The Integration of Multibeam Sonar Data with Huntec Sub-bottom Profile Data into a Marine GIS

by

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This thesis is accepted.

Dean of Graduate Studies

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Abstract

In recent years there have been tremendous advances in seafloor mapping technologies. At the core of these technologies are multibeam swath sonars capable of producing detailed bathymetry and imagery data that give insight into the shape and nature of the seafloor. Combining this with our increased ability to georeference spatially related datasets provides us with a powerful tool for establishing potential relationships among multiple datasets.

This thesis investigates the potential of a marine geographic information system for the integration, display, and interpretation of multibeam and seismic sub-bottom profile data. A recent investigation of the Northern California margin has collected bathymetry and seismic data in order to understand the formation of stratigraphic sequences on continental margins. By integrating seismic data into a marine geographic information system, seismic records can be interpreted simultaneously with other spatial marine data. The observations derived from the geographic information system are used to investigate two competing theories as to the formation of undulating seafloor morphology that exists at the base of the Humboldt slide zone. Ideally, the data integration will facilitate the extraction of relationships between seafloor morphology and sub-surface processes that may otherwise go unnoticed.

Acknowledgements

First and foremost I must thank my parents, Anne and Bob Galway, whose love and support made my education possible, and allowed me to pursue my childhood dreams. I gratefully acknowledge the friendship and support extended to me by the faculty, staff, and students of the department during my two and half years at UNB. A special word of thanks to Norbert Horvath and his colleagues at Interactive Visualization Systems, who developed the 3D Seismic SEG-Y program for visualization and displaying seismic data within the Fledermaus scientific visualization package. Equally important were the efforts of Martin Leese, whose insight into the UNIX world allowed me to create the unique programs and scripts needed to generate the desired seismic digital images. I am very grateful to Dr. Dave Wells, and Dr. John Hughes Clarke, who shared their vast knowledge about marine surveying, in an effort to broaden my horizons. Lastly, I must acknowledge the special role Dr. Larry Mayer played in maintaining my enthusiasm for marine research. Without his insight, advice and endless patience, this project would not have been possible. I will never forget our first meeting when I picked him up at the airport for a GAC/MAC Conference in Victoria. The four days of that conference will forever mark a turning point in my life, when so many doors were opened to me by Dr. Mayer, and for that I am deeply grateful.

I am still living my dream!

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CHAPTER 1: INTRODUCTION

1.1: The Problem

Over the past few years, rapid advances in technology have become the single most important factor in influencing the way marine geoscientists conduct research and analyze data. This is reflected by the development of state-of-the-art seafloor mapping instruments, such as multibeam sonar systems, which are capable of collecting both bathymetric and side-scan sonar data simultaneously. Equally impressive is the rate at which computer systems, software packages, and data storage media have improved over the same period of time. However, these advances come at a price; the volume of data involved in a marine investigation is monumental, considering that multibeam systems alone can collect several gigabytes of data per day. Marine scientists are now faced with data management issues on a daily basis and in order to effectively complete their tasks, must find ways to overcome these data management problems. The inherent capabilities of Geographic Information Systems (GIS) can improve the efforts of marine scientists in the management of data acquired from the marine environment, resulting in less data loss, faster data analysis, as well as more complete data interpretation (Hatcher, 1992). This thesis illustrates the use of GIS technology for the management, display and interpretation of scientific data collected in support of the STRATAFORM Project, with particular emphasis on the incorporation of seismic data.

1.2: GIS Background and Historical Information

The foundation of today's Geographic Information Systems (GIS) was established by the early work of Roger Tomlinson in the mid-1960s, when he recognized that digital computers could be used to map out and analyze the large amounts of information being collected by the Canada Land Inventory (Wright and Bartlett, 1999). His pioneering work aided scientists in addressing the problems of managing and interpreting increasingly larger and more complex earth science datasets. Although today there are many different definitions of a GIS, within the context of this thesis, a GIS is a "powerful set of tools for collecting, storing, retrieving, transforming and displaying spatial data from the real world for a particular set of purposes" (Burrough and McDonnell, 1998).

Throughout the literature, there are many examples that have illustrated that Geographic Information Systems are powerful tools for processing, analyzing, managing, and displaying spatial information. Early land-based applications have demonstrated that GIS can effectively integrate many types of data collected from the terrestrial environment in a cost and time effective way. As a result of using a GIS to organize the data, value is added to the individual data sets by allowing them to be interpreted as an integrated body of information rather than as separate entities (Hatcher, 1992). Additional benefits are that the inherent digital nature of a GIS allows for the efficient storage and manipulation of information. Through a GIS, digital information can be easily maintained, updated, combined, reorganized and retrieved much more rapidly than by using manual methods (Hatcher, 1992).

1.3: GIS and Its Application to Marine Data

While the use of GIS for land-based data has become quite common, the application of GIS technology to marine investigations is still a relatively novel idea. Given that over 70% of earth's surface is covered by the seafloor, this indicates that the primary application (and benefits) of GIS technology has been focused only on a small, albeit important, part of the earth's surface (Humphreys, 1989; Li and Saxena, 1993). Since most commercial GIS systems have been designed for land-based applications, current GIS packages may not be capable of providing all the functionality required for handling spatial marine data.

There are several reasons why the marine community has been slow in adopting GIS systems. First, few standard data formats exist for marine data. Second, datasets are typically very large and are often collected and processed using customized software packages, which inhibits the application of commercial off-the-shelf GIS to marine science investigations (Goldfinger et al., 1997). Third, and perhaps the most serious issue, is the question of awareness; since GIS technology has been predominantly the domain of the land information management community, marine geoscientists may simply not be aware of the potential application of GIS technology to marine investigations. For these reasons, many marine science investigations, such as researching relationships between biological and geophysical data, dumpsite monitoring, seafloor geomorphology and seismic interpretation, are still predominantly being handled by manual methods. In other cases, the potential use of GIS technology is limited by the lack of appropriate functionality required for a marine GIS (Li and Saxena, 1993). Nevertheless, GIS technology is still a useful tool for the integration and interpretation of marine data and the potential benefits of utilizing such technology far outweigh the deficiencies that currently exist.

1.4: Project Objective

A current effort underway at the Ocean Mapping Group (OMG), in the Department of Geodesy and Geomatics Engineering, University of New Brunswick (UNB), is the application of a marine GIS system to the storage, display and interpretation of a large volume of marine data collected off the coast of California in support of the STRATAFORM Project. One of the long-term goals of the STRATAFORM Project, is to understand the mechanisms by which continental-margin sediment is deposited, modified and preserved, so that strata recorded over various times scales can be interpreted (Nittrouer, 1999). In order to address this task, a large suite of investigative tools have been deployed in an attempt to develop a picture of the sedimentary and geologic processes of this region. Data collected to date include multibeam bathymetry data, backscatter imagery data, seismic data, core samples, current meter data, sediment trap data and other sedimentary physical properties data. A common denominator amongest all these datasets is that they were all collected with a known latitude and longitude, thus allowing us to geo-reference the data in a GIS package.

The application of GIS technology to the STRATAFORM Project has many potential benefits. First and foremost, it can aid scientists in their research by providing insight into complex relationships among datasets that share a common geographic location. The use of integration technology simplifies the fusion and interpretation of these datasets, thereby aiding scientists in elucidating relationships that otherwise might go unnoticed. Data fusion can facilitate the discovery of these relationships since scientists are no longer dependent on their ability to mentally integrate and visualize observations from different datasets to come up with relationships. In a GIS, should such relationships exist, they can be quickly identified with relative ease. Finally, a GIS that can collate a wide variety of data will not only help investigators discover potential relationships, but will also assist them in the dissemination of scientific results, as well as the organization and planning of subsequent investigations in the region.

The complex nature of the Northern California margin has helped fuel efforts to develop new and innovative ways of conducting marine research in the hopes of obtaining answers to puzzling geologic questions. The marine GIS detailed in this thesis is just one example of these efforts. What is unique about the marine GIS discussed in the pages below, is the integration of digital seismic data into the framework of the GIS. In a recent article by Goldfinger et al. (1997), the authors outlined how seismic trackline data were incorporated as a vector layer into a GIS package along with metadata stored in an attribute table. However, the actual seismic reflection profiles were stored in hard-copy, independent of the GIS. The metadata of the seismic trackline layer allowed for cross-correlation of the navigation data with the non-digital hardcopy seismic profiles. This solution is insufficient for our purposes, as we are attempting to retrieve and display seismic data from within the GIS package in order to facilitate the interpretation of the seismic data in conjunction with the other spatial marine data stored within the GIS.

More specifically, it is hoped that by integrating seismic, multibeam and other spatial marine data, new observations may arise that may help shed light on the formation of surficial morphology at the base of the Humboldt Slide Zone, a geologic feature that falls within the study area of the STRATAFORM Project. Currently, two competing theories exist that attempt to explain the formation of these features. One theory postulates that the undulating seafloor morphology is the result of slump failure in the region, while the second argument suggests that these features are, in fact, large scale bedforms that formed at the base of the Humboldt Slide. It is hoped that through the efforts of this GIS, the question as to the formation of these features will be resolved once and for all.

1.5: The Challenge of Integrating Seimic Data into a GIS

Seismic surveying is one of the most important geophysical investigative tools employed by geophysicists today. It has been widely employed in land applications, but finds its chief application in the marine environment. Single-channel reflection surveying is an example of seismic reflection surveying reduced to its bare essentials and is a simple but highly effective method of determining the nature of the subsurface seafloor structure (Kearey and Brooks, 1991). In seismic reflection surveying, seismic waves are propagated through the earth's interior and the travel times are measured of the waves that return to the surface after reflection (and refraction) at geological boundaries within the subsurface geology (Figure 1.1).

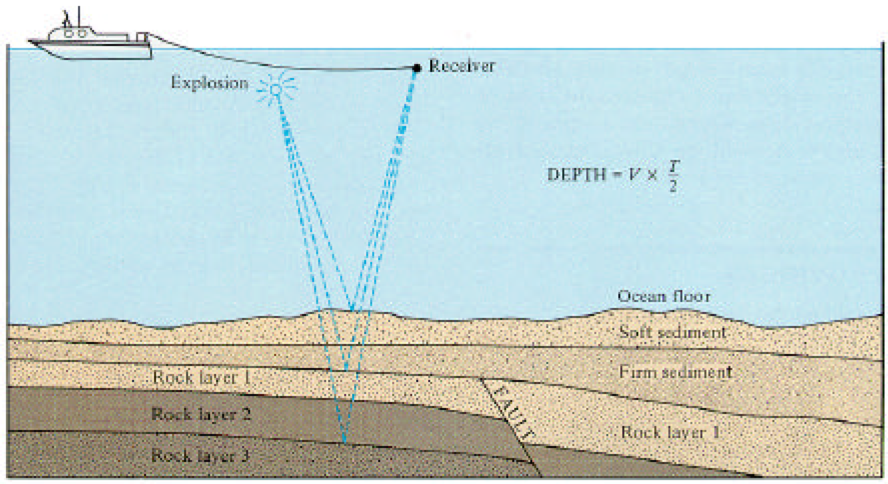


Figure 1.1: Illustration of the principles of marine seismic surveying (from Thurman [1989, p.81]).

In a single-channel marine reflection survey, an acoustic source is towed behind a survey vessel and triggered at a fixed firing rate. A hydrophone streamer towed by the same vessel picks up the returning signals reflected from the seabed and from sub-bottom reflectors. The output from the individual hydrophone elements are summed together and fed to a single channel amplifier and then to an analogue or digital recording system that records and displays the pattern of reflection events. This information is then used to derive information on the internal structure of the seafloor (Figure 1.2).

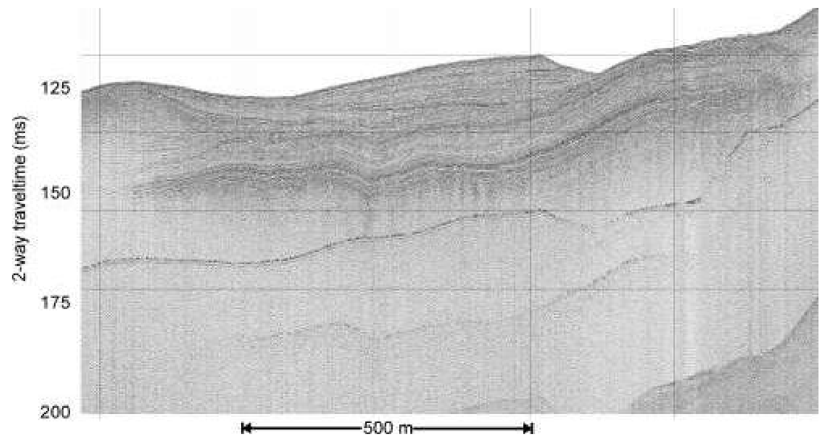


Figure 1.2: Example of a seismic plot from data collected by Huntec deep-tow system.

Traditionally, seismic profiles have been displayed as long paper charts that are viewed and interpreted in isolation from other marine data. A marine geologist would spread the trace record on a light table, make notes, refer to other thematic maps and mentally integrate the datasets. By incorporating the sub-bottom profile data into a marine GIS, the marine geologist can interpret these records in conjunction with bathymetry, backscatter imagery, core data, all with the click of a mouse button. This multi-dataset integration can facilitate the extraction of information and relationships that otherwise may go unnoticed.

In order to integrate seismic data into a GIS system, one must consider the nature of seismic data. For the purpose of integration into a GIS, there are two key components to seismic data; 1) the navigation trackline of the seismic data, and 2) the seismic profile data themselves. Most GIS systems are designed around displaying raster and vector layers in two dimensions, with very limited use of the third dimension (Goldfinger et al., 1997). The navigation component of seismic data can easily be incorporated into the GIS as a two-dimensional vector layer, however, our interest lies in the display of the third dimension - the seismic time profile (or depth). The challenge is to find a way to retrieve and display the digital seismic data from within the GIS.

This thesis consists of eight chapters. Chapter 1 provides background information regarding the evolution of Geographic Information Systems, their application to marine investigations, and the particular objectives of this thesis in integrating multibeam and seismic sub-bottom profile data into a marine GIS. Chapter 2 outlines the design and objectives of the STRATAFORM Project, reviews the EM-950/1000 multibeam sonar and Huntec seismic sub-bottom profile systems used to collect the spatial marine data that is the backbone of this thesis, and introduces the particular software packages required to perform this research. Chapter 3 consists of a review of the principles behind the collection of spatial marine data using the EM950/1000 multibeam sonar and the Huntec sub-bottom profile system. Chapter 4 presents the various steps involved in processing both the multibeam and sub-bottom data for integration into a marine GIS. Chapter 5 outlines the programming customizations required in order to successfully incorporate and retrieve seismic sub-bottom profile data from within the marine GIS. Chapter 6 explores the scientific visualization of multibeam and seismic sub-bottom data within the Fledermaus three-dimensional visualization environment. Chapter 7 reviews the geologic setting of the Northern California continental margin and discusses the two competing geologic theories behind the formation of the undulating seafloor morphology at the base of the Humboldt Slide. Chapter 8 consists of the conclusions drawn about the capabilities of the marine GIS developed for this thesis.

CHAPTER 2: DATA COLLECTED IN SUPPORT OF STRATAFORM

2.1: STRATAFORM Project Overview

The main objective of the STRATAFORM Project is to develop an understanding of the mechanisms by which continental-margin sediments are deposited, modified and preserved, so that strata accumulated over various times scales can be properly interpreted (Nittrouer, 1999). In order to achieve its objective, two different study areas were selected to be the focus of the STRATAFORM Project, one in Northern California and the other off the coast of New Jersey. Although both sites are located on the edge of the continental shelf of the United States, all similarities end there. The Northern California study area is an active collision margin with a coastal mountain range, narrow shelf (~20 km), and a significant supply of fluvial sedimentary input, primarily from the Eel River (Figure 2.1). In sharp contrast, the New Jersey site is a passive, trailing-edge margin with a coastal plain, broad shelf (~150 km), and limited sedimentary input (Nittrouer, 1999.) This thesis concerns itself only with data collected from the Northern California site, and focuses on the integration of multibeam and seismic sub-bottom profile data collected from this region.

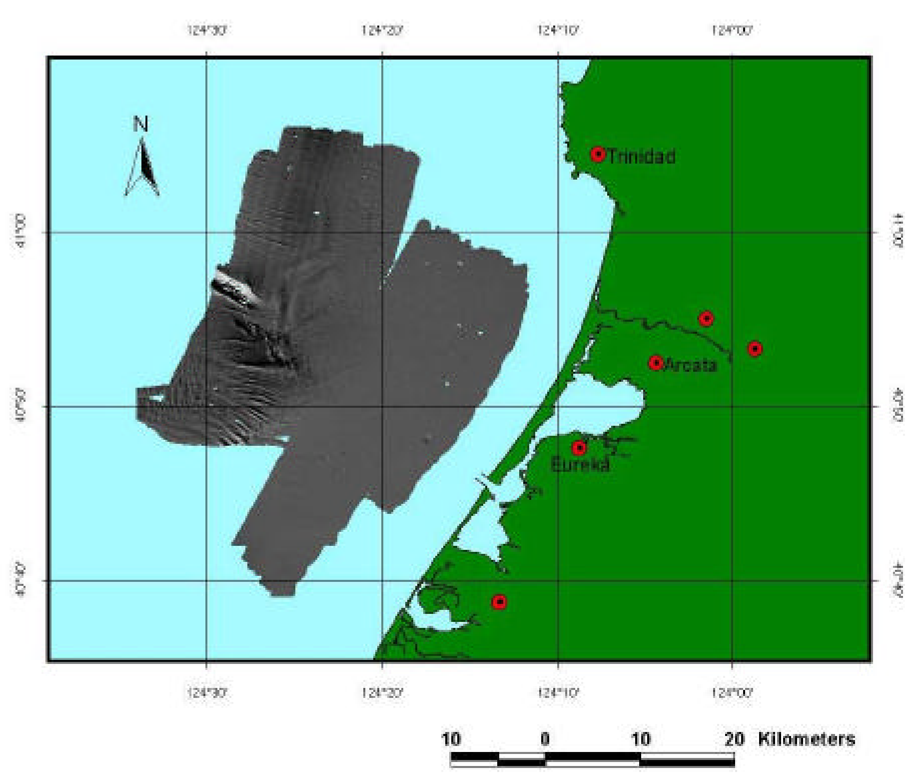


Figure 2.1: Overview of STRATAFORM study area off Eureka, California. Illustration consists of sun-illuminated bathymetry derived from multibeam data.

2.2: Data Description and Software Decisions

2.2.1 MULTIBEAM SONAR SURVEY

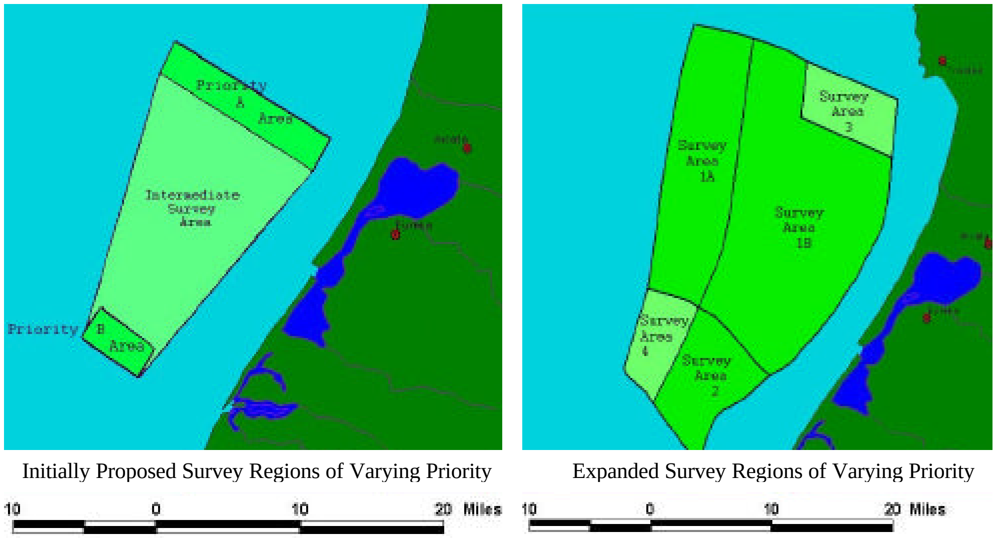
In 1994, a state-of-the-art Simrad EM-950/1000 multibeam sonar system (MBSS) was employed to collect the required bathymetry and co-registered sidescan imagery for the study area off Eureka, California. The advantage of using multibeam sonar compared to a conventional echosounder is that multibeam sonar systems can achieve 100% coverage of an area thus providing a substantial increase in data density and aerial coverage. More important is the ability of the latest generation of

MBSS to simultaneously collect high-resolution backscatter data in addition to bathymetric data.

The importance of 100% coverage to this project cannot be overstated. The bathymetric and backscatter layers form the backbone of the STRATAFORM GIS, providing a bathymetric, geomorphologic, and potentially lithologic framework upon which all subsequent investigations can be built. As a result, scientists can rest assured that their studies are based on a complete picture of morphological relationships rather than on the interpolation of sparsely spaced data.

At preliminary meetings involving the principal investigators of the STRATAFORM Project, it was decided that the survey would cover an area of approximately 500 km^2 between the Mad and Eel rivers, and would be constrained by the 40 m and 500 m contours. The extent of the survey region was later re-defined and expanded to almost twice the original size. In order to realistically survey this entire region, it was necessary to divide the area of investigation into a number of sub-areas of varying priorities (Figure 2.2). The highest priority area would be surveyed first, the vessel would then proceed to the next highest priority region, and then continue in this fashion until the allotted ship time had run out.

After the 14 days of surveying were completed in July 1995, approximately 850 km^2 of seafloor had been imaged, producing 7 Gigabytes of sonar data. The results of the survey were produced as a series of mapsheets that were prepared on board the survey vessel *Pacific Hunter* at the conclusion of the survey.



Initially Proposed Survey Regions of Varying Priority

Expanded Survey Regions of Varying Priority

Figure 2.2: Preliminary multibeam survey areas of varying priorities.

These mapsheets divided the survey area into 11 different regions and were designed to keep the array sizes for any given mapsheet at a workable size, with about 2000 x 2000 points per mapsheet (Figure 2.3 , Table 2.1). This sub-division of the survey region ensured that all sub-areas were gridded to yield a digital terrain model (DTM) of the highest possible resolution, depending on the water depth. The greater the water depth, the lower the resolution should be because of the increase in size of an acoustic footprint with increasing water depth.

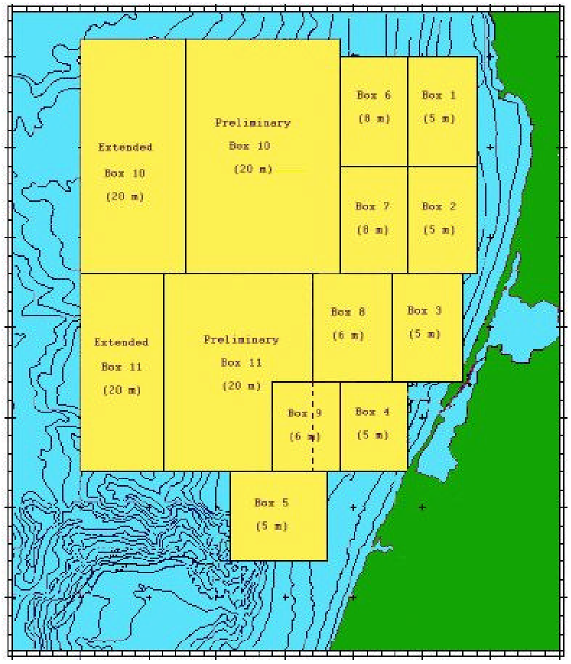


Figure 2.3: Outline of individual mapsheets with different grid spacing dependent on depth.

Table 2.1: Individual mapsheet parameters for STRATAFORM survey area

Box Number	Array Size	Grid Pixel Size (m)	Imagery Pixel Size (m)
1	**1401 x 2220**	**5**	**2.5**
2	**1401 x 2217**	**5**	**2.5**
3	**1401 x 2213**	**5**	**2.5**
4	**1401 x 1842**	**5**	**2.5**
5	**1961 x 1840**	**5**	**2.5**
6	**876 x 1388**	**8**	**4**
7	**876 x 1386**	**8**	**4**
8	**1401 x 1845**	**6**	**3**
9	**1168 x 1535**	**6**	**3**
10	**1331 x 1202**	**20**	**10**
11	**1331 x 1014**	**20**	**10**

2.2.2 SEISMIC SUB-BOTTOM PROFILE SURVEY

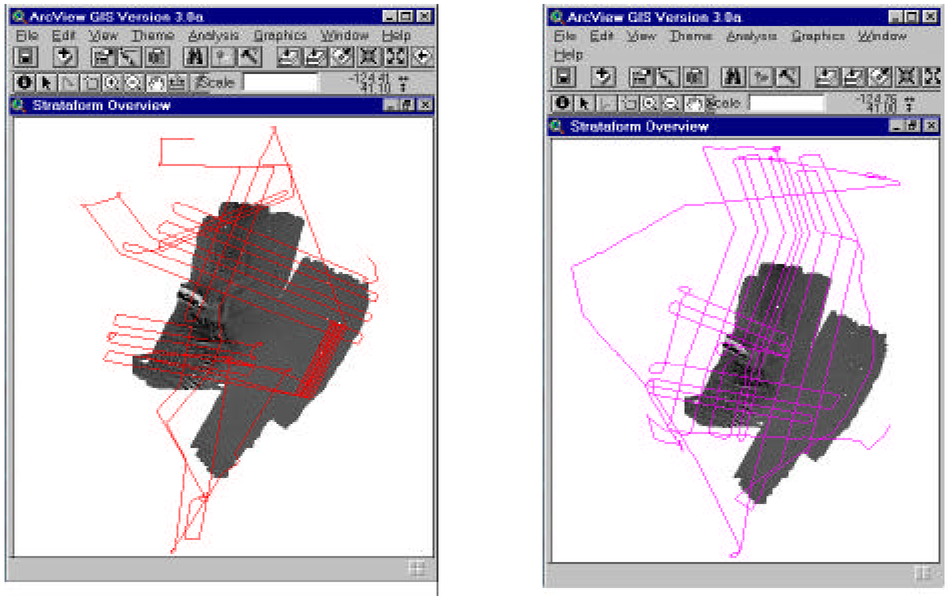
Marine investigations are not limited to only bathymetry or sonar imagery data. Long before multibeam systems, a combination of other marine investigative tools were available to scientists. One such investigative technique of major importance in many marine investigations is the profiling of the sub-surface of the seafloor by conducting high-resolution seismic surveying.

During the fall of 1995, a seismic survey was conducted to gather reconnaissance-scale maps of the surface morphologies and shallow (upper 40 m) sub-bottom characteristics of the shelf and slope offshore of the Eel River. This information would be the foundation for studies attempting to understand sedimentation patterns and the formation of stratigraphic sequences in this region (Field and Gardner, 1995). To carry out these studies, scientists used a Huntec deep-towed seismic system to collect the sub-bottom profile data, and a Datasonics SIS-1000 sidescan sonar system.

Like the multibeam survey design, this cruise had several survey regions defined with varying priorities:

1) Shallow seismic stratigraphy – shelf to slope
2) Slope surface morphology
3) Shelf side scan imaging
4) Humboldt slide zone
5) Eel delta and adjacent shelf

A subsequent survey was conducted the following year to expand the Huntec DTS and SIS 1000 coverage. Below are the trackline navigation data of both surveys superimposed on top of the sun-illuminated bathymetry (Figure 2.4).



1995 1996

Figure 2.4: Seismic trackline navigation for both years.

2.2.3 SOFTWARE PLATFORMS

2.2.3.1 ArcView GIS™ Package

The GIS software package used for this project was ArcView GIS™, an ESRI product that, although not a fully functional GIS platform like ESRI's ArcINFO™, contained all the necessary tools for data integration and exploration needed for this project. When analyzing the various GIS packages available, it was realized early on that, for the STRATAFORM GIS Project, a package capable of simply integrating and displaying marine spatial data would be sufficient. It was not necessary for this software package to be capable of carrying out sophisticated analyses on the marine spatial data since most of the data would be either positional data (navigation, core location), or digital maps that would already be processed and would simply require geo-referencing. The ArcView GIS packaged fulfilled these requirements.

A benefit of selecting ArcView GIS is its ease of use and a well designed Windows environment that is familiar to most people with a home computer. The learning curve of ArcView, while steep, certainly is lower than that required to operate a more sophisticated product, such as ArcINFO, effectively. Furthermore, the ability to customize ArcView's capabilities through the Avenue programming environment (see section 5.1.2) proved to be critical to the overall success of this project.

2.2.3.2 Multibeam Data Processing Software

The multibeam bathymetry and coincident sidescan backscatter data collected for this project were processed using the ***SwathEd*** suite of tools developed by the Ocean Mapping Group – UNB. ***SwathEd*** is a collection of software tools designed for Unix platforms that can be used for standard swath sonar processing and generation of map-like products such as digital elevation models, sidescan mosaics, and sun-illuminated imagery (Hughes Clarke, 1998a). The sun-illuminated bathymetry and the backscatter imagery will become the backdrop and key layers in the STRATAFORM GIS Project.

2.2.3.3 Seismic Processing Software

The seismic sub-bottom profiles data required external processing as well. It was decided to use the *Seismic Unix* processing package (Cohen and Stockwell, 1998), developed by the Center for Wave Phenomena at the Colorado School of Mines (CSM), to generate the digital sub-bottom profile images for incorporation into the marine GIS. The main motivation behind selecting *Seismic Unix* was that it is freeware and easily accessible over the Internet. Furthermore, in order to conduct our research, it was required to access the rudimentary levels of the seismic processing code in order to understand how the *Seismic Unix* package manipulates seismic data. With the *Seismic Unix* package, both the binary codes as well as the source codes are included, allowing for great flexibility in understanding how seismic SEG-Y data is converted from its raw form to a final digital image product.

CHAPTER 3:COLLECTION OF SPATIAL MARINE DATA

3.1: Multibeam Sonar System Employed

3.1.1 PRINCIPLES OF COLLECTING MULTIBEAM DATA

As an investigative tool for exploration, multibeam sonar systems have become the mainstay of many marine surveys. Most modern multibeam sonar systems (MBSS) have the ability to collect both high-resolution bathymetric information as well as providing sonar backscatter data, a measure of the strength of the signal return and an indicator of surficial sediment texture or material type.

Most multibeam sonar systems are based on a cross fan beam geometry generated by two transducer arrays mounted at right angles to each other either in an L or a T configuration (de Moustier, 1988). Each array produces a beam that is narrow in the direction of its long axis (Figure 3.1) and the intersection of the two results in a beam pattern that is delimited by the narrow widths of these beams (Figure 3.2).

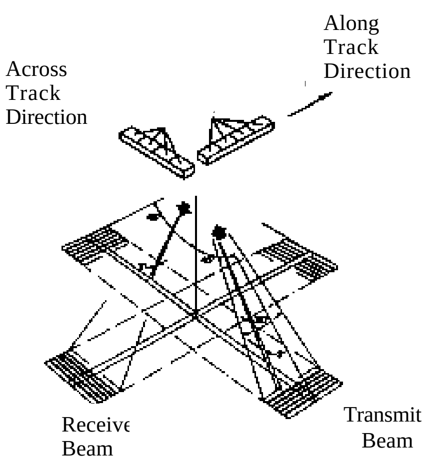


Figure 3.1: The orthogonal orientation of the two transducer arrays in a multibeam system. (Grant and Schreiber, 1990)

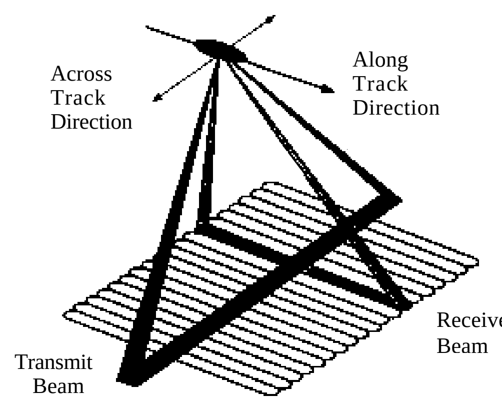


Figure 3.2: The intersection between transmit and receive beam patterns in a multibeam system (Nishimura, 1997).

In practice, these arrays are made up of a number of identical transducer elements that are equally spaced. In the transmitting transducer array, these elements are placed parallel to the ship's keel and project a vertical fan beam, that is narrow in the along-track direction and broad in the across-track (Farr, 1980). Beam steering is used to ensure that the mainlobe of the transmit beam pattern is vertically oriented (de Moustier, 1988). The typical beamwidth for a transmit array is 1° to 3° in the along-track direction and up to 150° (or more) in the across-track direction.

In order to obtain the necessary angular resolution of the non-nadir beams, the receiver array consists of a transducer array mounted orthogonally to the ship's direction of travel. The receiver array generates many fan-shaped receiving beams that are parallel to the ship's direction of travel; the system is sensitive to the narrow region on the seafloor that is formed by the intersection of the transmit and receive beams (Figure 3.2). Typically, the receive beamwidths are 1° to 3° in the across-track direction, and 20° in the along-track direction in order to accommodate the pitch attitude of the boat. The large width of the receive beam in the along-track direction ensures that the receive array will be oriented properly to detect the return signal regardless of the ship's motion (Figure 3.2).

After corrections for roll, pitch and yaw are calculated, and refraction corrections are applied based on an assumed or measured sound velocity profile, a depth to the seafloor for each beam can be determined. This value is based on the two-way travel time of the acoustic pulse, and the inclination angle of the beam (Farr, 1980). The variations in sound speed over the length of the water column must be taken into consideration in swath bathymetry because changes in the sound velocity profile (SVP) introduce refraction effects on the oblique beams.

Most conventional vertical beam echo sounders determine the travel time of the acoustic pulse by detecting the position of the sharp leading edge of the returned echo (amplitude detection) (Mayer and Hughes Clarke, 1995). Once this is determined, using the two-way travel time and with knowledge of the speed of sound in the water column, the depth can be calculated. This process is much more complex with a multibeam sonar system. In an MBSS, where the angle of incidence for the beams formed to each side of vertical (nadir) increases, the returned echo loses its sharp leading edge and the accurate determination of depth via amplitude detection becomes more difficult (Figure 3.3). An alternate solution is to use phase detection, an interferometric principle, as a means of determining the range to the seafloor for these oblique beams. With the EM 950/1000 MBSS, this is done by splitting each beam into two “halfbeams” through beam forming, and measuring the phase difference between these “halfbeams” over the duration of the return echo envelope, which gives a measure of the angle of arrival of the echo. The point at which there is no phase difference (the point at which the bearing of the return is normal to the seafloor) is determined, providing an accurate measure of the range to the seafloor in the middle of the beam (Mayer and Hughes Clarke, 1995). Both amplitude and phase detection are performed on each beam within the swath, and the system software selects the best detection method for a given beam and uses this in calculating depth. Typically, nadir (near-vertical) depths are calculated based on amplitude detection, while oblique beam depths are determined using phase detection methods.

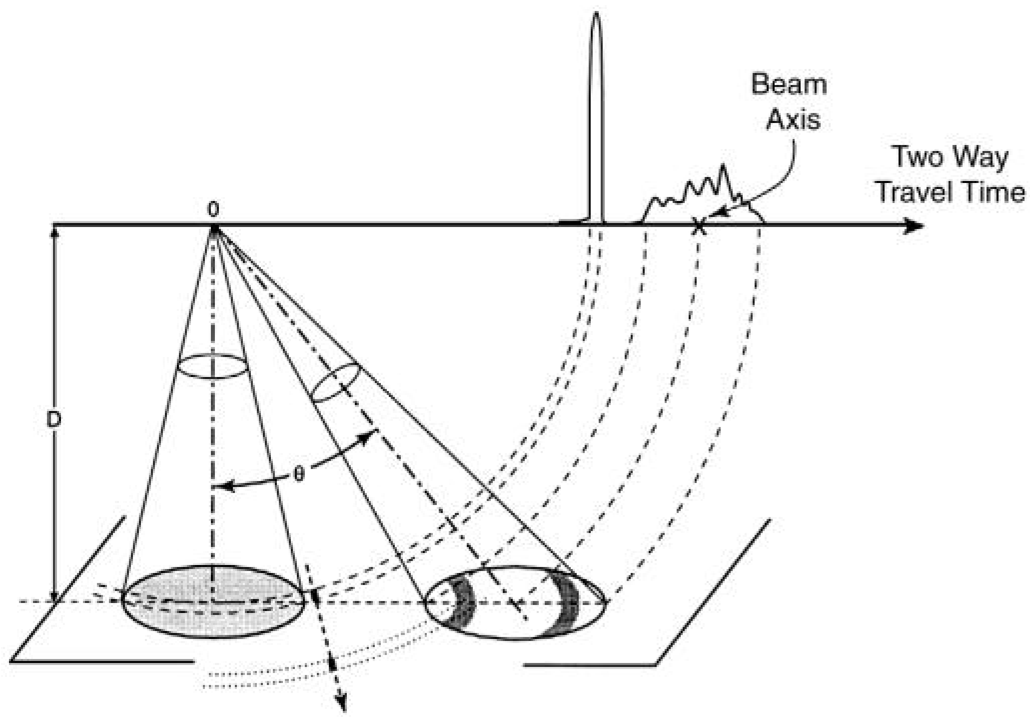


Figure 3.3: Nadir and oblique return echo (after de Moustier [1998, p.6]).

In addition to depth information, most modern day multibeam sonars can collect backscatter data, which is a measure of the amount of energy that returns to the sonar after scattering off the seafloor. The amount of backscattered energy is a function of many things, including the grazing angle, the surface roughness of the seafloor and the nature of the material type. The backscatter information is collected as a time series of echo amplitudes as the acoustic pulse for each beam moves through its particular footprint on the seafloor. These amplitudes are recorded at 0.2 to 2.0 msec sampling rate, depending on the water depth. This is a much finer sampling interval than the beam spacing, thereby producing many more backscatter values than depth values (Mayer and Hughes Clarke, 1995). These amplitudes can then be strung together from beam to beam, across the swath width, to produce a sidescan-like sonar image of the seafloor. Because the angular direction of each beam is known, the echo amplitude information for each beam can be correctly positioned relative to its neighbours within the swath and merged with the bathymetric and positioning data to generate an acoustic map of the seafloor (Mayer and Hughes Clarke, 1995). Thus these systems combine the ability to collect bathymetric data over a large area (obtaining a swath width of up to 7.5 times water depth is possible) with the capacity to produce a co-registered sidescan-like sonar imagery of the surveyed region.

3.1.2 THE SIMRAD EM 950/1000 MBSS

The frequency and operational characteristics of multibeam systems vary dramatically. These characteristics are closely tied to the nature of the type of survey the MBSS is designed to carry out; mainly, whether the system is going to be operated in shallow or deep-waters. For the Eureka study area, it was decided to employ a Simrad EM 950/1000 system owned by C&C Technologies of Lafayette, Louisiana.

The selection of the EM-950/1000 MBSS was tied to the water depths of the survey region. The continental shelf and slope in the Eureka study area required an MBSS that could not only survey the shallow waters of the shelf, but also an MBSS that could function in deeper waters. While most swath mapping systems have been developed for deep water surveys, the EM-950/1000 can successfully operate over a range of water depths from 10 metres to approximately 800 metres (Mayer and Hughes Clarke, 1995).

The Simrad EM-950/1000 operates at a frequency of 95 kHz and utilizes a semi-circular transducer with 128 staves that can be either mounted to the hull or installed on a portable ram. Because it is designed to collect data from shallow and deep-water environments, there are several different modes of operation for the system. For depths to about 150 m, the system operates in a shallow water or ultrawide mode, in which 60 beams are formed each separated by 2.5°, which results in a swath of 150° or 7.4 times the water depth. In the wide mode used in water depths of 150 m – 500 m, 48 beams are formed with a spacing of 2.5°, resulting in a 120 ° swath or 3.4 times water depth. The narrow mode is used in the deepest waters; 48 beams are formed separated by 1.25°, resulting in a swath of 60°, or 1.1 times the water depth (Mayer and Hughes Clarke, 1995).

3.2: Seismic Sub-bottom Profile System Employed

3.2.1 PRINCIPLES OF COLLECTING SEISMIC DATA

In seismic surveying, seismic sound waves are emitted by a seismic source and travel to the seafloor. These sound waves propagate through the seafloor and the travel times are measured of waves that return to the surface after reflection or refraction from a boundary where a change in acoustic impedance exists

(Figure 1.1). For the STRATAFORM Project, both multi-channel seismic and Huntec deep towed seismic (HDTS) high-resolution sub-bottom profile data were collected. For the purposes of this project, however, we are solely working with the HDTS data.

3.2.2 THE HUNTEC DEEP TOW SEISMIC SUB-BOTTOM PROFILER

The HDTS system is a high resolution, broad bandwidth, seismic profiling system intended for use in water depths generally found on continental shelves and margins (Figure 3.4). It is designed to collect high-resolution (<1 m) acoustic stratigraphy with as much as 50 m sub-bottom penetration (McKeown, 1975). The electronics for the transmitting and receiving systems are mounted within the body of a towed 'fish', which can be towed behind a surface vessel, at depths up to 300 m, and speeds to 8 knots.

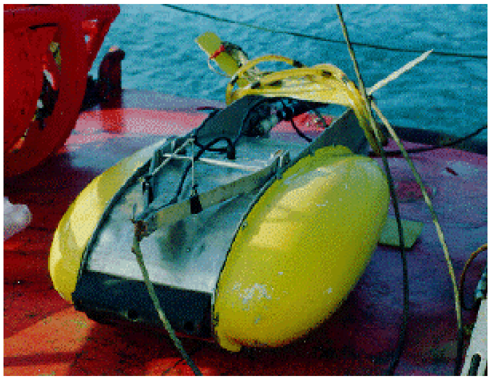


Figure 3.4: The housing casing of the Huntec Deep-Towed Seismic System.

The instrument uses an electrodynamic plate (‘boomer’) to generate the transmitted acoustic pulse, and the hydrophone receivers consist of a internal hydrophone mounted within the body of the ‘fish’, and an external hydrophone streamer towed behind the ‘fish’ (McKeown, 1975). Placing both the transmitter and receiver in a towed fish allows both to be positioned near the seafloor during a survey, which results in an increase in the incident signal strength and a decrease in the effect of surface generated noise. Furthermore, the proximity of the instrument to the seafloor increases the resolution of topographic features due to the smaller area of seafloor that is ensonified by each shot (McKeown, 1975).

The HDTS system generates energy from 500 Hz (for penetration) to 6.5 kHz (for the high-resolution required in most surficial geological profiling), with a narrow peak frequency centred around 3.5 kHz (Gardner et al., 1999).

In order to remove the effects of ‘fish motion’ from the graphic records, the position of the fish is continuously monitored, and the firing time of the boomer is controlled to counteract this motion. This results in an increase of the registration from shot to shot, as well as an increase in the amount of geologic detail which can be extracted from the graphic record (on the order of 15 cm) (McKeown, 1975). The combination of deep towing the vehicle close to the seafloor, as well of the coordination of the firing sequence to offset ‘fish’ motion, results in excellent high-resolution imaging of the surficial sedimentary layers. The horizontal resolution of this system is improved over other towed seismic systems because of the finite acoustic beamwidth (60 °) of the HDTS system source/receiver combination and the increased firing rate made possible by the proximity of the vehicle to the seafloor.

3.2.3 THE SEG-Y DIGITAL OUTPUT STANDARD FORMAT

Traditionally, the products generated from a seismic survey include analogue graphic paper charts as well as digital recording of the seismic data. In general, the seismic exploration community has adopted the Society of Exploration Geophysicists Y (SEG-Y) Exchange Tape Format fo recording and storaging digital seismic data. This has been the most common format of digitally recorded seismic data since the early 1980s. While it is widely used today, there are no guarantees that the format standards are used 'by the book.'

In a SEG-Y tape, a seismic 'tape reel' is divided into two main parts: the reel identification header and the individual trace data blocks (Figure 3.5). The reel identification header section contains information pertaining to the entire reel and is subdivided into two blocks: the first containing 3200 bytes of EBCDIC card image information, and the second consisting of 400 bytes of binary information relating to the contents of the tape reel. Each block is separated from the other by an Inter Block Gap (IBG) (Barry et al., 1974). The second main component of the SEG-Y format consists of the actual seismic traces. Each trace data block consists of a fixed 240-byte trace identification header within which all information pertaining to that individual trace is stored, and the data values of the seismic hydrophone receiving channel(s). All the values within the trace ID header are stored in binary form. The data that follow the trace header information, the actual trace sample data, is written in one of four possible 32 bit formats in IBM floating point notation as defined in IBM Form GA 22-6821 (Barry et al, 1974).

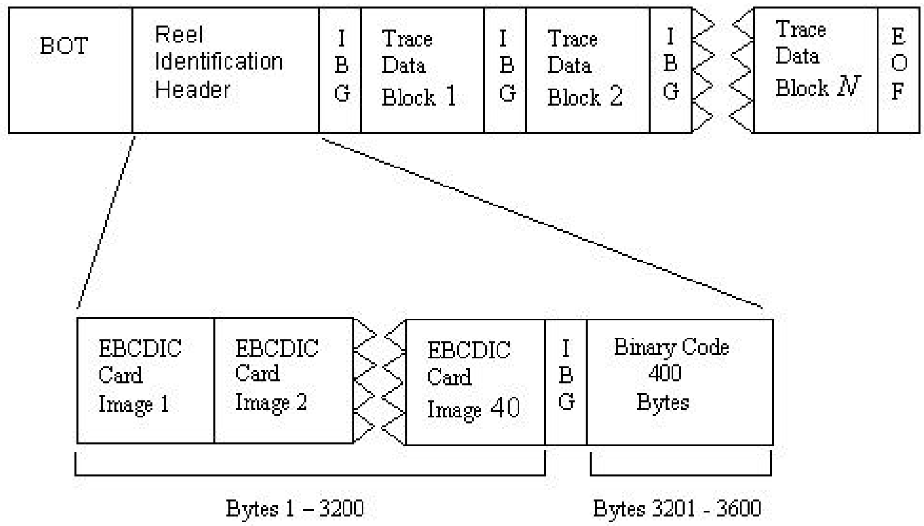


Figure 3.5: The SEG - Y Digital Tape Format for recording seismic data (after Barry et al. [1974, p.25]).

Several seismic processing packages currently exist for processing SEG-Y digital information, ranging from expensive commercial packages such a LANDMARK, to freeware packages like SEISMIC UNIX (SeisUnix) distributed by the Center for Wave Phenomena (CWP) at the Colorado School of Mines (CSM). As mentioned earlier, for this study the HDTS seismic data were processed using the Seismic Unix package.

CHAPTER 4:PROCESSING MARINE DATA

4.1: Processing Multibeam to Generate Raster Data

4.1.1 CLEANING MULTIBEAM DATA

The multibeam raw data were processed in near-real time during the acquisition survey, and for the purposes of this report no further reprocessing of the data was performed. However, it is important to briefly discuss the method by which multibeam data was edited using the UNB/OMG – Multibeam SwathEd software prior to generating the final digital map products.

The OMG's SwathEd multibeam processing package is a collection of software tools that run on Unix platforms, that can be used for standard swath sonar processing and generation of map-like products, such as digital elevation models, sidescan mosaics, and sun-illuminated imagery (Hughes Clarke, 1998a). Once a survey line is completed, the navigation data is interactively examined and edited using *jview*, one of the graphical viewing and processing tools of SwathEd. Within *jview*, the user can select bad navigation points for flagging and later rejection. Data associated with these erroneous navigation points will not be used when the navigation data is merged with the sounding data. Once the navigation editing is complete, the quality of the soundings themselves are inspected using the SwathEd editing tool displayed in Figure 4.1.

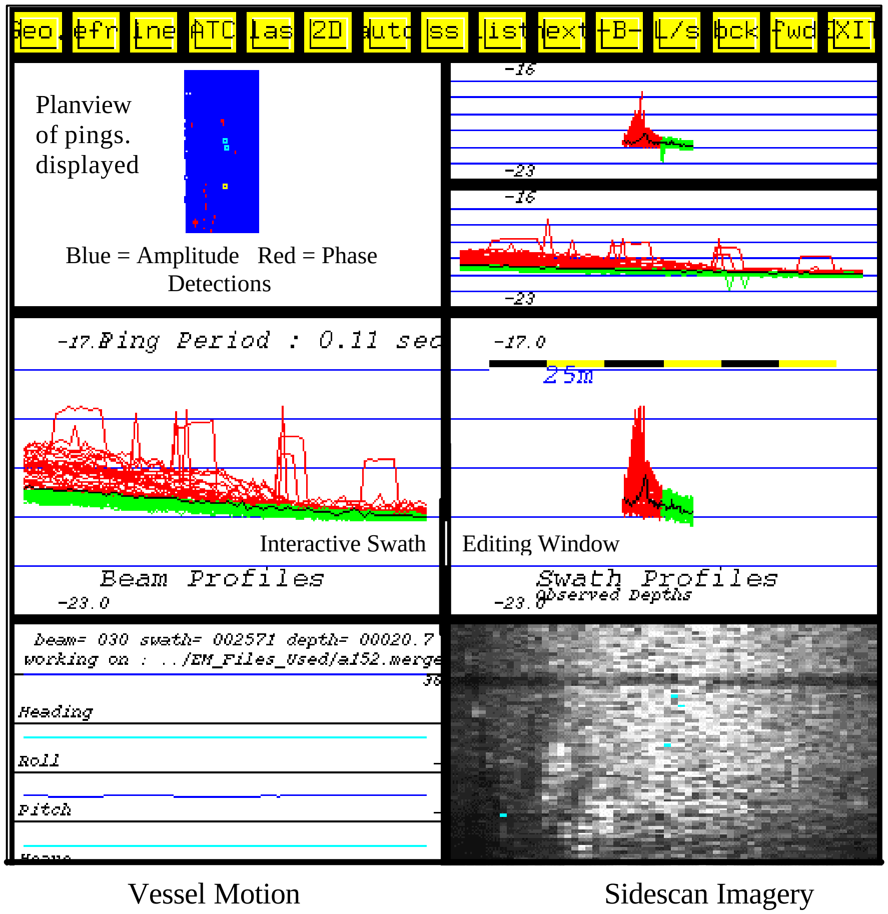


Figure 4.1: SwathEd graphical display of 80 stacked swaths (pings) from a multibeam system. Allows interactive editing and cleaning of data.

SwathEd is the core program of the OMG – multibeam processing package. It allows the user to examine 80 successive swaths stacked together in both across-track and along-track orientations, as well as display the backscatter imagery data and the vessel orientation (roll, pitch, yaw, and heading) for the period of time corresponding to the swath data being displayed. Erroneous sounding points can either be flagged automatically by a series of filters, or manually selected by the user who refers to the backscatter and orientation windows as an aid in deciding whether particular data points represent a real or false feature.

Upon completion of the cleaning of navigation and sounding data, they are merged together to geo-reference the sounding data with the appropriate positions. Tidal corrections and modification of refraction coefficients are subsequently added before passing this cleaned data to the bathymetric gridding and sidescan mosaicing utilities of the OMG processing package.

4.1.2 GRIDDING BATHYMETRIC DATA

Gridding is carried out by the UNB – SwathEd multibeam post-processing software. The basic principle of gridding bathymetric data is to take a dataset that has an uneven distribution in the density of sounding data points, and generate an orthogonal, regularly spaced series of nodes (Hughes Clarke, 1998b). The node values are determined by an averaging procedure that takes into account the influence of soundings that fall within a certain radius corresponding to the grid size. For regions where nadir and outer beams overlap, it is important to consider the varying contribution that nadir and outer beams ought to make to the final grid node value. Because of varying beam footprint dimensions and differences in bottom detect algorithms used in nadir and outer regions of the swath, it is appropriate to favour nadir beam values over outer beam values when determining the grid node value. In the UNB – SwathEd multibeam post-processing software, this function is performed in the gridding process by assigning beam weights to all beams, with nadir beams having a higher weight than outer beams. This ensures that in regions where nadir and outer beams coincide, the final grid cell value will be more heavily influenced by the nadir beam values than by the outer beam values.

As mentioned in Section 2.2.1, by sub-dividing the survey region into several smaller mapsheets, we can ensure that shallow water regions are gridded at the highest resolution possible given the water depth, and the deeper water depths are gridded at an appropriate resolution depending on the water depth. This grid size (resolution) is typically about 10% of the average water depth. The final product is a bathymetric map that combines all the individual mapsheets into one overview mapsheet that is degraded to the lowest resolution.

4.1.3 MOSAICING SIDESCAN BACKSCATTER DATA

The principle behind mosaicing sidescan data is similar to that of gridding. The basic difference is that, for the sounding data, only one value of depth based on the two-way travel time is provided for each beam. Sidescan measurements, on the other hand, are based on the collection of a time series of echo amplitudes as the acoustic pulse for each beam moves through its particular footprint on the seafloor. This produces many more backscatter values than depth values because the time-series of echo amplitudes is sampled at a much finer interval than the beam spacing. The backscatter time-series data collected within each beam footprint are joined together across the swath width, creating a continuous time-series trace in the across-track direction, with a much finer resolution than that of the gridded sounding data. For an entire line, the continuous time-series data for each ping are combined together one after the other to produce a sidescan strip for the survey line. From there, a sidescan mosaic of the surveyed region is created that consists of all the individual sidescan strips joined together.

4.2: Processing Seismic Data with Seismic Unix

4.2.1 OVERVIEW OF SEISMIC UNIX

Seismic Unix is a Unix-based processing environment, written in the C programming language, that extends the Unix operating system to include seismic processing and display capabilities. In the late 1980s and early 1990s, the increased availability of Unix work-stations in combination with a growing community of Unix-literate geophysicists, scientists, and academics, inspired a shift in the seismic industry towards using primarily Unix-based systems for seismic research and processing (Cohen and Stockwell, 1998). This in turn generated an increase in the interest level for Unix-based seismic processing software, including Seismic Unix. The earlier versions of Seismic Unix were primarily used in-house at the Center for Wave Phenomena, CSM, but once the package became easily available over the Internet, it began to be used by a much broader community (Cohen and Stockwell, 1998). Subsequently, it has been used in commercial, academic and government establishments, both as a seismic processing tool and for software development.

4.2.2 OVERVIEW OF SEISMIC PROCESSING STEPS: INCORPORATING SEISMIC WIGGLE PLOTS INTO A MARINE GIS

There are several steps involved in processing the Huntec DTS sub-bottom profile data for incorporation into the marine GIS. The first steps are reading the raw SEG-Y file and converting it to the format required by Seismic Unix (SU). Before any actual processing can take place, we must retrieve the seismic parameters stored in the trace header fields of each trace data block in the seismic line. The information will affect how the seismic processor divides the seismic line into smaller seismic data windows that can be viewed in the marine GIS. Dividing the seismic data into smaller segments is necessary because the large volume of seismic data prevents them from being displayed all at once. Once the seismic segments are created, the seismic data can be displayed using the SU plotting utilities. All the graphic plotting tools of SU create postscript format files, which are not suitable for viewing within the marine GIS. Therefore, the postscript files must be converted to TIFF images using Unix utilities capable of performing this task. The following flowchart illustrates the steps involved in processing a seismic line (Figure 4.2).

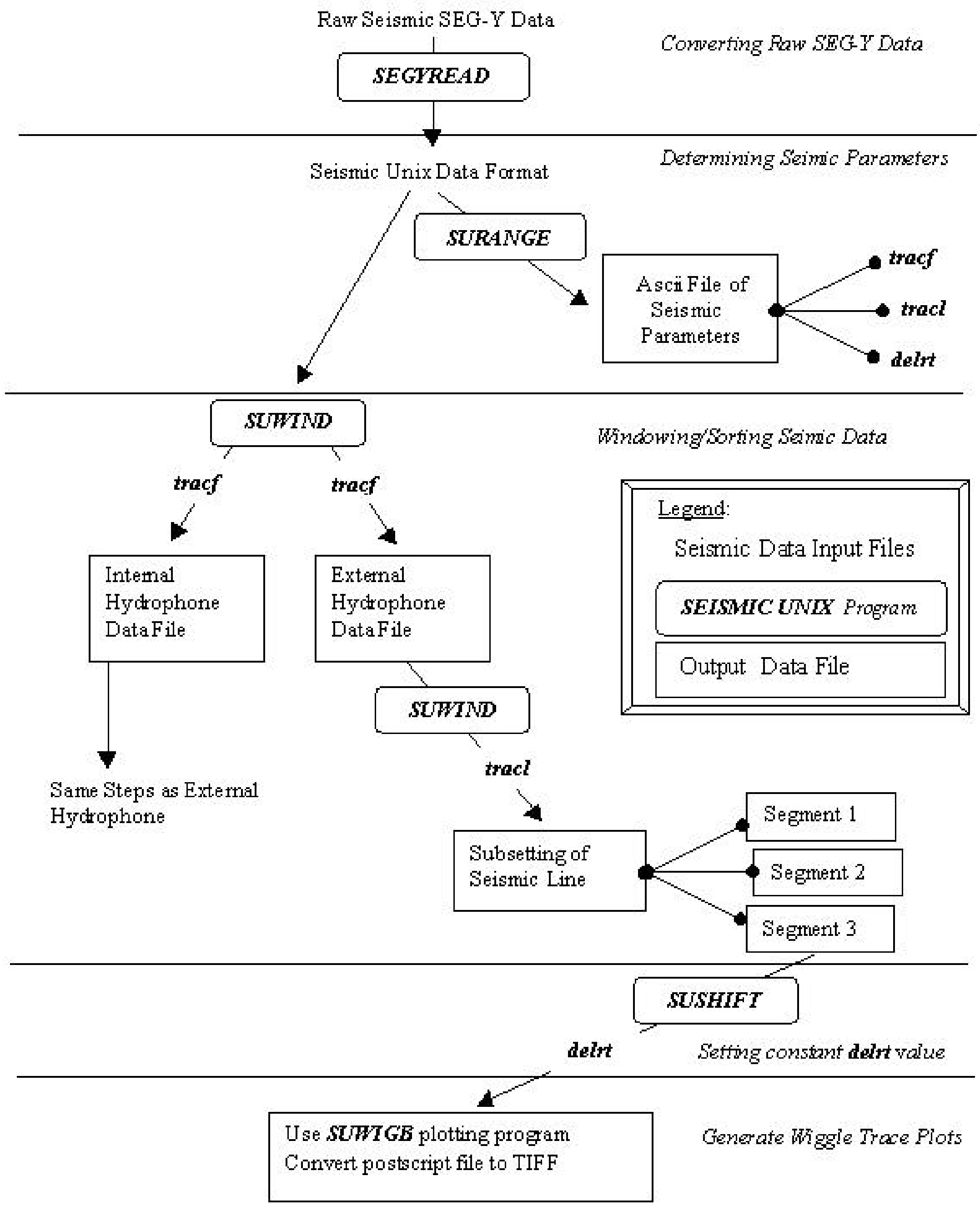


Figure 4.2: Seismic processing flowchart using seismic Unix (SU).

4.2.2.1 Seismic Processing: SEGYREAD

The first step in processing seismic data is to convert the digital SEG-Y datafile into the format required by SU. The SU data format is based on the trace portion of the SEG-Y data format. The main difference between the SEG-Y traces and the SU traces is that the data portion of SU is in the floating point format, written in the native binary format of the machine you are working on (Cohen and Stockwell, 1998). The program used to convert data from the SEG-Y format to the SU format is *segyread* (Figure 4.2) (see Appendix I).

The unix command line instruction to perform this task is as follows:

segyread tape=input filename endian=1 verbose=0 > standard output (newfile.su)

4.2.2.2 Seismic Processing: Trace Header Information: SURANGE

Before any processing can continue, the parameters for the particular seismic line that is being processed must be determined. This information is stored in the trace header portion of the trace data block. To retrieve these values, use *surange* to interrogate the dataset and return the full range of values within the trace headers (Figure 4.2) (see Appendix I).

The unix command line instruction to perform this task is as follows:

surange < line25.su > standard output

An example of the output from *surange* is as follows:

Table 4.1: ASCII dump of the trace header information from a SEG-Y file.

```
tracl=(1,6140)  tracr=(1,6140)  fldr=(1,6140)  tracf=(1,2) trid=1
sx=379579,381010) sy=4531167,4535760)
gx=379579,381010) gy=4531167,4535760)          Total of 6140 traces
delrt=(300,400) ns=2048 dt=125
year=95 day=258 hour=(21,22) minute=(0,59)  sec=(0,59)  timbas=2
```

4.2.2.3 Sorting Internal/External Hydrophone Data: SUWIND

Once the trace header parameters have been retrieved, several header fields require closer inspection (Table 4.1). An observant seismic processor should notice that there is a range of values in the ***tracf*** field (Table 4.1) which record the trace numbers within the field record. Recall that for the Huntec DTS equipment, there are two receiving hydrophones that record the seismic trace data; one is an internally mounted hydrophone and the other is a small hydrophone streamer towed slightly behind the 'fish'. The ***tracf*** records which hydrophone/channel the trace data information comes from, either the internal or external hydrophone. These two channels must be looked at individually, so the operator must extract trace data information from these two separate sources. This is carried out by using a windowing utility call *suwind* (Figure 4.2) (see Appendix I). In order to separate the traces corresponding to the two unique values of ***tracf = (1 ,2)***, the syntax would be as follows:

```
suwind < line25.su key=tracf min=1 max=1 > line25.ch1.su
suwind < line25.su key=tracf min=2 max=2 > line25.ch2.su
```

Furthermore, as seismic files can be very large depending on the length of time during which data was collected, the seismic processor should realize the data will have to be divided into smaller subsets in order to effectively view the seismic plots. This can be done in a variety of ways, either windowing the data into several discrete time blocks, i.e., several half-hour partitions, or by subsetting the data into numerous segments with a fixed number of traces per segment. After several trial runs, it was decided that the ***tracl*** field (Table 4.1) was the most appropriate field with which to sort and partition an SU file into manageable components. The *tracl* field corresponds to the trace sequence number within the seismic line; the size of the individual seismic segments is a variable typically set at~2500-3600 traces per segment.

In this example, it was decided to subset the seismic line into two equal parts of 3070 traces each. The *suwind* utility is capable of performing this task, using the following syntax (Figure 4.2).

```
suwind < line25.ch1.su key=tracl min=1 count=3070 > line25.ch1.3070.su
suwind < line25.ch1.su key=tracl min=3070 count=3070 > line25.ch1.6140.su
```

Lastly, and of most importance for the processing of high-resolution single channel seismic data, is the range of values stored within the ***delrt*** field (Table 4.1). The importance of this trace header field to seismic processing is outlined in section 4.2.2.4.

4.2.2.4 Seismic Processing: Changing *DELRT* Values: SUSHIFT

The ***delrt*** field (Table 4.1) corresponds to the delay in recording time between the initiation of the seismic source and the time when recording trace data samples begins. The adjustment of the bottom recording time delay is dependent on the water depth and the height of the tow vehicle. It will be altered numerous times in regions where there are large changes in vehicle height above the bottom.

In high resolution single channel seismic profiling the sample interval is short, and the shot rate and the number of samples are high. To reduce the trace data file size, the ***delrt*** time is constantly being changed, particularly over sloping terrain

(Cohen and Stockwell, 1998). In order to process and display a seismic section, certain adjustments must be made to the raw seismic data in order to obtain a constant ***delrt*** value for all seismic traces. This is because SU plotting parameters are dependent on the values stored in the trace data block header of the first trace plotted. All other subsequent traces displayed are plotted using the parameters found in the trace data block of the first trace.

Should the value of the *delrt* field change dramatically over the length of the raw seismic file, the output plot file will be distorted because of the dependence of the SU plotting utilities to the *delrt* value of the first trace. The values within the ***delrt*** must be consistent throughout the entire seismic line and therefore must be adjusted prior to generating any seismic plots. The *sushift* program, a utility of SU, is capable of assigning a single value to the *delrt* field, and thereby adjusting all individual traces so that they line up properly once plotted (Figure 4.2) (see Appendix I).

The size of the time window created using *sushift* is dependent upon three fields of information: the ***delrt*** field, the ***ns*** (number of samples) field, and the ***dt*** field (sample interval in micro-seconds) (Table 4.1). For *sushift,* the minimum value for the time window can be set to the minimum *delrt* value, while the maximum value of the time window is equal to maximum ***delrt*** + (***ns*** * ***dt***), i.e. tmax = 400 ms + (2048 samples * 0.000125 s), where (***ns*** * ***dt***) equals 0.256 seconds.

The unix command line instruction to perform this task, is as follows:

```
sushift<line25.ch1.3070.su tmin=0.30 tmax=0.625>line25.ch1.3070.nodelay.su
```

We now have a seismic file that has a constant ***delrt***, and that is ready for plotting.

4.2.2.5 Seismic Data Plots and TIFF Image Generation

Seismic Unix has several graphics utilities that can be used for plotting seismic data and generating postscript files of these seismic plots. However, outside of the Seismic Unix processing environment, these postscript files cannot be easily viewed. In order to make the digital seismic plots accessible by ArcView, they must be in a graphic file format like a TIFF (Tagged Image File Format). Therefore, once these postscript files were created, they were converted to TIFF images using a variety of UNIX operating system utilities (see Appendix II for conversion program). The script *make.2channel.tif.script,* included in Appendix II, was written in order to provide a means of generating the wiggle trace postscript plots and converting them to TIFF images.

4.2.2.6 Seismic Processing: Geo-Referencing Seismic Lines:

One of the most fundamental capabilities of any Geographic Information System, is the ability to deal with data in a spatial context. The marine GIS concept being explored here involves integrating a wide variety of data, all of which share a common geographic location. All of these data were collected offshore Eureka, California, hence the common denominator is positional information, which allows the marine GIS to collate this data in a spatial context.

For seismic data, each trace data block recorded in the SEG-Y format includes positional information (recorded in the trace header ***sx*** and ***sy*** fields), preceding the actual trace data (Figure 3.5, Table 4.1). Extracting this navigation data is as critical to the overall success of the marine GIS as generating the seismic wiggle trace plots themselves. The program *sugethw* is the seismic Unix utility that allows us to extract this information, or any other header information for that matter.

The following command is used to generate an ASCII file that consists of the x,y Universal Transverse Mercator (UTM) coordinates (easting, northing) for each trace data block.

```
sugethw <line25.ch1.3070.su key=sx,sy output=geom> n25x3070.txt
```

Table 4.2: This is a sample of the ASCII navigation data in UTM coordinates.

378629	4523342
378629	4523342
378629	4523346
378629	4523346
378629	4523346
378629	4523346
378630	4523349
378630	4523349

This information is the geographic location of the ship during a portion of the seismic survey, recorded in UTM coordinates. It is these position fixes from the SEG-Y tape that will be used to geo-reference the seismic sub-bottom profile into the marine GIS. Unfortunately, using the ship's position information to geo-reference the seismic data does introduces a positioning error because the towfish itself is somewhere behind the vessel when it is recording data. This phenomena is known as layback and can be corrected for in one of two ways: 1) if the amount of cable deployed as well as the wire angle are known, a layback correction value can be applied to the ship's position to more closely approximate the towfish's position, 2) a layback correction value can be calculated by determining the distance and bearing to a towfish behind a vessel using active acoustic ranging techniques like ultra-short baseline (USBL). The sub-bottom profile data collected for this research was not corrected for layback positioning error. This is not unusual when traditional seismic interpretation techniques of such seismic data are considered. Because seismic data of this nature has traditionally been interpreted using an analogue paper chart in isolation of other marine data, precise positioning of such data has not been a high priority. While this layback error does introduce some uncertainty into the proper geo-referencing of the data into the marine GIS, it is only on the order of a few hundreds of metres. When one considers the total size of the surveyed region, this registration error between the two datasets is minimal in comparison with the benefits that are derived from integrating the two datasets. It is important to be aware of this layback error so that its potential effects can be properly recognized in the marine GIS.

In order to import the seismic navigation information into the ArcView GIS package, the UTM coordinate values must be converted into latitude and longitude information. This is because ArcView employs latitude and longitude coordinates (dd-mm-ss) as its main coordinate reference frame. Within ArcView, you can display any spatial information with a variety of different projection options, as long as the original dataset is in the latitude and longitude format. This re-projection capability is uni-directional only; ArcView can re-project latitude and longitude data into a UTM coordinate system, however, ArcView cannot display UTM data into any other projection. Therefore, it is beneficial to convert all datasets into a latitude, longitude reference frame before uploading them to ArcView.

The transformation of the seismic navigation data from UTM to the latitude and longitude coordinate system was performed using PCI, a commercial image processing software package capable of the vector manipulations required. The conversion process is outlined in section 4.2.2.7.

4.2.2.7 Conversion of Point Data to Line Data Using PCI Software

The ASCII UTM files were imported into PCI using the VREAD (Read Vector File) utility, which converted the individual point coordinates of one seismic segment (1-3000 points) into a vector segment plotted in a UTM projection (Figure 4.3). Using the vector projection utility (VECPRO), the vector segment was then transformed from the UTM projection into latitude and longitude coordinates. Once re-projected, PCI is capable of exporting its internal PCI formatted files (.pix), into shape files (.shp), the graphic file format used by ArcView (EXPORT .pix to .shp). These ArcView shape files can then be overlaid on top of other spatial data stored within the GIS, as shown in Figure 4.4.

The images in Figure 4.4 are the entire seismic navigation lines for both 1995 and 1996 seismic cruises. In both cases, navigation data are superimposed on top of the sun-illuminated bathymetry of the region, and displayed by ArcView.

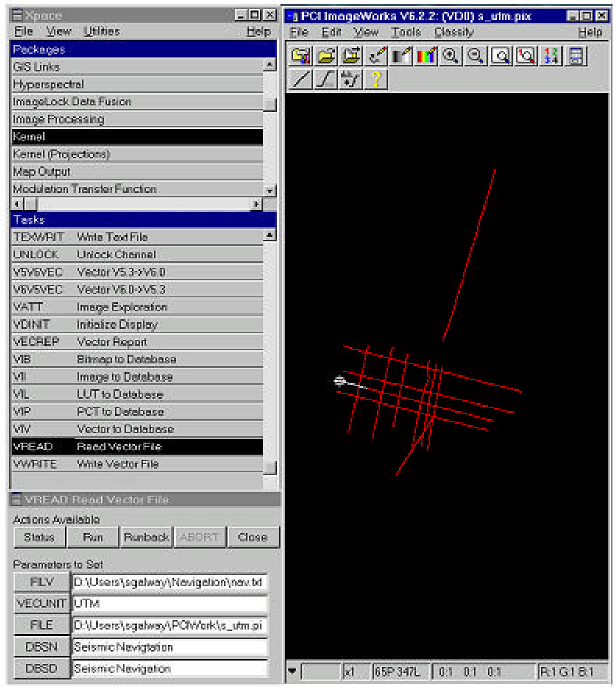
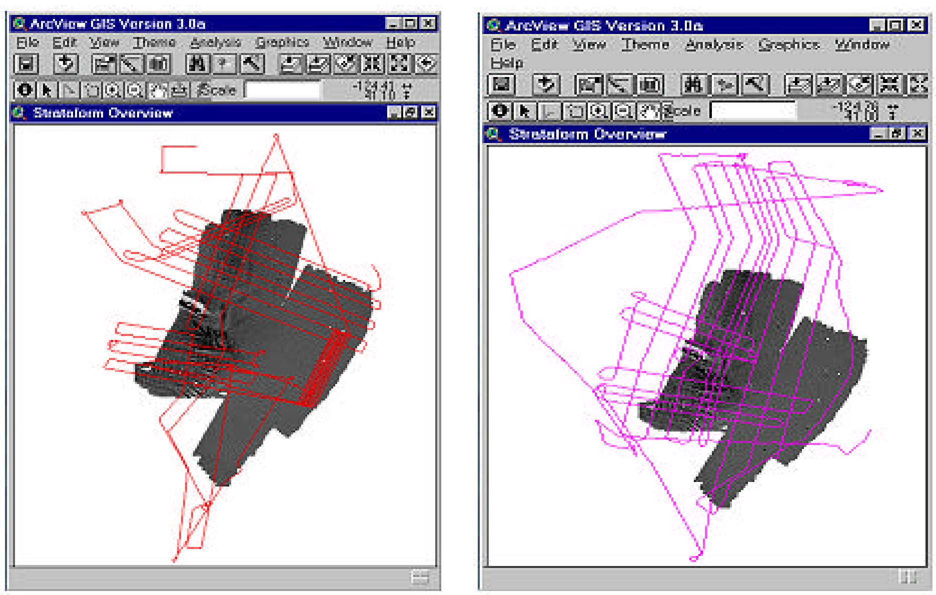


Figure 4.3: Using PCIWorks to read an ASCII x,y file and convert to a line segment in latitude and longitude coordinates from UTM (VECPRO).



(A): 1995 (B) 1996

Figure 4.4: Seismic trackline data superimposed on-top of sun-illuminated bathymetry.

CHAPTER 5:COMPILING SPATIAL MARINE DATA WITHIN ARCVIEW

5.1: Utilizing Seismic Data within GIS

5.1.1 ACCESSING SEISMIC PROFILE DATA WITHIN ARCVIEW

The final objective of integrating the seismic data into the marine GIS involves being able to retrieve and display the digital seismic TIFF images. Within Arcview there is a means of linking the navigation trackline theme to the digitally stored image file. By placing the cursor over a portion of the navigation theme, the user can retrieve the digital sub-bottom image file that corresponds to the seismic line segment located beneath the cursor (the lightning bolt) (Figure 5.1). This is possible because of the customization capabilities of ArcView using Avenue programming, which is the basic programming language of ArcView. By providing users with the ability to program and execute their own add-on modules, ArcView's capabilities are vastly extended. The following section illustrates the special programming scripts that were written in order not only to retrieve the digital seismic images, but also to provide the user with important metadata for each individual seismic section that is displayed within the marine GIS.

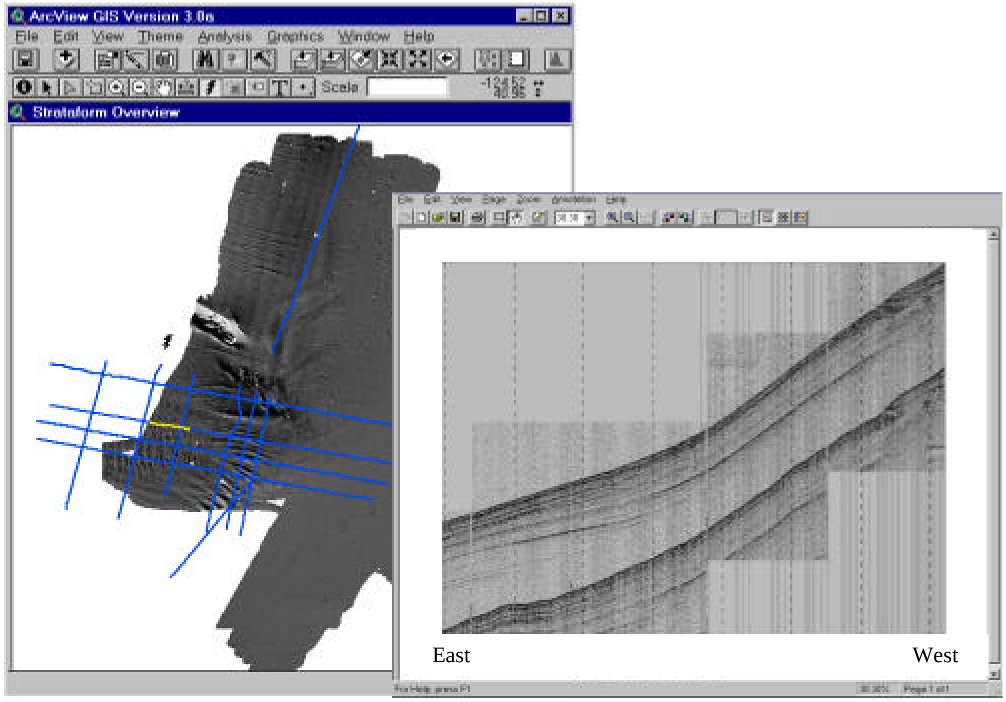


Figure 5.1: Retrieving and displaying digital seismic images using ArcView's hotlink capabilities.

5.1.2 ARCVIEW CUSTOMIZATION AND AVENUE PROGRAMMING

In order to extend the capabilities of ArcView to accommodate the retrieval and display of seismic images, two Avenue programming scripts were written. Although ArcView does provide a means of linking and retrieving image files that are outside the GIS project database, it was determined that the ability of ArcView's basic Hotlinking tool (the lightning bolt) was too simplistic for our purposes. ArcView's basic hotlink tool can indeed retrieve the seismic image file, however, it cannot retrieve and display metadata associated with the seismic segment being displayed. Furthermore, the hotlink tool does not identify or highlight the seismic segment that the user selected with the mouse, making it difficult to determine the precise location of the seismic image being retrieved. The user knows the vicinity of the cursor location, and the seismic line underneath, but nothing more precise than that. By finding a means of not only highlighting the seismic segment selected, but also displaying the metadata associated with the seismic image file, valuable information regarding seismic line identity, the precise location, collection date, the direction of navigation, and the individual traces displayed in the seismic plot can be provided.

The two Avenue scripts written to perform this task are relatively simple. The first script, called “Highlight Segment Selected” (Table 5.1), determines the segment selected by the user and if the argument “**`if(recordsfound = 1)then`**” is true, the script highlights the segment selected and passes information regarding this segment to the second script, “Display Segment Selected” (Table 5.2).

Table 5.1: The "Highlight Segment Script" written in Avenue programming language.

```
LineSelected = SELF
theView = av.GetActiveDoc
SeismicLine = theView.GetActiveThemes
SeismicTable = av.GetProject.FindDoc("Seismic Table").GetVtab
Segment = theView.GetDisplay.ReturnUserPoint
Cursor = #VTAB_SELTYPE_NEW
  for each Profile in SeismicLine
    if (Profile.CanSelect) then
      Profile.SelectByPoint(segment, cursor)
     end
  end
recordsfound = SeismicTable.GetNumSelRecords
    if (recordsfound = 0) then
           System.Beep
           av.Run("View.ClearSelect", LineSelected)
    end
if (recordsfound = 1) then
  av.DelayedRun("Display Segment Selected",LineSelected, 1)
end
if (recordsfound > 1) then
  msgbox.warning("You have selected multiple seismic
  images!"+NL+NL+"Please make a new selection!","Warning")
  av.Run("View.ClearSelect", LineSelected)
end
```

Once the variables from “Highlight Segment Selected” are passed to the “Display Segment Selected” script, the second script is responsible for retrieving the metadata of the selected segment from the seismic database table and displaying the seismic image plot (Figure 5.2). The image is displayed by an external viewing program (Kodak Windows Imaging) that is executed by the “Display Selected Segment” script. This function is possible because of the **`System.Execute`** command, which can invoke any application software located on the host machine, whether it be word processing software, or in our case, an image viewing application (Table 5.2). This capability is critical to the overall success of integrating digital seismic data into the Marine GIS.

Table 5.2: The "Display Segment Selected" script written in the Avenue programming language.

```
SeismicTable = av.GetProject.FindDoc( "Seismic Table" ).GetVtab
for each record in SeismicTable.GetSelection
  Field1 = SeismicTable.findfield("Line Number")
  Entry1 = SeismicTable.ReturnValueString(Field1, record)
  Field2 = SeismicTable.findfield("Trace Segment")
  Entry2 = SeismicTable.ReturnValueString(Field2, record)
  Field3 = SeismicTable.findfield("Orientation")
  Entry3 = SeismicTable.ReturnValueString(Field3, record)
  Field4 = SeismicTable.findfield("Profiles")
  Openfile = SeismicTable.ReturnValueString(Field4, record)
 LineParameters ="Line:" ++Entry1 +TAB+"Trace Numbers:" ++Entry2
acceptflag = msgbox.yesno( "Display Wiggle Plot:" +NL +NL
+LineParameters "Orientation:"++Entry3,"Loading Profile", True)
  if (acceptflag) then
    if (File.Exists(Openfile.AsFileName)) then
        System.Execute("C:\Windows\kodakimg.exe" ++Openfile)
    else
      System.Beep
        MsgBox.Warning("Warning:"  +NL+Openfile+NL+  "   does not
        open. Check Filename and Location.","Warning Message")
    end
  else
  av.Run("View.ClearSelect", Self)
  end
end
```

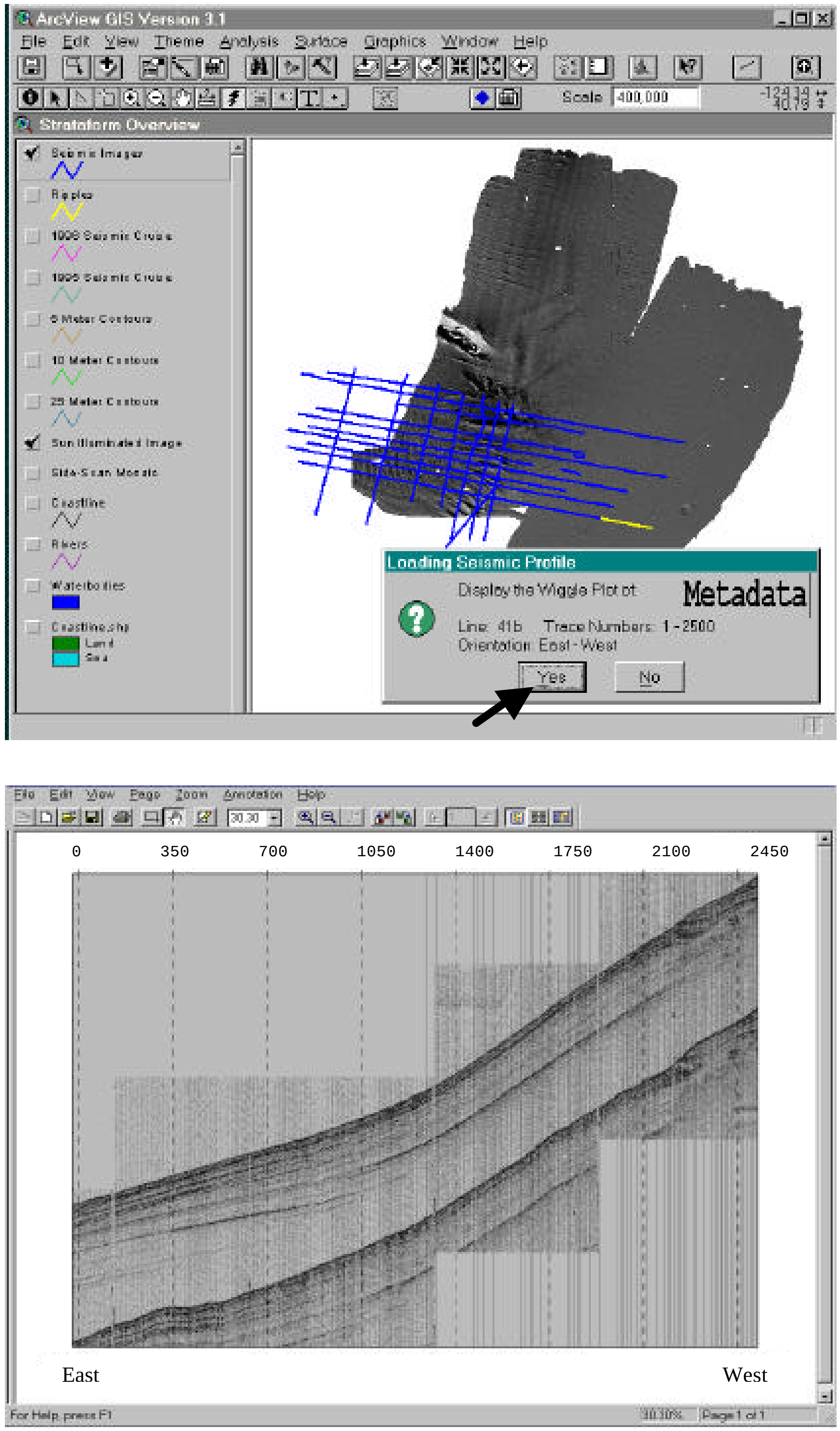


Figure 5.2: Retrieving metadata and subsequent display of corresponding seismic image.

5.2: Discussion of Problems Encountered with GIS

While the problems encountered with the two-dimensional marine GIS developed are not significant, they do require some discussion. The problem of georeferencing the seismic data using the ship's position has been previously mentioned in section 4.2.2.6. Fortunately, the co-registration error caused by not accounting for towfish layback is virtually unnoticeable when viewing seismic profile data within the marine GIS package. This is because the layback offset is on the order of a few hundreds of metres at most, which is a relatively small distance when compared to the length of the seismic segment being viewed. It is important to be aware of this problem so that its potential effects can be recognized.

When viewing the seismic data within the marine GIS, the ability to manipulate the seismic data is limited to the fundamental panning and zooming tools available within Windows Imaging. Since the seismic data consists of a TIFF image file, no actual seismic data manipulation, such as filtering or muting, can be carried out. Any such data processing operations must be carried out at the Seismic Unix processing level. In comparison to commercial seismic processing packages, this inflexibility seems rather restrictive, however, one must realize that the seismic processing packages are incapable of integrating multiple spatial datasets in the manner that a GIS, like ArcView, can.

Lastly, the effort involved in processing and preparing the seismic data for integration into the marine GIS was monumental, and very much an iterative process that slowly improved over time through trial and error. Only the Huntec data collected in the region of the Humboldt slide zone was incorporated into the marine GIS, which represents a relatively small portion of the total seismic data collected for the STRATAFORM Project, as displayed in Figure 4.4 and Figure 5.1. It would not be feasible to process all of the seismic data collected for STRATAFORM in a similar manner because of the time involved. However, the steps documented above, for the integration of seismic data into a marine GIS, provide a foundation for future efforts by other individuals.

CHAPTER 6:SCIENTIFIC VISUALIZATION

6.1: Three-Dimensional Data Visualization and Exploration

While GIS technology has made it possible to store, view, and manipulate spatially georeferenced datasets, there are some limitations that become particularly apparent when dealing with the large volumes of data collected by multibeam systems. The data density collected by these systems is incredibly high and, while this does present problems of data management, it does give us the opportunity to make use of modern data visualization tools to explore data in a manner that we never had before.

Currently, GIS systems interactively display two-dimensional raster and vector data very well, but are hard pressed to handle three-dimensional (3D) datasets, like digital terrain models, in an interactive manner. The two-dimensional nature of ArcView requires that the third dimension, in this case the depth dimension, becomes an attribute of the x,y position and be represented as a raster image where each pixel within the raster image is assigned a unique colour that corresponds to its depth (Figure 6.1). This allows three-dimensional datasets to be successfully displayed and interpreted within Arcview.

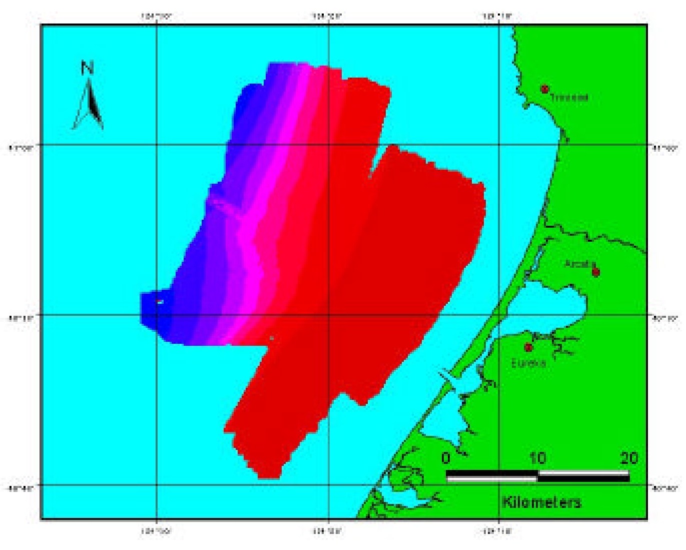


Figure 6.1: Raster colour coded bathymetry.

While this method of representing 3D data is perfectly acceptable, it does not allow us to take full advantage of the density of soundings generated by an MBSS. Ideally, in order to preserve information contained within a 3D dataset, we must view these data within an environment that preserves the three-dimensional nature of the data. The ability to visualize data within Arcview in a three-dimensional reference frame, while possible, is rather limited when compared to the capabilities of visualization packages available today. Within a GIS package like Arcview, these capabilities tend to be limited to static snapshots of a rendered surface, with very limited data exploration and interactivity (Figure 6.2).

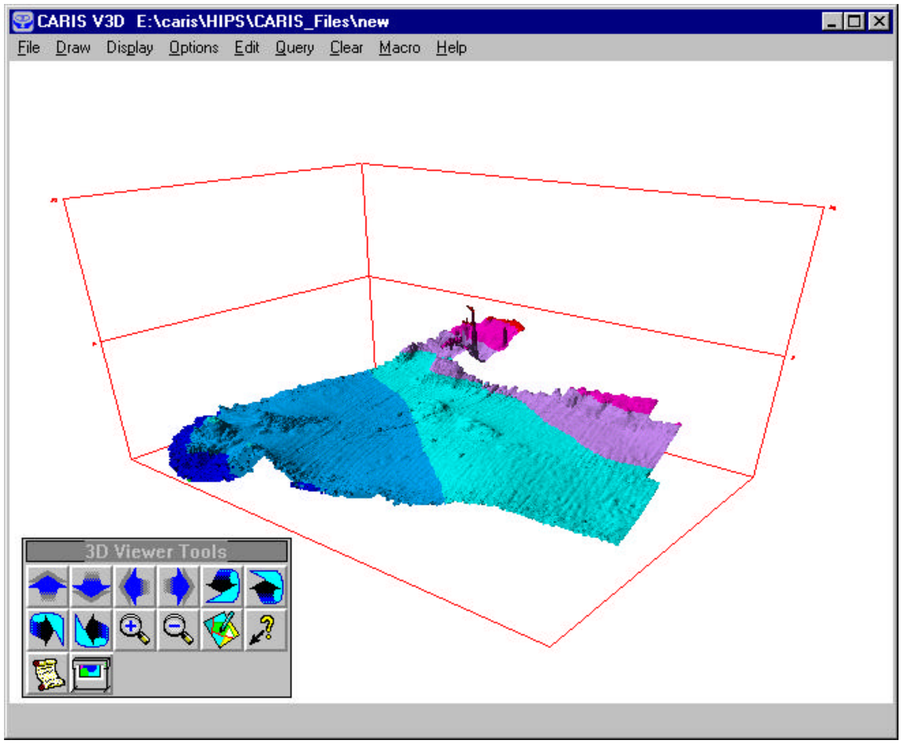


Figure 6.2: Static rendering of 3D surface with limited data exploration capabilities.

In order to effectively analyze massive multi-dimensional datasets, scientists have turned to the computer visualization world. In the early days of visualization, the number of calculations and the amount of hardware requirements for graphics limited the use of computer visualization techniques to super computers with special graphic processing stations. Furthermore, the nature of these systems was such that limited data exploration was possible, expert knowledge of the system was required, and a process of trial and error was necessary to obtain the desired visualization (Paton, 1995).

The improvements experienced in the computer world, with the advent of powerful, yet low cost, graphical workstations and on-screen user interfaces, has accelerated the development and use of interactive data visualization systems. These systems allow the user to interactively manipulate the exploration and visualization of data, in order to derive a better understanding of its underlying meaning. Scientific visualization is the process by which a visualization package converts numeric data into a visual representation of the data in order to facilitate the exploration and interpretation of complex datasets. It has been recognized that the human visual system has an enormous capacity for receiving and interpreting data quickly, and therefore should be an integral part of any attempt to understand large and complex datasets (Paton et al., 1997).

With multibeam datasets we are no longer limited to presenting bathymetric data as isolated soundings or interpolated contours on the seafloor. Instead, we can create full digital terrain models that take advantage of the inherent data density of multibeam systems, and generate realistic looking 3D representations using visualization techniques to highlight surficial features. Much like the first aerial photographs or satellite imagery, multibeam sonar data in combination with modern scientific visualization software has given us new insight into seafloor topography and better understanding of seafloor processes (Paton et al., 1997).

6.2: Fledermaus Scientific Visualization Software

Fledermaus, distributed by Interactive Visualization Systems, is a suite of software tools designed to allow interactive data exploration in a three-dimensional visual format, and to permit users to quantitatively interrogate the data within 3D space for geographic information and other attributes like depth or backscatter strength (Paton et al., 1997). Fledermaus allows the user to 'fly' freely through the 3D dataset using a six-degree of freedom mouse, called "The Bat", that uses natural hand motions to provide a means of interfacing with the system for data exploration. Because of the human visual system's enormous capacity for receiving and interpreting data quickly, this interactive 3D data exploration is an exceptional tool for the interpretation and understanding of complex spatial relationships (Paton et al., 1997).

A wide variety of three-dimensional data can be displayed within a Fledermaus "scene." It is possible to have digital elevation maps (DEM) draped with sonar backscatter data or aerial photographs integrated with coastal DEMs or seismic sub-bottom profile data. (Figure 6.3). All of the objects are geo-referenced within 3D space, and any 3D positional information or other attribute data can be extracted using spatial queries from any 3D perspective. Although Fledermaus does not perform many of analytical functions that are common to GIS systems used in the land information management community, it is, to a degree, a three-dimensional GIS.

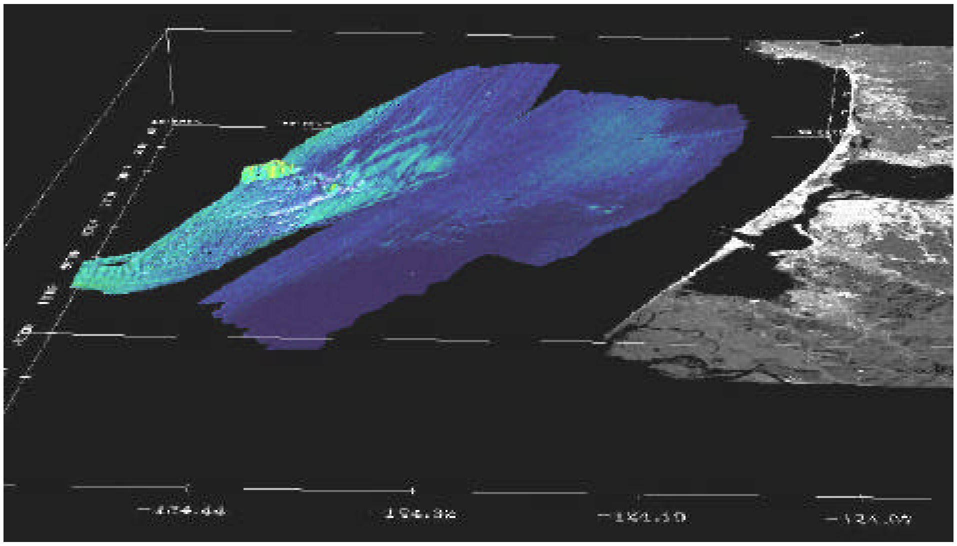


Figure 6.3: Display of 3D surfaces within Fledermaus scientific visualization package.

6.2.1 HOW FLEDERMAUS WORKS

In order to project an image of the virtual 3D world onto a two-dimensional projection plane, the virtual 3D world must undergo a transformation. This transformation is performed using a perspective projection, which is a function of the distance and orientation from which the dataset is being viewed. Within the virtual 3D world, the viewing perspective is simulated by placing a virtual camera within the three-dimensional scene, the position of which is controlled by the user. The resulting image seen on the 2D screen is the virtual camera's view of the three-dimensional world, after being transformed by perspective projection (Paton, 1995).

Equally important to the projection of a 3D virtual world onto a 2D screen is the ability to effectively interact and explore the dataset within the visualization environment (Ware and Osborne, 1990). As mentioned earlier, Fledermaus performs this task by using a six-degree of freedom mouse that allows the users to interactively manipulate the location of the virtual camera within 3D data space. Although this is not the only method of data exploration within Fledermaus, it is the most innovative.

A significant component of the Fledermaus software package is its ability to maintain a graphic representation of a large dataset (> 10 million points), while the position of the virtual camera is being altered by the user. While the viewing perspective is being altered during data exploration, Fledermaus degrades the visual display of data but immediately updates and re-renders the visualization scene at full resolution once the user determines a new viewpoint from which to visualize the data. This dynamic rendering allows the user to explore a huge three-dimensional dataset without overloading the computer hardware capabilities. This concept represents a significant improvement over the static snapshots of a 3D surface used by many earlier visualization packages, and still currently employed by many GIS packages as their means of displaying 3D data.

6.2.2 VISUALIZATION OF SPATIAL MARINE DATA WITH FLEDERMAUS

6.2.2.1 Multibeam Bathymetry and Backscatter Data

Within Fledermaus, the multibeam bathymetric data can be represented as a 3D surface, with the latitude and longitude providing geo-referencing information and the depth contributing to the shape of the 3D surface. The objective of displaying this 3D surface within Fledermaus is to allow the user to explore and extract spatial relationships from the data in an intuitive and efficient manner. In order to develop an understanding of spatial relationships within a 3D scene, it is important to provide as many 3D spatial cues as possible. These cues help identify surface features of the digital terrain, making spatial relationships in the visualized data much easier to perceive

When dealing with surface data, like a digital terrain model of the seafloor, there are a number of techniques that can be applied to such data to highlight surficial features. These techniques include pseudo-colouring, sun-illumination, and surface shading. These visualization techniques provide visual cues to help the human visual system to perceive spatial relationships that exist in 3D space, while viewing the 2D representation.

Pseudo-colouring is a process similar to rasterization, in which a sequence of colors is assigned to a series of data values (in this case – depth). For a 2D GIS, it is the colour-coded 2D raster image that would be displayed. However, with a visualization package, this colour-coded depth data can be mapped onto the digital terrain model, resulting in a colour-coded map of the seafloor from which surficial features can be easily detected. While it is quite common for a colour map to be applied to depth data, any other spatial variable, like multibeam backscatter strength, can also be displayed using a colour map that would then correspond to seafloor texture or composition (Paton et al., 1997).

Additional visualization cues that can be used to impart knowledge with respect to spatial relationships are illumination and shading techniques. These involve manipulating the position of a light source, and casting shadows of the appropriate lengths depending on the orientation and azimuth of the light source with respect to the surface. The combined effects of these visualization techniques all help to enhance features of the 3D surface, and allow the users to detect spatial relationships that exist in the 3D virtual world, while observing the 2D representation.

6.2.2.2 Visualization of Sub-bottom Profile Data with Fledermaus

Although the visualization of MBSS data is currently the most common application of Fledermaus, it is not the only multi-dimensional data that can be displayed within Fledermaus. Other 3D dimensional data, such as seismic sub-bottom profile data, can be incorporated into a Fledermaus “scene.” The nature of seismic data is such that as information regarding the sub-surface geology of the surveyed region is being collected, also being recorded is the positional information that corresponds to the time each source pulse was initiated. This positional data can be used to generate a vector map of the ship’s navigation during seismic surveying in order to geo-reference the location of sub-bottom profile information.

Traditionally, the products generated from a seismic survey include analogue graphic paper charts as well as digital recordings of the seismic data collected. Typically, the analogue paper charts are the product of choice used by investigators for analysis and interpretation, while the digital information acts as a long-term storage medium from which addition paper charts can be generated.

With Fledermaus, we have the ability to import this digital seismic data and incorporate it with surficial data, literally hanging the seismic profile from the bathymetric data (Figure 6.4 and 6.5). The first return recorded by the seismic sub-bottom profiler corresponds to the bathymetric surface delineated by the multibeam sonar. This fusion of the multibeam and seismic data provides a unique view of the data, similar to that used by oil and gas exploration companies when they generate digital products from a 3D seismic survey. Visual analysis of these datasets in an integrated fashion may provide insights into seafloor processes that are responsible for shaping surface geomorphology and sub-surface structures that may otherwise have gone unnoticed had the individual datasets been examined in isolation.

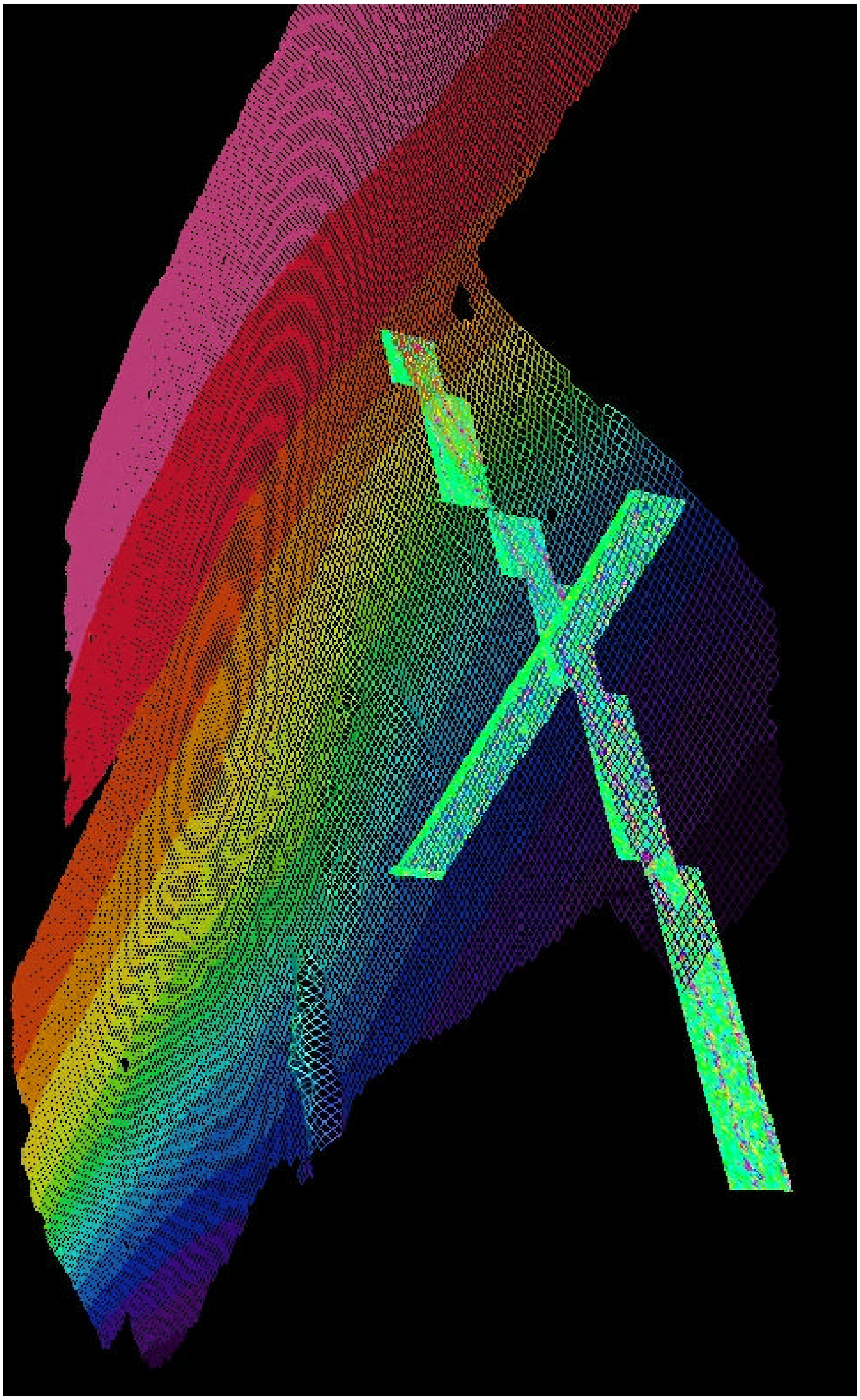


Figure 6.4: Fledermaus rendering of bathymetry (mesh surface) and sub-bottom profile data (vertical planes)

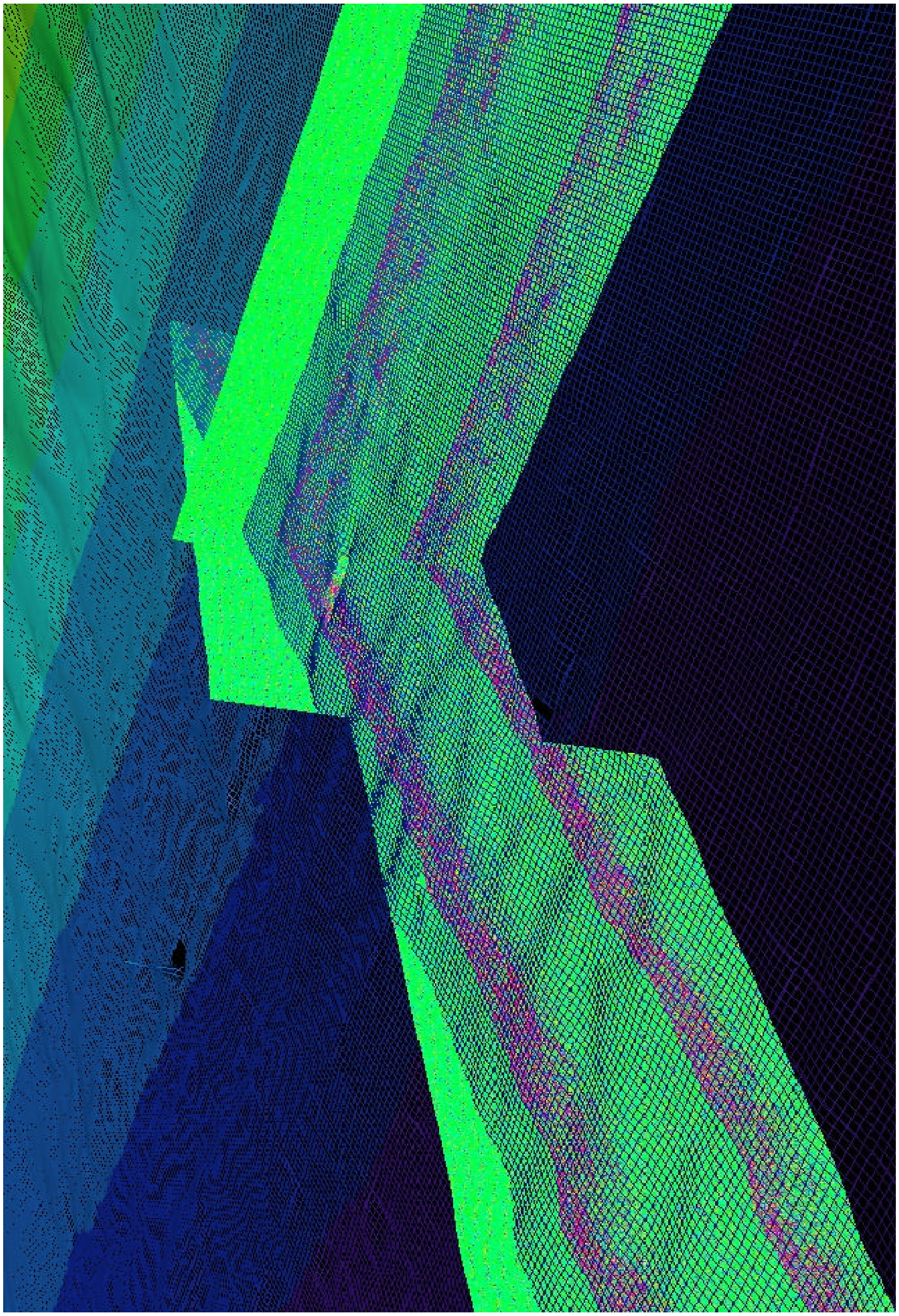


Figure 6.5: Closeup of bathymetric surface and sub-bottom profile data in format similar to a fence diagram.

In its raw form, the seismic data is not a 3D surface but rather a time slice extending into the seafloor sub-surface. Seismic reflection events occur at geologic horizons, where a difference in acoustic impedance exists between adjacent sedimentary layers. For seismic reflection surveying, if an accurate determination of depth and thickness of sedimentary units is required, it is necessary to determine the sound velocity within the sediments through physical property studies. If the sub-surface sedimentary properties, like grain size, density and porosity, are measured through piston or gravity coring techniques, then the sound speed within each sedimentary layer can be modeled, and a depth value to each horizon can be determined. There are other seismic surveying techniques, like seismic refraction, or multi-channel seismic surveying, which are capable of extracting sedimentary velocity information without having to resort to physical property measurements. For the purpose of this thesis, however, these techniques were not investigated.

If only the relative positions of geologic horizons are necessary, then applying an assumed sound speed of 1500 m/s to the seismic record to extract an approximate depth and thickness of individual layers is acceptable. It is likely that the actual sound velocity in the sediment is greater than 1500 m/s, because of increased grain to grain contact. Using a velocity value that may be smaller than the actual velocity will result in an under-estimation of depths to and thicknesses of sedimentary units. For our purposes, since only knowledge of the relative sub-surface architecture is necessary, applying an assumed sound speed to the seismic record is adequate, as long as there is an awareness of how this assumption can potentially affect the appearance of the seismic record.

This is in fact what has been done with the Fledermaus SEG-Y Reader module developed by the Ocean Mapping Group in conjunction with colleagues at Interactive Visualization Systems. The positional information from the SEG-Y header file is used to geo-reference the location of seismic lines. The trace data is mapped to a vertical plane that begins with the first sampled data point in the seismic record, and extends to the last sampled data point in that record (Figure 6.6). Although the raw seismic data is recorded in the time dimension, within Fledermaus the sub-bottom profile data has in fact been converted to the depth dimension by applying an assumed velocity of 1500 m/s to the seismic dataset. While the relative positions of geologic units is maintained, the actual depth and thickness of these units are not accurately modeled in this manner, as the speed of sound undoubtedly changes within individual geologic units. For our purposes, this technique is acceptable, as we are only interested in the subsurface architecture of the sediments, not the exact thickness of individual units. Only through physical property studies of the sediments or conduction of either a seismic refraction or multi-channel seismic survey can more accurate depth and thickness estimates be made.

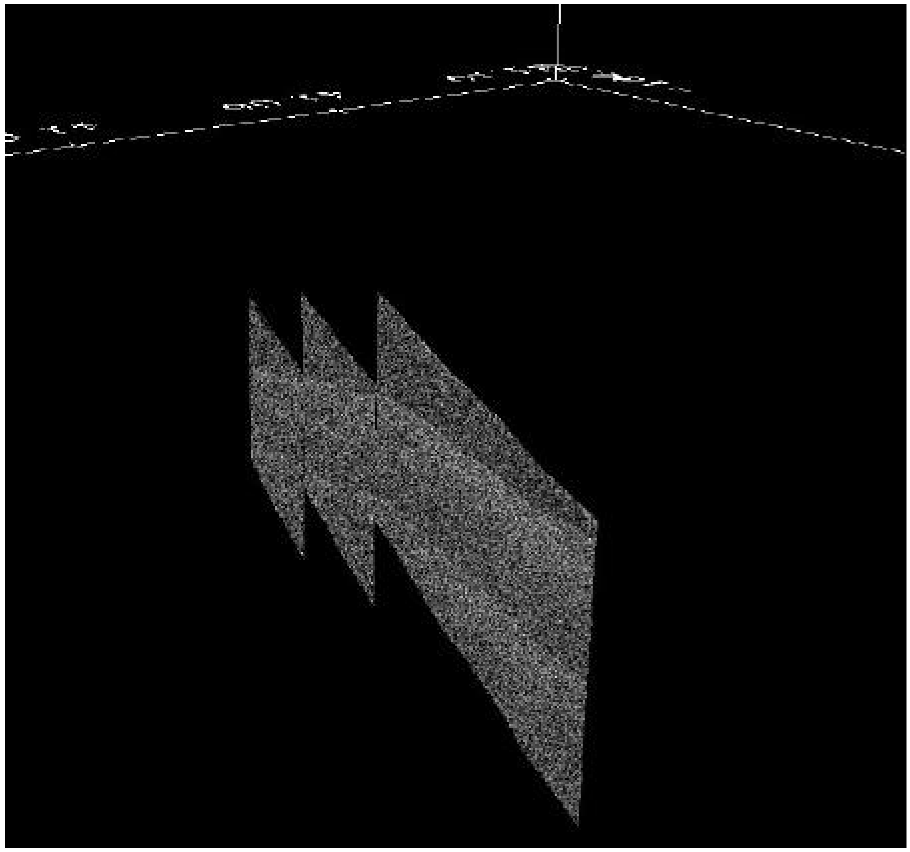


Figure 6.6: Illustration of seismic sub-bottom profile data mapped to a vertical plane.

6.3: Discussion of Problems Encountered Visualizing Seismic Data with Fledermaus

Unlike the two-dimensional marine GIS where the fish positioning error caused by layback did not cause significant problems, within Fledermaus using the ship's positioning information located in the SEG-Y position fields (***sx, sy***) to register the seismic line does creates a noticeable georeferencing error in the seismic data. This is apparent at the intersection point of the two seismic profiles displayed in Figure

6.5, where the first returns of both seismic sections do not agree. This layback offset is also noticeable when looking at the bathymetric relief and comparing it to the relief of the first return of the seismic section. In the horizontal domain, the x,y position of the various peaks and valleys of both surfaces should match. In Figure 6.5, there is a noticeable, albeit small, misalignment between the two surfaces.

Of greater concern is the vertical displacement between the seafloor bathymetry and the first return of the seismic data, visible in Figure 6.5. These are the same surfaces and thus should correspond exactly. While the exact cause of this offset is unknown, there are a couple of possibilities. Since the vertical offset is relatively small, it could be the result of: 1) tidal reduction of the multibeam data using incorrect tidal values, 2) an incorrectly calibrated depth sensor used to determine depth to the towfish, 3) seismic data that was never tidally reduced, and 4) the application of incorrect sound velocity to seismic data. Fortunately, this vertical offset between the two surfaces has proved to be beneficial, because it in fact made the datasets somewhat easier to view in Fledermaus. Had the two surfaces lined up exactly, it would have been a little more difficult to extract detail from the top of the seismic section because of interference with the bathymetric surface.

Another problem experienced when viewing seismic data in Fledermaus was one of sheer data volume. A seismic SEG-Y data file is very large, and thus very memory intensive to display, particularly when using a visualization package like Fledermaus. Interactively exploring the multibeam and seismic data simultaneously was hampered by the amount of time required to update the seismic profile once a new view orientation was selected by the user. Furthermore, in order to display the greatest amount of seismic detail as possible, one had to be zoomed right in close to the vertical seismic profile, which meant Fledermaus was projecting a two-dimensional vertical profile to a two-dimensional screen, negating the purpose of viewing seismic data within a 3D visualization package.

CHAPTER 7: GEOLOGIC SETTING

7.1: Overview of Northern California Margin Geology

The location of the Eureka, California, STRATAFORM study area falls within the limits of the Eel River Basin that extends northward from Cape Mendocino (40° 30’ N) for nearly 200 km to the California - Oregon border, and from the coastline seaward to the edge of the continental slope. The Eureka study area is an active convergent margin with a coastal mountain range, narrow shelf (~20 km) and a significant supply of fluvial sedimentary input, primarily from the Eel River (Nittrouer, 1999). It is located just north of the Mendocino triple junction where the Pacific, Gorda, and North American plates converge. The continental slope off northern California delineates the inferred eastern boundary of the Gorda (also known as the Juan de Fuca) plate where it is being subducted, along the Cascadia Subduction Zone, beneath the North American plate (Field et al., 1980) (Figure 7.1).

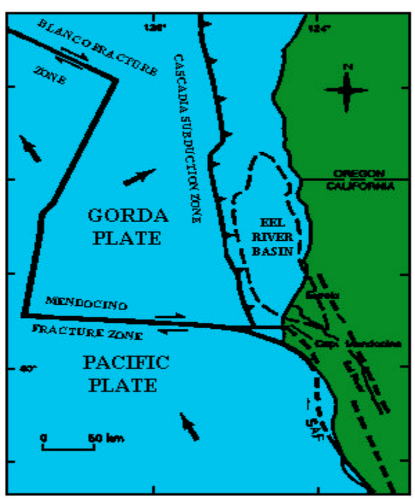


Figure 7.1: Tectonic elements of the Northern California Margin and the location of the Eel River Basin (after Orange [1999, p. 370]).

The Eel River Basin consists of sediments ranging from the early-middle Miocene to the present, and stratigraphic studies have detected several transgressive/regressive sequences that document relative sea-level changes in the region (Orange, 1999). Increased erosional processes on land in northern California, and large sedimentary input into the basin during the late Pleistocene through Quaternary periods, occurred partly because of tectonically-induced uplift caused by the plate interactions, the subduction of the Gorda slab, and the northern movement and collision of the Mendocino triple junction (Orange, 1999). These tectonic forces uplifted and exposed young sedimentary packages which were easily eroded by the Eel River and its tributaries; the eroded sediments were then deposited on the continental margin. The surficial sediments of the northern California continental margin are typically Holocene in age, and the faults that cut this surficial sedimentary package are identified as Holocene as well (Orange, 1999). These Holocene sediments conformably overlie Pleistocene sediments, but in seismic sub-bottom profile data this horizon is sometimes difficult to detect (Field et al., 1980).

The seafloor morphology of the continental margin developed in response to late Tertiary and Quaternary plate movements, but it has also been influenced by a variety of other geologic forces, including sedimentary transport, deposition and erosional/mass wasting processes (Field et al., 1980; Orange, 1997). The region is riddled with numerous active folds and faults indicative of the tectonic strain being experienced by this region. The nature and range of seafloor relief resulting from folding due to tectonic strain, and the amount of deformation experienced by Holocene sediments, supports the idea that the Eel River basin has been shaped by compressional forces throughout the Quaternary, and perhaps longer (Field et al., 1980). The major force behind this basin deformation is likely the result of the subduction of the Gorda plate beneath the continental margin (Field et al., 1980). This underthrusting of the continental margin is an ongoing phenomenon caused by plate tectonics, and has implications for the formation and modification of present day sedimentary sequences.

7.2: Processes that Alter Continental Margin Morphology

The northern California continental margin is an area of rapid sedimentation and, because of local tectonic activity, it is subjected to large and frequent earthquakes with magnitudes ranging from 3.0 - > 7.0 on the Richter scale. The epicenters of these earthquakes are concentrated in the southern region close to the location of the Mendocino triple junction (Figure 7.2). These geologic processes interact together to create a setting where tectonic activity and sedimentary loading can dramatically alter the morphology and stratigraphy of the continental margin, through folding, faulting and erosional processes such as mass-wasting events. In summary, the geological forces in action on the northern California continental margins are such that the sedimentary depositional environment is highly unstable.

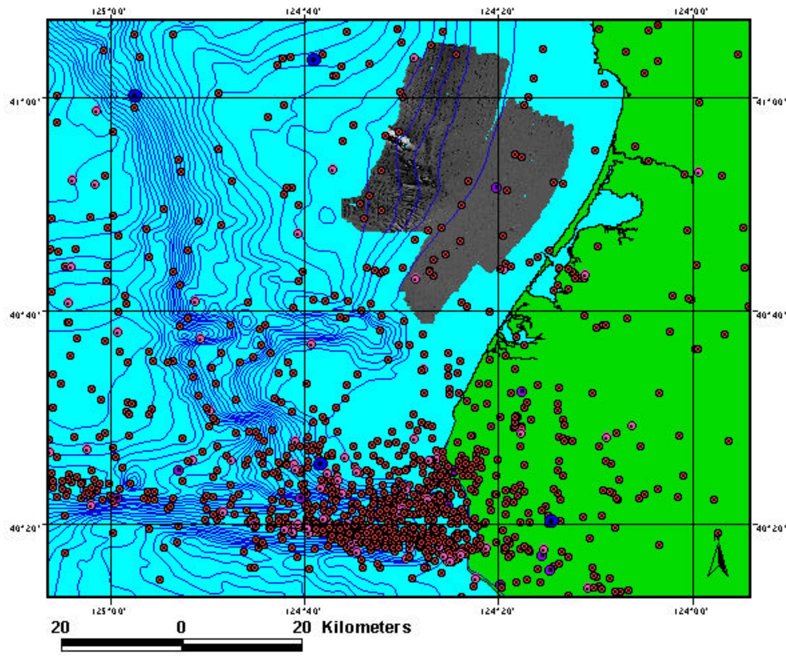


Figure 7.2: Earthquake epicentres on the northern California margin from 1974 – 1997 (courtesy D. Orange, USGS).

Seafloor instability refers to the potential of the seafloor to undergo morphological and stratigraphic changes initiated by abrupt geologic events, as a result of tectonic uplift, earthquakes and erosional processes like submarine landslides (Field et al., 1980). On the northern California margin, several causes of seafloor instability have been identified: 1) slide failure, 2) unstable sediment masses , 3) tectonic activity, 4) accumulations of shallow gas, and 5) the presence of gas hydrates (Field et al., 1980). Any one of these factors can alter seafloor morphology and sediment stratigraphy of the continental margin.

Slide failures cause sediments to undergo movement as discrete units with little or no internal deformation. Slide failures can be further broken down into either 'glides' or 'slumps' depending on whether the movement was translational along a planer surface (glides) or rotational along a curved surface (slumps) (Field et al., 1980). Slump failures are a common mass-wasting process that alter many modern day continental shelves and several slump failure features exist on the northern California margin, indicative of the sediment instability in this region. Some of the geologic clues used to identify slump failures include: 1) evidence of dislocation and movement of sediments, 2) beds that have undergone rotation and reorientation, 3) lack of internal deformation of the sediments, and 4) the presence of a gently dipping curved surface where sediment failure occurred (Field et al., 1980).

Of particular interest to this project is a slump feature located west of Eureka, California, referred to as the Humboldt Slide feature. It has been interpreted as consisting of a continuous series of rotated and translated sedimentary units, offset in the westward direction, that begin at the shelf edge and extend out onto the continental plateau (Figure 7.3). The slide encompasses an area close to ~200 km^2 between the 250 m and the 600 m isobaths, and estimates of the volume of sediment involved are on the order of ~6 km^3 (Gardner et al., 1999).

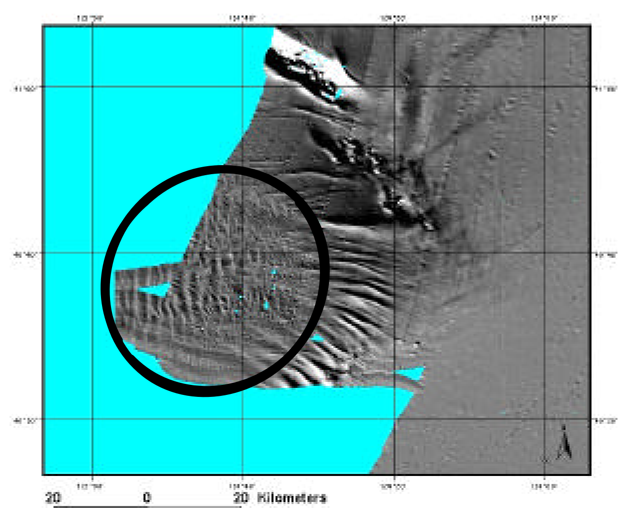


Figure 7.3: Plan view of sun-illuminated bathymetry of Humboldt Slide Feature. Circle delineates region of Humboldt Slide.

Deep penetration seismic records have located buried slumps in the same area that are recognizable by broken and rotated reflectors. The thickness and depth of these historic slumps are variable but typically are 50 m thick and extend as deep as 370 m below the seafloor surface (Field et al., 1980). Thus slump failures are common in the marine sediments of this area, and contributing factors to this erosional activity are the high sedimentation and high tectonism experienced by this region. The presence of historic slumps is indicative of the instability of the sedimentary depositional regime.

7.3: Description of Humboldt Slide Geology

7.3.1 OVERVIEW

The Humboldt slide feature lies within a shallow bowl-shaped depression. It is bordered by the continental shelf break to the east, the Little Salmon Fault to the north, and a bathymetric high not displayed in Figure 7.3 to the south. The eastern most point of the feature occurs at the 220 m isobath and it extends offshore to the 650 m isobath. Unlike typical submarine landslides, this feature does not have an abrupt headwall, but the eastern-most portion of the feature is steeper (3° - 6°) than the slope further seaward (1° - 2°) (Figure 27)(Gardner et al., 1999). The surface sediment morphology in the upper portion of the feature has been described by various authors as 'hummocky' in nature (Field et al., 1980, Gardner et al., 1999), while towards the base of the feature, the morphology is characterized by a series of ridge crests and swales (Figure 7.5 and Figure 29) (Gardner et al., 1999).

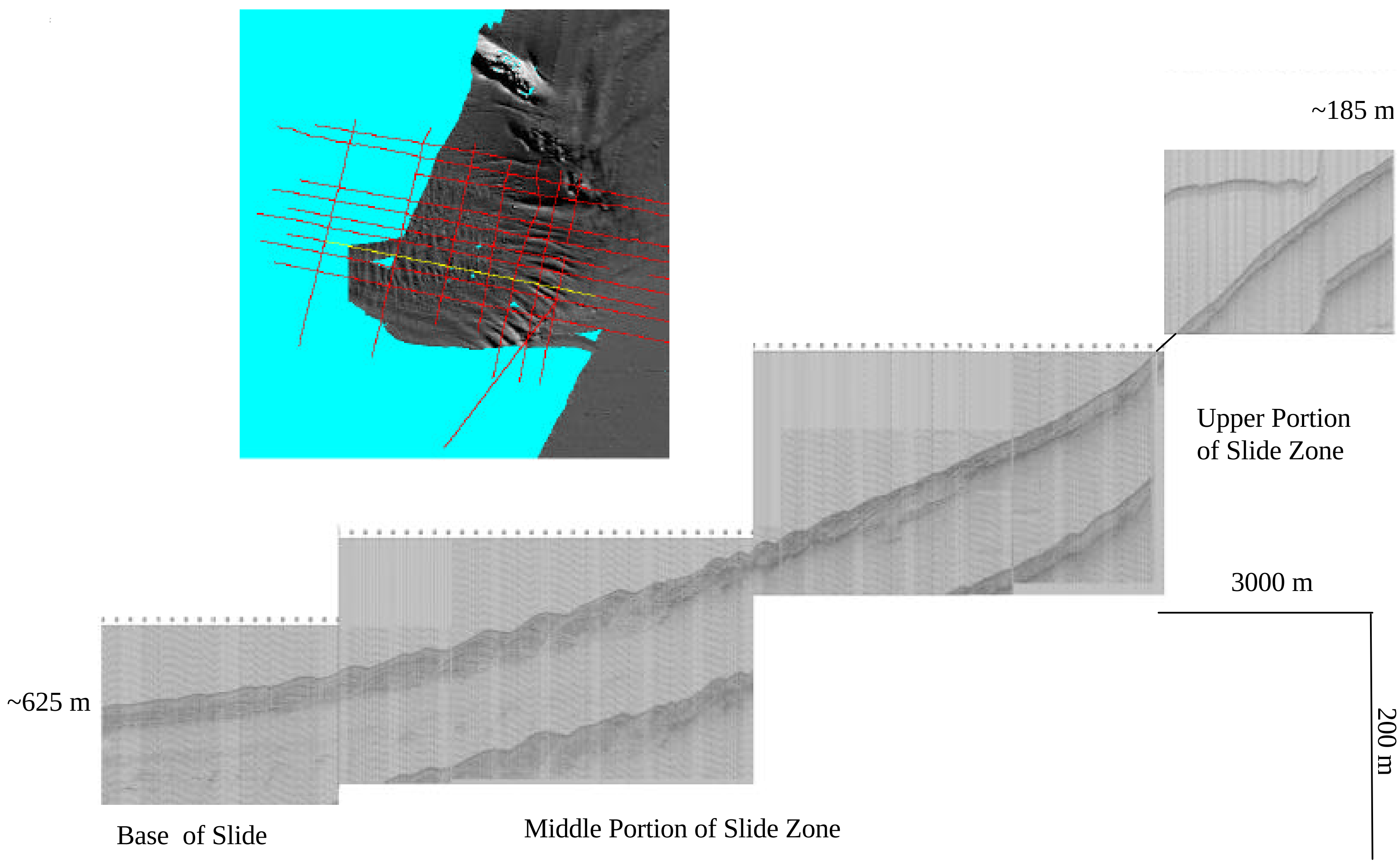


Figure 27: Change in slope from the top to the bottom of the slide, using subbottom profile data from Line 43, collected in 1995.

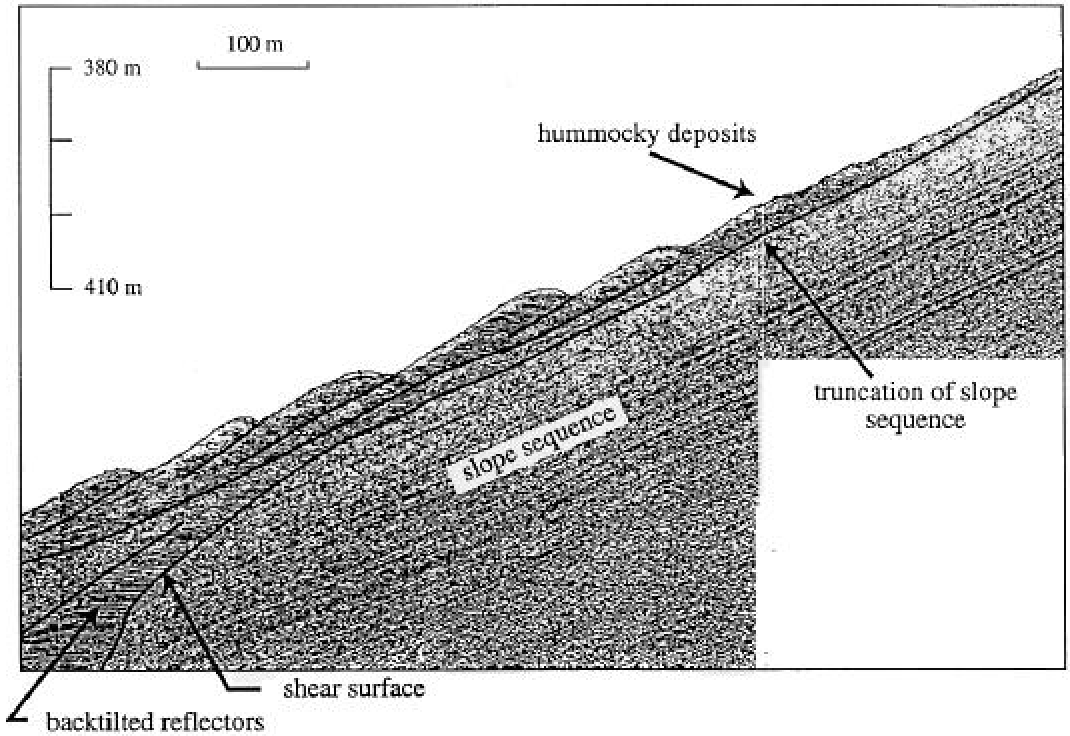


Figure 7.5: ‘Hummocky’ surface morphology in upper portion of slide zone (from Gardner et al. [1999, p. 331]).

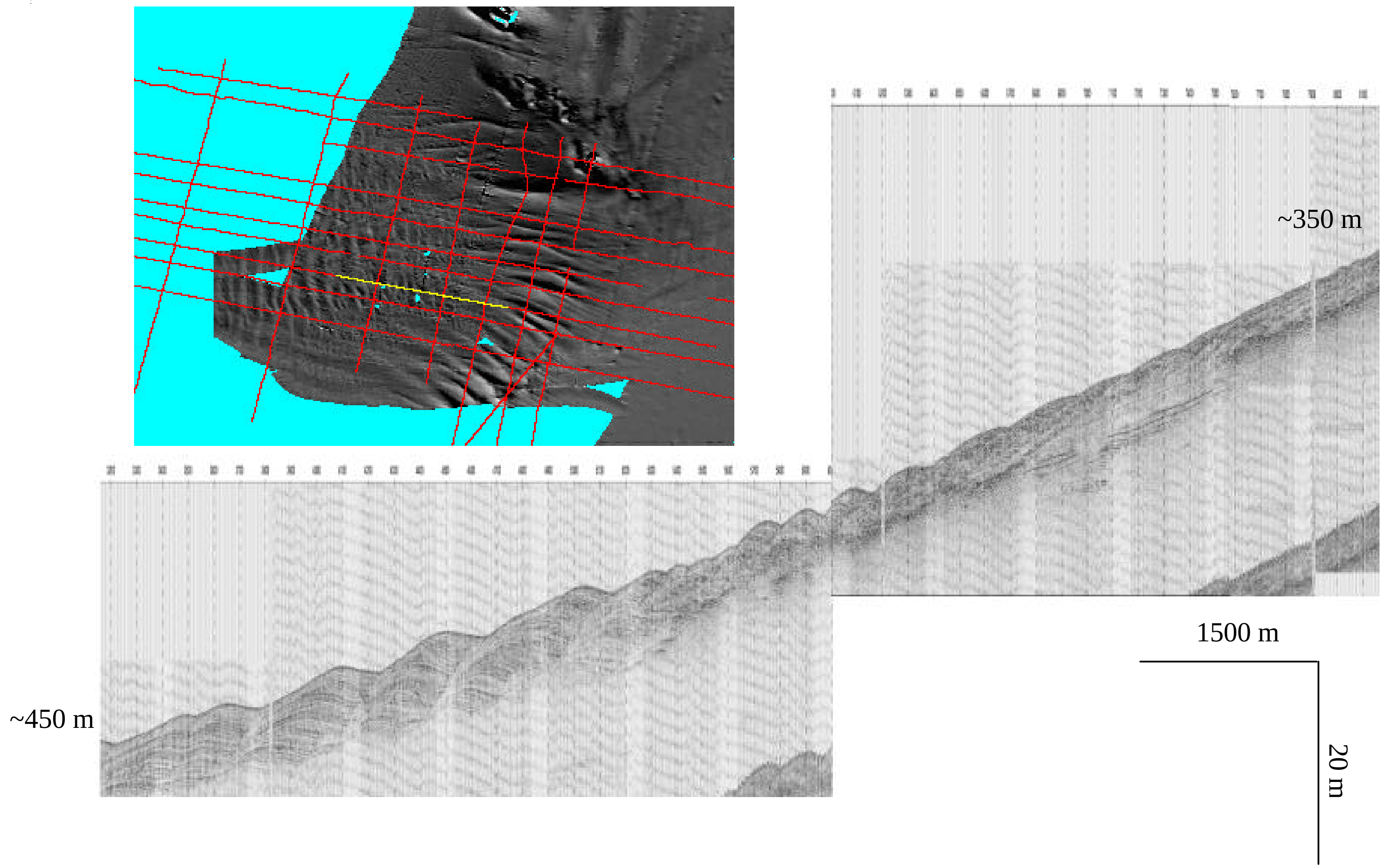


Figure 29: Series of ridges and swales in middle of Humboldt Slide, using subbottom profile data from Line 43, collected in 1995.

7.3.2 HEAD OF THE SLIDE FEATURE

The head of the slide lies between the 200 m to 400 m isobaths and consists of an erosional gully zone. Sub-bottom profile data have been interpreted in this region as consisting of shelf sediments that have been truncated with approximately 5–15 m of sediment having been removed, and unconformably overlain by ‘hummocky deposits’ approximately 5 m thick that lack coherent internal reflectors (Figure 7.5) (Gardner et al. 1999).

7.3.3 MAIN PORTION OF SLIDE FEATURE

The main body of the slide has been interpreted as being a zone of back-tilted and gently folded sedimentary blocks (Figure 7.7). A surficial 10 m thick acoustically transparent layer of sediment covers these back-tilted blocks. The landward facing side of each back-tilted block is bounded by a gently warped surface delimited by the termination of reflectors that is considered to be a shear surface (Gardner et al., 1999). Below the sediment-water interface, these surfaces dip seaward at an angle of ~8° and flatten out to merge with underlying reflectors at about 65 m below the sediment-water interface (Gardner et al., 1999). Each block appears to consists of anticlinally folded reflectors that dip landward 2° to 4° and seaward at 4° to 6°, with the landward dipping reflectors illustrating potential drag folding along the separating surfaces (Figure 7.7) (Gardner et al., 1999).

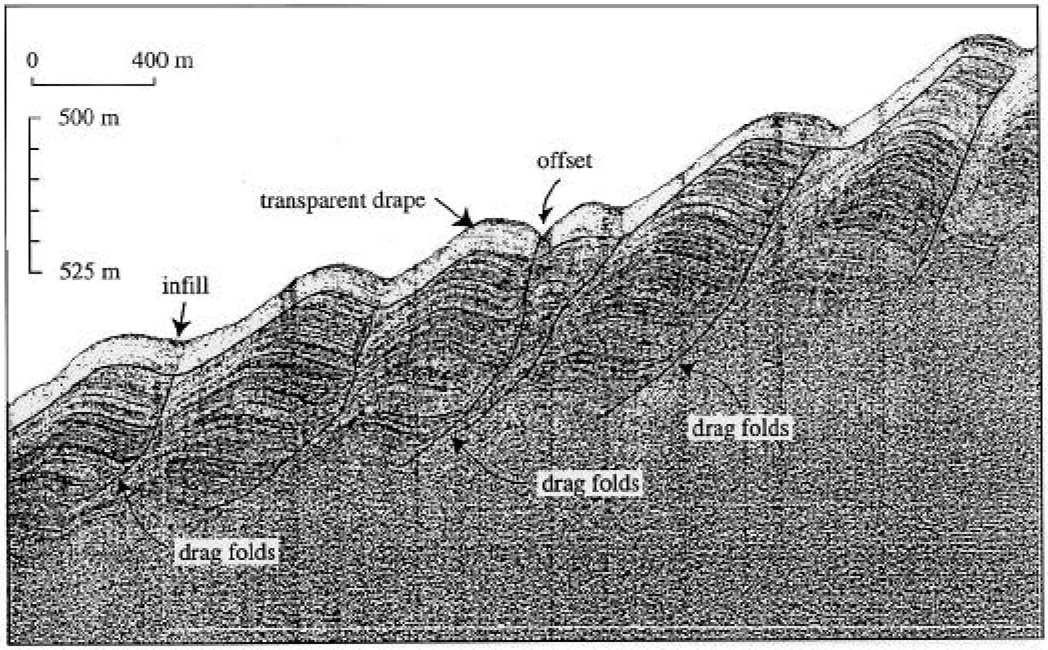


Figure 7.7: Segment of Huntec Line 145 located in main portion of slide illustrating rotation and deformation of slide block units (from Gardner et al. [1999, p. 332])

7.3.4 TOE OF THE SLIDE FEATURE

The seafloor morphology at the base of the slide is characterized by gently rolling folds with vertical variations on the order of 2 m or less (Figure 7.8). The axes of these folds are between 75 and 150 m apart, and their vertical extent decreases as you move offshore (Gardner et al., 1999)

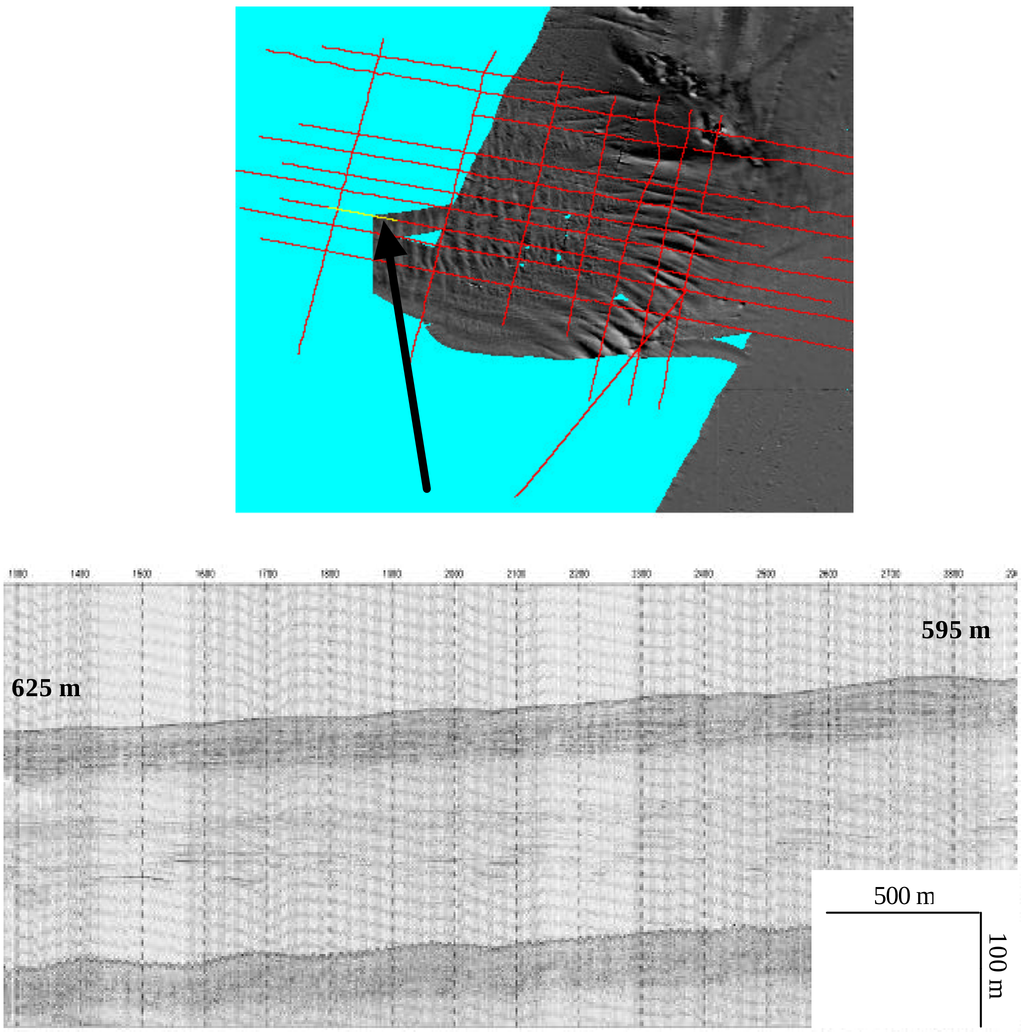


Figure 7.8: Seafloor morphology at the base of the slide exhibiting gently folded sediments.

7.4: The Formation of Surficial Morphology of Interest: Slump Failure or Antidunes?

7.4.1 DIFFERING GEOLOGIC INTERPRETATIONS

The undulating surficial morphology at the base of the Humboldt Slide, described as ridge and swale topography, has also been interpreted as bedform features. Examination of the bathymetry and seismic data led to two different hypotheses as to their formation: the features were formed either by bedforms that developed on the slope, or by large-scale slope failure (Gardner et al., 1996) (Figure 7.9).

As described earlier, the Humboldt Slide Zone has been interpreted in the past as a classic submarine landslide with retrogressive slide blocks (Field et al., 1980, Gardner et al., 1999). While many investigators have accepted that the origin of the morphology is the result of mass-wasting processes, there is a second school of thought that suggests that the formation of the block features are the result of a depositional regime capable of generating antidune bedform features (Gardner et al., 1996).

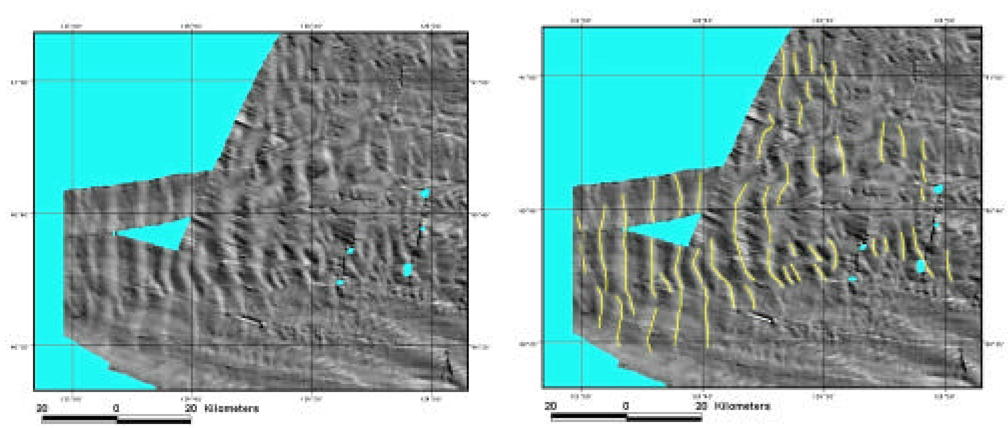


Figure 7.9: The region of interest at the base of slide: Slump failure or bedforms?

Recall that there are several geologic clues that can be used to identify slump failure activity. These include looking for evidence of dislocation and movement of sediments, the presence of beds that have undergone rotation and reorientation, the lack of internal deformation within the sedimentary package, and lastly, the existence of gently dipping shear surfaces along which failure could occur (Field et al., 1980). Many of these telltale signs exist in the sediments of the Humboldt Slide region. In the case of the Humboldt Slide feature, it is important to understand all of the geologic conditions at this site as any slump failure that may have occurred in this region would have been the result of a combination of forces as opposed to any single factor. The slump failure hypothesis is discussed in the following section.

7.4.2 SLUMP FAILURE HYPOTHESIS

Interpretation of the architecture and geometry of the Humboldt Slide Zone from multibeam and seismic data suggest that there were a combination of factors that lead to the formation of this feature. It is believed that an orderly sequence of events occurred in concert with one another as the region experienced sediment failure (Gardner et al., 1999). The main body of the Humboldt Slide is interpreted as having undergone extensional related shearing of the slope sequence followed by rotation and folding of the various blocks defined by shear planes (Figure 7.10 and Figure 7.11). This failure started in the middle of the slide and progressed both upslope (hence retrogressive) and downslope (progressive) simultaneously (Gardner et al., 1999). This explanation is based on the observation that the greatest displacement of blocks occurs in the middle of the feature, while those units both upslope and downslope experienced progressively less movement. The deformation experienced by the blocks in the main portion of the slide was a combination of downslope translation and shallow rotational movements. The relatively undisturbed nature of the sedimentary blocks suggests that the displacement and downslope movement along shear-planes was limited. As a result, sediments further downslope did not experience failure but underwent compressional deformation as they absorbed the translational forces occurring further upslope (Gardner et al., 1999).

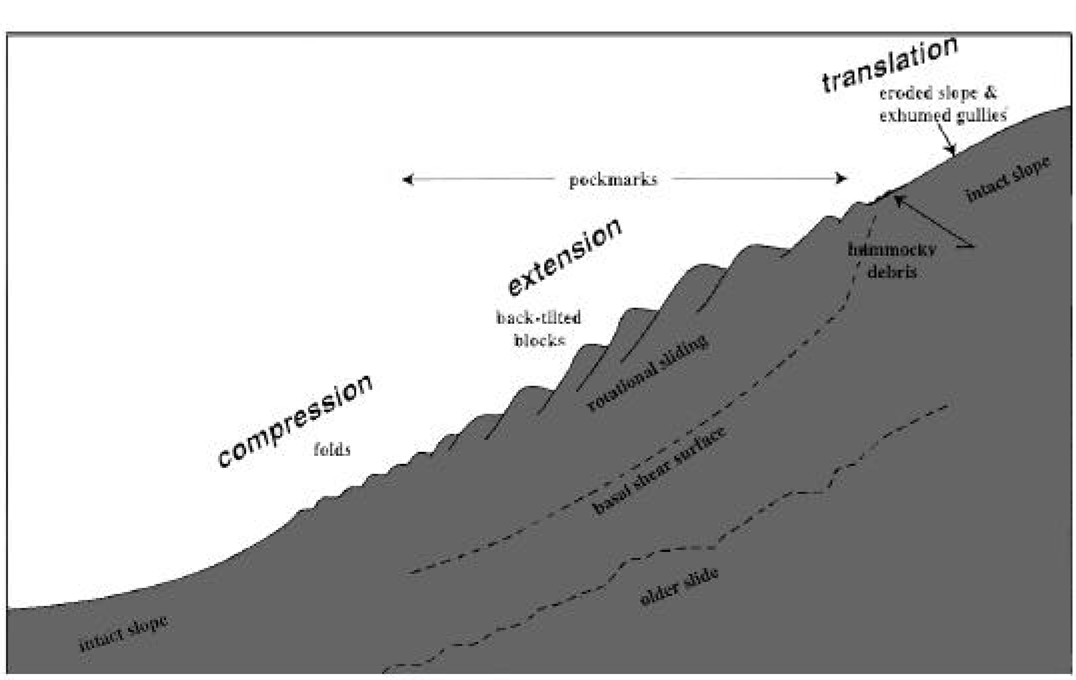


Figure 7.10: Diagram illustrating the different structural elements of the slide (from Gardner et al. [1999, p. 336]).

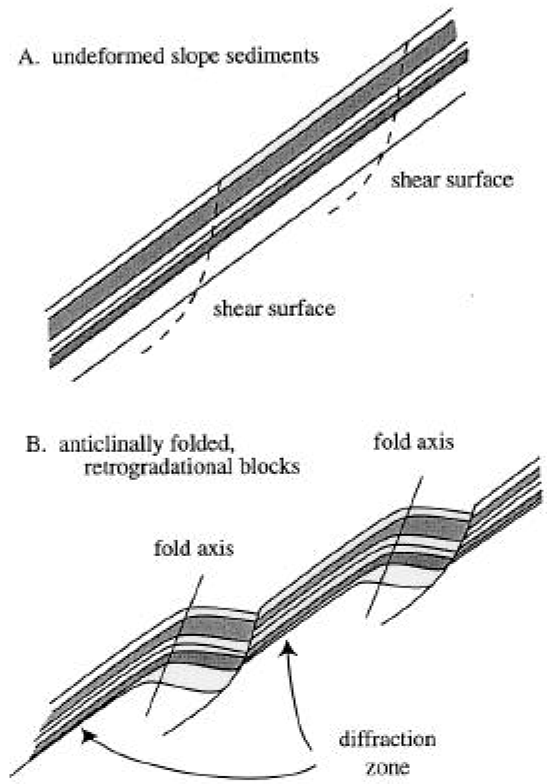


Figure 7.11: Diagram illustrating the nature of the deformation experienced by the slide blocks in the main portion of the Humboldt Slide (from Gardner et al. [1999, p. 336])

Some of the contributing factors that may have initiated a slump failure include: 1) local tectonic uplift and depression, 2) large sediment supply from Eel River, and its deposition on shelf and slope, 3) presence of subsurface gas and its effects on sedimentary strength, and 4) earthquake activities (Gardner et al., 1999). No one single factor can be considered more important than any other, but when considered in concert with one another, as outlined in the following paragraphs, they can produce a feasible scenario for the initiation of a slump failure event responsible for the formation of the Humboldt Slide Zone.

The Humboldt Slide is surrounded by areas that have been subjected to tectonic uplift caused by tectonic deformation due to plate interactions (Gardner et al., 1999). The northern portion of the Humboldt Slide is flanked by a plunging anticline that extends beneath the shelf sediments and follows a trend similar to that of the Little Salmon Fault. To the south, another area of tectonic uplift exists, and these two uplifted zones have worked together to cause a progressive oversteepening of the slope (Gardner et al., 1999). This change in slope over time will produce a gradual increase in the gravitational forces acting on the sedimentary sequences deposited on the slope.

The effects of tectonic uplift in the regions surrounding the Humboldt Slide created a local depression that became a favourable location for the deposition of large quantities of sediment being delivered to the margin by the Eel River. Only a small portion of this fluvial sedimentary material actually remains on the shelf; most of it is carried downslope and offshore. In regions where rapid sedimentation is occurring, greater pore pressures are generated because water does not have a chance to escape (Gardner et al. 1999). Because of these high pore pressures, these sediments will be poorly consolidated and more susceptible to failure.

This susceptibility to failure is further increased by subsurface gas content in the sediments of the Humboldt Slide. It is common to discover the presence of gas within sedimentary units that are rapidly deposited and derive from organic-rich terrigenous material. The presence of gas will affect pore-fluid pressures and the consolidation state of the sediments, thus increasing the sediment's susceptibility to failure (Gardner et al., 1999).

The last consideration that needs to be discussed with respect to the Humboldt Slide is the influence of seismic and earthquake activity in the region. Earthquakes and tremors can cause submarine landslides by initiating short-term catastrophic stresses that weaken sediment integrity. Given the number of earthquakes that have occurred in the vicinity of the Humboldt Slide, displayed in Figure 7.2, it is plausible that an earthquake could have been instrumental in initiating a sequence of events involving the previously mentioned factors that resulted in a slump failure in this region.

7.4.3 AN ALTERNATE HYPOTHESIS: ANTIDUNE BEDFORM FEATURES

As mentioned earlier, another interpretation of the multibeam and seismic data concludes that the stratified units at the base of the Humboldt feature are the result of a depositional regime that formed antidune bedform features. The stratified blocks that contribute to the undulating surface morphology visible in Figure 7.9, appear as elongated ridges that in some cases are undisrupted for 3 km or more, and extend continuously in a north-south direction. To some scientists, this somewhat regular and continuous surface morphology seemed more consistent with giant ripples or bedforms than what would result from catastrophic mass-wasting processes (Gardner et al., 1996). Such a sedimentary slump failure ought to produce a more chaotic and less laterally continuous surface morphology than what is observed in this region (Lee, 1999).

Furthermore, interpretations of the internal architecture derived from the seismic sub-bottom profile data differ from scientist to scientist. The bounding surfaces that separate these stratified blocks appear as shear planes to some, but are convex in nature rather than the usual listric shape associated with slump blocks (Gardner et al., 1996). Surface reflectors within these blocks dip in a shoreward direction, and are interpreted by some as forming topographic lows at the top of the blocks that are not being filled by sediment (Lee, 1999). Sedimentation rates in this area are relatively high due to the large fluvial sedimentary input from the Eel River. Given this high rate of sedimentary input, it is difficult to imagine that these regions would not be susceptible to sedimentary deposition. This lack of sedimentary infilling is indicative of either very recent slumping, or a depositional regime similar to that responsible for the formation of antidune bedforms, that would prevent sediment deposition in these topographic lows.

7.4.3.1 An Overview of Bedforms, Cross-Stratification and Antidunes

The shoreward dipping beds display similarities to the internal architecture that would be created by antidune bedforms, in which cross bedding stratification would be oriented in the upstream direction, and the antidunes themselves migrate upsection. The belief held by some scientists is that turbidity currents flowing off the shelf during major storms could create a depositional regime that would produce climbing bedforms and convex bounding surfaces. It is possible that such a depositional regime could generate a surface morphology and subsurface architecture similar to that observed at the base of the Humboldt feature (Lee, 1999).

In fluvial sedimentary environments, where there is unidirectional flow of water and entrained sedimentary material, the surface morphology of the bed is rarely flat, but rather is characterized by the development of ripples and other bedform features (Boggs, 1987). In most cases, the internal architecture of such bedform features consists of internal cross-laminae that dip in the downcurrent direction. Bedform features form when sediment is eroded and entrained from the stoss (upstream) side of the bedform, carried up to the crest, and then deposited on the lee (downstream) side of the bedform where it avalanches down the lee slope to form cross-laminations oriented in the downcurrent direction (Figure 7.12) (Boggs, 1987). However, under special circumstances consistent with upper-flow regimes (high flow velocity), the surface morphology of the bed develops into antidunes, which are low-undulating bedforms that migrate upstream and consist of cross-bedding oriented in the upstream direction (Figure 7.13) (Boggs, 1987). In the submarine environment, antidune cross-bedding geometry has been reported to have been preserved at the base of some turbidity flows (Boggs, 1987).

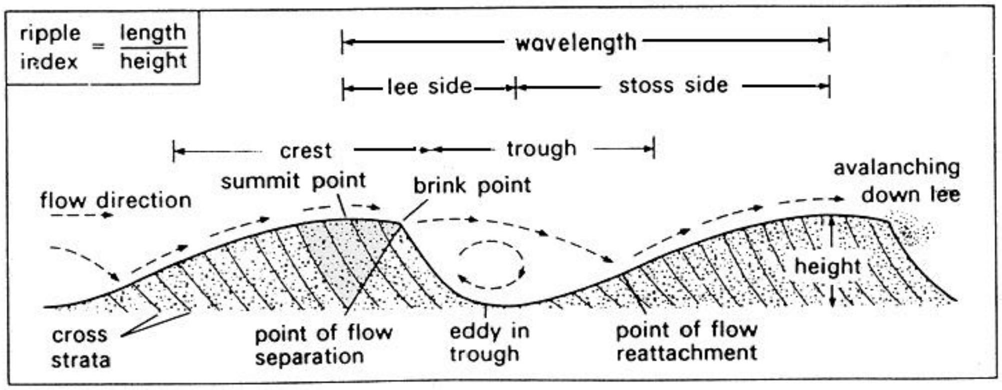


Figure 7.12: Formation of crossbedding in sedimentary ripples and sandwaves (from Boggs [1987, p.147]).

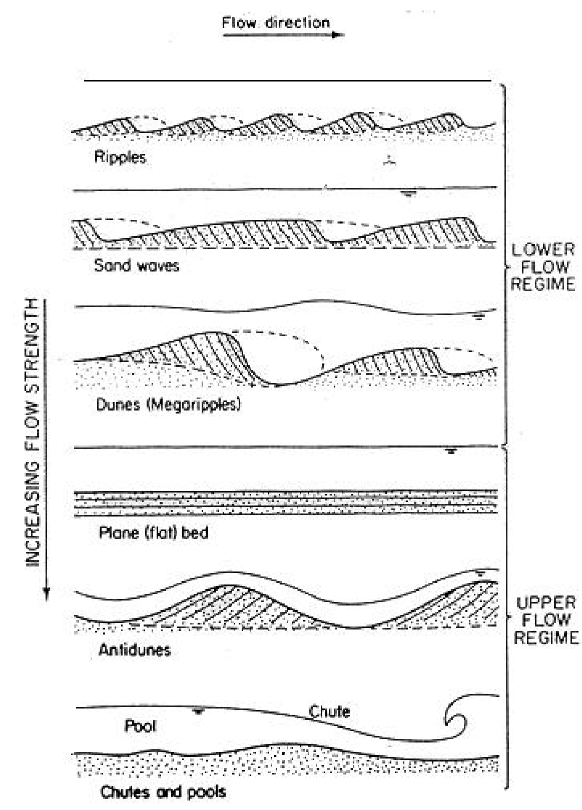


Figure 7.13: Cross-bedding orientation of bedform types antidunes (from Boggs [1987, p.146]).

It the case of the Humboldt Slide Zone, it has been suggested that during periods of elevated sea level, turbidity currents derived from the formation of a hyperpycnal plume could generate the stratified beds observed at the base of the amphitheatre formed by the Humboldt Slide Zone (Lee, 1999). The deposition of layered sedimentary units resulted from standing internal waves that formed at the base of the amphitheatre where the slope rapidly decreases (Lee, 1999). Sediment deposition occurs when hydrologic conditions change sufficiently to alter the conditions that once made it possible to sustain sediment entrainment and transportation (Boggs, 1987). This sudden change in slope could be sufficient to cause the turbidity current to enter a depositional phase in this region. Flume studies have shown that density currents undergo hydraulic jumps at major slope reduction areas, which results in the deposition of bedforms below the point where the slope change occurred (Lee, 1999). While the formation of bedform features at the base of a turbidity current has been documented (e.g., Boggs, 1997), the submarine conditions that would have to prevail in order to generate a turbidity current capable of generating antidune-like features are quite complex.

7.5: Reconstructing Paleo-Sedimentary Environments from Spatial Marine Data

By collecting a variety of spatial marine data and interpreting them collectively, geologists are attempting to reconstruct depositional and re-working events, based upon only the preserved depositional products of an earlier sedimentary environment. In short, scientists are attempting to find relationships among preserved sedimentary sequences on the northern California margin that lend insight into the depositional mechanisms and environments that existed previously, in order to develop an understanding of present-day continental margin formation. This is a formidable task, and requires the application of knowledge derived from many different aspects of sedimentary geology, not only from theoretical studies but also from field studies. Given the wide scope of geologic concepts that must be considered, it is inevitable that interpretations of a given geologic setting by various scientists are going to differ. This thesis attempted to facilitate the reconstruction of past depositional conditions by integrating various spatial marine datasets within the context of a GIS, in the hope that by doing so, we could resolve once and for all the mechanism by which the features at the base of the Humboldt Slide were formed.

7.5.1 OBSERVATIONS DERIVED FROM MARINE GIS: INTEGRATED SEISMIC AND MULTIBEAM DATA INTERPRETATION

When it comes to discussing the original mechanism of formation of the Humboldt Slide Zone, there is no dispute surrounding the interpretation that the amphitheatre geometry of the Humboldt Slide Zone was originally formed by a submarine landslide. Furthermore, there is a consensus that evidence supporting historic buried slumps in this region is indeed preserved within the geologic record. The geometries of the older episodes of failure are similar to that of the Humboldt Slide (Gardner et al., 1999).

There is a difference of opinion, however, with respect to the present-day surface morphology and sub-surface architecture that exists at the base of the Humboldt Slide Zone. While both arguments discussed above have their merits, observations derived from studying seismic and bathymetric data within the marine GIS , lead this author to support the interpretation that the features at the base of the Humboldt Slide Zone are the result of a slump failure that produced retrogradational extensional slide blocks, and compressional forces further downslope. Some of the reasoning behind this belief is outlined below.

7.5.1.1 Discussion of Surface Morphology of Multibeam Data

It was the undulating surface morphology, distinctly visible in sun-illuminated imagery, and its similarity to bedform features that initiated closer inspection of the Humboldt Slide and its formation. While it has been suggested that the seafloor morphology ought to be more chaotic and less laterally continuous than what is observed, the slump failure hypothesis does provide a plausible explanation for the continuous undulating surficial morphology observed.

The slump failure hypothesis indicates that the suficial morphology is not only a result of the surface irregularities caused by the rotated and translated slide blocks themselves, but also the result of compressional forces that deformed the sediments at the base of the slide into a series of gently rolling folds. Depending on the amount of compressional force experienced by the sediments at the base of the slide, it is plausible that ridge crests would form that would be uninterrupted and laterally continuous and not have nearly the chaotic nature expected of them. Further interpretation of the bathymetry data reveals no other observations that could help resolve these two hypothesis.

7.5.1.2 Discussion of the Subsurface Architecture from Seismic Data

The interpretation of the subsurface architecture of the seismic data is one of the more important aspects that can help distinguish between whether or not the features in question are the result of a mass wasting process or in fact represent a predominantly depositional feature. The geometry of the bedding planes within these units provides clues to whether they are antidune bedform features with cross-bedding oriented in the upslope direction, or whether in fact the units have undergone deformation as a result of rotation and downslope movement along shear planes caused by slump failure.

Although there is an element of similarity between the landward dipping internal reflectors seen in Figure 7.14, and the cross-bedding orientation of antidune bedform features in Figure 7.13, there does appear to be identifiable shear surfaces and fold axes along which these slide blocks could have been anticlinally folded. While a cursory glance at the internal reflectors may lead one to initially distinguish only landward dipping reflectors in these unit, closer inspection reveals that, while landward dipping reflectors are more predominant, shallow seaward dipping reflectors do exist. The presence of these shear planes, and the anticlinal folding experienced by the slide blocks that produced both land and seaward dipping reflectors, lend more credence to the slump hypothesis than does the outward similarity that the landward dipping reflector displays toward antidune-like features.

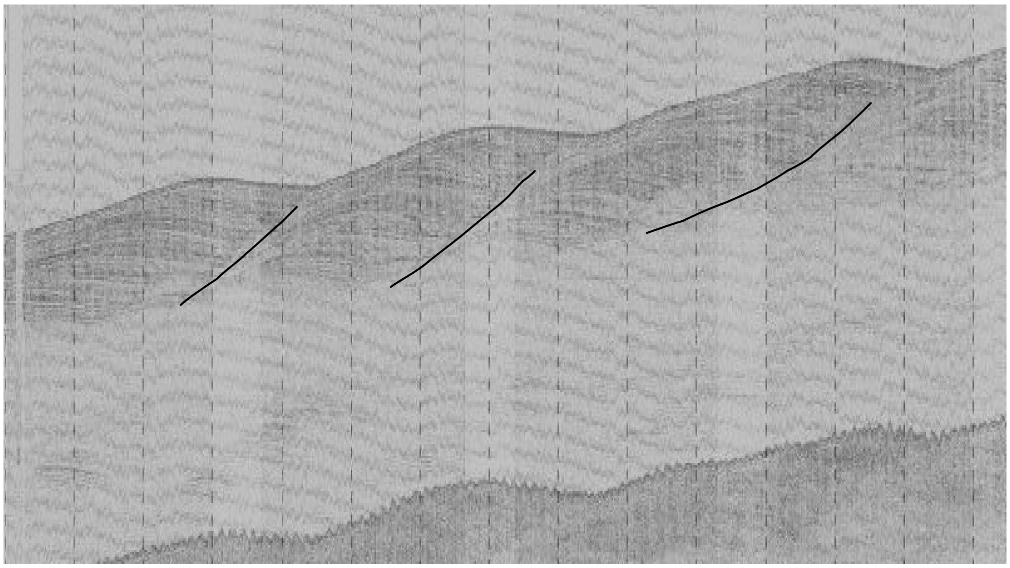


Figure 7.14: Internal sub-bottom architecture from middle portion of slide that contains surfaces interpreted as shear planes (lines).

The issue that these shear surfaces do not display the usual listric nature associated with slump failures is complicated by the fact that their geometry in the seismic profiles could be anomalous and a result of the acoustic diffraction artifacts, rather than a true representation of their shape (Lee, 1999). More work needs to be done to try and establish whether these are indeed shear surfaces, either by conducting an extensive core retrieval program, or by developing some synthetic seismic models to test the behaviour of acoustic signals at shear surface boundaries and to compare these models to what has been observed in the sub-bottom profile data from Eureka, California.

CHAPTER 8: CONCLUSIONS

8.1: Evaluation of Marine GIS for the Interpretation of Multibeam and Seismic Data

Even in the digital age, the printed map is still the most common form of presentation and storage of spatially referenced data. In the case of spatial marine data, the storage, display and processing of these datasets tends to be conducted using highly sophisticated and customized software packages that place severe limitations on potential users of the data. The solution is to organize this spatial marine data within a digital environment designed specifically to manage spatially referenced datasets, regardless of size. Such technology is available from GIS software.

For the STRATAFORM Project, a wide variety of spatial marine data was collected in order to further the scientific objectives of the project. This presented scientists with severe data management issues from the very beginning, given that principal investigators for this project are spread out all over North America. Collating marine data from this investigation into a marine GIS could alleviate some of these issues. Of particular focus for this thesis was the fusion of multibeam and seismic data into a marine GIS framework to allow for the simultaneous interpretation of these two inter-related datasets. This goal of integrated multibeam and seismic data was driven primarily by the fact that, even today, the most common form of presenting seismic data is the analogue paper chart. With the recent improvements experienced in both GIS and scientific visualization technology, it was time to explore the fusion of multibeam and seismic data within the digital realm.

While the original intent of integrating seismic and multibeam data into a marine GIS was to facilitate the interpretation of these datasets, it has become apparent that when dealing with the seismic data within the GIS, the capabilities for detailed seismic interpretation are rather limited. The ability to manipulate seismic data within the GIS in its current format, to aid in the extraction of seismic information, is inadequate when compared to capabilities of commercial seismic processing packages. While this hinders its use for comprehensive seismic interpretation, it does not preclude the use of the seismic data within the GIS to help scientists elucidate other relationships that could benefit from the fusion of sub-bottom profile data with other spatial marine data. In fact, the importance of having access to the digital seismic data within the context of other spatial marine data cannot be overstated. One of the underlying principles of GIS technology is that it is applied to data management issues in support of the decision making process.

This is of particular importance with regards to the organization and planning of subsequent investigations in the Eureka study area. A GIS project that is populated with a wide variety of spatially related data is a powerful tool that can be effectively used in the decision making process.

In the context of the Eureka Study area, very few sedimentary cores have been successfully recovered from the continental slope, particularly in the region of the Humboldt Slide. Without the comprehensive sedimentary physical property data available from long sedimentary cores, it is not possible to perform a rigorous quantitative slope stability analysis. Ideally, a comprehensive drilling program can be designed with the aid of the marine GIS, with critical cores being recovered from key locations as determined by examining the integrated multibeam and seismic data. Stratigraphic studies of these core may shed light on, or even unequivocally resolve, the dispute surrounding the formation of the undulating surface morphology at the base of the Humboldt Slide Zone.

This thesis has demonstrated a specific application of GIS technology and scientific visualization packages to multibeam and seismic sub-bottom profile data collected in support of the STRATAFORM Project. While not completely successful in establishing new geologic relationships that help advance our understanding of the formation of continental margin stratigraphy, the efforts behind this thesis have demonstrated that such use of integration and visualization technology, will, at a minimum, assist in the organization, storage and display of marine spatial data. Furthermore, it clearly will help facilitate the dissemination of scientific results and planning of subsequent investigations in the region.

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Appendix I: The Various SeisUNIX Programs Used

SEGYREAD - read an SEG-Y tape

```
    segyread > stdout tape=
or
SEG-Y data stream ... | segyread tape=-  > stdout

  Required parameter:
   tape=       input tape device or seg-y filename
  Optional parameters:
   buff=1      for buffered device (9-track reel tape drive)
               =0 possibly useful for 8mm EXABYTE drives
   verbose=0   silent operation
               =1 ; echo every 'vblock' traces
   vblock=50   echo every 'vblock' traces under verbose option
   hfile=header      file to store ebcdic block (as ASCII)

   bfile=binary      file to store binary block
   over=0            quit if bhed format not equal 1, 2, or 3
               = 1 ; override and attempt conversion
   conv=1            convert data to native format
               = 0 ; assume data is in native format
   ns=bh.hns   number of samples (use if bhed ns wrong)
   trmin=1           first trace to read
   trmax=INT_MAX     last trace to read
   endian=1    set =0 for little-endian machines(PC's,DEC,etc.)
   errmax=0    allowable number of consecutive tape IO errors

   For a SEG-Y diskfile use tape=filename.
   Remark: a SEG-Y file is not the same as an su file.
   A SEG-Y file consists of three parts: an ebcdic header,
   a binary reel header, and the traces.  The traces are
   (usually) in 32 bit IBM floating point format.  An SU file
   consists only of the trace portion written in the native
   binary floats.
```

SUWIND - window traces by key word

```
     suwind <stdin >stdout [options]

 Required Parameters:
       none

 Optional Parameters:
       verbose=0       =1 for verbose
       key=tracl       Key header word to window on (see segy.h)
       min=LONG_MIN    min value of key header word to pass
       max=LONG_MAX    max value of key header word to pass
       abs=0           =1 to take absolute value of key header word
       j=1             Pass every j-th trace ...
       s=0             ... based at s  (if ((key - s)%j) == 0)
       count=ULONG_MAX ... up to count traces
       reject=none     Skip traces with specified key values
       accept=none     Pass traces with specified key values(see
notes)
 Options for vertical windowing (time gating):
       tmin = 0.0              min time to pass
       tmax = (from header)    max time to pass
       itmin = 0               min time sample to pass
       itmax = (from header)   max time sample to pass
       nt = itmax-itmin+1      number of time samples to pass

 Notes:
       On large data sets, the count parameter should be set if
       possible.  Otherwise, every trace in the data set will be
       examined.  However, the count parameter overrides the accept
       parameter, so you can't specify count if you want true
       unconditional acceptance.
       The accept option is a bit strange--it does NOT mean accept
       ONLY the traces on the accept list!  It means accept these
       traces, even if they would otherwise be rejected (except as
       noted in the previous paragraph).  To implement accept-only,
       you can use the max=0 option (rejecting everything).  For
       example, to accept only the tracl values 4, 5 and 6:
                  | suwind max=0 accept=4,5,6 |
       On most 32 bit machines, LONG_MIN, LONG_MAX and ULONG_MAX
       are about -2E9,+2E9 and 4E9, they are defined in limits.h.
       Selecting times beyond the maximum in the data induces
       zero padding (up to SU_NFLTS) The time gating here is to the
       nearest neighboring sample or time value. Gating to the
       exact temporal value requires resampling if the selected
       times fall between samples on the trace. Use suresamp to
       perform the time gating in this case. It doesn't really make
       sense to specify both itmin and tmin,    but specifying
       itmin takes precedence over specifying tmin. Similarly,
       itmax takes precedence over tmax and tmax over nt.
```

SUSHIFT

“In the high resolution single channel seismic profiling the sample interval is short, the shot rate and the number of samples are high.To reduce the file size the delrt time is changed during a profiling trip. To process and display a seismic section a constant delrt is needed. The *sushift* program does this job.”

```
SUSHIFT - shifted/windowed traces in time

 sushift &lt;stdin &gt;stdout [tmin= ] [tmax= ]

 tmin ... min time to pass
 tmax ... max time to pass

 defaults for tmin and tmax are calculated from the first trace.
 verbose=1 : echos parameters to stdout

 Background :
 tmin and tmax must be given in seconds


 The SEG-Y header variable delrt (delay in ms) is a short integer.

 That's why in the example shown below delrt is rounded to 123 !
   ... | sushift tmin=0.1234 tmax=0.2234 | ...
```

SUGETHW - sugethw writes the values of the selected key words

```
  sugethw key=key1,... [output=] <infile [>outfile]

Required parameters:
key=key1,...           At least one key word.

Optional parameters:
output=ASCII     output written as ASCII for display
                 =binary for output as binary floats
                 =geom   ASCII output for geometry setting
verbose=0        quiet
                 =1 chatty

Output is written in the order of the keys on the command
line for each trace in the data set.

Example:
     sugethw < stdin key=sx,gx
writes sx, gx values as ASCII trace by trace to the terminal.
```

Appendix II: Unix Script Written to Generate Seismic Unix Postscript Files and Convert to TIFF images.

```
#!/bin/sh
####################################################################
###
# 2Channel TIF Script
#
#  Script Written to Generate SeisUNIX Wiggle Plots and convert
#
#  .ps to .tif files for viewing
#
#  Sean Galway -Ocean Mapping Group UNB    Dec 29, 1998
#
#  Revised
#
#  June 18,1999
#
####################################################################
###
#
#  $1  line_number ONLY
#  $2  channel
#  $3  hour/segment trace #
#  $4  pass every jth trace (Pass Every Trace in most cases)
#  $5  start time for Fast Dimension Axis
#  $6  end time for Fast Dimension Axis
#  $7  excursion scaling factor
#  $8  perc
#  $9  width of image (~# of traces/70) in inches **NEVER GO ABOVE
48"
echo ''


#  CALCULATION OF REQUIRED PARAMETERS FOR GENERATING PGM FILES
pixelwidth=`bc <<END
        scale=0
        ($9+2)*250
END`
rez_parameters='-g'$pixelwidth'x2750'

#THIS MAKES THE IMAGE FROM THE CHANNEL 1 HYDROPHONE

echo ''
echo 'Making Channel '$2' Postscript Image'
echo ''
echo 'Line '$1'   Ch '$2'     Hour/Trace Segment    ' $3 '    is
Being Processed'
echo 'Parameters are:    Start Time=   '$5'      End Time=   '$6'
j='$4
echo 'Excursion Factor of   '$7 '  Traces Clipped at the '$8'th
Percentile'
echo ''

supswigb < line$1.ch$2.$3.nodelay.su key=tracl nbpi=250 interp=1 \
        xbox=1.0 ybox=1.2 hbox=9.0 wbox=$9 \
```

```
        x1beg=$5 \
        x1end=$6 \
        grid2=dash \
        style=seismic \
        xcur=$7 \
        perc=$8 \


        title="North                                      \
        Line $1 - Channel $2 Hour/Trace Segment $3 - j=$4 – \
        xcur=$7  perc=$8                                South" \
        > Postscript.Files/line$1.ch$2.$3.ps
title='North  Line '$1' - Channel '$2' Hour/Trace Segment '$3' -
j='$4'      xcur='$7' perc='$8' South'
echo 'Created .ps File'
echo 'Resolution Parameters ' $rez_parameters
echo 'Ghostscript Conversion to .PGM Files Underway'
echo "quit" | gs -sDEVICE=pgmraw \
        -r250 \
        $rez_parameters \
        -sOutputFile=Postscript.Files/line$1.ch$2.$3.pgm.raw \
        -dNOPAUSE -q \
        Postscript.Files/line$1.ch$2.$3.ps
echo 'Ghostscript Conversion Finished!'
echo ''

#THIS MAKES THE IMAGE FROM THE CHANNEL 2 HYDROPHONE

#changing the parameters for the next channel
newCH=`bc <<END
      scale=0
      $2 + 1
END`
newEXC=`bc <<END
      scale=1
      $7*0.9
END`
echo ''
echo 'Making Channel '$newCH' Postscript Image'
echo ''
echo 'Line '$1'   Ch '$newCH'     Hour/Trace Segment    ' $3 '
is Being Processed'
echo 'Parameters are:    Start Time=   '$5'      End Time=   '$6'
j='$4
echo 'Excursion Factor of   0'$newEXC '  Traces Clipped at the
'$8'th      Percentile'

supswigb < line$1.ch$newCH.$3.nodelay.su key=tracl nbpi=250
interp=1 \
        xbox=1.0 ybox=1.2 hbox=9.0 wbox=$9 \
        x1beg=$5 \
        x1end=$6 \
        grid2=dash \
        style=seismic \
        xcur=$newEXC \
```

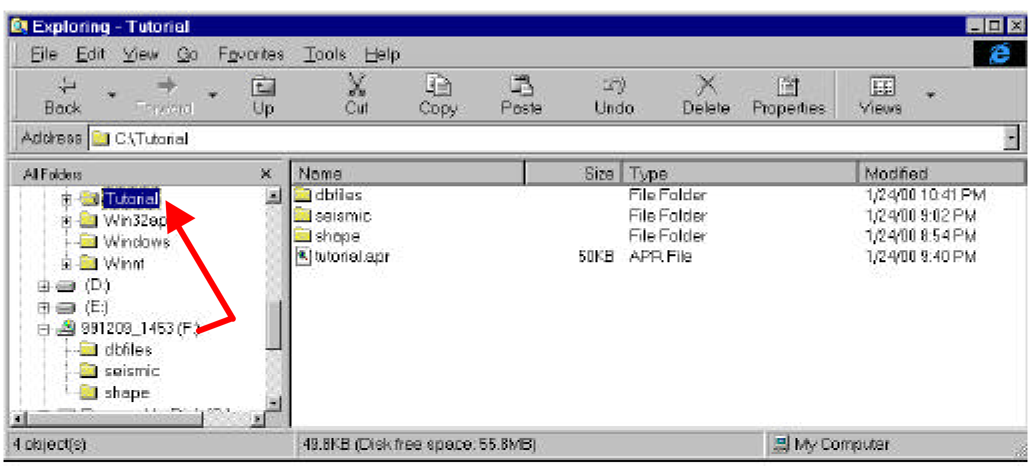
```
        perc=$8 \
        title="North                                       \
        Line $1 - Channel $newCH Hour/Trace Segment $3 - j=$4 -
        xcur=0$newEXC  perc=$8
South" \
        > Postscript.Files/line$1.ch$newCH.$3.ps
title='North  Line '$1' - Channel '$newCH' Hour/Trace Segment '$3'
-
      j='$4' - xcur=0'$newEXC' perc='$8' South'
echo 'Created .ps File'
echo 'Resolution Parameters '$rez_parameters
echo 'Ghostscript Conversion to .PGM (Portable Grey Map) Files
      Underway'

      echo "quit" | gs -sDEVICE=pgmraw \
        -r250 \
        $rez_parameters \
        -sOutputFile=Postscript.Files/line$1.ch$newCH.$3.pgm.raw \
        -dNOPAUSE -q \
        Postscript.Files/line$1.ch$newCH.$3.ps
echo 'Ghostscript Conversion Finished!'
echo ''
echo ''

#Merge the Two Image files one atop the other using pnmcat Program
echo 'Merging the Two Files: Ch '$2' and Ch ' $newCH
pnmcat -white -topbottom -jleft
Postscript.Files/line$1.ch$2.$3.pgm.raw
Postscript.Files/line$1.ch$newCH.$3.pgm.raw >
Postscript.Files/line$1.both.$3.pgm.raw
echo 'Done!'

echo''
echo 'PNMTOTIFF Conversion Underway (.PGM to .TIF)'

pnmtotiff Postscript.Files/line$1.both.$3.pgm.raw >
../TIFimages.ftp/$1x$3.tif

#rm Postscript.Files/line$1.ch$2.$3.p*
#rm Postscript.Files/line$1.ch$newCH.$3.p*
#rm Postscript.Files/line$1.both.$3.p*
echo ''
echo 'Image Generation Complete! '
echo ''
echo 'You Must EXTRACT NAVIGATION Data for Segment '$3' - USE
NAV.COORD.SCRIPT'
```

Appendix III: Tutorial for the Setup of the ArcView GIS Seismic CD-ROM for the Eureka STRATAFORM Study Area

In order to use the seismic CD-ROM project generated as a part of this thesis, you will be required to already own an installed copy of ArcView GIS (Version 3.1, preferred). Although most of the project on the CD-ROM is already configured for your use, because some of the functions are machine dependent, there is a little work that must be done in order to allow ArcView to access the seismic images.

Step 1:

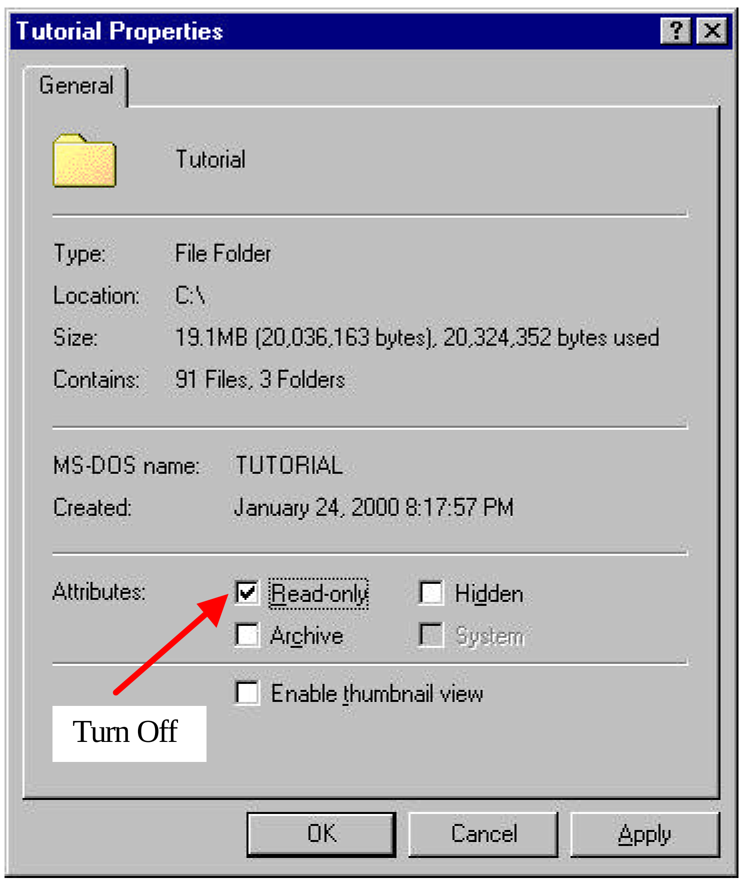
Make a directory on your computer that will be dedicated to the ArcView Seismic Project. There are many subfolders that must be copied to this directory from the CD-ROM. Name this directory anything of your choice or call it **c:/tutorial**.



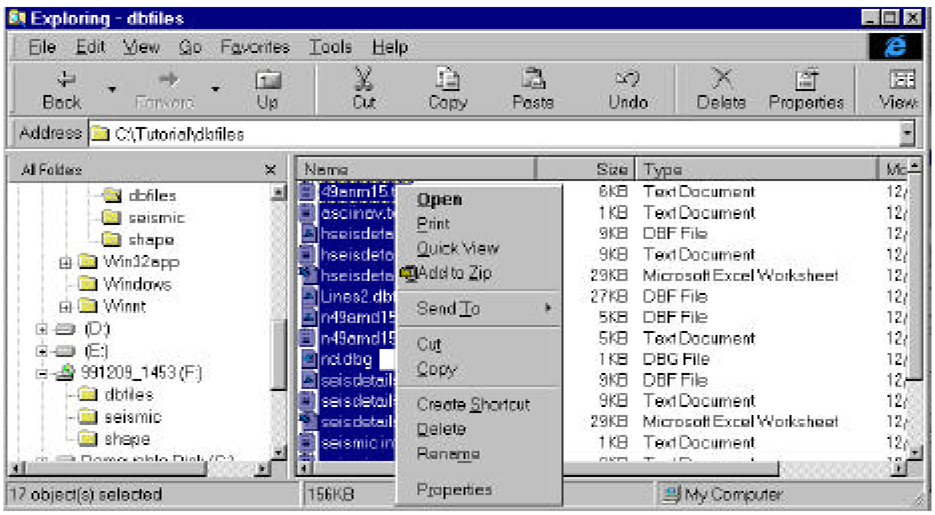
Step 2:

Copy the file and directory structure directly from the CD-ROM into this new "**c:\Tutorial**" directory. Because the source medium is a CD-ROM, everything on this CD-ROM will be **Read-Only** and therefore we must change this status before moving any further.

To alter the **Read-Only** status, highlight the newly copied directories and open up the properties window with the right mouse buttom and turn off the **Read-Only** Toggle

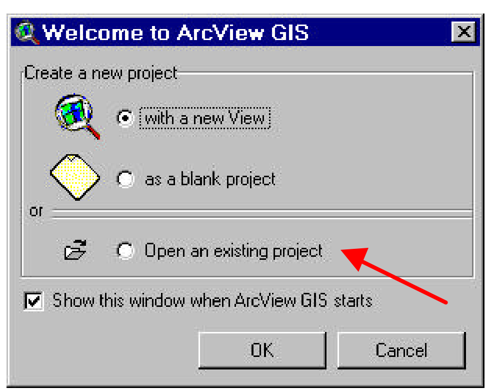


Unfortunately, this only changes the status of the folders not the files located in the folders. In order to alter the status of all files, you must navigate into the appropriate folder, select all the files using CTRL-A or highlighting them with the mouse, and click the right mouse button to access the properties window and turn off the **Read-only** and **Archive** button in the same manner as you did earlier. Do this for all folders.

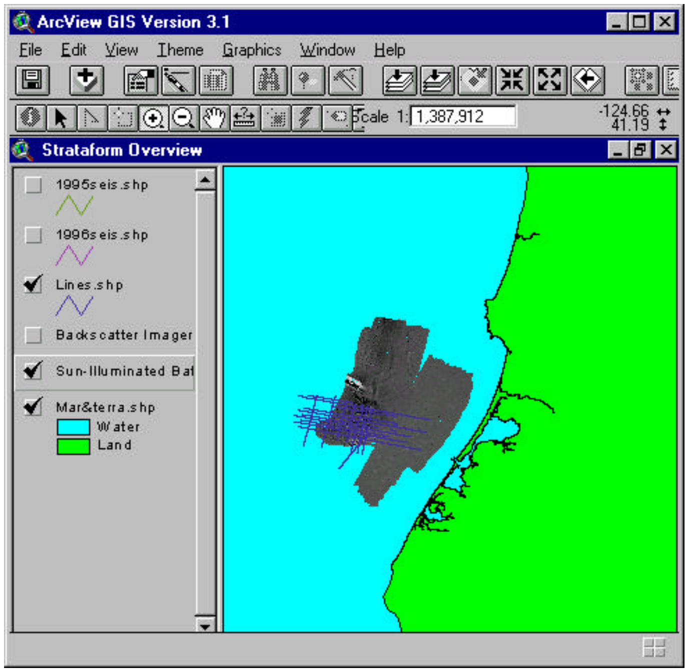


Step 3:

Start ArcView and Open the Existing Project called **tutorial.apr** the tutorial directory.

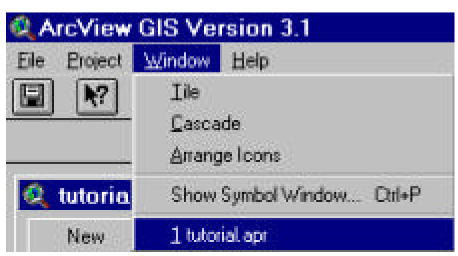


You now should have a window that looks something like the following.

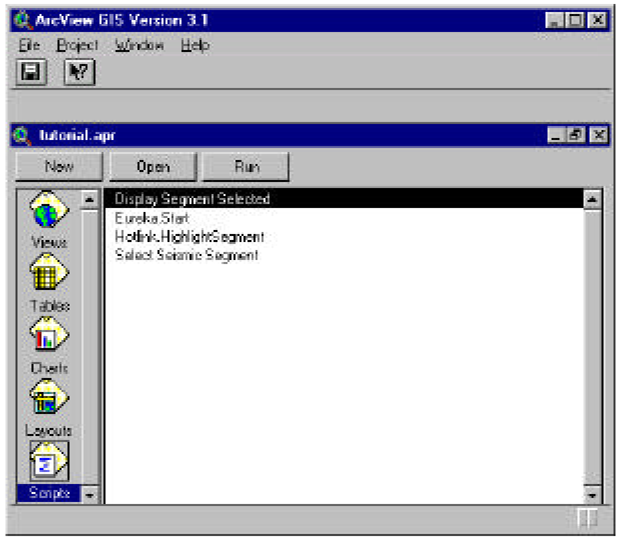


Step 4:

In order to view the seismic images, we need to modify the Avenue Scripts that control the seismic viewing tools to conform to your specific machine. Click on the **Windows** option on the file menu and select the **tutorial.apr** listing.



This opens up the Project Window where we can alter the Scripts by selecting the Script Button and opening the Avenue Script called **Display Segment Selected.**



Display Segment Selected Script:

```
 SeismicTable = av.GetProject.FindDoc("Seismic Line
Information").GetVtab

 for each record in SeismicTable.GetSelection
   Field1 = SeismicTable.findfield("Line Number")
   entry1 = SeismicTable.ReturnValueString(Field1, record)
   Field2 = SeismicTable.findfield("Trace Segment")
   entry2 = SeismicTable.ReturnValueString(Field2, record)
   Field3 = SeismicTable.findfield("Orientation")
   entry3 = SeismicTable.ReturnValueString(Field3, record)
   Field4 = SeismicTable.findfield("Profiles")
   Openfile = SeismicTable.ReturnValueString(Field4, record)

  LineParameters ="Line:" ++entry1 +TAB+" Trace Numbers:" ++entry2

 acceptflag = msgbox.yesno( "Display the Wiggle Plot
of:"+NL+NL+LineParameters +NL+"Orientation:"++entry3,"Loading
Seismic Profile", True)

   if (acceptflag) then
     if (File.Exists(Openfile.AsFileName)) then
      System.Execute("C:\Windows\kodakimg.exe" ++Openfile)
     else
       System.Beep
     MsgBox.Warning("Warning:"  +NL+Openfile+NL+  "   does not
open. Check Filename and Location.","Hot Link Warning Message")
     end
   else
   av.Run("View.ClearSelect", Self)
   end
 end
```

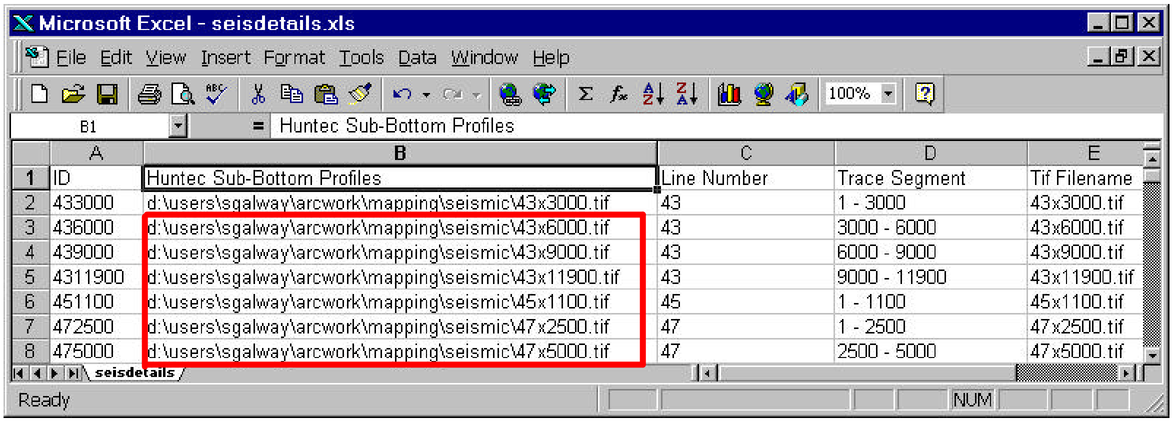
We must change the path of the **System.Execute**(red arrow) command line to correspond to the application you are going to use to view the seismic images. On most Windows 95/98 systems, **Kodak Imaging** is sufficient.

Once you have changed the **System.Execute** line to correspond to the appropriate application, you must compile the **Display Segment Selected** script by clicking the check mark symbol from the Script Window ToolBars

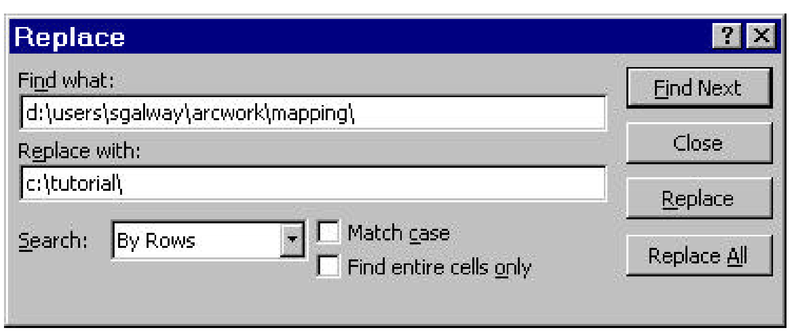
Step 5:

The next step involves changing the entries of the **Seismic Line Information** Table which essentially is a lookup table that provides the metadata and file locations for the various seismic images. Return to the Project Window by using the drop-down menu (Window/tutorial.apr), and select the Tables option. Open the table called **Seismic Line Information**, and from the **Table** drop-down menu, select the **Remove All Joins Option**. Open the **Table/Properties** option, and make sure all **Fields** have a check mark in the **Visible** box. It is important to display all the fields of this table in order to be able to join related tables/datasets together at a time (we will do this in just a few moments).

Open up an Excel spreadsheet, and locate the **seisdetails.xls** file in the **c:\Tutorial\dbfiles**"seisdetail.xls".



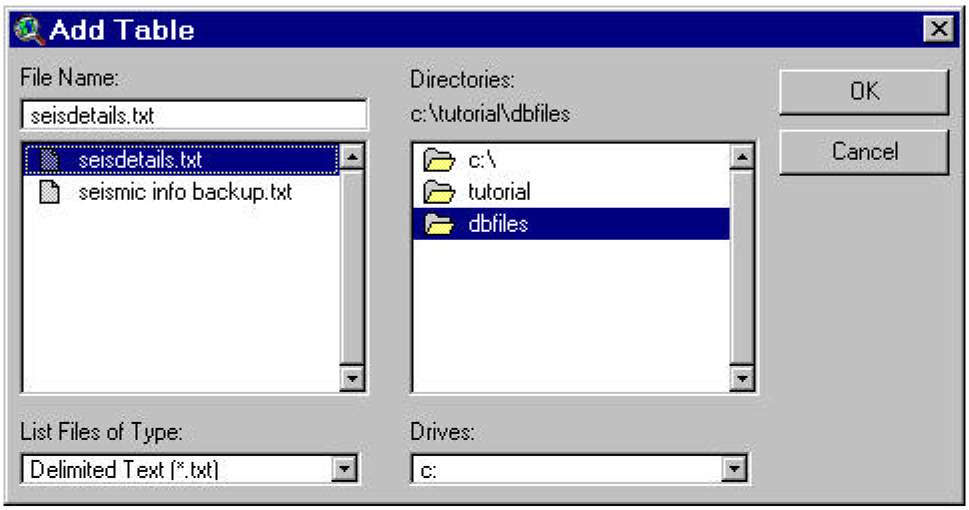
We have to change the location pointers for the different seismic images to correspond to your particular setup. Since you have maintained a similar directory structure, all we have to do is replace the **d:\users\sgalway\arcwork\mapping** pointer, with the appropriate directory path that points to the **seismic directory** you copied from the CD-ROM (**c:\tutorial**). Highlight all of Column B (**Huntec Sub-Bottom Profiles)** and select the **Edit/Replace** (CTRL-H) option from the drop-down window.



Once you have updated the file location for all the records, save the file as an Excel spreadsheet in case you need to use it later. Making a second copy of the seisdetail spreadsheet but save it as a Text File (*.txt). It is this text file that we are going to import into ArcView. Close Excel.

Step 6:

Return to the ArcView Project Window Dialog box. Makes sure you are located in the Tables portion of the project. Select the **Add** table button, and locate the **seisdetails.txt** file in your **c:\Tutorial\dbfiles** directory.



Once you have added the text file, you must quickly export it out of ArcView as a *.dbf file. Arcview can read DBASE, INFO, and TEXT. However, the DBF files that are written by MS Excel do not get properly translated, hence, use a text file option, and export/import a *.dbf file from ArcView. To export the **seisdetail.txt** table, open it and then select the **File/Export** option from the drop-down menu. Indicate the source directory and make sure you convert the *.txt file to a *.dbf file. Follow the **Add Table** steps outlined above to import the new **seisdetails.dbf** file into your ArcView project.

We are now ready to join the **Seismic Trackline Navigation** data to the metadata located in the **seisdetails.dbf** file.

Step 7:

Open the **seisdetails.dbf** files (**Project Window/Tables/seisdetails.dbf)** and highlight the column labelled as ID. In another window, open the **Seismic Line Information** table, and highlight the **Integer1/ID Column.** These columns contain a series of numbers that are unique ID numbers corresponding to a specific seismic navigation segment. Both the seismic trackline navigation table and the seismic metadata information table contain the same numbers, and it is this ID field that we are going to use to "join" these related datasets together.

Make sure the **Seismic Line Information** Table is the active table (place the cursor in the blue title bar and click to ensure this is the active window), and select the **Table/Join** option from the drop-down menu (CTRL-J or the Join hotkey will do the same thing)**.**

These two tables should now appear as one.

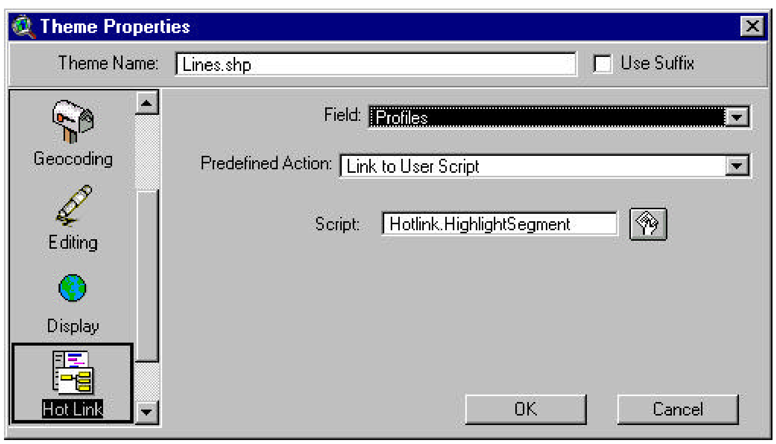
Now that these tables are joined, we have to update the column header labels by selected **Table/Properties** from the drop down menu, and filling in the **Alias** field to provide more appropriate names for these fields.

Original Field Name	New Field Name (alias)
Shape	no change needed
orientatio~	Orientation

interger1~	ID
id~	ID
Huntec-sub~	Profiles * **N.B> This field must be called Profiles**
Line_numbe~	Line Number
Trace_segm~	Trace Segment
Tif_filena~	TIF Filename

Step 8:

The final step is to configure the ArcView project to know that the Seismic Trackline data is connected/hotlinked to external TIF Images. Return to the main Viewing Window and select the **Theme/Properties** option from the drop-down window menus. The following window should appear. Makes sure everything is exactly as illustrated below.



Once all these steps are completed, you are ready to view seismic images from within the GIS project. Simply make the **Seislines (lines.shp)** theme active, choose the hotlinking tool from the menu bar (**lightning bolt**), and place the cursor overtop of the seismic segment you want to view. Enjoy!

Vita

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