U.S Department of the Interior
U.S. Geological Survey

CRUISE REPORT

R/V *SURF SURVEYOR* CRUISE S1-00-CL

MAPPING THE BATHYMETRY OF CRATER LAKE, OREGON

July 22 to August 2, 2000

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Open-File Report 00-405

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2000

Introduction

During the Spring of 1999, the US Geological Survey (USGS) Pacific Seafloor Mapping Project (PSMP) was contacted by the US National Park Service Crater Lake National Park (CLNP) to inquire about the plausibility of producing a high-resolution multibeam bathymetric map of Crater Lake. The purpose was to generate a much higher-resolution and more geographically accurate bathymetric map than was produced in 1959, the last time the lake had been surveyed. Scientific interest in various aspects of Crater Lake (aquatic biology, geochemistry, volcanic processes, etc.) has increased during the past decade but the basemap of bathymetry was woefully inadequate. Funds were gathered during the early part of 2000 and the mapping began in late July, 2000.

Crater Lake (Fig. 1) is located in south central Oregon (Fig. 2) within the Cascades Range, a chain of volcanoes that stretches from northern California to southern British Columbia. Crater Lake is the collapsed caldera of Mt. Mazama from a climatic eruption about 7700-yr ago (Nelson et al., 1988; Bacon and Lanphere, 1990; Bacon et al., 1997).

Figure 1. Panoramic view of Crater Lake

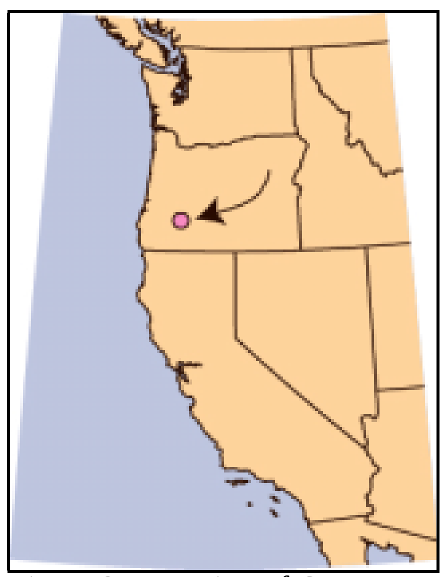

Figure 2. Location of Crater Lake, Oregon (red circle).

The floor of Crater Lake has only been mapped three times since the lake was first stumbled upon by gold prospectors in the 1853. The first survey was carried by out by

William G. Steel during a joint USGS-US Army expedition under the direction of Maj. Clarence E. Dutton in 1886 (Dutton, 1889). Steel's mapping survey collected 186 soundings using a Millers lead-line sounding machine (Fig.3). The resulting map (Fig.4) shows only soundings and no attempts were made to generate contours. The second survey, conducted in 1959 by the US Coast and Geodetic Survey, mapped the bathymetry of Crater Lake with an acoustic echo sounder using radar navigation and collected 4000

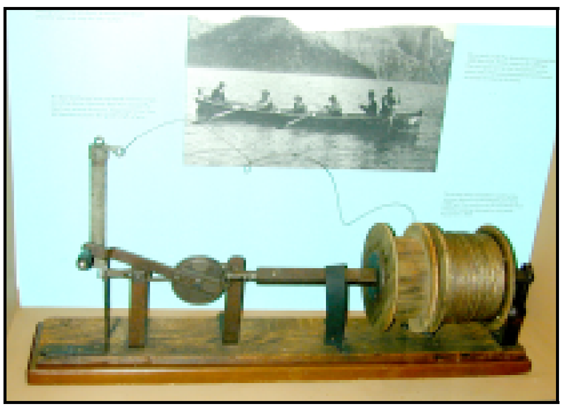

Figure 3. Sounding machine used by Dutton's 1886 expedition.

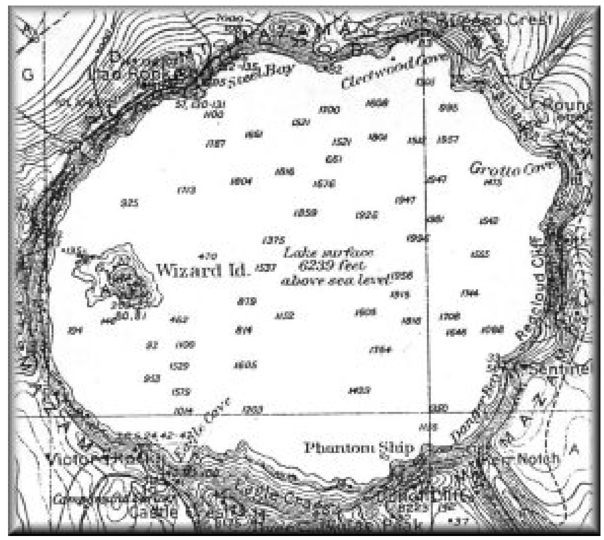

Figure 4. Map of soundings collected by Wm. Steel during the 1886 expedition.

soundings. The data were contoured by Williams (1961) and Byrne (1962) and the result is a fairly detailed map of the large-scale features of Crater Lake (Fig. 5). The third mapping survey, the one of this report, was a joint USGS-NPS project carried out under a Cooperative Agreement with the Center for Coastal and Ocean Mapping, University of New Hampshire. The 2000 survey used a Kongsberg Simrad EM1002 high-resolution multibeam mapping system owned and operated by C&C Technologies, Inc. of Lafayette, LA.

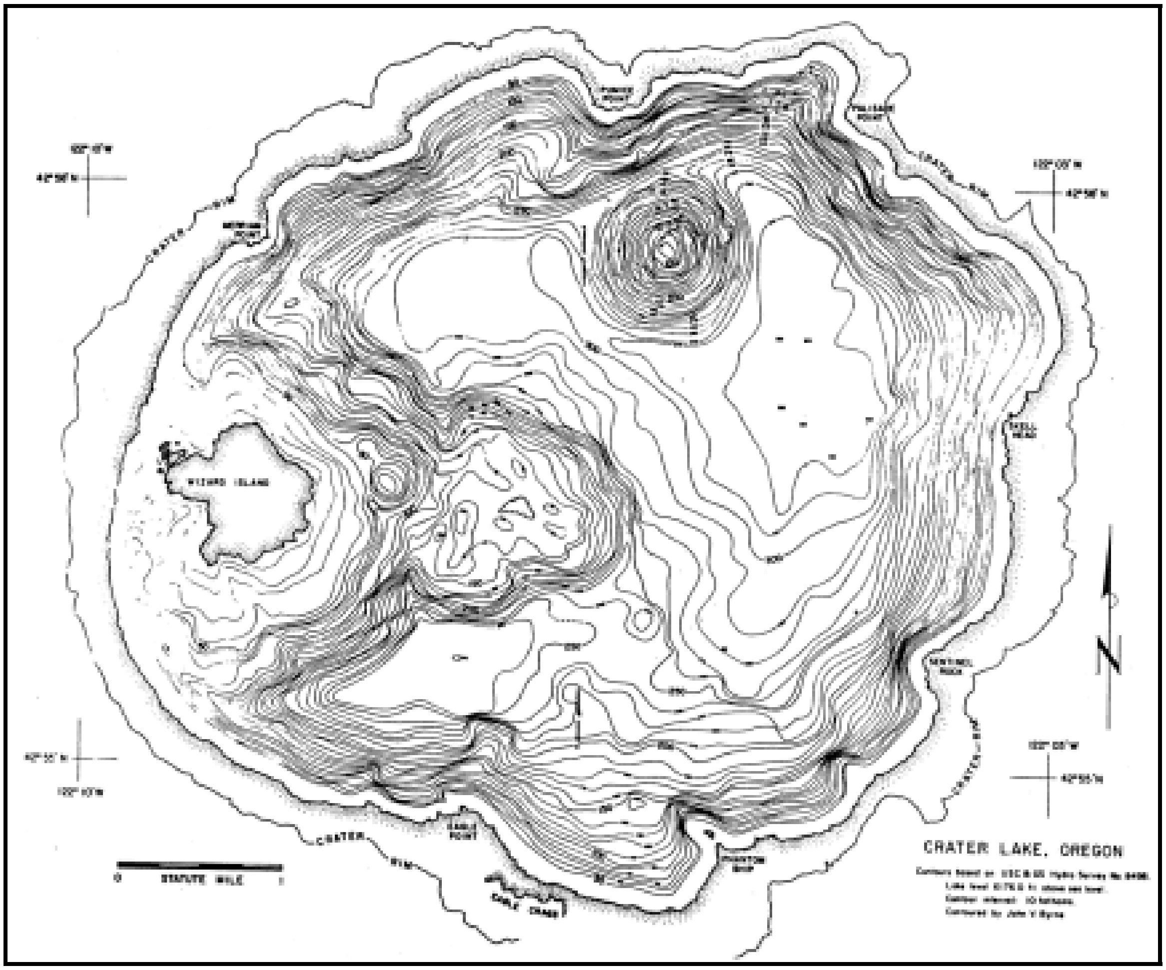

Figure 5. Bathymetry of Crater Lake from 1959 Coast & Geodetic Survey Hydro Survey No. 8498. After Byrne (1961).

The Kongsberg Simrad EM1002 High-Resolution Multibeam Mapping System

There are several different brands of high-resolution multibeam mapping systems that are appropriate for shallow-water surveys. After a review of the currently available systems, we chose to use for this cruise the Kongsberg Simrad EM1002 system because; (1) it is the latest generation of high-resolution multibeams with a frequency appropriate for the known depths of Crater Lake, (2) it is based on the highly successful EM1000 system, (3) it has the ability to map large areas at high speed without compromising data quality and, most importantly, (4) it has the ability to simultaneously produce high-resolution, calibrated backscatter imagery. We used an EM1002 system owned and operated by C&C Technologies, Inc. (Lafayette, LA) installed aboard the 26-ft *Surf Surveyor* (Fig. 5) for the Crater Lake survey.

Figure 5. RV *Surf Surveyor* .

An overview of high-resolution multibeam mapping systems can be found in Hughes-Clarke et al. (1996). The Simrad EM1002 system operates at frequencies of 98 kHz (inner ±50˚ swath centered at nadir) and 93 kHz (the outer ±20˚) from a semi-circular transducer (Fig. 6) mounted on the forward edge of the keel. The system was designed to operate in several modes through a range of depths from 5 to approximately 800-m. The shallow (ultrawide) mode, used to maximum depths of about 200 m, forms 111 receive beams with a spacing of 2° distributed across track and 2° wide along track. The beam

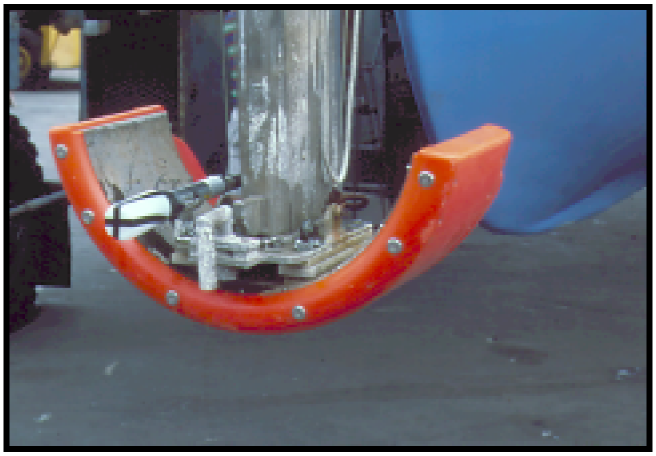

Figure 6. Simrad EM1002 transducer.

geometry can generate up to a 150° swath that can cover as much as 7.4 times the water depth. The wide mode is used for depths between 150 and 400 m, and the deep mode is used for depths of greater than 400 m. There are options within each mode for beam distribution (equiangular or equidistant) and pulse lengths (0.2, 0.7, and 2 ms). The specific options used for the Crater Lake survey are discussed in the data processing section below.

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

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

Ancillary Systems

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

The Crater Lake survey was navigated with (INS) provided by a TSS Applied Analytic POS/MV model 320 inertial motion sensor (IMU) as well as dual Trimble model 4000 DGPS with a commercial SatLoc satellite differential station. Spatial accuracy (positions) for the mapping is ±0.5 m. In addition, the POS/MV records vehicle motion (pitch, roll, yaw, and heave) at 100 Hz with an accuracy of 0.02° for roll, pitch, and yaw, and 5% of heave amplitude or 5 cm.

Sound-velocity profiles were calculated each day so that ray-tracing techniques could be used to determine the effect of acoustic refraction in the water. A SeaBird model 19-02 CTD was deployed the first day of operations to get a good reference SVP. Two additional sound-velocity sensors are installed at the transducer to directly determine the speed of sound in water. All the SVP data were fed directly into the Simrad EM1002 processor for instantaneous beam forming and ray tracing of each individual beam.

Data Sources and Type

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

Table 1. Kongsberg Simrad EM1002 data stream.

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

Table 2. Ancillary data sources

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

Mounting Alignment Values:

The accurate reduction of swath bathymetric data critically depends on a proper knowledge of the geometry and relative positions of the sonar transducer to the motion sensor, the ship, and the positioning-system antennae (Fig. 7). C&C Technologies, using standard surveying techniques, measured these values before the survey began. All values are measured relative to the transducer.

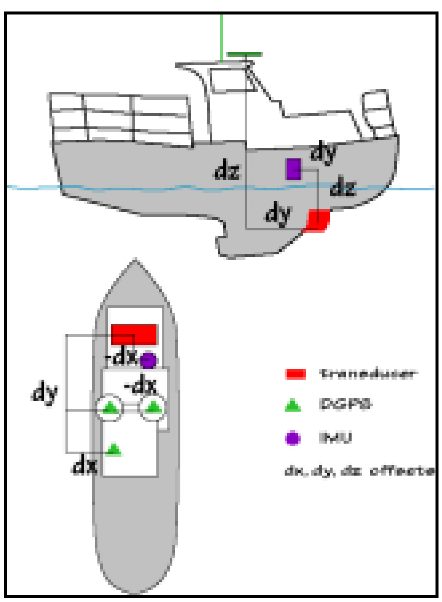

Figure 7. Schematic of required measured offsets.

Attitude Compensation:

The POS/MV model 320 inertial motion unit (IMU), a full DGPS-aided inertial navigational system, was used as the primary attitude sensor and directly interfaced to the Simrad EM1002 and provided 100-Hz measurements of boat attitude to 0.01°. The POS/MV also provided a vertical reference. The POS/MV was chosen as the primary motion sensor because it has high accuracy specifications, it is insensitive to long-period horizontal accelerations, and it provides an inertial position solution that is reliable through DGPS outages of periods of less than about one or two minutes.

EM1002 Operational Modes

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

The Crater Lake survey was carried out in the EA mode. In the EA mode, the EM1002 was operated with a 0.2 ms pulse length in waters less than 150 m deep, and the swath width was constrained to 120° swath. In waters deeper than 150 m, the EM1002 switched to a 0.7 ms pulse length and restricted to an 800-m swath width.

Data Transformations

Lake Level Datum

All soundings were measured in meters below lake level, then referenced to elevations above mean sea level so as to construct a digital elevation model (DEM) that was seamless with the existing USGS 10-m DEM of the surrounding land. Each sounding was subtracted from 1883.1 m, the measured elevation of the lake surface during the five days of the mapping (USGS gage no. 11492200 (Fig. 8) referenced to 6100 ft {1859.8 m] above sea level). The lake level was +23.31 (7.11 m) above the gage reference level on the

Figure 8. USGS lake-level gage number 11492200

first day of the patch testing and only dropped 0.3 ft (0.09 m) during the five days of mapping. Measured water levels during the mapping were acquired from the water-gauge website (http://oregon.usgs.gov/rt-cgi/gen_stn_pg?).

Bathymetry

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

Backscatter

The Kongsberg Simrad EM1002 provides a backscatter-intensity time series for the bottom insonification period for each of the 111 individual beams. The corrections applied by the shipboard recording system are listed in Table 3.

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

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

Table 3. Corrections applied to each beam for backscatter.

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

response of the lake floor. We then invert this function to minimize the beam pattern and angular variations.

Kongsberg Simrad uses a variable gain within 15° of vertical to reduce logged dynamic range at nadir and near-nadir. The sidescan data at this stage had a Lambertian response (Urick, 1983) backed out and the beam pattern corrected with respect to the vertical and all receive beams had been roll stabilized. Consequently, corrections have been made for variations in the beam-forming amplifiers but not variations in the individual transducer stave sensitivities of the physical array. Additional transformations were required to produce calibrated backscatter measurements. These include (1) removal of Lambertian model, (2) true lake floor slope correction, (3) refracted ray-path correction, (4) residual beam-pattern correction, and (5) aspherical-spreading corrections.

Patch Test

Despite the careful measurements of transducer alignments and offsets, the true geometry of the installed system can only be determined through the determination of the self-consistency of lake floor measurements. A full patch test procedure to check for proper system alignments and to calibrate any time delay and gyro misalignment was completed at Lake Tahoe, California a week prior to our arrival at Crater Lake . The

EM1002 data were directly compared to data collected in Lake Tahoe during the 1998 mapping (Gardner et al., 1998; 2000). The static adjustments were determined from the patch test and entered into the Simrad software. We also conducted a series of patch tests once the boat was in Crater Lake whereby the system was run back and forth across both a flat area and a steep slope of the lake floor to determine if there were residual roll, pitch, heading, or timing offsets that required correction factors.

Navigation Filtering

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

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

Data Processing

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

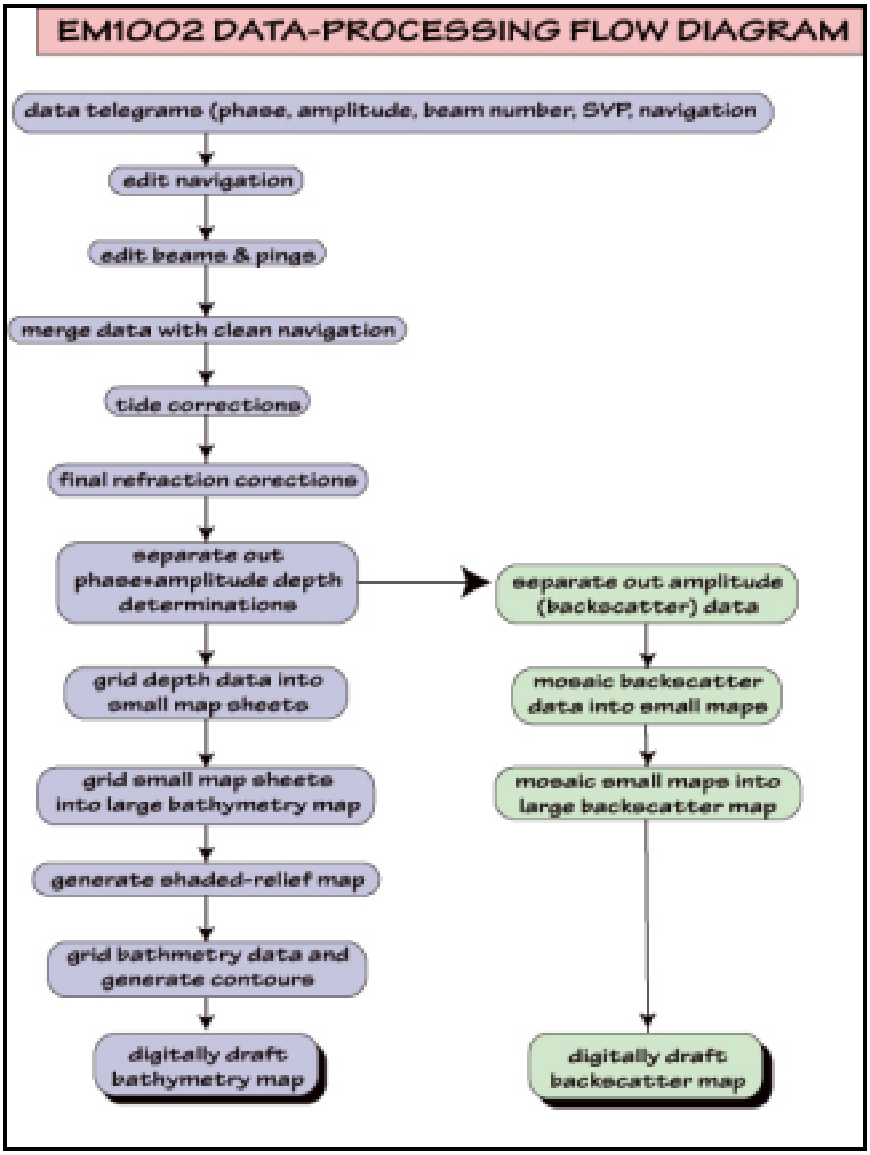

Figure 9. Data-processing flow for EM1002 Crater Lake mapping.

Refraction Issues

The single biggest limitation on the quality of sounding data is water-column refraction. Refraction-related anomalies grow non-linearly with beam angle and the resulting artifacts can create short-wavelength topographic features that may be misinterpreted as lake bed geology. There was some concern prior to the cruise that suspected strong water stratification would present a problem for the beam steering and ray tracing of individual beams. Although a strong thermocline was measured, repeated CTD casts allowed us to correct for refraction effects. A representative water-velocity profile is shown in Figure 10. In fact, no additional empirical refraction corrections were necessary during processing. If all of the alignments were correctly determined, Kongsberg Simrad states that the depth resolution of the EM1002 is 30 cm or 0.1% of water depth, whichever is larger.

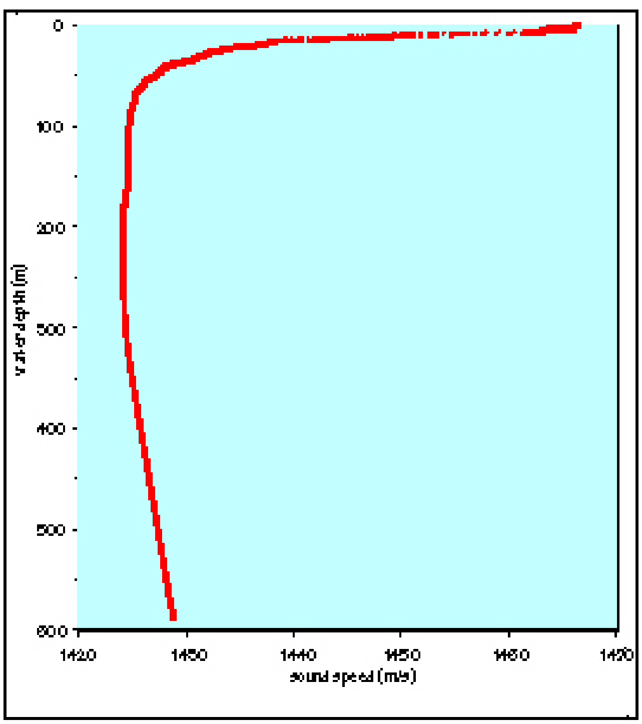

Figure 10 Profile of measured sound speed in Crater Lake for July 29, 2000.

The Maps

The overview maps of backscatter and shaded relief that accompany this report were generated from larger-scale subarea maps (Fig. 11). The 2-m-resolution subarea maps were combined to produce the series of overview maps of the entire area (Figs.12 and 13). The detailed subarea maps are 463 m by 675 m in size and were produced at 1 m/pixel, the maximum resolution as determined by water depths and beam angle. Contour maps represent the more traditional method of displaying bathymetry. The contours were derived from the gridded elevations. The resultant contours were smoothed with a 3-point running average for the overview maps. Even at the original contour grid, more than 90% of the data had to be discarded so as to only show some chosen contour interval. A much better representation of bathymetry, using 100% of the data is a shaded-relief map. A shaded- relief map (Fig. 12) is a pseudo-sun-illumination

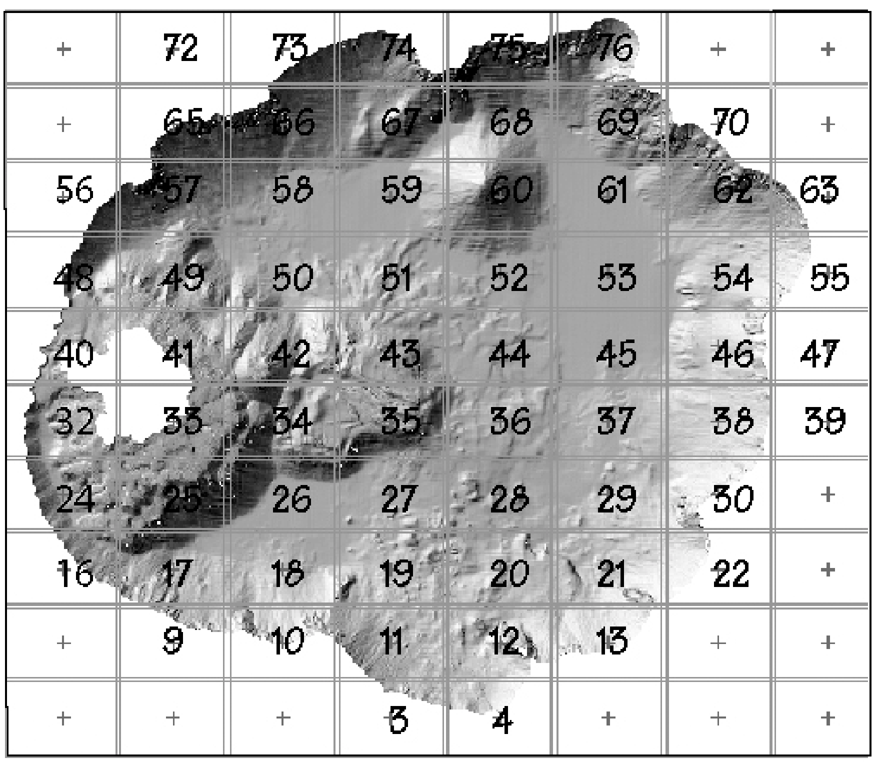

Figure 11. Subarea maps and their area numbers. The resolution of each subarea map is a 2 m/pixel.

of a topographic surface using the Lambertian scattering law (equation 1), where SI is the pseudo-sun intensity, K is a constant that allows for even background, and ϕ is the angle between the pseudo sun and the bathymetric surface.

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

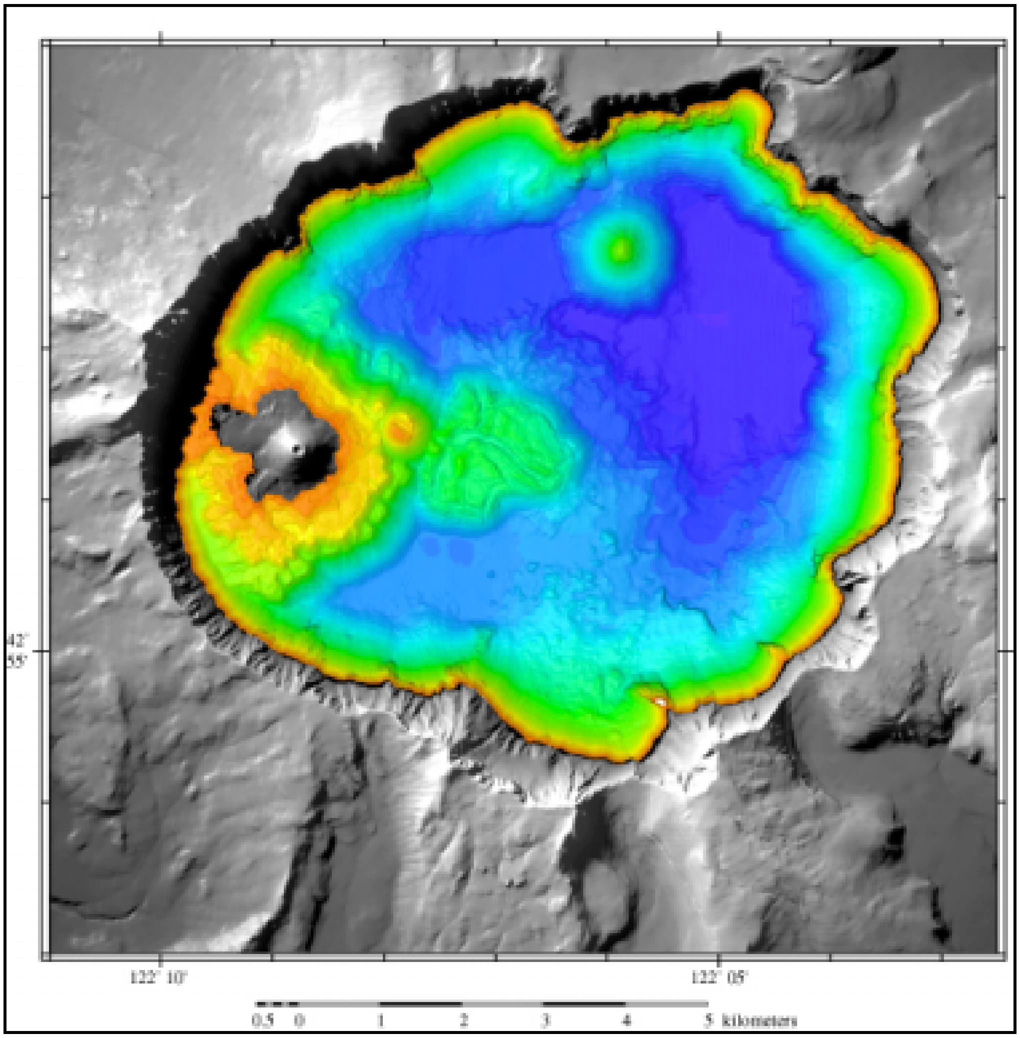

Figure 12. Colored shaded-relief bathymetry (2-m resolution) of Crater Lake. Reddish orange is shallowest, dark blue is deepest. Gray is land (10-m USGS DEM).

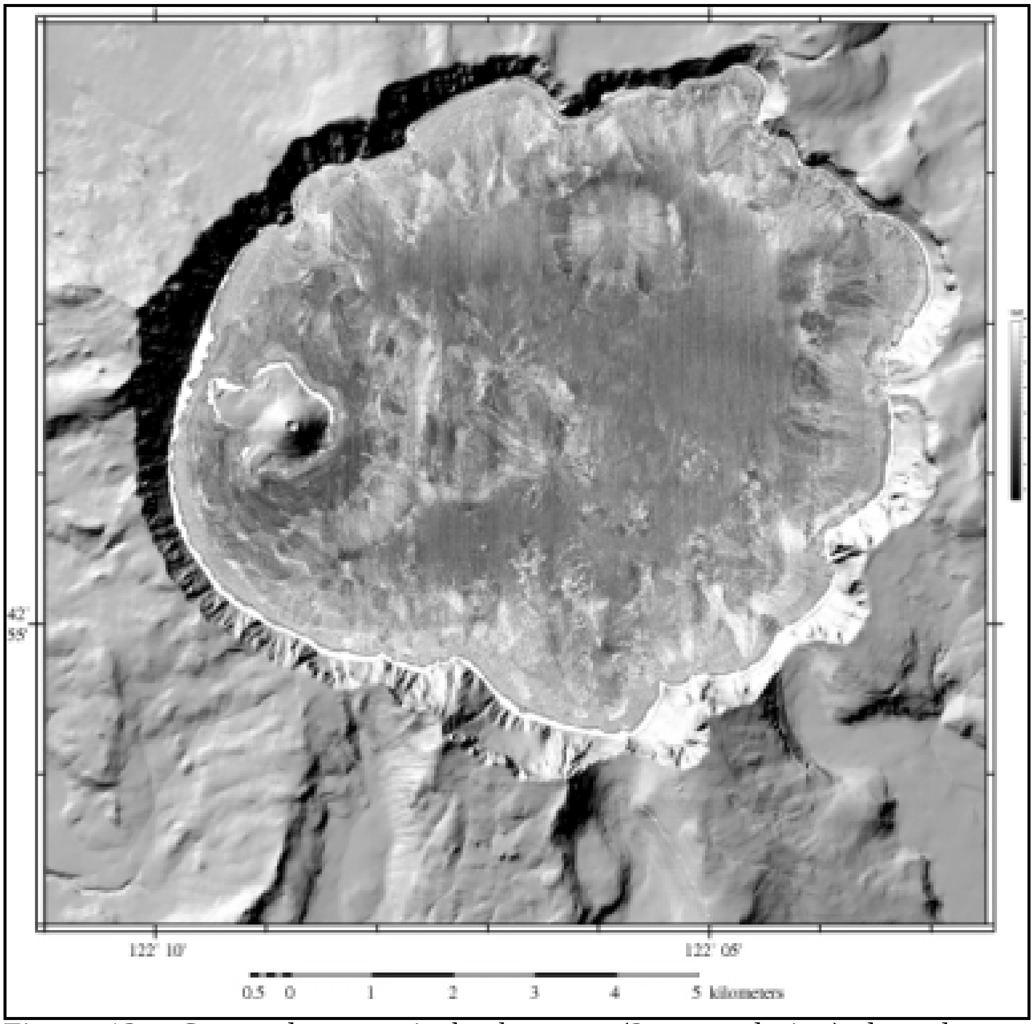

Figure 13. Grayscale acoustic backscatter (2-m resolution) draped over bathymetry of Crater Lake. Lighter tones are higher backscatter. Gray is land (10-m USGS DEM).

The backscatter map (Fig. 13) is a representation of the amount of acoustic energy, at ~95 kHz, that is scattered back to the receiver from the lake floor. The Kongsberg Simrad EM1002 system has been calibrated at the factory and all gains, power levels, etc. that are applied during signal generation and detection are recorded for each beam and are used to adjust the amplitude value prior to recording. Consequently, the backscatter was calibrated to an absolute reflectance of the lakebed. However, the amount of energy, measured in decibels (dB), is some complex function of constructional and destructional interference caused by the interaction of an acoustic wave with a volume of sediment or, in the case of hard rock, the rock material. The backscatter from sediment is volume reverberation to at least 5 cm caused by lake bed and subsurface interface roughness above the Rayleigh criteria (a function of acoustic wave length; Urick, 1983), the composition of the sediment, and its bulk properties (water content, bulk density, etc.). Although, it is not yet possible to determine a unique geological facies from the backscatter value, reasonable predictions can be made from the backscatter based on the known local geology.

It can not be stressed too strongly that one of the great advantages of this survey is that every sounding of the bathymetry is accurately georeferenced and coregistered with the backscatter. Consequently, each pixel on the map has a latitude, longitude, depth, and backscatter value assigned to it.

Daily Log

Saturday, July 22

The US Geological Survey (USGS), C&C Technologies, Inc. (C&C), and University of New Hampshire (UNH) groups all arrived at Crater Lake National Park on Saturday, July 22. We all met with the National Park Service (NPS) personnel and were told that the commercial helicopter contracted by the NPS for our deployment had not been released from fire-fighting duties in Montana. The NPS was working on another commercial helicopter operator as well as the possibility of using a military helicopter as a contingency. The contracted helicopter company (Erickson Air Crane) had concerns about our estimated weight of the boat and they required us to have accurate weights on the boat and the equipment van.

Sunday, July 23

We dispatched the boat to a crane company in Medford, OR and the boat and the equipment van were weighed using a NPS scale hung from a mobile crane. The boat and equipment van were then trucked to Crater Lake NP. Sunday afternoon was spent unpacking the equipment van, weighing each item in it, and then re-packing the van. In the late afternoon we were informed by NPS that a Monday helicopter lift was not possible but Tuesday morning remained a possibility.

Monday, July 25

Early Monday morning we were informed that the commercial helicopter would not be released from fire-fighting duties so the NPS immediately began to inquire about the possibility of a military helicopter. By Monday afternoon it appeared a high likelihood that a US Army Reserve Chinook helicopter could be called in to lift the boat into the lake.

Tuesday, July 26

We were told by the NPS at a 0800 hr meeting on Tuesday to truck the boat up to the rim of Crater Lake (Fig. 14) and prepare for a military helicopter lift at about noon. At about 0900 hr we were told that the military helicopter was in the air. However, at about 1100 hr we were informed that that there would be a two-hour delay in the arrival of the helicopter. And finally, at about 1600 hr we were told that there would be no helicopter lift on Tuesday and that a Wednesday lift was even questionable. Apparently, someone in the chain of military command in Atlanta, Georgia was holding up approval for the lift.

Wednesday, July 27

We were informed by the NPS early Wednesday morning that the US Army authorities in Atlanta were unwilling to give verbal approval and required signatures up their chain of command. They suggested this process might take several days. By 1100 hr we were

informed that there would be no helicopter operations on Wednesday.

At this point, a discussion between C&C, UNH, and USGS determined that, if the boat was not in the lake by darkness on Friday, July 28th, then we would be forced to terminate the operation and pack up and depart because the cost of standby would begin to use operational funds. In addition, the multibeam, IMU, and workstations, as well as C&C personnel were required back in Lafayette by C&C Technologies for the mobilization of a class 1 research vessel in Hong Kong. That decision was passed on to Mr. Mack Brock, NPS at 1200 hr.

Figure 14. *RV Surf Surveyer* leaving the Crater Lake NP staging area on its way to the helicopter landing site.

Thursday, July 27

We were informed on Thursday morning that there would be no helicopter lift on Thursday because of military red tape. However, by late Thursday afternoon we were informed that there was a high likelihood that a military helicopter would be available Friday.

Friday, July 28 (JD 210)

We were informed Friday morning that a military helicopter had been dispatched to Crater Lake to lift us into the lake. The helicopter arrived at 1415 hr and by 1530 hr the boat was in the water (Fig. 15) and by 1600 hr the equipment van was on Wizard Island. The remainder of the day was spent getting personal gear down the trail and setting up the field station on Wizard Island (Fig. 16).

Figure 15. RV *Surf Surveyor* being lowered onto Crater Lake.

Figure 16. Equipment van landing on Wizard Island.

Early Friday morning the NPS used their research boat to collect a CTD cast using both their Seabird CTD and the C&C CTD to intercalibrate the two instruments. A CTD cast is required to begin the patch-test procedure. A sound-velocity profile was calculated from the cast and entered into the Simrad software for refraction calculations and ray bending. The NPS collected CTD casts several times a day for our sound-velocity profiles (SVP). The *Surf Surveyor* departed the Wizard Island dock (Fig. 17) at 0900 hr to begin the patch test. The initial patch test used the in-between mode over the flat basin floor in the middle of the lake. Patch testing was completed by 1300 hr and the survey began.

Figure 17. RV *Surf Surveyor* at Wizard Island dock.

Saturday, July 29 (JD211)

The day was spent mapping the perimeter of the lake as close to the shore as was possible. Mark Buktenica (NPS) was stationed on the bow to guide the boat away from rocks.

Sunday, July 30 (JD212)

All day was spent running north-south lines working from immediately east of Wizard Island toward the east. About 60% of the lake was mapped. However, when the data tapes were downloaded, we discovered that the navigation port was not sending navigation strings to the Simrad software, which means the datagram recorded by the Hydromap software had no navigation data. Fortunately, all the sensors, including navigation, are recorded separately as well as integrated into the Hydromap datagram, so we had navigation files. The problem was to reformat the DGPS data file so that it would be accepted by the processing software. We spent all evening devising a way to read in the DGPS GPGGA datagram into our processing software and finally, at about midnight, were successful.

The Wizard Island field station (Fig. 18) has a diesel generator and a bank of batteries charged with a solar panel and an inverter. We tested out the battery power by switching from the generator to the batteries with only the two workstations online. The UPSs (uninterruptable power supply) immediately started sounding alarms and one immediately shut off, crashing one workstation. The second UPS switched to its internal battery and allowed enough time to shut down the second workstation. The result of this test was that all computers had to be shut down each night.

Figure 18. Wizard Island field station for the mapping project.

We also discovered that all of the offsets between sensors had not been entered into the IMU (inertial motion unit) software nor into the mergeNav script. All the data from Saturday and Sunday had to be remerged with the appropriate offsets, then regridded and remosaicked.

Monday, July 31 (JD213)

The first thing Monday morning the generator would not start. Consequently, we had no power to the computers. We discovered that the generator the battery was dead. The battery was replaced and the generator was restarted.

Monday was "press day"; a morning that the press was allowed on the water in the NPS RV *Neuston* to photograph the RV *Surf Surveyor* actually mapping, as well as a visit to the field station on Wizard Island. Most of the day was spent reprocessing Saturday and Sunday's data to correct for offsets and the navigation loss.

At 1245 hr the diesel generator powering the workstations ran out of gas and only one UPS backed up a workstation; the other UPS died, crashing the second workstation. Repeated efforts could not restart the generator, apparently because of debris sucked into the fuel filter when the diesel ran dry. Finally, at 1445 hr, with a cleaned fuel filter and diesel in the tank, the generator started and we got back to processing data.

The entire day was spent trying to reformat the various navigation files from Sunday's data so that one of them could be read by our processing software. Finally, near midnight, a fix was devised and tested. The fix required reading the navigation file recorded by Hydromap.

The mapping continued throughout the day and all but a small deep-water area and some shallow-water areas were completed. Chaski slide was entirely mapped and the below-water segment appears to be a debris avalanche, similar to the one discovered in Lake Tahoe during the 1998 mapping (Gardner et al., 2000). The area of the crater's rim directly above the slide has also failed and may be related to the below-lake failure (Fig. 19).

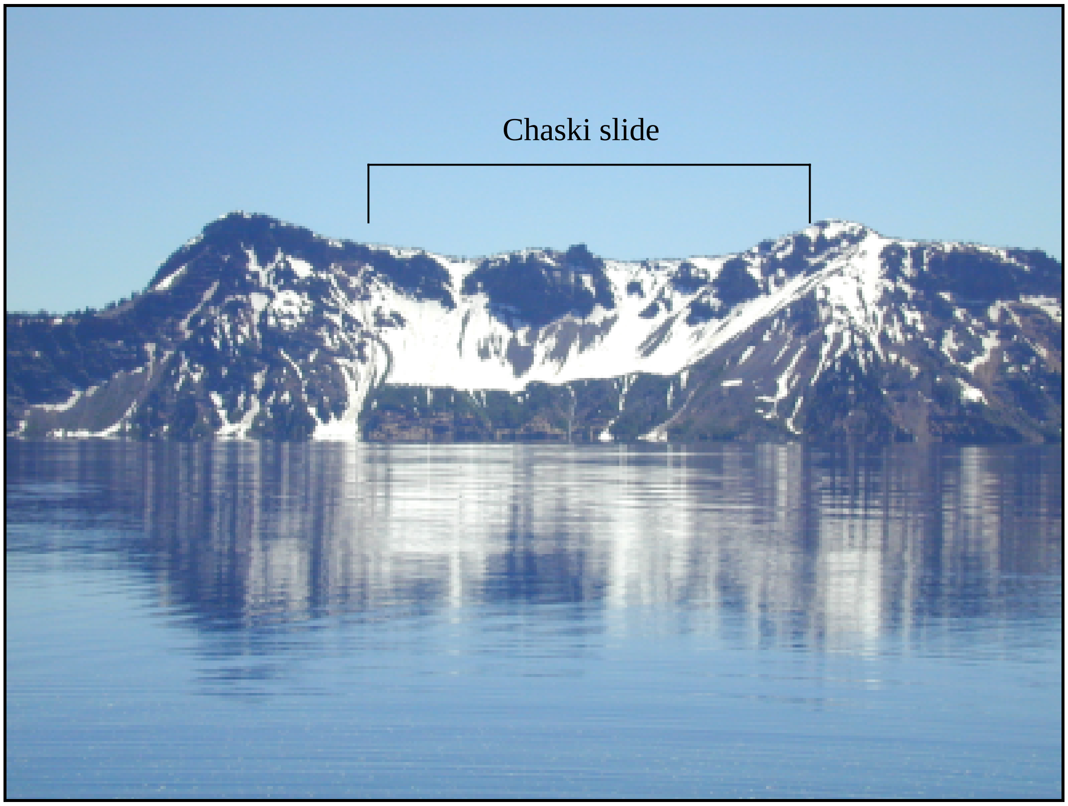

Figure 19a. Chaski slide as seen from above lake level. View looking southeast.

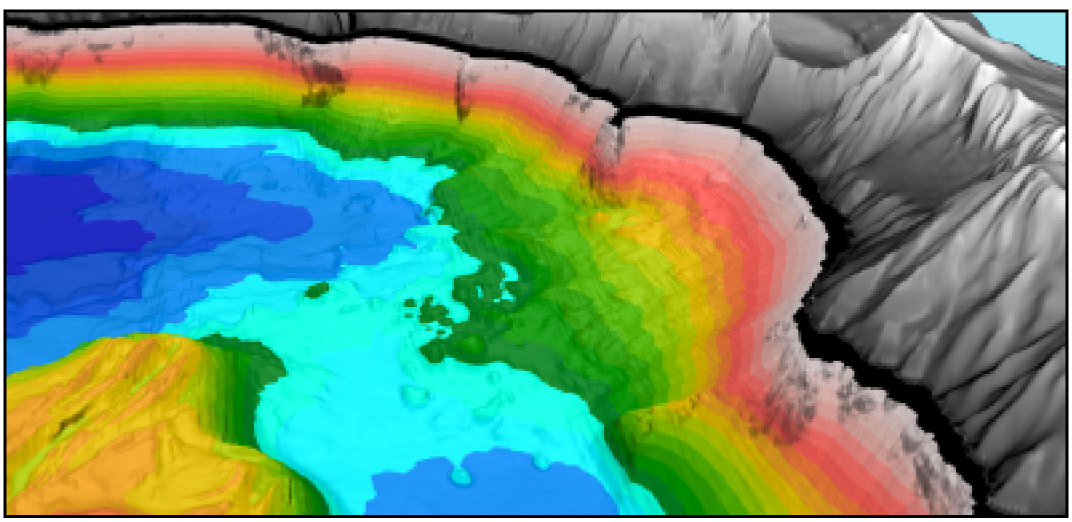

Figure 19b. Chaski slide as seen with no water in Crater Lake. View is looking south.

Tuesday, August 1 (JD 214)

The mapping commenced by circumnavigating the lake twice to fill in data gaps and finally to beam-steer the transducer to ensonify as close to the shore as possible. Sunday's data were processed, then Monday's, and by 1000 hr the data processing was caught up with the data collection.

Wednesday, August 2 (JD 215)

The day was spent filling in small gaps to insure 100% coverage. We collected the data tape at noon so that the processing could be finished in the evening in time for packing the equipment van for an early-morning departure. The final few hours of data collected in the afternoon were quickly processed and the final maps (Figs. 12 and 13) were produced by 1800 hr.

The processing computers were shut down and the equipment van was packed by 2100 hr.

Post-cruise Processing

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

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