CRUISE REPORT

RV *OCEAN SURVEYOR* CRUISE O-1-00-GM

THE BATHYMETRY AND ACOUSTIC BACKSCATTER OF THE PINNACLES AREA, NORTHERN GULF OF MEXICO

May 23, through June 10, 2000

Venice, LA to Venice, LA

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The Bathymetry of The Pinnacles Area, Gulf of Mexico

BACKGROUND:

An extensive deep (~100 m) reef tract occurs on the Mississippi-Alabama outer continental shelf (OCS). The tract, known as "The Pinnacles", is apparently part of a sequence of drowned reef complexes along the "40-fathom" shelf edge of the northern Gulf of Mexico (Ludwick and Walton, 1957). It is critical to determine the accurate geomorphology of deep-reefs because of their importance as benthic habitats for fisheries. The Pinnacles were mapped by Ludwick and Walton (1957) using a single-beam echo sounder but the spatial extent and morphology were interpreted from a series of widely separated, poorly navigated bathymetric profiles. Other recent studies, supported by Minerals Management Service (MMS), used towed sidescan sonars and single-channel seismic-reflection profiling. None of the existing studies provide the quality of geomorphic data necessary for reasonable habitat studies.

The fish faunas of shallow hermatypic reefs have been well studied, but those of deep ahermatypic reefs have relatively ignored. The ecology of deep ahermatypic reefs is fundamentally different from hermatipic reefs because autochthonous intracellular symbiotic zooxanthellae (the carbon source for hermatypic corals) do not form the base of the trophic web. Instead, exogenous plankton, transported to the reef by currents, serves as the primary carbon source. Deep OCS reefs also lie below the practical working depths for SCUBA; consequently, remote investigations from a ship or *in situ* investigations using submersibles or ROVs are required.

Community structure and trophodynamics of demersal fishes of the Pinnacles are presently the focus of USGS reseach. A goal of the research is to answer questions concerning the relataive roles played by geomorphology and surficial geology in the interaction with and control of biological differentiation. OCS reefs are important because we now know that such areas are important coral reef fish havens, key spawning sites, and a critical early larval and juvenile habitats for economically important sport/food fishes. Also, deep-reef ecosystems as well as the fish populations they sustain are impacted by intensive oil-field development. It is now known that deep OCS reefs function as a key source of re-population (via seasonal and ontogenetic migration) of already heavily impacted inshore reefs. A reflection of this realization is the recent closure by the Gulf States Fisheries Management Council of a 600 mi^2 area of the Florida Middle Grounds (another unmapped major "40-fathom" OCS reef complex) to commercial fishing to preserve grouper spawning aggregations.

It is known that the Pinnacles reefs support a lush fauna of ahermatypic hard corals, soft corals, black corals, sessile crinoids and sponges - together forming a living habitat for a well-developed fish fauna. The fish fauna comprises typical Caribbean reef fishes and Carolinian shelf fishes, plus epipelagic fishes, and a few deep-sea fishes. The base of the megafaunal invertebrate food web is plankton, borne by essentially continuous semi-laminar currents flowing predominantly out of the SW, up, along and across the shelf edge. These currents are intercepted by pinnacles reefs, which lie roughly in two linear tracts, parallel to the coastline (Fig. 1). USGS research initiated in 1997 (Sulak et al., in progress) has demonstrated that the Pinnacles reef fish fauna is dominated by planktivorous fishes. Ongoing food habits, trophic web and stable isotope analyses by the USGS are reinforcing a basic picture of deep OCS reefs as ecosystems based on exogenous current-borne plankton. Long-term current meter deployments have demonstrated that the >3 m, <16m relief of the Pinnacles reefs disrupts the prevailing currents, inducing local complexity (F. Kelly, Texas A&M Univ., pers. comm.) favorable to plankton and planktivores. Geodetically accurate bathymetry maps, coregistered with calibrated acoustic backscatter maps, are critical to delineate benthic biotopes, and are essential to correlate biological community differentiation with the physical environment. Previous mapping of the Pinnacles area using the TAMU[2] towed single-beam sidescan system (Anonymous., 1999) employed technology with inherent deficiencies in backscatter calibration, bathymetric precision, and geo-referencing. The resulting bathymetric interpretations of TAMU^2 data are further degraded by ship-track-parallel artifacts that obliterate geomorphology rendering them inadequate to provide high-resolution mapping of individual target reefs (typical maximum relief 15 m, diameter 200-500 m). The sidescan-sonar surveys of the area (Laswell et al., 1990) suffer many of the same deficiencies as the TAMU^2 data so they add no quantitative and little qualitative information about the geomorphology and surficial geology.

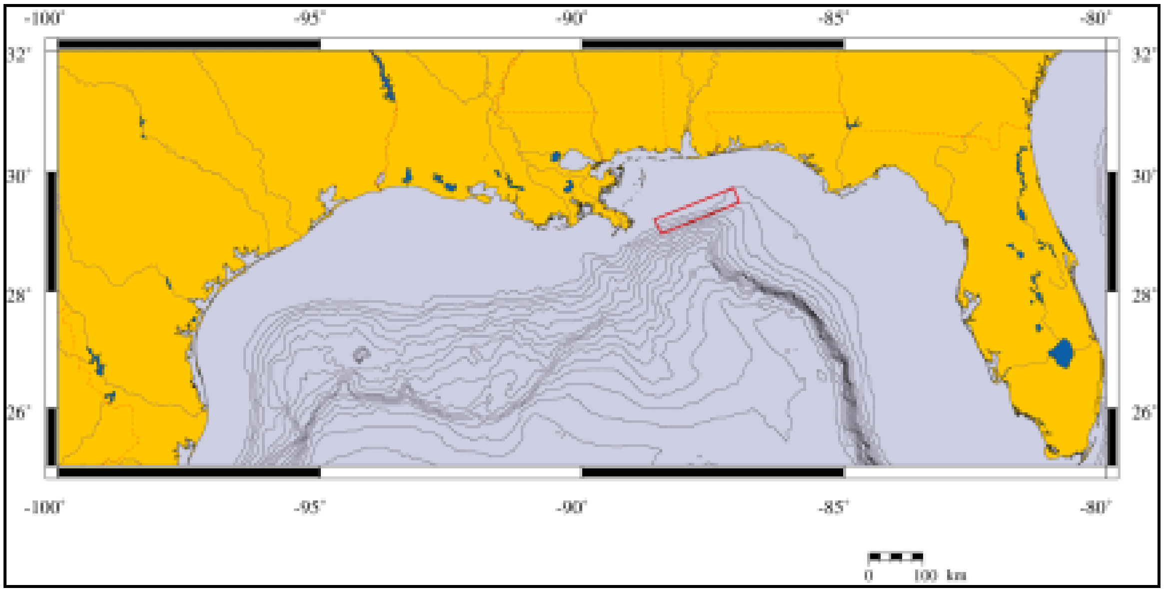

Figure 1. Location map of The Pinnacles area (red rectangle).

Objective:

Our objective was to map as large an area of the outer shelf deep reefs off Alabama-Mississippi as the project budget allowed using a state-of-the-art multibeam mapping system. The cruise used a Kongsberg Simrad EM1002, the latest generation of high-resolution multibeam mapping systems (HRMBS). The EM1002 produces both accurate georeferenced bathymetry and coregistered, calibrated, acoustic backscatter. These data should prove extremely useful in relating dominant species groups (which display highly specific biotope affinities) to the geomorphology (*e.g.*, reef flattop, forereef crest, reef wall, reef base, circumreef talus zone, circum-reef, high-reflectivity sediment apron). The mapping is the first phase of a two-phase study of the Pinnacles area. The second year of this study (FY01) will concentrate on measuring the currents in and around the reefs as well as continued census of the fish populations.

The Kongsberg Simrad EM1002 High-Resolution Multibeam Mapping System

There are several different brands of high-resolution multibeam mapping systems that are appropriate for shallow-water surveys. After a review of the currently available systems, we chose to use for this cruise the Kongsberg Simrad EM1002 system because; (1) it is the latest generation of high-resolution multibeams with a frequency compatible with the depths we were interested in, (2) it is based on the highly successful EM1000 system, (3) it has the ability to map large areas at high speed without compromising data quality and, most importantly, (4) it has the ability to simultaneously produce high-resolution, calibrated backscatter imagery. For the Pinnacles survey, we used an EM1002 system owned and operated by C&C Technologies, Inc. (Lafayette, LA) installed aboard the 108-ft *Ocean Surveyor* (Fig. 2).

An overview of high-resolution multibeam mapping systems can be found in Hughes-Clarke, et al. (1996). The Simrad EM1002 system operates at frequencies of 98 kHz (inner ±50˚ swath centered at nadir) and 93 kHz (the outer ±20˚) from a semi-circular transducer (Fig. 3) mounted on a rigidly attached ram running through a moon pool in the ship (Fig. 4). The system was designed to operate in several modes through a range of depths from 5 to approximately 800-m. The shallow (ultrawide) mode, used to maximum depths of about 200 m, forms 111 receive beams with a spacing of 2° distributed across

Figure 2. The RV *Ocean Surveyor*.

track and 2° wide along track. The beam geometry generates a 150° swath that can cover as much as 7.4 times the water depth. The other two modes, wide mode, and deep mode, are for depths of greater than 200 m and were not used for the Pinnacles mapping. There are options within each mode for beam distribution (equiangular or equidistant) and pulse lengths (0.2, 0.7, and 2 ms). The specific options used for the Pinnacles survey are discussed in the data processing section below.

Most conventional vertical-incidence echo sounders determine the time of arrival of the returned pulse (and thus the depth) by detecting the position of the sharp leading edge of the returned echo, a technique called *amplitude detection.* In multibeam sonars, where the angle of incidence increases for each consecutive receive beam to either side of the vertical, a returned echo loses its sharp leading edge and the accurate depth determination becomes inaccurate. To address this problem, the EM1002 multibeam system uses an interferometric principle in which each beam is split, through electronic beamforming, into “half beams” and their phase difference is calculated to provide a measure of the angle of arrival of the echo. The point at which the phase is zero (i.e., where the wavefront of the returned echo is normal to the receive-beam bore) is determined for each beam and provides an accurate measure of the range to the seafloor. Both amplitude and phase detection are recorded for each beam and then the system software picks the “best” detection method for each beam, based on a number of quality –control measurements, and uses this method to calculate depth.

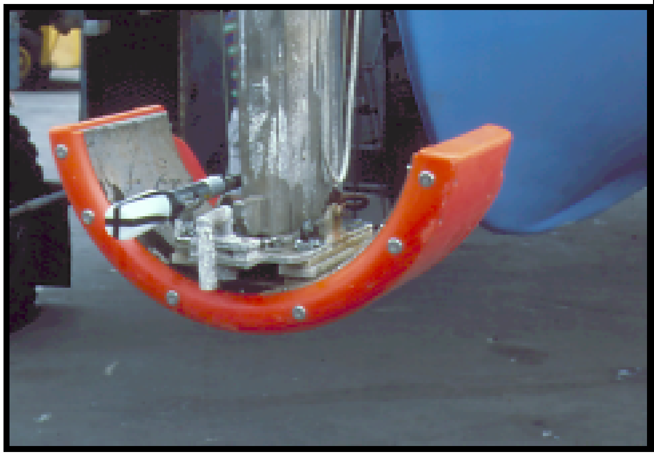

Figure 3. Kongsberg Simrad EM1002 transducer

Figure 4. Standpipe of EM1002.

The EM1002 also provides quantitative seafloor-backscatter data that can be displayed in a sidescan-sonar-like image (see Maps section below). The backscatter images can be used to gain insight into the spatial distribution of seafloor properties. A time series of echo amplitudes from each beam is recorded at 0.2- to 2.0-ms sampling rate, depending on the water depth. The echo amplitudes are sampled at a much faster rate than the beam spacing and can be processed from beam-to-beam to produce a backscatter image with the theoretical resolution of the sampling interval (15 cm at 0.2 ms). The amplitude information can be placed in its geometrically correct position relative to the across-track profile because the angular direction of each range sample is known. The EM1002 software corrects the amplitude time series for gain changes, propagation losses, predicted beam patterns and for the insonified area (with the simplifying assumptions of a flat seafloor and Lambertian scattering). Subsequent processing (see Processing section below) uses real seafloor slopes and applies empirically derived beam-pattern corrections to produce a quantitative estimate of seafloor backscatter across the swath.

Ancillary Systems

In addition to the multibeam sonar array, a multibeam mapping survey requires a careful integration of a number of ancillary systems. These include: (1) a differentially corrected Global Positioning System (DGPS); (2) an accurate measure the heave, pitch, roll, and heading of the vessel, all to better than 0.01° and the transformation these measurements to estimates of the motion of the transducer at the times of transmission and reception (motion sensor); (3) a method to precisely determine the sound-speed structure of the water column, using measurements of temperature, salinity and depth with one, or a combination of, an CTD, XSV, and XBT, and the calculation of sound velocity profiles [SVP].

The Pinnacles survey was navigated with inertial positioning (INS) provided by a TSS Applied Analytic POS/MV model 320 inertial motion sensor (IMU) as well as dual Trimble model 4000 DGPS with a commercial SkyFix satellite differential station. Spatial accuracy (positions) for the mapping are ±0.5 m. In addition, the POS/MV records vehicle motion (pitch, roll, yaw, and heave) at 100 Hz with an accuracy of 0.02° for roll, pitch, and yaw, and 5% of heave amplitude or 5 cm. An additional IMU , a TSS DMS-05, was used to compare the pitch, roll, heave, and heading with the POS/MV.

Sound-velocity profiles were calculated several times each day so that ray-tracing techniques could be used to determine the effect of acoustic refraction in the water. A SeaBird model 19-02 CTD was deployed the first day of operations to get a good reference SVP. Sippican T-7 expendable bathythermographs (0 to 600-m water depth) were routinely collected anytime it was suspected that the water structure had changed during the course of the survey. Sippican expendable sound velocimeters were used as backups to the XBTs. An additional sound-velocity sensor is installed on the *Ocean Surveyor* to determine the speed of sound in water directly at the transducer. This sensor requires seawater to be pumped from an intake at the transducer up through a sound-velocity sensor in the engine room. All the SVP data are fed directly into the Simrad EM1002 processor for instantaneous beamforming and raytracing of the individual beams.

Data Sources and Type

Raw EM1002 data telegrams were acquired over a shipboard Ethernet network. The data stream is shown in Table 1. In addition, a number of ancillary data sources were also acquired by C&C Technologies (Table 2).

Table 1. Kongsberg Simrad EM1002 data stream.

- entered static sonar alignment parameters.
- applied sound velocity profiles.
- external navigation data (1-Hz DGPS)
- ship-relative bathymetric profile data.
- beam-relative backscatter intensity data

Table 2. Ancillary data sources

- transducer temperature, conductivity and (derived) sound speed data.
- POS/MV 1-Hz position and attitude data (over Ethernet).
- independent serial record of DGPS data stream (GPGGA format).
- digital 21-Hz attitude from TSS-335B.
- original SeaBird SVP data

Mounting Alignment Values:

The accurate reduction of swath bathymetric data critically depends on a proper knowledge of the geometry and relative positions of the sonar transducer with to the motion sensor, the ship, and the positioning-system antennae (Fig. 5). C&C Technologies, using standard surveying techniques, measured these values before the survey began (Table 3). All values are measured relative to the transducer.

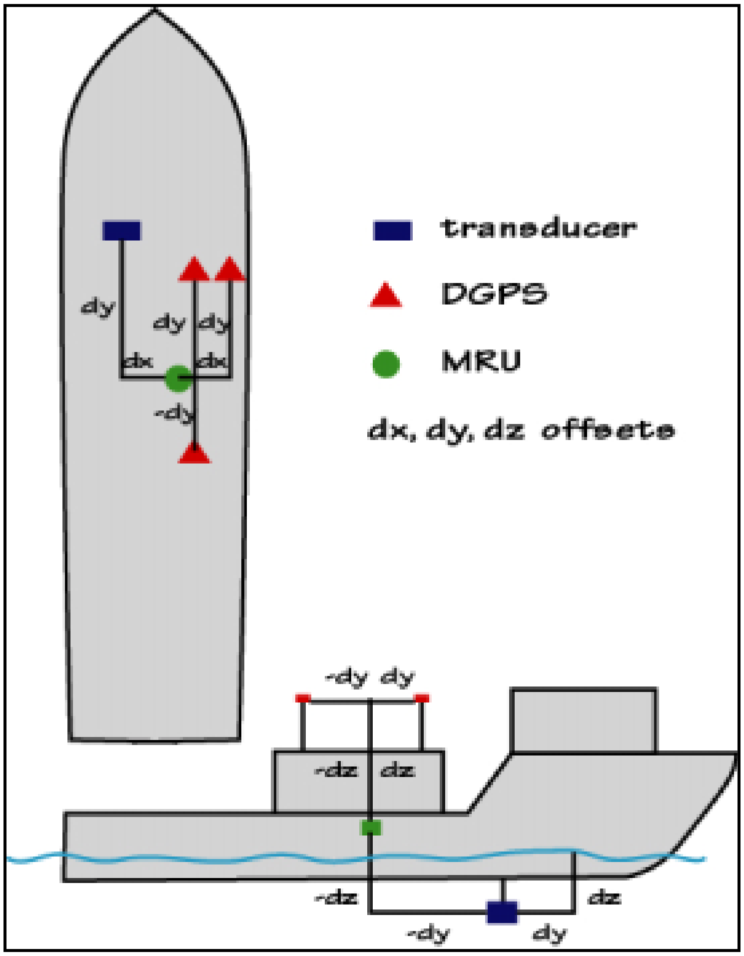

Figure 5. Schematic of required measured offsets.

Attitude Compensation:

Three Vertical Reference Units were available onboard the *Ocean Surveyor* to measure the pitch, roll, and yaw. The POS/MV model 320 inertial motion unit (IMU), a full DGPS-aided inertial navigational system, was used as the primary attitude sensor and directly interfaced to the Simrad EM1002 and provided 100-Hz measurements of boat attitude to 0.01°. The POS/MV was chosen as the primary motion sensor because it has high accuracy specifications, it is insensitive to long period horizontal accelerations, and it provides an inertial position solution that is reliable through DGPS outages of periods of less than about one or two minutes. The second unit was a DMS-05 that measured heading, pitch, and roll, and the third unit was the dual DGPS system.

Table 3. Offsets to sensor alignments on the RV *Ocean Surveyor*

Reference to IMU level arm: x –0.5 m, y-0.1 m, z -2.34 m
Reference to primary GPS lever arm: x -7.97m, y 1.52 m, z -8.36 m
Reference to vessel lever arm: x 0,y 0,z 0
IMU frame wrt reference frame:x 0.48 m, y 0.2 m, z 0 m
Reference to heave lever arm: 0,0,0
Reference to auxiliary 1 GPS lever arm: 0,0,0
Reference to auxiliary 2 GPS lever arm: 0,0,0
Reference to sensor 1 lever arm (0,0,0
Reference to sensor 2 lever arm: 0,0,0
Sensor 1 frame wrt reference frame: x 1.193 m,y -0.180 m,z 0
Sensor 2 frame wrt reference frame: 0,0,0

GAMS parameter setup
2-antenna separation: 2.518 m
heading calibration threshold: 0.8˚
heading correction: 0.0

Simrad installation parameters
Motion sensor delay: 18 ms
Pitch installation angle +2.19˚
Waterline –2.32 m
Outer beam angle offset 0.0160˚

EM1002 Operational Modes

There are several operational modes available for the EM1002. The differences in the modes are a function of pulse length, beam spacing, and angular sector. The pulse length controls the amount of energy transmitted into the water column. The system can be operated in an “equiangular” (EA) mode in which the beams are spaced at equal angles apart, resulting in a non-linear (increasing spacing away from nadir) spacing of sonar footprints on the seafloor. The system can also be operated in an "equidistant” (EDBS) mode in which the beams are spaced such that the sonar footprints are equally spaced in the across-track profile. The EDBS geometry is achieved by generating variable beam-angular spacings. Although EDBS has advantages in data handling (i.e., provides even sounding density), there are two limitations. The beams in the 140° and 150° modes are spaced wider than their beam widths and results in incomplete coverage that produces a striping close to nadir. This problem disappears as the swath width closes to ~120°. However, the second limitation occurs because of attitude uncertainties and imperfect refraction models that can result in sounding errors that grow with angle from the vertical. Because these limitations render the outermost beams less reliable than for the EA mode, we preferred to use the EA mode.

The Pinnacles survey was begun in the EA mode. In the EA mode, the EM1002 was operated with a 0.2 ms pulse length in waters less than 150 m deep, that provided a 150° swath. In waters deeper than 150 m, the EM1002 switched to a 0.7 ms pulse length that generated a 120° swath. However, during the initial patch testing the Simrad controller rejected the EA mode so we switched to the EDBS mode.

Data Transformations

Tides

At sea predicted tides from the Morgan City and Cat Isle tide stations were used by first reducing the tide amplitudes at both stations by 10%, on the suggestion by NOAA’s

Office of Tides, to compensate for the distance to the operating area from the two tide stations. Next, locations were picked about 30% east of the western boundary of the survey area, and about 30% west of the eastern boundary. An inversed-squared distance was calculated between the nadir position of each ping and the nearest of the two tide stations, and a tide correction was assigned. The predicted tide models for Morgan City and Cat Isle were compared to the measured tide at the Panama City Beach tide gage after the cruise to ensure that tide corrections were appropriate. NOAA’s Office of Tides determined that a 0.89 factor should be used for the survey area when referenced to the Panama City Beach tide measurements.

Bathymetry

All bathymetric data were adjusted through Kongsberg Simrad software for (1) transducer draft, (2) static roll, pitch and gyro misalignments, (3) roll at reception, (4) refracted ray path, and (5) beam steering at transducer interface. Post-logging transformations included (1) transformation of navigation from antenna to transducer, (2) correction for positioning to sonar time shifts, (3) tide, and (4) any unaccounted-for static attitude misalignments.

Backscatter

The Kongsberg Simrad EM1002 provides a backscatter-intensity time series for the bottom insonification period for each of the 111 individual beams. The corrections applied by the shipboard recording system are listed in Table 4.

A set of required backscatter data transformations is performed by specialized software written by the Ocean Mapping Group at the University of New Brunswick. The transformations include conversion of each beam backscatter time series to a horizontal range equivalent, splicing the 111 beam traces together to produce one full slant-range corrected trace, and removal of residual beam-pattern effects. Although the system software corrects for average beam pattern, there are ± 2 dB ripples in the average beam pattern that vary from transducer to transducer.

Table 4. Corrections applied to each beam for backscatter.

- source power adjustments.
- spherical spreading compensation.
- attenuation compensation (using operator entered 30 dB per km.).
- TVG adjustments.
- designed beam-pattern compensation.
- calculation of insonified area (assuming a flat seafloor at the nadir depth).
- application of a Lambertian model
  using flat seafloor equivalent grazing angles) to reduce the dynamic
  range of the data (stored at 8 bit (0= -128dB, 255 = 0 dB.).

Our processing approach to backscatter was to stack several thousand pings to view the angular variation of received backscatter intensity as a function of beam angle. Inherent in this function is both the transmit and receive sensitivities, as well as the mean angular response of the seafloor. We then invert this function to minimize the beam pattern and angular variations.

Kongsberg Simrad uses a variable gain within 15° of vertical to reduce logged dynamic range at nadir and near-nadir. The sidescan data at this stage have had a Lambertian response backed out and the beam pattern has been corrected with respect to the vertical and all receive beams have been roll stabilized. Consequently, corrections have been made for variations in the beam-forming amplifiers but not variations in the stave sensitivities of the physical array. Additional transformations were required to produce calibrated backscatter measurements. These include (1) removal of Lambertian model, (2) true seafloor slope correction, (3) refracted ray-path correction, (4) residual beam-pattern correction, and (5) aspherical-spreading corrections.

Patch Test:

Despite the careful measurements of transducer alignments and offsets, the true geometry of the installed system can only be determined through the determination of the self-consistency of seafloor measurements. To facilitate such a determination, we conducted a series of “patch tests” in the Pinnacles area whereby the system was run back and forth across oil field pipelines on the seafloor to determine if there were residual roll, pitch, heading, or timing offsets that required correction factors.

A full patch test procedure was started prior to data collection on May 22 to calibrate any time delay, and gyro misalignment. The static adjustments were estimated from the patch test are listed in Table 5.

Table 5. Adjustments to shipboard alignments used for the Pinnacles survey

- time delay (0 ms)
- gyro misalignment (+2.19˚).
- roll misalignment (0.0).
- pitch misalignment (-2.5) degrees.

- The time delay was entered in to the UNB post-processing software.
- The roll offset was entered into the POS/MV.
- The gyro misalignment was entered into the Simrad OPU.

Navigation Filtering

The 1-Hz DGPS and 100-Hz INS navigation data were logged with the Kongsberg Simrad EM1002 software. The Simrad Bottom Detection Unit (BDU) time stamps the depth and sidescan telegrams and was slaved to a shipboard SUN Sparc 20 that was synched to the GPS 1 PPS. The navigation telegrams were externally stamped by the Trimble 4000 GPS receiver. The receiver antenna positions were shifted to the transducer position according to the X and Y offsets using the POS/MV output (Table 3).

Every 1-Hz navigation fix was checked for gross time and/or distance jumps by graphical examination during data processing. Outliers were interactively interrogated for time, flagged and rejected (or re-accepted). All navigation jumps greater than 20 s were automatically flagged as uninterpolatable.

Data Processing

Shipboard data processing (Fig. 6) consisted of (1) the editing the 1-Hz navigation fixes to flag bad fixes; (2) examining each ping of each beam to flag outlier beams, bad data, etc.; (3) merging the depth and backscatter data with the cleaned navigation; (4) correcting all depth values mean low low water tide; (5) performing additional refraction corrections, if necessary, for correct beam raytracing; (6) separating out the amplitude measurements for conversion to backscatter; (7) gridding depth and backscatter into a geographic projection at the highest resolution possible with water depth; (8) regridding individual subareas of bathymetry and backscatter into final georeferenced map sheets; (9) gridding and contouring the bathymetry; and (10) generation of the final maps. Nearly finalized maps were completed in the field during the transit to port and the final maps that accompany this report were completed one week after the end of the cruise.

Refraction Issues

The single biggest limitation on the quality of sounding data is water-column refraction. Refraction-related anomalies grow non-linearly with beam angle and the resulting artifacts can create short-wavelength topographic features that may be misinterpreted as seabed geology.

There was some fear prior to the cruise that suspected strong water stratification would present a problem for the beam steering and ray tracing of individual beams. Although a strong thermocline was measured, repeated CTD and XBT casts allowed us to correct for refraction effects. A representative water-velocity profile is shown in Figure 7.

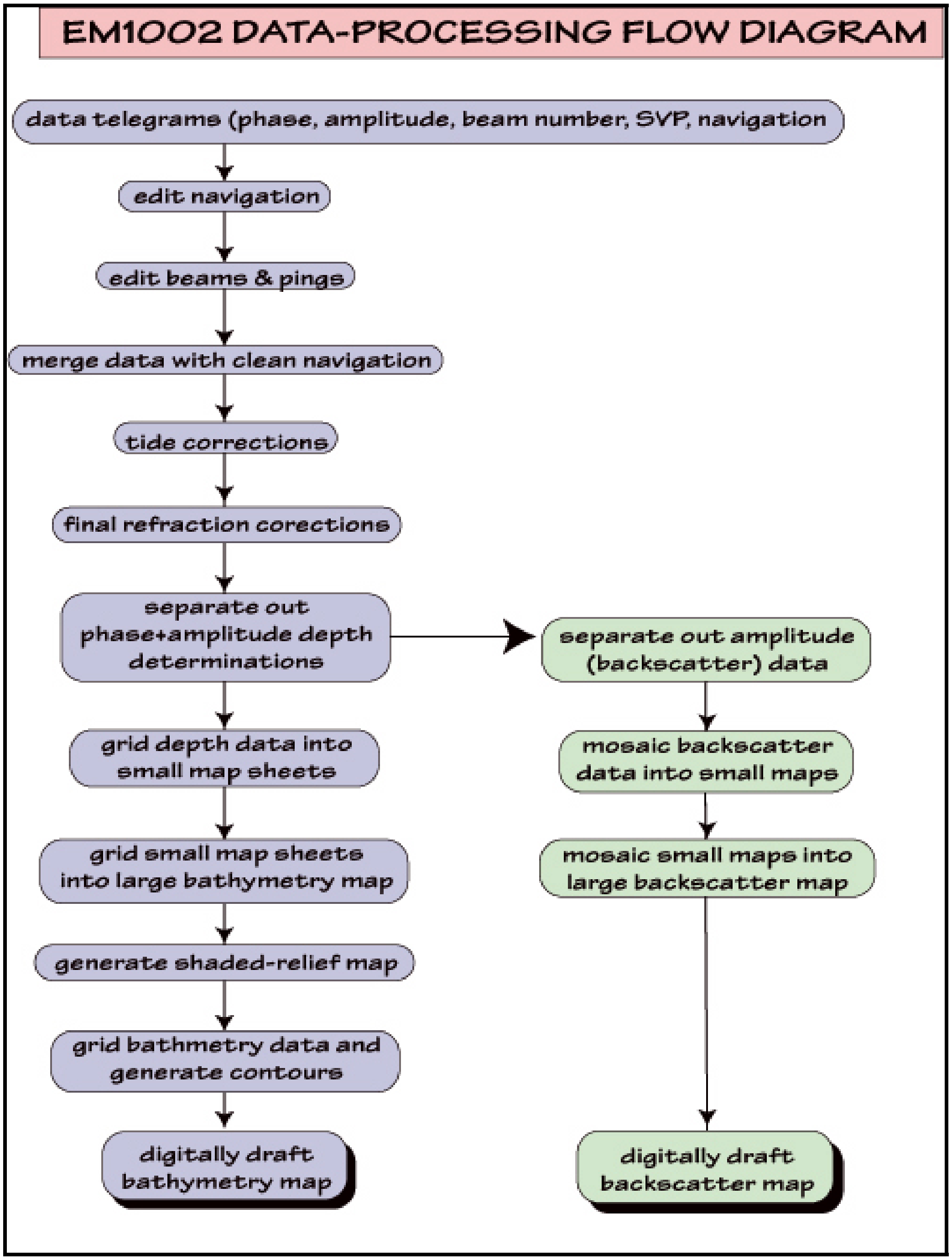

Figure 6. Shipboard data processing flow for EM1002 Pinnacles survey.

In fact, no additional empirical refraction corrections were necessary during processing. If all of the alignments were correctly determined, Kongsberg Simrad states that the depth resolution of the EM1002 is 30 cm or 0.1% of water depth, whichever is larger.

Tide Datum

Predicted tides from the Panama City Beach (Entrance), FL tide-gage location were calculated from the World Tide program. Prior to the cruise, the Tide Group at NOAA, Silver Spring, MD provided the 0.89 scaling factor and time offsets of +12 min for high tide and 0 min for low tide. The scaling factor and time offsets were applied to the predicted tides and a file of 6-min tide predictions for the duration of the cruise were calculated. After the cruise, the actual measured tides at the Panama City Beach tide gage were downloaded and compared to the predicted tides (Fig. 7).

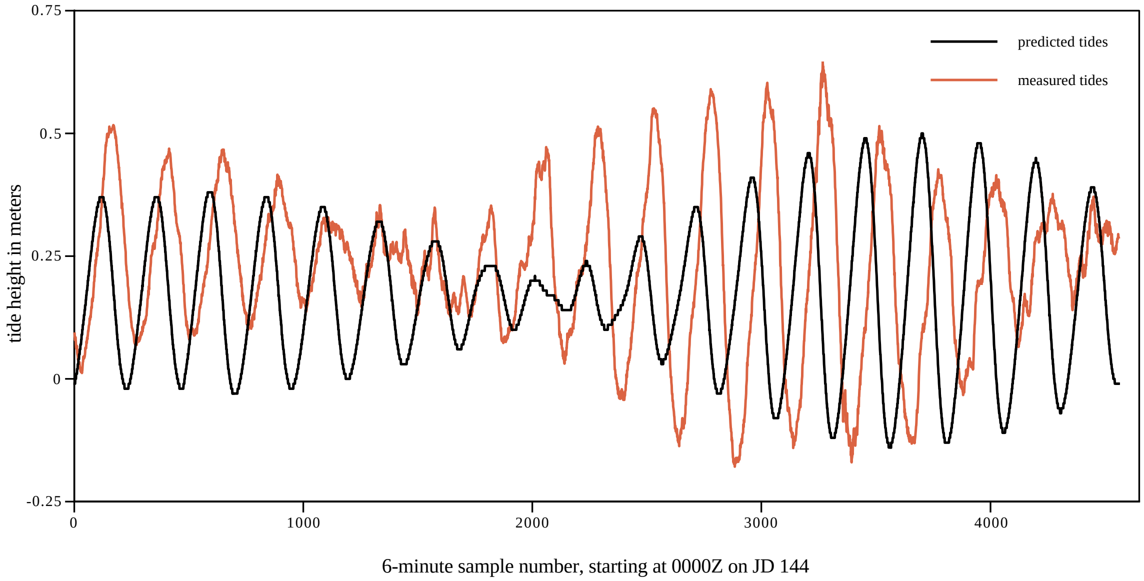

Figure 7. Plots of predicted (black line) and measured (red line) 6-minute tides at Panama City Beach tide station (NOAA station number 8729210

The Maps

The overview maps of backscatter and shaded relief that accompany this report were generated from larger-scale subarea maps (Fig. 8 and Table 6). The 4-m-resolution subarea maps were regridded at 8 m to produce the series of overview maps of the entire area (Figs.9 and 10). This regridding sacrifices resolution in the shallower areas but allows the entire area to be mapped. The detailed subarea maps are 3750 columns (14 km) by 2500 rows (10 km) in size and were produced at the maximum resolution as determined by water depths and beam angle.

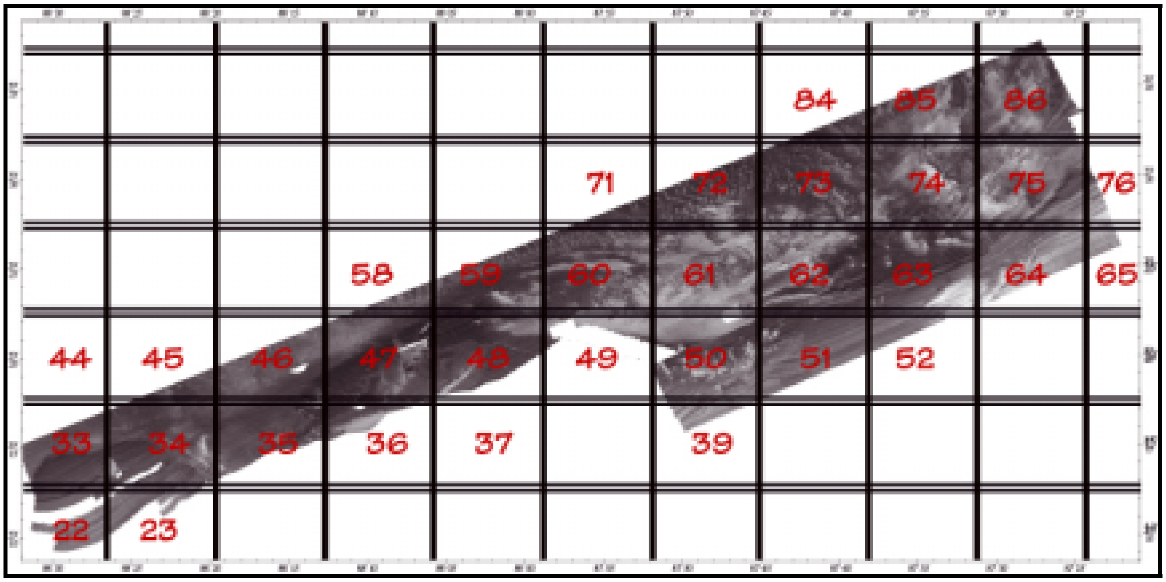

Figure 8. Individual map sheets used for Pinnacles map construction. Image behind boxes is acoustic backscatter for the area.

Contour maps are a traditional method of displaying bathymetry. Contours were derived from the gridded elevations and smoothed with a 3-point running average for the overview maps. Even at the original contour grid, more than 90% of the data had to be discarded so as to only show some chosen contour interval. A much better representation of bathymetry, using 100% of the data is a shaded-relief map.

Table 6. Map numbers, resolution in meters/pixel and size in pixels

Map no.	resolution	size	Map no.	resolution	size
area22	4	3750x2500	area58	4	3750x2500
area23	4	3750x2500	area59	4	3750x2500
area33	4	3750x2500	area60	4	3750x2500
area34	4	3750x2500	area61	4	3750x2500
area35	4	3750x2500	area62	4	3750x2500
area36	4	3750x2500	area63	4	3750x2500
area37	4	3750x2500	area70	4	3750x2500
area38	4	3750x2500	area71	4	3750x2500
area44	4	3750x2500	area72	4	3750x2500
area45	4	3750x2500	area73	4	3750x2500
area46	4	3750x2500	area74	4	3750x2500
area47	4	3750x2500	area82	4	3750x2500
area48	4	3750x2500	area83	4	3750x2500
area49	4	3750x2500	area84	4	3750x2500
area50	4	3750x2500	area85	4	3750x2500
area51	4	3750x2500	area95	4	3750x2500
area57	4	3750x2500	area96	4	3750x2500

A shaded-relief map (Fig. 9) is a pseudo-sun-illumination of a topographic surface using the Lambertian scattering law (equation 1), where SI is the pseudo-sun intensity, K is a constant that allows for even background, and Φ is the angle between the pseudo sun and the bathymetric surface.

$$SI = K * \cos \Phi \qquad \text{(Eq. 1)}$$

The backscatter map (Fig. 9) is a representation of the amount of acoustic energy, at ~95 kHz, that is scattered back to the receiver from the seafloor. The Kongsberg Simrad EM1002 system has been calibrated at the factory and all gains, power levels, etc. that are applied during signal generation and detection are recorded for each beam and are used to adjust the amplitude value prior to recording. Consequently, the backscatter is calibrated

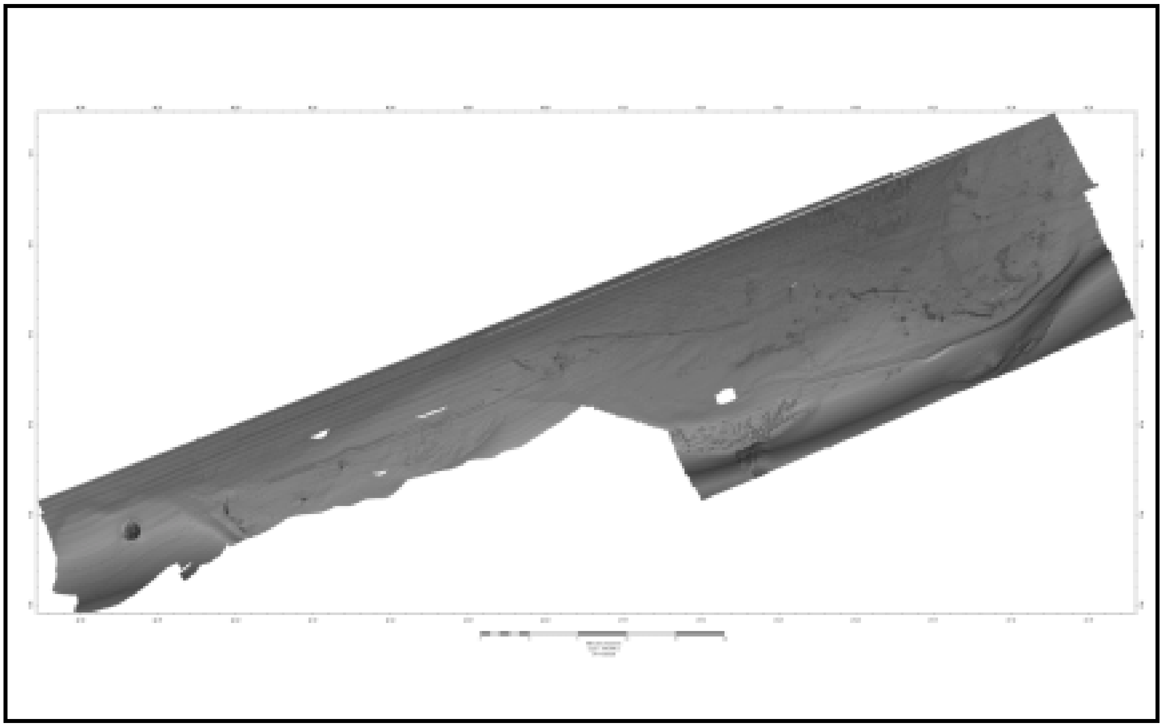

Figure 9. Shaded-relief bathymetry of the entire area surveyed during cruise. Illumination is from an azimuth of 315˚, elevation of 45˚.

to an absolute reflectance of the seabed. However, the amount of energy, measured in decibels (dB), is some complex function of constructional and destructional interference caused by the interaction of an acoustic wave with a volume of sediment or, in the case of hard rock, the rock material. The backscatter from sediment is volume reverberation to at least 5 cm caused by seabed and subsurface interface roughness above the Rayleigh criteria (a function of acoustic wave length), the composition of the sediment, and its bulk properties (water content, bulk density, etc.). Although, it is not yet possible to determine a unique geological facies from the backscatter value, reasonable predictions can be made from the backscatter based on the known local geology.

One of the great advantages of this survey is that every sounding of the bathymetry is accurately georeferenced and coregistered with the backscatter. Consequently, each pixel on the map has a latitude, longitude, depth, and backscatter value assigned to it.

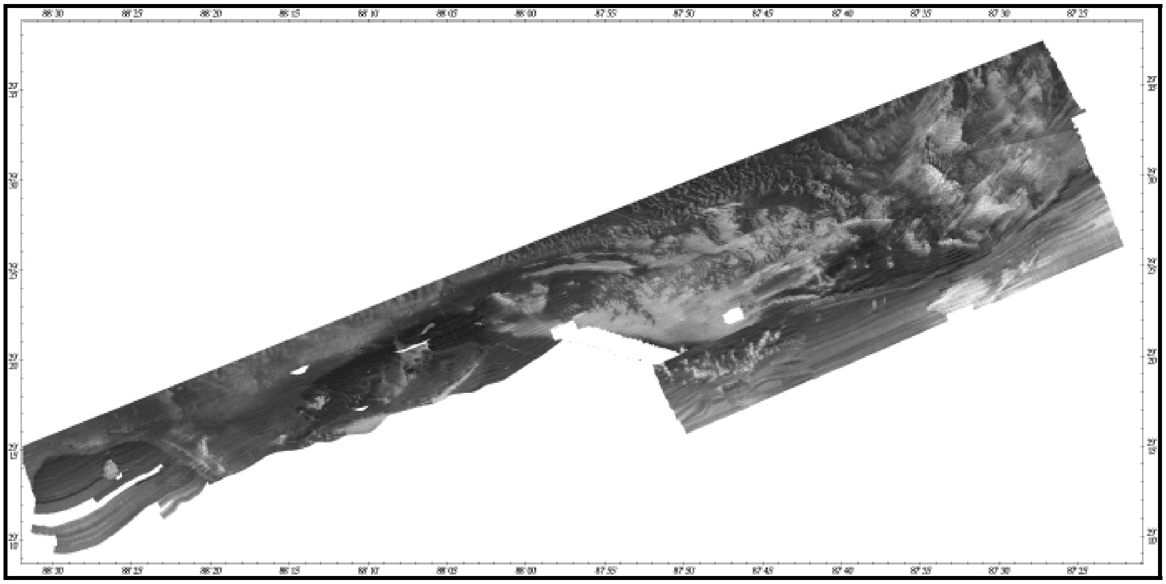

Figure 10. Acoustic backscatter of the entire area surveyed during cruise. Light areas are higher backscatter than dark areas.

Daily Log

May 22, 2000 (Monday) JD 143 (local time GMT +5)

USGS team traveled to Lafayette, LA. Arsenault's bags were lost getting to Lafayette so Arsenault and Calder stayed in Lafayette to retrieve them from the next flight. The rest of the team drove 4 hours to Venice, LA and boarded the ship at 11:30 pm. The computers were set up and tied down.

May 23, 2000 (Tuesday) JD 144

Arsenault and Calder arrived onboard at 01:30 L. During the prior weekend it was discovered that the Simrad software was recording a huge file size for backscatter and Hydromap was not formatted for the large size. C&C worked on a software patch for the problem all weekend but had no resolution by Tuesday. The ship stayed tied to the dock during the morning while the problem was worked out.

Lines were cast at 1030 L and we sailed down the Mississippi River for two hours and then out into the Gulf of Mexico. We steamed out to deep water and at 2000 L we hove to for a CTD cast to calculate the sound velocity profile. The velocity profiler at the transducer gave a conflicting reading with the CTD so casts with both an XSV (expendable sound velocimeter) and a CTD were made to compare the velocity profiles. A satisfactory profile was established and the patch test began. The EM1002 was set up to run in the equal-angle (EA) mode but the Simrad controller continuously and rapidly adjusted the swath width over a wide range. When the system was put in the equal-distance (EDBS) mode, the controller settled down and consistent swath width was maintained. We decided to stick with the ED mode.

May 24, 2000 (Wednesday) JD 145

The XSV and CTD once again gave conflicting profiles of sound velocity in the upper 10 m of the water column. The Simrad software would not accept the file from the velocity profiler at the transducer so sound speed at the transducer had to be manually entered into the Simrad software. A persistent 0.5 to 1.0-m roll (?) artifact appeared in the data, seen especially in the outer beams (Fig. 11). There did not appear to be any correlation between roll and pitch so the problem appeared to be involved with the motion sensor and not a misalignment. The Simrad console was reading the POS/MV datagram but the Simrad receive beamforming appeared to not be using the recorded roll. We spent the better part of the day, after completing test Line 8, trying to isolate the problem.

In addition to the roll artifact, a bathymetry artifact was immediately apparent at the sector boundaries at ±50˚ from nadir. This artifact produced a 0.5 to 1.0-m ridge that runs parallel to the ship track corresponding to the outer beams (Fig. 12). The artifact could be caused by beamforming problems or, less likely, by the difference in seafloor response from the different sector frequencies (98 vs 93 kHz). There is no corresponding effect on the acoustic backscatter image.

We commenced a series of test lines to determine whether the roll artifact was induced from a pitch motion, a transducer misalignment, or a POS/MV misalignment. The results of the test suggested the POS/MV had a small yaw misalignment and new offsets were input at the Simrad console. The new offsets reduced, but did not eliminate, the sector-boundary problem but the roll artifact persisted.

We decided to use a combined tide model after significant depth offsets occurred the bathymetry between adjacent lines using the Panama City Beach predicted tides supplied by NOAA. We used the predicted tides at Cat Isle and Morgan, using a linear inverse-squared distance interpolation between a point ~20 km east of the western boundary of the survey and a point 20 km west of the eastern boundary and the navigation fix. This change appeared to produce acceptable tide corrections.

May 25, 2000 (Thursday) JD 146

We ran a test line throughout the night so that we would have overlapping lines to investigate the continuing roll artifact. A southwest course put us running into the sea (about 1 m) and produced a significant amount of pitching and rolling. A northeast course put us running with the sea with less motion, thereby suggesting a motion-sensing/misalignment problem.

The X and Y offsets from the transducer to the IMU were re-measured with a steel tape and a 0.5-m error was found in both the X and Y offsets because the wrong standpipe was being referenced. The new values were entered into the Simrad console and the pronounced roll/pitch artifacts were reduced and the sector boundaries were diminished.

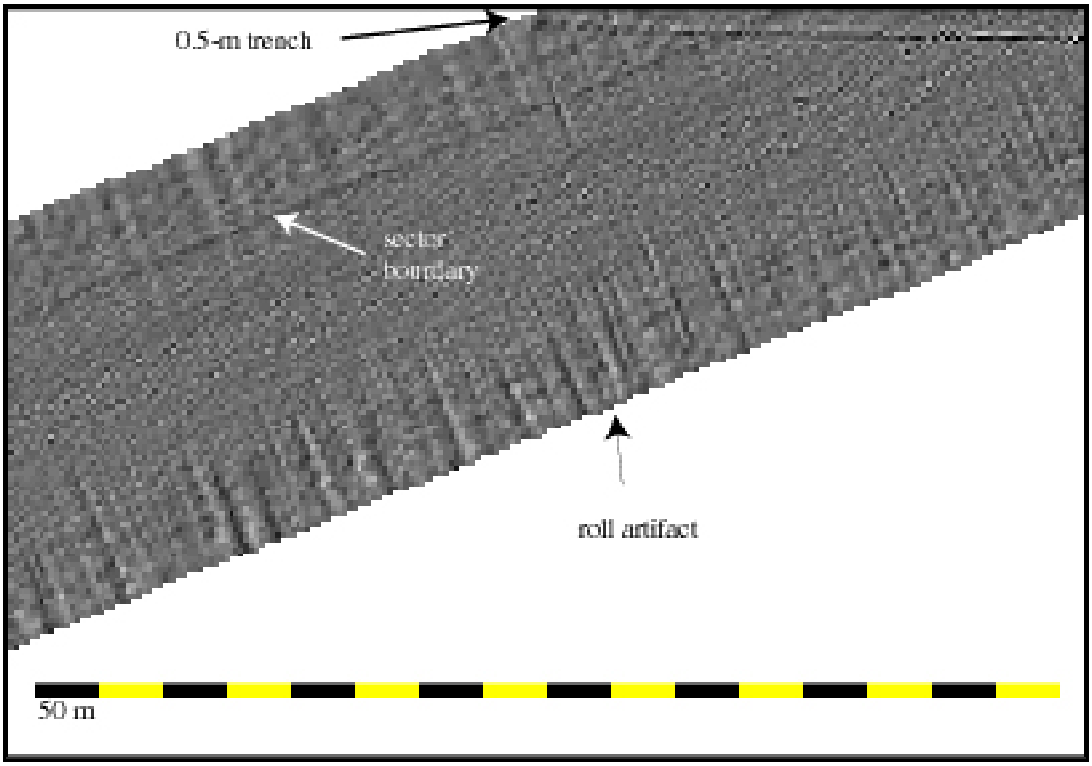

Figure 11 Portion of shaded-relief from Line 8 showing the ~50 cm sector boundary and the roll artifact. Note the 0.5-m deep “trench” on the seafloor, presumably related to all the oil industry in the area.

At 1530L (2030Z) we decided to begin the survey. When the extent of the survey was planned, two lines were added to the north boundary to allow for the system testing. We decided not to rerun those lines because (1) it would take 2 days, (2) the high-priority areas are to the south and west, and (3) it appears that most of the second line can be reprocessed in the lab and salvaged.

May 26, 2000 (Friday) JD 147

Calm seas during the night allowed the collection of very clean data. Two pipelines were crossed and provided the opportunity to analyze the data for any gyro offsets. The images of the pipelines suggest we have a very small (<0.5˚) static offset in the POS/MV gyro. Even though we were successfully mapping, the outer beam ripples (see Fig. 12) continued to cause concern. There is a possibility that the transducer ram has a very small amount of play, thereby causing a slight movement in the transducer. The ram was tightened as much as possible and the survey continued.

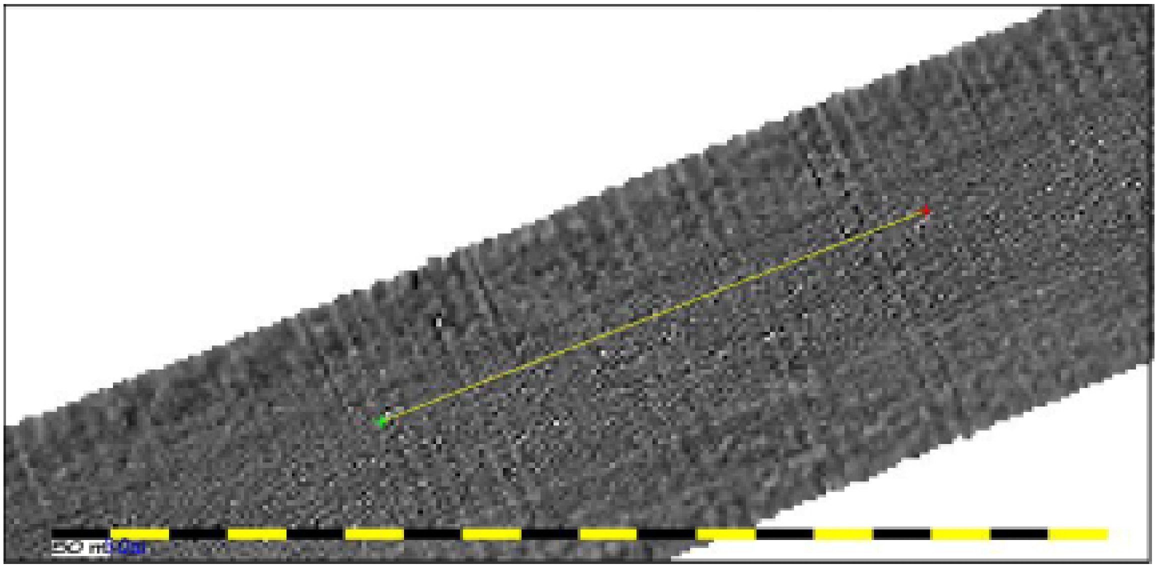

Figure12. Shaded relief image of Line 31. Compare with Figure 11. Notice the pronounced roll (?) artifact is reduced. A profile along the thin yellow line shows the slight heave (?) artifact is less than 15-cm high.

Seas began to build by mid morning and reached ~ 2 m by mid afternoon. The seas caused significant roll and pitch, degrading the data. Curiously, the Simrad software apparently could not use the output from the POS/MV to completely stabilize the receive beams. Later in the day we collected three parallel lines and began to see what appeared to be the effects of bad tide values. The survey area is very long (~65 km) and the tides at the southwest end may not be identical to the tides in the middle or northeast end. The NOAA Tide Group gave us tides only for the center of the survey area. In addition, the three lines identified a static roll bias in the data. The effects of the roll bias shows as a slight (~50 cm) offset in depths, causing a step in a profile drawn perpendicular to the tracks (Fig. 13). All the data collected to date had to be reprocessed using the unrollOMG –pitch_offset program. The reprocessing took all our time and we were unable to analyze the quality of the acoustic backscatter.

In addition, we had three lines crossing a pipeline on the seafloor, providing an opportunity to recalibrate the POS/MV gyro. The recalibration indicated a –3˚ misalignment. This was a puzzle because the POS/MV gyro was satisfactorily aligned during the patch test earlier in the week. A –3˚ static offset was put into a special script written to only rerun the mergeTide program on all the data collected to this point. The reprocessing results showed perfect alignment of a pipe on the seafloor, the ultimate test of good gyro calibration. The –3˚ static offset was put into the Simrad software offsets and the problem appeared to be eliminated.

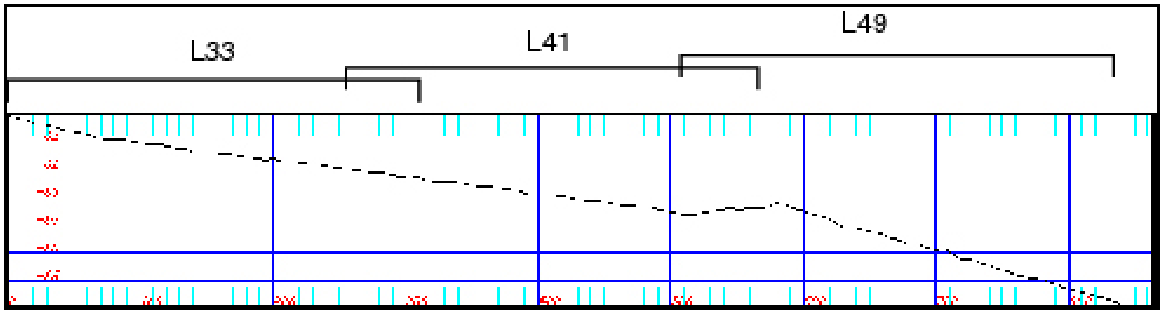

Figure 13 Profile of depth vs distance across Lines 33, 41, and 49. L33 and L41 are headed NE and Line 49 is headed SW. Notice the plateau at the overlap of L41 and L49 and the slope of the L49 compared to the slope of L33 and L41. The plateau and change in slope are the effects of a 3˚ static roll bias.

May 27, 2000 (Saturday) JD 148

At about 0300L, the GPS satellites went silent for an hour. The silence seems to have been unscheduled repair work by the Air Force. The INS of the POS/MV continued to provide high-quality navigation fixes but a small amount of drift off line occurred during the hour.

The seas continued at 2-m with 1.5-m swells quartering the survey courses. The ship motion, especially pitch, continued to cause some degradation to the data, both from aeration as well as motion. Pitching with the *Ocean Surveyor* causes severe aeration, air trapped under the bow and then air bubbles stream past the transducer causing loss of signal. The transducer was lowered to its maximum depth but the aeration persisted.

May 28, 2000 (Sunday) JD 149

The seas moderated some with better data quality and the ~15 cm motion artifact was reduced. The Simrad computer crashed in the early morning and when rebooted would not accept POS/MV updates. The problems was solved with a half hour spent fiddling with the Simrad software. We also continued tweeking with the offsets and found that a 0.3˚ change in pointing angle of the transducers reduced the motion artifact.

May 29, 2000 (Monday) JD 150

Calm seas all day improved the data quality over what was already generally excellent quality. However, because of the calm seas and flat seafloor, the C&C engineers detected a small (~1˚) error in the transducer–pointing direction and a –2.5˚ offset in transducer pitch. We spent most of the day reprocessing the existing data with a series of fixes to correct for these offsets. The reprocessing for pitch required *unRoll_OMG –pitch_offset –2.5 *.merged* whereas the heading required rerunning *mergeNav –declin +2.8 *.merged*. All this reprocessing had to be done on the /work5 disk so that the realtime processing was not interrupted. Eventually, once we confirm the fixes were proper, the offsets were put into the Simrad software and the problem was eliminated.

May 30, 2000 (Tuesday) JD 151

We worked through the night and half the day making and testing the appropriate fixes for the pitch and heading errors. While the reprocessing was running in the background on /work5, the new data were being processed on the work3 disk with no offset corrections so that we could continuously check on the quality of the data. In the mid morning, in about 120-m water depths, we found that the multibeam telegrams starting having no ETX (the flag that marks the end of a beam telegram). The lack of an ETX flag meant that the processing software could not locate the end of the datagram, so it dropped that ping's backscatter. We found that the C&C Hydromap software also was having the same problem. A call was made back to C&C in Lafayette and their senior programmer was tasked to fix the problem.

In the meantime, until we receive the software patch, we transited into water less than 100-m deep and continued surveying. The seas were calm and the data quality was very good. The Simrad processor crashed midday, but was successfully rebooted.

May 31, 2000 (Wednesday) JD 152

The seas built up during the night and became a sustained 2+ m plus a 1+ m swell throughout the day. The ship experienced considerable pitching, rolling, and yawing that affected the data. In addition, the ship was riding high in the water because we were running low on fuel with only about 2000 gal remaining. Arrangements were made to return to Venice, LA for fuel and groceries on Thursday. We surveyed in very rough seas and swell until about 2300 L when we stopped mapping and loaded a new version of Hydromap software with the length-of-telegram fix. An hour was spent collecting data that filled in a deep-water line with the new software to determine whether the patch fixed the problem. We broke off at 2355 L and transited to Venice for refueling and groceries

June 1, 2000 (Thursday) JD 153

James Chance, Vice President of C&C Technologies, visited the ship while refueling to discuss the data artifacts. The latest software patch to Hydromap fixed the backscatter telegram-length problem. Although the sector boundaries still showed in the data, this artifact did not significantly degrade the data so we decided to continue mapping with the present software. Jim Chance decided to participate in Leg 2 to help clear up some of the offset and artifact problems encountered on Leg 1. Arsenault decided to leave and return to New Hampshire.

The tide model was tested while we were refueling and transiting back to the map area. Instead of using interpolated tides between two stations, we chose one station (Morgan) and used it to correct for tides. There was no discernable difference between the two results.

It was discovered late in the day that there was a major offset error from the IMU to the transducers. The errors meant that all navigaton fixes had to be displaced+5.3 m forward and 1.55 m to port. All the Simrad datagrams had the offset errors so the merged files had to be corrected. The remainder of the day was spent testing the effects of correcting the errors. We determined that all of the offsets that had been made to make the pipelines line up were only trying to compensate for the initial navigation offset. Tests were made on a few lines by taking the merged files from a backup and applying only the navigation offset and the gyro misalignment of +2.8˚. The results showed that the pipelines align properly but the stairstep in reciprocal lines (static roll offset) still appeared in the processed data. It was reluctantly concluded that the backup merged files had improper Simrad offsets giving us the 0.3˚ roll-to-port offset. This was tested by starting with the raw Simrad datagram and creating a new merged file. The results of the test showed no stair steps. A script was then written to bring in all raw datagrams from Line 1 through Line 186 and apply only the navigation offset, gyro misalignment, and the Morgan tides. However, backing out the pitch corrections and changes in transducer depth that had been entered into the Simrad software were more vexing to remove.

We departed Venice at 1830 L and transited back to the work area.

June 2, 2000 (Friday) JD 154

We arrived at the work area at 0330L and commenced patch testing, which took the remainder of the day. This testing was to isolate the heave and pitch artifacts and to determine whether the Hydromap software patch was indeed allowing us to read in the full backscatter data string in depths deeper than 150 m. It became readily apparent that we were experiencing a pitch-induced roll artifact that suggested an alignment problem. After hours of patch testing, it was concluded that the software for the POS IMU was not properly interpreting the gyro reading. A spare independent motion sensor, a TSS DMS-05, was set up and headings were compared with the POS heading. The results of this test showed a mismatch between headings of the two IMUs. A test was run where the DMS-05 heading was fed directly into the Simrad software, whereas roll, pitch, and heave were supplied by the POS/MV. All offsets were zeroed except the lever-arm offsets of the IMU to the transducer. A patch test was conducted over a linear reef with a steep southern slope and we eventually calibrated the heading. We continued working through the night to patch test for roll and pitch.

June 3, 2000 (Saturday) JD 155

Early in the morning the final patch tests were conducted and we determined a pitch offset of +2.10˚. However, the seas were glassy smooth and we experienced almost no motion so the tests were not conclusive. The quality of the patch-test data looked excellent so at 1130 L we commenced mapping. We ran three adjacent lines of about 30-minutes each to confirm the lack of roll biases in the data. The results looked excellent so we recommenced running the long lines of the survey.

In the meantime, the first 185 lines were reprocessed in the background in batch mode to remove all the incorrect static offsets applied at the Simrad level during the first leg of the cruise that contaminated our merged files.

June 4, 2000 (Sunday) JD 156

Seas remained calm and the data quality was excellent. The almost complete lack of ship motion eliminated the motion artifacts that plagued the first leg of the cruise.

We began to encounter an artifact on the backscatter data when we passed into waters deeper than ~120 m. The Simrad datagram (.em1002 file) apparently has a very long backscatter record and both the Hydromap and processing software can not find the end-of-record mark, the same problem we encountered on Leg 1. This problem dumps the backscatter telegram and we get no image data for that ping. This problem was not present in shallow (<120 m) water..

June 5, 2000 (Monday) JD 157

Seas were slightly lumpy throughout the day but the data quality remained excellent. We determined that the predicted-tide model we were using (morgan90) was creating offsets between our lines. This is probably because the lines are ~8 hr long and whatever small tide we have here is varying over the length of a line. Consequently, we commenced regridding all the bathymetry with no tide correction to see the effect.

The high quality of the data confirm that we have finally determined all the offset angles and lever arms. The remaining problem with the heading from the POS/MV has been circumvented by using the DMS-05 for heading. The problem we were seeing with the Hydromap not writing the full backscatter telegram was fixed by a patch emailed to the ship. Once Hydromap was recompiled with the new patch, we have had no further problem with the backscatter telegram in depths greater than 100 m.

June 6, 2000 (Tuesday) JD 158

A small low-pressure front passed over us giving cloudy and rainy conditions but calm seas. The data quality continued to be excellent. It became apparent that we had to alter our track lines so that the high-priority Ludwig and Walton (1957) pinnacles and the Rough Tongue areas (see Fig. 14) could be mapped before we ran out of time and fuel. I decided to concentrate our remaining time in thoroughly mapping the two areas, leaving a large area in the southwest and smaller areas in the southeast unmapped at this time. The unmapped areas are deeper than 100 m, the deepest pinnacles reported in this region, and lies outside the priority areas established for this cruise.

At 2000 L, the graphics board on the SGI workstation died. A major reprocessing job was running in the background, merged files were being backed up on MOs, and swathediting was in progress. Diagnostics were run on the SGI but no indication appeared that any hardware was down. However, during reboot, when the SGI would switch from the low-end graphics showing startup to the High Impact graphics board the screen would go black. All processing was shifted to the X-window emulator on the Macintosh G4 and processing continued.

June 7, 2000 (Wednesday) JD 159

The wind picked up during the night and the seas began running 4 to 6 ft by day break. The ship motion did not degrade the quality of the data, but motion artifacts began to appear. Once again, the artifacts appear as related to roll, although the ship motion was +5˚ of pitch, ±5˚ roll, and ±10˚ yaw. The wind and swell had subsided by mid afternoon and the data quality continued to be excellent. The loss of the SGI workstation meant that we were unable to perform quality control by using the 3D flythrough capabilities of the machine. This also eliminated our ability to produce maps, oblique views, etc.

By late afternoon the seas were down and the motion artifacts disappeared below the the limit of resolution.

June 8, 2000 (Thursday) JD 160

Mapping the Ludwig and Walton area (see Fig. 14) of pinnacles was completed in early morning and, based on what we have now mapped, we extended the mapping to the east following the 100-m isobath. The seas remained calm and the data quality remained excellent throughout the morning but came up to about 6-ft by mid afternoon..

June 9, 2000 (Friday) JD 161

The seas were running 6 foot and a 20 to 25 kt wind blew all day. The data did not suffer much because of the weather and we almost completed the block of outer shelf-upper slope between the Ludwig and Walton area and the Far Tortuga pinnacles (Fig. 14). However, we were forced to terminate the cruise at 1900 hr L to begin the transit to Venice, LA to make our scheduled arrival time.

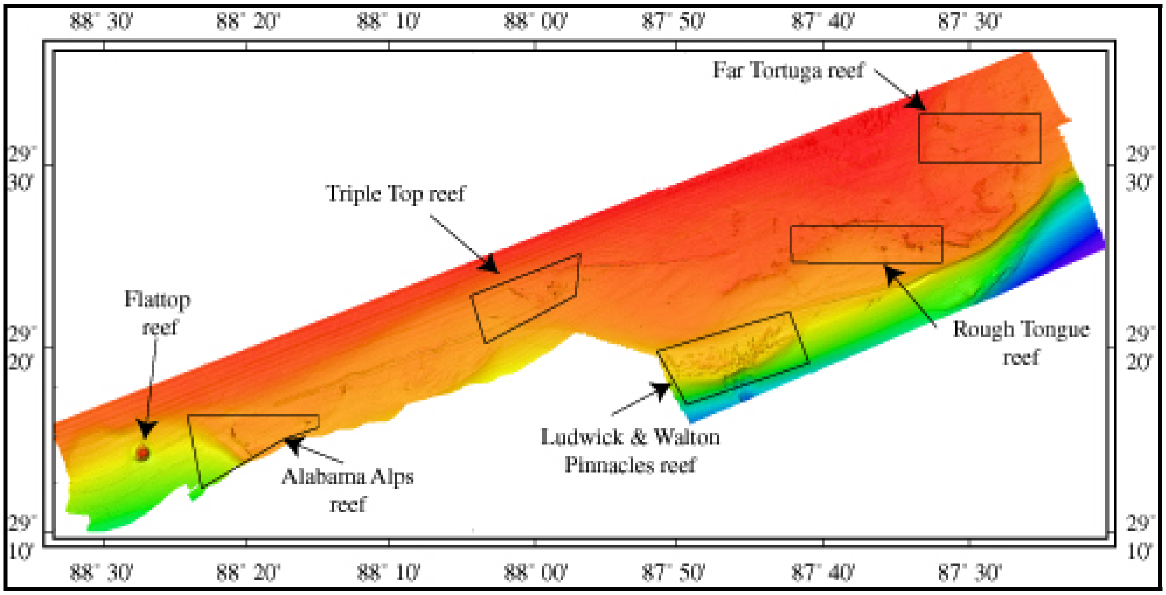

Figure 14. Color shaded-relief bathymetric map of area mapped during cruise. Water depths range from 40 (reds) to 350 m (purples) deep. The names of features are only for internal use.

July 22, through July 28, 2000

C&C Technologies sent the RV *Ocean Surveyor* , equipped with a Kongsberg Simrad EM1000, to the operations area to complete the planned mapping. No one from the USGS or UNH were aboard so the data were collected in an unsupervised mode. The EM1000 uses the same 95-kHz frequency as the EM1002 but has only 60 rather than 111 receive beams. The EM1000 was used in the equil-angle mode. Details of the EM1000 can be found in Gardner et al. (1998).

Post-cruise Processing

Post-cruise processing was necessary on the data set. As outlined in the Daily Log, many problems were encountered in system alignments. The final processed data have most, but not all, of these problems corrected. However, during the post-cruise phase, it was discovered that a mistake appeared in the Simrad software that records the datagrams. Two values of acoustic backscatter are determined by the multibeam system; BSn is the backscatter at nadir and BSo is the backscatter at 25° from nadir. The backscatter is calculated as linear between BSn and BSo and then as a function of the cosine^2 of the angle from BSo to the far beams. The gains applied to the received signals are derived from these relationships. The datagram was supposed to record BSn and the difference (BSn-BSo) in two separate fields. Unfortunately, both fields have the value of BSo. The result is a reduced backscatter intensity of from –6 to as much as –13 dB. Because the values are dynamically generated, and because they were not properly recorded, it is impossible to recover the values of BSn.

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