Naval Research Laboratory

Washington, DC 20375-5320

NRL/FR-MM/7420--02-10,012

Bathymetric Error Evaluation for Submarine Cruises in the Arctic Ocean Based on Track Crossover Differences

WOO-YEOL JUNG
PETER R. VOGT
IRENE JEWETT

Marine Physics Branch
Marine Geosciences Division

March 15, 2002

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave Blank*)

2. REPORT DATE

March 15, 2002

3. REPORT TYPE AND DATES COVERED

FINAL

4. TITLE AND SUBTITLE

Bathymetric Error Evaluation for Submarine Cruises in the Arctic Ocean Based on Track Crossover Differences

5. FUNDING NUMBERS

N/A

6. AUTHOR(S)

Woo-Yeol Jung, Peter R. Vogt, and Irene F. Jewett

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
Washington, DC 20375-5320

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/FR-MM/7420--02-10,012

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Imagery and Mapping Agency (NIMA)
12310 Sunrise Valley Drive
Reston, VA 20191 - 3449

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

A

13. ABSTRACT (*Maximum 200 words*)

(U) Single-beam echo-soundings from 1958 to 1988 submarine cruises (more than 120,000 km track) to the deep Arctic Basin, and from 1993 to 1999 SCICEX submarine cruises to the same region (ca. 100,000 km track) are evaluated for their accuracy by calculation of crossover differences (CODs). Where two tracks cross, any depth difference indicates that one or both soundings are in error. We show that the 1993 to 1999 CODs are significantly lower than the 1958 to 1988 CODs, so that to first order the CODs are a measure of 1958 to 1988 sounding error. In the case of SCICEX vs SCICEX and pre-SCICEX vs pre-SCICEX CODs, the assumption that errors in each category of CODs are independent and normally distributed implies statistically that the errors are on the order of 70% of the CODs, which are generally in the range of meters to tens of meters for the first category and 10s to 100s for the older data. Of the three types of error, Type I is incorrect depth at the right place, Type II is the right depth displaced to the wrong place by navigation error, and Type III is caused simply by interpolation of soundings to the track intersection point. In this report we use simulated perfect bathymetry to estimate Type III errors, showing that the effect of this error on CODs is small. A strong dependence of COD on local slope suggests that the Type III (navigation-generated) errors dominate. This dependence is used to estimate the CODs, and hence sounding errors, along tracks away from track intersections. The rich sounding database near the North Pole yields the most credible bathymetry if only the 1993 to 1999 data are used, with all other soundings excluded. The potential of aerogravity data to “predict” topography in poorly sounded, high relief area is demonstrated.

14. SUBJECT TERMS

Bathymetric Error Evaluation, Arctic Submarine Cruises, Crossover Differences

15. NUMBER OF PAGES

25

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

CONTENTS

BATHYMETRIC ERROR EVALUATION FOR SUBMARINE CRUISES TO THE ARCTIC BASIN BASED ON TRACK CROSSOVER DIFFERENCES

INTRODUCTION

This report summarizes an analysis of nadir echo-sounder water depth differences at intersections of submarine tracks in the deep Arctic Basin. The analysis was motivated primarily by the need to assess the accuracy of 1958 to 1988 soundings. This assessment was made possible by recent (1993 to 1999) Scientific Ice Expeditions (SCICEX) submarine cruises to the Arctic Basin. Wherever a better-navigated SCICEX track crosses an older line of soundings, the depth difference at the intersection point will largely reflect measurement or navigation errors in the older data. However, in this report we also examine SCICEX vs SCICEX track intersections for crossover differences (CODs).

To clarify the distinction between crossover differences and sounding errors at the track intersections, we pose the following simplified version of the problem: Assume that two sounding datasets, A and B (for example, two cruises, or the data from two cruises collected in the same physiographic province), each have normally distributed sounding error distributions, s_A and s_B, and a mean error of zero. Assume further that the errors are independent – which certainly is true when different cruises are compared. The true depth at a track intersection is unknown, as we can only calculate the COD. Let C be the distribution of CODs, which will also have a zero mean, but a different distribution, whose s_C we can estimate. Consider the following two limiting situations: (1) Both cruises (or datasets) have comparable errors, so $s_A \sim s_B$; and (2) one cruise (or dataset) is much more accurate than the other, so, if the accurate data are called A, then $s_A / s_B \sim 0$. As a rough approximation, we suppose that situation (1) applies to CODs between/among pre-SCICEX cruises and between/among SCICEX cruises, whereas situation (2) applies to SCICEX/pre-SCICEX CODs. To the extent that the latter is true, $s_B \sim s_C$ represents the error of pre-SCICEX soundings. For situation (1), we solve the equation:

$$\sigma_C = \mathbf{f}\,(\sigma_A, \sigma_B) = (\sigma_A{}^2 + \sigma_B{}^2)^{1/2} = \sigma_A \sqrt{2},$$

so that $s_A = (1/\sqrt{2})s_C$. In other words, the standard deviation of the actual errors is only about 70% of the CODs calculated for this report, to the extent the above assumptions apply.

The U.S. Navy made Sturgeon-class nuclear submarines available for the unclassified SCICEX research program in the Arctic Ocean from 1993 through 1999. SCICEX cruises collected many types of high-quality data in the Arctic Ocean. Prior to the SCICEX cruises, single-beam bathymetric data collected by transiting U.S. nuclear submarines had remained classified until released to the public in July of 1999. NRL (Code 7420) “re-navigated” the pre-SCICEX cruises between 1958 and 1982, digitized the analog sonar records, and merged the data for first-order analysis. These data were digitally “blunder-checked” for gross errors and bad soundings (three complete cruises were deleted from the dataset). Other Arctic bathy-

Manuscript approved September 17, 2001.

metric data made available to us at the time of our analysis include irregularly distributed soundings from ice stations/islands and ice-breakers as shown in Fig. 1. **(See accompanying CD for all figures.)**

The SCICEX 98 and 99 cruises used the Seafloor Characterization and Mapping Pods (SCAMP), a geophysical survey system for use on submarines. SCAMP consists of a swath-mapping sonar known as the Sidescan Swath Bathymetric Sonar (SSBS), the High Resolution Subbottom Profiler (HRSP) (a swept frequency or “chirp” subbottom profiler), a marine gravimeter, and the computer infrastructure to control, monitor, log, and validate the data (SCICEX-98, -99 Science Cruise Report, 1998, 1999). Bathymetry in the SCAMP system is determined from measurements of the phase difference between signals derived from the four rows/side array transducers (SCICEX-99 Science Cruise Report). The SSBS-derived bathymetry data were not available to us at the time of our analysis and were not used in this report. SCICEX submarines navigated by Submarine Inertial Navigation Systems (SINS), with locations updated by GPS when the submarine surfaced. However, the data collected between 1958 and 1988 were navigated entirely by SINS over long distances and are no match for GPS-controlled data. If and when individual submarines made North Pole surfacings, SINS was updated by TRANSIT satellite fixes. However, pre-SCICEX operations were generally conducted under submerged conditions. Whereas SINS is subject to some positional drift, the GPS-enhanced SCICEX data are reported to show high internal consistency, as implied by the low bathymetric crossover differences observed during each cruise (Coakley and Monahan 1999).

Given the reported success of SCICEX cruises (Coakley et. al. 1997), the overall bathymetric data quality from those cruises is expected to be higher than for data collected on pre-SCICEX cruises. Therefore, we use the SCICEX bathymetry as a standard for evaluating the older bathymetric data. No comparisons have previously been made between SCICEX and pre-SCICEX datasets at track crossings. An analysis of the older data (pre-SCICEX) against each other, and then against the modern SCICEX data, helps determine the reliability of operational charts produced from submarine cruise data in the high Arctic. One purpose of this study is to evaluate the accuracy and reliability of both SCICEX and pre-SCICEX datasets. Another purpose is to derive an empirical model to estimate probable sounding errors for all the data and to append this estimated uncertainty to each sounding in the bathymetric data files.

DATA SOURCE / PREPARATION

The bathymetric datasets used in our analysis are 1) the “older” (pre-SCICEX) submarine cruises released by the U.S. Navy for public distribution on a CD-ROM (U.S. Navy 1999) under the title “Bathymetry Collected by United States and United Kingdom Nuclear Submarines in the Arctic Region 1958 to 1983;” 2) the 1993 to 99 SCICEX single-beam bathymetry provided by Dr. Bernard Coakley; and 3) additional sounding data from pre-SCICEX cruises between 1983 and 1988 that were provided by N. Z. Cherkis (formerly NRL Code 7420). In this analysis, the pre-SCICEX datasets are divided into three subgroups: SUBSET-1 from 1958 through 1962 (six files total), SUBSET-2 from 1966 through 1972 (six files total), and SUBSET-3 from 1973 through 1982 (ten files total). The additional data from N. Cherkis (from 1983 through 1988) were compiled from ten different cruises but were grouped into one subgroup, SUBSET-4. The SCICEX files comprise six cruises on PARGO (1993), POGY (1994), CAVALLA (1996), ARCHERFISH (1997), and HAWKBILL (1998, 1999) and are all grouped into one subgroup, SCICEX. All the water depths from submarine cruises are obtained by adding the uncorrected soundings below the transducer to the transducer depth, determined from a pressure gauge. No corrections were made for vertical or horizontal variations in sound speed. A constant (nominal) sound speed of 1500 m/s was assumed throughout. Table 1 summarizes the total number of data points and track length in each subgroup used in our analysis.

The first step of the data preparation was a visual inspection of all the data points on paper plots or on a computer graphics screen to remove spikes, tares, and other obviously erroneous data points or groups of data points. The “despiking” of data, as well as the elimination of bad navigation points, was accomplished subjectively, based on long-term NRL experience with analyzing bathymetric data. Specifically, for this purpose, we used the plots of all the data points in the depth vs time (or data number) profile, as well as on a latitude vs longitude track-plot, to visually mark bad data points. In case of doubt, soundings were left in the database. It was also discovered that the pre-SCICEX datasets (U.S. Navy 1999) contain track segments “out of order”, i.e., not in the order the track was actually run, while other segments are present as duplicates on the CD. The accompanying CD-ROM includes our re-edited version of the datasets, which omits data spikes (outliers) and duplicated track segments, and presents the files in what we inferred to be the proper order.

Upon removal of bad data points and duplicate profile sections, those bathymetric tracks crossing the 90°E to 90°W meridian were further segmented into separate files because the crossover difference calculating program (XOVER) we used (Wessel 1989) could only handle a file whose maximum and minimum longitude span is less than 180°. Files with large data gaps were further segmented to avoid calculation of CODs within the data gaps. Table 2 lists the file name assigned to every segmented file, together with the total number of data points, track length, and mean/median data point separation of that file. The program XOVER requires the presence of time information for each data point. However, the pre-SCICEX datasets provided to us do not include such time information, while the SCICEX datasets include the time of measurement. We therefore added fictitious time information to the pre-SCICEX data points prior to COD analysis. We simply took the cumulative data counter number as the “faked” time (i.e., one minute data gap) information. However, the “faked” times are not included in the cleansed bathymetric files on the accompanying CD-ROM.

Where CODs occur at track intersections, one or the other sounding (or both) must be in error at the intersection point (but note Type III errors below). Where one line of soundings is correct, or nearly so, the COD will be a measure of error in the other line (for example, in a pre-SCICEX track, to the extent that sounding along a SCICEX track crossing it is essentially correct).

ERROR SOURCES

Three classes of sounding errors may contribute to the CODs calculated in the present analysis: I) Intrinsic errors in the depth measurement itself; II) Errors due to incorrect spatial placement of a sounding, mostly due to navigation errors; and III) Errors in our interpolation of soundings to the points of track intersection (crossover). The purpose of this report is to estimate errors of Type I and II; however, doing so requires estimation of the Type III errors, which are introduced by the crossover analysis used in this study.

An incomplete list of possible Type I errors, including small ones usually neglected, includes the following: A) errors due to registration of side-echoes vs nadir returns in rough terrain, generally causing the depth below the vessel to be underestimated; B) errors due to low seafloor/water acoustic impedance contrast, causing the bottom-detect algorithm to mistake shallow subbottom reflectors for the bottom, or to skew the calculated bottom to a depth greater than the seafloor depth; C) temporal changes in the sound velocity structure, causing temporal changes in the vessel-bottom reflection time; D) temporal changes in the height of the ocean surface, due to tides, air pressure or wind changes, or ocean current changes; E) erroneous correction for the depth of the submarine’s transducer below the sea-surface.

Type II errors depend on bottom roughness at bathymetric horizontal scales on the order of 100s of meters and up. If the bottom is flat, a navigation error will not cause a depth error; if the bottom is rough, the steeper the seafloor slope, the larger the navigation-induced depth error will generally be. However, this rule of thumb only holds for relatively small navigation errors with a significant component in the up or down-slope direction. A large navigation error could move a deep sounding entirely across a local ridge and into the next valley, so the sounding might not appear erroneous. Such large navigation errors (greater than 5 or 10 km) are present in the older submarine cruise data but can be identified by examining a section of profile vs an isolated sounding, and additionally, by comparison with independently known gravity anomalies (see below). If soundings are displaced, by navigation errors, in a direction parallel to the slope or in any direction on a level summit plateau or valley floor, they would not be apparent as bathymetric errors.

Type III errors, caused by interpolation of depth, along two crossing sounding lines to the point of track intersection, are similarly absent for level seafloor, and generally increase with increasing bottom roughness at bathymetric horizontal scales greater than a few hundred meters on typical deep (a few km) ocean floor. Type III errors diminish to zero as the spacing between adjacent soundings goes to zero, or if the sea bottom in the area occupied by the two pairs of soundings closest to the track crossing approaches a horizontal or tilted plane.

In general, bathymetric errors of almost all types should be smaller over abyssal plains (like the Canada Abyssal Plain) than over rough terrain e.g. on the Alpha or Nansen-Gakkel Ridges as shown in Fig. 1. Any large errors (tens of meter and higher) over seafloor plains can only be of Type I. The analysis in this report compares calculated CODs to local bathymetric gradients because, as pointed out above, errors of all three types are likely to be greater over rough terrain than over plains. Errors in low or zero-slope regions will give an estimate of the total Type I error. In addition, the errors are examined as a function of water depth, because very low slopes correspond to the shallowest water (shelves and plateau summits) and deepest water (abyssal plains). Most high slopes, however, occur at intermediate depths (the continental slopes, Chukchi Borderland, Alpha-Mendeleev Ridge, Lomonosov Ridge, and Nansen-Gakkel Ridge).

CROSSOVER ANALYSIS

The calculation of COD is straightforward once a pair of bathymetric files (listed in Table 2) is selected. The program XOVER searches for an intersection point by partitioning the tracks into smaller pieces and then comparing these pieces with each other (Wessel 1989). XOVER has options for a mode of interpolation to calculate the COD at an intersection, as well as for a data gap limit, to avoid computing a COD where the time (and distance) separation between two consecutive points is large. In our analysis, the COD was calculated from the four soundings closest to each track intersection (two from each track) by a linear interpolation scheme. (The influence of linear interpolation on the CODs, i.e., Type III errors, which depend on topographic relief and data point separation, is discussed in the following section.) The option for data gap omission was set to a large number (99999) to find all the CODs, regardless of data gaps. This scheme may have resulted in some spurious CODs, but such a strategy was necessary because time information for the pre-SCICEX datasets remains classified. To minimize the number of unwanted CODs at large data gaps, we segmented the datasets into smaller subsets, separated at data gaps. (The pre-SCICEX bathymetric datasets had been prepared by digitizing different echograms from different cruises and combining these into a larger file. These digitized files did not include navigation information. The merged files, however, contained both time and location. Times and dates were deleted prior to release of the CD-ROM to the public by the U.S. Navy in July of 1999).

The CODs were grouped into two categories: “internal,” where CODs were calculated from individual cruise portions (each a separate file), and “external,” where CODs were calculated by comparison with another cruise. Where originally larger files had to be segmented into smaller ones as a result of large geographic data gaps, the computed CODs from the original file were then grouped into the “internal” category. For example, pre-SCICEX Subset 1 consists of six different files with file names from 1-104 to 1-602 (Table 2). Therefore, a COD was grouped into the SUBSET 1 "internal" (i.e., *xover_1.int* in the accompanying CD-ROM) when it was calculated from each individual file, but grouped into SUBSET-1 "external" (i.e., *xover_1.ext* in the CD-ROM) where it was calculated from a different combination among six files. The complete listing of the CODs is provided on the accompanying CD-ROM; Table 3 shows a sample COD listing. The locations of CODs are plotted with a track plot for each subset in Fig. 2.

To visually determine if the patterns of CODs are related to physiography, we plotted the CODs on a bathymetric contour map of the Arctic Ocean as shown in Fig. 3. The overall geographic distribution shows that CODs generally exhibit larger values over the ridges, continental slopes, and seamount areas, and smaller values over the basin areas. In some places, the COD distribution is heavily clustered because of highly localized SCICEX (ARCHERFISH) platform maneuvering during onboard oceanographic measurements and water sampling. Figure 4 presents an example of clustered CODs. Large numbers of CODs, mostly internal CODs from SCICEX cruises as displayed in Table 4, reflect a number of such clusters. The location and value of CODs as shown in Fig. 4, however, appear to demonstrate the reliability of the program XOVER to calculate CODs. The CODs were binned with respect to the averaged intersection water depth for each subset; the total number of occurrences, mean, standard deviation, and maximum amplitude within each bin are presented in Table 4. Scatter plots of the CODs vs mean intersection depth show that the majority of SCICEX points are more densely distributed within a narrow band of error, throughout all water depths, compared to pre-SCICEX data as displayed in Fig. 5. Among SCICEX scatter plots, the HAWKBILL internal CODs exhibit a greater scatter compared to other SCICEX data, which may be attributed to the fact that most of HAWKBILL CODs are located in the rugged bottom topography of the Nansen-Gakkel Ridge. We have also plotted a simple arithmetic median of absolute CODs for each depth interval, superimposed on a frequency vs. water depth histogram, which is depicted in Fig. 6.

In level areas, CODs that exceed a certain value determined by the small slope are due to factors other than navigation error. As previously noted, presumably the CODs will be much larger over topographic slopes, and should, therefore, be distributed from an upper limit determined by the maximum slope, and scattering down to zero. (One could get a zero COD if the navigation error happens to parallel the local topographic contours, in the absence of other errors.) If the COD is large compared to the local terrain, this relationship would not hold, although the COD would still show a relation to relief in the area. To examine if there is a relationship between the slope angles and CODs, we first determined slope angle components along the bathymetric tracks by taking a three-point average at every data point, as shown in Fig. 7. We then determined the average slope angle from the nearest four data points for every track intersection. Scatter plots of the COD vs mean slope angle for each subset are presented in Fig. 8. The CODs were also binned with respect to mean slope angles, as in the case of binning by water depth, and these results were tabulated in terms of the number of occurrences, the mean of absolute CODs, the standard deviation, and the maximum value within each slope angle bin, as shown in Table 5. Figure 9 is a plot of the median of absolute COD against slope angle, superimposed on a frequency histogram for each bin angle. Rare high mean values may reflect incomplete removal of bad data points ("spikes").

To estimate Type III errors, we further examined the relation between the COD and the data point separation at the intersections, following the method that was used above for the intersection water depth and slope angle. The average data point separation was determined by taking the average of the distance of two neighboring data points over tracks at the intersection. Figure 10 shows scatter plots of the COD vs the mean separation distance for each subset. Overall, pre-SCICEX points are more widely spaced than SCICEX soundings. Figure 11 shows that most of the SCICEX median sounding separations are less than 1 km, whereas some pre-SCICEX median separations exceed 10 km. The larger separations between pre-SCICEX soundings may not all be due to lack of measurements. Some larger separations (gaps) may be attributed to unidentified file connection points, for files not appropriately segmented in this analysis. As mentioned previously, Type III errors over flat, level seafloor will be negligible regardless of the data point separation, while they could be significant with increasing bottom relief. The scatter plot for the case of the HAWKBILL seems to support this premise: the plot shows a wide range of CODs, regardless of the averaged data point separation, and most of the high HAWKBILL CODs are located over the rugged Nansen-Gakkel Ridge.

For decades, crossing the North Pole itself has been one of the goals on many nuclear submarine cruises in the Arctic Ocean. Consequently, many soundings have been made in the vicinity of the North Pole. A close look at such historical measurements in the area may thus shed light on how echo sounding and navigation have improved over time. Figure 12(a) is a geographic distribution of soundings within a ca. 2.2 km radius of the North Pole. Depths were also plotted against radial distance from the Pole, as shown in Fig. 12(b). Generally, all recent SCICEX soundings cluster around an uncorrected water depth of 4169±4 m at the North Pole (4111 m corrected by Matthews' tables (1939); 4115 m corrected by Carter's tables (1980)), whereas the older pre-SCICEX depths are distributed across a wider range of about 50 to 125 m from this mean North Pole depth. Figures 12(c) and 12(d) depict a best-fitting regional plane fitted to SCICEX soundings near the North Pole. This plane dips southeastward (when looking north along the zero meridian) at about 9.6 arcsec (2.67 : 1000) slope angle. A southeastward deepening bottom is not unexpected, as the North Pole is located on the lower Eurasian flank of the Lomonosov Ridge, near the edge of the Amundsen Abyssal Plain. The calculated slope angle is typical for lower continental rises in the world ocean.

Because the International Bathymetric Chart of the Arctic Ocean (IBCAO) chart and database (Jakobsson et al. 2000) is the latest and presumably most accurate seafloor map for the Arctic Ocean, we compared the sounding datasets used for our report with the IBCAO gridded dataset for an area within ca. 8 km of the North Pole, as shown in Figs. 12(e), 12(f), and 12(g). To facilitate this comparison, we first gridded and contoured our "SCICEX only" dataset, as illustrated in Fig. 12(e). The "SCICEX plus pre-SCICEX" dataset was similarly treated, as shown in Fig. 12(f). In both cases, we used the same 2.5 km grid spacing used in the IBCAO dataset, which is shown contoured in Fig.12(g). The "SCICEX only" contours show a relatively smooth lower continental rise (we use the latter term because the nearby Lomonosov Ridge is a micro-continent), sloping gently downward toward the Amundsen Basin (Pole Abyssal Plain). This overall morphology is consistent with some earlier charts (e.g., Perry et. al. 1985), but not with the IBCAO chart, which shows moderate relief in this area. The contours in Fig. 12(e) are also consistent with the contours and other plots for the small area in the immediate vicinity of the North Pole, as shown in Fig. 12(c). Finally, the smooth seafloor character (ca. 35 m total relief across the chart area of Fig. 12(e)) is consistent with individual echo-sounder profiles across the area, which show a smooth seafloor. When the same area is gridded and contoured by inclusion of all SCICEX and pre-SCICEX soundings we used for this report, the resulting seafloor map presented in Fig. 12(f) shows a total relief of 60 m, and several unnatural-looking closed highs and lows, a topography with several tens of meters relief. The overall gentle slope toward the Pole Abyssal Plain is still evident. We consider the highs and lows to be artifacts, introduced by inclusion of lower-accuracy pre-SCICEX submarine and other soundings used in Russian Ministry of Defence (1999).

The IBCAO-generated contours for this area, presented in Fig. 12(f), look even more "unnatural," and the total relief according to this version exceeds 100 m. Some of this unnatural relief is due to inclusion of pre-SCICEX data, but the large differences between Fig. 12(f) and Fig. 12(g) suggest that IBCAO included additional soundings, and interpreted them differently, so as to produce the contours in Fig. 12(g). In any case, the IBCAO seafloor picture in this area near the North Pole has evidently been distorted by artifacts, caused by inclusion of soundings of low accuracy. While the IBCAO chart and database are surely an improvement over earlier charts over most of the Arctic Ocean, at least near the North Pole the older chart of Perry et al. (1985) shows a more accurate view, at the lower resolution of that chart, than does the IBCAO chart. We are sure of this because of the accuracy of the SCICEX sounding database, which we have verified for this report.

TYPE III ERRORS PREDICTED FROM SIMULATION

To examine how different data point separations affect the COD interpolated to the track intersections over a high relief seafloor (i.e., to estimate Type III errors introduced by our interpolation), we first generated a “perfect” bathymetry dataset with closely spaced soundings and a zero COD at every track intersection. We posed the question: what would happen to the calculated COD if progressively more sparse sounding datasets were created by progressive decimation (deletion) of soundings from this “perfect” dense dataset? Relatively flat areas like the Canada Basin would not show rapidly increasing CODs, but high-relief areas are more likely to have variable CODs as the data point separation (spacing) increases. To evaluate the magnitude of this “method generated” error source, we took all the available soundings over the Alpha Ridge and gridded them to form a “perfect” dataset, as shown in Fig. 13. In Fig. 14, we then linearly interpolated this gridded bathymetry with a variable sample interval along selected lines. After adding fictitious time information to each interpolated data file, we ran the program XOVER for every sounding pair to calculate CODs. The results show that the mean COD for each depth interval increases as the data sample interval increases. The COD at every intersection increases as the sounding separation increases over the Alpha Ridge, as shown in Fig. 15. As expected, in Fig. 16, our simulation reveals that the COD increases more sharply over steep topographic-gradient seafloor areas than over smoother seafloors. However, our “perfect” bathymetry is probably smoother than the actual bathymetry, so Type III errors are probably somewhat larger than derived from our simulation.

PREDICTING TOPOGRAPHY FROM GRAVITY

NRL has been mapping gravity and magnetic anomalies of the Arctic Ocean area aboard fixed-wing aircraft since the 1970s. The advantages of airborne measurements (as opposed to icebreaker, submarine, and ice island data) are not only more densely and evenly spaced data but also reliable, continuous GPS navigation control. Figure 17(a) is a map of free-air anomalies over the Alpha Ridge, based on NRL’s airborne gravity measurements. To exploit the presence of high-quality gravity anomaly datasets in the Arctic Ocean, we have “predicted” bathymetry from gravity anomalies, following Jung and Vogt (1992) and Sandwell and Smith (1999). The inversion algorithm is based on knowledge that short wavelength (20 to 200 km) gravity anomalies are closely correlated with seafloor topographic features in that part of the spatial spectrum. Figure 18 presents three sample profiles of predicted bathymetric profiles that were interpolated along the observed submarine-based bathymetry, together with the airborne gravity values interpolated from the NRL data over the Alpha Ridge. The results clearly show that the observed bathymetric relief appears offset from the predicted profile. Since the airborne gravity data were collected with accurate kinematic GPS navigation, we tentatively attribute the mismatches to navigation errors on the submarine cruise. This technique (using gravity to “predict” bathymetry) could correct some bad navigation errors in the observed pre-SCICEX submarine bathymetry in areas of high-quality, dense airborne gravity coverage. At this time, more than 60% of the Arctic Ocean area has been surveyed by the NRL Code 7420 Aerogeophysics Program. Further exploration of this technique is beyond the scope of the present project, but could be undertaken if funding is made available in the future.

ERROR PREDICTION AWAY FROM TRACK INTERSECTIONS

The empirical correlation between mean and median COD and the seafloor slope angle can be exploited to estimate maximum error along tracks away from track intersections. Upon derivation of an empirical relation between slope angles and pre-SCICEX and SCICEX CODs as depicted in Fig. 19, we can use this relation to estimate the bathymetric errors at other (non-crossover) points along sounding lines, as shown in Fig. 20. This estimated maximum COD is appended as the last column in each of the tables, also provided on the accompanying CD. It should be noted that the seafloor slope angle, computed along-track, generally underestimates the true slope. For example, in an extreme case, where a track runs parallel to the depth contours, the computed slope angle will be zero, and therefore also the predicted error. A better way to predict error would be to use a local planar slope angle at every data point, as we did in the North Pole area. However, only in a very few areas are soundings frequent enough, within a given radial distance of a given point, to allow computation of a best fitting plane. Table 6 is a sample of the appended error, and Fig. 20 is a map of the predicted errors and calculated CODs in the Arctic Ocean. The predictions are based on subjective linear fits to the computed relation between slopes and CODs shown in Fig. 19. We chose to be conservative, i.e., to err on the side of overestimating the actual error.

CONCLUSIONS AND RECOMMENDATIONS

More than 120,000 km of pre-SCICEX (1958 to 1988) and 100,000 km of SCICEX (1993 to 1999) submarine cruise tracks in the Arctic Ocean were analyzed to assess bathymetric errors, on the basis of track crossover depth differences. The total number of calculated CODs is 2312 within the pre-SCICEX files (983 external and 1329 internal CODs); 79086 within the SCICEX files (1737 external and 77349 internal); and 2674 between the pre-SCICEX and SCICEX files. Mean/median CODs increase with bottom slope, particularly in the case of the SCICEX dataset, suggesting that navigation errors are a significant source of depth error (Note that some Type I errors also increase with slope). A few CODs of many 100s to several 1000s of meters probably reflect isolated spikes or outliers that have not been completely edited out in the data preparation procedure. The median SCICEX internal COD is in the 1 to 5 m range where slope angles are less than 2°, and in the 5 to 50 m range where slope angles exceed 2°. The SCICEX external CODs are in the 5 to 10 m range where slope angles are less than 1°, and 50 to 400 m where slope angles exceed 1°. The median pre-SCICEX internal COD is in the 5 to 40 m range for slope angles less than 1°, and in the 30 to 100 m range where slope angles exceed 1°. The pre-SCICEX external COD is in the 25 to 75 m range for slope angles less than 1°, and in the 50 to 500 m range where slope angles exceed 1°.

The total number of CODs for SCICEX vs SCICEX files is 79086, and its mean and median are 12.1 m and 1.9 m, respectively. The total number of CODs for pre-SCICEX vs pre-SCICEX is 2319, and its mean and median are 90.3 m and 34.3 m. The total number for SCICEX vs pre-SCICEX CODs is 2674, with mean and median values of 123.1 m and 38.8 m, respectively. The mean and median COD of SCICEX vs SCICEX is about 0.68% and 0.07% of the water depths, while those of pre-SCICEX vs pre-SCICEX is 5.01% and 1.61%, respectively. The mean and median COD of SCICEX vs pre-SCICEX COD comprise 6.17% and 1.56% of water depths, respectively. The very low values of SCICEX vs SCICEX COD mainly reflect the large number of geographically clustered intersections in areas of oceanographic measurements.

The depth at the North Pole was estimated to be 4169±6 m (4111±6 m upon correction by Matthews' tables; 4115±6 m by Carter's tables) from 119 SCICEX soundings within a ca. 2.2 km radius of the Pole. Pre-SCICEX soundings claimed to have been made near the North Pole differ by up to ca. 50 to 125 m from this mean SCICEX North Pole uncorrected depth (4169 m). These depth discrepancies probably reflect navigation errors on some of the earlier cruises, which may therefore have missed the North Pole, perhaps by up to 20 km or more.

We have also demonstrated the potential value of NRL's aerogravity data (e.g., Brozena et al. 1997) for improving Arctic bathymetry at spatial scales from ca. 20 to 200 km wavelengths, and for detecting and perhaps correcting for large navigation errors in the early submarine cruises. Gravity data are of value for "bathymetric prediction" because most of the variance of the gravity anomalies in this band in the ocean basins is due to the density structure represented by seafloor topography (e.g., Jung et al. 1999). The airborne gravity field data can be used as a guide to adjust the SINS-navigated bathymetric data. NRL Code 7420 is prepared to further develop and exploit this technique to improve the accuracy of Arctic Basin bathymetry in sparsely sounded areas if funding can be found.

ACKNOWLEDGMENTS

We thank Richard Martino (NIMA) for funding this study. B. Coakley (then at LDEO) supplied the U.S. Navy nadir echo-sounding data from the SCICEX cruises. We further thank H. Fleming, L. Kovacs, J. Brozena, J. Gardner, and N. Cherkis for their input of ideas and data, and L. Kovacs, N. Cherkis, and J. Gardner for reviewing this report.

Table 1 — A Summary Sheet of Data Files Used in this Analysis

PRE-SCICEX (1958-1988)

BEFORE PROCESSING:

Subset	Files	Points	Length
SUBSET 1 (1958-1962)	6 files	66331 points	
SUBSET 2 (1966-1972)	6 files	18425 points	
SUBSET 3 (1973-1982)	10 files	115773 points	
SUBSET 4 (1983-1988)		3790 points	

AFTER PROCESSING:

Subset	Files	Points	Length
SUBSET 1 (1958-1962)	12 files	52763 points	36054 km
SUBSET 2 (1966-1972)	10 files	17466 points	15997 km
SUBSET 3 (1973-1982)	20 files	105791 points	48901 km
SUBSET 4 (1983-1988)	10 files	2910 points	11944 km

SCICEX (1993-1999)

AFTER PROCESSING:

Cruise	Year	Files	Points	Length
PARGO	(1993)	6 files	12276 (25900*) points	8694 km
CAVALLA	(1995)	5 files	53176 (59989*) points	20461 km
POGY	(1996)	5 files	60623 (64300*) points	25879 km
ARCHERFISH	(1997)	2 files	31416 (42707*) points	15968 km
HAWKBILL	(1998)	4 files	30302 (44727*) points	19444 km
HAWKBILL	(1999)	5 files	52132 (60867*) points	31436 km

* Original data points including zero depths and outliers

Table 2 — List of File Names with Total Data Points, Track Length, and Mean/Median Data Point Separation

Pre-SCICEX: SUBSET-1

file name	total number	total length (km)	interval (km) mean	interval (km) median
1-104	2112	2317.04	1.10	0.62
1-201	3474	2851.68	0.82	0.41
1-202	2316	962.80	0.42	0.29
1-203	4504	2671.32	0.59	0.38
1-300	11445	5352.82	0.47	0.20
1-302	877	582.71	0.66	0.58
1-401	3605	2783.11	0.77	0.61
1-402	3465	2569.56	0.74	0.47
1-403	4171	3268.53	0.78	0.49
1-502	2318	1981.50	0.85	0.50
1-504	2965	2954.97	1.00	0.56
1-602	11511	7765.89	0.67	0.37
subtotal:	52763	36054.45		

Pre-SCICEX: SUBSET-2

file name	total number	total length (km)	interval (km) mean	interval (km) median
2-101	8190	2819.59	0.34	0.19
2-201	1542	1182.69	0.77	0.61
2-202	2803	1946.58	0.69	0.54
2-301	270	2606.04	9.65	6.91
2-501	1670	2009.13	1.20	0.68
2-502	1810	2062.58	1.14	0.70
2-503	383	499.32	1.30	0.71
2-601	216	668.68	3.10	2.74
2-6031	397	1520.96	3.83	3.27
2-6032	185	695.80	3.76	3.48
subtotal:	17466	15998.66		

Pre-SCICEX: SUBSET-3

file name	total number	total length (km)	interval (km) mean	interval (km) median
3-1001	513	3946.56	7.69	5.03
3-102	15831	5800.56	0.37	0.29
3-201	5001	1875.32	0.37	0.21
3-202	4619	1781.09	0.39	0.30
3-301	13562	2471.88	0.18	0.11
3-401	26653	7913.44	0.30	0.20
3-402	11372	2940.31	0.26	0.19
3-403	4089	1904.81	0.47	0.32
3-404	1011	473.89	0.47	0.45
3-502	3094	2816.53	0.91	0.81
3-601	1324	734.52	0.55	0.32
3-602	1057	768.10	0.73	0.53
3-604	7232	2045.16	0.28	0.23
3-606	2316	1083.58	0.47	0.34
3-701	535	713.37	1.33	0.90
3-703	284	325.76	1.15	0.75
3-802	3712	3266.69	0.88	0.70
3-804	2428	2161.14	0.89	0.71
3-901	695	3776.08	5.43	4.87
3-903	463	2123.39	4.59	3.92
subtotal:	105791	48900.57		

Pre-SCICEX: SUBSET-4

file name	total number	total length (km)	interval (km) mean	interval (km) median
4-100	77	472.04	6.13	3.09
4-101	571	2604.03	4.56	3.30
4-103	903	2138.39	2.37	1.77
4-104	376	1293.81	3.44	3.73
4-107	95	1626.01	17.12	16.34
4-108	128	504.39	3.94	3.60
4-4	104	366.93	3.53	3.47
4-5	546	2570.04	4.71	4.59
4-6	56	275.95	4.93	4.73
4-9	54	128.20	2.37	2.88
subtotal:	2910	11943.82		

SCICEX

file name	total number	total length (km)	interval (km) mean	interval (km) median
archer01	1680	986.15	0.59	0.45
archer02	29736	14981.78	0.50	0.43
cavalla01	39903	14623.78	0.37	0.34
cavalla02	1666	851.17	0.51	0.44
cavalla03	4561	2029.32	0.44	0.40
cavalla04	467	187.21	0.40	0.39
cavalla05	6579	2769.27	0.42	0.39
pargo01	575	791.13	1.38	1.20
pargo02	9589	6761.25	0.71	0.44
pargo03	831	437.16	0.53	0.44
pargo04	358	217.98	0.61	0.44
pargo05	200	96.71	0.48	0.39
pargo06	723	389.14	0.54	0.44
pogy01	7948	3522.09	0.44	0.44
pogy02	1870	611.46	0.33	0.24
pogy03	33721	12058.98	0.36	0.31
pogy04	5118	3617.80	0.71	0.62
pogy05	11966	6068.99	0.51	0.52
hb98n0	903	280.69	0.31	0.16
hb98n1	4292	4706.96	1.10	0.51
hb98s1	9766	5221.54	0.53	0.45
hb98s2	15341	9735.00	0.63	0.51
hb99n0	259	340.17	1.31	0.93
hb99n1	2493	1622.19	0.65	0.58
hb99n2	9497	6920.60	0.73	0.61
hb99s1	39573	22245.27	0.56	0.48
hb99s2	310	307.80	0.99	0.77
subtotal:	156570	566079.76		

Table 3 — Sample XOVER Output List
for ARCHERFISH (Internal COD) with the
Latitude and Longitude, COD, Average
Intersection Water Depth, and Track Headings

archer01 vs archer01

Latitude	Longitude	COD (m)	Mean Depth (m)	Heading 1	Heading 2
84.25327	26.30179	-5.44	3963.7	337.3	57.6
84.26042	26.28282	1.61	3960.8	295.6	205.0
84.26046	26.28203	1.68	3960.8	295.6	355.1
84.25445	26.29754	-0.37	3961.2	4.2	200.6
84.25386	26.25236	0.25	3961.9	123.8	231.9
84.25459	26.24157	0.46	3961.8	123.8	199.5
84.25352	26.25336	0.37	3961.8	197.8	51.6
84.25469	26.24005	0.41	3961.8	123.8	206.1
84.25372	26.25401	1.00	3961.5	197.8	25.2
84.26092	26.27285	0.21	3961.9	337.4	22.7
84.26183	26.26906	0.42	3961.8	337.4	269.0

Table 4 — Tabulated COD for Each Subgroup with Frequency, Mean, Median, Standard Deviation, and Maximum COD within Each 0.5 km Intersection Depth Interval

pre-scicex subset 1 (1958-1962): internal COD

depth (meter)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
0- 500	5	17.53	9.69	20.24	57.71
500-1000	2	208.49	208.49	175.74	384.23
1000-1500	1	46.20	46.20	0.00	46.20
1500-2000	8	132.31	134.12	96.46	362.25
2000-2500	14	146.03	86.40	158.55	488.98
2500-3000	14	337.15	200.06	414.24	1436.24
3000-3500	1	31.14	31.14	0.00	31.14
3500-4000	6	5.05	7.10	3.25	9.73
4000-4500	17	41.34	26.50	39.54	126.97
>4500	0	0.00	0.00	0.00	0.00

pre-scicex subset 1 (1958-1962): external COD

depth (meter)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
0- 500	2	21.47	21.47	18.28	39.75
500-1000	2	271.38	271.38	221.36	492.73
1000-1500	4	161.30	63.49	208.59	521.32
1500-2000	4	194.47	100.91	177.23	501.06
2000-2500	2	293.34	293.34	229.61	522.95
2500-3000	3	59.52	56.82	9.77	72.60
3000-3500	2	581.50	581.50	547.79	1129.29
3500-4000	9	160.06	47.63	318.74	1054.81
4000-4500	26	72.90	75.01	42.86	178.48
>4500	0	0.00	0.00	0.00	0.00

pre-scicex subset 2 (1966-1972): internal COD

depth (meter)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
0- 500	16	51.28	17.42	81.44	323.89
500-1000	4	587.29	888.50	413.27	1066.20
1000-1500	0	0.00	0.00	0.00	0.00
1500-2000	2	123.88	123.88	77.11	200.99
2000-2500	3	280.45	203.90	122.66	453.53
2500-3000	1	179.17	179.17	0.00	179.17
3000-3500	0	0.00	0.00	0.00	0.00
3500-4000	0	0.00	0.00	0.00	0.00
4000-4500	6	20.98	7.74	26.21	59.92
>4500	3	40.94	40.84	9.31	52.39

pre-scicex subset 2 (1966-1972): external COD

depth (meter)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
0- 500	0	0.00	0.00	0.00	0.00
500-1000	0	0.00	0.00	0.00	0.00
1000-1500	0	0.00	0.00	0.00	0.00
1500-2000	0	0.00	0.00	0.00	0.00
2000-2500	0	0.00	0.00	0.00	0.00
2500-3000	0	0.00	0.00	0.00	0.00
3000-3500	1	787.63	787.63	0.00	787.63
3500-4000	0	0.00	0.00	0.00	0.00
4000-4500	10	115.72	67.61	111.19	294.50
>4500	0	0.00	0.00	0.00	0.00

pre-scicex subset 3 (1973-1982): internal COD

depth (meter)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
0- 500	186	14.08	7.31	17.98	108.74
500-1000	19	72.98	38.03	106.16	495.16
1000-1500	16	145.43	96.77	160.04	505.36
1500-2000	38	68.64	20.66	152.44	793.85
2000-2500	64	116.45	76.23	143.61	753.24
2500-3000	46	193.25	105.83	213.05	733.91
3000-3500	86	81.90	45.10	111.34	603.20
3500-4000	144	85.42	64.80	98.71	811.07
4000-4500	18	125.46	48.87	197.96	798.49
>4500	7	62.44	43.93	56.96	194.76

pre-scicex subset 3 (1973-1982): external COD

depth (meter)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
0- 500	87	32.06	22.81	32.59	179.74
500-1000	6	163.01	162.61	99.80	329.10
1000-1500	13	138.60	91.42	111.25	400.93
1500-2000	12	94.63	81.32	68.01	218.70
2000-2500	16	184.91	116.03	197.10	792.93
2500-3000	33	174.76	88.20	231.46	1057.88
3000-3500	31	219.21	102.08	286.52	1020.86
3500-4000	28	158.34	122.21	167.63	601.71
4000-4500	27	45.49	13.22	106.53	539.06
>4500	1	883.00	883.00	0.00	883.00

pre-scicex subset 4 (1983-1988): internal COD

depth (meter)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
0- 500	17	46.40	7.43	84.50	274.14
500-1000	0	0.00	0.00	0.00	0.00
1000-1500	10	33.97	39.94	28.64	99.68
1500-2000	10	55.01	40.57	52.45	148.87
2000-2500	4	9.95	10.75	5.84	17.40
2500-3000	1	0.90	0.90	0.00	0.90
3000-3500	271	21.92	11.05	42.56	609.45
3500-4000	310	31.34	19.84	35.23	233.03
4000-4500	4	35.97	14.42	51.32	124.41
>4500	0	0.00	0.00	0.00	0.00

pre-scicex subset 4 (1983-1988): external COD

depth (meter)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
0- 500	5	15.81	0.00	19.56	43.93
500-1000	2	192.93	192.93	192.93	385.87
1000-1500	6	15.07	19.04	13.16	38.27
1500-2000	1	363.13	363.13	0.00	363.13
2000-2500	1	28.95	28.95	0.00	28.95
2500-3000	1	99.73	99.73	0.00	99.73
3000-3500	6	36.77	36.37	23.73	95.38
3500-4000	58	28.34	20.83	29.46	132.22
4000-4500	1	9.56	9.56	0.00	9.56
>4500	0	0.00	0.00	0.00	0.00

Table 4 — Tabulated COD for Each Subgroup with Frequency, Mean, Median, Standard Deviation, and Maximum COD within Each 0.5 km Intersection Depth Interval (continued)

pre-scicex subset 1 (1958-1962) vs subset 2 (1968-1972): external COD

depth (meter)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
0- 500	1	100.82	100.82	0.00	100.82
500-1000	2	177.07	177.07	30.11	207.18
1000-1500	4	252.28	416.76	200.84	482.14
1500-2000	4	257.64	159.86	291.87	757.74
2000-2500	5	356.60	342.55	241.54	780.93
2500-3000	3	357.12	184.19	359.76	857.96
3000-3500	10	489.46	593.78	328.90	1002.20
3500-4000	12	259.14	222.69	254.35	906.41
4000-4500	19	80.70	38.08	83.83	276.93
>4500	0	0.00	0.00	0.00	0.00

pre-scicex subset 1 (1958-1962) vs subset 3 (1973-1982): external COD

depth (meter)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
0- 500	23	82.10	23.41	143.65	484.22
500-1000	10	142.81	37.52	263.22	917.15
1000-1500	11	137.38	63.24	147.41	435.32
1500-2000	9	166.68	127.33	214.41	756.32
2000-2500	19	298.56	185.09	337.26	1378.23
2500-3000	26	136.75	73.08	176.63	608.99
3000-3500	23	271.43	211.83	278.67	1180.44
3500-4000	22	169.91	101.80	198.41	632.26
4000-4500	47	166.48	36.95	346.10	1687.95
>4500	0	0.00	0.00	0.00	0.00

pre-scicex subset 2 (1968-1972) vs subset 3 (1973-1982): external COD

depth (meter)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
0- 500	0	0.00	0.00	0.00	0.00
500-1000	1	22.17	22.17	0.00	22.17
1000-1500	2	235.46	235.46	141.77	377.24
1500-2000	0	0.00	0.00	0.00	0.00
2000-2500	1	56.46	56.46	0.00	56.46
2500-3000	7	355.10	383.64	142.43	583.34
3000-3500	3	380.09	330.54	141.84	573.20
3500-4000	10	145.39	40.29	258.43	889.75
4000-4500	6	66.20	38.71	101.74	291.52
>4500	0	0.00	0.00	0.00	0.00

pre-scicex subset 4 (1983-1988) vs subset 1 (1958-1962): external COD

depth (meter)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
0- 500	3	136.33	192.10	83.94	199.19
500-1000	4	106.90	102.37	111.81	290.92
1000-1500	5	119.65	32.87	135.49	362.02
1500-2000	4	219.40	265.91	210.05	543.68
2000-2500	4	184.02	313.47	136.94	326.97
2500-3000	4	547.46	520.23	588.51	1515.93
3000-3500	1	1578.77	1578.77	0.00	1578.77
3500-4000	14	378.71	460.22	143.04	513.73
4000-4500	31	98.48	85.60	82.30	257.15
>4500	0	0.00	0.00	0.00	0.00

pre-scicex subset 4 (1983-1988) vs subset 2 (1968-1972): external COD

depth (meter)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
0- 500	0	0.00	0.00	0.00	0.00
500-1000	0	0.00	0.00	0.00	0.00
1000-1500	1	113.09	113.09	0.00	113.09
1500-2000	0	0.00	0.00	0.00	0.00
2000-2500	2	1052.92	1052.92	70.23	1123.14
2500-3000	0	0.00	0.00	0.00	0.00
3000-3500	0	0.00	0.00	0.00	0.00
3500-4000	1	85.60	85.60	0.00	85.60
4000-4500	2	76.46	76.46	0.11	76.57
>4500	0	0.00	0.00	0.00	0.00

pre-scicex subset 4 (1983-1988) vs subset 3 (1973-1982): external COD

depth (meter)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
0- 500	34	66.88	32.25	65.28	251.65
500-1000	16	164.61	177.55	83.52	315.73
1000-1500	1	184.14	184.14	0.00	184.14
1500-2000	4	9.89	11.99	7.99	22.00
2000-2500	3	208.15	297.51	136.83	312.11
2500-3000	0	0.00	0.00	0.00	0.00
3000-3500	84	79.10	80.00	32.45	290.97
3500-4000	23	101.94	82.35	46.12	212.00
4000-4500	27	83.97	86.49	48.31	233.93
>4500	0	0.00	0.00	0.00	0.00

Table 4 — Tabulated COD for Each Subgroup with Frequency, Mean, Median, Standard Deviation, and Maximum COD within Each 0.5 km Intersection Depth Interval (continued)

scicex all (1993-1999): external COD

depth (meter)	total number	COD meter) mean	median	s.d. (meter)	max. COD (meter)
0- 500	82	20.22	8.10	32.84	143.35
500-1000	131	74.44	27.48	150.32	1099.50
1000-1500	123	177.29	59.32	245.73	1366.78
1500-2000	216	138.08	31.52	206.31	1483.11
2000-2500	261	92.84	46.87	125.44	754.40
2500-3000	192	117.91	45.90	160.67	846.66
3000-3500	187	154.03	94.07	176.67	1151.66
3500-4000	333	83.38	7.82	158.61	1091.87
4000-4500	198	59.24	4.12	183.95	1222.18
>4500	14	353.18	331.20	205.46	765.24

pre-scicex all (1958-1988) vs scicex all (1993-1999): external COD

depth (meter)	total number	COD (meter) mean	median	s.d. (meter)	max. COD (meter)
0- 500	204	35.93	19.75	46.82	291.32
500-1000	126	120.45	73.10	129.21	861.44
1000-1500	128	311.04	119.80	389.19	1574.31
1500-2000	141	226.12	138.17	271.55	1864.83
2000-2500	131	308.72	96.32	445.36	1888.81
2500-3000	141	268.62	87.38	453.09	2297.77
3000-3500	160	261.73	133.85	301.38	1410.10
3500-4000	381	113.24	40.41	177.36	1005.85
4000-4500	1244	51.92	17.10	101.51	1546.50
>4500	18	389.90	287.02	343.73	1596.75

scicex pargo (1993) : internal COD

depth (meter)	total number	COD (meter) mean	median	s.d. (meter)	max. COD (meter)
0- 500	0	0.00	0.00	0.00	0.00
500-1000	3	4.00	1.08	4.86	10.85
1000-1500	2	2.85	2.85	1.08	3.93
1500-2000	7	31.42	20.45	25.32	74.22
2000-2500	7	23.37	2.94	50.05	145.86
2500-3000	8	13.01	7.36	13.49	40.44
3000-3500	2	20.47	20.47	15.79	36.26
3500-4000	13	6.25	1.29	11.72	36.55
4000-4500	2	3.13	3.13	1.35	4.49
>4500	0	0.00	0.00	0.00	0.00

scicex pogy (1996) : internal COD

depth (meter)	total number	COD (meter) mean	median	s.d. (meter)	max. COD (meter)
0- 500	127	4.92	2.58	5.47	27.05
500-1000	148	36.26	11.87	131.79	1143.75
1000-1500	742	12.11	6.00	19.27	235.41
1500-2000	3958	7.30	2.00	22.20	613.70
2000-2500	3805	7.75	2.60	37.46	1409.51
2500-3000	3271	15.57	3.22	70.31	2081.96
3000-3500	215	75.36	4.60	408.39	3257.21
3500-4000	18614	1.33	0.64	7.26	355.21
4000-4500	128	7.30	1.00	62.58	710.14
>4500	1	773.86	773.86	0.00	773.86

scicex cavalla (1995) : internal COD

depth (meter)	total number	COD (meter) mean	median	s.d. (meter)	max. COD (meter)
0- 500	30	8.76	2.00	14.83	76.75
500-1000	75	3.34	2.50	5.30	45.30
1000-1500	289	6.25	2.75	13.08	101.00
1500-2000	352	9.06	3.75	17.83	147.68
2000-2500	241	13.67	8.80	13.05	60.00
2500-3000	102	13.42	4.60	25.13	176.45
3000-3500	67	29.63	7.00	83.51	433.57
3500-4000	273	5.50	2.00	11.85	75.00
4000-4500	373	3.87	1.81	8.05	133.00
>4500	1	238.00	238.00	0.00	238.00

scicex archerfish (1997) : internal COD

depth (meter)	total number	COD (meter) mean	median	s.d. (meter)	max. COD (meter)
0- 500	421	1.97	1.71	1.44	10.62
500-1000	1940	3.09	1.37	4.78	37.69
1000-1500	1424	12.41	6.79	15.82	116.39
1500-2000	1475	3.41	2.20	6.60	133.34
2000-2500	3913	14.40	4.25	21.22	146.91
2500-3000	2164	9.35	5.71	11.65	138.52
3000-3500	525	10.68	1.06	22.83	120.77
3500-4000	6020	2.10	1.11	2.43	27.19
4000-4500	69	2.91	1.00	5.22	30.29
>4500	0	0.00	0.00	0.00	0.00

scicex hawkbill (1998-99) : internal COD

depth (meter)	total number	COD (meter) mean	median	s.d. (meter)	max. COD (meter)
0- 500	1217	4.57	2.33	10.58	139.33
500-1000	3923	20.50	4.70	55.89	897.27
1000-1500	2249	31.72	13.72	57.29	1289.75
1500-2000	3120	18.48	4.39	75.46	957.42
2000-2500	2118	17.05	4.20	49.95	783.53
2500-3000	3048	25.52	3.76	70.22	700.89
3000-3500	2161	25.79	4.23	101.66	1047.66
3500-4000	4881	8.94	1.98	34.54	1058.95
4000-4500	3422	7.76	1.89	52.79	1241.17
>4500	382	14.11	3.00	31.81	327.35

Table 4 — Tabulated COD for Each Subgroup with Frequency, Mean, Median, Standard Deviation, and Maximum COD within Each 0.5 km Intersection Depth Interval (continued)

pre-scicex subset 1 (1958-1962) vs scicex all (1993-1999): external COD

depth (meter)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
0- 500	33	25.86	21.42	20.41	98.21
500-1000	24	57.46	49.61	32.23	132.67
1000-1500	44	309.83	171.51	286.89	887.01
1500-2000	48	138.37	103.27	130.72	516.71
2000-2500	46	214.65	102.91	264.65	1153.04
2500-3000	51	280.50	133.41	346.57	1695.95
3000-3500	53	174.70	70.05	239.03	1410.10
3500-4000	111	62.04	11.04	156.87	1005.85
4000-4500	585	50.54	17.56	54.17	347.39
>4500	1	24.10	24.10	0.00	24.10

pre-scicex subset 2 (1963-1972) vs scicex all (1993-1999): external COD

depth (meter)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
0- 500	0	0.00	0.00	0.00	0.00
500-1000	1	15.65	15.65	0.00	15.65
1000-1500	8	523.00	744.11	323.78	882.78
1500-2000	5	245.64	74.79	241.47	563.50
2000-2500	4	333.70	433.04	193.57	477.03
2500-3000	6	258.82	454.60	206.78	464.19
3000-3500	25	495.63	469.42	348.97	1205.98
3500-4000	60	185.50	135.46	187.73	801.23
4000-4500	120	53.60	4.72	210.15	1546.50
>4500	6	307.79	289.47	69.74	460.83

pre-scicex subset 3 (1973-1982) vs scicex all (1993-1999): external COD

depth (meter)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
0- 500	123	31.72	19.68	34.16	189.09
500-1000	61	157.72	136.59	142.35	861.44
1000-1500	63	326.20	80.40	467.01	1574.31
1500-2000	72	304.29	228.35	313.36	1864.83
2000-2500	40	611.79	552.53	630.22	1888.81
2500-3000	66	310.06	51.35	574.20	2297.77
3000-3500	71	231.31	133.85	254.93	938.09
3500-4000	149	139.38	51.80	202.15	885.25
4000-4500	445	44.05	10.14	110.18	1116.72
>4500	11	467.95	274.90	410.79	1596.75

pre-scicex subset 4 (1983-1988) vs scicex all (1993-1999): external COD

depth (meter)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
0- 500	48	53.64	17.32	74.91	291.32
500-1000	40	104.03	58.74	126.55	402.23
1000-1500	13	111.22	45.30	150.68	598.58
1500-2000	16	131.54	29.53	280.74	1143.95
2000-2500	41	116.16	62.98	165.28	828.98
2500-3000	18	86.27	72.80	68.44	209.67
3000-3500	11	345.77	190.79	419.25	1348.51
3500-4000	61	71.46	59.75	62.30	424.76
4000-4500	94	95.62	81.92	45.15	248.81
>4500	0	0.00	0.00	0.00	0.00

Table 5 — Tabulated COD for Each Subgroup with Frequency, Mean, Median, Standard Deviation, and Maximum Value within Each One-Degree Interval. The CODs are all Absolute Values.

pre-scicex subset 1 (1958-62) : internal COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	25	58.02	6.00	95.30	362.25
1.0 - 2.0	8	70.75	53.14	79.90	236.43
2.0 - 3.0	9	89.62	45.61	94.37	324.48
3.0 - 4.0	5	56.38	45.71	48.90	116.27
4.0 - 5.0	3	69.93	9.73	92.10	200.06
5.0 - 6.0	2	180.92	180.92	.17	181.09
6.0 - 7.0	3	320.27	338.98	145.99	488.98
7.0 - 8.0	0	.00	.00	.00	.00
8.0 - 9.0	1	86.40	86.40	.00	86.40
9.0 - 10.0	0	.00	.00	.00	.00
10.0 - 11.0	0	.00	.00	.00	.00
11.0 - 12.0	0	.00	.00	.00	.00
12.0 - 13.0	0	.00	.00	.00	.00
13.0 - 14.0	0	.00	.00	.00	.00
14.0 - 15.0	0	.00	.00	.00	.00
15.0 - 16.0	0	.00	.00	.00	.00
16.0 - 17.0	0	.00	.00	.00	.00
17.0 - 18.0	0	.00	.00	.00	.00
18.0 - 19.0	0	.00	.00	.00	.00
19.0 - 20.0	0	.00	.00	.00	.00
20.0 - 21.0	0	.00	.00	.00	.00
21.0 - 22.0	0	.00	.00	.00	.00
22.0 - 23.0	0	.00	.00	.00	.00
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	0	.00	.00	.00	.00
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	0	.00	.00	.00	.00
> 30.0	0	.00	.00	.00	.00

pre-scicex subset 2 (1966-72) : internal COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	15	178.33	36.32	325.61	1066.20
1.0 - 2.0	8	44.01	17.42	57.56	179.17
2.0 - 3.0	1	368.64	368.64	.00	368.64
3.0 - 4.0	0	.00	.00	.00	.00
4.0 - 5.0	0	.00	.00	.00	.00
5.0 - 6.0	0	.00	.00	.00	.00
6.0 - 7.0	2	192.45	192.45	8.54	200.99
7.0 - 8.0	1	453.53	453.53	.00	453.53
8.0 - 9.0	0	.00	.00	.00	.00
9.0 - 10.0	1	203.90	203.90	.00	203.90
10.0 - 11.0	0	.00	.00	.00	.00
11.0 - 12.0	0	.00	.00	.00	.00
12.0 - 13.0	0	.00	.00	.00	.00
13.0 - 14.0	0	.00	.00	.00	.00
14.0 - 15.0	0	.00	.00	.00	.00
15.0 - 16.0	0	.00	.00	.00	.00
16.0 - 17.0	0	.00	.00	.00	.00
17.0 - 18.0	0	.00	.00	.00	.00
18.0 - 19.0	0	.00	.00	.00	.00
19.0 - 20.0	0	.00	.00	.00	.00
20.0 - 21.0	0	.00	.00	.00	.00
21.0 - 22.0	0	.00	.00	.00	.00
22.0 - 23.0	0	.00	.00	.00	.00
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	0	.00	.00	.00	.00
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	0	.00	.00	.00	.00
> 30.0	0	.00	.00	.00	.00

pre-scicex subset 1 (1958-62) : external COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max.COD (meter)
.0 - 1.0	43	127.27	63.73	263.01	1436.24
1.0 - 2.0	10	130.69	66.62	166.54	521.32
2.0 - 3.0	5	106.17	54.03	107.57	320.71
3.0 - 4.0	3	540.73	492.73	410.67	1065.98
4.0 - 5.0	2	370.41	370.41	260.70	631.11
5.0 - 6.0	2	815.18	815.18	314.12	1129.29
6.0 - 7.0	0	.00	.00	.00	.00
7.0 - 8.0	1	383.50	383.50	.00	383.50
8.0 - 9.0	0	.00	.00	.00	.00
9.0 - 10.0	0	.00	.00	.00	.00
10.0 - 11.0	0	.00	.00	.00	.00
11.0 - 12.0	0	.00	.00	.00	.00
12.0 - 13.0	0	.00	.00	.00	.00
13.0 - 14.0	0	.00	.00	.00	.00
14.0 - 15.0	0	.00	.00	.00	.00
15.0 - 16.0	0	.00	.00	.00	.00
16.0 - 17.0	0	.00	.00	.00	.00
17.0 - 18.0	0	.00	.00	.00	.00
18.0 - 19.0	0	.00	.00	.00	.00
19.0 - 20.0	0	.00	.00	.00	.00
20.0 - 21.0	0	.00	.00	.00	.00
21.0 - 22.0	0	.00	.00	.00	.00
22.0 - 23.0	0	.00	.00	.00	.00
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	0	.00	.00	.00	.00
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	0	.00	.00	.00	.00
> 30.0	0	.00	.00	.00	.00

pre-scicex subset 2 (1966-72) : external COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	16	114.46	41.23	191.87	787.63
1.0 - 2.0	2	181.05	181.05	113.44	294.50
2.0 - 3.0	0	.00	.00	.00	.00
3.0 - 4.0	0	.00	.00	.00	.00
4.0 - 5.0	0	.00	.00	.00	.00
5.0 - 6.0	0	.00	.00	.00	.00
6.0 - 7.0	0	.00	.00	.00	.00
7.0 - 8.0	0	.00	.00	.00	.00
8.0 - 9.0	0	.00	.00	.00	.00
9.0 - 10.0	0	.00	.00	.00	.00
10.0 - 11.0	0	.00	.00	.00	.00
11.0 - 12.0	0	.00	.00	.00	.00
12.0 - 13.0	0	.00	.00	.00	.00
13.0 - 14.0	0	.00	.00	.00	.00
14.0 - 15.0	0	.00	.00	.00	.00
15.0 - 16.0	0	.00	.00	.00	.00
16.0 - 17.0	0	.00	.00	.00	.00
17.0 - 18.0	0	.00	.00	.00	.00
18.0 - 19.0	0	.00	.00	.00	.00
19.0 - 20.0	0	.00	.00	.00	.00
20.0 - 21.0	0	.00	.00	.00	.00
21.0 - 22.0	0	.00	.00	.00	.00
22.0 - 23.0	0	.00	.00	.00	.00
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	0	.00	.00	.00	.00
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	0	.00	.00	.00	.00
> 30.0	0	.00	.00	.00	.00

Table 5 — Tabulated COD for Each Subgroup with Frequency, Mean, Median, Standard Deviation, and Maximum Value within Each One-Degree Interval. The CODs are all Absolute Values. (continued)

pre-scicex subset 3 (1973-82): internal COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	267	47.76	7.86	122.86	753.24
1.0 - 2.0	32	121.15	54.28	202.65	798.49
2.0 - 3.0	26	60.34	28.00	84.38	326.99
3.0 - 4.0	16	79.42	36.83	121.10	505.36
4.0 - 5.0	24	102.85	74.40	139.17	664.33
5.0 - 6.0	26	126.75	51.60	166.28	597.31
6.0 - 7.0	29	136.00	78.00	169.10	811.07
7.0 - 8.0	20	85.25	75.73	64.76	242.00
8.0 - 9.0	17	106.75	88.75	80.81	308.70
9.0 - 10.0	21	74.16	47.38	95.82	487.98
10.0 - 11.0	15	151.08	100.49	161.90	603.20
11.0 - 12.0	16	110.05	99.98	84.47	339.34
12.0 - 13.0	14	70.31	55.00	47.02	158.43
13.0 - 14.0	11	97.54	77.85	84.46	315.35
14.0 - 15.0	11	78.60	72.74	45.24	149.84
15.0 - 16.0	6	99.96	47.44	122.79	369.40
16.0 - 17.0	8	64.90	67.27	58.39	194.76
17.0 - 18.0	7	77.59	55.37	51.20	192.67
18.0 - 19.0	7	125.32	90.89	72.63	234.99
19.0 - 20.0	7	58.01	42.42	40.19	140.62
20.0 - 21.0	6	82.74	50.61	65.95	221.88
21.0 - 22.0	8	65.59	43.93	48.82	161.82
22.0 - 23.0	2	20.25	20.25	4.25	24.50
23.0 - 24.0	5	110.58	75.25	103.06	308.00
24.0 - 25.0	4	83.75	73.46	69.38	200.00
25.0 - 26.0	8	77.68	90.14	19.81	96.97
26.0 - 27.0	3	77.82	97.00	27.12	97.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	2	64.51	64.51	16.49	81.00
29.0 - 30.0	0	.00	.00	.00	.00
> 30.0	0	.00	.00	.00	.00

pre-scicex subset 4 (1983-88) : internal COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	594	25.40	14.55	32.72	274.14
1.0 - 2.0	18	79.55	42.88	136.93	609.45
2.0 - 3.0	4	63.72	68.83	25.71	99.68
3.0 - 4.0	3	42.97	41.78	5.61	50.36
4.0 - 5.0	2	79.00	79.00	35.83	114.83
5.0 - 6.0	0	.00	.00	.00	.00
6.0 - 7.0	2	93.40	93.40	41.81	135.22
7.0 - 8.0	1	36.54	36.54	.00	36.54
8.0 - 9.0	0	.00	.00	.00	.00
9.0 - 10.0	1	55.59	55.59	.00	55.59
10.0 - 11.0	1	19.56	19.56	.00	19.56
11.0 - 12.0	0	.00	.00	.00	.00
12.0 - 13.0	0	.00	.00	.00	.00
13.0 - 14.0	0	.00	.00	.00	.00
14.0 - 15.0	0	.00	.00	.00	.00
15.0 - 16.0	0	.00	.00	.00	.00
16.0 - 17.0	0	.00	.00	.00	.00
17.0 - 18.0	1	162.37	162.37	.00	162.37
18.0 - 19.0	0	.00	.00	.00	.00
19.0 - 20.0	0	.00	.00	.00	.00
20.0 - 21.0	0	.00	.00	.00	.00
21.0 - 22.0	0	.00	.00	.00	.00
22.0 - 23.0	0	.00	.00	.00	.00
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	0	.00	.00	.00	.00
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	0	.00	.00	.00	.00
> 30.0	0	.00	.00	.00	.00

pre-scicex subset 3 (1973-82): external COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	156	54.79	29.84	90.30	767.75
1.0 - 2.0	41	142.42	81.32	185.20	1057.88
2.0 - 3.0	13	231.01	140.43	286.83	1020.86
3.0 - 4.0	12	173.22	144.53	201.82	792.93
4.0 - 5.0	9	208.55	83.52	241.41	725.56
5.0 - 6.0	6	180.56	130.11	189.73	539.06
6.0 - 7.0	6	279.16	288.86	184.47	548.99
7.0 - 8.0	5	227.62	220.10	139.18	453.50
8.0 - 9.0	3	431.76	235.49	315.83	877.36
9.0 - 10.0	2	133.54	133.54	11.56	145.10
10.0 - 11.0	5	420.92	143.20	415.84	968.76
11.0 - 12.0	0	.00	.00	.00	.00
12.0 - 13.0	0	.00	.00	.00	.00
13.0 - 14.0	0	.00	.00	.00	.00
14.0 - 15.0	1	6.00	6.00	.00	6.00
15.0 - 16.0	1	95.82	95.82	.00	95.82
16.0 - 17.0	0	.00	.00	.00	.00
17.0 - 18.0	0	.00	.00	.00	.00
18.0 - 19.0	0	.00	.00	.00	.00
19.0 - 20.0	0	.00	.00	.00	.00
20.0 - 21.0	0	.00	.00	.00	.00
21.0 - 22.0	0	.00	.00	.00	.00
22.0 - 23.0	0	.00	.00	.00	.00
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	0	.00	.00	.00	.00
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	0	.00	.00	.00	.00
> 30.0	0	.00	.00	.00	.00

pre-scicex subset 4 (1983-88) : external COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	85	31.96	22.36	45.56	363.13
1.0 - 2.0	5	94.42	28.84	146.28	385.87
2.0 - 3.0	1	99.73	99.73	.00	99.73
3.0 - 4.0	0	.00	.00	.00	.00
4.0 - 5.0	0	.00	.00	.00	.00
5.0 - 6.0	0	.00	.00	.00	.00
6.0 - 7.0	0	.00	.00	.00	.00
7.0 - 8.0	0	.00	.00	.00	.00
8.0 - 9.0	0	.00	.00	.00	.00
9.0 - 10.0	0	.00	.00	.00	.00
10.0 - 11.0	0	.00	.00	.00	.00
11.0 - 12.0	0	.00	.00	.00	.00
12.0 - 13.0	0	.00	.00	.00	.00
13.0 - 14.0	0	.00	.00	.00	.00
14.0 - 15.0	0	.00	.00	.00	.00
15.0 - 16.0	0	.00	.00	.00	.00
16.0 - 17.0	0	.00	.00	.00	.00
17.0 - 18.0	0	.00	.00	.00	.00
18.0 - 19.0	0	.00	.00	.00	.00
19.0 - 20.0	0	.00	.00	.00	.00
20.0 - 21.0	0	.00	.00	.00	.00
21.0 - 22.0	0	.00	.00	.00	.00
22.0 - 23.0	0	.00	.00	.00	.00
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	0	.00	.00	.00	.00
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	0	.00	.00	.00	.00
> 30.0	0	.00	.00	.00	.00

Table 5 — Tabulated COD for Each Subgroup with Frequency, Mean, Median, Standard Deviation, and Maximum Value within Each One-Degree Interval. The CODs are all Absolute Values. (continued)

pre-scicex subset 1 vs subset 2: external COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	29	84.77	47.32	81.13	276.93
1.0 - 2.0	8	355.84	211.03	309.52	917.01
2.0 - 3.0	5	279.88	170.28	255.57	780.93
3.0 - 4.0	6	350.65	342.55	328.89	1002.20
4.0 - 5.0	4	292.70	416.76	184.13	491.89
5.0 - 6.0	4	728.83	757.74	118.02	906.41
6.0 - 7.0	4	498.02	541.05	210.75	809.15
7.0 - 8.0	0	.00	.00	.00	.00
8.0 - 9.0	0	.00	.00	.00	.00
9.0 - 10.0	0	.00	.00	.00	.00
10.0 - 11.0	0	.00	.00	.00	.00
11.0 - 12.0	0	.00	.00	.00	.00
12.0 - 13.0	0	.00	.00	.00	.00
13.0 - 14.0	0	.00	.00	.00	.00
14.0 - 15.0	0	.00	.00	.00	.00
15.0 - 16.0	0	.00	.00	.00	.00
16.0 - 17.0	0	.00	.00	.00	.00
17.0 - 18.0	0	.00	.00	.00	.00
18.0 - 19.0	0	.00	.00	.00	.00
19.0 - 20.0	0	.00	.00	.00	.00
20.0 - 21.0	0	.00	.00	.00	.00
21.0 - 22.0	0	.00	.00	.00	.00
22.0 - 23.0	0	.00	.00	.00	.00
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	0	.00	.00	.00	.00
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	0	.00	.00	.00	.00
> 30.0	0	.00	.00	.00	.00

pre-scicex subset 1 vs subset 4: external COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	52	155.54	88.53	239.86	1578.77
1.0 - 2.0	10	441.18	441.31	397.81	1515.93
2.0 - 3.0	3	345.50	326.97	95.70	470.87
3.0 - 4.0	1	543.68	543.68	.00	543.68
4.0 - 5.0	3	259.55	265.91	111.31	392.58
5.0 - 6.0	0	.00	.00	.00	.00
6.0 - 7.0	0	.00	.00	.00	.00
7.0 - 8.0	1	313.47	313.47	.00	313.47
8.0 - 9.0	0	.00	.00	.00	.00
9.0 - 10.0	0	.00	.00	.00	.00
10.0 - 11.0	0	.00	.00	.00	.00
11.0 - 12.0	0	.00	.00	.00	.00
12.0 - 13.0	0	.00	.00	.00	.00
13.0 - 14.0	0	.00	.00	.00	.00
14.0 - 15.0	0	.00	.00	.00	.00
15.0 - 16.0	0	.00	.00	.00	.00
16.0 - 17.0	0	.00	.00	.00	.00
17.0 - 18.0	0	.00	.00	.00	.00
18.0 - 19.0	0	.00	.00	.00	.00
19.0 - 20.0	0	.00	.00	.00	.00
20.0 - 21.0	0	.00	.00	.00	.00
21.0 - 22.0	0	.00	.00	.00	.00
22.0 - 23.0	0	.00	.00	.00	.00
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	0	.00	.00	.00	.00
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	0	.00	.00	.00	.00
> 30.0	0	.00	.00	.00	.00

pre-scicex subset 2 vs subset 4: external COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	3	79.51	76.57	4.31	85.60
1.0 - 2.0	0	.00	.00	.00	.00
2.0 - 3.0	1	113.09	113.09	.00	113.09
3.0 - 4.0	0	.00	.00	.00	.00
4.0 - 5.0	1	1123.14	1123.14	.00	1123.14
5.0 - 6.0	0	.00	.00	.00	.00
6.0 - 7.0	1	982.69	982.69	.00	982.69
7.0 - 8.0	0	.00	.00	.00	.00
8.0 - 9.0	0	.00	.00	.00	.00
9.0 - 10.0	0	.00	.00	.00	.00
10.0 - 11.0	0	.00	.00	.00	.00
11.0 - 12.0	0	.00	.00	.00	.00
12.0 - 13.0	0	.00	.00	.00	.00
13.0 - 14.0	0	.00	.00	.00	.00
14.0 - 15.0	0	.00	.00	.00	.00
15.0 - 16.0	0	.00	.00	.00	.00
16.0 - 17.0	0	.00	.00	.00	.00
17.0 - 18.0	0	.00	.00	.00	.00
18.0 - 19.0	0	.00	.00	.00	.00
19.0 - 20.0	0	.00	.00	.00	.00
20.0 - 21.0	0	.00	.00	.00	.00
21.0 - 22.0	0	.00	.00	.00	.00
22.0 - 23.0	0	.00	.00	.00	.00
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	0	.00	.00	.00	.00
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	0	.00	.00	.00	.00
> 30.0	0	.00	.00	.00	.00

pre-scicex subset 1 vs subset 3: external COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	111	92.89	34.64	157.20	1180.44
1.0 - 2.0	30	222.30	127.33	344.04	1687.95
2.0 - 3.0	12	239.52	106.19	367.96	1378.23
3.0 - 4.0	13	272.67	211.83	221.67	756.32
4.0 - 5.0	7	426.87	458.15	326.91	917.15
5.0 - 6.0	3	537.68	602.68	411.94	1006.54
6.0 - 7.0	4	263.13	236.65	207.31	608.99
7.0 - 8.0	3	374.66	469.50	254.33	627.70
8.0 - 9.0	2	209.90	209.90	116.61	326.52
9.0 - 10.0	1	1141.35	1141.35	.00	1141.35
10.0 - 11.0	1	27.28	27.28	.00	27.28
11.0 - 12.0	1	353.01	353.01	.00	353.01
12.0 - 13.0	2	621.73	621.73	367.60	989.33
13.0 - 14.0	0	.00	.00	.00	.00
14.0 - 15.0	0	.00	.00	.00	.00
15.0 - 16.0	0	.00	.00	.00	.00
16.0 - 17.0	0	.00	.00	.00	.00
17.0 - 18.0	0	.00	.00	.00	.00
18.0 - 19.0	0	.00	.00	.00	.00
19.0 - 20.0	0	.00	.00	.00	.00
20.0 - 21.0	0	.00	.00	.00	.00
21.0 - 22.0	0	.00	.00	.00	.00
22.0 - 23.0	0	.00	.00	.00	.00
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	0	.00	.00	.00	.00
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	0	.00	.00	.00	.00
> 30.0	0	.00	.00	.00	.00

pre-scicex subset 2 vs subset 3: external COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	13	76.48	38.71	86.53	255.43
1.0 - 2.0	4	306.45	377.24	85.00	383.64
2.0 - 3.0	3	304.58	12.31	413.78	889.75
3.0 - 4.0	2	43.43	43.43	13.02	56.46
4.0 - 5.0	4	329.17	573.20	250.71	583.34
5.0 - 6.0	1	470.27	470.27	.00	470.27
6.0 - 7.0	2	380.15	380.15	49.61	429.76
7.0 - 8.0	1	258.79	258.79	.00	258.79
8.0 - 9.0	0	.00	.00	.00	.00
9.0 - 10.0	0	.00	.00	.00	.00
10.0 - 11.0	0	.00	.00	.00	.00
11.0 - 12.0	0	.00	.00	.00	.00
12.0 - 13.0	0	.00	.00	.00	.00
13.0 - 14.0	0	.00	.00	.00	.00
14.0 - 15.0	0	.00	.00	.00	.00
15.0 - 16.0	0	.00	.00	.00	.00
16.0 - 17.0	0	.00	.00	.00	.00
17.0 - 18.0	0	.00	.00	.00	.00
18.0 - 19.0	0	.00	.00	.00	.00
19.0 - 20.0	0	.00	.00	.00	.00
20.0 - 21.0	0	.00	.00	.00	.00
21.0 - 22.0	0	.00	.00	.00	.00
22.0 - 23.0	0	.00	.00	.00	.00
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	0	.00	.00	.00	.00
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	0	.00	.00	.00	.00
> 30.0	0	.00	.00	.00	.00

pre-scicex subset 3 vs subset 4: external COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	175	86.41	79.42	54.99	315.73
1.0 - 2.0	9	108.98	91.23	86.30	290.97
2.0 - 3.0	5	112.07	97.78	97.43	297.51
3.0 - 4.0	2	163.47	163.47	148.64	312.11
4.0 - 5.0	1	21.72	21.72	.00	21.72
5.0 - 6.0	0	.00	.00	.00	.00
6.0 - 7.0	0	.00	.00	.00	.00
7.0 - 8.0	0	.00	.00	.00	.00
8.0 - 9.0	0	.00	.00	.00	.00
9.0 - 10.0	0	.00	.00	.00	.00
10.0 - 11.0	0	.00	.00	.00	.00
11.0 - 12.0	0	.00	.00	.00	.00
12.0 - 13.0	0	.00	.00	.00	.00
13.0 - 14.0	0	.00	.00	.00	.00
14.0 - 15.0	0	.00	.00	.00	.00
15.0 - 16.0	0	.00	.00	.00	.00
16.0 - 17.0	0	.00	.00	.00	.00
17.0 - 18.0	0	.00	.00	.00	.00
18.0 - 19.0	0	.00	.00	.00	.00
19.0 - 20.0	0	.00	.00	.00	.00
20.0 - 21.0	0	.00	.00	.00	.00
21.0 - 22.0	0	.00	.00	.00	.00
22.0 - 23.0	0	.00	.00	.00	.00
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	0	.00	.00	.00	.00
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	0	.00	.00	.00	.00
> 30.0	0	.00	.00	.00	.00

Table 5 — Tabulated COD for Each Subgroup with Frequency, Mean, Median, Standard Deviation, and Maximum Value within Each One-Degree Interval. The CODs are all Absolute Values. (continued)

scicex (archerfish, 1997) : internal COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	11572	2.36	1.25	4.42	96.67
1.0 - 2.0	2361	7.67	4.50	10.26	89.76
2.0 - 3.0	1274	12.54	7.43	15.52	97.62
3.0 - 4.0	799	16.15	9.17	18.75	138.52
4.0 - 5.0	603	21.26	14.12	22.50	144.02
5.0 - 6.0	385	23.13	15.55	22.91	130.02
6.0 - 7.0	289	20.91	12.34	21.25	101.19
7.0 - 8.0	184	30.55	22.06	25.73	120.77
8.0 - 9.0	116	29.97	24.39	21.71	92.50
9.0 - 10.0	98	29.54	20.66	23.93	96.19
10.0 - 11.0	60	37.47	36.37	25.31	116.15
11.0 - 12.0	44	38.44	41.25	30.37	105.73
12.0 - 13.0	53	40.60	35.16	31.73	116.39
13.0 - 14.0	40	35.71	27.07	29.98	108.44
14.0 - 15.0	18	32.69	27.65	28.86	121.09
15.0 - 16.0	12	58.72	82.74	34.67	113.47
16.0 - 17.0	11	24.32	21.23	27.73	99.78
17.0 - 18.0	6	27.56	7.90	35.27	100.33
18.0 - 19.0	7	44.71	26.12	35.62	123.45
19.0 - 20.0	6	48.76	37.48	45.94	146.91
20.0 - 21.0	1	5.13	5.13	.00	5.13
21.0 - 22.0	1	26.83	26.83	.00	26.83
22.0 - 23.0	2	40.61	40.61	28.51	69.12
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	0	.00	.00	.00	.00
25.0 - 26.0	1	27.99	27.99	.00	27.99
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	1	34.19	34.19	.00	34.19
29.0 - 30.0	0	.00	.00	.00	.00
> 30.0	0	.00	.00	.00	.00

scicex (cavalla, 1995) : internal COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	1283	5.38	2.00	16.26	433.57
1.0 - 2.0	249	9.84	6.00	11.87	78.93
2.0 - 3.0	114	21.95	10.40	45.38	426.33
3.0 - 4.0	54	22.34	11.97	49.36	360.89
4.0 - 5.0	32	16.86	9.52	18.67	76.41
5.0 - 6.0	9	13.77	10.00	10.92	34.02
6.0 - 7.0	13	10.66	7.17	8.34	32.12
7.0 - 8.0	4	19.09	24.85	16.77	44.02
8.0 - 9.0	4	8.65	11.62	7.18	19.00
9.0 - 10.0	9	36.52	21.22	43.54	147.68
10.0 - 11.0	5	13.24	2.00	22.27	57.58
11.0 - 12.0	5	16.83	9.00	15.73	39.15
12.0 - 13.0	3	93.28	137.82	65.98	142.02
13.0 - 14.0	4	44.81	33.00	54.04	136.22
14.0 - 15.0	3	60.08	43.32	54.01	133.00
15.0 - 16.0	2	2.50	2.50	.50	3.00
16.0 - 17.0	2	36.50	36.50	33.50	70.00
17.0 - 18.0	0	.00	.00	.00	.00
18.0 - 19.0	0	.00	.00	.00	.00
19.0 - 20.0	1	10.57	10.57	.00	10.57
20.0 - 21.0	0	.00	.00	.00	.00
21.0 - 22.0	0	.00	.00	.00	.00
22.0 - 23.0	0	.00	.00	.00	.00
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	0	.00	.00	.00	.00
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	1	93.88	93.88	.00	93.88
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	0	.00	.00	.00	.00
> 30.0	0	.00	.00	.00	.00

scicex (hawkbill, 1998-99) : internal COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	17957	6.57	2.17	26.66	934.00
1.0 - 2.0	3710	22.50	6.11	74.61	1241.17
2.0 - 3.0	1719	40.61	11.24	97.72	1061.58
3.0 - 4.0	1006	50.77	16.86	103.46	1099.97
4.0 - 5.0	644	53.05	20.00	112.92	1222.85
5.0 - 6.0	388	70.39	23.00	136.62	1090.39
6.0 - 7.0	336	65.85	27.33	102.59	897.27
7.0 - 8.0	199	64.53	27.34	127.63	1289.75
8.0 - 9.0	140	67.02	22.18	106.04	863.21
9.0 - 10.0	98	70.54	33.64	88.76	428.71
10.0 - 11.0	89	87.04	26.33	129.17	677.57
11.0 - 12.0	69	69.30	33.67	80.24	373.64
12.0 - 13.0	46	51.80	32.57	71.85	349.43
13.0 - 14.0	38	68.67	51.04	57.85	278.00
14.0 - 15.0	33	66.95	32.05	81.28	315.91
15.0 - 16.0	26	68.94	43.92	78.72	293.20
16.0 - 17.0	13	109.33	57.00	127.64	450.36
17.0 - 18.0	11	139.05	91.25	144.79	482.96
18.0 - 19.0	6	110.07	101.01	107.89	301.00
19.0 - 20.0	2	7.92	7.92	7.03	14.95
20.0 - 21.0	2	240.14	240.14	67.86	308.00
21.0 - 22.0	2	198.83	198.83	70.96	269.79
22.0 - 23.0	3	149.84	113.22	110.95	300.28
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	2	45.85	45.85	36.16	82.00
25.0 - 26.0	1	271.99	271.99	.00	271.99
26.0 - 27.0	1	101.19	101.19	.00	101.19
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	1	52.48	52.48	.00	52.48
29.0 - 30.0	0	.00	.00	.00	.00
>30.0	0	.00	.00	.00	.00

scicex (pargo, 1993) : internal COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	28	4.30	1.66	7.67	40.44
1.0 - 2.0	12	39.11	36.26	38.61	145.86
2.0 - 3.0	2	6.90	6.90	3.96	10.85
3.0 - 4.0	0	.00	.00	.00	.00
4.0 - 5.0	0	.00	.00	.00	.00
5.0 - 6.0	0	.00	.00	.00	.00
6.0 - 7.0	0	.00	.00	.00	.00
7.0 - 8.0	0	.00	.00	.00	.00
8.0 - 9.0	0	.00	.00	.00	.00
9.0 - 10.0	0	.00	.00	.00	.00
10.0 - 11.0	1	28.63	28.63	.00	28.63
11.0 - 12.0	0	.00	.00	.00	.00
12.0 - 13.0	0	.00	.00	.00	.00
13.0 - 14.0	0	.00	.00	.00	.00
14.0 - 15.0	0	.00	.00	.00	.00
15.0 - 16.0	0	.00	.00	.00	.00
16.0 - 17.0	0	.00	.00	.00	.00
17.0 - 18.0	0	.00	.00	.00	.00
18.0 - 19.0	0	.00	.00	.00	.00
19.0 - 20.0	0	.00	.00	.00	.00
20.0 - 21.0	0	.00	.00	.00	.00
21.0 - 22.0	0	.00	.00	.00	.00
22.0 - 23.0	0	.00	.00	.00	.00
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	0	.00	.00	.00	.00
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	0	.00	.00	.00	.00
> 30.0	0	.00	.00	.00	.00

scicex (pogy, 1996) : internal COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	23607	2.71	.81	35.61	3257.21
1.0 - 2.0	3403	8.47	2.47	66.49	3088.31
2.0 - 3.0	1377	8.10	3.44	15.56	201.24
3.0 - 4.0	844	16.02	3.76	105.74	2931.33
4.0 - 5.0	511	20.47	4.94	57.15	773.86
5.0 - 6.0	330	14.55	5.53	30.80	331.75
6.0 - 7.0	219	24.47	10.63	48.52	362.15
7.0 - 8.0	144	12.67	5.00	19.64	127.48
8.0 - 9.0	112	16.27	7.19	36.20	355.21
9.0 - 10.0	108	14.04	4.49	31.91	285.97
10.0 - 11.0	80	15.18	3.06	35.59	302.33
11.0 - 12.0	73	10.95	4.08	15.32	61.06
12.0 - 13.0	45	15.52	11.48	13.53	55.97
13.0 - 14.0	19	27.22	8.35	68.09	311.34
14.0 - 15.0	21	15.69	8.14	15.67	43.02
15.0 - 16.0	6	28.04	23.57	25.78	62.83
16.0 - 17.0	10	18.28	8.11	24.06	68.77
17.0 - 18.0	2	6.28	6.28	6.21	12.49
18.0 - 19.0	4	45.83	57.96	23.09	72.86
19.0 - 20.0	0	.00	.00	.00	.00
20.0 - 21.0	2	18.63	18.63	7.56	26.18
21.0 - 22.0	2	9.09	9.09	4.20	13.29
22.0 - 23.0	3	.53	.55	.42	1.03
23.0 - 24.0	2	36.79	36.79	26.85	63.64
24.0 - 25.0	2	29.56	29.56	23.39	52.95
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	1	8.25	8.25	.00	8.25
> 30.0	4	20.73	25.96	8.90	32.44

Table 5 — Tabulated COD for Each Subgroup with Frequency, Mean, Median, Standard Deviation, and Maximum Value within Each One-Degree Interval. The CODs are all Absolute Values. (continued)

scicex all (1993-99) : external COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	977	41.68	8.10	108.72	1099.50
1.0 - 2.0	248	107.14	56.50	166.37	1483.11
2.0 - 3.0	152	158.13	99.52	189.87	1222.18
3.0 - 4.0	97	212.66	145.45	175.57	845.26
4.0 - 5.0	80	227.70	179.87	194.54	1091.87
5.0 - 6.0	54	284.44	173.31	282.91	1366.78
6.0 - 7.0	35	275.24	283.02	188.37	776.48
7.0 - 8.0	22	240.68	202.04	219.76	922.63
8.0 - 9.0	31	246.57	193.66	205.02	846.66
9.0 - 10.0	6	306.85	276.64	246.95	708.13
10.0 - 11.0	13	349.45	316.43	163.93	692.54
11.0 - 12.0	4	254.27	272.93	147.47	464.08
12.0 - 13.0	5	511.32	424.64	353.06	1151.66
13.0 - 14.0	2	398.93	398.93	366.30	765.24
14.0 - 15.0	1	811.40	811.40	.00	811.40
15.0 - 16.0	1	634.52	634.52	.00	634.52
16.0 - 17.0	5	420.40	293.27	273.62	752.06
17.0 - 18.0	0	.00	.00	.00	.00
18.0 - 19.0	2	212.77	212.77	1.16	213.93
19.0 - 20.0	0	.00	.00	.00	.00
20.0 - 21.0	0	.00	.00	.00	.00
21.0 - 22.0	0	.00	.00	.00	.00
22.0 - 23.0	1	196.82	196.82	.00	196.82
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	1	127.18	127.18	.00	127.18
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	0	.00	.00	.00	.00
>30.0	0	.00	.00	.00	.00

pre-scicex subset 2 (1966-72) vs scicex all (1993-99) : ext. COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	141	50.65	4.69	143.51	882.78
1.0 - 2.0	35	248.04	92.96	318.94	1546.50
2.0 - 3.0	7	312.40	353.97	173.03	469.42
3.0 - 4.0	15	460.08	343.22	344.61	1205.98
4.0 - 5.0	10	579.81	528.77	277.04	1008.25
5.0 - 6.0	8	386.92	289.49	176.10	780.79
6.0 - 7.0	6	308.22	424.52	163.70	460.83
7.0 - 8.0	4	178.38	137.17	177.97	477.03
8.0 - 9.0	4	373.17	562.18	267.71	684.60
9.0 - 10.0	1	152.93	152.93	.00	152.93
10.0 - 11.0	1	412.69	412.69	.00	412.69
11.0 - 12.0	1	186.84	186.84	.00	186.84
12.0 - 13.0	0	.00	.00	.00	.00
13.0 - 14.0	0	.00	.00	.00	.00
14.0 - 15.0	1	83.10	83.10	.00	83.10
15.0 - 16.0	0	.00	.00	.00	.00
16.0 - 17.0	1	1418.76	1418.76	.00	1418.76
17.0 - 18.0	0	.00	.00	.00	.00
18.0 - 19.0	0	.00	.00	.00	.00
19.0 - 20.0	0	.00	.00	.00	.00
20.0 - 21.0	0	.00	.00	.00	.00
21.0 - 22.0	0	.00	.00	.00	.00
22.0 - 23.0	0	.00	.00	.00	.00
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	0	.00	.00	.00	.00
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	0	.00	.00	.00	.00
>30.0	0	.00	.00	.00	.00

pre-scicex subset 4 (1983-88) vs scicex all (1993-99) : ext. COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	265	82.00	67.88	101.34	1143.95
1.0 - 2.0	54	104.43	62.08	115.75	402.23
2.0 - 3.0	10	234.64	155.71	229.50	828.98
3.0 - 4.0	6	278.13	101.98	480.63	1348.51
4.0 - 5.0	3	180.35	162.40	140.66	360.89
5.0 - 6.0	1	670.16	670.16	.00	670.16
6.0 - 7.0	0	.00	.00	.00	.00
7.0 - 8.0	1	913.38	913.38	.00	913.38
8.0 - 9.0	1	146.71	146.71	.00	146.71
9.0 - 10.0	1	95.41	95.41	.00	95.41
10.0 - 11.0	0	.00	.00	.00	.00
11.0 - 12.0	0	.00	.00	.00	.00
12.0 - 13.0	0	.00	.00	.00	.00
13.0 - 14.0	0	.00	.00	.00	.00
14.0 - 15.0	0	.00	.00	.00	.00
15.0 - 16.0	0	.00	.00	.00	.00
16.0 - 17.0	0	.00	.00	.00	.00
17.0 - 18.0	0	.00	.00	.00	.00
18.0 - 19.0	0	.00	.00	.00	.00
19.0 - 20.0	0	.00	.00	.00	.00
20.0 - 21.0	0	.00	.00	.00	.00
21.0 - 22.0	0	.00	.00	.00	.00
22.0 - 23.0	0	.00	.00	.00	.00
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	0	.00	.00	.00	.00
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	0	.00	.00	.00	.00
>30.0	0	.00	.00	.00	.00

pre-scicex subset 1 (1958-62) vs scicex all (1993-99) : ext. COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	819	64.25	18.55	111.42	1410.10
1.0 - 2.0	80	110.29	61.73	153.22	1005.85
2.0 - 3.0	39	277.99	130.47	374.32	1695.95
3.0 - 4.0	20	228.13	151.89	219.06	711.83
4.0 - 5.0	13	332.85	238.31	274.82	983.10
5.0 - 6.0	9	359.42	393.38	211.10	711.00
6.0 - 7.0	5	443.62	484.09	296.60	862.79
7.0 - 8.0	5	562.91	494.70	228.24	1002.57
8.0 - 9.0	2	288.58	288.58	242.76	531.35
9.0 - 10.0	2	661.74	661.74	413.96	1075.70
10.0 - 11.0	1	497.91	497.91	.00	497.91
11.0 - 12.0	0	.00	.00	.00	.00
12.0 - 13.0	0	.00	.00	.00	.00
13.0 - 14.0	1	579.77	579.77	.00	579.77
14.0 - 15.0	0	.00	.00	.00	.00
15.0 - 16.0	0	.00	.00	.00	.00
16.0 - 17.0	0	.00	.00	.00	.00
17.0 - 18.0	0	.00	.00	.00	.00
18.0 - 19.0	0	.00	.00	.00	.00
19.0 - 20.0	0	.00	.00	.00	.00
20.0 - 21.0	0	.00	.00	.00	.00
21.0 - 22.0	0	.00	.00	.00	.00
22.0 - 23.0	0	.00	.00	.00	.00
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	0	.00	.00	.00	.00
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	0	.00	.00	.00	.00
>30.0	0	.00	.00	.00	.00

pre-scicex subset 3 (1973-82) vs scicex all (1993-99) : ext. COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	747	50.59	11.76	154.56	2297.77
1.0 - 2.0	101	188.37	80.33	301.99	2168.72
2.0 - 3.0	68	270.88	145.84	293.23	1222.28
3.0 - 4.0	36	299.26	196.33	271.69	962.78
4.0 - 5.0	30	351.08	327.41	339.05	1522.85
5.0 - 6.0	33	474.66	366.31	408.56	1502.73
6.0 - 7.0	19	645.96	453.69	536.16	1864.83
7.0 - 8.0	17	421.52	280.27	379.74	1203.25
8.0 - 9.0	15	793.40	699.82	645.79	1879.80
9.0 - 10.0	7	342.20	408.16	138.11	462.04
10.0 - 11.0	10	549.67	536.50	510.53	1806.50
11.0 - 12.0	2	1005.34	1005.34	848.53	1853.87
12.0 - 13.0	7	529.64	518.96	319.13	977.87
13.0 - 14.0	5	306.52	270.47	84.52	463.41
14.0 - 15.0	2	946.30	946.30	848.71	1795.01
15.0 - 16.0	1	1888.81	1888.81	.00	1888.81
16.0 - 17.0	1	386.96	386.96	.00	386.96
17.0 - 18.0	0	.00	.00	.00	.00
18.0 - 19.0	0	.00	.00	.00	.00
19.0 - 20.0	0	.00	.00	.00	.00
20.0 - 21.0	0	.00	.00	.00	.00
21.0 - 22.0	0	.00	.00	.00	.00
22.0 - 23.0	0	.00	.00	.00	.00
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	0	.00	.00	.00	.00
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	0	.00	.00	.00	.00
>30.0	0	.00	.00	.00	.00

pre-scicex all (1958-88) vs scicex all (1993-99) : external COD

slope angle (degree)	total number	COD (meter) mean	COD (meter) median	s.d. (meter)	max. COD (meter)
.0 - 1.0	1972	60.49	18.47	131.03	2297.77
1.0 - 2.0	270	156.18	66.03	244.09	2168.72
2.0 - 3.0	124	272.54	144.92	312.05	1695.95
3.0 - 4.0	77	310.47	196.33	307.20	1348.51
4.0 - 5.0	56	378.55	343.42	322.66	1522.85
5.0 - 6.0	51	444.39	365.15	352.31	1502.73
6.0 - 7.0	30	544.69	441.34	470.60	1864.83
7.0 - 8.0	27	429.90	337.33	355.64	1203.25
8.0 - 9.0	22	641.71	531.35	594.98	1879.80
9.0 - 10.0	11	360.66	275.82	265.17	1075.70
10.0 - 11.0	12	533.95	497.91	467.70	1806.50
11.0 - 12.0	3	732.51	186.84	793.02	1853.87
12.0 - 13.0	7	529.64	518.96	319.13	977.87
13.0 - 14.0	6	352.06	323.22	127.76	579.77
14.0 - 15.0	3	658.57	97.59	803.61	1795.01
15.0 - 16.0	1	1888.81	1888.81	.00	1888.81
16.0 - 17.0	2	902.86	902.86	515.90	1418.76
17.0 - 18.0	0	.00	.00	.00	.00
18.0 - 19.0	0	.00	.00	.00	.00
19.0 - 20.0	0	.00	.00	.00	.00
20.0 - 21.0	0	.00	.00	.00	.00
21.0 - 22.0	0	.00	.00	.00	.00
22.0 - 23.0	0	.00	.00	.00	.00
23.0 - 24.0	0	.00	.00	.00	.00
24.0 - 25.0	0	.00	.00	.00	.00
25.0 - 26.0	0	.00	.00	.00	.00
26.0 - 27.0	0	.00	.00	.00	.00
27.0 - 28.0	0	.00	.00	.00	.00
28.0 - 29.0	0	.00	.00	.00	.00
29.0 - 30.0	0	.00	.00	.00	.00
>30.0	0	.00	.00	.00	.00

Table 6 — Sample Data Files with Predicted Error Appended.
See Text for Explanation.

SCICEX (archer01.tag)

time	latitude	longitude	depth(m)	error(m)
5905.50	84.008949	26.403580	3965.61	.06
5905.50	84.013885	26.427151	3966.02	.19
5905.52	84.016647	26.414249	3966.47	.95
5905.54	84.020241	26.411840	3969.96	.82
5905.55	84.026009	26.406731	3969.91	1.07
5905.57	84.028221	26.391171	3966.51	1.08
5905.59	84.031830	26.414989	3966.43	.01
5905.60	84.036781	26.412510	3966.55	.03
5905.63	84.043495	26.422331	3966.61	.00
5905.65	84.049629	26.429440	3966.56	.29
5905.67	84.052200	26.438339	3965.65	.21
5905.72	84.063637	26.448610	3966.71	.05
5905.73	84.071556	26.465019	3966.40	.13
5905.75	84.072365	26.459940	3966.29	.10
5905.77	84.079742	26.472771	3966.30	.17
5905.78	84.081963	26.481230	3965.83	.11
5905.82	84.088249	26.454969	3966.27	.01
5905.85	84.096771	26.439980	3965.64	.06
5905.87	84.104034	26.447170	3965.63	.01
5905.89	84.106407	26.430429	3965.60	.17

PRE-SCICEX (1-104.tag)

latitude	longitude	depth(m)	error(m)
75.004097	217.790894	3667.00	.65
75.013802	217.760498	3664.80	3.44
75.018204	217.749496	3660.80	.04
75.029099	217.733704	3669.80	1.39
75.043098	217.713394	3663.90	1.45
75.053596	217.698196	3663.90	1.57
75.066498	217.679504	3658.00	1.89
75.077187	217.664200	3657.00	.23
75.089104	217.646896	3658.90	2.08
75.102287	217.627808	3664.80	1.68
75.120300	217.560196	3665.80	1.30
75.136803	217.469696	3674.80	.70
75.155296	217.367798	3670.80	1.19
75.165802	217.310501	3678.90	1.46
75.176300	217.252899	3678.00	.08
75.183601	217.212708	3678.90	4.76
75.186401	217.197403	3684.80	4.50
75.189987	217.177704	3684.80	.00
75.192703	217.162704	3684.80	8.34
75.194702	217.151794	3677.00	3.72

REFERENCES

U.S. Navy, 1999. *Bathymetry Collected by United States and United Kingdom Nuclear Submarines in the Arctic Region, 1958 – 1983*, CD-ROM, Washington, DC.

J.M. Brozena, M.F. Peters, and R. Salman, 1997. "Arctic Airborne Gravity Measurements Program," Proc. Int. Symp. Gravity, Geoid, and Marine Geodesy, Tokyo: 1996 (special volume).

D.J.T. Carter, 1980. *Echo-Sounding Correction Tables*, Third Edition, Hydrographic Department, Ministry of Defence, Taunton, United Kingdom.

B.J. Coakley, J.R. Cochran, and M.G. Langseth, 1997. "Axial Morphology at Ultra-slow Spreading Rates: Observations of the Arctic Mid-Ocean Ridge from the USS POGY," *Eos Trans.* **78**, 662.

B.J. Coakley and D. Monahan, 1999. "Refinement of Arctic Ocean Bathymetry: From GEBCO to SCICEX," *Eos Trans.* **80**, S191.

M. Jakobsson, N.Z. Cherkis, J. Woodward, R. Macnab, and J. Harding, 2000. "Shaded Relief of the Arctic Ocean and Adjacent Continents (chart)," IBCAO, Report no. 306, Inst. of Geology and Geochemistry, Univ. of Stockholm, Stockholm, Sweden.

W.Y. Jung, and P.R. Vogt, 1992. "Predicting Bathymetry from Geosat-ERM and Shipborne Profiles in the South Atlantic Ocean," *Tectonophysics* **210**, 235-253.

W.Y. Jung, J.B. Brozena, L.C. Kovacs, N.Z. Cherkis, and P.R. Vogt, 1999. "Alpha Ridge, Arctic Ocean: Relation of Topography to Gravity and Magnetics," *Eos Trans.* **80**, S190.

D.J. Matthews, 1939. "Tables of the Velocity of Sound in Pure Water and Sea Water for Use in Echo-sounding and Sound-ranging," Hydrographic Department, Admiralty, London.

R.K. Perry, H.S. Fleming, J.R. Weber, Y. Kristoffersen, J.K. Hall, A. Grantz, and G.L.Johnson, 1985. "Bathymetry of the Arctic Ocean (chart)," *Geol. Soc. Am.* **MC-56**.

Russian Ministry of Defence, St. Petersburg, 1999. Bottom Relief of the Arctic Ocean (chart).

D.T. Sandwell and W.H.F. Smith, 1999. "Bathymetric Estimation," *Satellite Altimetry and Earth Sciences*, Academic Press, San Diego, CA.

SCICEX-98 Basic Data Package, Arctic Sub Lab, Sept. 1998, CD-ROM.

SCICEX-99 Basic Data Package, Arctic Sub Lab, Sept. 1999, CD-ROM.

SCICEX-98 Science Cruise Report, USS Hawkbill, 1998, p. 46.

SCICEX-99 Science Cruise Report, USS Hawkbill, 1999, p. 30.

P. Wessel, 1989. "XOVER: A Cross-over Error Detector for Track Data," *Computers & Geosciences* **15**, 333-346.