

Chapter 4

Methods: Collection and Processing of Geophysical, Sedimentary, and Hydrologic Data

Side-Scan Sonar Collection, Processing, and Analysis

Side-Scan Collection and Processing. Side-scan sonar data were collected in a series of surveys in the IRB and MS study areas from 1996 through 1998. The initial survey in the MS area was completed in May 1996 (MS96M), utilizing 100 kHz side-scan sonar. A second survey in that area was completed in July 1998 (MS98JL) utilizing 500 kHz side-scan sonar. 500 kHz side-scan surveys in the IRB study area were completed in May 1996 (IRB96M), October 1997 (IRB97O), November 1997 (IRB97N), July 1998 (IRB98JL), and twice in November 1998, before (IRB98N1) and after (IRB98N2) the passage of a cold front.

The MS96M survey consisted of 22 contiguous north-south lines collected in an area bounded by 83° 04' W and 83° 07' W and 27° 54' N and 27° 58' N (Figure 3). Side-scan sonar were collected using an EG&G model 272-T single frequency (100 kHz) tow fish, deployed from the R/V Bellows, using Elics DelphSonar v. 1.30 software and a SEAMAP SONARLINK Model DL1 sonar fish interface. Navigation for georeferencing was collected using a Trimble Navigation NavTrac XL global positioning system (GPS) and NavBeacon differential global positioning system (DGPS) and transmitted directly to DelphSonar during side-scan surveying. The MS98JL survey data were collected in a subsection of the MS96M area, using an EG&G model 272-TD dual frequency tow fish (100 and 500 kHz), deployed from the R/V Price.

The IRB area, a subsection of an area previously studied by Harrison (1996), was located between 82° 53' W and 82° 55' W and 27° 56' N and 27° 57' N (Figure 3). The first 500 kHz survey in this area (IRB96M) was completed utilizing the EG&G dual frequency tow fish and Trimble DGPS, deployed from the R/V Bellows. Subsequent surveys -- IRB97O, IRB97N, IRB98JL, IRB98N1 and IRB98N2 -- were conducted from the R/V Price.

Parameter options for the side-scan sonar data collection were held constant between the IRB97O, IRB97N, IRB98JL, IRB98N1, and IRB98N2 surveys to facilitate comparisons of the time series of images. Variables, including sonar and recording ranges, sampling frequency, gains, power spectrum range, and offset correction, are detailed in Table 2. There were some variations in the recording range and the power spectrum offset between the early IRB surveys (IRB97O and IRB97N) and subsequent surveys. These differences may account for some of the variations in backscatter strength observed the side-scan surveys.

After collection, all sonar data were processed utilizing DelphWin software. Processing consisted of: 1) navigation smoothing and corrections for the along-track and across-track tow fish positions relative to the DGPS antenna, and 2) image enhancement options (choice of pixel resolution, manual time variable gain (TVG) settings, altered offset corrections, and other display variables) to produce images satisfactory for qualitative comparison for all surveys. Images for the MS96M and IRB96M were produced at 1 m x 1 m pixel resolution. All other images were produced at 0.2 m x 0.2 m pixel resolution. A gray scale pallet of 1-256 was utilized. Areas of high backscatter intensity -- generally coarse sediments and exposed hardgrounds -- appear as dark grays (high gray scale values); areas of low backscatter intensity -- generally fine sediments -- appear as light grays (low gray scale values). Processed images were viewed and analyzed using both DelphMap v. 1.11 and MapInfo v. 4.5 software.

Table 2. Side-scan sonar acquisition parameters used for IRB surveys.

SETTING	IRB97O	IRB97N	IRB98JL	IRB98N1	IRB98N2
Sonar/Recording Ranges (m per channel)	55/50	55/50	50/45	50/45	50/45
Sampling Frequency (Hz)	10,000	10,000	10,000	10,000	10,000
Power Spectrum Range (mV)	5000	5000	5000	5000	5000
Power Spectrum Offset Correction (mV)	-200/-200	-200/-200	-100/-100	-100/-100	-100/-100
SONARLINK Gains (Port/Starboard Channels)	3.5/3.5	3.5/3.5	3.5/3.5	3.5/3.5	3.5/3.5

Side-Scan Analysis. Processed side-scan images were exported from the DelphMap GIS software in TARGA (*.tga) format, then imported and geocoded in MapInfo GIS software. The boundaries between the low backscatter sand bodies and the high backscatter trough areas were digitized as an overlay for each image (Figure 5). Several small, low backscatter features, which were found to occur consistently between surveys, were also digitized and included in each overlay.

Determination of movement along the digitized high-low backscatter borders was made within the range of potential errors in the DGPS navigation. The DGPS error tolerance was determined to be $\pm 2-7$ m (personal communication, V. Valdeperas, Trimble, Inc.). In addition, side-scan mosaics were examined for offsets in continuous features between adjacent lines. These offsets, where feature borders did not line up between adjacent side-scan swaths, were attributed to navigation, data collection, and processing errors. Based on the DGPS error and the observed track-to-track offsets within mosaics, a ± 10 m random error was determined to be large enough to account for all such errors. A ± 10 m buffer was then created around the digitized lines of the side-scan overlays, representing the potential position of the digitized boundary within the random error tolerance (Figure 5). Changes in the positions of the digitized borders were then measured by comparing the time series of overlays in each study area.

Figure 5

The MS study area was divided into eight sub-areas for analysis of movement of the sand body-trough borders (Figure 6). The IRB study area was divided into seven sub-areas for analysis of movement of the ridge-trough borders and two small low backscatter features (Figure 7). The November 1998 sub-study area in the IRB study area was divided into four sub-areas for analysis of movement of the ridge-trough borders (Figure 8). Comparisons were then made between the time series of overlays in each study area. Both quantitative and qualitative assessments were made of the position changes. Where the changes in border positions were great enough to exceed the buffers established for each line, the area of change between them was digitized as a polygon. The area of each polygon was calculated and interpreted to represent the minimum movement of the high/low backscatter boundary over time.

The method employed for measuring movement along these digitized boundaries assessed the minimum amount of change which can be safely assumed, given the navigational and processing errors inherent in the side-scan data. However, some of the movement observed, that was not great enough to exceed the error tolerance buffers, could also represent real change over time, especially if it appears systematic and consistent, rather than random. Therefore, in addition to quantifying the movement of digitized boundaries, a qualitative assessment of movement was also made for each boundary comparison, even when not in excess of the error tolerance. Such changes were then discussed in terms of qualitative, morphologic changes in features (e.g., size and shape).

In the MS area, the MS96M and MS98JL boundary overlays were opened simultaneously and changes in position of digitized boundaries compared. In the IRB area, the same comparisons were made between the IRB96M and IRB97N overlays, and the IRB96M and IRB98JL overlays.

Figure 6

Figure 7

Figure 8

The direction of change in borders was differentiated as either movement in a northerly and/or easterly direction (positive along-shore and cross-shore vectors in an x,y plane coordinate system), or movement in a southerly and/or westerly direction (negative vectors). Because of the northwest-southeast orientation of the sand bodies in both study areas, only sediment movement perpendicular to or oblique to their axes was able to be detected by this method. Movement along the ridge axes would not be resolvable using the side-scan images and GIS analyses. The areas of polygons representing movement in each of the two movement directions were summed, the differences between them representing net movement in the northerly/easterly (n/e) or southerly/westerly (s/w) set of directions along a given boundary.

Collection, Processing and Analysis of Surface Sediment Samples

Sediment Sample Collection. Three sediment collection transects were established at the IRB site and two at the MS site. Samples were collected across one transect each for the MS96M and MS98JL surveys (Figure 9) after each corresponding sonar survey. A Shipek grab sampler deployed from the R/V Bellows was used for the MS96M samples and a Ponar grab sampler deployed from the R/V Price for the MS98JL samples. Surface sediment samples were collected by divers across three transects in the IRB area (southwestern sub-study region, Figure 10) after each side-scan sonar survey.

Planning for the MS96M sampling transect was based on the side-scan mosaic, and extended east to west across the primary sedimentary feature in the study area, from its northeast-facing side to its southwest-facing side, oblique to its axis (Figure 9). For MS98JL, the transect was perpendicular to the axis of the ridge, approximately covering its width (Figure 9). For the IRB surveys, all three transects were planned perpendicular to the ridge axis, across the primary ridge in the sub-study region at its widest point, at its northwestern terminus, and at its southeastern terminus (Figure 10). The sample collection

Figure 9

Figure 9

Figure 10

Figure 10

points were established along the transects in both study areas, providing 7 sampling points along the MS96M transect, 10 along the MS98JL transect, and 11 equally spaced sampling points per transect (33 total) at the IRB site for each survey.

For those samples collected using ship-deployed grab samplers in the MS study area, each collection location was marked with a DGPS position as the sampler touched bottom. Recovered sediment was then transferred to pre-marked sample bags. Because it was not feasible to mark the DGPS location of every diver-collected sample in the IRB area, the first and last collection sites of each transect were marked with buoys by the divers and their positions recorded by the boat's DGPS upon recovery of the buoys. In between these marked sites, samples were collected by divers navigating along the transect, measuring sampling points at equal distances with a tape measure. Samples at each point were collected in pre-marked Nasco Whirl-pak[®] bags.

This procedure was repeated after each side-scan sonar survey (except IRB96M and IRB97O), providing a time series of sediment samples concurrent with the sonar data over the project period.

Sample Processing. Sediment samples were removed from their collection bags and placed in 600 ml beakers. To ensure the entire sample was processed, all sediment was removed from each bag by rinsing the inside of each bag with deionized water (DIW) buffered with 180 mg/l sodium metaphosphate (NaPO_x) to assist in disaggregation and to raise the DIW pH to prevent carbonate dissolution. Buffered water was used throughout processing. It should be noted that, for sediments collected in the MS area in 1996 (MS96M), samples were split into two roughly equal portions as they were removed from their collection bags and placed into beakers. For all other samples, the entire sample was analyzed as a unit.

Each beaker was then filled with 200 ml of chlorine bleach and the contents stirred to remove organic matter in the sample. Samples were allowed to settle over 24 hours, were stirred again, and allowed to settle for another 24 hours. After settling, the bleach was decanted and replaced with approximately 200 ml of buffered water. Samples were again stirred and allowed to settle. This process was repeated three times in order to remove all the bleach and thoroughly rinse all samples.

After the third rinse, samples were filtered with buffered water through a 62.5 μm sieve to separate the silt and clay (fine) fractions from the sand-size and larger (coarse) fractions. Fine and coarse samples were placed into pre-weighed labeled beakers and dried at 80° C, about 24 hours. Dried samples were then cooled in desiccators and weighed.

Grain Size Analysis. Once weighed, each sample was gently stirred with a glass rod to disaggregate the sediment. Grain size distribution for each sample was determined using a stacked set of Dual Manufacturing, three inch diameter, U.S. standard sieves. These sieve stacks were shaken for fifteen minutes to separate each sample into constituent grain sizes. The sample from each sieve interval was then weighed and recorded and the entire sample archived for later mineralogical analysis.

The stacked set of sieves were made up of the following phi (ϕ) increments: -2.25, -2.0, -1.5, -1.0, -0.5, 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.75, and 4.0. All sample sets were analyzed with these $\leq 0.5 \phi$ increment sieves, except the samples collected in the MS area in May 1996. Grain size analysis for these samples was done prior to the availability of less than 1 ϕ interval sieves; therefore these data were reported in whole ϕ increments.

From the grain size distribution data obtained for each set of sediment samples, average grain size, sorting, and the relative amount of silt and clay in each bulk sample were calculated. The percentage of silt and clay was obtained by dividing the net weight of the

total fine fraction by the total sample weight (the sum of the net dry weight of the fine fraction and the net dry weight of the coarse fraction). [Note: During dry sieving, a residual portion of fine ($< 63 \mu\text{m}$) material was usually obtained and included with that obtained by wet-sieving, to yield a total fine fraction.]

Average grain size and sorting for the coarse ($> 63 \mu\text{m}$) fraction of each sample was calculated using the method of moments, a weighted mean of the relative weights for each class (ϕ) size and the standard deviation about that mean, as described by Folk (1980) and modified by Lewis and McConchie (1994a). Classifications and descriptions of mean grain sizes and degrees of sorting defined or adapted by Folk (1980) were utilized.

Carbonate Content Analysis. A measure of the carbonate fraction of each sample, via insoluble residue analysis, was determined using the sand-size portion (larger than $63 \mu\text{m}$ or 4ϕ , and smaller than 2 mm or -1ϕ) of the samples. The entire contents of each sample were first passed through a -1ϕ sieve, which excluded sediments larger than 2 mm , termed "granule" and larger on the Wentworth scale (Folk, 1980), that were primarily shell material or carbonate lithoclasts.

After separating the sand size fraction, the sample was split several times until a 3-6 g sub-sample was obtained. Samples were placed in pre-weighed labeled beakers and the total weight recorded. Each sample was then placed under a fume hood and 20 ml of 10% HCl were added to each aliquot and the sample stirred with a glass rod. Each aliquot received subsequent additions of 20 ml of 10% HCl until the carbonate dissolution reaction ceased. Buffered water was then added and the aliquots allowed to settle overnight. The supernatant was then removed and additional buffered water was added to rinse the aliquots. These were again allowed to settle, the supernatant was removed, and the samples were then

placed in drying ovens at 80° C. Dried samples were then cooled in desiccators and weighed.

The net weight of the remaining material -- the insoluble residue -- was subtracted from the net weight of the original sub-sample to yield an approximation of the carbonate fraction of the sand-size portion of the full sample. Replicate analyses were randomly performed on 20% of each batch of samples for quality control purposes.

Statistical methods were then utilized to compare the sedimentary properties over spatial and temporal scales. Correlation coefficients between all properties -- mean grain size, sorting, percent carbonate, and percent fine material -- were calculated and tested for significance to identify relationships between the four properties in each sample set. These four properties were also compared by time series. F-tests (analyzing the variances of the respective property distributions) and t-tests (analyzing the means of the respective property distributions) were calculated using methods suggested by Sokal and Rohlf (1981) and Rohlf and Sokal (1981). These tests were used to determine if there were significant differences in the mean grain size, sorting, percent carbonate, or percent fine material between the following sets of samples:

- MS96M and MS98JL
- IRB97N and IRB98JL
- IRB98N1 and IRB98N2

Significant differences in sedimentary properties between sample sets may indicate redistribution or reorganization of sediments by various mechanisms in the intervening time period.

Statistical analyses were also used to compare sedimentary properties with the side-scan sonar backscatter signal. At sediment sampling locations for which there were DGPS coordinates, the side-scan sonar backscatter intensity was approximated using the average gray scale value of the pixels (scale of 1-256) within a 10 m radius of the DGPS fix. Correlation coefficients were calculated and tested for significance between the four

sedimentary properties and the mean and standard deviation (sorting) of the gray scale values at each location. Statistically significant relationships were then noted. Multiple regression analyses were then calculated (Sokal and Rohlf, 1981) for each data set between mean gray scale value (dependent variable) and the sedimentary properties of mean grain size, sorting, percent carbonate, and percent fine material (independent variables). In the resulting regression summaries, coefficients for each independent variable and their significance were calculated. These coefficients could then be used with values of the independent variables at a given location to create an equation to predict the mean gray scale value of the side-scan backscatter intensity at that location from sedimentary properties. Regression equations were created for a variety of data groupings (all MS data, all IRB data, MS and IRB 500 kHz data) and compared with actual data to assess the accuracy with which the regression equations predicted side-scan backscatter intensity.

Collection, Processing, and Analysis of Box Cores

Diver-deployed box cores were collected coincident with the MS98JL and IRB98JL surveys (Figures 9 and 10). Six box cores were collected in the MS area in July 1998, two each near the two termini of the sediment sampling transect and two near the transect midpoint. Eight box cores were collected in the IRB sub-study region during July 1998, two each near the two termini of sediment sampling transect #2, two near the transect midpoint, and two from a sedimentary feature in the trough on the southwest side of the main sand ridge. Two additional cores were obtained in November 1998 at the transect midpoint site near the location of a current meter deployment.

Box Core Collection. Box cores were collected using a system of modified Klovans-style metal box corers as employed by Beavers (1999) and described by Greenwood et al. (1984). Dimensions of each coring unit were 15 cm wide by 30 cm long and 10 cm deep at

the widest point (top) (Figure 11). Each box has a panel which slides along furrows on either side of the open face of the box, effectively opening and closing the box core. The cores were collected by first anchoring the R/V Price at each designated site. Divers descended to the site and, using a compass, oriented two opened coring units, such that the 10 cm side of one unit was approximately parallel to the axis of the ridge and the same side of the other unit was perpendicular to the ridge axis, which had an approximate azimuth of 315°. The orientations of the open sides of the cores relative to the ridge axis, as well as the distance between the two cores, were noted by the divers.

The coring units were then inserted vertically into the sediment and hammered in, using a sliding weight on a handle which extended vertically upward from the top of the core. The cores were hammered in until the inside of the top of the coring unit reached the sediment-water interface. The door panels were then inserted into each core, closing the box, and each was removed from the sediment and placed in a plastic container for transport to the surface using a dive lift bag. This procedure was repeated at each location.

Box Core Processing. Once returned to the sedimentology laboratory, the cores were opened and allowed to dry partially overnight. Excess sediment was planed off each core until a uniform slab approximately 2 cm thick remained. During this process, sediment sub-samples were taken from 0-2 cm and from 13-15 cm depth in each core, except for the two cores taken in November 1998, which were sub-sampled at 2 cm intervals from the top to ~20 cm depth in the cores. The sides of each core were also trimmed to reduce the slab width to less than 15 cm. A thin metal plate was then inserted beneath the slab and an acrylic tray, pre-labeled with the orientation of each core's open side, was placed on top. The entire sample was then removed from the coring unit and inverted. The slab was then further planed to approximately 1 cm, the level of the sides of the acrylic tray.

Figure 11

The cores were then photographed with a depth scale, orientation, and location identification, before the sediment had dried completely. The cores were also described and logged, noting their location and orientation with regard to the ridge axes, the depth location of any embedded shells, apparent changes in color or grain size, and the shape and location of visible sedimentary structures. The cores were then allowed to air dry completely (approximately 24 hours).

Resin peels were then prepared from each box core slab using techniques described by Burger et al. (1969) and employed by Beavers (1999) and Greenwood et al. (1984). Printed labels, identifying each core location, orientation with respect to the ridge axes, and the date of collection, were prepared for each core. Fine mesh cheesecloth was cut to cover each slab tray, leaving ~2 cm excess over each edge. A thin coat of epoxy resin and hardener, used for boat repairs, was applied with a paint brush over the cheesecloth. This resin permeated the sediment slab, preserving structural and bioturbation features and immobilizing other embedded material such as shells. The printed identification labels were applied to the wet resin for permanent identification.

Cores were dried overnight. Once dried, each embedded core peel was removed from its tray and the excess cheesecloth trimmed away. A water hose was used to remove loose sediment from the exposed side of the peel, revealing preserved sedimentary features. The completed peels were allowed to dry and were photographed, to be scanned in for later computer analysis.

Box Core Analysis. Scans of the core peels were imported into Canvas[®] graphics software. Sedimentary structures, such as laminations, storm layers, burrows, and other identifiable changes were digitized. Structures from the duplicate cores were compared, as well as differences between sampling sites in each area and between the IRB and MS areas.

Sediment sub-samples from the box cores were processed and analyzed for grain size distribution using the same methods, described above, for surface sediment samples.

Collection and Analysis of Current Meter Data

Collection of Current Meter Data. InterOcean S4[®] electromagnetic current meters (Figure 12) were deployed three times to obtain hydrologic data in the study areas. The first two deployments were completed on April 25, 1998. Current meters were deployed in both the IRB and MS study areas. The midshelf study area current meter, designated MS98S4, was located at 27° 56' 35.5" N and 83° 05' 36" W (Figure 9). The inner shelf current meter, designated IRB98S4A was located at 27° 56' 19.4" N and 82° 54' 26" W (Figure 10).

The MS98S4 deployment utilized a concrete slab with a fixed mooring rod to anchor the current meter, raising the current meter base approximately 0.3 m above the seafloor. The IRB98S4A deployment utilized a slightly different platform, consisting of a concrete slab with a 15 cm upright section of 7.62 cm diameter PVC pipe attached. The current meter mooring rod was then inserted in the pipe and a bolt inserted through holes drilled in the pipe, through the mooring rod bushing, to secure the current meter to the platform. The base of the current meter then sat approximately 0.2 m above the seafloor (Figure 12).

Each current meter was set to collect data for five minutes every hour, providing five one-minute time-averaged current velocities (speed in cm/s, and azimuth) per hour at each site. The MS98S4 sensors were located approximately 0.5 m above the seafloor; the IRB98S4A sensors were located approximately 0.4 m above the seafloor. Both current meters were equipped with battery power for a three month deployment.

Data for the IRB98S4A deployment were collected from 16:00 GMT on 4/27/98 through 19:00 GMT on 7/30/98. Data for the MS98S4 deployment were collected from

Figure 12

16:00 GMT on 4/27/98 through 23:00 GMT on 5/4/98. The MS98S4 deployment was interrupted by the accidental dredging of the instrument from the seafloor by a shrimp boat trawling in the study area. Fortunately, the S4[®] was returned. However, on advice from the owner of the shrimping operation, the instrument was not re-deployed in that area as it is an area frequently trawled by commercial shrimpers.

A third current meter deployment was conducted in November 1998 in the IRB area (IRB98S4B). Bottom current velocities at 27° 56' 19.3" N and 82° 54' 26" W were collected from 20:00 GMT on 11/19/98 through 14:20 GMT on 11/25/98, recording hydrologic conditions between side-scan surveys IRB98N1 on 11/9/98 and IRB98N2 on 11/25/98. This deployment period was chosen to coincide with the passage of a weak cold front through the area, after the IRB98N1 survey on November 9, 1998. In order to detect the effects of wave orbitals generated by frontal winds on the bottom current velocities, the S4[®] was programmed to take continuous velocity measurements at the maximum frequency of 2 Hz; minimum recording rate was a vector average every six seconds (InterOcean Systems, Inc., 1994).

Current Meter Data Analysis. Current vectors for the MS98S4 and IRB98S4A deployments were broken into their u (cross shore) and v (along shore) components using techniques suggested by Fanchi (1997), in which:

$$u = r (\cos \phi) \quad \text{and} \quad v = r (\sin \phi)$$

where: r is the speed (cm/s) of the S4[®] current vectors, and
 ϕ is the azimuth (converted to radians) of the S4[®] current vectors

The five one-minute averages of u and v from each hour were then averaged together, respectively, providing hourly mean cross-shore and along-shore velocity components at each location for the length of their respective deployment periods. Mean velocities over these time-averaged scales are dominated by tidal current oscillations (Nielsen, 1992).

Plotting u vs. v produces a tidal current ellipse, indicating the magnitude and dominant direction of tidal currents over the data collection period.

Current vectors for the IRB98S4B deployment were also broken into their u and v components and graphed relative to time. Data from the S4[®] deployments were then used, along with sedimentary grain size data, in calculating indices of sediment transport. Shield's β (Middleton and Southard, 1984), a threshold measurement indicating initiation of sediment transport, is the ratio of current shear stress, τ_0 , to drag forces represented by sediment grain size (D_s) and specific gravity (γ), such that:

$$\beta = \tau_0 / g D_s (\gamma_s - \gamma) \quad \text{where } \tau_0 = C_d \rho_w U^2$$

This measure was compared to boundary Reynolds number, Re , which is the ratio of shear stresses acting on particle movement (represented by skin friction velocity, u_* , and D_s) to viscous forces that retard movement (ν , kinematic molecular viscosity) (Middleton and Southard, 1984). Re is calculated:

$$Re = u_* D_s / \nu \quad \text{where } u_* = (\tau_0 / \rho_w)^{1/2}$$

Plotting these parameters against one another for a series of mean grain sizes and bottom current velocities provides an indication of the conditions necessary for initiation of sediment movement and whether such conditions exist in the MS and IRB study areas.

