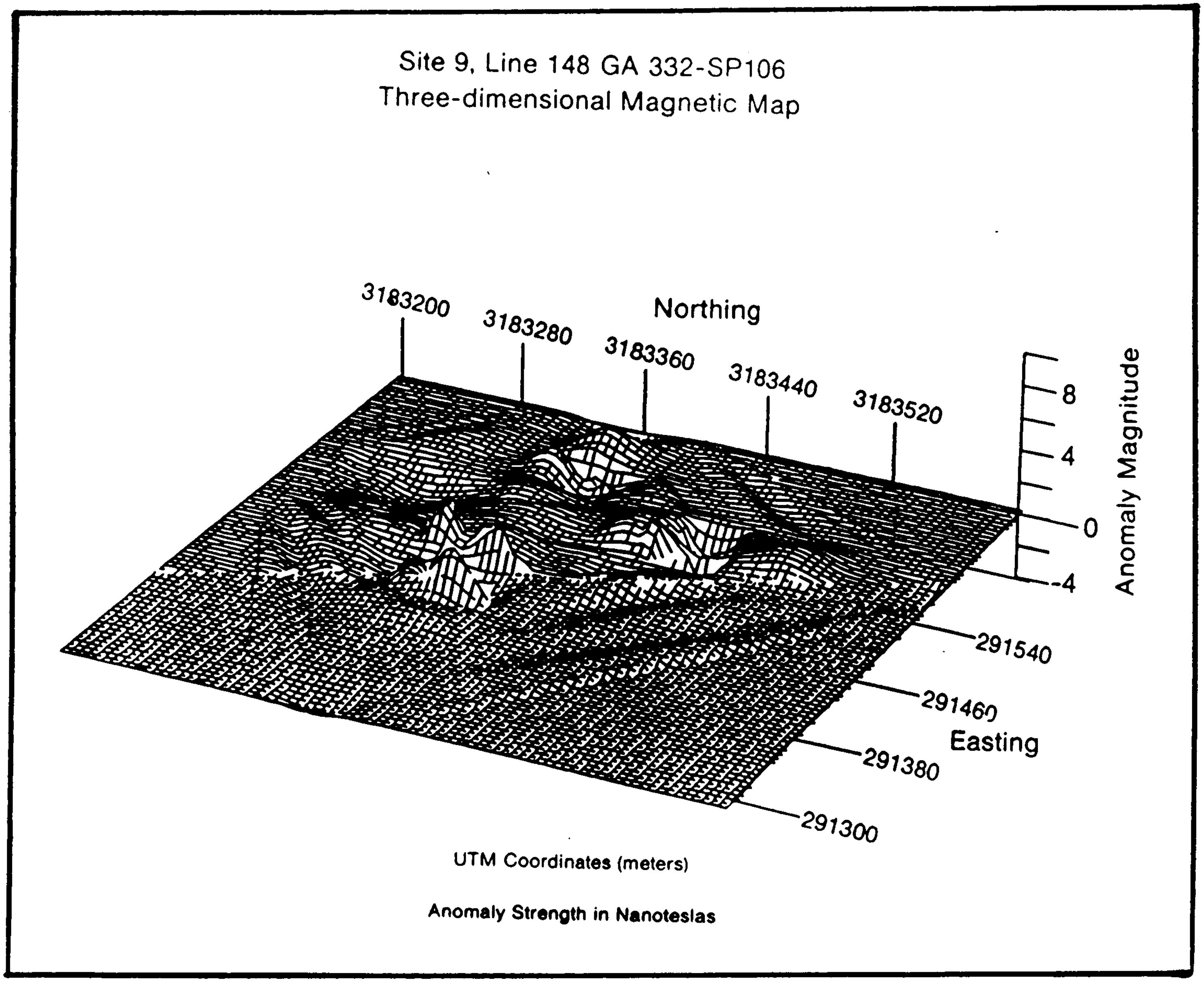


FIGURE II-81. Three dimensional plot of site 9, 148 GA 332.

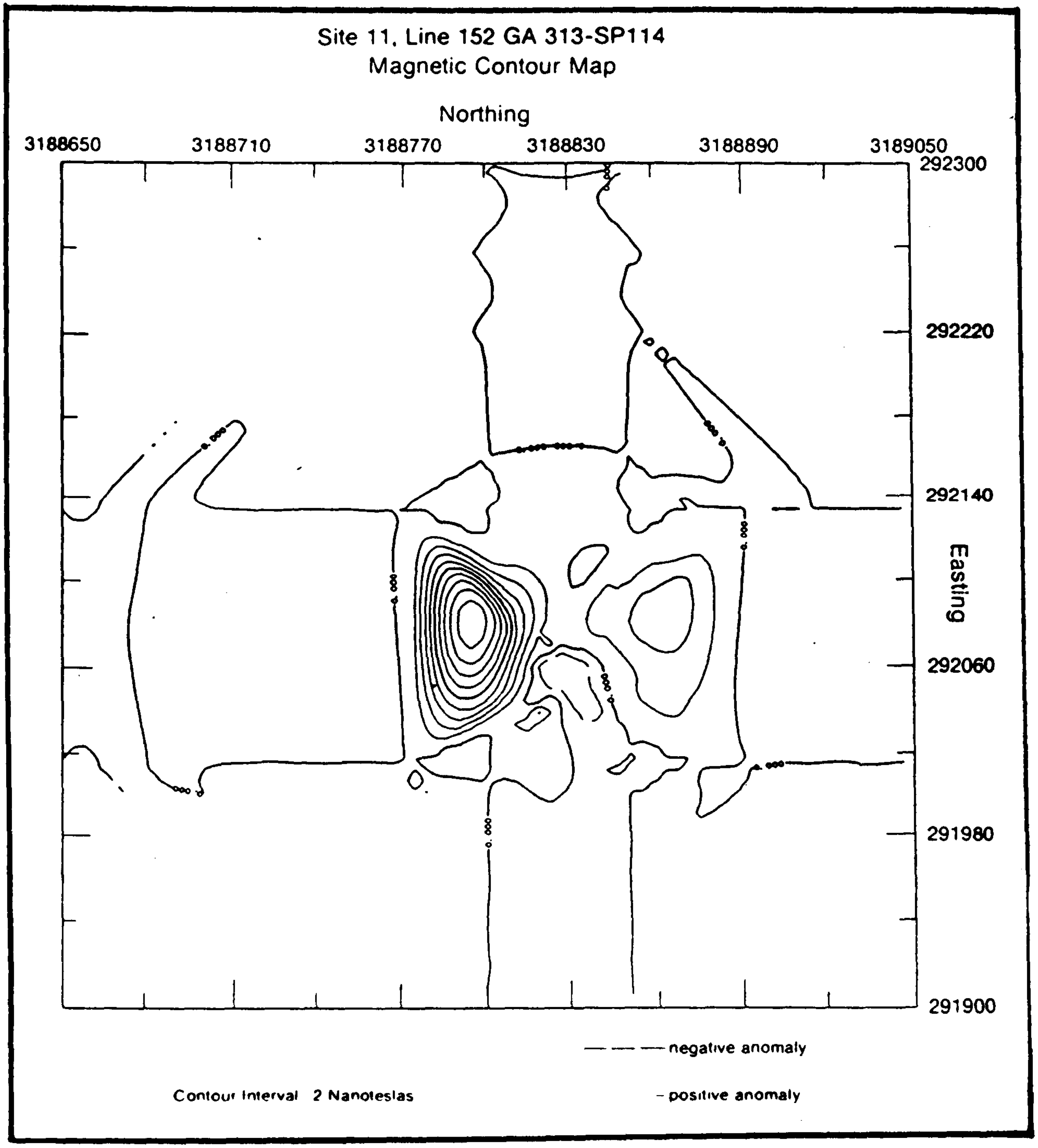


FIGURE II-82. Contour plot of site 11, 152 GA 313.

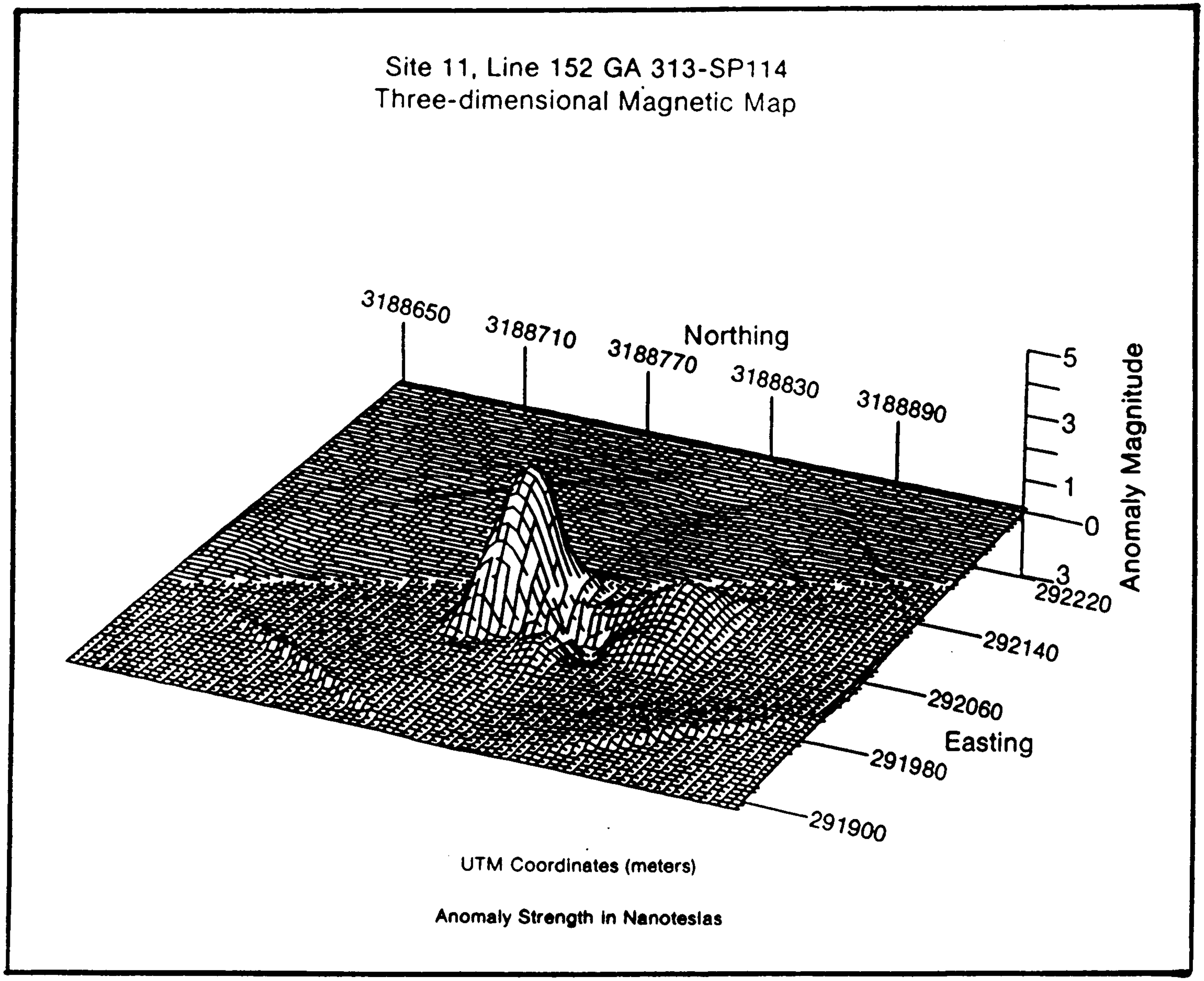


FIGURE II-83. Three dimensional plot of site 11, 152 GA 313.

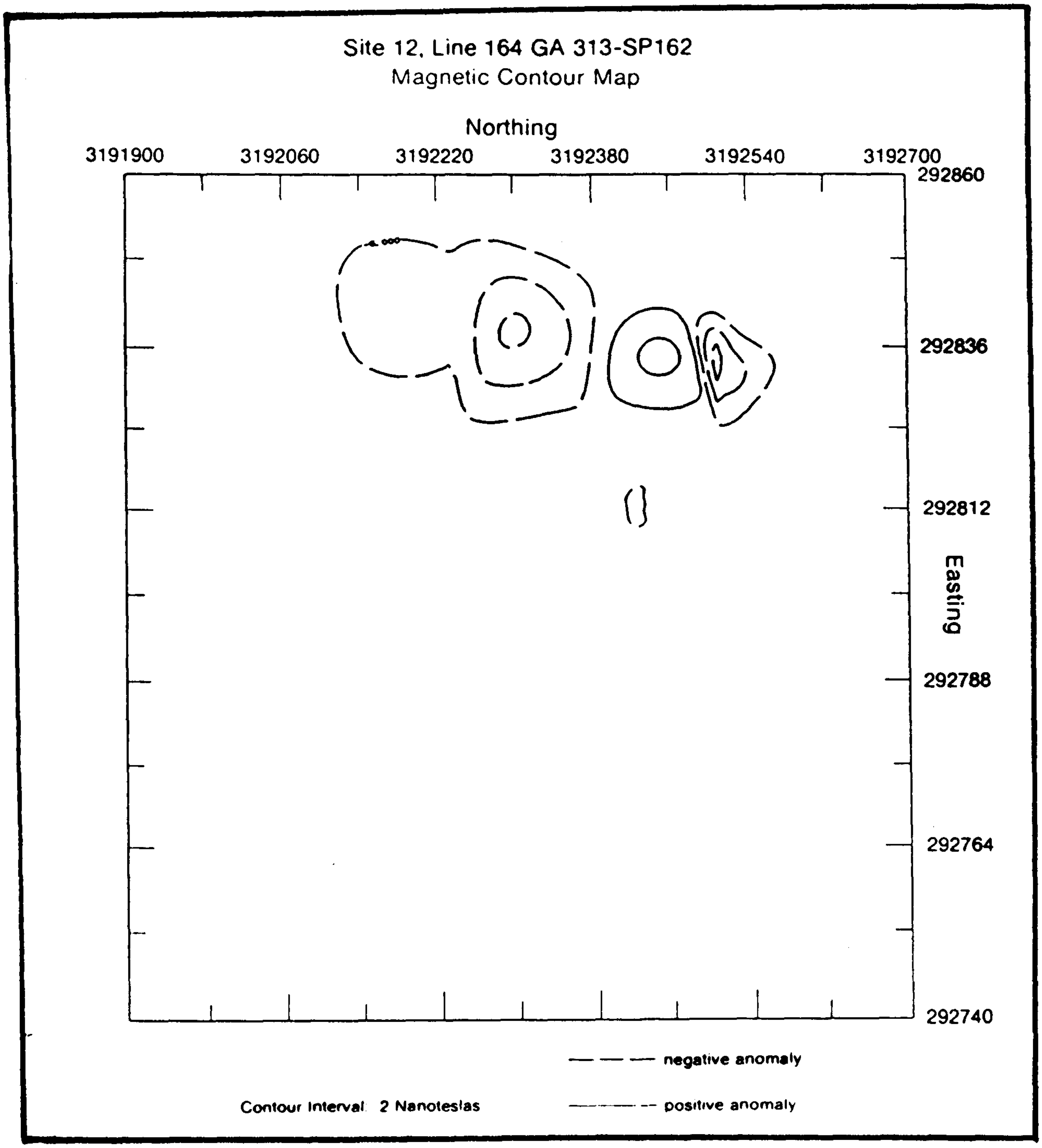
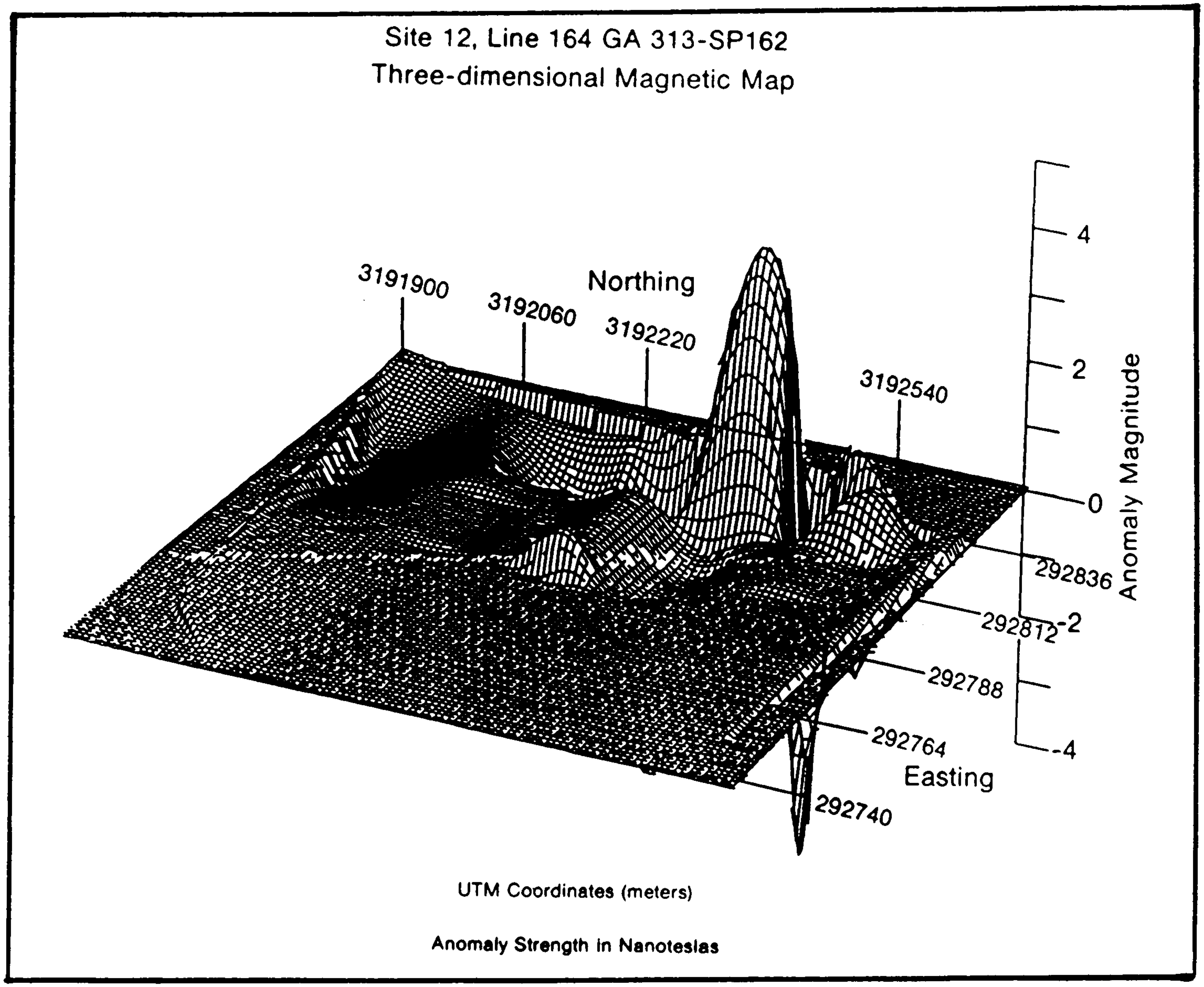


FIGURE 11-84. Contour Plot of site 12, 164 GA 313.



Site 12, Line 164 GA 313-SP162
Three-dimensional Magnetic Map

UTM Coordinates (meters)

Anomaly Strength in Nanoteslas

FIGURE II-85. Three dimensional plot of site 12, 164 GA 313.

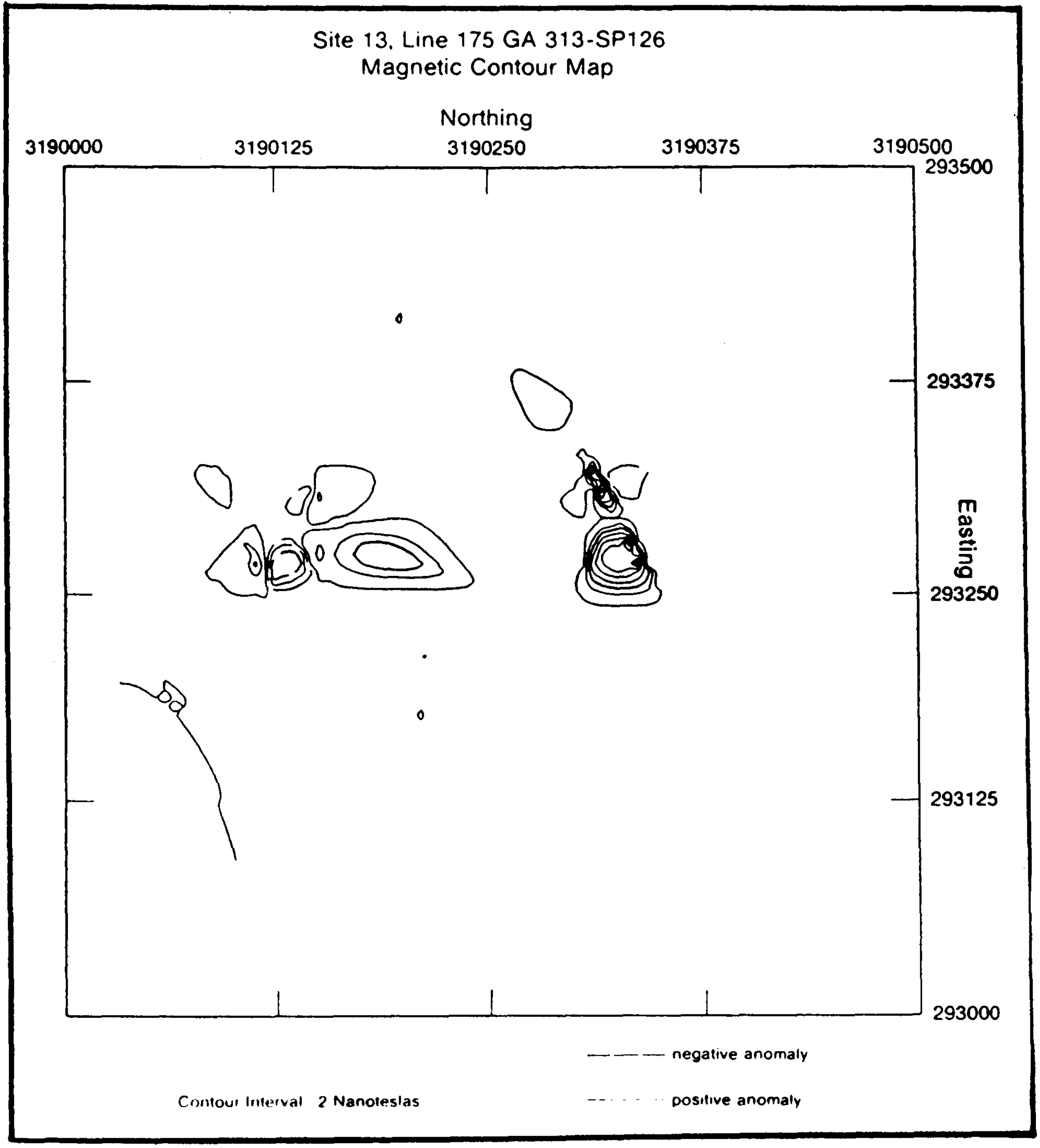


FIGURE II-86. Contour plot of site 13, 175 GA 313.

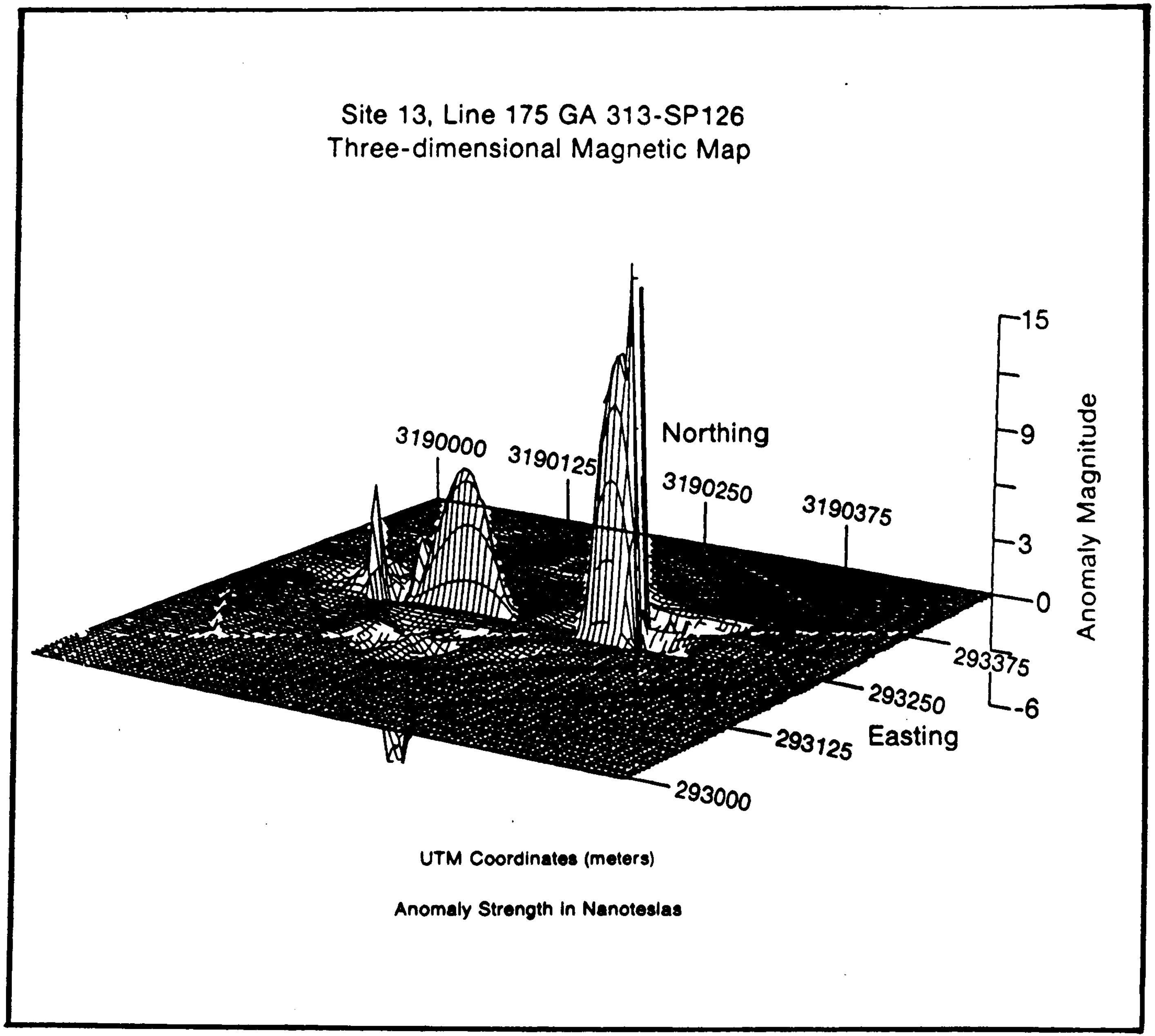


FIGURE II-87. Three dimensional plot of site 13, 175 GA 313.

14.1.4.8 Site 14, Line 185 GA 313-SP145

This is a cluster of anomalies with a dipolar feature of 50 nT (Appendix K, Figure K-14b) and adjacent anomalies (Appendix K, Figure K-14c,d) of lesser amplitudes.

The graphical presentations (Figures II-88 and II-89) give a good view of the spatial relationship as well as the distinct localities of the sources. The difference in amplitudes militate against an interpretation of the features as cable, chain or pipe. The impression is one of scattered debris that is buried as groundtruthing by divers found no exposed materials or metal detector readings.

14.1.4.9 Site 18, Line 202 GA 313-SP118

This side-scan sonar contact and magnetic anomaly is a good example of the type of marine debris located within an offshore structure toss zone. The source was identified as a two door refrigerator (Appendix K, Figure K-18a). This is not so apparent without the observation of the groundtruth divers. One could never determine the character of the feature from the magnetic data alone (Appendix K, Figure K-18b,c) even with the perspective of graphics (Figures II-90 and II-91). What is of note is the detectability of the localized magnetic signature against the larger gradient of the nearby platform.

14.1.4.10 Site 19, Line 205 GA 313-SP115

This side-scan sonar contact and magnetic anomaly was identified as a 55 gallon steel drum with assorted debris such as beer cans and wood associated with it. Its sonogram (Appendix K, Figure K-19c) shows a distinct image at 100 kHz. The magnetic signature is of a distinct dipole of 29 nT (Appendix K, Figure K-19a) when the sensor is directly over the object. When originally found the feature was only detected by side-scan sonar. The display of the data acquired during relocation prior to groundtruthing dives (Figures II-92 and II-93) shows a localized anomaly of minimal duration and amplitude consistent with expectations of a source such as this.

14.1.4.11 Site 20, Line 207 GA 313-SP147

This side-scan sonar contact and magnetic anomaly was found to be another barrel. Its magnetic and sonar signatures are identical to those seen for site 19 (Appendix K, Figures K-20a-d) (Figures II-94 and II-95). The dipolar signature diminishes in amplitude within 30 m of the source making it magnetically invisible to surveys using linespacing of 50 m or more.

14.1.4.12 Site 21, Line 229 GA 313-SP108

Detected only by magnetometer during resurvey (Appendix K, Figure K-21a) (Figures II-96 and II-97) relocation signatures of this 6 m pipe were consistent with those expected for an object of this type (Appedix K, Figure K-21b-d). As the pipe was buried in 15-20 cm of mud it could only be relocated by probing and the use of a metal detector.

Graphical display of the data shows a sharply linear feature.

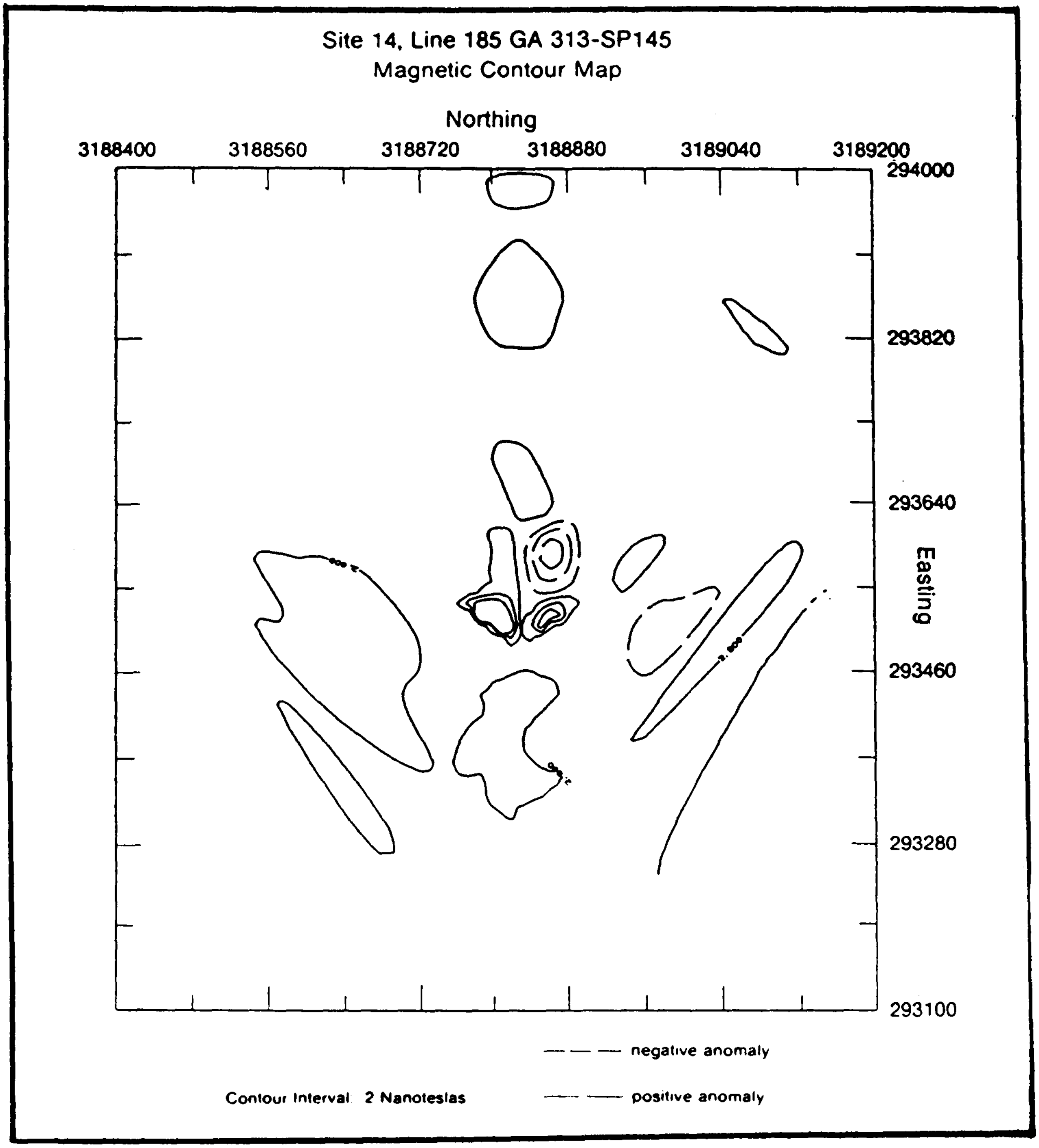


FIGURE II-88. Contour plot of site 14, 185 GA 313.

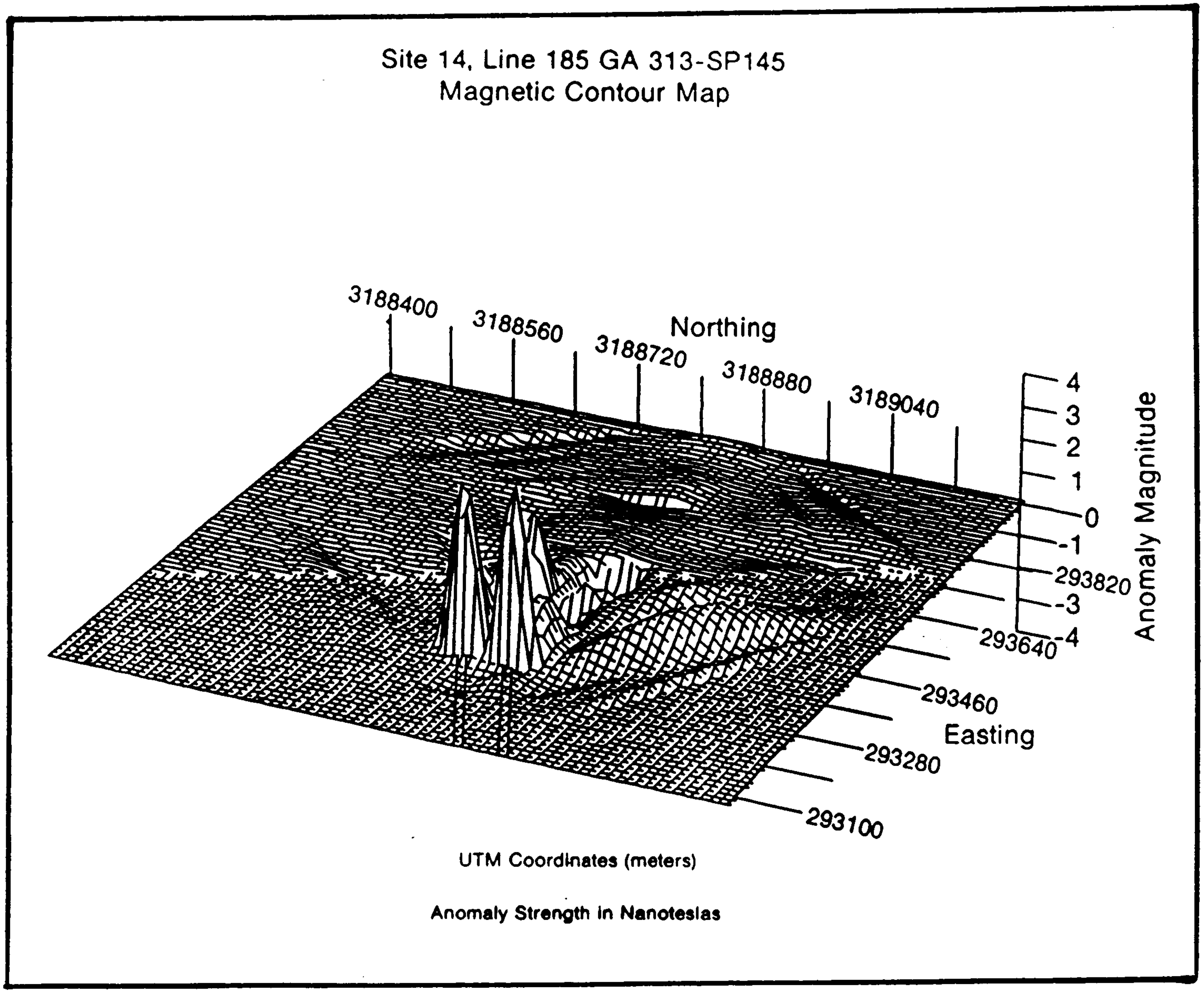


FIGURE II-89. Three dimensional plot of site 14, 185 GA 313.

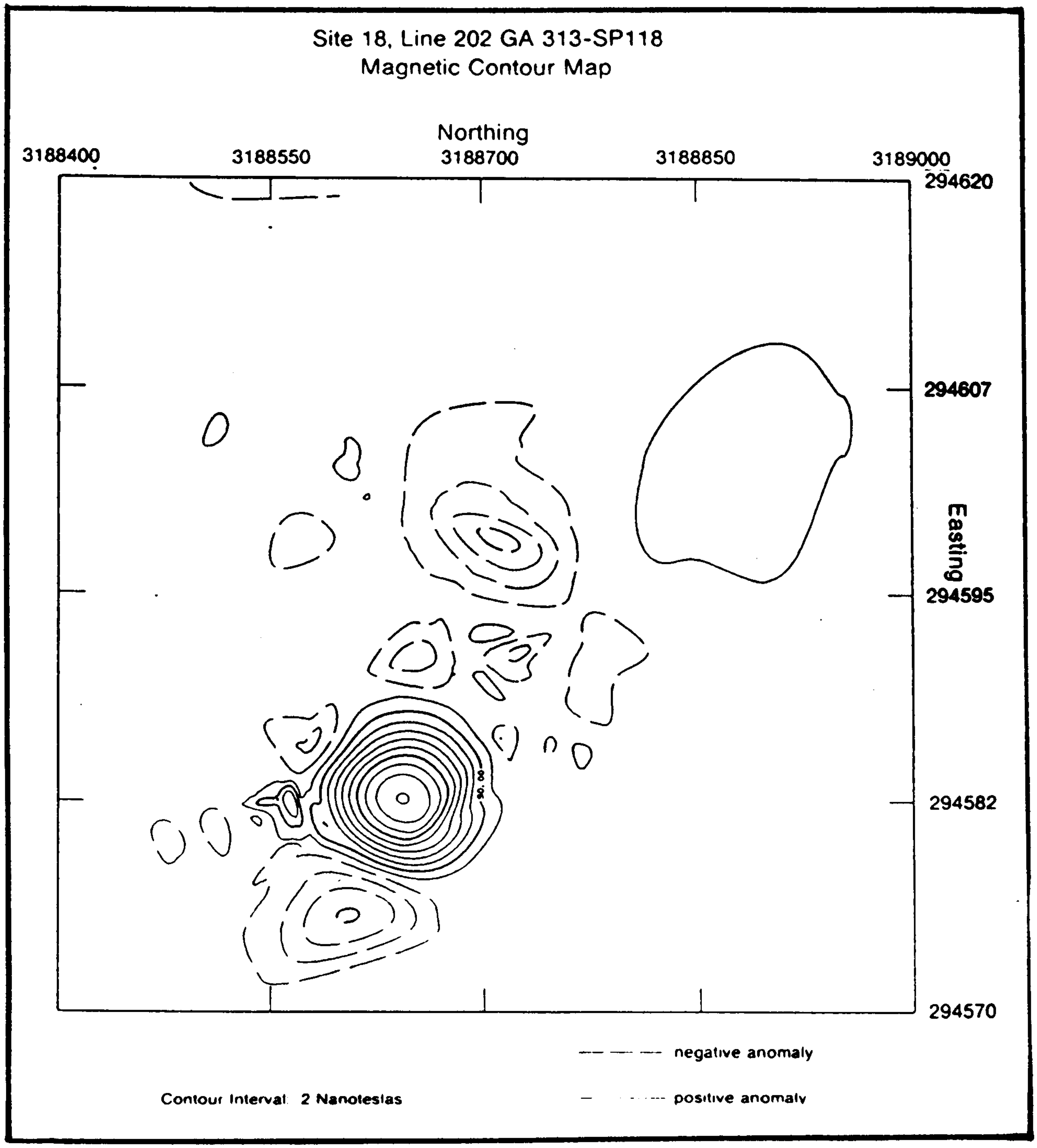


FIGURE II-90. Contour plot of site 18, 202 GA 313.

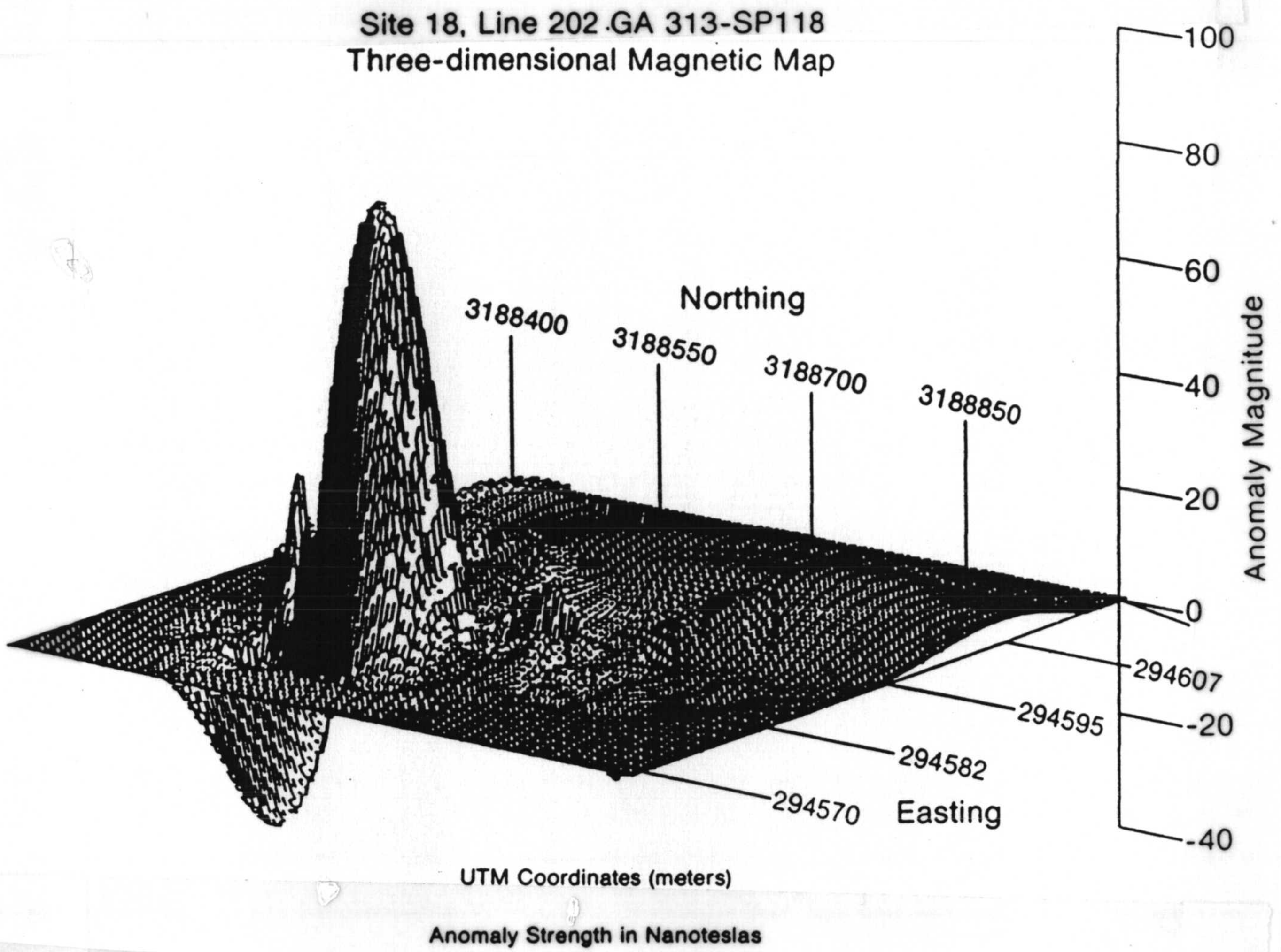


FIGURE II-91. Three dimensional plot of site 18, 202 GA 313.

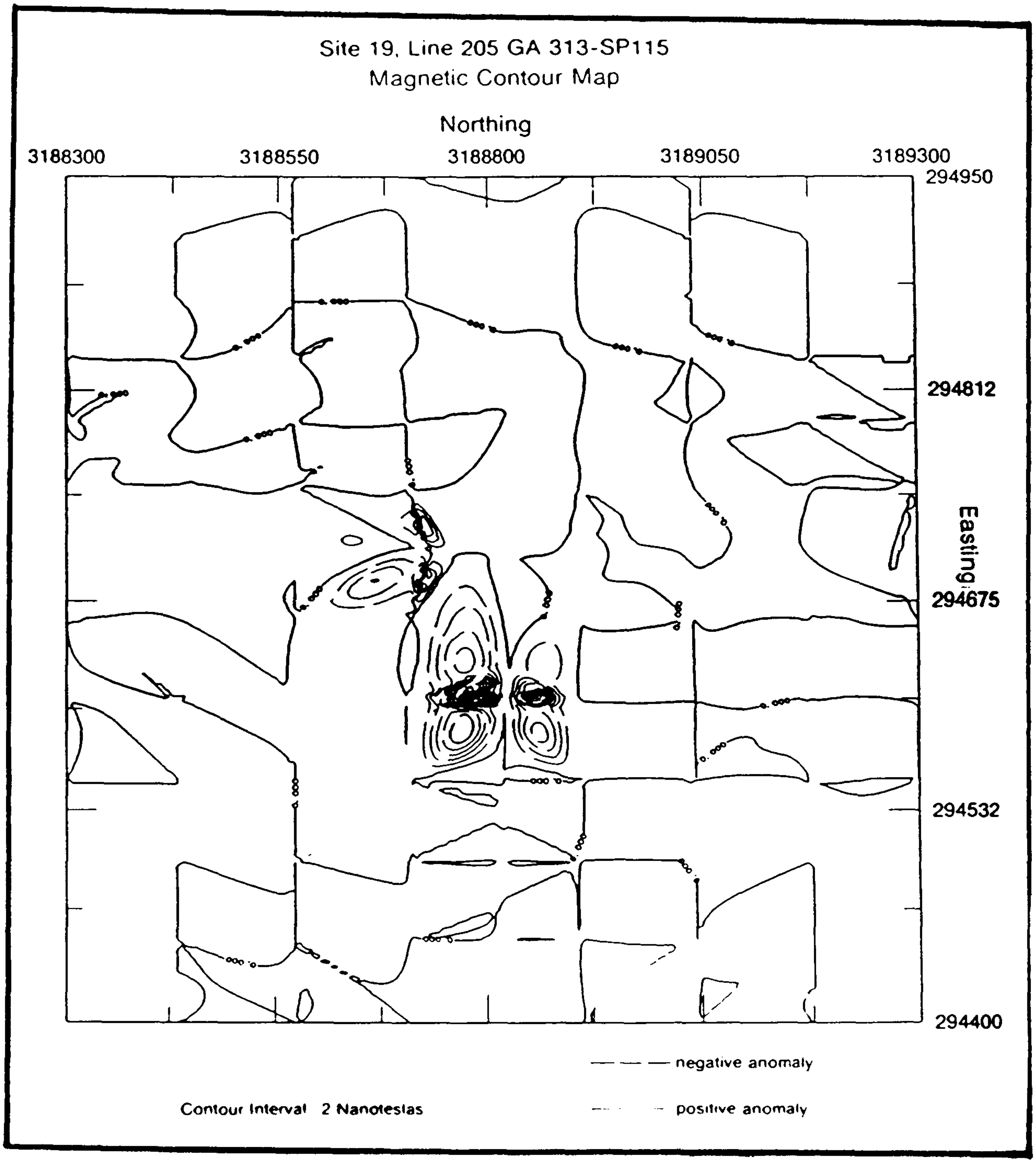


FIGURE II-92. Contour plot of site 19, 205 GA 313.

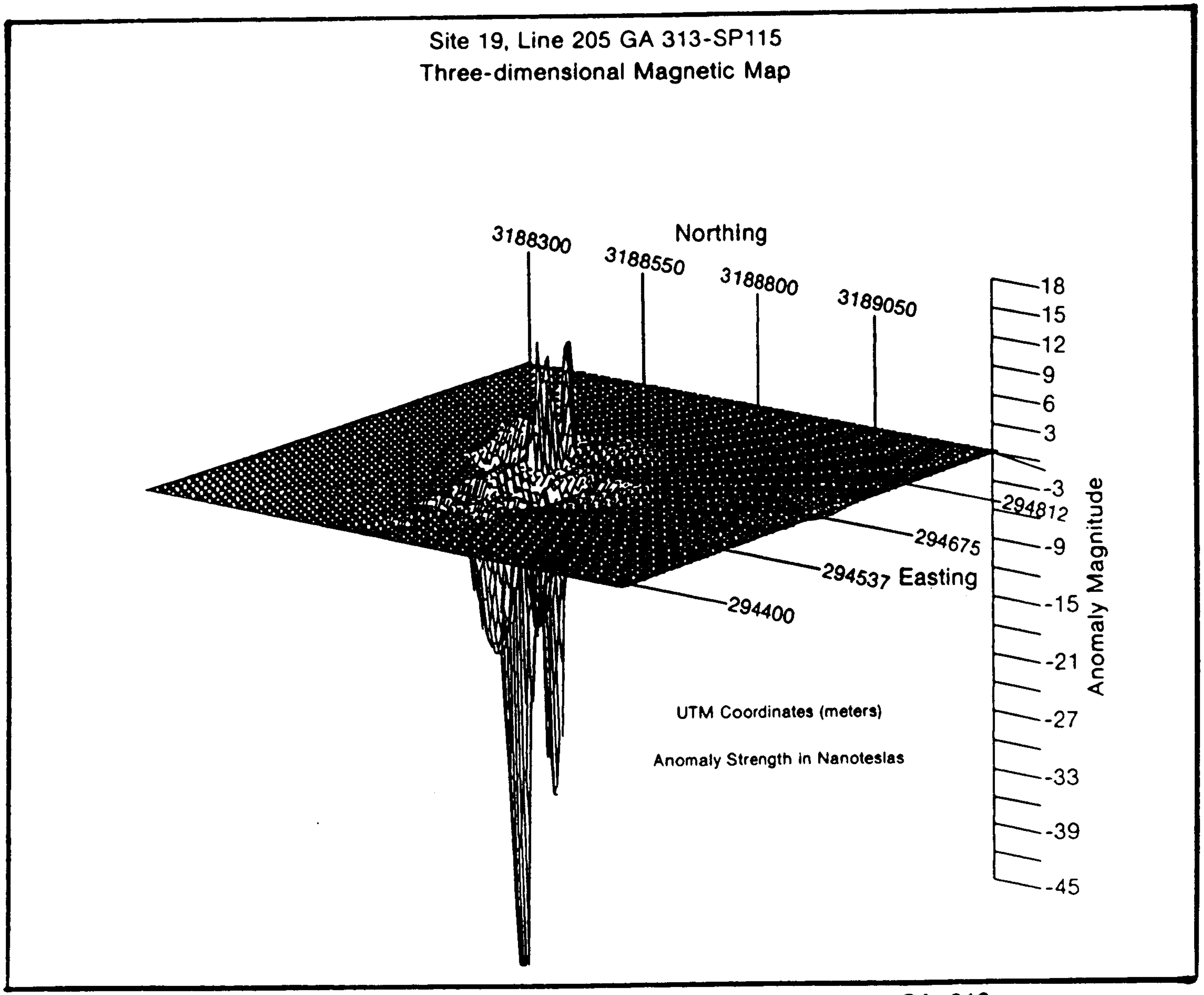


FIGURE II-93. Three dimensional plot of site 19, 205 GA 313.

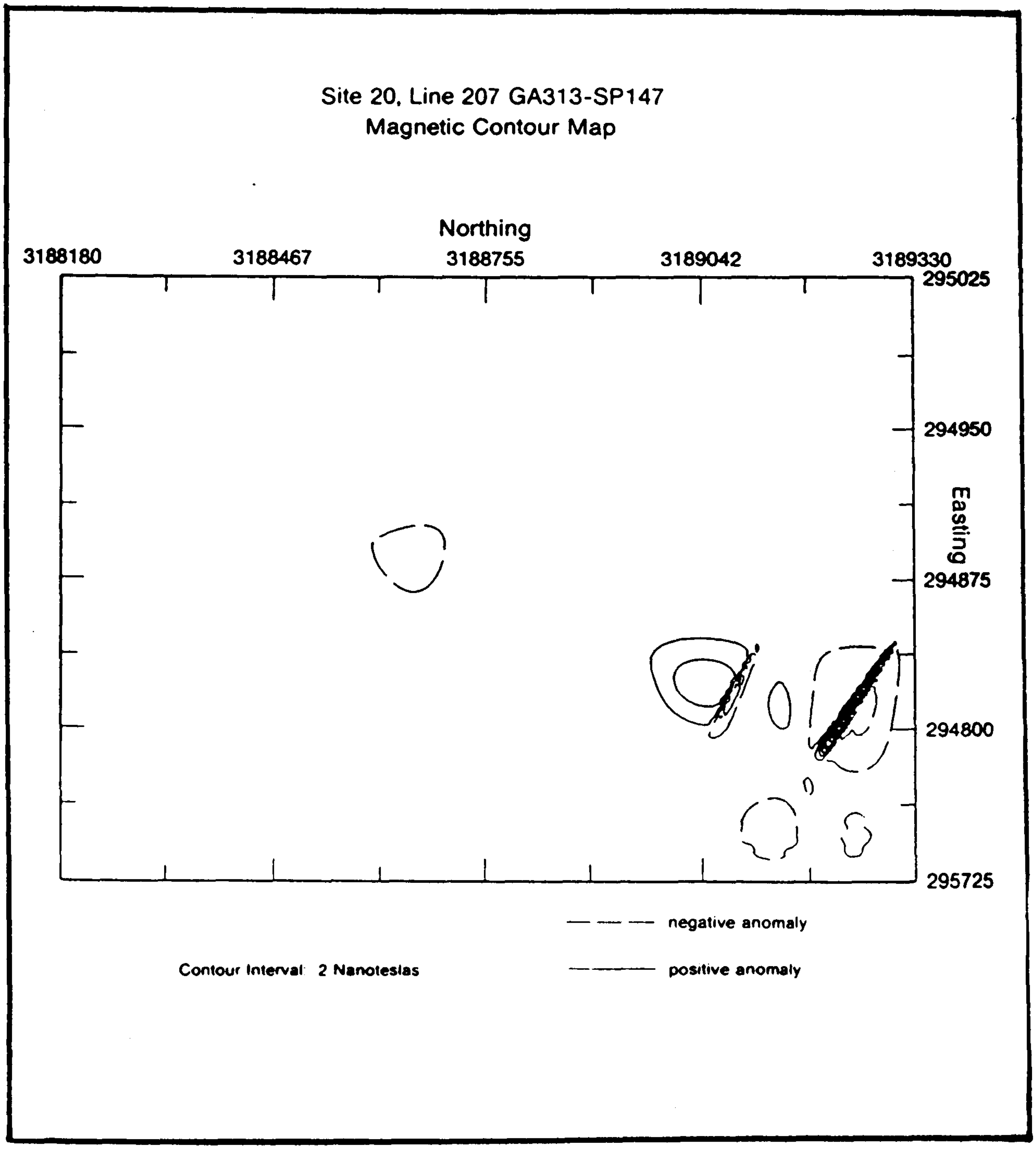


FIGURE II-94. Contour plot of site 20, 207 GA 313.

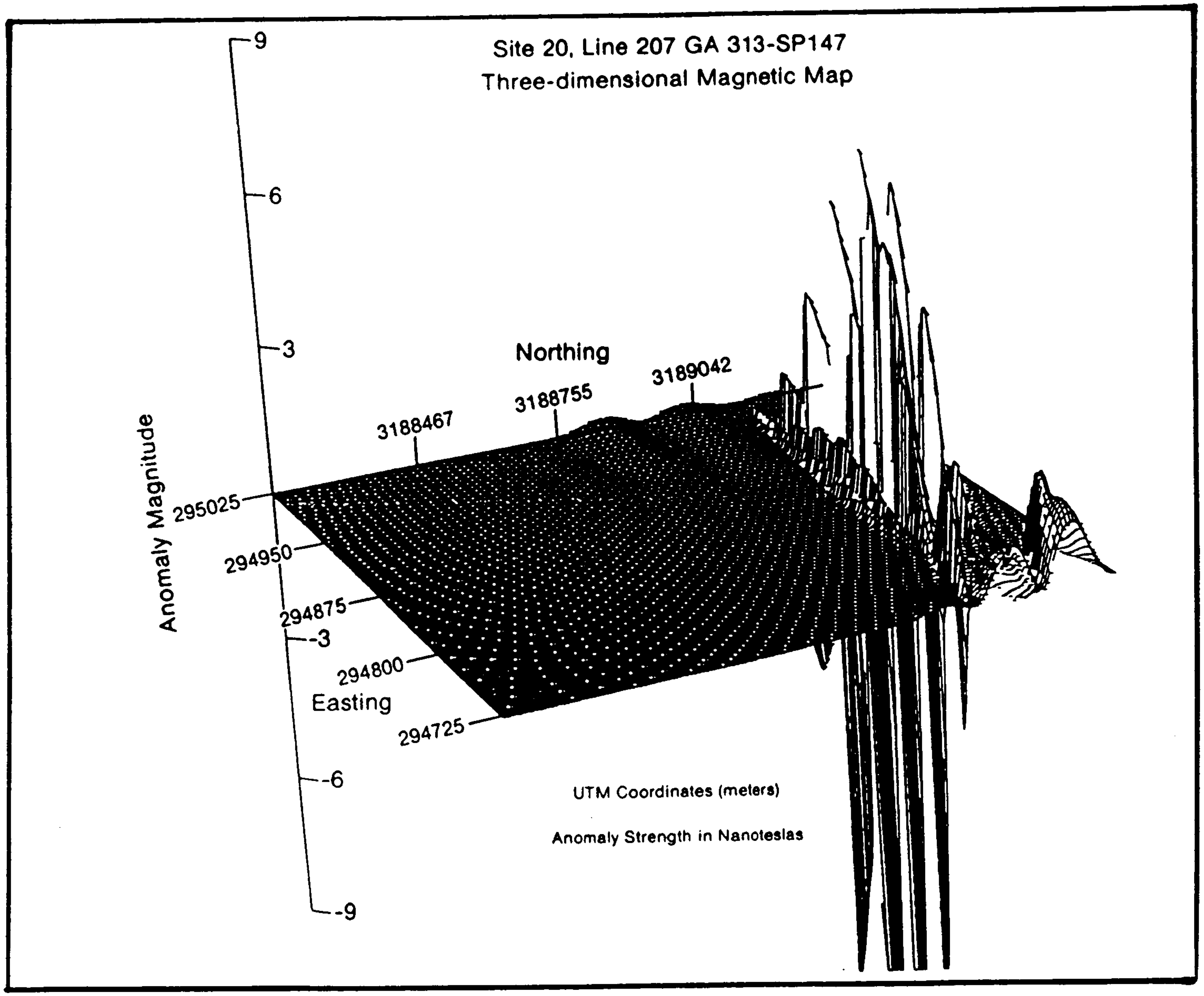


FIGURE II-95. Three dimensional plot of site 20, 207 GA 313.

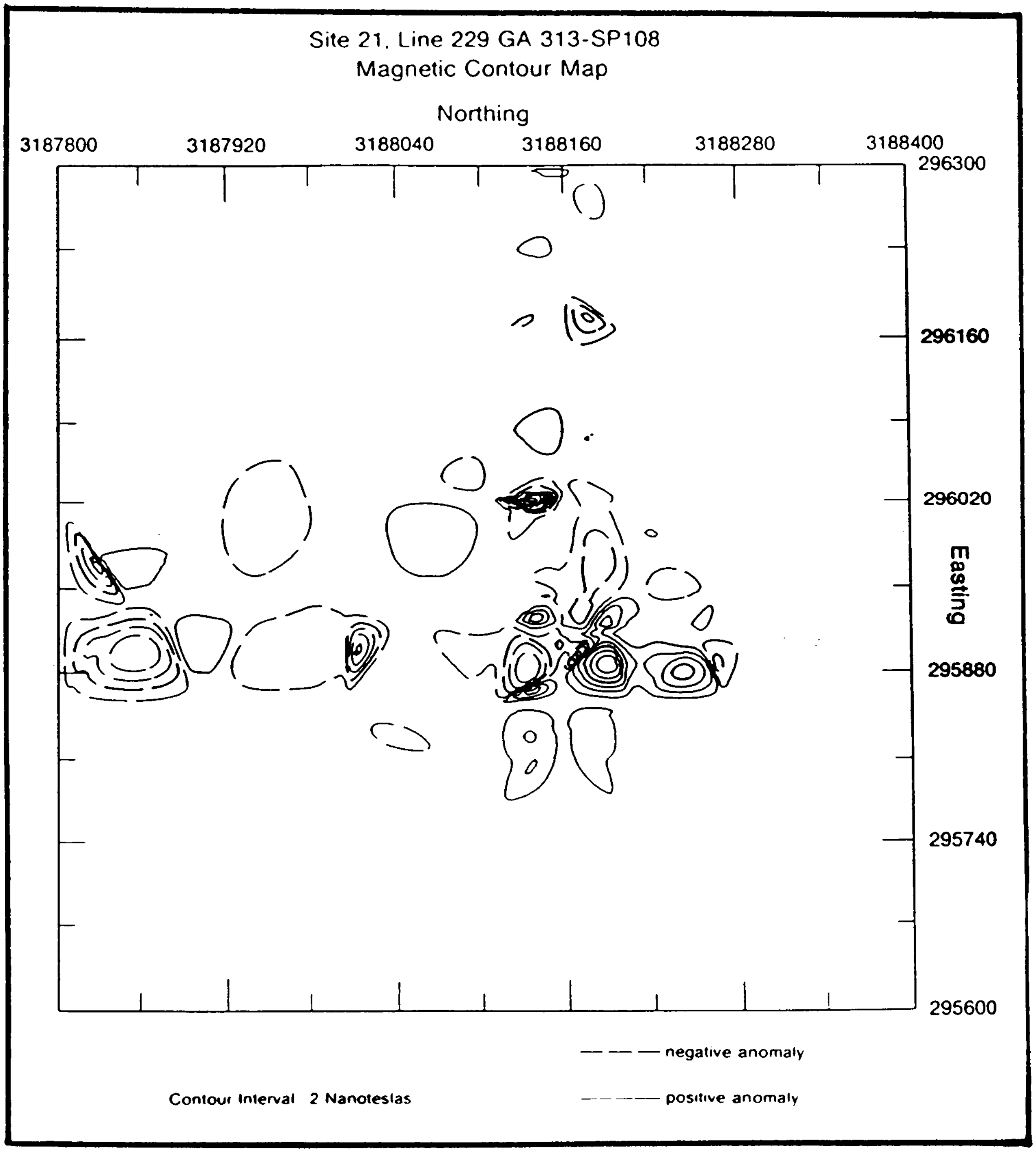


FIGURE II-96. Contour plot of site 21, 229 GA 313.

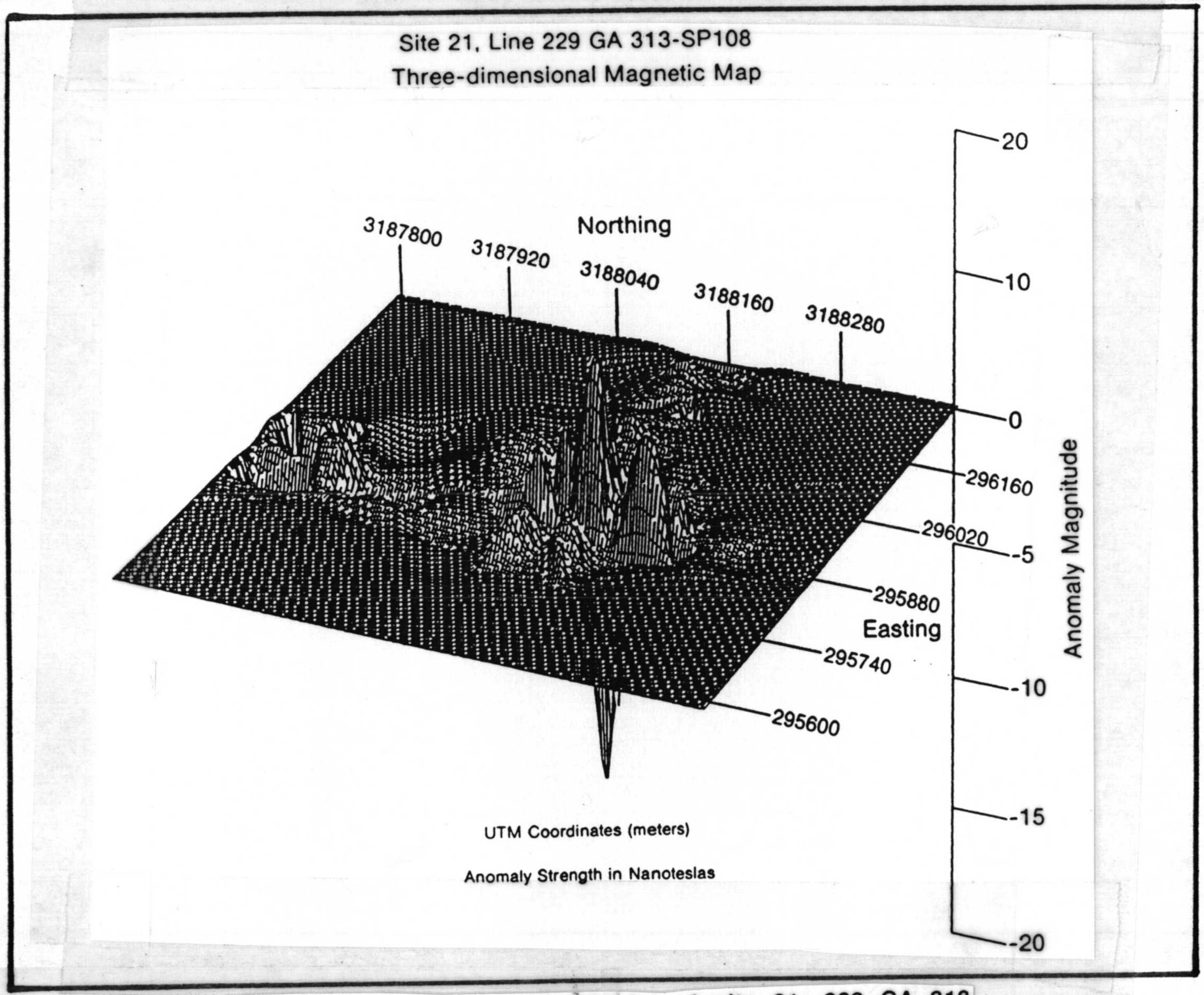


FIGURE II-97. Three dimensional plot of site 21, 229 GA 313.

14.1.4.13 Site 23, Line 305 GA 332-SP110

This side-scan sonar contact and magnetic anomaly represents the only shipwreck element found during the study within the three lease block areas. It was found on an east-west tie line and was seen as a magnetic dipole of low amplitude (Appendix K, Figure K-23a) but of some duration (41 m). It was not detected by the side-scan sonar during resurvey and only seen during relocation. The reason for this, we believe, was the fact the object was directly under the survey vessel and not picked up in the secondary sonar signal lobes or the object was perpendicular to the path of the towfish. The object was identified as the main mast of a modern shrimp trawler. The overall length was eight meters with assorted cable, chain and debris (buckets, cans) associated with it. The data (Figures II-98 and II-99) shows a highly localized dipolar feature. The graphic displays of the relocation data presents a picture of a linear magnetic feature similar to that seen for the pipe at Site 21.

14.2 Anomaly Characterization and Pattern Recognition of Modern Ferromagnetic Debris and Potential Cultural Resource.

Arnold (1975, 1980, 1982) and other workers (Bevan 1986; Garrison 1981, 1986; Mistovich 1983; Saltus 1986 and Weymouth 1986) have written on the problem of discriminating marine debris from cultural resources or shipwrecks. Arnold (1980, 1982) has groundtruthed over 60 anomalies, 17 of which were shipwrecks of various periods. Irion (1985, 1986) examined 33 anomalies in Mobile Bay two of which were shipwrecks. Gearhart (1988) located two shipwrecks during a magnetic survey of Ocean Beach in California. Stickel (personal communication) surveyed and groundtruthed the remains of a 1925 harbor tug in Los Angeles Harbor. Based on such a growing set of empirical data and that contained within this study some characterization or pattern recognition can be derived for shipwrecks and modern ferromagnetic debris.

In terms of the goals of this study, the question of anomaly characterization and pattern recognition is really a series of questions relating to the specific methodologies:

1. Can one differentiate, with a high confidence level, between modern ferromagnetic debris and potential cultural resources using present MMS survey methodology?

2. Can we differentiate, with a high confidence level, between modern ferromagnetic debris and potential cultural resources using a methodology such as that used in the present study--50 m or less survey intervals and groundtruthing?

The opinions of several of the authors such as Arnold, Saltus, Gagliano (CEI 1977, Vol II), Ruppe (1982) and others, suggest the answer to the first question is no except in the most obvious cases.

Saltus (1986) effectively critiques the present MMS criteria to differentiate debris from shipwrecks. The principal reason for the lack of success in finding shipwrecks using the present methodology arises from the burial context of the historic shipwreck. As Arnold (1980, 1982) states:

> "...there are those who advocate that if there is no side-scan target then there is no wreck...In groundtruthing 47 significant anomalies in Texas waters, only six cases, or about 13 percent, showed any debris protruding above the bottom ."

Most historic shipwrecks are buried and preclude detection or discrimination using side-scan sonar. The decision as to whether the shipwreck is present turns is based on the ambiguous

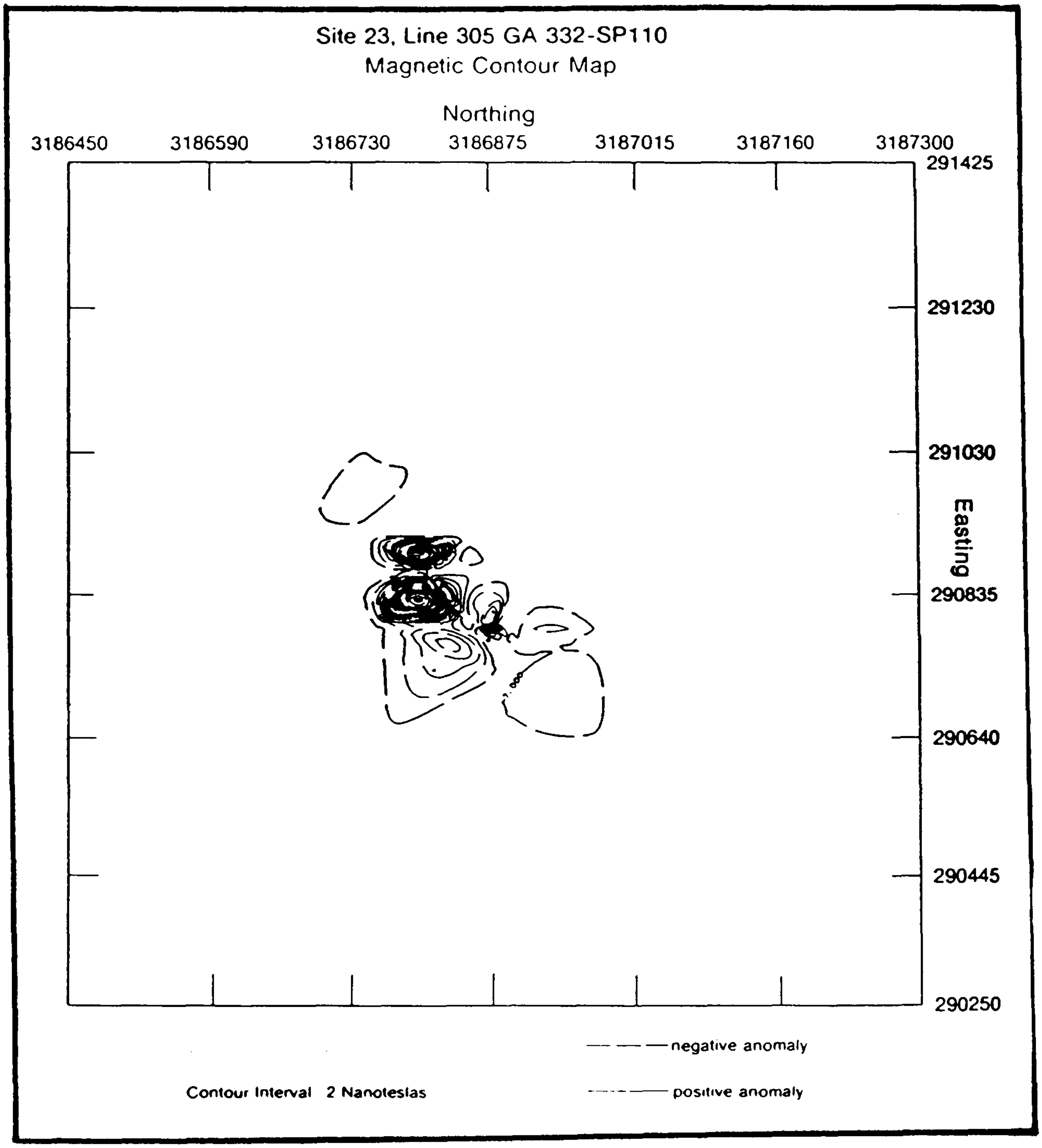


FIGURE II-98. Contour plot of site 23, 305 GA 332.

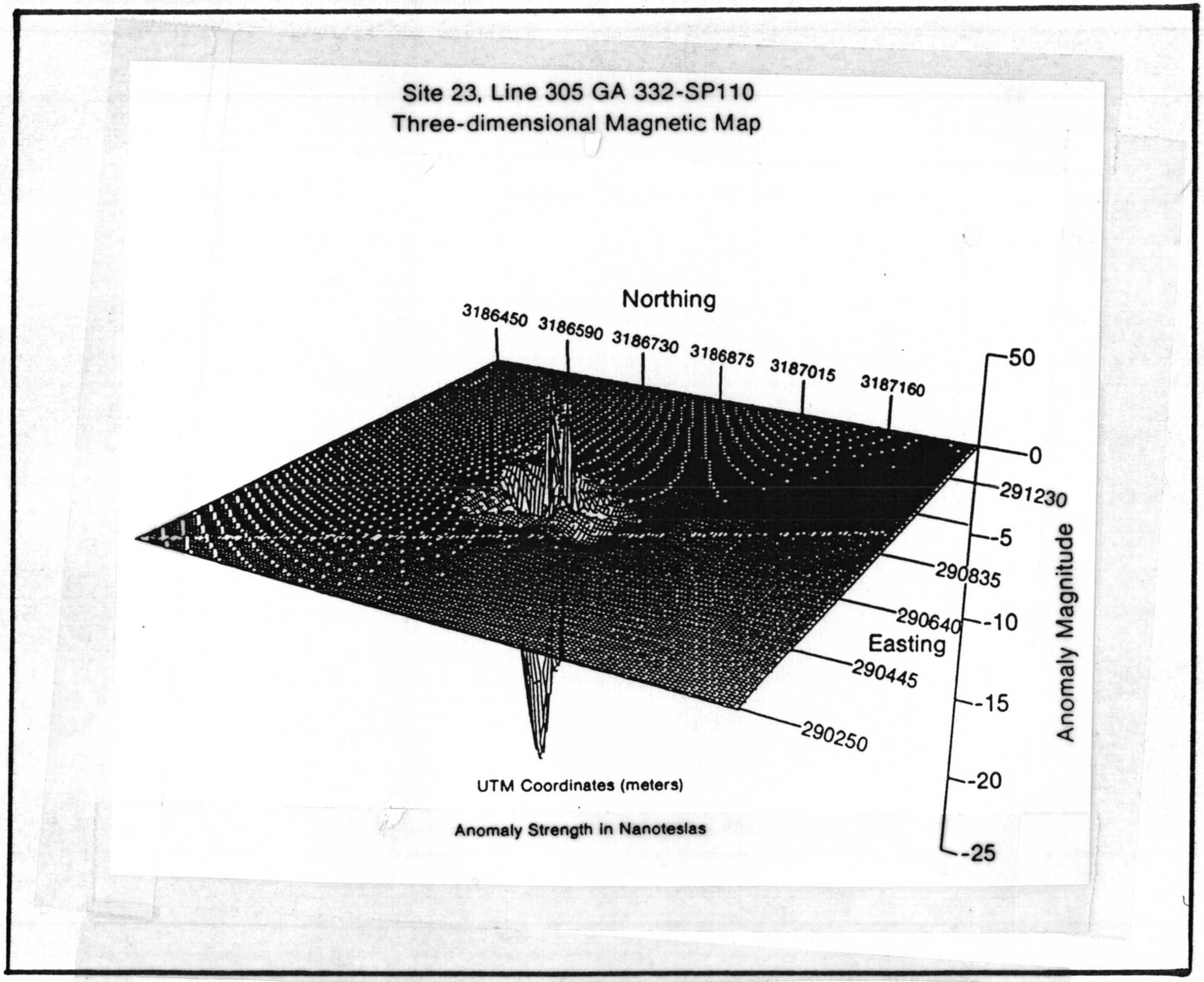


FIGURE II-99. Three dimensional plot of site 23, 305 GA 332.

nature of a single line or two of magnetic data. This has not been sufficient so the discovery success of the present MMS survey methodology as required in NTL 75-3 has been expectedly low.

The answer to the second question is more positive if the present study's methodology is used. Reliance on a closer grid interval or linespacing alone will increase the success in anomaly identification. If we rely on instrumental data alone, then the line interval of the survey is critical. This traces directly from principles in archaeomagnetism and from our present day correlation of variables in archaeomagnetism as they relate to specific sources.

Von Frese (1984, 1986) described a variety of archaeological sources, associated with historic terrestrial sites from an analysis of their geometrics and relative amplitudes. Monopole anomalies, for example, exhibit radially symmetric amplitudes that frequently indicate features such as wells or pits. Dipolar anomalies are characterized by two signatures of opposite sign and unequal magnitude. These are generally affiliated with iron artifacts, hearths, bricks, tiles, etc. Structural features, such as trenches and walls, may exhibit weakly dipolar signatures and linear trends. Von Frese (1986) concluded that the majority of dipoles in historic sites exhibit large amplitude, short duration anomaly geometries with distinctive remanent magnetization components that are characteristic of *near-surface iron objects.* The directions of the remanent moments, as indicated by the location of smaller peaks relative to larger peaks, tend to be quite arbitrary for these sources.

Arnold (1980, 1982) has presented a body of data in the form of magnetic profiles taken over a suite of identified archaeomagnetic sources. No attempt has been made to apply the formulae for amplitude determination and spectral analysis discussed by Breiner (1973, Sections 14.1.1.2 - 14.1.1.4; and Von Frese, Appendix L). What is missing in Arnold's presentation is a display of the spatial relationship between the adjacent profile lines. This spatial character of the magnetic data allows us to resolve size and shape within a magnetic feature or features. This relationship of magnetic signatures and spatial distribution is at the core of determining patterns for shipwrecks and the discriminating these patterns from those of ferromagnetic debris.

We agree with Von Frese in his conclusion that the majority of dipoles or archaeomagnetic anomalies are derived from near surface iron objects. This is true for shipwrecks as well as historic land structures. Arnold (1982) has explicitly taken the magnetic data from such sources and defined what he terms a "classical shipwreck signature."

> "The anomaly showed up on six tracks, which suggested a large mass of iron. During relocation the fathometer indicated an object rising above the bottom with associated scour depression." (Arnold 1982).

For this characterization Arnold (1982) used a lane spacing of 50 m. He states further:

> "The pattern of anomalies on adjoining survey tracks is the key to identifying significant anomalies and distinguishing them from those far more numerous anomalies caused by isolated iron debris, which often show up on only one track."

The pattern of anomalies is thus one key to discriminating between anomalies associated with historic shipwrecks and debris. Arnold (1982) presents the caveat that not all anomalies distinguished by the pattern of readings he describes will be shipwrecks. Large objects such as discarded wire cable can produce similar anomalies. Indeed, we have seen this to be true with the results of this study, although graphical presentation of the profile data showed a spatial pattern that may be associated with cable or wire (Figure II-32). Arnold concludes that physical examination is the only way to determine the cause of anomalies as remote sensing data is rarely sufficient to stand on its own.

Mistovich (1983) has defined a pattern for magnetic readings indicative of a shipwreck which has broken apart and scattered its cargo over a wide area. He defines this pattern as a cluster of "three or more anomalies within an area of 50,000 m." This area is not as great as it first seems representing the square of approximately 225 m. Mistovich admits that the definition is probably too liberal for the more concentrated wreckage which could be expected in protected environments as opposed to an active coastline (Irion 1986). Mistovich's model was developed for the Texas coast, a high energy environment capable of dispersing material over a large area.

Clausen and Arnold (1975; Figure II-100) have presented a three-dimensional graphic plot of the wreck of a 16th century Spanish vessel lost on the lower Texas coast. This ship is a small 150-250 ton nao. It shows a scatter of ferrous components extending over an area of 10,000 sq m (CEI 1977, Vol II: 82). Clausen (1966) reports that it is not unusual to encounter shipwrecks that cover as much as 100,000 sq m although 50,000 sq m is more common. This is clearly the basis for Mistovich's cluster pattern model.

Garrison (1986) has presented magnetometer data of a 19th century shipwreck, WILL O' THE WISP lost off Galveston Island, Texas. Shown in Figures II-101 and II-102, this shipwreck's archaeomagnetic area is roughly 55,000 sq m. Groundtruthing studies of this shipwreck presented a pattern similar to that outlined by Arnold, e.g. the shipwreck is detected as significant anomalies on multiple lines. Fathometer readings showed an object or objects above the bottom with an associated scour depression parallel to the axis of the vessel. Divers recorded the remains of a fire tube boiler, a spider gear or flange and the line of a partially exposed strake (Figure II-103).

Anuskiewicz has presented magnetometer data on another 19th century vessel, GIL BLAS, sunk off Hillsboro Beach, Florida (Anuskiewicz n.d.). Shown in Figure II-104, we see a distribution of archaeomagnetic anomalies over 10,000 sq m concentrated in the upper quarter of the contour plot of the site.

Gearhart (1988, 1989) presented definitive graphical representations of two shipwrecks from Ocean Beach, San Francisco, California (Figure II-105). Gearhart (1988) expressly evaluated his data using Delgado and Murphy's (1984) hypotheses concerning anomaly patterning for environmentally exposed shipwreck sites (Gearhart 1988). These hypotheses or expectations for beach zone wrecks have merit in our consideration of the larger class of near and offshore sites. The methodology used in the Gearhart study is best styled as mid range theory building--the construction of bridging arguments between observed physical variables and the interpretation of the archaeological record or context (Schiffer 1975; Leone 1988).

In their models for anomaly patterns, Delgado and Murphy (1984) define these types of wrecks - (1) buoyant hull; (2) buoyant hull fracture; and (3) buoyant structure (Gearhart 1988). Type 1 is an intact or articulated remains of a ship's hull whose anomaly pattern is expected to be a linear series of anomaly peaks. Type 2 represents a pattern of a multiple anomalies due to hull breakup and debris scatter. This pattern has been observed with wreckage of a Civil War anti-torpedo craft on Mustang Island, Texas where debris radiated landward from the principal wreckage (Smith, et. al. 1987). The suspected site of GIL BLAS (Figure II-44) represents a Type 2 pattern. Type 3 represents a scatter of wreck fragments no longer in close association. The pattern is scattered anomalies over an area of several kilometers. This pattern is that observed by Matheson (1988) for the ATOCHA. It would be plausible for any ship lost in a high energy, high current environmnt.

Gearhart's plots (Figure II-105) are of Type 1 (KING PHILLIP) and Type 2 (REPORTER). An interesting speculation that arises from this model is the probable transitition of site patterns over time in high energy environments and the pattern expected for wrecks in low energy zones.

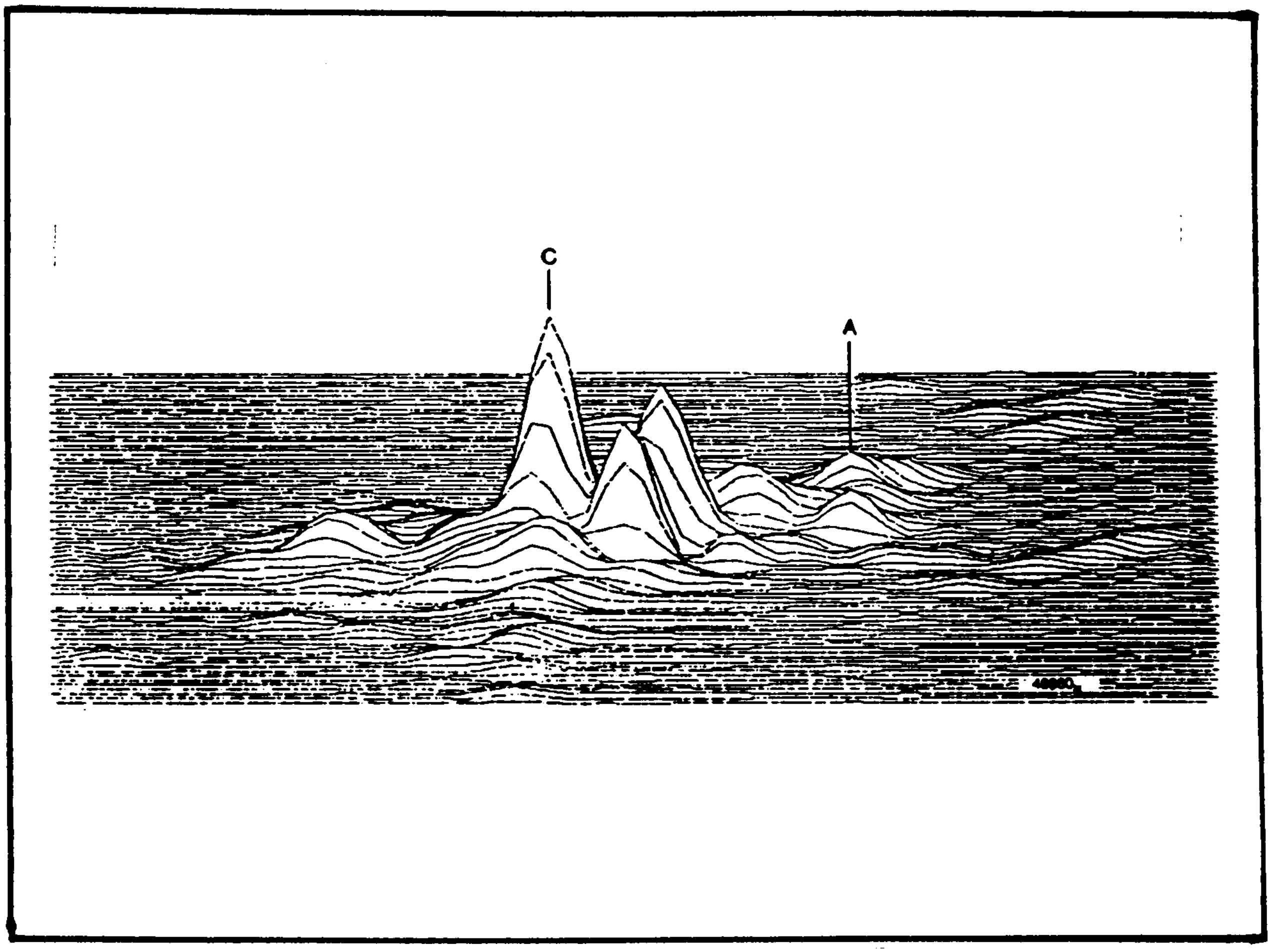


FIGURE II-100. Three dimensional plot of 16th century ship (after Clausen and Arnold 1975).

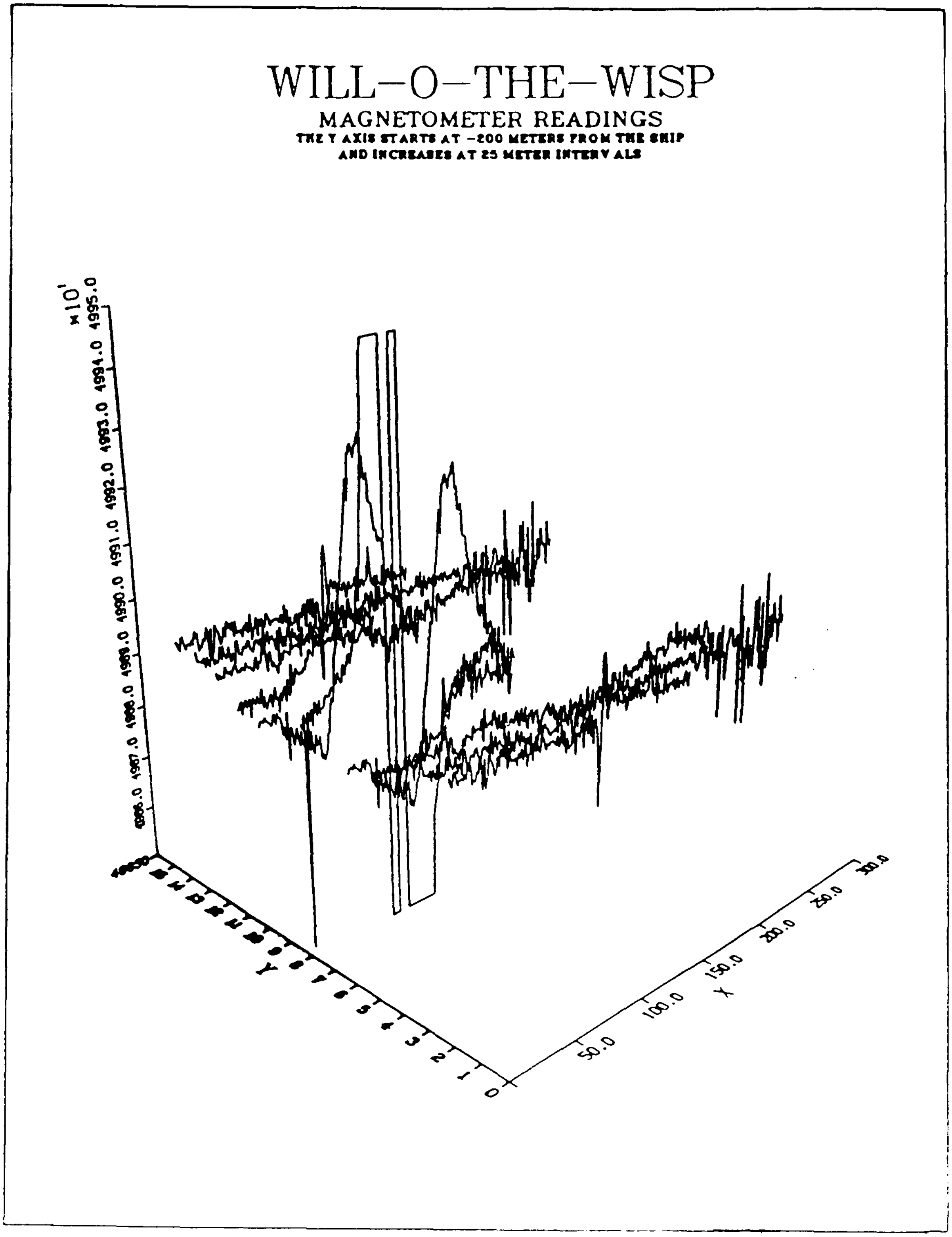


FIGURE II-101. Magnetic profiles, WILL O' THE WISP.

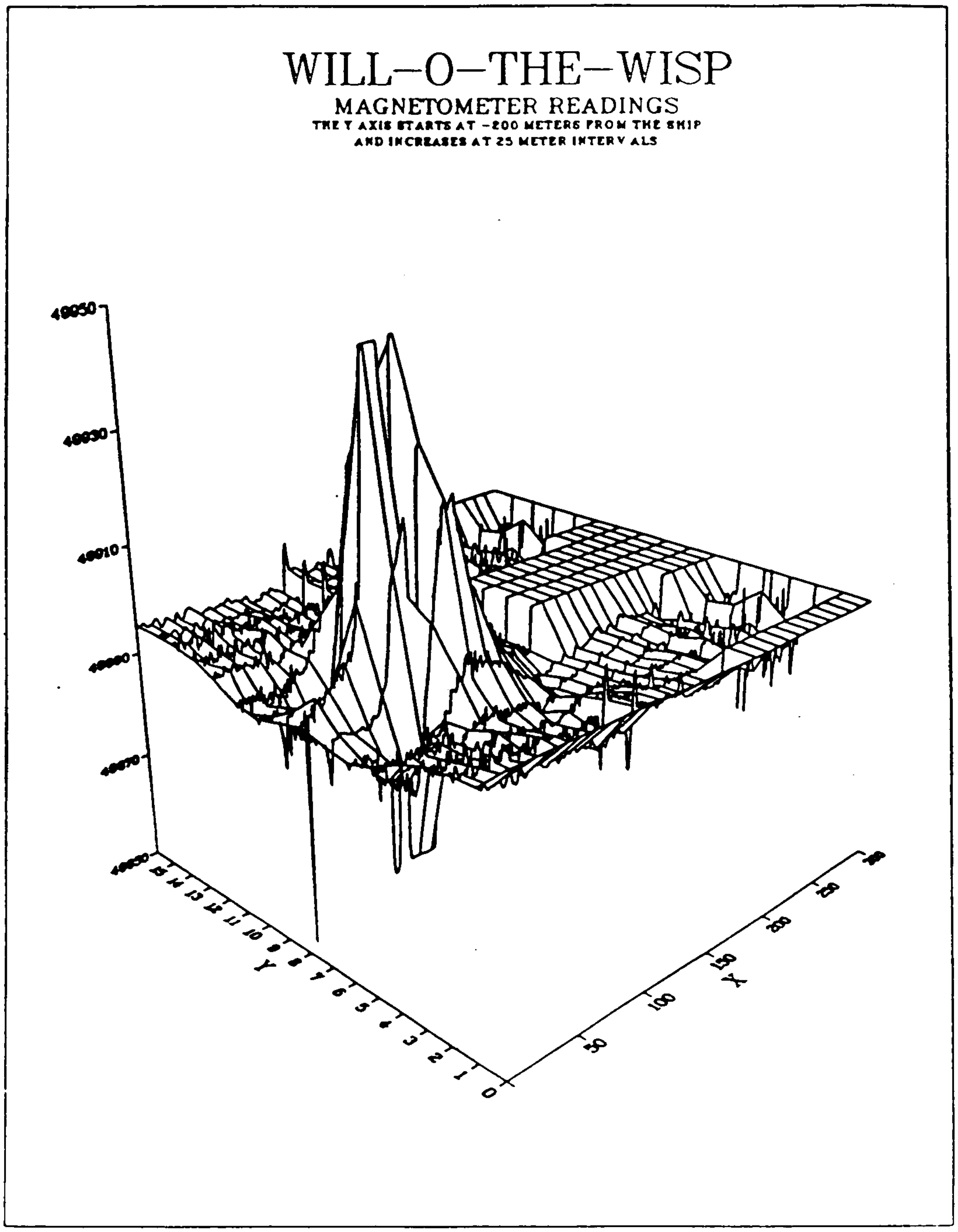


FIGURE II-102. Three dimensional plot of magnetic anomalies of the WILL O' THE WISP.

FIGURE II-103 View of machinery of the WILL O' THE WISP (Courtesty Larry R. Martin)

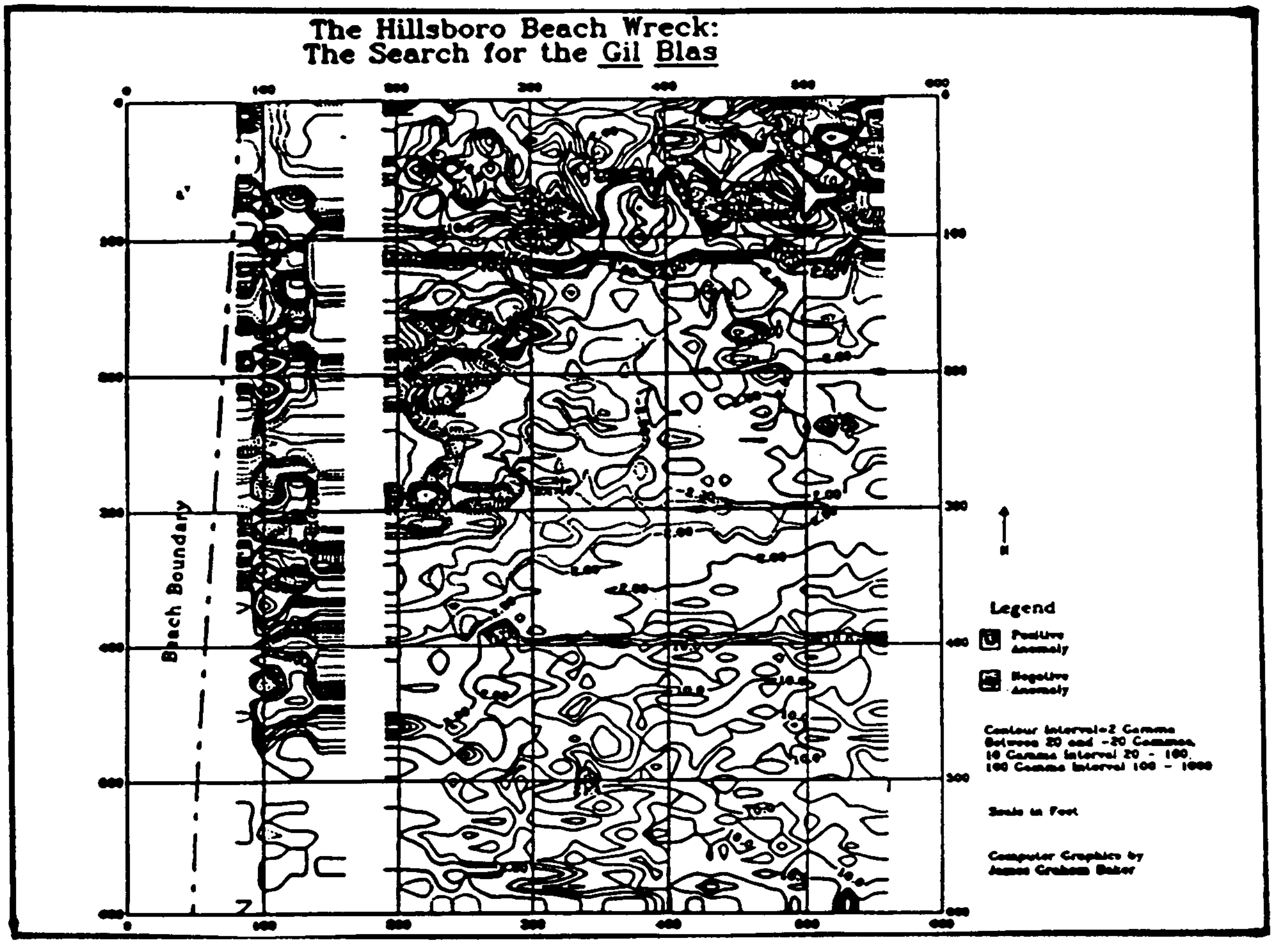


FIGURE II-104. Contour plot of the Hillsboro Beach Wreck (Courtesy Rik A. Anuskiewicz).

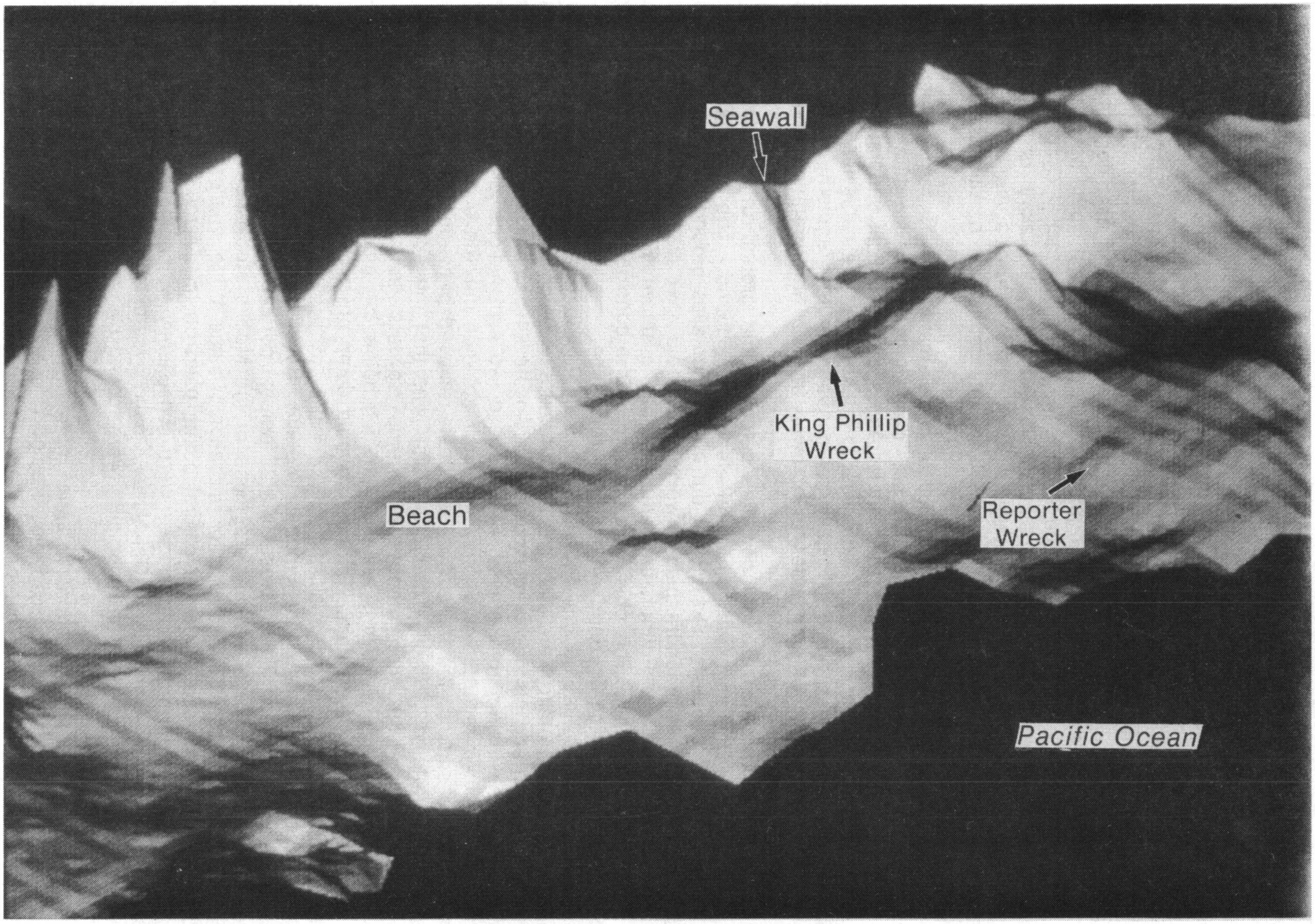


FIGURE II-105 INTERGRAPH three-dimensional plot of the KING PHILLIP and REPORTER wrecks, Ocean Beach, California (Courtesy Espey, Huston & Associates, Inc.)

Common to most of these examples is the pattern articulated by Arnold, Arnold and Clausen, Mistovich, and others that a shipwreck as an archaeomagnetic feature can be defined as *a cluster of multiple anomalies within an area of 50,000 sq m or less.* As a working definition it rests on a growing body of empirical data which seems to support it. Isolated anomalies over a large spatial area with little or no expression on adjacent survey lines of reasonable width will, in most instances, be marine debris. We have seen this in this study. The one shipwreck element, a steel mainmast, did not fall on adjacent survey lines but is an artifact of the survey methodology where tie lines were not surveyed at the 50 m linespacing used for the principal grid. Groundtruthing survey lines run at 10 m intervals suggest the mast would have been seen on adjacent lines and certainly it would be seen as a sonar contact. That it could be discriminated as an element of shipwreck based on instrumental data alone is not plausible because the feature is a pipe, albeit one that was a structural element of a vessel. Its anomaly signature is that of a pipe (Figures II-97 and II-98). Only verification by divers ascertained its identity as a part of sunken vessel.

Another anomaly found by this study, a coil of cable, mimics the pattern defined for a shipwreck by Arnold. Although the graphical display of the magnetic profile data suggests the probable nature of the feature, diver inspection increases our analytical understanding even more so. The equality of the disparate anomalies do suggest that the cable feature could be differentiated from a shipwreck which typically demonstrates more irregularity in its multiple anomaly peaks. Uniformity of amplitudes point away from an interpretation of a multiple anomaly feature as a shipwreck.

In the present study, the bulk of anomalies detected and groundtruthed were modern ferromagnetic debris. One shipwreck structural element was found. The fact that it was a modern wreck does not diminish the fact that out of 20 anomalies groundtruthed, one was a shipwreck artifact. Without groundtruthing however, we would have classified this artifact as modern ferromagnetic debris. Further, the remainder of the shipwreck may not be near the location of the relocated mast. This observation brings us to a consideration of a rather unique aspect of modern ferromagnetic debris--mobility or relocation.

Irion (1986) reported that all the anomalies investigated in one Mobile Harbor survey were modern debris. One-third were steel cable discarded after being worn or broken. What is interesting is that Irion and his co-workers could not relocate 24 percent of anomaly positions originally seen in their instrumental survey. They posed two explanations for the absence of the anomalies from their recorded positions; first, their absence may have been the result of positioning error; or second, the anomalies had been removed between the original survey (1982) and groundtruthing (1985). Their conclusion was that the second explanation was more plausible due to the high number of shrimp trawlers fishing their survey area. Informants told them that shrimp nets are drug an inch below the mudline thereby snagging anything lying directly on the bottom. Shrimpers would dump anything snagged in their nets causing a constant movement of material.

We have observed the same phenomenon in the Gulf. Several significant anomalies (seven out of 28) were not relocated. This represents a 25 percent portion of our sample selected for groundtruthing study. Our explanations are those of the Mobile study--positioning error or removal. We discounted positioning error after relocation of some of the smallest anomalies and sonar contacts. Further, recalibration at control points used on the March (1988) resurveys and the August (1988) groundtruthing studies were consistently within the range of error of the positioning systems (1-3 m for the Del Norte X-band system and 5 m for the STARFIX system). Our conclusion was that the anomalies were moved by trawling activity between the two surveys.

What does this mean to the characterization of modern ferromagnetic debris? It is a characteristic of this debris that it is capable of being relocated or moved by fishing trawlers active year round in the Gulf. Portions of shipwrecks fall into this category as well, given our example of the shrimp boat main mast. In the recent case of the EL NUEVO CONSTANTE , the discovery was made by a shrimp fisherman who hung his nets on the wreck. The bulk of shipwrecks, by their mass and complexity, cannot be moved by trawling disturbance, but, as we have seen, elements such as the mast can be. We believe this also explains the lack of correlation in the number of anomalies seen on the original lease block surveys and our later resurveys. The anomalies are not there anymore. By extension, we can argue that this phenomenon is characteristic of only debris, primarily of a modern origin. We also believe the anomalies created do not mimic patterns expected for historic shipwrecks.

In summarizing this discussion of instrumental patterns of shipwrecks and modern ferromagnetic debris, these are some salient characteristics that can be used to confidently differentiate the two when given sufficient information:

Anomaly and Side-scan Sonar Patterns Characteristic of Historic Shipwrecks

1. multiple peak anomalies or spatial frequency;
2. differential amplitude anomalies;
3. areal distribution ≥10,000 square m;
4. long gradients and duration;
5. axial or linear orientation of anomalies;
6. scour areas associated with anomalies;
7. exposed structure is geometrically complex and associated with anomalies; and
8. relative locational permanence.

Anomaly and Side-scan Sonar Patterns Characteristic of Modern Ferromagnetic Debris

1. single peak anomalies or no spatial frequency;
2. few if any differential amplitudes;
3. localized areal distribution ≤10,000 square m;
4. sharp gradients and short duration;
5. random, non-axial orientation of anomalies;
6. scour areas with no associated anomalies;
7. exposed debris geometrically simple; and
8. locational transience.

In these pattern definitions the assumption is made that the methodology is one of 50 m or less lane interval. Groundtruthing is not assumed. Criteria One through Three are self-evident. Criteria Four and Five require some explanation as they relate to distance and speed. A survey speed of eight knots will produce a shorter duration signature than one done at four knots. The emphasis here is on the difference in overall duration even with this disparity. The amplitude duration will be longer in almost all cases when a shipwreck is involved. Fall off and duration is sharp for debris at almost all survey speeds. These debris also behave as point sources in terms of orientation. Criteria Six and Seven depend on the burial nature and breakup of the source. Shipwrecks are harder to bury than debris although numerous examples can be cited. Modern era shipwrecks are more likely to protrude from bottom sediments except near shore where wrecking and burial is accelerated by strong currents and wave action. Still in these environments, we can point to wrecks as the ARCADIA, WILL O'THE WISP, EL NUEVO CONSTANTE as examples where sonar images can demonstrate those features such as complexity and scouring. In each case of modern debris detected by our surveys, the features are geometrically simple. Scour patterns or scars, such as the leg scars of the jack-up rig or the anchor drags, are not complex. Absence of any one or more criterium does diminish our confidence in the identification of the feature but taken *in toto* the recognition of these criteria at a site increases our ability to discriminate the two classes of phenomena--shipwrecks and debris. The inclusion of groundtruthing enhances our ability to identify the two.

What weakens the recognition of these criteria is the use of a survey methodology at a wider spacing used in this study. Specifically, in the resurveys and in earlier tests, such as the WILL

O' THE WISP one cannot discern multiple peak anomalies on adjacent lines of 150 m distance. Differential amplitudes for anomalies cannot be confidentially discerned as the lesser anomalies are masked by larger ones. Duration can be guaged but generally only on one line. This allows debris to mimic archaeomagnetic anomalies without the discrimination available with multiple profiles. Orientation works to our disadvantage with single line anomalies. At distances over 50 m, orientation drastically affects fall off rates for anomalies. Of all the criteria, sonar images are least affected. In the recent relocation of the Confederate cruiser CSS ALABAMA the presence of a scour trench on the port side was a distinguishing feature in the instrumental data (Max Guerant, personal communication). If any unburied structure is present, a present day side-scan sonar system should detect it. In the absence of associated magnetic anomalies, it is difficult to characterize the contact.

Finally, using the existing survey methodology of 150 m linespacing can we characterize and differentiate modern ferromagnetic debris and potential cultural resources, such as historic shipwrecks, by means other than increasing survey coverage?

Authorities such as Arnold (1986), Bevan (1986), and Weymouth (1986) have suggested both technical and analytical methods. These include illustration of all reported anomalies and intercomparison with data (such as Arnold 1980, Saltus 1980, and Rhodes 1980) obtained by groundtruthing or experimentation (Arnold 1986). Bevan (1986) suggested instrumental techniques for differentiating old iron from modern steel but the measurements cannot be obtained with instrumentation currently in use on lease surveys. Von Frese's (1986b) suggestions of reducing anomalies to the north geomagnetic pole or vertical polarization by use of first principles could facilitate the recognition of remnently magnetic features. Significant differences in the remnent magnetism may allow the discrimination of old iron from modern steel as Bevan suggests. The assumption is that a difference in remnant magnetism exists between the two facies of ferrous materials. This remains to be established by empirical study and is beyond the scope of this study.

Saltus (1986) sees little improvement by retaining the present MMS analytical factors to discriminate between shipwrecks and debris. While it may not be analytically possible to contrast iron and steel by remnant magnetization one may be able to characterize anomalies as to their inductive magnetization. This component of an anomaly has a strong dependence on declination and inclination characteristics of the geomagnetic field (Von Frese 1986). The argument here would rely on the structural complexity of a shipwreck having a large or detectable inductive magnetization. Anomalies without this component could be classified as exclusively ferromagnetic features and by logical extension, debris. Again, this is an analytical approach that could improve the detection of and discrimination between classes of ferromagnetic materials and be used within the current methodology.

Another approach relying on numerical analysis of data obtained with the present methodology involves the statistical evaluation of variation in magnetic signatures. By returning to a simple display of the magnitude of the spatial frequency of anomalies, such as Clausen's 1966 example, it is possible to use this data in a calculation of diversity (Shannon and Weaver 1949) or Brillouin's variation of the same measure (Brillouin 1962). The Shannon-Weaver formula is:

$$H_{max} = \sum_{i=1}^{s} (Pi)(\log_2 Pi) \qquad \text{(Eq. 6)}$$

Where s = the number of classes

P_i = the proportion of the sample in the ith class

Brillouin's variation is:

$$H = \frac{1}{N} \log \frac{N!}{N_1! \; N_2! \quad N_s!}$$

(Eq. 7)

Where N = the total population in categories wherein members are represented proportionately as $N_1, N_2 ...N_n$.
S = the number of classes or categories

In Clausen's data s = 3. If we apply this formula to the Clausen data we have the classes $S_1 = 12$ (low), $S_2 = 12$ (medium), and $S_3 = 22$ (high), which yields a value of H equal to 0.32. This is a relative value with little to compare it to. To do this one applies a rank-order classification to a ferromagnetic debris site. Less complex, these sites should yield a diversity index significantly lower than that of Clausen's.

Using a suite of variables common to magnetic anomalies, a factor analysis was done to examine any pattern or associations that can aid in the discrimination of modern ferromagnetic debris and historic shipwrecks. Using data from this study and others (Clausen 1966; Clausen and Arnold 1975; Arnold 1980; Garrison 1986; and Anuskiewicz n.d.) it was possible to derive values for four variables: (1) number of peaks on an equal number of traverses of the feature; (2) an estimate of the anomaly area in sq m; (3) the anomaly duration as distance; and (4) the maximum amplitude over the anomaly.

Some of the data are rough estimates taken from data sets not originally intended for such analysis. Nonetheless, it was possible to obtain realistic values for the variables such that an exploratory analysis could be done. The results shown in Appendix M are summarized as follows:

1. The factor analysis isolated two factors that account for about 75% of the variance;
2. The communality summary indicates the variation in the individual variables that can be accounted for by the others is high (~80%). Combined they tend to improve the predicability;
3. The factors partition along duration and amplitude for one and frequency and area for the other. The variable of area loads on Factor 1, while duration loads at a similiar level on Factor 2;
4. Factor 1 is interpreted as related to debris signatures being more likely to reflect a pattern of low amplitude and short duration; and
5. Factor 2 is interpreted as more likely to reflect greater spatial frequency (e.g. peaks per unit area, which is more characteristic of historic shipwrecks than debris).

The use of statistical analysis of magnetic data is possible with this study's datasets and others generated outside of those typically obtained under NTL 75-3. This is due to the nature of those data versus those available from the cultural resources surveys conducted under NTL 75-3. This study's data was digitized and compiled for the specific types of statistical manipulation such as filtering, gradient removal, and spectral analyses carried out and reported herein. None of this has ever been done using data acquired under NTL 75-3. In most instances, the data exist only as raw strip chart records typically reported piecemeal and available only upon request by MMS technical reviewers. At this writing ony one company, ARCO, has experimented with digital data acquisition. Simple displays of such data allow easy anomaly recognition on adjacent lines (Figure II-71) and the application of exploratory pattern recognition using multivariate techniques such as discussed here.

14.3 Summary and Conclusions

The Task II study analyses have been directed at the following objectives taken from the scope of services for this contract. They were:

1. Determine the relationship between survey linespacing and anomaly detection;
2. Determine the influence of oil and gas structures on magnetic anomaly distribution;
3. Characterize and differentiate, with a high degree of confidence, between modern ferromagnetic debris and potential cultural resources. This method must be applicable to present source material available to MMS cultural resource analysis.

The following is a summary of the results:

1. The detection of magnetic anomalies increases in direct proportion to the lane spacing used, e.g. the 150 m line interval detects one-third of the anomalies found using a 50 m line interval. This result may be specific to this particular study and the linear trend may differ with other data.

2. The developed lease block surveyed with oil and gas structures had the highest number of magnetic anomalies relative to the two undeveloped blocks surveyed. We conclude that development increases the number of anomalies of modern origin.

3. The present survey methodology is not developed enough to differentiate, at a high confidence level, between modern ferromagnetic debris and potential cultural resources. It represents a compromise between scientific and economic goals.

The present study has demonstrated methods by which one *can* more confidently characterize modern ferromagnetic debris and potential cultural resources. Pattern recognition has been demonstrated by using 50 m or less lane spacing by other state and federal agencies such as the Texas Antiquities Committee, the National Park Service, and the U.S. Army Corps of Engineers or by use of groundtruthing.

Recommendations to alter the present methodology have been made in past MMS sponsored studies notably CEI (1977, Vol II) and SAI (1982, Vol 4) that still have merit. These include: conducting side-scan, magnetometer, and sub-bottom profiling surveys using 50 m linespacing in high shipwreck potential areas and limiting vessel speed to 2-3 m/s (4-6 knots). The recommendations in both Tasks I and II combine to reduce the general survey area on the OCS but increase the effectiveness of the surveys in lease block areas of reported shipwrecks with a high potential for their preservation.

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The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Royalty Management Program** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.