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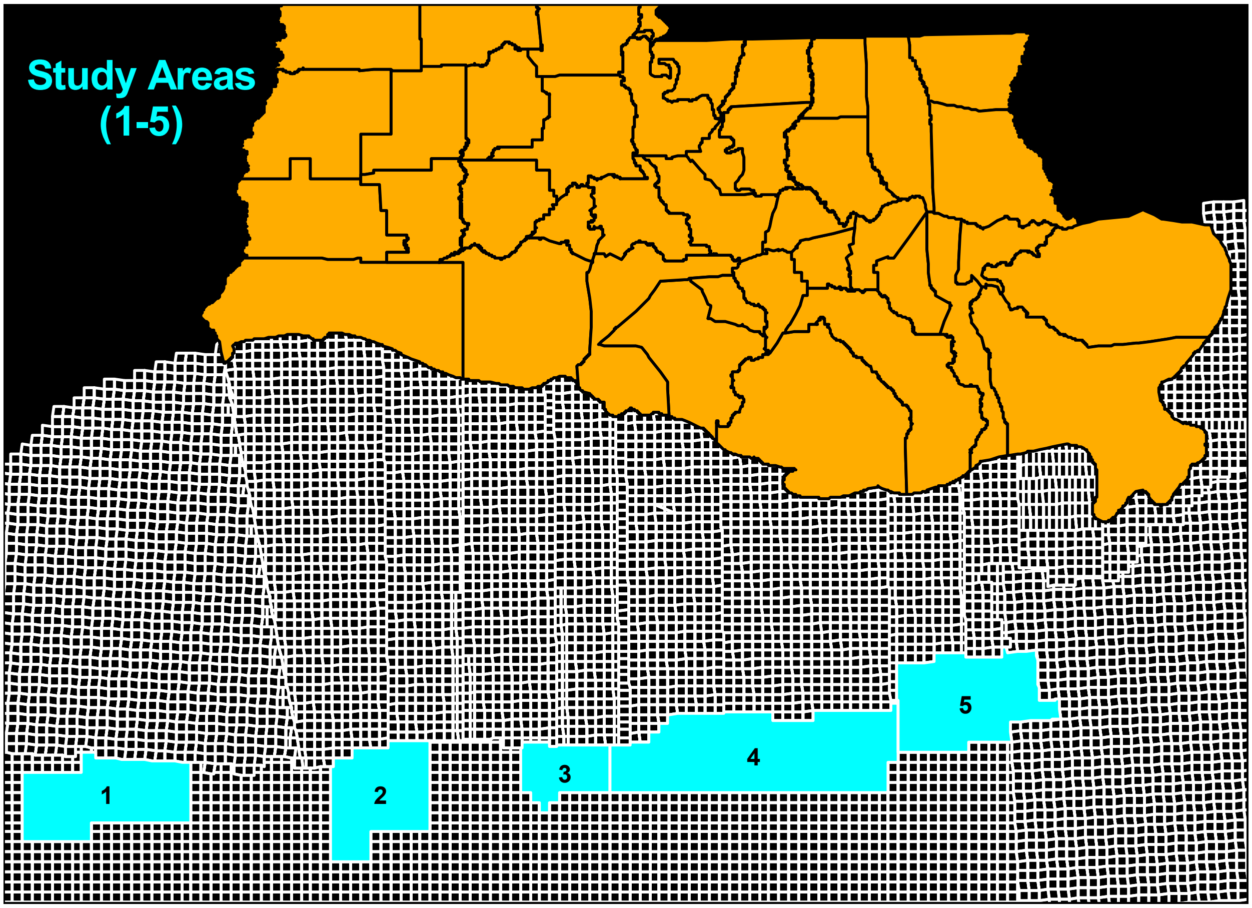
MMS 2005-067

Coastal Marine Institute

Mapping Areas of Hard Bottom and Other Important Bottom Types: Outer Continental Shelf and Upper Continental Slope



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

Cooperative Agreement
Coastal Marine Institute
Louisiana State University

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Mapping Areas of Hard Bottom and Other Important Bottom Types: Outer Continental Shelf and Upper Continental Slope

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PREFACE

This Final Report summarizes the procedures utilized and the results of the mapping efforts reached as a result of the preparation of the deliverables for the project, “Mapping Areas of Hard Bottom and Other Important Bottom Types: Outer Continental Shelf and Upper Continental Slope.” Some of the tasks and approaches evolved during the course of the project and are documented below. The geohazards on the upper continental shelf were mapped from a variety of sources, including high-resolution geohazard seismic and industry-provided seismic surveys.

SUMMARY

As the petroleum industry moves into deeper and deeper waters of the northern Gulf of Mexico continental slope, it is important to locate and map areas of seafloor features like faults and areas of hard bottom that may constitute risks that may impact drilling, locating production platforms, laying pipelines, and related activities. Because of continued success in finding hydrocarbons in deep water using 3-D seismic and improved processing techniques, the northern Gulf of Mexico OCS is clearly the most actively expanding and deepwater oil and gas province in the world. In addition, subsalt and ultra-deep subsurface opportunities are initiating a new wave of exploration on the shelf and at the shelf edge. For these reasons, it is extremely important to locate and understand the risks associated with the spectrum of geohazards that occur within the OCS region.

This project was designed to convert existing seafloor maps compiled from high-resolution seismic profiles, side-scan sonar data, and bathymetry acquired in 182 OCS lease blocks to MMS-approved GIS format for use in geohazards evaluations. Six mapping categories were used: (1) undisturbed seafloor, (2) seafloor erosion, (3) hard bottom areas (carbonate banks, bioherms, hardgrounds, and outcrops), (4) faults, (5) acoustic wipeout zones, and (6) mass movement features. In addition to converting existing maps produced at Coastal Studies Institute through an industry consortium, mapping of new 3-D seismic surface amplitude data filled many of the gaps in the high-resolution acoustic data sets. The goal was to extend the mapping wherever possible to water depths of 1,000 m. All mapped data were converted to MMS-GIS compatible products. Past experience has clearly shown that understanding the processes that are associated with geohazards and locations of potential “trouble spots” on the seafloor saves money and lives. This project produced a set of seafloor maps from five mapping areas that can be used for planning man’s activities in the OCS region of the northern Gulf of Mexico from the shelf edge to a depth of 1,000 m.

ACKNOWLEDGMENTS

The authors would like to acknowledge and thank the companies of the petroleum industry that contributed high-resolution acoustic data (seismic profiles, side-scan sonar coverage, and bathymetry) from 182 OCS lease blocks for the original consortium mapping effort. We also gratefully acknowledge the student workers and Coastal Studies Institute drafting and cartographic personnel who helped standardize and assemble the original data sets into a consistent map format. Mr. Jesse Hunt Jr. of the Minerals Management Service, Office of Resource Evaluation, deserves acknowledgment for his assistance in producing 3-D seismic surface amplitude maps for use in filling data gaps in our mapping areas where additional high-resolution data sets could not be acquired for use on this project. In addition, we would like to thank Mr. Hunt for his assistance in helping obtain permission from owner companies for use of the 3-D seismic surface data.

Special thanks are offered to the following dedicated, graduate assistants of the Louisiana Geological Survey Cartographic Section, for their tireless efforts toward the GIS data development: Vishweshwar R. Admal, Anuradha Eragani, Swathi Kambalapally, Xiaojue Pan, Satish M. Shetty, Ping K. Liu, Sait Ahmet Binselam, Prammagnaanam Vijaiamernath, D. Pamula Lakshmi "Deepti," Yu Wang, Louis M. Temento. Finally, Lee Thormalen, Chief of Mapping and Boundary Branch, of the Minerals Management Service (Denver), provided assistance with unreleased, recently corrected, lease block corner coordinate data. These data proved to be essential for the accurate georeferencing of some of the source data images.

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INTRODUCTION

The search for and production of hydrocarbons from the Gulf of Mexico has steadily been moving into deeper and deeper water. It is safe to characterize the northern Gulf of Mexico continental slope as the most mature deep-water oil and gas province in the world. Even though this statement can be made with confidence following the first impressive deep water production originally found by Shell-Amoco at COGNAC and now followed by many other companies, only a small portion of this vast area has actually been tested with the drill bit. In addition, advances in 3-D seismic technology and collection of long offset multicomponent seismic data are opening up old shelf and shelf edge areas to a new wave of subsalt and ultra-deep subsurface exploration. Consequently, expanded deepwater operations in the northern Gulf are expected in the future. Operations in the slope province are not without enormous risks, both economic and natural. The economic risks are assumed by the company or companies investing in a given slope prospect. Natural risks such as geohazards, however, fall under the watchful eye of the Minerals Management Service that is responsible for managing the natural and economic resources of America. This responsibility includes an enormous offshore area with an annual income of billions of dollars. The Gulf of Mexico provides the leading income from America's deepwater oil and gas production.

Geohazards of several major types are known to exist in the marine environment of the Gulf of Mexico. These geohazards can be summarized into (a) slope failures, (b) faulting, (c) fluid and gas expulsion, (d) gas hydrates, and (e) variable bottom types (lithified hard bottoms to extremely soft fluid muds). Numerous geohazards exist on the northern continental slope because of its history of dynamic interaction between massive inputs of sediment over short periods of time (usually periods lowered sea level) and the compensating movement of underlying salt. Figure 1 shows the configuration of the northern and northwestern Gulf's continental slope surface as depicted from computer enhanced multibeam bathymetry data. This image clearly illustrates that the slope surface is characterized by rather flat and featureless intraslope basins separated by higher and much more complex topography. These areas surrounding the intraslope basins are highly faulted and generally supported by salt bodies in the shallow subsurface. They are also regions of fluid and gas flux to the modern seafloor. Because of salt-supported topography with steep slopes, faulting, and fluid-gas migration to the slope surface these areas forming the periphery of intraslope basins are regions where geohazards of many types are frequently concentrated.

Careful study and mapping of geohazards is important and has paid substantial dividends in the past. For example, as the search for oil and gas moved across the continental shelf of Louisiana in the 1960's and 70's, many important fields were discovered in the vicinity immediately seaward of the modern Mississippi River delta. In the early stages of this exploration, $100s of millions were lost to platform failures and pipeline breaks before the processes causing these catastrophic accidents were understood. Mapping of the delta front with side-scan sonar plus high resolution seismic and conducting site-specific studies led to a detailed understanding that the entire shelf fronting the Mississippi River delta was impacted by sediment failures and submarine landslides (Coleman, et al, 1974; Coleman and Garrison, 1977; Roberts et al., 1980, and Coleman and Prior, 1982;). The study of these features and the processes that forced them paid huge dividends, especially the detailed mapping of the entire delta front area.

Once this research was completed, companies operating off the delta were able to avoid locating platforms and pipelines where they would be prone to sediment failure. Since this early era of geohazards awareness, with the exception of recent events due to Hurricane Ivan, no platforms have been lost and pipeline breaks have been minimal. Similarly, the study undertaken in this project should serve an equally valuable function in that accurate mapping of bottom types can help steer man's activities in deep water away from the potential geohazards-impacted areas.

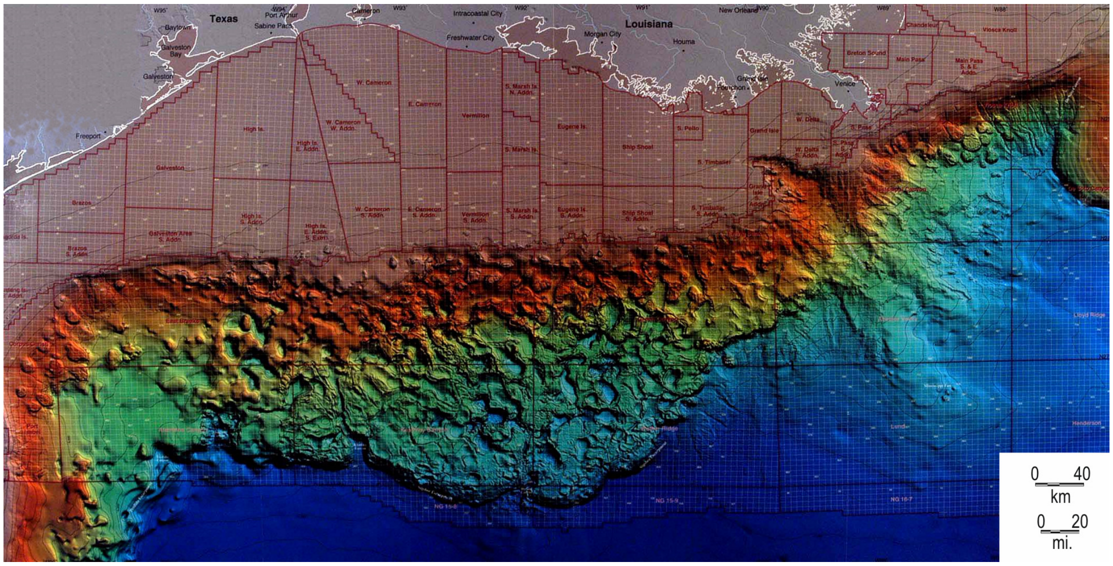

Figure 1. This computer-enhanced image of the northern Gulf of Mexico continental slope emphasizes the geologic complexity of this area as reflected in the configuration of the modern seafloor. The shelf edge and upper continental slope are the areas of focus for this mapping project.

HIGH - RESOLUTION ACOUSTIC MAPPING

In the mid-1980's, a consortium of petroleum companies operating the Louisiana-East Texas OCS contributed high resolution acoustic data, used for geohazards evaluations, to Coastal Studies Institute for evaluation and mapping. These data were to be analyzed in such a way as to provide a consistent database for understanding seafloor conditions in an area of expanding petroleum exploration and production in the deeper waters of the northern Gulf of Mexico. In total, 182 blocks of data were contributed to this project, which was supervised by Dr. James M. Coleman. Table 1 summarizes the general locations of these data sets. Each block had 3.5 kHz and most had sparker profiles. A total of 133 of these blocks had complete side-scan sonar coverage. Line spacing of both the high-resolution seismic and side-scan sonar data was generally 152 m and data were usually acquired in a grid pattern.

Table 1

Summary of the locations of the data sets.

Area	Number of Blocks
East Cameron	1
East Breaks	35
Garden Banks	33
Eugene Island	1
Ewing Bank	40
Green Canyon	64
Atwater Valley	1
Mississippi Canyon	7
TOTAL	182

Table 1 lists the lease areas of blocks that were mapped in detail and Figure 2 illustrates an example of the original mapping using high-resolution acoustic data from the Green Canyon area. Since the original maps were produced, hydrocarbon exploration and production on the continental slope has rapidly expanded and subsalt as well as ultradeep subsurface exploration has revitalized by-passed shelf and upper slope areas. Therefore, many new shelf and shelf edge areas are being revisited regarding potential geohazards.

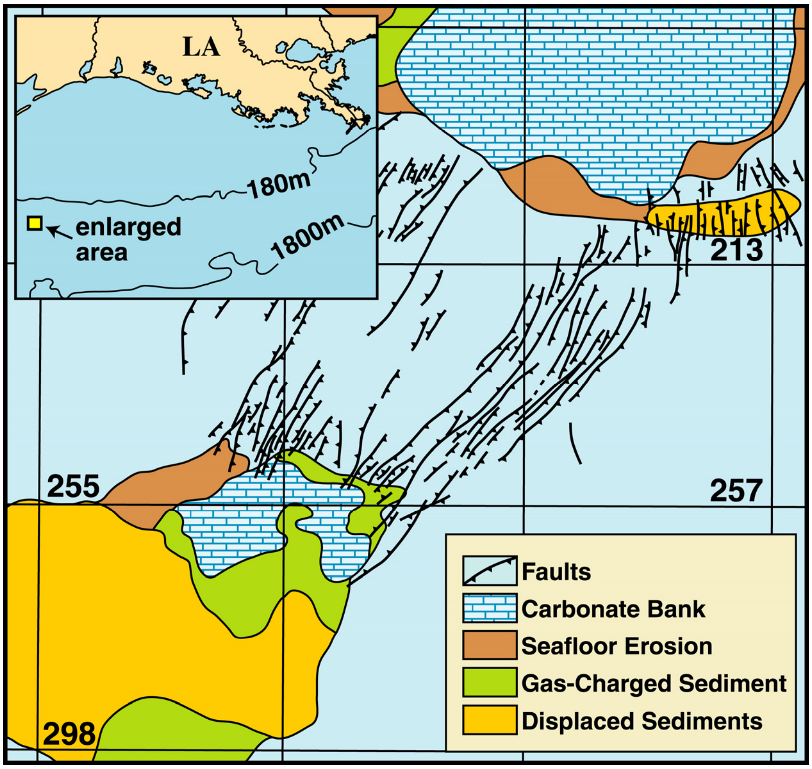

Figure 2. This illustration of the surficial geology in a small part of the Green Canyon lease area is a product of the original mapping effort on which this current project is based (Coleman et al., 1991).

3-D SEISMIC SURFACE AMPLITUDE MAPPING

Within the five mapping areas, discussed late, data gaps existed from mapping of the original high resolution acoustic data sets. These data gaps existed for several reasons: (a) companies would not release data to the original mapping project, (b) data had been acquired, but could not be found in time for use on the initial mapping effort, or (c) high resolution acoustic data had not been collected in these areas. As part of the present mapping project, the research team tried to find original high resolution data sets that had been acquired since the original mapping was accomplished in the mid-1980's or data collected earlier but not used in the original project to fill data gaps. It was quickly discovered that very little original data still exist. Many companies now only retain the summary reports prepared by the survey companies after the engineers and geologists have completed their assessment of the original data records. The Minerals Management Service's archives for high-resolution data were also investigated as a source for this project, but data from many needed areas were not available or only summary maps unuseable for project objectives were retained. Therefore, the lack of a critical mass of high resolution acoustic data products to fill our data gaps forced another approach.

Because the areas of interest to this project are included in several regional 3-D seismic grids, it was an available option to use 3-D seismic surface amplitude data to help fill data gaps and perhaps improve and extend mapping originally accomplished with high-resolution acoustic data. It was realized from the outset that not all of our mapping categories could be accomodated using surficial data only. For example, mass movement deposits (shallow subsurface) and seafloor erosion are two categories not attainable using 3-D seismic surface amplitude data. However, it was quickly discovered that faulting and hard bottom areas were more faithfully represented in the surface amplitude data than in the original high-resolution data sets. Even areas that were categorized as acoustic wipeout zones in high-resolution seismic data sets could be predicted with a high degree of confidence using 3-D seismic surface amplitude data. Therefore, the researchers responsible for this MMS-sponsored mapping project became confident of the results obtained by augmenting the maps created from a high-resolution acoustic data base with maps created from a 3-D seismic surface amplitude data base. The details of converting the original maps from high-resolution acoustic data and those from 3-D seismic surface amplitude data to our final products are discussed in following section of this report.

MAPPING CATEGORIES

The continental slope of the Gulf of Mexico is a region of gently sloping seafloor that extends from the shelf edge, or roughly the 200 m isobath, to the upper limit of the continental rise, at a general depth of 2,800 m. The slope encompasses more that 500,000 km^2 of smooth and gently sloping surfaces, prominent escarpments, knolls, intraslope basins, ridge and valley topography, and submarine channels (Martin and Bouma, 1978; Coleman et al., 1991). The most complex province is the Texas-Louisiana slope, comprising a 120,000 km^2 area of banks, knolls, intraslope basins, and domes. The average gradient of the slope is on the order of 1° to 3°, but locally, slopes greater than 20° are common. This varied topography is associated with salt diapirism and salt withdrawal beneath the intraslope basins. The features produce a wide spectrum of potential subaqueous geohazards. Mapping of high-resolution acoustic data was organized into the following six categories. Figure 3 illustrates seismic characteristics and seafloor views of each of these categories:

Undisturbed seafloor – Large areas of the region mapped display a relatively smooth seafloor that produces regular undisturbed acoustic reflections on seismic profiles and little or no bathymetric relief (Roberts, 1995). The upper 30-60 m of the sediment column show little or no disturbance of the sedimentary sequence. In these regions, a thin "sedimentary drape" is usually found and borings indicate that the drape is Pleistocene and Holocene in age. This type of seismic signature generally indicates that there is little potential for slope failure, significant faulting, or migration of fluids and gases to the modern seafloor.

(1) Seafloor erosion – Seafloor erosion, even in relatively deep water is extremely common and widespread, especially in those areas that contain subaqueous relief features (Roberts, 1995). In the regions mapped, sediment removal ranged from only a few meters to many tens of meters. Such erosion in deep water areas could pose a significant hazard to bottom-laid pipelines. Several possibilities exist to explain the observed seafloor erosion: a) erosion took place at an earlier time (probably during a period of lowered sea level), b) mass-movement processes have resulted in stripping sediment from the slopes, c) continual slow erosive processes by currently unknown bottom currents operative over a long period of time, or d) present-day erosion of undefined frequency and magnitude by Loop Current-driven processes.

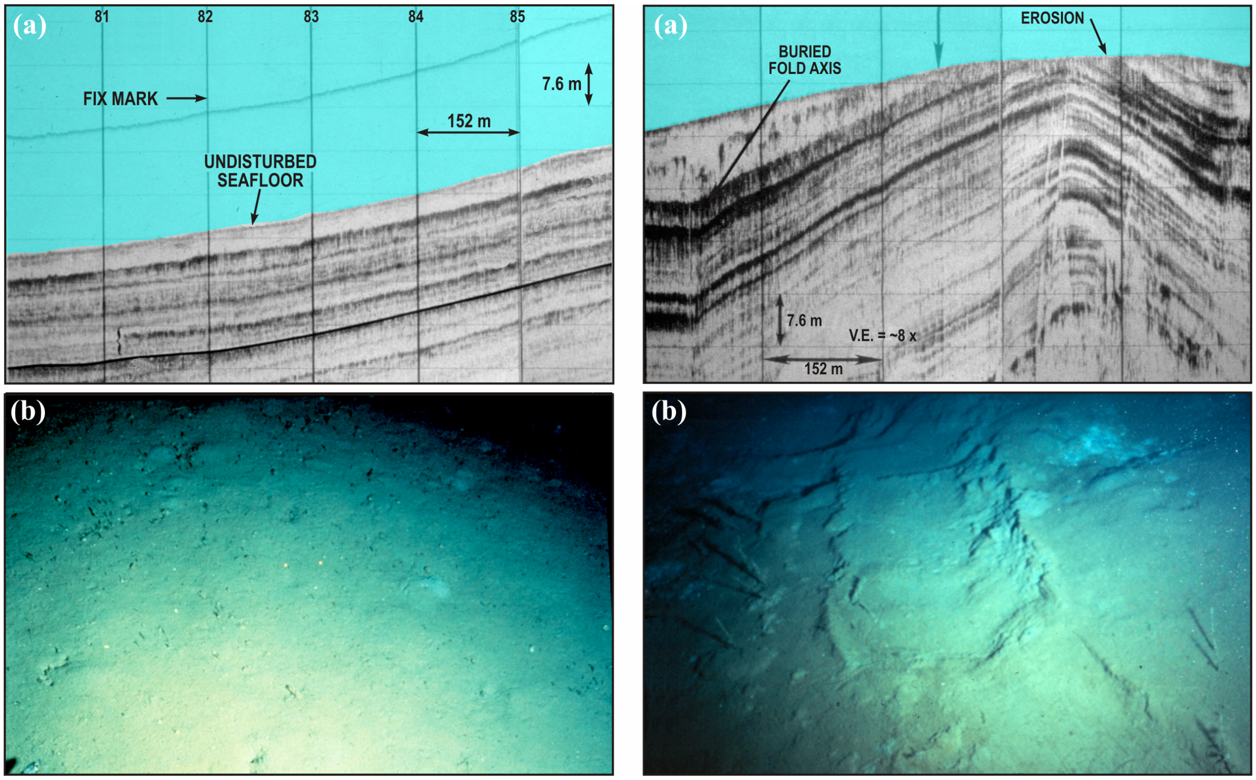

Figure 3A

Figure 3B

Figure 3. This composite figure illustrates the types of seafloor conditions and features that have been mapped as part of the CSI-Industry consortium and were mapped for this project. These mapping categories are as follows: (A) Undisturbed seafloor: (a) Seismic line and (b) seafloor photograph illustrate normal, undisturbed seafloor conditions. (B) Seafloor erosion: (a) This high-resolution seismic profile illustrates erosional truncation of upturned bedding at the apex of an anticlinal fold over a salt structure. (b) The seafloor photograph shows outcropping beds in an area of seafloor erosion. (continued)

(2) **Hard bottom** (bioherms, hardgrounds, carbonate banks, and outcrops) – Variations in sea level during the late Pleistocene had a significant control on the type, rate, and distribution of sedimentation on the continental slope. During periods of lowered sea level, diapiric highs beyond the shelf edge provided a substrate for colonization of organisms and produced bioherms and carbonate cemented banks, similar to Flower Garden Bank along the current shelf edge of western Louisiana. In deeper waters, below the photic zone at periods of lowered sea level, hardgrounds and carbonate buildups also developed, but from quite different biologic and geochemical processes. At these depths normal reef-building biota could not survive, but the seepage of hydrocarbons to the seafloor provided an energy source to sustain special benthic communities. In addition, the microbial utilization of these hydrocarbons at the seafloor produced calcium and magnesium carbonates that result in hardbottom conditions in the form of cemented hardgrounds to massive carbonate buildups (Roberts and Aharon, 1994). In special cases, exotic minerals like barite can add to hardground and mound development (Roberts and Carney, 1997). These hydrocarbon seep-related processes of hardbottom formation have been active throughout the Pleistocene and they are still active today (Roberts and Aharon, 1994; Roberts, 1996; Roberts and Carney, 1987).

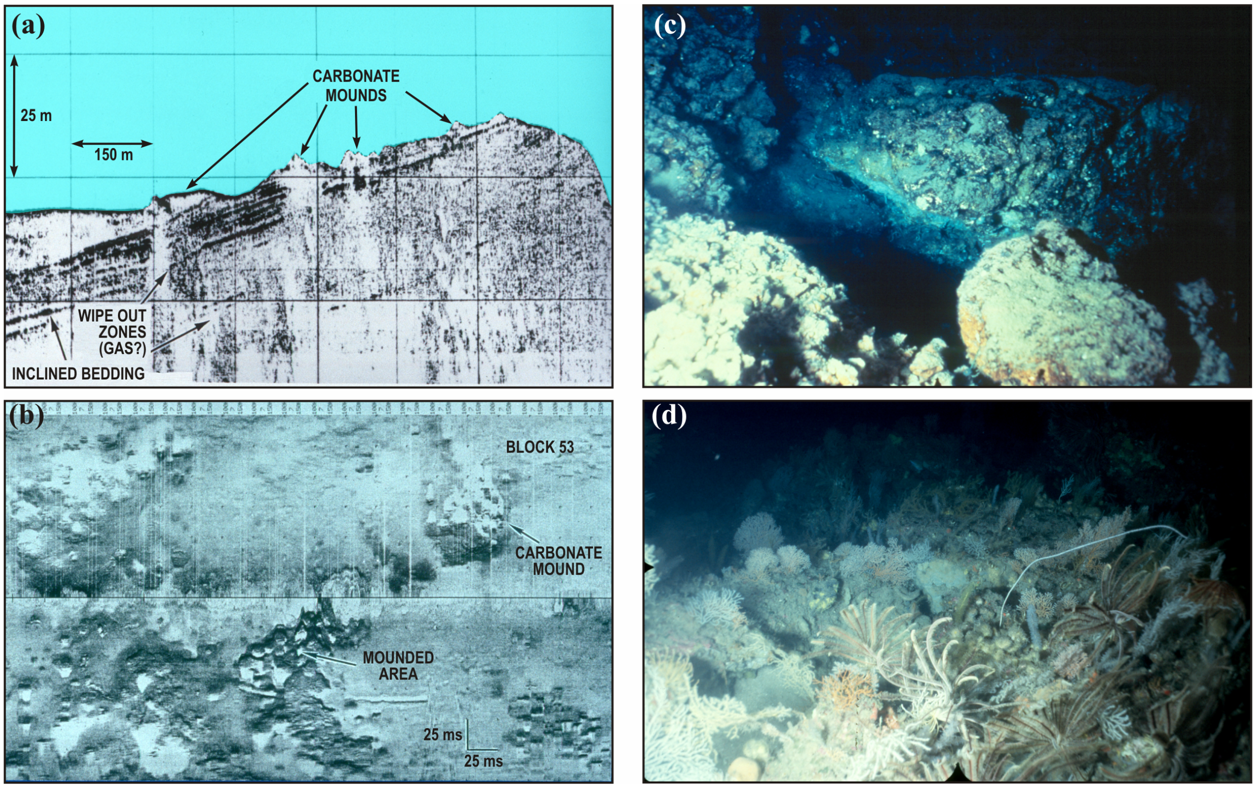

Figure 3. (C) Hard Bottom Areas: This category incorporates several hardbottom types. (a) The high-resolution seismic profile illustrates a field of seafloor mounds composed of authigenic Ca-Mg carbonates. This carbonate is a by-product of microbial metabolism of hydrocarbons. Note the acoustic wipe-out zone (gas?) beneath each mound. (b) This side-scan sonar image shows the spatial distribution of carbonate mounds typical of many slope areas that are supported beneath by shallow salt masses. (c) Below the photic zone, mounded authigenic carbonates display little biogenic cover, as shown in this seafloor photograph taken at a depth of 281 m. (d) As this seafloor photograph of a mound top (water depth of 164 m) clearly shows, hardbottoms in the photic zone are covered with a biogenic veneer consisting of sponges, crinoids, coralline algae, and many other benthic organisms. (continued)

(3) Faults – Complex fault patterns are caused by a variety of mechanisms, but sediment loading, differential compaction, diapiric intrusion, and salt withdrawal are the major mechanisms that produce faulting on the continental slope. In the regions mapped, faulting, especially the shallow-seated faults, are extremely complex and were one of the most common in feature mapped features. Many of the shallow faults cut the present seafloor and are possibly active at the present time. Most of the complex and sometimes radial fault patterns are associated with salt diapers (Roberts and Doyle, 1998).

(4) Acoustic wipeout zones – Acoustic wipeout have long been recognized on high-resolution seismic data in the shallow water areas. Mapping in deeper waters has shown that such features are also very common in deep water (Roberts, 1995). The presence of bubble phase biogenic methane and petrogenic gases, and severe disturbance of the shallow sediment column all generally tend to result in acoustic wipeouts. Gas charged mud vents are extremely common in many of the blocks mapped. Hard bottom areas that are thoroughly cemented or characterized by closely spaced, authigenic carbonate mounds cause reflection or scattering of high-resolution seismic energy also can result in acoustic wipeout zones in the shallow subsurface.

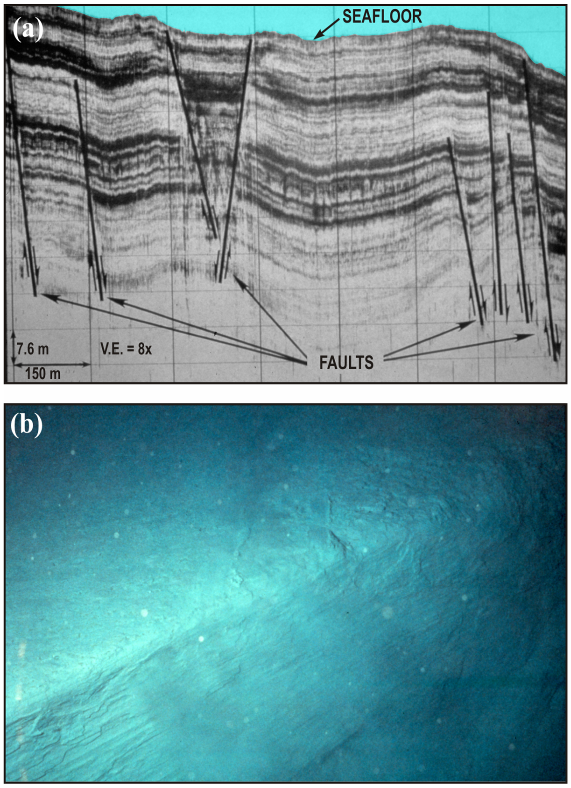

Figure 3D

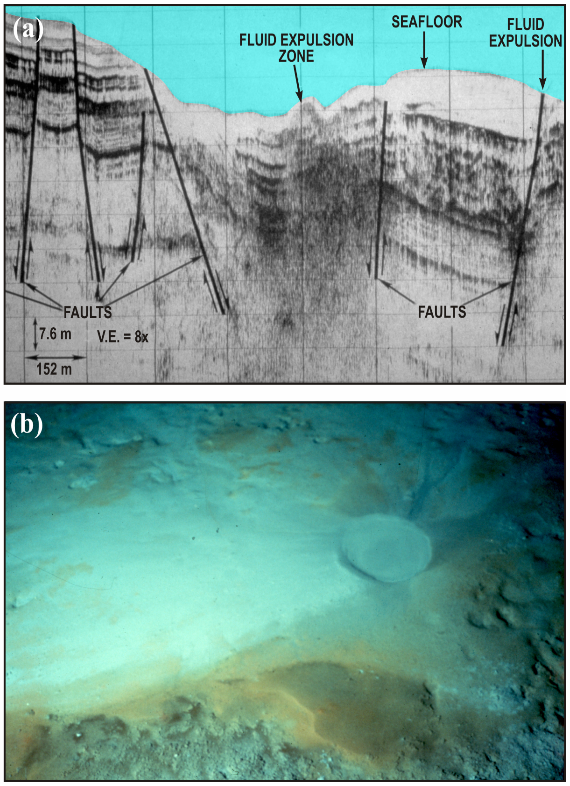

Figure 3E

Figure 3. (D) Faulted Seafloor Areas: Much of the slope province is extensively faulted with substantial offsets at the modern seafloor. (a) This high-resolution seismic profile illustrates an area of faulting that affects the modern seafloor. (b) This bottom photograph shows the face of a fault scarp on the continental slope. (E) Acoustic Wipe-Out Zones: (a) These zones as imaged on high-resolution seismic profiles display no internal reflection events. This seismic response is usually attributed to the presence of bubble phase gas which scatters the acoustic energy. (b) As this seafloor photograph over an acoustic wipe-out zone clearly shows, fluid and gas expulsion features, such as this mud volcano, are frequently correlated with acoustic blanking on seismic records. (continued)

(5) Mass movement features – Subaqueous mass movement features were present in the data evaluated (Coleman and Prior, 1982). Most of the deposits interpreted as resulting from mass movement were associated with relatively steep slopes adjacent to salt diapirs. Some may in fact be flows derived from fluidized sediment expulsion, a process shown to be common in the northern Gulf of Mexico continental slope province (Roberts and Carney, 1997). The age of many of these mass movement deposits, although quite common, is presently unknown. Some of these features, however, are quite large and could pose a significant geohazard if they are presently active.

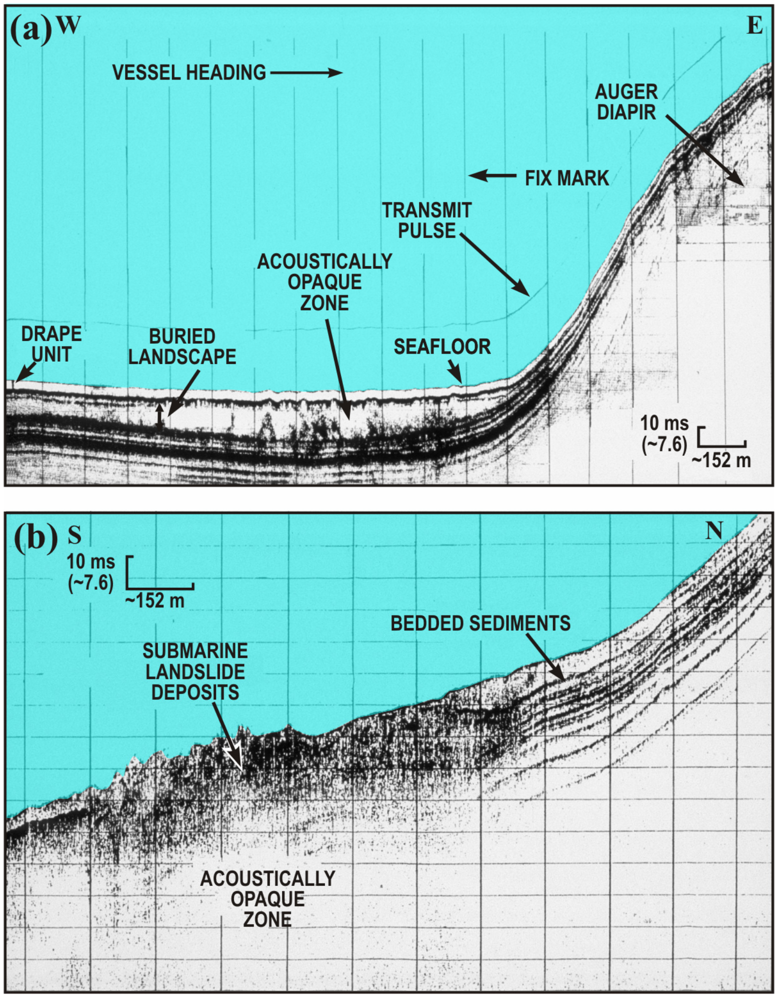

Figure 3F

Figure 3. (F) Mass Movement: One of the most important categories of geohazards in the northern Gulf of Mexico OCS is sediment failure and mass movement. These processes manifest themselves as submarine landslides and a variety of creep-related phenomena. (a) This high-resolution seismic profile illustrates a submarine landslide deposit now covered by a hemipelagic drape deposit. (b) The submarine landslide deposit in this seismic profile illustrates a high degree of bottom irregularity due to large blocks of transported sediment.

METHODOLOGY, PHASE ONE

The original source data, with which we began, were hardcopy maps of all five of the Areas that had been mapped during the 1980s CSI "High-resolution Geophysical Study Louisiana – Texas Continental Slope" study (Figure 4). These data included the geologic themes, (a) undisturbed seafloor, (b) seafloor erosion, (c) hard bottom, (d) faults, (e) acoustic wipe-out zones, (f) mass movement features, for an area of 182 lease blocks along with the block boundaries. The GIS tasks of Phase One of the current study were to digitize these source data, georeference them, assemble them into a digital mosaic, and develop GIS data layers from the mosaic. The process description is as follows.

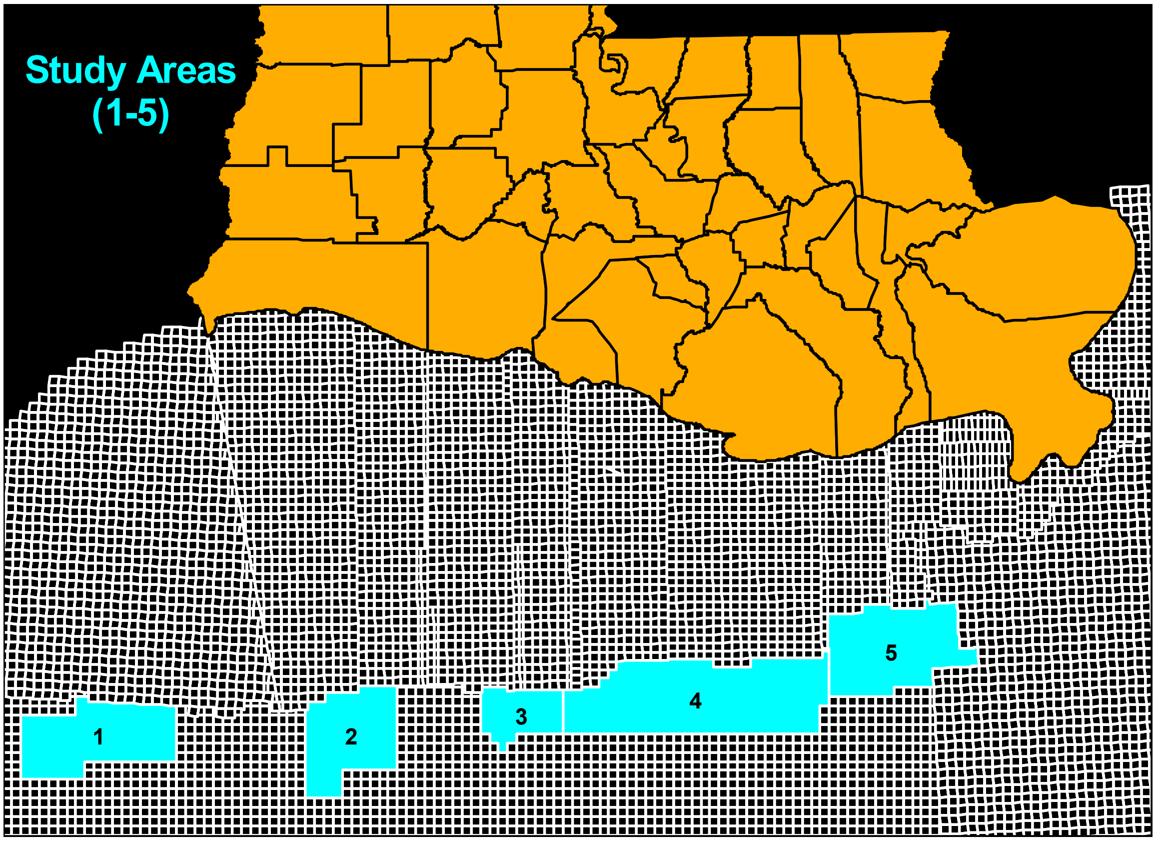

Figure 4. Five original study areas.

Digitization of Source Maps: The digitizing step was performed in ten different digitizing sessions, using a large format Calcomp digitizing tablet, an Intergraph NT workstation, and Intergraph's MGE GIS software. The digitizing had to be performed in so many different sessions; because, the source maps were as tall as 52 inches and as wide as 110 inches. An example of these source maps appears in Figure 5. During the digitizing process, the source data were digitized on different levels within the MGE *design file* data structure in order to isolate the various themes of geologic information so that they could be easily separated later. The lease block boundaries were also digitized on a separate level. The corners of these boundaries would be needed for the georeferencing step.

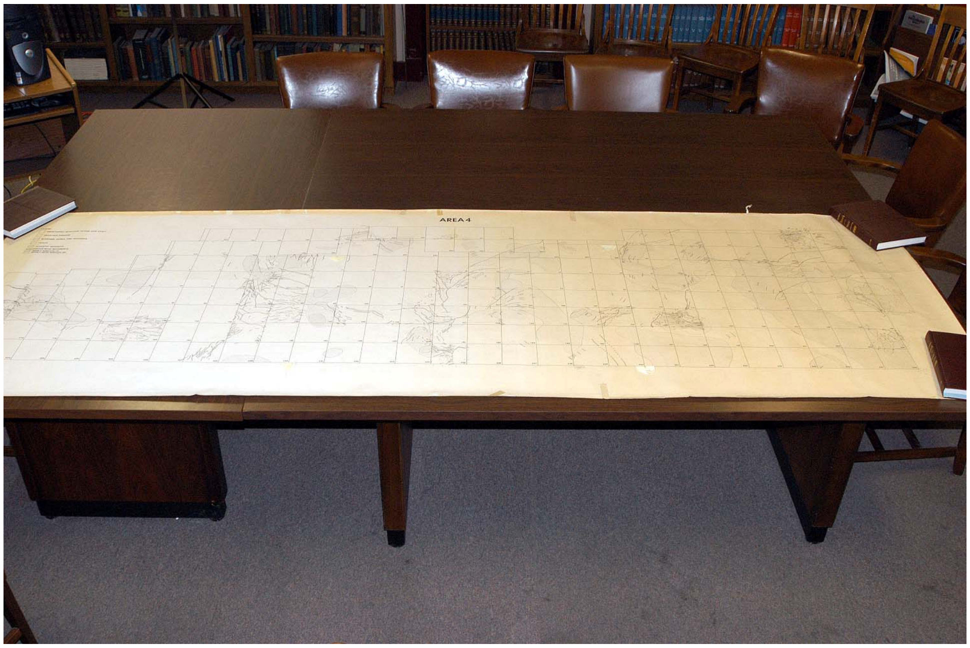

Figure 5. Hardcopy source map for Area 4.

Georeferencing Source Maps: The georeferencing step was performed on an Intergraph NT workstation, using Intergraph's MGE GIS software, with the aid of the MMS "Outer Continental Shelf Official Protraction Diagrams," (Figure 6). Specific corners of the digitized lease boundaries were selected for use in the georeferencing process. The correct geo-coordinates, for each of the selected corners, were determined by researching the MMS "Outer Continental Shelf Official Protraction Diagrams."

The georeferencing of the digitized data could then be performed by assigning the correct geographic coordinates for each of the selected corners of the digitized lease boundaries (see Figure 7), using the Control Point Setup module of MGE, and subsequently reprojecting the digitized data, using the Projection Manager module of MGE. This process was repeated for the output from each of the ten different digitizing sessions.

Vector Mosaic Assembly: The mosaic assembly step was performed on an Intergraph NT workstation, using Intergraph's MGE GIS software. First a blank Intergraph *design file* (.dgn) was created; and the file's projection was established as UTM, Zone 15, NAD27. Each and every georeferenced Intergraph *design file* was then opened as "reference files" that overlay the blank file. Using the "Fence" and "Copy" functions, all of the digital linework that appears in the georeferenced *design files* were then "fence-copied" into the new blank file. Since the source files were georeferenced, all of the lines in the resulting mosaic *design file* should now have been in their correct geospatial locations. This was verified by overlaying the *design file* with an ArcInfo GIS coverage of the Outer Continental Shelf Official Lease Blocks, provided by MMS. The geospatial correlation between the corners of the digitized lease blocks and those of the MMS GIS coverage were assessed for accuracy.

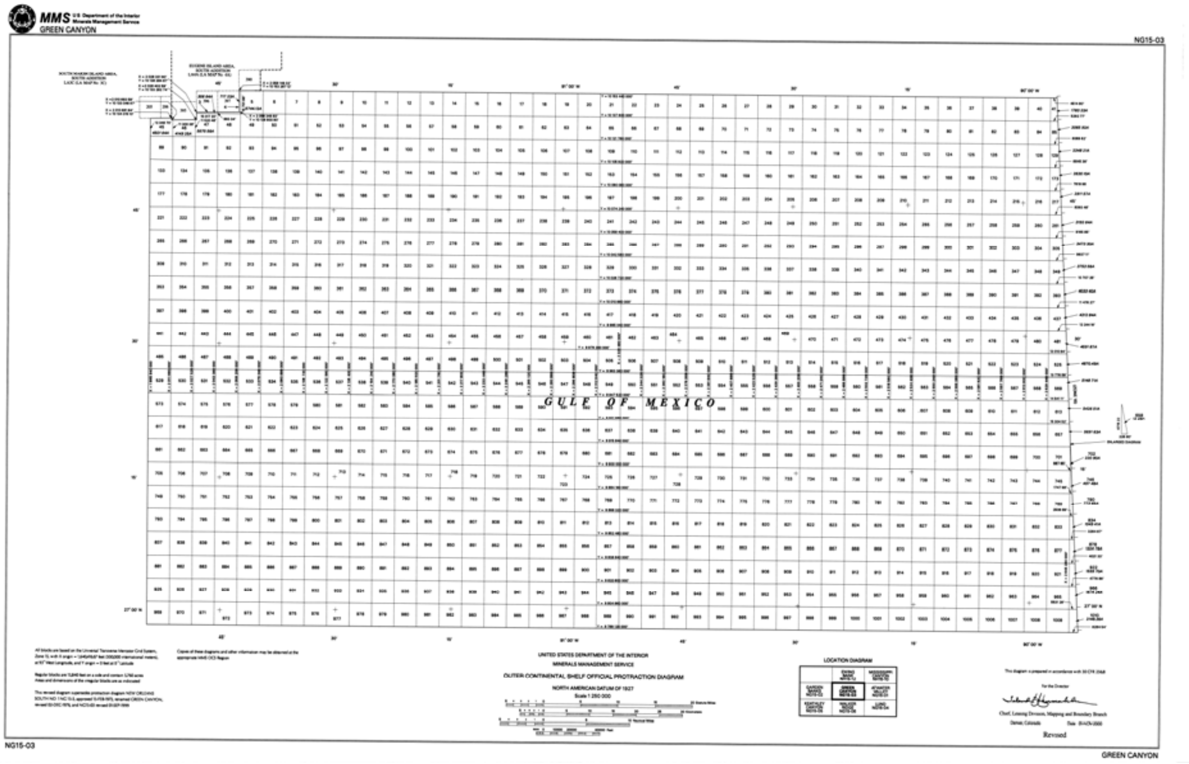

Figure 6. Example of an MMS "Outer Continental Shelf Official Protraction Diagrams."

Once all of the digitized and georeferenced data were contained within one *design file*, the next task was to edgematch each and every *design file* to their adjacent *design files*. After edgematching, the final task of assembling the digital mosaic was to perform line-cleaning functions on the data. This operation included the use of the Intergraph MGE Base Mapper Line Cleaning functions, "Duplicate Line Processor" and "End Point Processor" as well as a significant amount of manual line cleaning and quality assessment tasks.

Topology Construction: The GIS development was performed on an Intergraph NT workstation, using Intergraph's MGE GIS software, and both ESRI's ArcInfo and ArcView software. Once the georeferenced, and edgematched, digital mosaic was clean, that is, that it contained no extra or duplicate lines, it could then be developed into GIS data layers. As mentioned earlier, during the digitizing process, the source data were digitized on different levels in order to isolate the various themes of geologic information so that they could be easily separated at a later time. That time had now come. Since none of the polygons overlapped other polygons, all digital linework were separated by levels, and saved into two *design files,* one for linear features (faults) and one for polygonal features (all remaining geologic themes). In ArcInfo GIS software these *design files* were translated into ArcInfo "*coverages*," which were projected as UTM, Zone 15, NAD27. Finally, topology could be constructed for both geologic theme *coverages,* using the ArcInfo "Build" command. The following themes: undisturbed seafloor, seafloor erosion, hard bottom, acoustic wipe-out zones, and mass movement features, were each built into polygon features. The faults were built into line features. We now had two GIS data layers, together providing all of the six geologic themes of the 1980s source data.

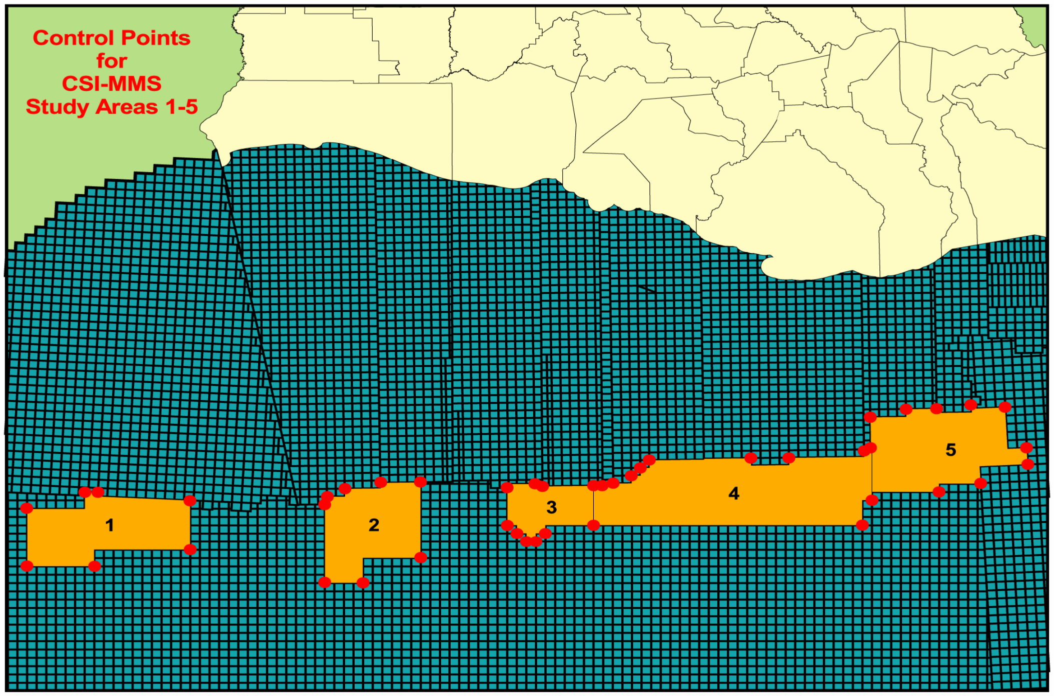

Figure 7. Lease block corners selected as control points for the georeferencing process.

Population of Database Attributes: Each GIS feature, line or polygon, in each of the two ArcInfo *coverages* was now linked to an attribute record in the GIS database. For the database attribution process the two ArcInfo *coverages* were translated into ArcView *shapefiles*. In ArcView, each GIS feature, line or polygon, was matched to its source element on the source maps, identified by its geologic type, and attributed accordingly within the database. For the polygons, this process was not difficult, though it was tedious. However, the faults proved to be quite difficult. Each individual digitized line segment had to be attributed as to whether the strike was on the left side or the right side of the fault. Once this extremely tedious task was completed. The individual line segments could be "unioned" together to form faults. Now all the attributed GIS features could be symbolized automatically by using the database attributes. At the end of Phase One the hardcopy map data from the 1980s CSI "High-resolution Geophysical Study Louisiana – Texas Continental Slope" project had successfully been developed into two GIS data layers, in the form of ArcView *shapefiles*.

METHODOLOGY, PHASE TWO

The original source data for Phase Two were tabloid size, color printouts of computer screen captures of surface amplitude data near or within the project's five original study areas (Figure 8). The surface amplitude data is a component of the MMS 3-D seismic database of the Gulf of Mexico continental shelf slope. At the time these screen captures were being saved, only the surface amplitude data and the offshore lease blocks were displayed. The surface amplitude data would be used for geologic interpretations, during the mapping process, while the offshore lease blocks were needed for georeferencing purposes. While most of the process description refers to the development of GIS data for geologic polygons, a similar and much simpler process was followed to develop GIS data for geologic lines (faults). The process description is as follows.

Source Data Preparation: The color printouts were scanned at a resolution of 300 dots per inch, on a flat bed computer scanner. By first using the Latitude and Longitude tick marks along the edges of the scan images to identify the correct Lease Block Area from which the image came, and then by using both the pattern of the lease block boundaries and the lease block numbers on the scan images, the geographic area of coverage of each image was located on the MMS "Outer Continental Shelf Official Protraction Diagrams." The precise coordinates for each of the lease block boundaries are recorded on these diagrams. After choosing the best combination of lease block corners to use for georeferencing each image, the corresponding coordinates for each of the selected corners were obtained from the "Outer Continental Shelf Official Protraction Diagrams" (see Figure 6). These selected corners and their coordinates were recorded on tabloid size photocopies of the original color printouts, of computer screen captures of surface amplitude data, here-to-fore referred to as "Raster Control Sheets".

The process of georeferencing the scan images (of the color print-outs of computer screen captures) was a complex algorithm employing ERDAS Imagine (Ver. 8.6), a digital image processing and raster GIS software package and ESRI ArcView (Ver. 3.3), a vector GIS software package. During each Imagine georeferencing session, extensive efforts were made to achieve a Total RMS value, for all of the selected control points combined, of 1.0 or less. After each image was georeferenced in Imagine, it was exported from ERDAS Imagine in a GEO-TIFF file format. The GEO-TIFFs were then overlayed with the MMS Lease Block Boundary GIS vector data within ArcView so that they could be examined for geospatial accuracy. The lease block corners in the images (raster data layer) were compared to the corresponding corners in the vector data layer by measuring the displacement in feet. If they were over 150 feet out of place for some portion of the image, additional control points were selected; and, the georeferencing process was performed again for that image.

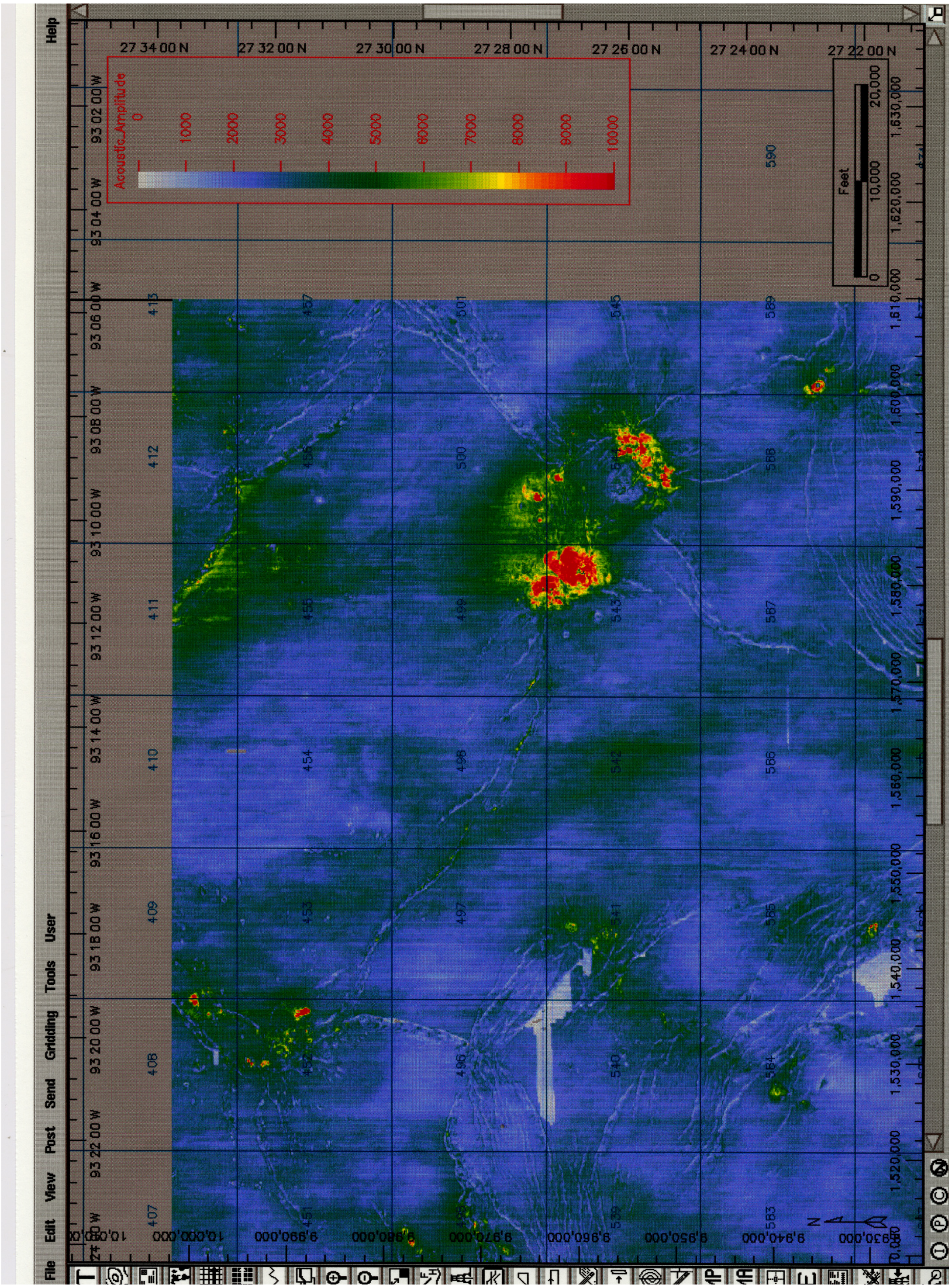

Figure 8. Example of a scan of a screen capture printout of surface amplitude data from the MMS 3-D seismic data.

After each image was successfully georeferenced, it was "cropped" to remove the extraneous portion of the screen capture, leaving only an image of the data that had been displayed on the computer screen (at the time of the capture), and then exported as a GEO-TIFF. The Total RMS and the Maximum Error (displacement) values for each scan image were recorded on each Raster Control Sheet. The source data preparation process was very time consuming and tedious; but, we were quite pleased with the outcome. Future use of the term "source data" in this report will refer to the total collection of, or any portion of, the georeferenced images of the surface amplitude data only, originating from the color printouts, of computer screen captures of surface amplitude data, provided by MMS.

Source Map Preparation: In order to prepare maps of the source data, we constructed an ESRI ArcView GIS *project* in which we could bring together the georeferenced source data images, the GIS vector geology data and study area boundaries that we produced in the first year of this research project, and the MMS vector GIS data of the offshore lease blocks, all overlain in a geospatial environment. Footprints of the desired source maps were created as individual rectangular polygons and arranged in a pattern that provided an efficient coverage of the areas covered by source data, allowing for slight overlapping of adjacent footprints. A unique ESRI ArcView GIS *project* was saved from the original for each of the 35 source maps; then each project was edited in preparation for plotting the 24 X 36 inch maps.

After the digital source maps were cartographically prepared, they were plotted in color, at a scale of 1:100,000, on clear film, using a six-color large format inkjet plotter. Figure 9 represents Area 2, Map 13 Source Map, as an example of these 35 source maps. Each source map was then trimmed to a standard size and punched with a seven-hole film registration punch. Thirty-five sheets of mylar were also punched for future registration with each of the source maps. Smaller scale maps of each of the five geographic *Areas* within the project study area, were plotted on paper, to be used by the geologists for a smaller scale perspective of the source data. These smaller scale maps included two types for each Area, 1) a Source Imagery Mosaic, including all the georeferenced images of source data overlain by the geologic vector GIS data from the first year of the project, and, 2) a Source Vector Mosaic, including only the geologic vector GIS data from the first year. Figure 10 represents the Area 4 East, Source Imagery Mosaic, as an example of these 14 source data mosaic maps.

Interpretive Geologic Mapping: The interpretive geologic mapping process employed traditional manual mapping techniques. With a Source Map (described above) registered by a seven-pin film registration pin strip, to a blank sheet of Mylar, on a large light table, the geologic features were mapped, using different colors of plastic lead mechanical pencils. Utilizing surface amplitude component of the MMS 3-D seismic data, the geologic features that could be mapped included, areas of hard bottom, faults, and interpreted acoustic wipeout zones. Even though acoustic wipeout zones were interpreted in the subsurface profiles of the 1980s high-resolution data during Phase One, the strong geospatial correlation of these zones and patterns in the 3-D seismic surface amplitude data allowed for the confident mapping of acoustic wipeout zones in the surface amplitude data. Other geologic themes (mapping categories) from Phase One that depended on subsurface data (seafloor erosion, and mass movement features) could not be confidently mapped using the 3-D seismic surface amplitude data alone.

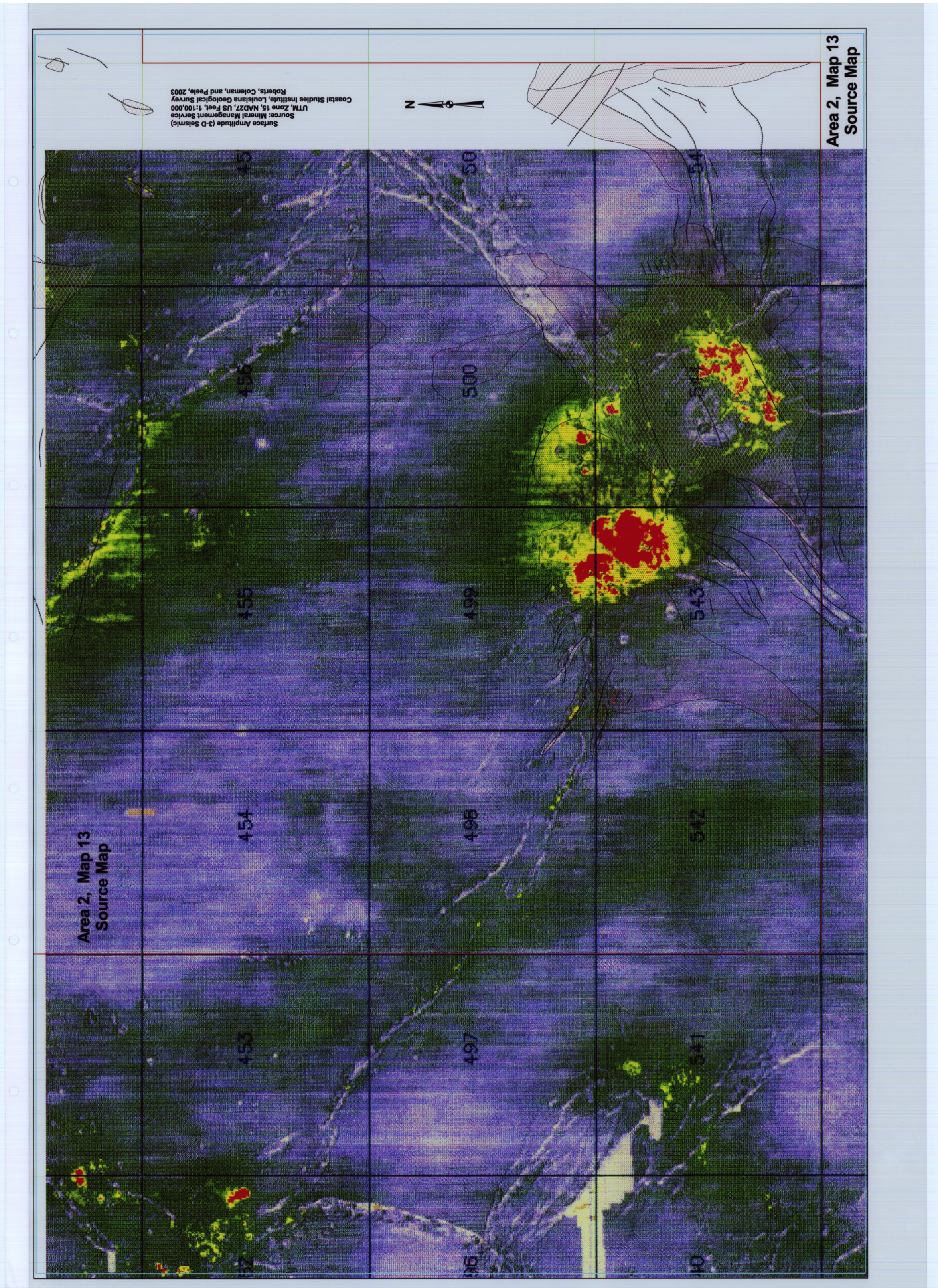

Figure 9. Example of the source maps, compiled from source data for the geologists to use in interpretive mapping.

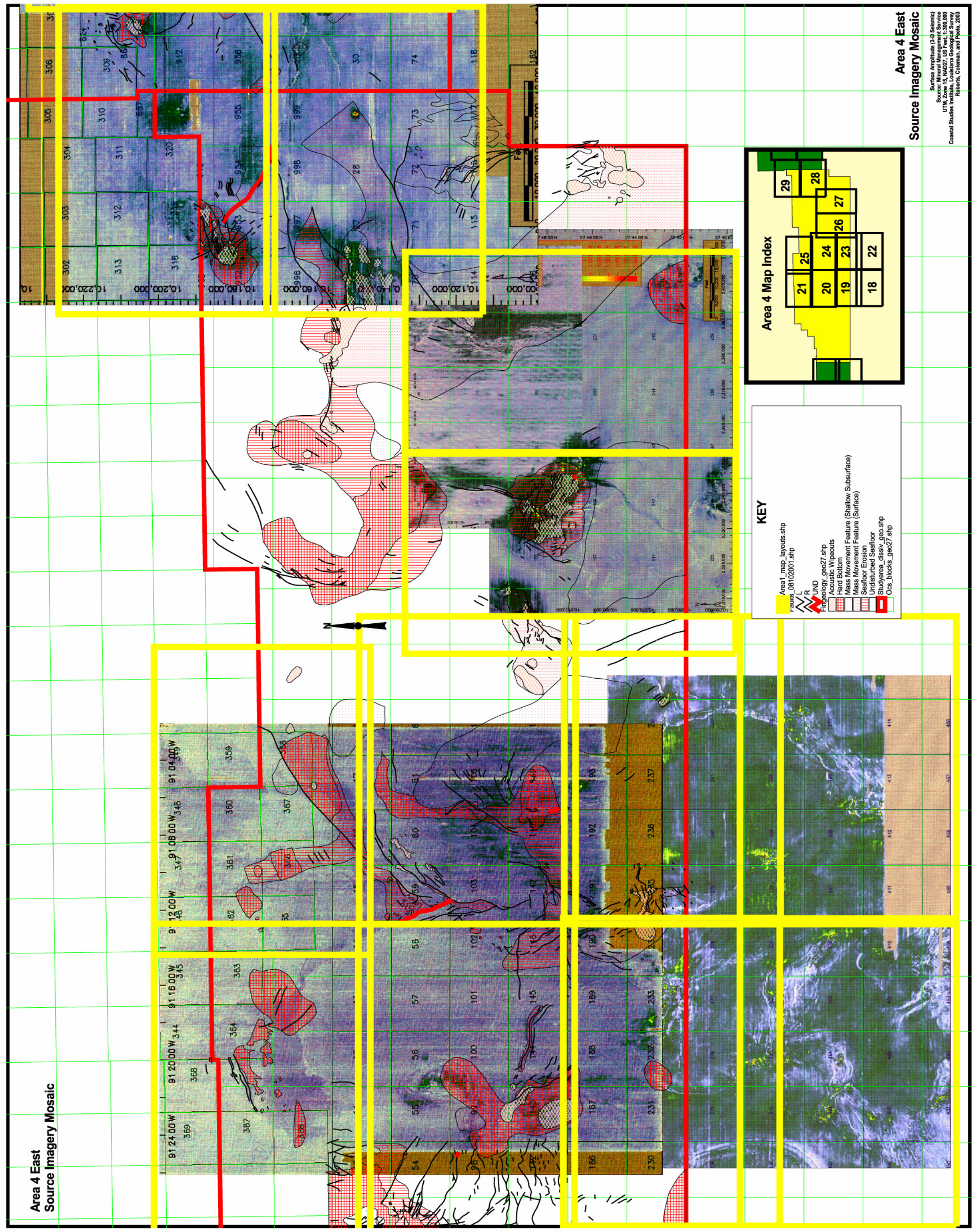

Figure 10. Example of a source imagery mosaic, documenting the GIS environment of overlain source data and source map footprints (yellow), at a smaller scale (1:300,000).

Along with the geologic features, spatial reference points were mapped with crosses to be used later for georeferencing. The reference points included Lease Block corners (whenever possible) and the intersection of lease boundaries and map footprints (when necessary).

Three colors of plastic lead pencils were used for the mapping, red, black, and blue. Red was used to map the linear geologic features, faults. Black was used to map the polygonal geologic features: areas of hard bottom, and acoustic wipeout zones. Standard abbreviations were labeled within each polygon to identify the type of polygonal geologic feature. Blue was used to transfer the geospatial reference points from the source maps to the Mylar. Figure 11 represents a scan of one of the Original Geologic Maps produced through the Interpretive Geologic Mapping Process.

Digitization of Geologic Maps: The 35 Original Geologic Maps were scanned on a large format roller bed scanner to produce both a Run Length Encoded (RLE) format black and white image for digitizing, and a JPEG color image for visual reference and illustrations (see Figure 11). Each scanned RLE image was digitized using INTERGRAPH GEOVEC vector GIS software. The automated line following function of GEOVEC, know as Directional Trace Line Strings, was employed for digitizing the raster lines of the RLE image. When properly configured, this function produces a high-fidelity vector line string, semi-automatically. All necessary corrections to the automated line strings were made using the Partial Delete function and the Place Line function. The output of this digitizing process is an INTERGRAPH *design file* for each of the 35 Original Geologic Maps.

As mentioned above, each of the three colors (red, black, and blue) that appear on the Original Geologic Maps were used for mapping the linear geologic features, the polygonal geologic features, and the geospatial reference points, respectively. Different colors and different levels within the *design files* were used to facilitate the maintenance of the separation of these features throughout the remainder of the data development process. Linear geologic features and polygonal geologic features would need to be developed into separate GIS data layers; and the geospatial reference points would only be used for georeferencing the INTERGRAPH *design files*, the next step in the process.

Georeferencing Original Geologic Maps: The JPEG scanned images of geologic maps were printed for use in selecting the best set of reference points to be used for georeferencing each digitized *design file.* Figure 12 is an example of one of these tabloid size prints, here-to-fore referred to as Vector Control Sheets. The Control Point Setup function of INTERGRAPH MGE vector GIS software was employed for the georeferencing process.

On each Vector Control Sheet, the set of selected geospatial reference points for that *design file* were circled and numbered according to the order in which they should be defined in the georeferencing process. Some of the selected reference points are circled with a single circle; while some are circled with two circles. Coordinates for the reference points circled with single circles are Lease Block corners, and as such, were obtained by researching the appropriate MMS Official Lease Block Protraction Diagram, the most accurate, precise and definitive source of Lease Block corner coordinates.

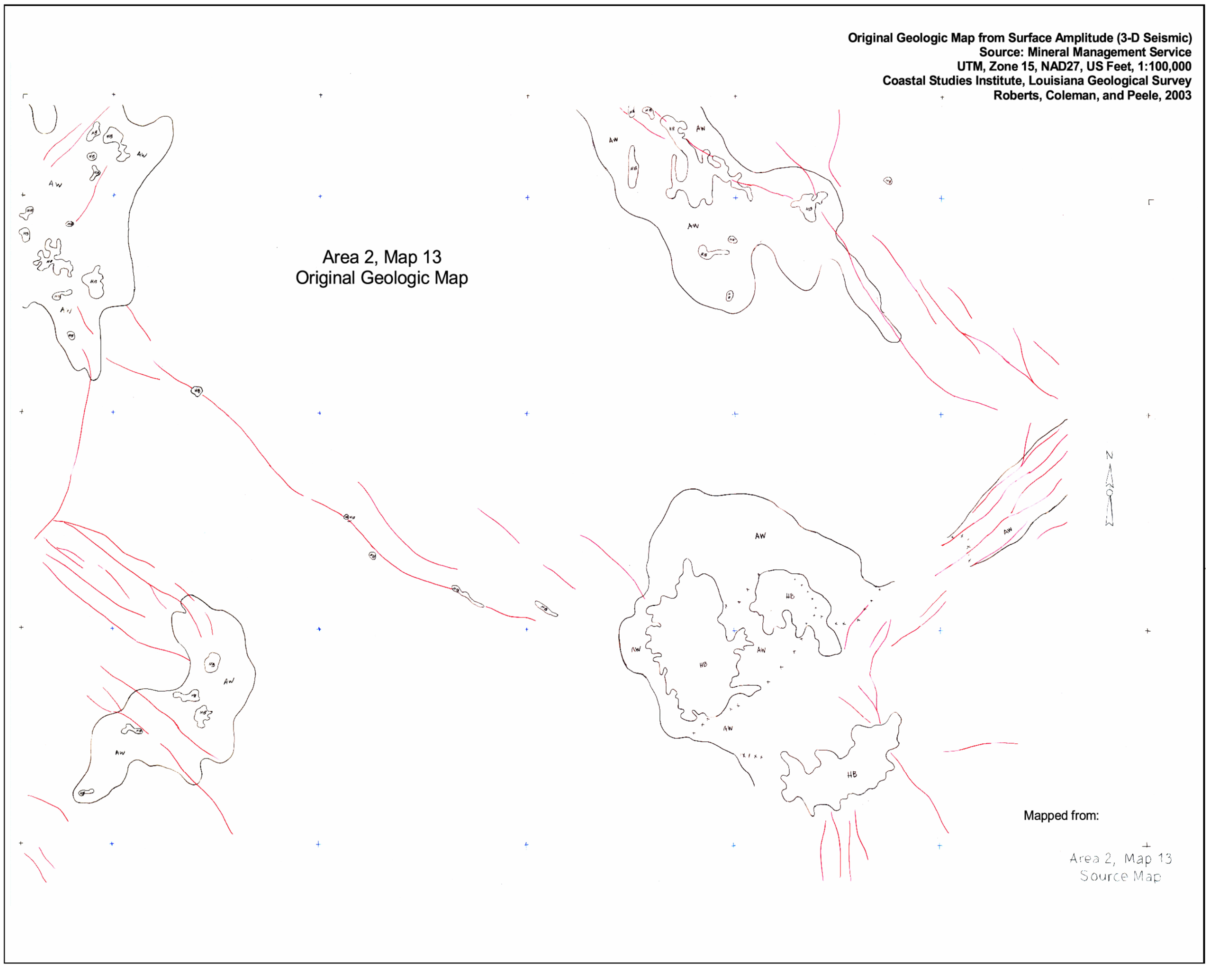

Figure 11. Example of the original geologic maps, documenting the geologic features mapped from the MMS 3-D seismic surface amplitude data, at the scale of 1:100,000.

Figure 12. Example of the vector control sheets, documenting the georeferencing process for *design files* of the original geologic map.

In some cases, at the northern extremes of Study Areas 4 and 5 (see Figure 13), the Lease Block corner coordinates did not appear on the most recently available Official Lease Block Protraction Diagrams that could be downloaded from the MMS website.

The reference points circled with two circles are either the intersection of Lease Block boundaries and Source Map footprint boundaries or the intersection two Source Map footprint boundaries. These coordinates were obtained by researching the individual ESRI ArcView GIS Projects referred to above in the section on Source Map Preparation. Zooming in beyond the scale of 1:1, for each of these points, the most accurate available coordinates were obtained.

The 35 individual *design files* that were produced in the digitization process were then georeferenced using the researched coordinates for the set of selected geospatial reference points for each *design file*.

Vector Area Mosaics Assembly: A vector mosaic was created for each of the five Study Areas. Each mosaic consists of an INTERGRAPH *design file* containing all of the vector lines from all of the digitized *design files* for the corresponding Area. The assembly of these Area Mosaic *design* files was performed within INTERGRAPH MGE by creating a new (blank) *design file*, attaching each of the digitized *design files* for the corresponding Area as Reference Files (overlays), placing a *fence* around all of the vector lines, and simply copying the contents of the *fence* into the newly created *design file*. Figure 13 represents the Original Geology Vector Mosaic for Area 4. From this point forward in the data development process, the 35 individual *design files* of the Original Geologic Maps were archived. The next step was to perform initial edgematching of the overlap of adjacent Original Geologic Maps, on the five newly created Vector Area Mosaics.

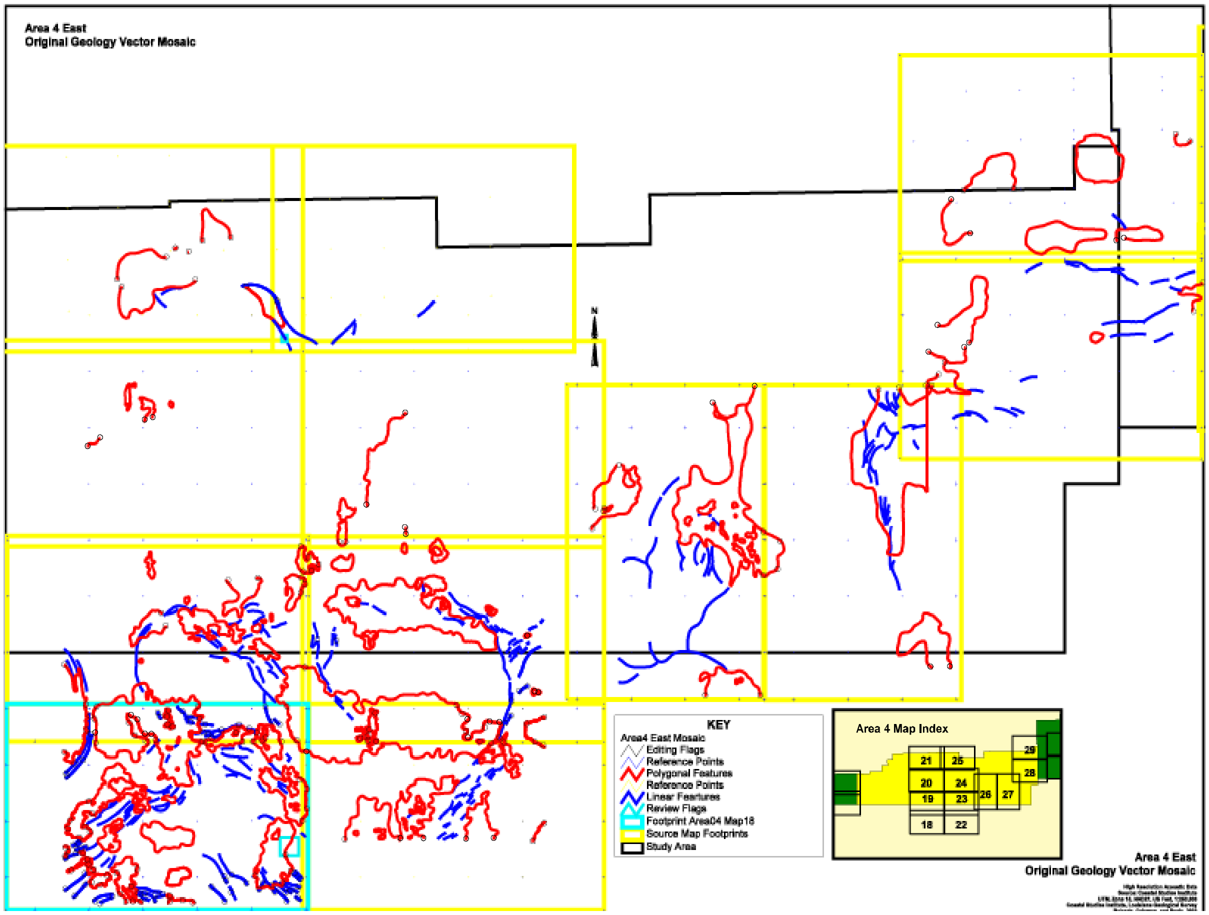

Figure 13. Example of the original geology vector mosaics, documenting all the newly digitized and georeferenced original geologic maps. There are five digital mosaics, one for each of the study areas.

Initial Edgematching: The initial edgematching process consisted of the following three tasks: 1) selecting the best choice of any overlapping lines to represent the geologic features visible in the source data, 2) editing the endpoints of these digital lines, when necessary, by adding lines to intersect properly with the existing GIS vector data of the 1980s CSI High-resolution Acoustic Data, 3) and arbitrarily closing polygons as needed, by adding lines. This initial edgematching process was performed by viewing the Vector Area Mosaic *design files* overlaying the surface amplitude images in the ESRI ArcView GIS environment while selecting the best choice of lines in these same *design files,* within the INTERGRAPH MGE environment. The initial edgematching process was performed on the five Vector Area Mosaics.

The line selections were only required in the areas of overlap of the Original Geologic Maps, because in these overlap areas the interpretive mapping occurred twice. To make the selections we simply changed both the color and the level of the best lines in the *design files*. No original lines were deleted, in case they might be needed again. Throughout the remaining, non-overlapped areas of each Vector Area Mosaic, all of the lines representing polygon boundaries had their colors and levels changed to match the selected lines in the overlap areas.

Editing the endpoints consisted of extending the digitized lines to allow for intersection with existing boundaries of the high-resolution acoustic data polygons. Sometimes these extensions were straight and sometimes curved, depending on the nature of the intended intersection. If the 3-D seismic surface amplitude data polygon was intended to be of a different classification than the adjacent high-resolution acoustic data polygon, the extension of the digitized lines were straight. If the 3-D seismic surface amplitude data polygon was intended to be of the same classification as the adjacent high-resolution acoustic data polygon, the extension of the digitized lines were curved to smooth the intersection. In the latter case, the new polygon is intended to extend the area of the high-resolution acoustic data polygon.

All of the edit lines, extending digitized lines, and those of the arbitrary polygon closures were made on a separate level and in a different color in the Vector Area Mosaic *design files*. This would allow the added lines to be distinguished from the digitized lines, mapped by the geologists, throughout the remainder of the project.

After all five Vector Area Mosaic *design files* had been edgematched, two mosaic *design files* were created, in order to complete the edgematching process, while also allowing the final two graduate assistants on the GIS team to continue to work in parallel. One mosaic included Areas 1, 2, and 3; while the other mosaic included Areas 4 and 5. The process for creating these two mosaic *design files* is described above, in the section entitled Vector Area Mosaics Assembly. Since Areas 4 and 5 are adjacent to each other, additional edgematching was required in the mosaic of Areas 4 and 5.

Whenever the GIS team was uncertain of the intent of the geologist, they placed a circular polygon “flag”, in a new ArcView “First_Review_Flags” *shapefile*, surrounding the questionable area. These flags would facilitate the First Edgematching Review process.

First Edgematching Review and Corrections: After the Initial Edgematching process was complete, the results were reviewed by the geologists interactively with the GIS team. This process involved the geologists reviewing the problem areas that had been flagged during the previous process along with the GIS team. The geologist provided resolutions to the confusion; and the GIS team documented their instructions. Usually the resolution involved decisions on the part of the geologists regarding areas of overlapping Original Geologic Maps where interpretive mapping occurred twice.

While viewing the georeferenced images of the color print-outs of computer screen captures from MMS 3-D seismic surface amplitude data, overlain by transparent polygons of both the high-resolution acoustic data polygons and the 3-D seismic surface amplitude data polygons; the confusion the GIS team had, regarding the intent of the geologists, was resolved for each flagged area. As the geologists provided the resolutions for each “flag” polygon, instructions for resolution were recorded in the corresponding database records of the “First_Review_Flags” ArcView *shapefile*. These instructions were consulted and implemented by the GIS team, while completing the edgematching for each flagged area. By the end of this process the digital lines in the two mosaic *design files* should have formed complete boundaries for the polygons that were intended by the geologist in the Interpretive Mapping Process described above.

Line Cleaning: The final task to perform in INTERGRAPH MGE was line cleaning. This process consisted of eliminating duplicate lines, lines that have the same two endpoints in common, and eliminating dangling ends, lines that were not involved in the closure of polygons.

First, the Duplicate Line Processor function was utilized to eliminate all duplicate lines. This process also breaks intersections of all lines that cross. The breaking of intersections allows the dangling ends to be located using the Endpoint Processor function. This function allows the placement of flags at each dangling end. Then, by zooming-in to the flags, one by one the dangling ends were selected and deleted. At this point the digital lines were ready to be made into polygons.

Topology Construction: Polygons were created from the digital lines of the mosaic *design files* within ESRI ArcInfo Workstation GIS software. First, the *design files* were translated into ArcInfo *coverages.* Then, the “Build” command was employed to calculate polygon topology for the *coverages.* Finally, each *coverage* was translated into an ArcView *shapefile.*

Population of Database Attributes: The final task for Phase Two of the Methodology was to attribute each GIS feature (digital line or polygon) with the appropriate geologic feature designation. This process was performed within the ArcView 3.3 GIS environment. Study Areas 1,2 and 3 and Study Areas 4 and 5 remained separated, to allow simultaneous work by the two Graduate Assistants. The geologists had previously notated abbreviations for the geologic feature designations, on the 35 Original Geologic Maps. Once the attributing process was finished, Phase Two of the Project Methodology was complete.

METHODOLOGY, PHASE THREE

The source data for Phase Three included the data products from Phase One, GIS vector data of the 1980s CSI High-resolution Acoustic Data, and from Phase Two, GIS vector data of the 2000 MMS 3-D Seismic Surface Amplitude Data. The objective of Phase Three was to produce a composite GIS data layer that combines the data from Phases One with those from Phase Two. The final products would be one composite GIS polygon layer for geologic aerial features and one composite GIS line layer for geologic linear features (faults). While most of the process description refers to the development of the composite GIS polygon layer, a similar and much simpler process was followed to develop GIS data for the faults. The process description is as follows.

Database Preparation: Both, the High-Res Acoustic Data and the Surface Amplitude data had been attributed during Phase One and Phase Two, respectively. Before these two GIS data layers could be combined, the databases of each were examined to assure that the field headings were unique to each database. Also, an additional field was added to each of these two *shapefiles*. The new field, entitled "Source," was populated with a reference to the original source data for all of the feature records in each of these *shapefiles*. This technique provided a way to maintain the data source information through the process of combining the two data layers. The Database Preparation process was performed within the ArcView 3.3 GIS environment. After the two *shapefile* databases had been prepared, these two data layers could be combined.

Source Data Footprints: The other two polygon data layers that were needed to combine with the geology polygon layers were the study area boundaries, which represented the study areas for the 1980s CSI High-resolution Acoustic Data surveys, and the geospatial "footprints" of the 2000 MMS 3-D Seismic Surface Amplitude Data images. Each of these represent the limits of data for their corresponding data source. The study area boundaries had already been created during Phase One. Now in Phase Three, the "footprints" of the georeferenced and clipped, 2000 MMS 3-D Seismic Surface Amplitude Data images were digitized, as polygons, in a new shapefile within ArcView 3.3. Topology was built in ArcInfo; and, the "footprints" were translated back into a *shapefile*. All four *shapefiles* were now ready to be combined.

Combining GIS Layers: In order to combine four GIS data layers, in such a way that would allow every line that appears in each of the four source *shapefiles* to appear in the combined *shapefile*, a GIS function known as a "Union," was selected as the most appropriate and efficient technique for combining the *shapefiles*. A Union of these four *shapefiles* was performed within the ArcView 3.3 "Geoprocessing Wizard" environment. The ArcView script, "explode," was run on the output composite *shapefile*. This script assures that each GIS feature (line or polygon) has a unique record in the *shapefile* database. The resulting *shapefile* was then thoroughly examined for accuracy.

The accuracy assessment revealed that the ArcView 3.3 Geoprocessing Wizard function, "Union," did in fact, faithfully include all of the lines, from all four of the source *shapefiles*, in the output composite *shapefile*. However, the lines had been shifted by less than one meter. This would not have been a matter of concern except that, when the "Union" function began to create the database for the output features (polygons), each output polygon overlay two source features. Therefore, the majority of the polygons in the output composite *shapefile* had incorrect attributes in their unique database records. Obviously, this was a major problem.

Database Corrections: To correct the database problem from the "Union" of the source *shapefiles*, the database records for each and every polygon in the output composite *shapefile* was compared to the corresponding polygons in the two source data *shapefiles*; and manually corrected, accordingly. This way the data could be corrected with the highest level of confidence, in the shortest amount of time. Once the database had been corrected, attention was turned to cleaning the linework in the composite *shapefile*.

Polygon Edgematching: Even though the Union function did transfer all of the lines, from both of the source *shapefiles*, into the output composite *shapefile*, considerable work remained to eliminate sliver polygons, smooth intersections between some adjacent polygons, and Union adjacent polygons of the same geomorphology. These edgematching tasks were performed within ArcView 3.3, by either splitting polygons in two, unioning adjacent polygons into one, or a combination of both splitting and unioning. After the edgematching process was complete, the output composite *shapefile* was ready for review.

Whenever the GIS team was uncertain of what should be done in a certain area, they placed a circular polygon "flag", in a new ArcView "Second_Review_Flags" *shapefile*, surrounding the questionable area. These flags would facilitate the Second Edgematching Review process.

Second Edgematching Review and Corrections: Together, the geologists and the GIS team interactively reviewed the composite *shapefile*. This process involved the geologists reviewing the problem areas that had been flagged during the previous process along with the GIS team. The geologist provided resolutions to the confusion; and the GIS team documented their instructions. Usually the resolution involved decisions by of the geologists regarding differences in the geomorphological designations between the two source *shapefiles*. These differences primarily occurred in small polygons around the periphery of larger geomorphic features. Most of these smaller polygons were created during the "Union" process.

While viewing the georeferenced images of the color print-outs of computer screen captures from MMS 3-D seismic surface amplitude data, overlain by transparent polygons of both the high-resolution acoustic data polygons and the unioned output composite *shapefile*; the confusion was resolved for each flagged area. As the geologists provided the resolutions for each "flag" polygon, instructions for resolution were recorded in the corresponding database records of the "Second _Review_Flags" ArcView *shapefile*. These instructions were consulted and implemented by the GIS team, while correcting the problems for each flagged area. By the end of this process the remaining polygons in the composite *shapefile* should have accurately represented the geomorphology of the study areas, as intended by the geologists.

Merging Final Mosaic: As mentioned earlier, in the Initial Edgematching section of Phase Two of the methodology, two mosaics were created to allow simultaneous work by the two remaining Graduate Assistants. The mosaic of Study Areas 1, 2 and 3 and the mosaic of Study Areas 4 and 5 had remained separated up to this point. Since the Graduate Assistants would no longer be needed, the final mosaic of all five study areas could be assembled. This process was performed with the Merge function of the ArcView 3.3, Geoprocessing Wizard. This Merge function brought all GIS features and corresponding database records, from each of the two source mosaics, into the one final mosaic. At this time the database needed to undergo final editing.

Final Database Editing: The next task for Phase Three of the Methodology was to finalize the database attributes for all GIS features (digital lines or polygons). After the Database Corrections process (described above), each GIS feature had been attributed with abbreviations of the appropriate geologic feature designations. The database tables for both GIS layers were finalized by including expanded definitions for each feature type and by deleting any extraneous fields. This Final Database Editing process was performed within the ArcView 3.3 GIS environment. Once the database was finalized, the GIS layers were ready for the final construction of topology.

Topology Construction: The final construction of topology was built for both the geologic polygon GIS layer and the geologic line layer (faults) within ESRI ArcInfo Workstation GIS software. First, the *shapefiles* were translated into ArcInfo *coverages.* Then, the "Build" command was employed to calculate topology for each of the *coverages.* Finally, each *coverage* was translated into an ArcView *shapefile.* These final *shapefiles* would be reviewed by MMS before the final data delivery would be made.

MMS Data Review: The final *shapefiles* were prepared for MMS review by creating an ArcView 3.3 *project* in which these composite geology GIS layers were overlain with other GIS data layers. This final report was also printed. This ArcView *project* including the final geologic *shapefiles* and the digital map series was recorded on CD-ROM along with a digital copy of the final report. This CD-ROM along with the final report were then sent to MMS for final review.

Final Modifications: After reviewing the final geologic *shapefiles*, the decision was made to simply reproject the final data into Geographic, NAD27, decimal degrees. The justification for this decision follows.

The original compilations of GIS data were performed within either Universal Transverse Mercator (UTM), Zone 15 North coordinate system, referenced to the North American Datum 1927 (NAD27), or UTM Zone 16 North coordinate system, referenced to NAD27, depending whether the study area was located within Zone 15 North or 16 North. Only the eastern most portion of Study Area Five was located within Zone 16.

After being compiled within UTM Zone 16N, NAD27, the eastern most portion of Study Area Five was reprojected into UTM Zone 15N, NAD27 and subsequently merged into a mosaic with the remainder of Study Area Five which had been compiled within UTM Zone 15N, NAD27. The intended result of this process was to have all of the data in the most appropriate common UTM coordinate system, UTM Zone 15N.

Almost all of the data compiled during this project represent mapping features within UTM Zone 15N. The data that represents features within UTM Zone 16N only extend approximately 31 km into Zone 16N. At this late stage of the project, given the scale of accuracy of these data and the small portion of data within Zone 16, the authors decided that the potential improvement of the spatial accuracy the portion of data within Zone 16N did not warrant the amount of work required to separate the Zone 16N portion of the data from the Zone 15N portion, reproject these data back into UTM Zone 16N, NAD27, reproject both portions into Geographic, NAD27, and then merge the portions back together.

Please note that the process steps described in this section should be followed by anyone who wishes to improve the spatial accuracy of the small portion of these GIS data that fall within UTM Zone 16N.

Cartography: A map series was produced using the final data. The series includes one map of the entire study area at a scale of 1:500,000 and five maps, that together cover the entire study area at a scale of 1:100,000. The 1: 500,000 scale map is represented in Figure 14. An example of one of the 1: 100,000 scale maps, is represented in Figure 15.

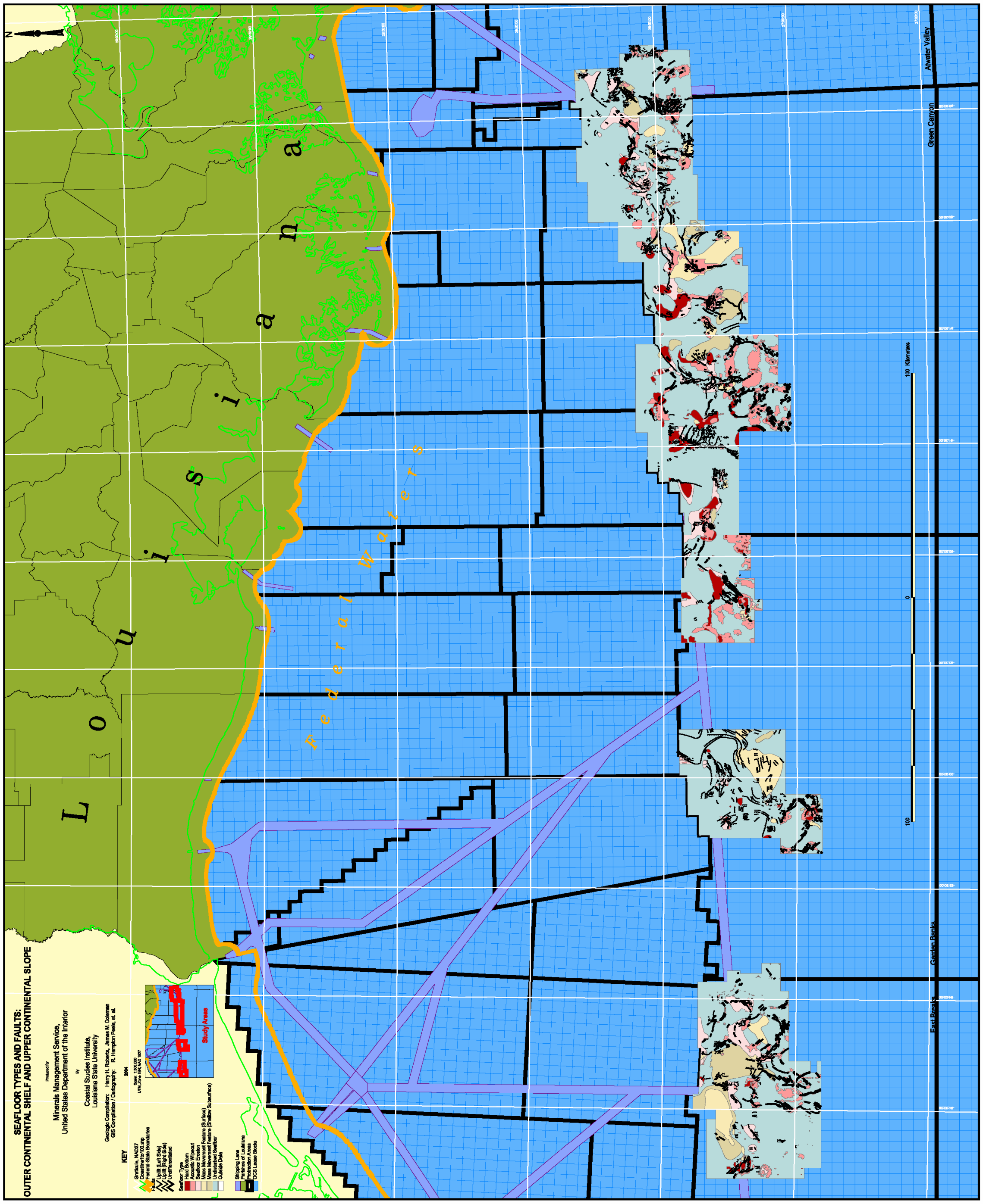

Figure 14. Reduction of the final hardcopy map (scale 1:500,000) of the project's five study areas.

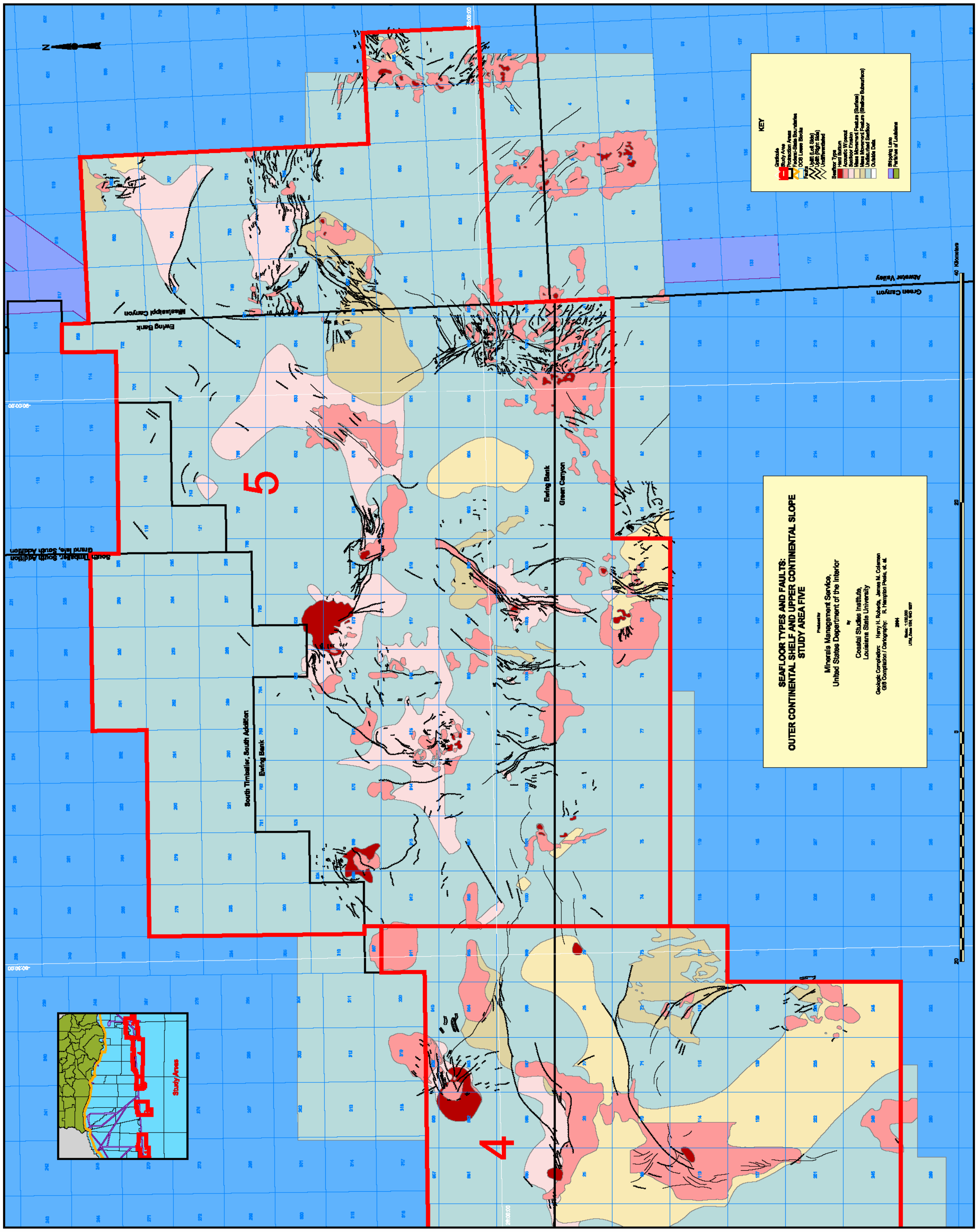

Figure 15. Reduction of the final hardcopy map (scale 1:100,000) of the project's study area number 5.

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APPENDIX A

The following is a listing of the 1015 OCS Lease Blocks that intersect, in area, with the study areas that were mapped during the course of this research project, conducted under MMS Cooperative Agreement No. 1435-01-99-CA-30951.

Protraction Name and (Number)

Atwater Valley (NG16-01)

Block Numbers: 1, 2, 3, 4, 5,
45, 46, 47, 48, 49,
92, 93,

East Breaks (NG15-01)

Block Numbers: 74, 75,
117, 118, 119,
120, 121, 122, 123, 124, 125, 126, 127, 128, 129,
155, 156, 157, 158, 159,
160, 161, 162, 163, 164, 165, 166, 167, 168, 169,
170, 171, 172, 173,
199,
200, 201, 202, 203, 204, 205, 206, 207, 208, 209,
210, 211, 212, 213, 214, 215, 216, 217,
243, 244, 245, 246, 247, 248, 249,
250, 251, 252, 253, 254, 255, 256, 257, 258, 259,
260, 261,
287, 288, 289,
290, 291, 292, 293, 294, 295, 296, 297, 298, 299,
300, 301, 302, 303, 304, 305,
331, 332, 333, 334, 335, 336, 337, 338, 339,
340, 341, 342, 343, 344, 345, 346, 347, 348, 349,
375, 376, 377, 378, 379,
380, 381, 382, 383, 384, 385, 386, 387, 388, 389,
390, 391, 392, 393,
419,
420, 421, 422, 423, 424, 425, 426, 427, 428, 429,
430, 431, 432, 433, 434, 435, 436, 437,
463, 464, 465, 466, 467, 468, 469,
470, 471, 472, 473, 474, 475, 476, 477, 478, 479,
480,
507, 508, 509,
510, 511, 512, 513, 514, 515, 516, 517, 518,
552, 553, 554, 555, 556, 557, 558, 559,
560, 561, 562,
596, 597, 598, 599,
600, 601, 602, 603, 604, 605, 606,

East Cameron Area, South Addition (LA2A)

Block Numbers: 371, 372, 373, 374, 375,
380, 381,

Protraction Name and (Number) Continued

Eugene Island Area, South Addition (LA4A)

Block Numbers: 365, 366, 367, 368, 369,
370, 371, 372, 373,
383, 384, 385, 386, 387, 388, 389,
390, 395, 396, 397,

Ewing Bank (NH15-12)

Block Numbers: 658,
701, 702,
743, 744, 745, 746,
781, 782, 783, 784, 785, 786, 787, 788, 789,
790, 791,
824, 825, 826, 827, 828, 829,
830, 831, 832, 833, 834, 835,
867, 868, 869,
870, 871, 872, 873, 874, 875, 876, 877, 878, 879,
903, 904, 905, 906, 907, 908, 909,
910,
911, 912, 913, 914, 915, 916, 917, 918, 919,
920, 921, 922, 923,
932, 933, 937, 938, 939,
940, 944, 945, 946, 947, 948, 949,
950, 951, 952, 953, 954, 955, 956, 957, 958, 959,
960, 961, 962, 963, 964, 965, 966, 967,
975, 976, 977, 978, 979,
980, 981, 982, 983, 984, 985, 986, 987, 988, 989,
990, 991, 992, 993, 994, 995, 996, 997, 998, 999,
1000, 1001, 1002, 1003, 1004, 1005, 1006, 1007, 1008, 1009,
1010, 1011,

Garden Banks (NG15-02)

Block Numbers: 21, 22, 23, 24,
60, 61, 62, 63, 64, 65, 66, 67, 68,
76, 77, 78, 79,
80, 81, 82, 83, 84, 85,
102, 103, 104, 105, 106, 107, 108, 109,
110, 111, 112,
120, 121, 122, 123, 124, 125, 126, 127, 128, 129,
145, 146, 147, 148, 149,
150, 151, 152, 153, 154, 155, 156,
164, 165, 166, 167, 168, 169,
170, 171, 172, 173, 177,
189,
190, 191, 192, 193, 194, 195, 196, 197, 198, 199,
200, 208, 209,
210, 211, 212, 213, 214, 215, 216, 217,
221,
233, 234, 235, 236, 237, 238, 239,
240, 241, 242, 243, 244,
252, 253, 254, 255, 256, 257, 258, 259,

Garden Banks (NG15-02) continued

Block Numbers: 260, 261, 265,
278, 279,
280, 281, 282, 283, 284, 285, 286, 287, 288,
297, 298, 299,
300, 301, 302, 303, 304, 305, 309,
310,
322, 323, 324, 325, 326, 327, 328, 329,
330, 331, 332,
340, 341, 342, 343, 344, 345, 346, 347, 348, 349, 353, 354,
365, 366, 367, 368, 369,
370, 371, 372, 373, 374, 375, 376,
387,
397, 398,
408, 409,
410, 411, 412, 413, 414, 415, 416, 417, 418, 419,
420,
452, 453, 454, 455, 456, 457, 458, 459,
460, 461, 462, 463,
496, 497, 498, 499,
500, 501, 502,
540, 541, 542, 543, 544, 545, 546,
584, 585, 586, 587, 588, 589,

Grand Isle Area, South Addition (LA7A)

Block Numbers: 113, 114, 115, 116, 117, 118, 119,
120, 121,

Green Canyon (NG15-03)

Block Numbers: 3, 4, 5, 6, 7, 8, 9,
10, 11, 12, 13, 14, 15, 16, 17, 18, 19,
20, 21, 22, 23, 24, 25, 26, 27, 28, 29,
30, 31, 32, 33, 34, 35, 36, 37, 38, 39,
40, 41, 45, 46, 47, 48, 49,
50, 51, 52, 53, 54, 55, 56, 57, 58, 59,
60, 61, 62, 63, 64, 65, 66, 67, 68, 69,
70, 71, 72, 73, 74, 75, 76, 77, 78, 79,
80, 81, 82, 83, 84, 85, 89,
90, 91, 92, 93, 94, 95, 96, 97, 98, 99,
100, 101, 102, 103, 104, 105, 106, 107, 108, 109,
110, 111, 112, 113, 114, 115, 116, 117, 118, 119,
120, 121, 122, 123, 124, 125,
133, 134, 135, 136, 137, 138, 139,
140, 141, 142, 143, 144, 145, 146, 147, 148, 149,
150, 151, 152, 153, 154, 155, 156, 157, 158, 159,
160, 161, 162,
177, 178, 179,
180, 181, 182, 183, 184, 185, 186, 187, 188, 189,
190, 191, 192, 193, 194, 195, 196, 197, 198, 199,

Protraction Name and (Number) Continued

Green Canyon (NG15-03) continued

Block Numbers: 200, 201, 202, 203, 204, 205,
221, 222, 223, 224, 225, 226, 227, 228, 229,
230, 231, 232, 233, 234, 235, 236, 237, 238, 239,
240, 241, 242, 243, 244, 245, 246, 247, 248, 249,
265, 266, 267, 268, 269,
270, 271, 272, 273, 274, 275, 276, 277, 278, 279,
280, 281, 282, 283, 284, 285, 286, 287, 288, 289,
290, 291, 292, 293,
318, 319,
320, 321, 322, 323, 324, 325, 326, 327,
362, 363, 364, 365, 366, 367, 368, 369,
370, 371,
406, 407, 408, 409,
410, 411, 412, 413, 414, 415,
450, 451, 452, 453, 454,

High Island Area, East Addition, South Extension (TX7C)

Block Numbers: A400,

High Island Area, South Addition (TX7B)

Block Numbers: A587, A588, A589,
A590, A591, A592, A593, A594, A595, A596,

Mississippi Canyon (NH16-10)

Block Numbers: 617, 618, 619,
620,
661, 662, 663, 664,
705, 706, 708,
749,
750, 751, 752,
793, 794, 795, 796, 797,
837, 838, 839,
840, 841, 842,
881, 882, 883, 884, 885, 886,
925, 926, 927, 928, 929,
930,
969,
970, 971, 972, 973,

Ship Shoal Area, South Addition (LA5A)

Block Numbers: 343, 344, 345, 346, 347, 348, 349,
350, 352, 353, 354, 355, 356, 357, 358, 359,
360, 361, 362, 363, 364, 365, 366, 367, 368,

Protraction Name and (Number) Continued

South Marsh Island Area, South Addition (LA3C)

Block Numbers: 199,
200, 201, 202, 203, 204, 205,

South Timbalier Area, South Addition (LA6A)

Block Numbers: 253, 254, 255, 256, 257, 258, 259,
260, 261, 262, 263, 264, 265, 266,
277, 278, 279,
280, 281, 282, 283, 284, 285, 286, 287, 288, 289,
290, 291, 292, 293, 294,
301, 302, 303, 304, 305, 306, 307, 308, 309,
310, 311, 312, 313, 314, 316, 317, 318, 319,
320,

Vermilion Area, South Addition (LA3B)

Block Numbers: 411, 412, 413,

West Cameron Area, South Addition (LA1B)

Block Numbers: 644, 645, 646, 647,
658, 659,
660,

The Department of the Interior Mission

MARCH 3, 1849

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 **Minerals Revenue Management** 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.

MMS Securing Ocean Energy & Economic Value for America