Results from the Amchitka Oceanographic Survey

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Executive Summary

In preparation for the 2004 field work, a literature search was conducted for material related to Amchitka Island and a bibliography was created. Appropriate tables and graphics were scanned and archived. Geologic fault lines and the coastline were digitized from existing maps, and historical bathymetry data were acquired from NOAA. All data discussed in this report are available at http://www.ims.uaf.edu/research/johnson/amchitka and the CRESPII web site.

A detailed bathymetry, side scan sonar and conductivity-temperature-depth (CTD) survey was completed to the northeast of Amchitka Island offshore of the Cannikin and Long Shot test sites. The historical bathymetry is in general agreement with the newly acquired data. To our knowledge, the side scan sonar survey is the first to be completed offshore of Amchitka and it shows the presence of sediment and areas of slumping in contrast to prior literature. These new data could serve as a baseline for future work.

A closely spaced CTD survey was completed with emphasis on measuring salinity within the bottom 1 to 2 meters. From the gathered data, there is no evidence for large-volume or broad scale freshwater outflow from the bottom between the 20 to 100 m isobaths offshore of the Cannikin and Long Shot sites. However, as many as six of the stations show bottom salinity that falls below three standard deviations from what might be expected based on local conditions. Future surveys may benefit from initiating searches for freshwater sources at these stations. Caution is urged, however, as signal contamination (turbidity, zooplankton) remains a possibility within the bottom boundary layer that can not be distinguished from anomalously fresh water.

Using the data we have collected as a guide, it is recommended that a sampling strategy be developed that includes sampling of sediment pore-water for salinity measurement at selected locations around Amchitka. Comparison of the pore water salinity with CTD data and Niskin bottle salinity data near the ocean floor may provide additional information on possible freshwater migration with groundwater movement from the bottom.

Acknowledgements

We thank the Captain and crew of the F/V *Ocean Explorer*, Sookmi Moon, physical oceanographer (now at NOAA-PMEL), Stephen Gaffigan, and the rest of the team from the Naval Undersea Warfare Center, Keyport, Washington (Mike Farnam, Brian Bunge, Bill Heather, and Tim Jameson, Ed Draper). Their expertise and hard work were essential to our success.

1. Introduction

Underground nuclear testing on Amchitka Island, Alaska at the Milrow, Long Shot, and Cannikin test sites has led to the possibility that radionuclides could migrate with groundwater movement from one or more of the blast cavities. Possible pathways may be along fault lines or follow freshwater percolating down from the surface and then migrating seaward below the ocean until finally moving up through the ocean floor into the overlying seawater. A schematic diagram of an idealized migration path is shown in Figure 1 where the depths of Long Shot and Cannikin are shown by the blue and red circles, respectively. This cross section shows Amchitka's surface elevation and ocean depths shown to the left (Pacific Ocean) and right (Bering Sea) to distance of about 3 km.

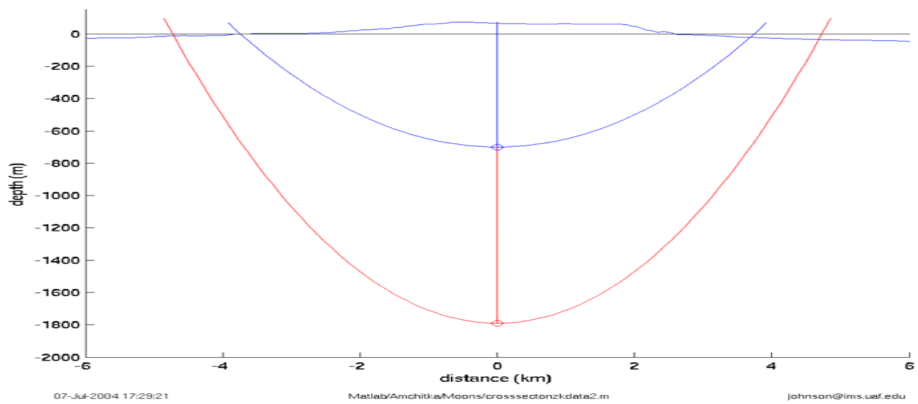


Figure 1. Schematic of idealized parabolic pathways for possible migration from the blast cavity. Long Shot is shown in blue and Cannikin in red. Note that the aspect ratio compresses the horizontal scale to about half.

Freshwater near the sea floor may be indicative of groundwater movement through the sub-bottom. One way to look for possible freshwater is to sample the ocean salinity offshore of Amchitka Island. Finding and measuring a relatively freshwater signal is difficult because fresh water is more buoyant than seawater and rapidly mixes with the overlying fluid and reduces any signal. Despite such challenges, the CRESPII team determined that a large signal might be detectable and worth investigation. The research described here was guided by the following core questions.

1.1. Overarching questions

1. Is there evidence of freshwater discharge through the ocean floor in areas that were previously identified as most likely to have freshwater discharge originating from the test shots?
2. Is there evidence of sedimentation on the ocean floor off-shore of the test sites? Sediments have the potential to accumulate radionuclides.
3. To what extent can previous work help the design of our sampling plan?

1.2. Objectives

1. Conduct a literature review to aid planning of the biological, physical, and geophysical marine and terrestrial sampling. Provide background information on prior work on Amchitka Island, including information on the original test site studies.
2. Acquire previous bathymetry data to identify most likely locations for freshwater discharge through the ocean floor originating from the test shots.
3. Digitize (scan) and review historic maps and aerial photography of Amchitka.
4. Review geologic maps to identify fault lines that potentially may serve as conduits for groundwater movement.
5. Make new bathymetric measurements off-shore of the Cannikin and Longshot sites (primary) and Milrow (secondary) to determine whether geologic features exist relevant to assessing freshwater discharge from the ocean floor. Limited ship time prevented measurements at Milrow.
6. Make new side-scan sonar measurements off-shore of the Cannikin and Longshot sites (primary) and Milrow (secondary) to determine whether there is accumulated sediment. Prior reports suggested a bottom scoured by ocean currents. Limited ship time prevented measurements at Milrow.
7. Make measurements of salinity (and temperature and depth) off-shore of the Cannikin and Longshot sites (primary) and Milrow (secondary) to determine whether there is measurable freshwater discharge through the ocean floor. Collect profiles with an emphasis on the bottom 2 m layer. Limited ship time prevented measurements at Milrow.

This remainder of this report is divided into three sections. The following section provides details of the data mining from original reports, publications, and the internet. The next section describes the results of our 2004 field work around Amchitka Island on board the F/V *Ocean Explorer* which was chartered because it is well suited for work in Alaskan waters. The final section summarizes our findings.

2. Background

2.1. Geology

Amchitka Island is one of many islands of the Aleutian Island chain in western Alaska. Amchitka Island, 55 km long and 5.5 km wide, lies in the western portion of the Aleutian Volcanic Arc which developed geologically about 55 million years ago. Amchitka Island is located at 51° 32' N Latitude, 179° 00' E Longitude and has an approximate area of 300 km^2. Recent knowledge about plate tectonics along with contemporary observations reveal that this region is among the most dynamically active. More than 90 percent of the seismic energy recorded within the United States during the instrumental record was within the Aleutian Volcanic Arc. For example, magnitude-8 earthquakes occur at approximately decadal time intervals along the Aleutian arc, with half of the six largest earthquakes occurring between 1957 and 1965 (Eichelberger et al., 2002).

To put some perspective into the magnitude of the Amchitka tests, the below timeline compares the size of man-made and naturally occurring events.

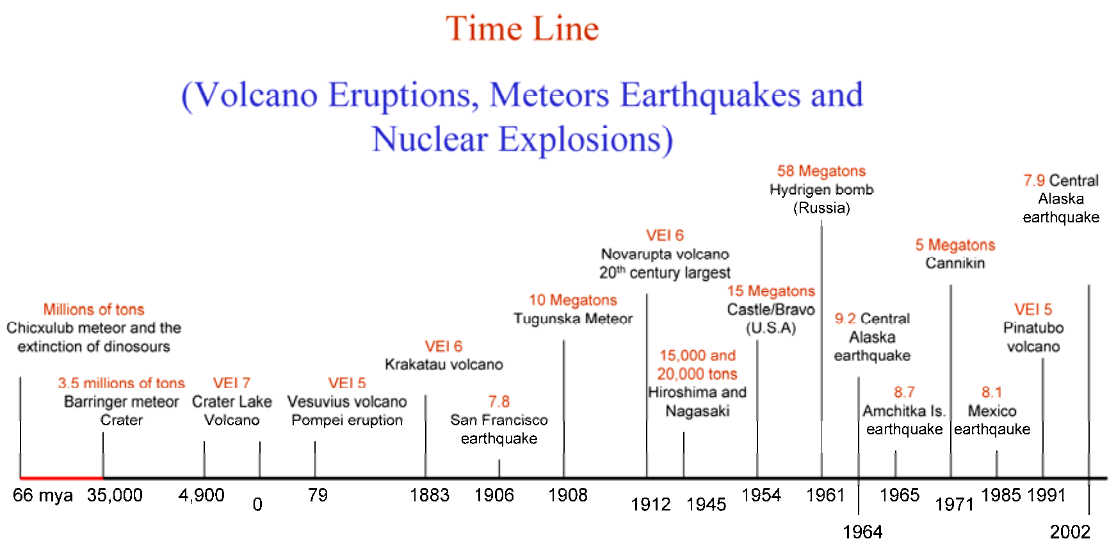


Figure 2. Timeline of volcanic eruptions, major earthquakes and man-made blasts. VEI is volcanic eruption index.

2.2. History

American troops landed on Amchitka to establish The Naval Air Facility on 24 February 1943. Near the end of World War II, Amchitka Island was an advance location for planning the invasion of the northern islands of Japan (the Kuriles). The southeastern portion of the island housed an infantry division of about 13,000. At this time Amchitka had three runways. "Fox" was shortest and closest to what is now Constantine Harbor. "Charlie" and "Baker" were longer, and with "Charlie" at 10,000 feet in length, it was at that time the world's longest runway. By 1949-1950, the Air Force presence on Amchitka had dropped to about 40.

During the postwar period, Amchitka Island was a military outpost providing a radio range station and alternate landing site for aircraft flying the Aleutian Islands. It was also a weather monitoring site for Russian weather reports where six full time radio operators monitored Russian weather broadcasts.

Between 1950 and 1961 Amchitka Island was used in the Distant Early Warning network. Between 1965 and 1971 Amchitka was the site for underground nuclear testing. Between 1986 and 1993 it was used for construction and operation of the Relocatable Over the Horizon Radar.

2.3. Underground Nuclear Testing

Amchitka Island is the site of three underground nuclear detonations conducted on 29 October 1965 (“Long Shot”), 2 October 1969 (“Milrow”), and 6 November 1971 (“Cannikin”). Long Shot was detonated at a depth of 700 meters and had an 80 kiloton yield. It was detonated shortly after a nearby magnitude-8.7 earthquake to determine whether monitoring techniques could differentiate between natural seismicity and nuclear explosions. Milrow was a seismic calibration test detonated at a depth of 1,220 meters with an approximate one megaton yield. Cannikin, a test of the proposed

Spartan missile warhead, was detonated at a depth of 1,790 meters, with a yield slightly less than five megatons. Table 1 lists details of the tests.

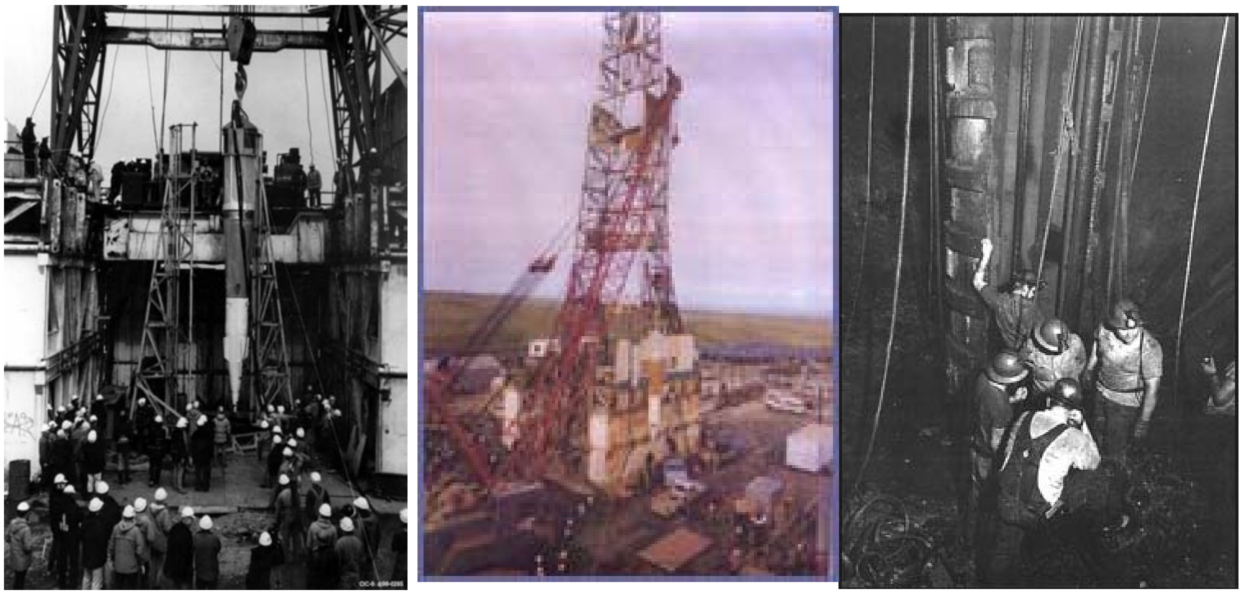


Figure 3. Left and middle show the missile warhead. Right are minors in the Cannikin shaft.

Data from the Nevada Test Site shows what happens following an underground nuclear blast. Upon detonation, nearby rock vaporizes or melts into a puddle of magma on the floor of the explosion cavity. Part of this magma turns to glass. The roof of the cavity may collapse in a second wave of fracturing forming a chimney to the surface. The shock from the detonation causes extensive fracturing well beyond the blast site.

Most radionuclides remain within the magma-turned-glass cavity. Some radionuclides move up with the silicate vapor from the vaporized rock and then settle within the collapsed chimney. Today, one of the key areas of investigation for Amchitka is whether groundwater percolating through the test sites may carry radioactive materials towards the ocean. This is the focus of the research described in this report.

Of the three Amchitka tests, only Cannikin produced any surface expression that is obvious today. The Cannikin explosion extended out through existing geological faults and drove groundwater 20 feet from the land surface. Within two days of the detonation, a crater formed almost 2 km wide and 12 m deep.

Near ground zero, Cannikin was measured at magnitude-6.8 and the largest subsidence event that followed was 4.9. Subsidence and faulting dammed nearby White Alice Creek, which then filled portions of the explosion cavity and collapsed chimney, forming Cannikin Lake. There were individual fractures up to 2 km in length with as much as 6 m of vertical displacement. At the Bering Coast there was about a meter of uplift.

2.4. Historical Bathymetry Data

NOAA archives bathymetric survey data from1939 to the present. Ship positioning has evolved from celestial navigation, to LORAN, and now to GPS having errors of a few meters. Significant challenges exist when incorporating prior data into a modern bathymetry database. To ensure confidence in modern oceanographic charts, NOAA collects and archives marine bathymetric survey data and performs quality control on those data. NOAA data are available from the National Ocean Service web site (www.oceanservice.noaa.gov/). The survey data near Amchitka Island were interpolated to UTM coordinates by Mr. Robert Aguirre, NOAA. The tracks of the survey data for charts of the Rat Islands are shown below.

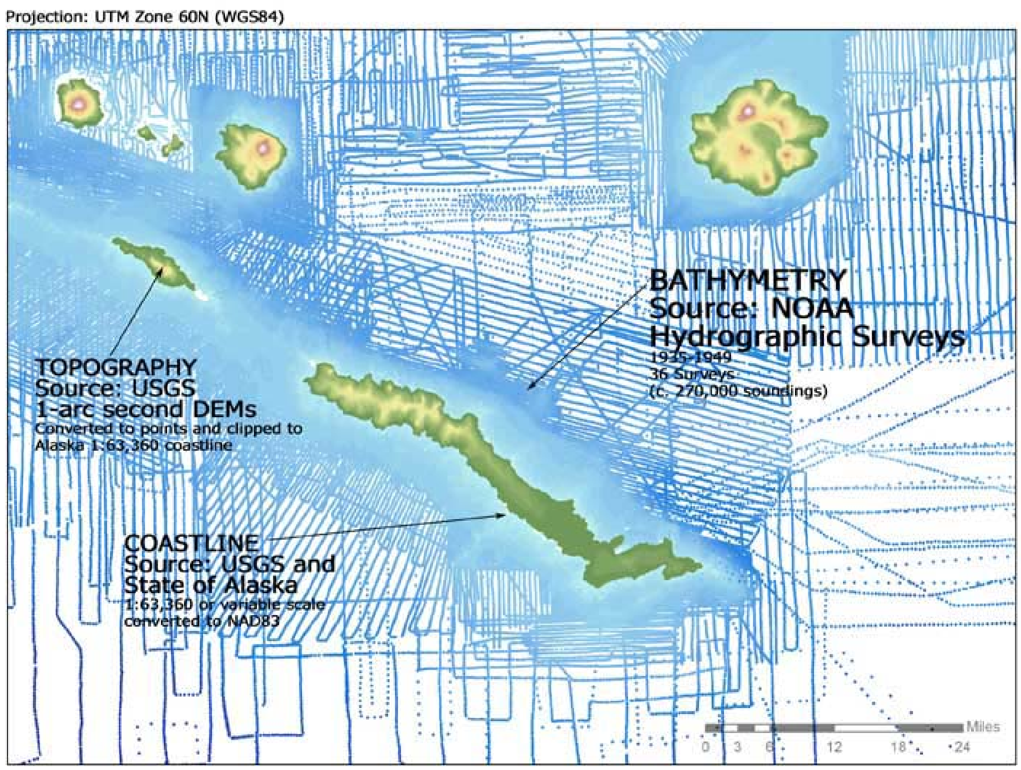


Figure 4. NOAA cruise tracks used for the bathymetry data base.

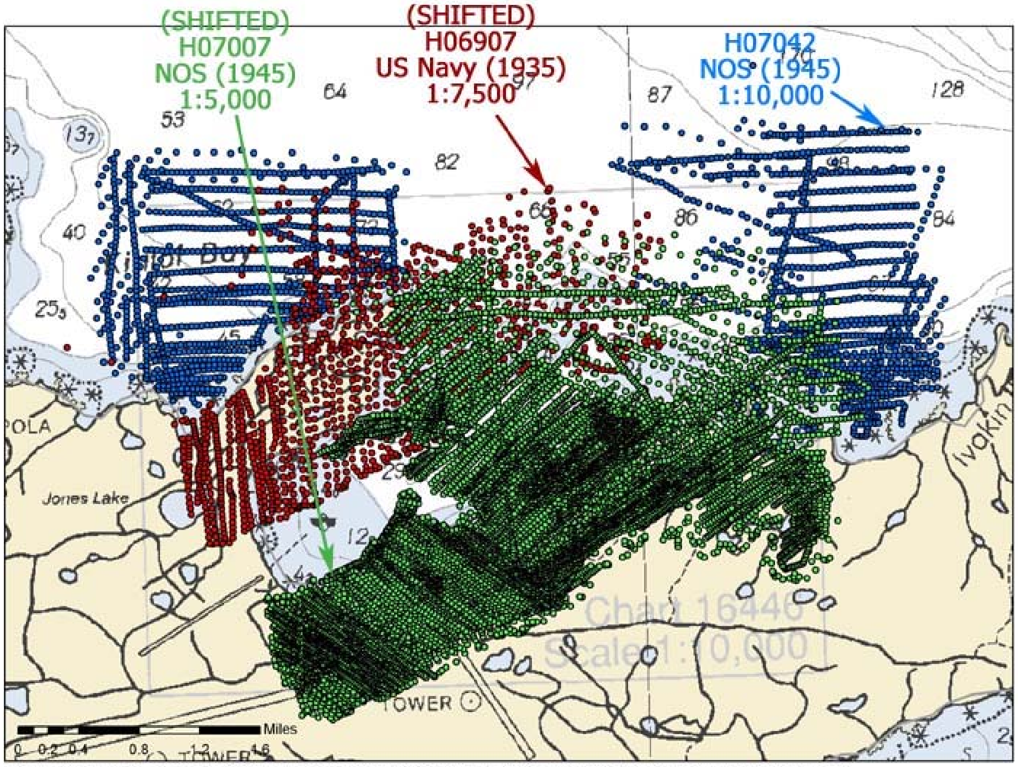


Figure illustrating probable horizontal control problem in two 1935 and 1945 Constantine Harbor surveys.

Figure 5. NOAA figure showing position problems in 1935 and 1945 survey data. Note ship positions in shallow water and over land.

Prior to this study, the interpolated, gridded data set assembled by Mr. Aguirre was acquired by Dr. Zygmunt Kowalik at the Institute of Marine Science, University of Alaska Fairbanks, for use in numerical models unrelated to this study. The UTM data were interpolated to latitude-longitude coordinates which are more suitable for numerical modeling work. Johnson acquired the bathymetry data to use as the baseline data set for Amchitka and nearby regions. The data have a resolution of 3 secs in latitude and 6 secs in longitude. They are available as an ascii file "RatIslandBathymetry.dat" listed in Table 2. The latitude-longitude bathymetry data were offset to the west by 1 minute to visually align with coastline data digitized from other maps. This offset is likely a minor numerical issue that was unresolved during discussions between Aguirrre and Kowalik, but to explore this we extracted the original NOAA survey data. While plotting the cruise tracks it was noted that some of the positions were incorrect (over land). Two options were discussed: use the data from Aguirre and Kowalik or re-evaluate the NOAA quality controlled data to create a new bathymetry data set. Time and budgetary constraints led us to use the existing bathymetry data set with an offset to align over existing coastline data around Amchitka Island. We also digitized coastline and fault line data from maps from Lewis et al., (1960). A graphic of the final product blending the coastline, fault and bathymetry data is shown below. Graphic files of these and other charts are available from the author's website (http://www.ims.uaf.edu/research/johnson/amchitka).

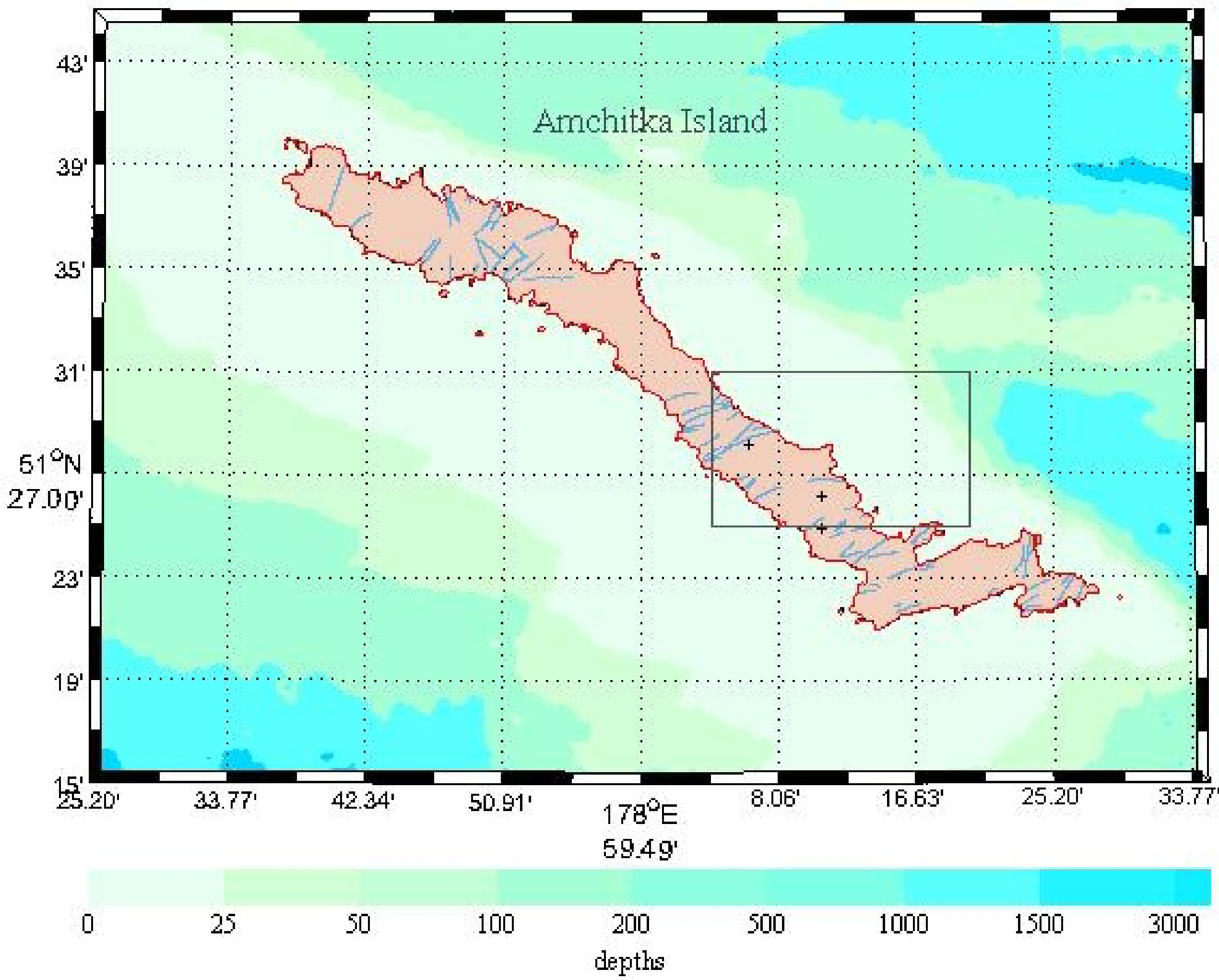


Figure 6. Contours of ocean depths (meters), Amchitka Island coastline (red), geological fault lines (grey) and test sites (+) from the acquired historical data. Black box shows approximate study area enlarged in later figures.

2.5. Aerial Photos

Both before and shortly after the nuclear testing, aerial photos were taken over Amchitka Island. These photographs are archived at the University of Alaska Fairbanks. We have scanned at high resolution most of these photos over areas felt to be of interest to Amchitka researchers. The high resolution files are available upon request from Mark Johnson, University of Alaska Fairbanks. A collection of low-resolution images from photos over each transect is available from the web site (http://www.ims.uaf.edu/research/johnson/amchitka) as Microsoft Powerpoint files and are listed in Table 2 as AmchitkaAerialPhotosLine1.ppt, AmchitkaAerialPhotosLine4.ppt , and AmchitkaAerialPhotosLine16.ppt. Aerial survey transects describing the aerial photo sequences along with an example photo are shown below.

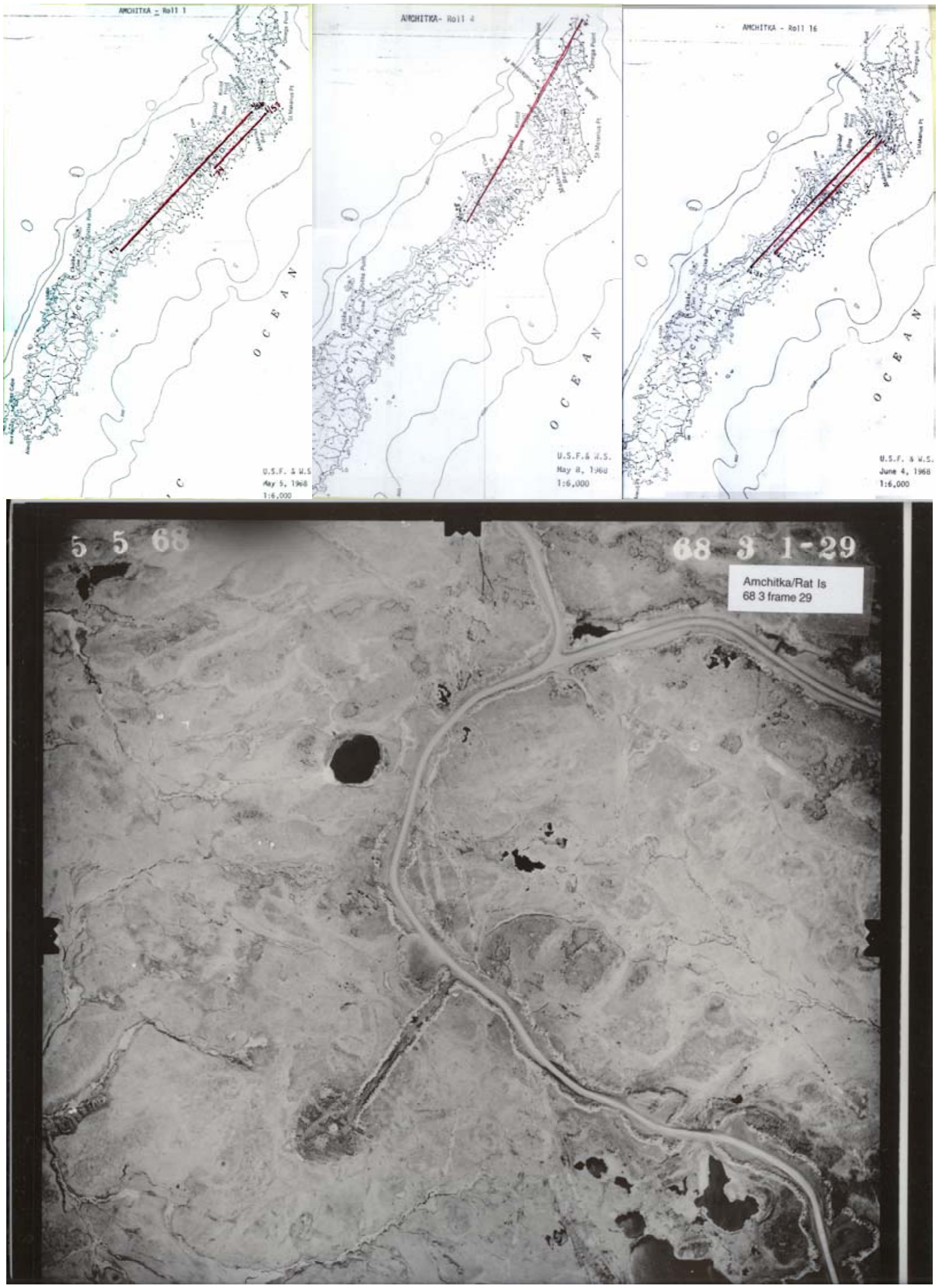


Figure 7. Top. Scanned images showing survey lines for aerial photos taken prior to and shortly after nuclear testing over southeastern Amchitka Island. Bottom. Example photo of test site mid-way along transect 1 (transect 1 is shown in upper left).

2.6. Charts

There is a great deal of information in the literature concerning Amchitka Island and its nuclear testing. In order to have as much information as possible while in the field, a number of charts were scanned and are available as described in Table 2.

2.7. Bibliography

A listing of Amchitka literature is available (Table 2). A complete list of the all archived data, including bibliographies, is shown in Table 2.

3. Methodology

3.1. Sampling rationale

Our goal was to survey the region offshore of Long Shot, Cannikin, and Milrow from as near to shore as safety permits (about the 20 m isobath) and offshore to the 100 m isobath or to a distance 4 km for Long Shot, 6 km offshore for Cannikin, and 6 km for Milrow. These distances are based on the transport model estimates of the second edge (99% CI) distance from shoreline for any possible leakage (DOE, 2002). Details from this report are summarized in Table 3. The survey regions are bounded to the north and to the south by the location and direction of fault lines nearest to each blast site (see Figure 6). Existing fault lines were visually extended offshore in a line parallel to the fault (approximately northeast) to define an area for detailed sampling. We completed our highest priority survey offshore Long Shot and Cannikin. A Milrow survey was not done because of constraints imposed by the available ship time.

3.1.1. Bathymetry mapping

To determine whether there are features in the bathymetry around Amchitka that could influence freshwater discharge from the bottom, we completed a very high (2 m) resolution mapping of bottom depths using modern positioning and multibeam echosounding. Bathymetry mapping also ensured that the side scan sonar could be towed safely.

The bathymetry to the northeast of the Cannikin and Long Shot sites from about 20 to 100 m depth was mapped to 2 m resolution using an SM2000 multibeam echosounder. The SM2000 multibeam sonar has a range scale of 400 meters, interrogated the bottom at 1.92 pings per second, with receiver gain at 35%. For the multibeam data post processing, the Qinsy processing module (Validator) was used to visually inspect each multibeam survey transect for data anomalies. All anomalies deemed to be erroneous were flagged "bad" and not exported to the final data set. The Validator allows the user to inspect the data in multiple views such as a profile, swath (along track), plan, and 3-dimensional. The bathymetry data were de-tided and then mapped onto a 2 m grid. The final validated and de-tided points were then exported into ascii-xyz data files. The data set is DM2m60N.asc (see Table 2).

3.1.2. Side scan sonar survey

The historical literature suggests that sediments were scoured from the bottom due to high velocity ocean currents. To evaluate this, a side scan sonar mapped the bottom texture over the same area as the bathymetric survey using a Datasonics SIS 1000 side scan sonar. It has a range scale of 200 meters which produces a 400 meter swath width. Gain settings were as follows: Port Side Scan Channel: -15 dB Transmit, -15 dB Receive; Starboard Side Scan Channel: -15 dB Transmit, -15 dB Receive; and Sub-bottom Channel: -15 dB Transmit; -18 dB Receive. The instrument was towed at several knots using an industry standard armored coaxial tow cable with impedance of 30 to 75 ohms and attenuation of 50 dB maximum at 3 MHz. and a cable length of 1000 meters. The following characteristics apply: transmitter transducers were two six element transducer arrays; receive hydrophones were two six element hydrophone arrays; the acoustic source level was +225 dB re 1 μPa @ 1 meter with range of 25 to 750 meters each channel; a frequency range with sweeps in the 90 kHz to 110 kHz band and port and starboard side scan sonar sweep in opposite directions; the transducer radiation was 0.5° horizontal composite, 70° vertical with side lobe suppression of -20 dB, by shading; the receiver gain was user adjustable from 0 to 42 dB in 3 dB increments; time varied from –20 to 40 dB in automatic discrete steps.

3.1.3. Conductivity, temperature, and depth (CTD) profiling

Eighty oceanographic stations along twelve (12) transects running normal to the bathymetric slope were occupied using a Sea-Bird 19 CTD (http://www.seabird.com/) to measure conductivity (salinity), temperature, and pressure (depth). The CTD was calibrated by Sea-Bird both before and after the cruise. Resulting salinity accuracy is about 0.001. Resulting temperature accuracy is about 0.01°C. The CTD was lowered at no more than 30 m per minute until an approximate 2 m altitude was reached, and then the CTD was held close to that depth for 2 minutes to measure salinity near the bottom. Adjustments to the depth of the CTD were made in real-time based on variations in the measured altitude from an acoustic altimeter attached to the CTD with shipboard readout. CTD data were collected as 0.5 second averages and were processed using Sea-Bird processing software. The temperature (°C) and salinity (dimensionless PSU) were aligned in time with pressure to correct for lags in the sampling stream using Sea-Bird software. Further analysis and plotting were done at the Institute of Marine Science, University of Alaska Fairbanks.

Salinity data are reported here in Practical Salinity Units (PSU). The Practical Salinity Scale defines salinity as the conductivity ratio of a sample to that of a solution of 32.4356 g of KCl at 15°C in a 1 kg solution. Thus, seawater at 15°C with a conductivity equal to this KCl solution has a salinity of 35. In this report, no units are used following given salinity values because PSU is a dimensionless number.

3.1.4. Discrete water and sediment sampling

Seawater samples were taken using Niskin bottles at a number of sites determined by Conrad Dan Volz, University of Pittsburgh. Sediment grab-samples were taken at selected sites based on at-sea results of the side scan sonar survey to differentiate among different bottom types. Both fine and coarse grained sediment samples were retrieved and varied by location.

3.2. Ship positioning

Qinsy software (Quality Positioning Systems (QPS) (www.qps.nl) version 7.30) was used as an integrated navigation system to record the data input from different types and makes of external positioning and attitude sensors placed on board the F/V *Ocean Explorer*. The sensors included a Trimble Ag132 differential GPS positioning system, TSS DMS05 Attitude sensor (Pitch, Roll, Heave), Meridian Gyrocompass, and a Trackpoint II Ultra Short baseline sub-surface acoustic positioning system (for Sidescan sonar towfish positioning). The Qinsy system was used to record the raw multibeam sonar data from the SM2000 echosounder. Ship positioning was recorded and logged using the Trackpoint II USBL with interrogate rates as follows: 3 second transmit and receive during CTD drops; 4 second during Side scan sonar operations.

4. Results

4.1. Bathymetry survey

The transect lines to map the bathymetry are shown in Figure 8 and a contour map of the resulting bathymetry is shown in Figure 9. This data set is available (see Table 2). Nearshore bathymetry is rugged with large boulders and abrupt changes in depth such that further mapping closer to shore was not done. In general, the bottom gently slopes offshore. No features were mapped to suggest faults or cavities where freshwater could discharge.

4.2. Side scan sonar survey

Transect lines similar to those of the bathymetric survey were followed while towing the sonar. The resulting images were mapped into a single mosaic. Transect lines are shown in Figure 11 and the side scan mosaic is shown in Figure 12. There appear to be regions where slumping of the sediments has occurred, and regions of bottom fracture and compression as well. Whether these resulted from the blasts or were present prior to that time cannot be determined, although slumping and compression could certainly result from nuclear detonation. The slumping and compression visible in the side scan mosaic are consistent with the compression contours following Cannikin (see Figure8.TIFF in Table 2).

4.3. CTD water column sampling

Eighty stations were occupied where CTD data were collected from the surface to the bottom (Figure 12A). The station naming convention is either "C" (offshore Cannikin) or "L" (offshore Long Shot) followed by the transect number (1 through 6 from south to north for each region) and followed by the station number beginning with 1 near shore and incrementing offshore. Thus, C1-1 is adjacent to Cannikin, line 1, station 1, and L2-5 is off Long Shot, second line, fifth station offshore. Each station took about 15 minutes to complete during which the ship drifted with wind and current. Ship drift paths while the CTD was profiling are shown in Figure 12B.

Salinity data from L1 through L6 and from C1 through C6 were contoured as vertical sections (Figure 13) with the offshore direction to the right of the figure. Each transect took several hours to complete, so the tidal signal is slightly aliased along each individual section. Multiple sections took longer, so comparing sections introduces aliasing of the tidal signal.

Vertical sections show no obvious evidence of broadly distributed freshwater at the bottom. However, small scale seeps could produce a local freshwater signal that could be revealed in individual profiles of salinity. To examine this, vertical profiles at each station were produced (Figure 14). In both the CTD down cast and up cast from each profile, we looked for unusual changes in salinity near the bottom by computing the slope of salinity vs. depth for the 5 m layer above the bottom 2 m layer. The salinity standard deviation in the 5 m thick layer was computed and used to estimate the std range of the bottom salinity. Although spurious salinity readings can result from turbid bottom boundary layers, and from material entering the salinity pump (such as gelatinous zooplankton and similar material) we have no way of determining whether such a signal is from "contamination" or from a real source of freshwater. The CTD casts in figure 14 have the necessary conditions for freshwater anomalies near the bottom, and future efforts to determine freshwater might begin at any of the following stations: C1-2, C3-4, C4-1, C4-4, C5-1, L2-2. However, from the collected data, there is no evidence for consistent, large-volume, or broad-scale freshwater outflow in the bottom waters of the study region from 20 m to 100 m offshore.

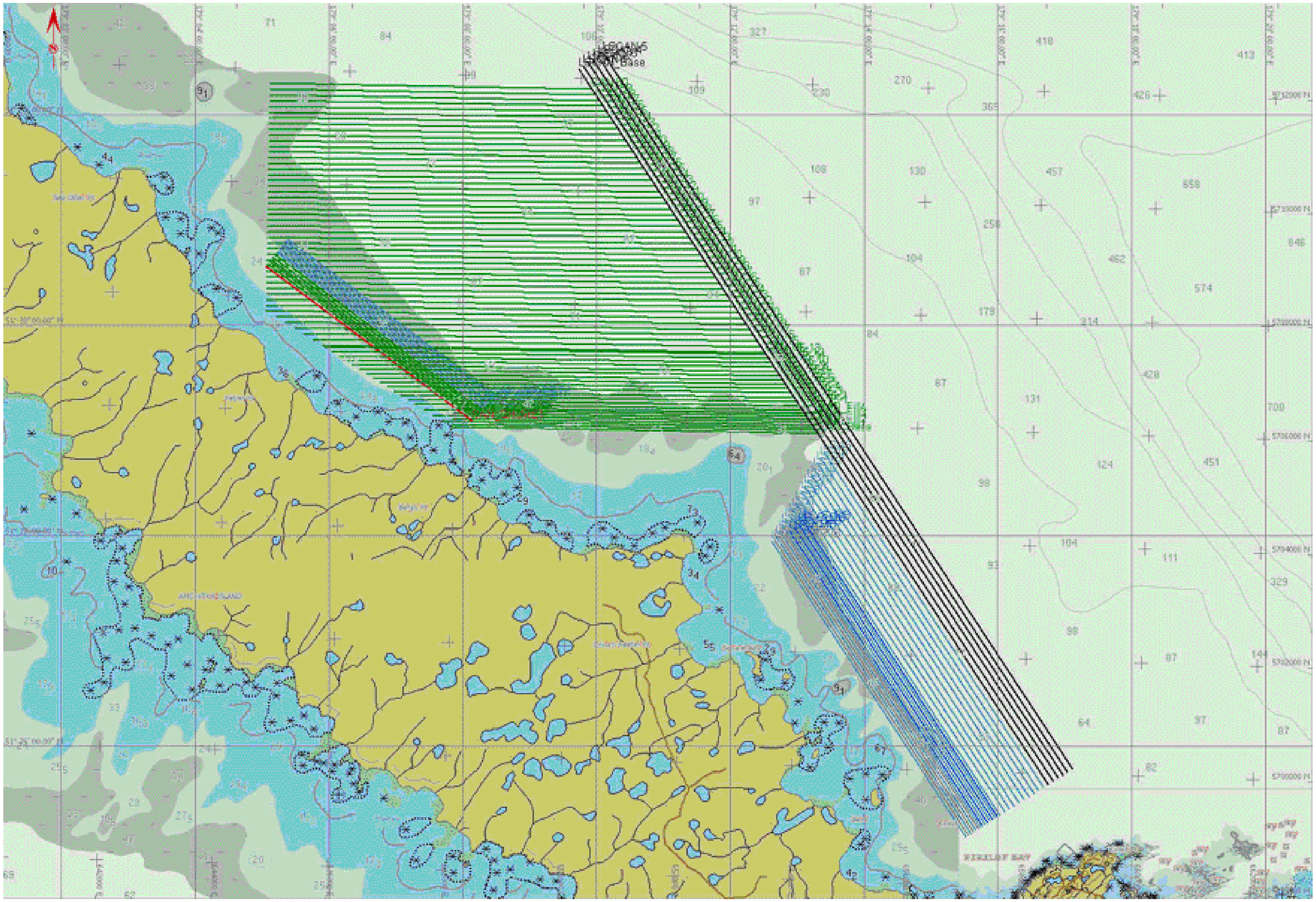


Figure 8. Transect lines for multibeam bathymetric survey.

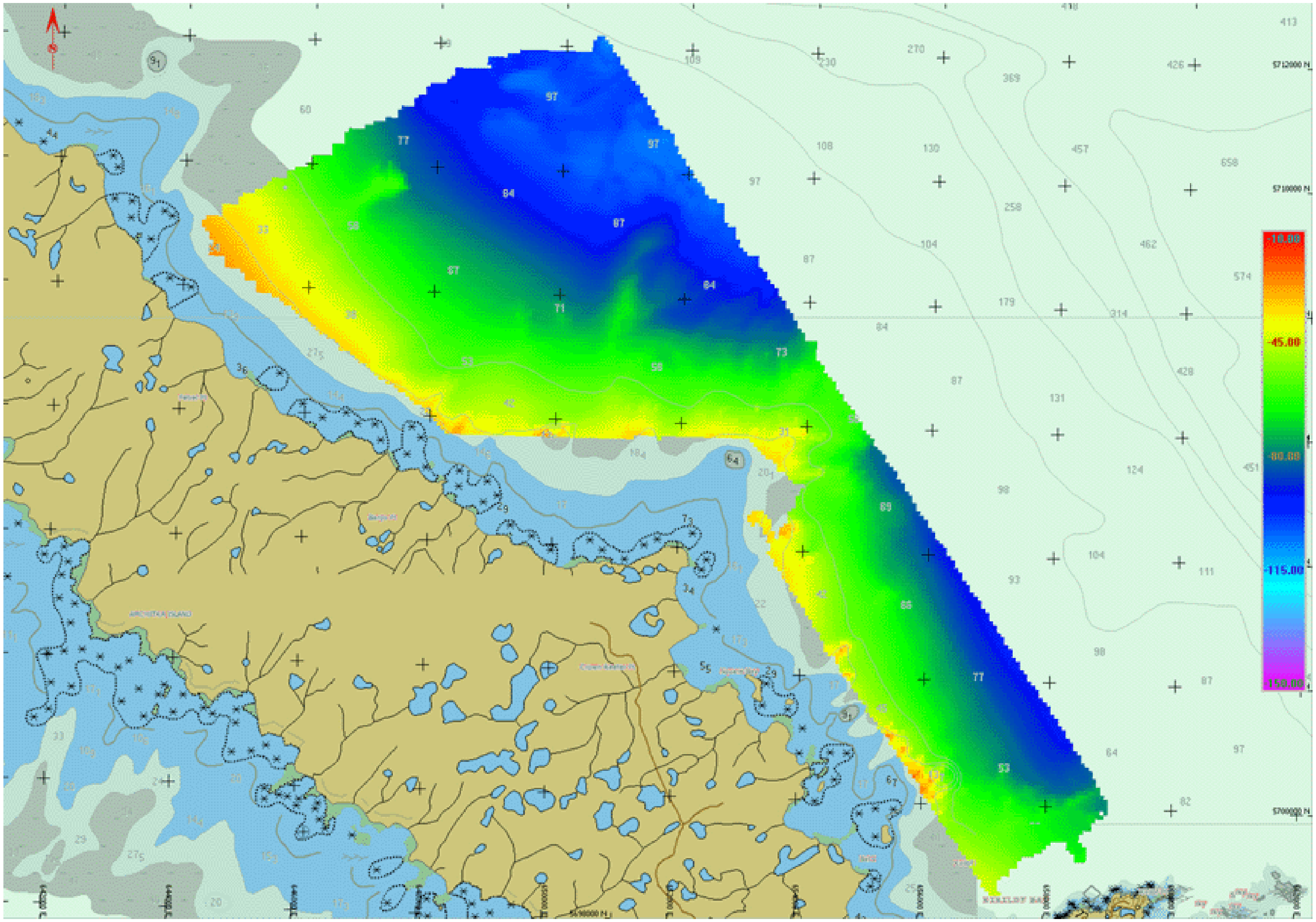


Figure 9. Contours of bathymetry from multibeam survey.

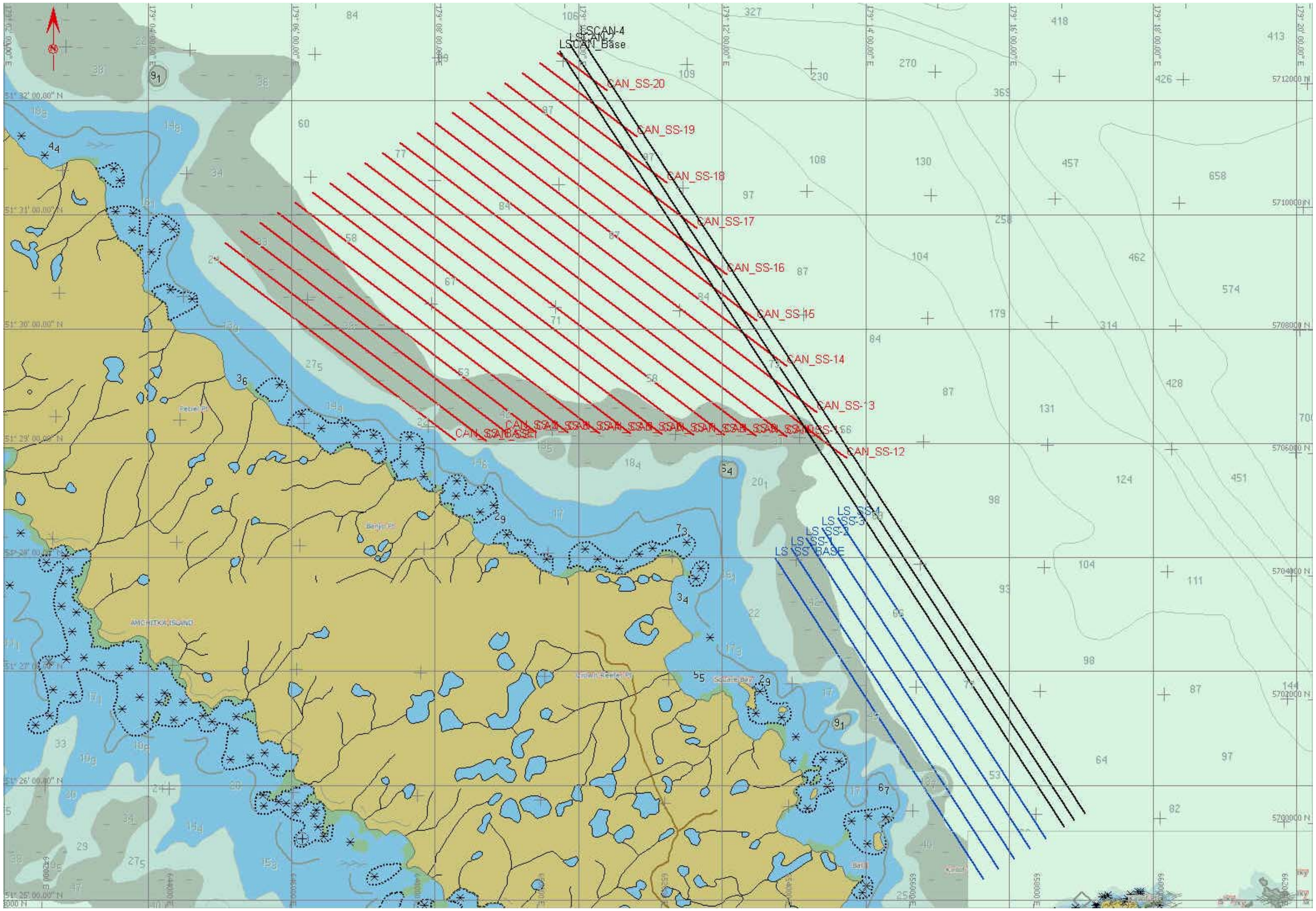


Figure 10. Transect lines for the side scan survey.

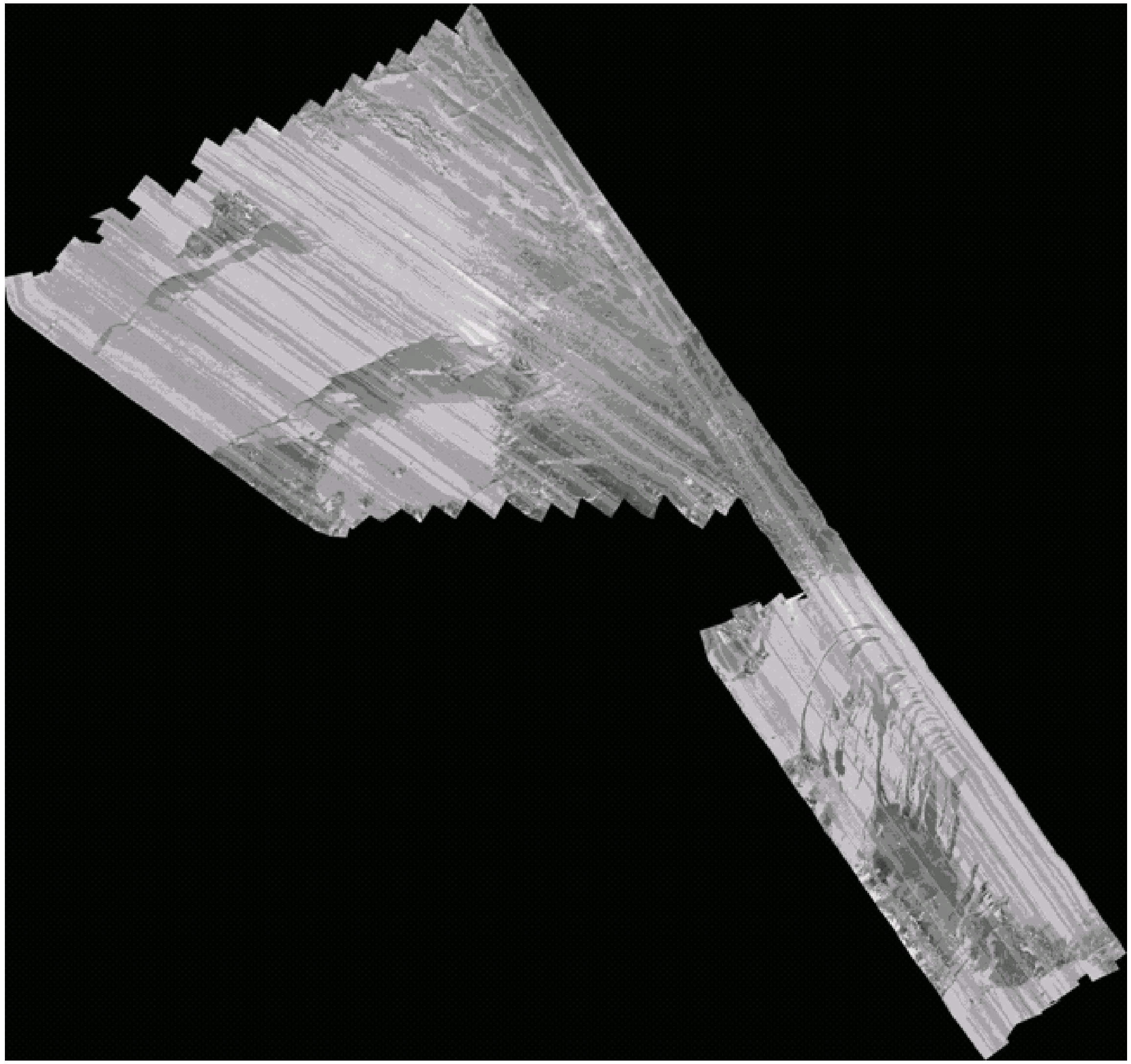


Figure 11. Side scan mosaic over region shown in Figure 10. Areas of apparent slumping offshore from the Cannikin site in the upper part of the frame, and almost parallel, curvilinear features off Long Shot in the lower right.

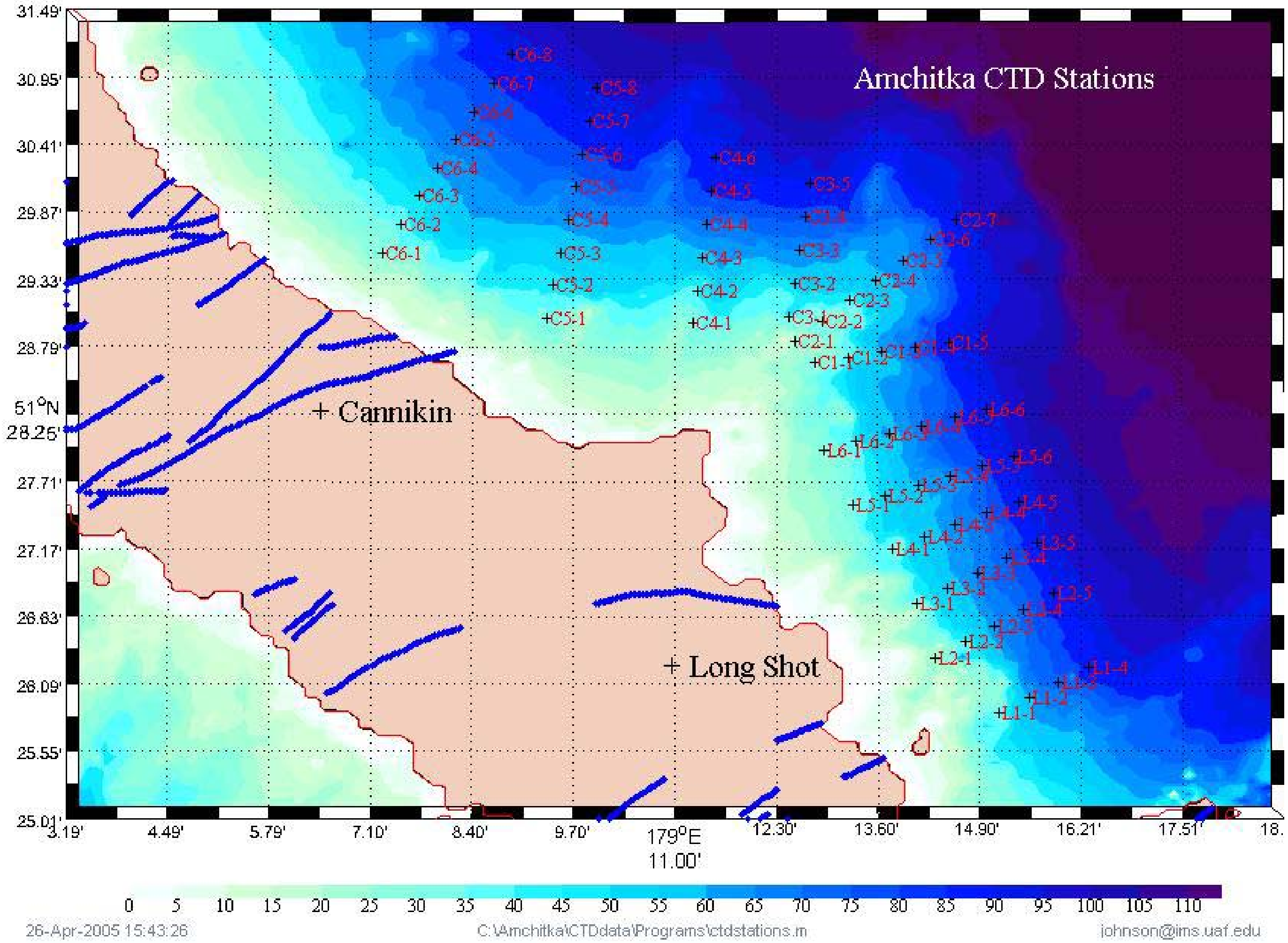


Figure 12. (A) CTD station locations. Blue lines on land show fault lines from historical maps.

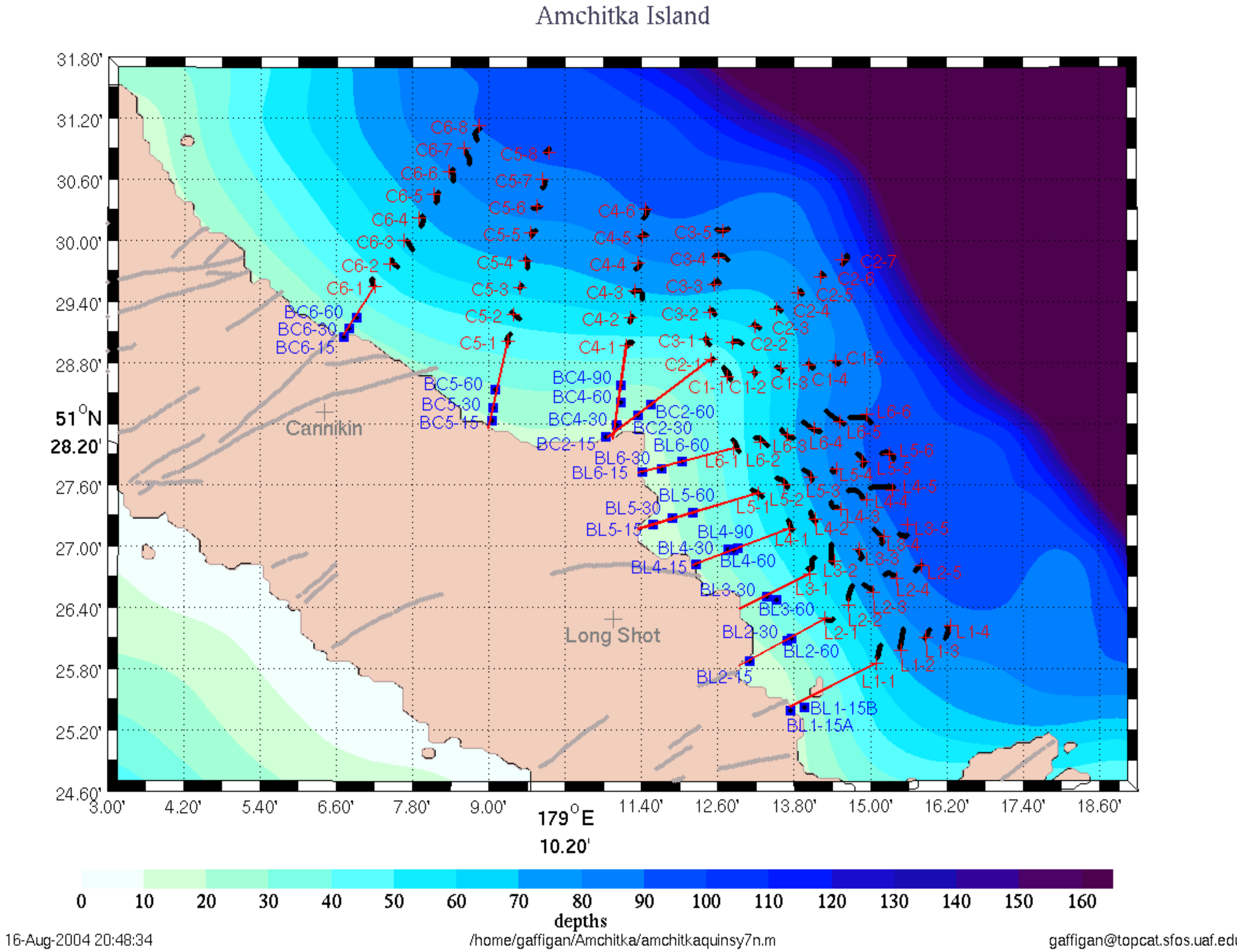


Figure 12. (B) CTD station locations with ship drift shown in black. Nearshore stations occupied by divers are marked by filled squares with red heading lines connecting to the CDT lines.

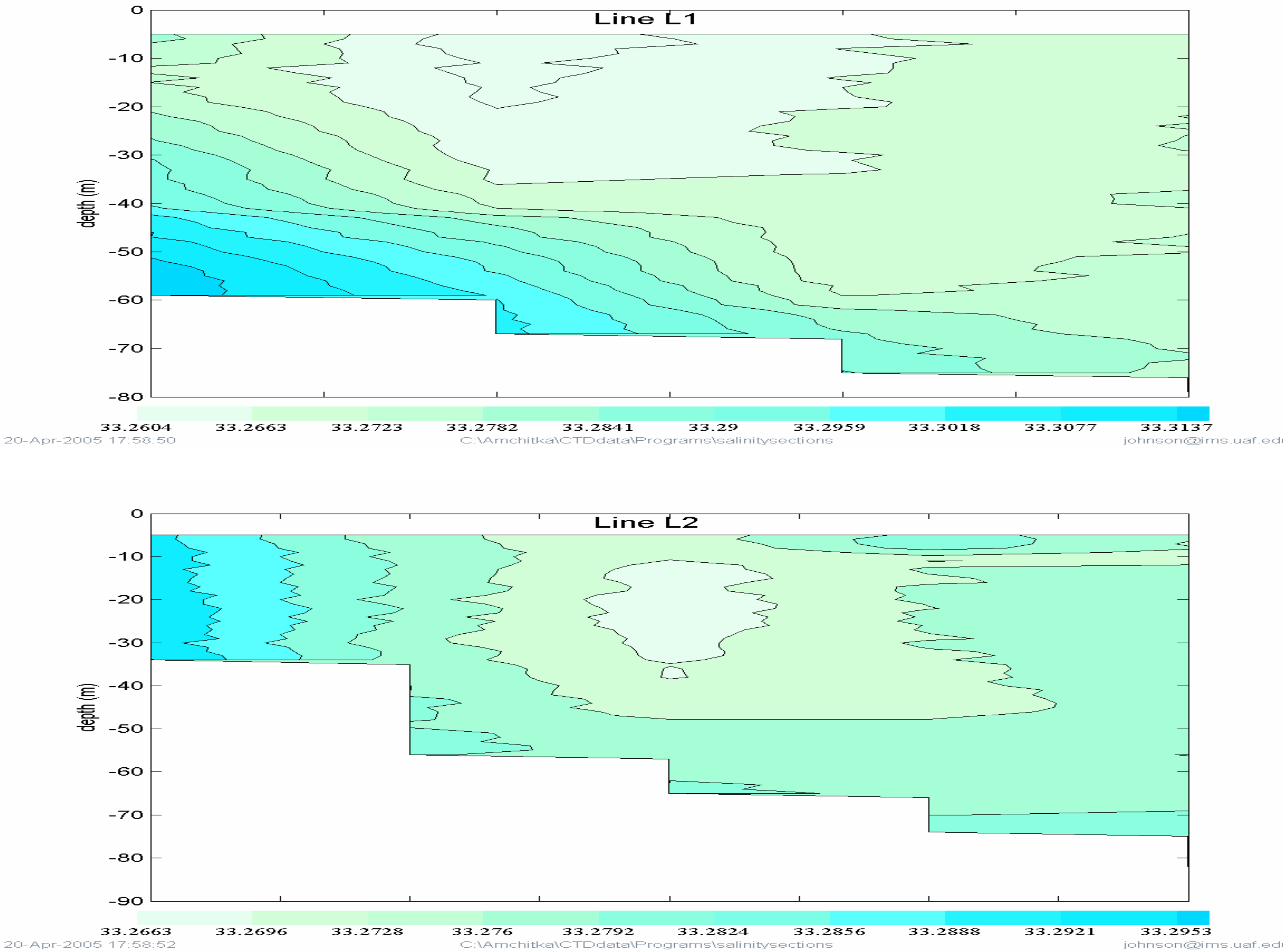
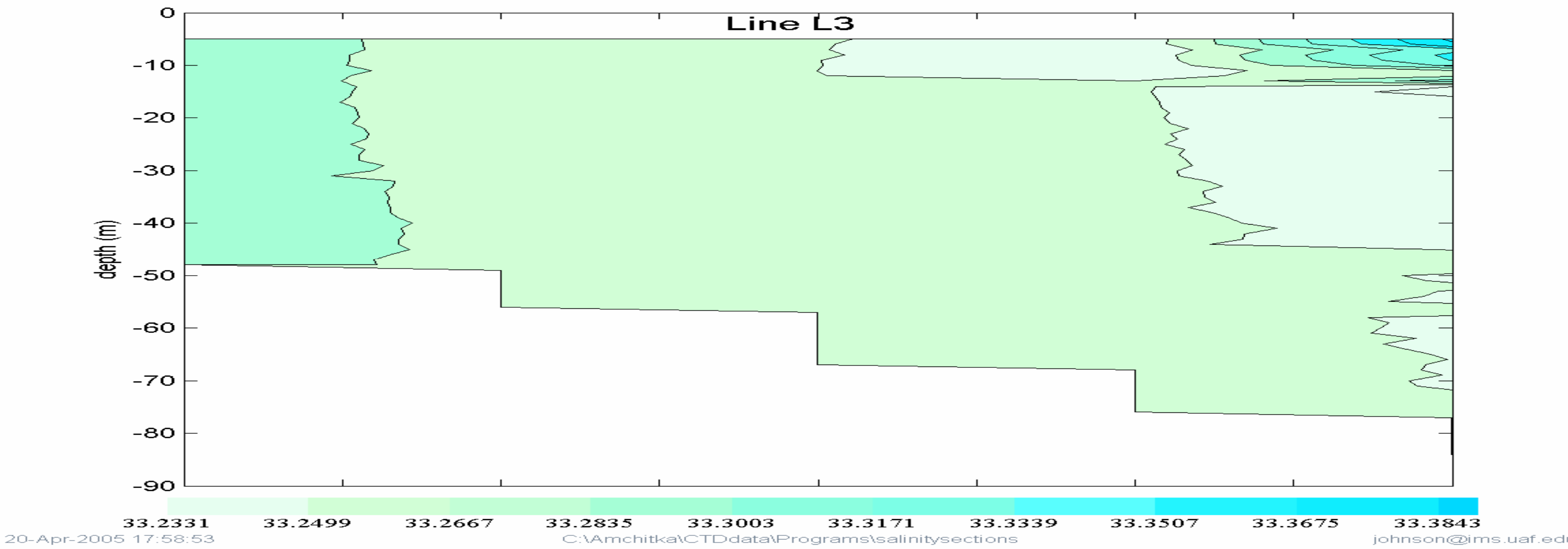


Figure 13. (A) Line L1. (B) Line L2. Note that the salinity scale changes.



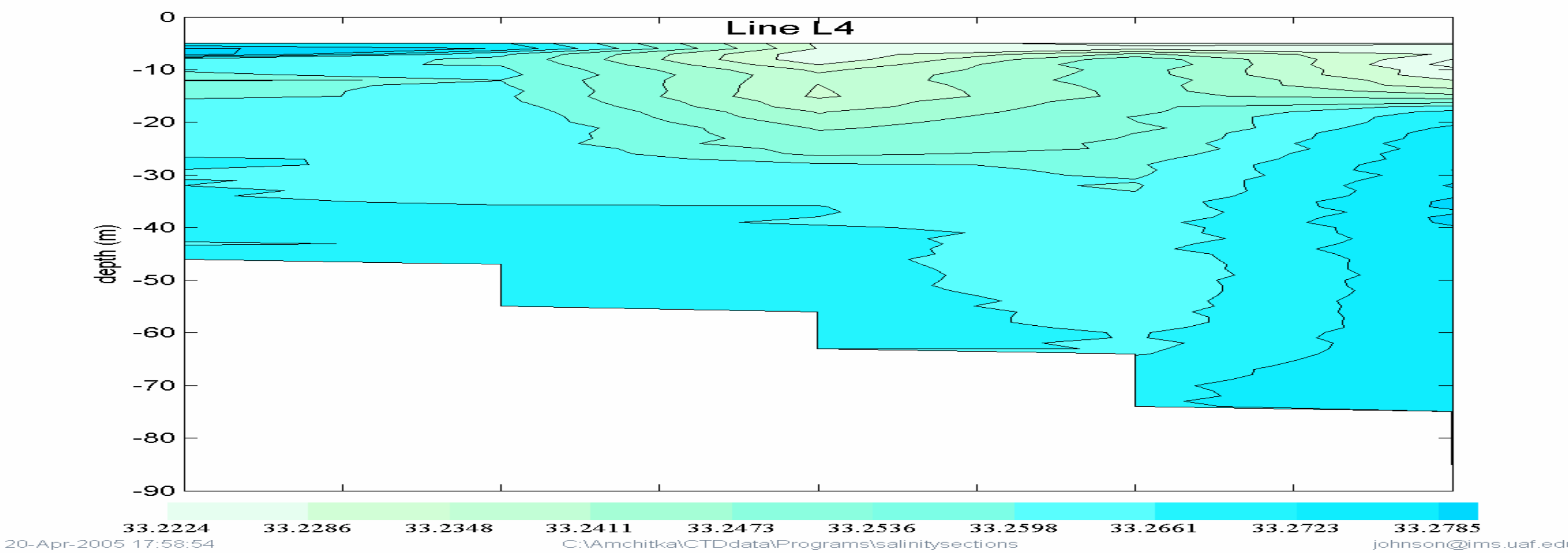
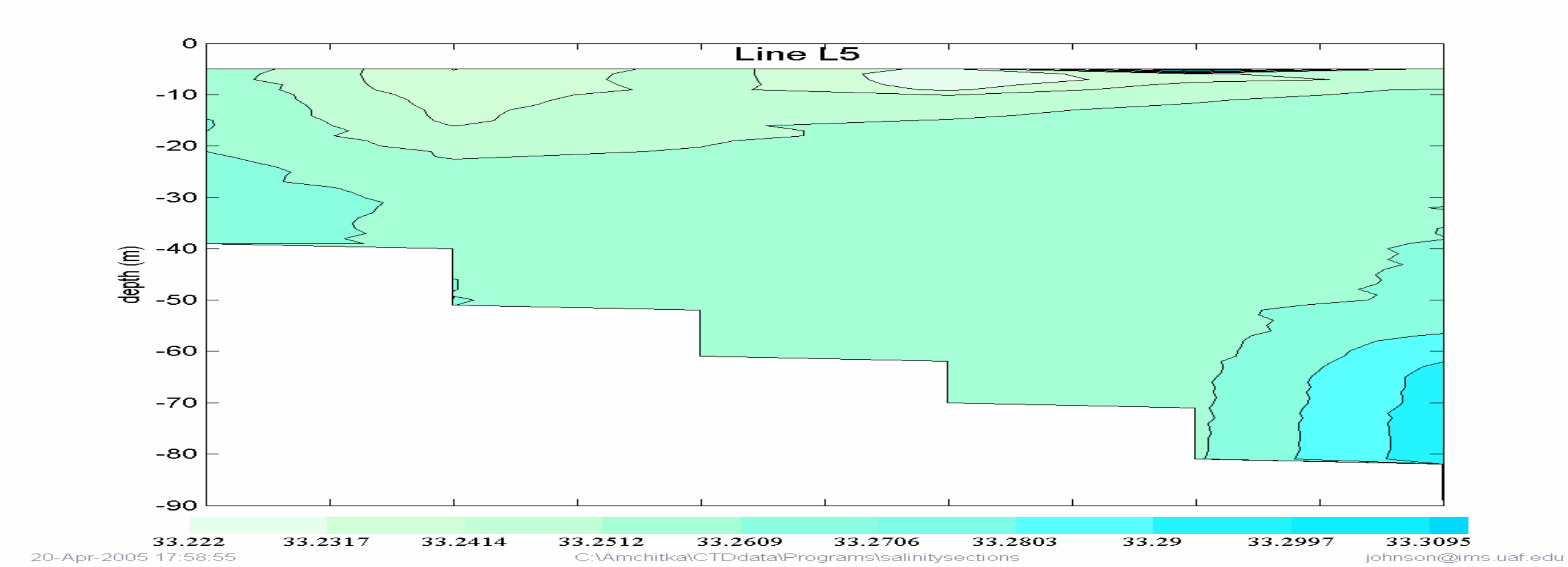


Figure 13. (C) Line L3. (D) Line L4. Note that the salinity scale changes.



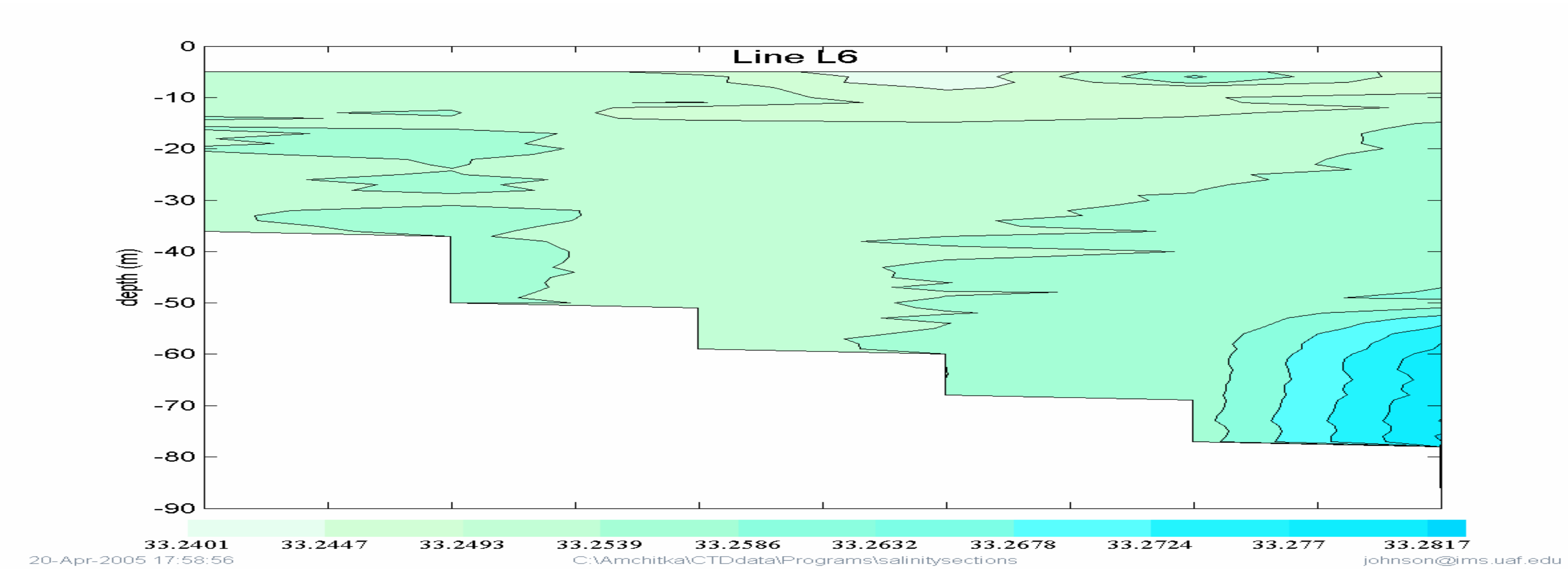
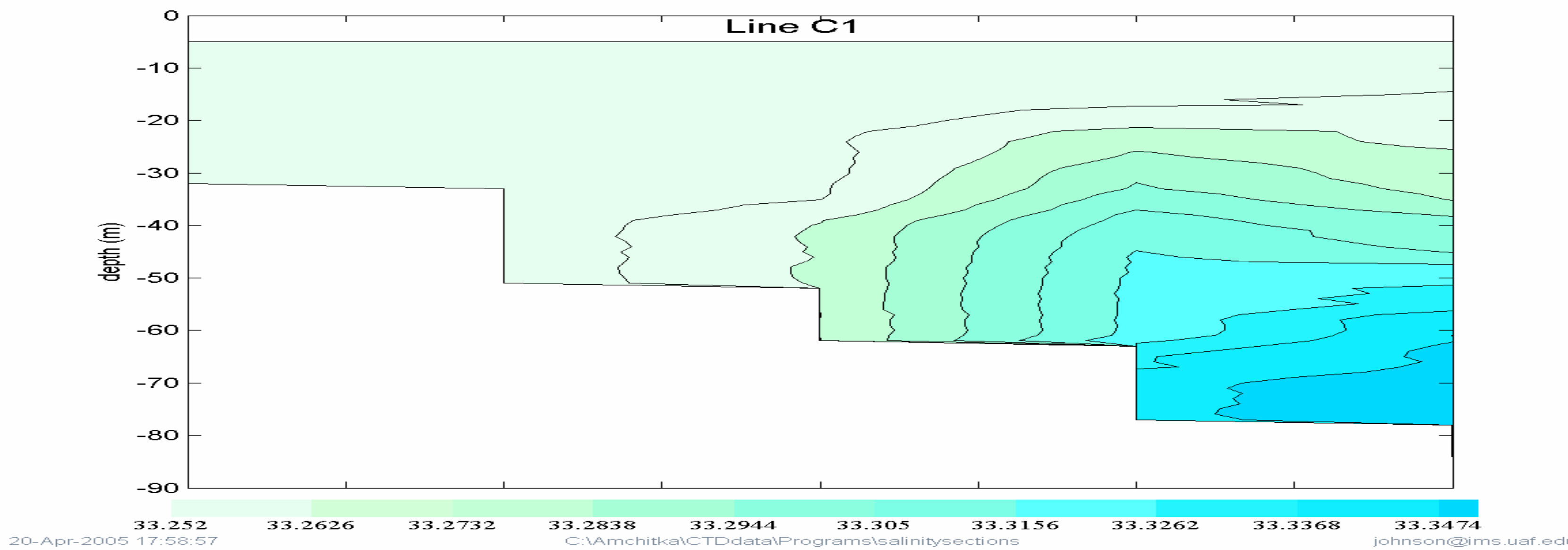


Figure 13. (E) Line L5. (F) Line L6. Note that the salinity scale changes.



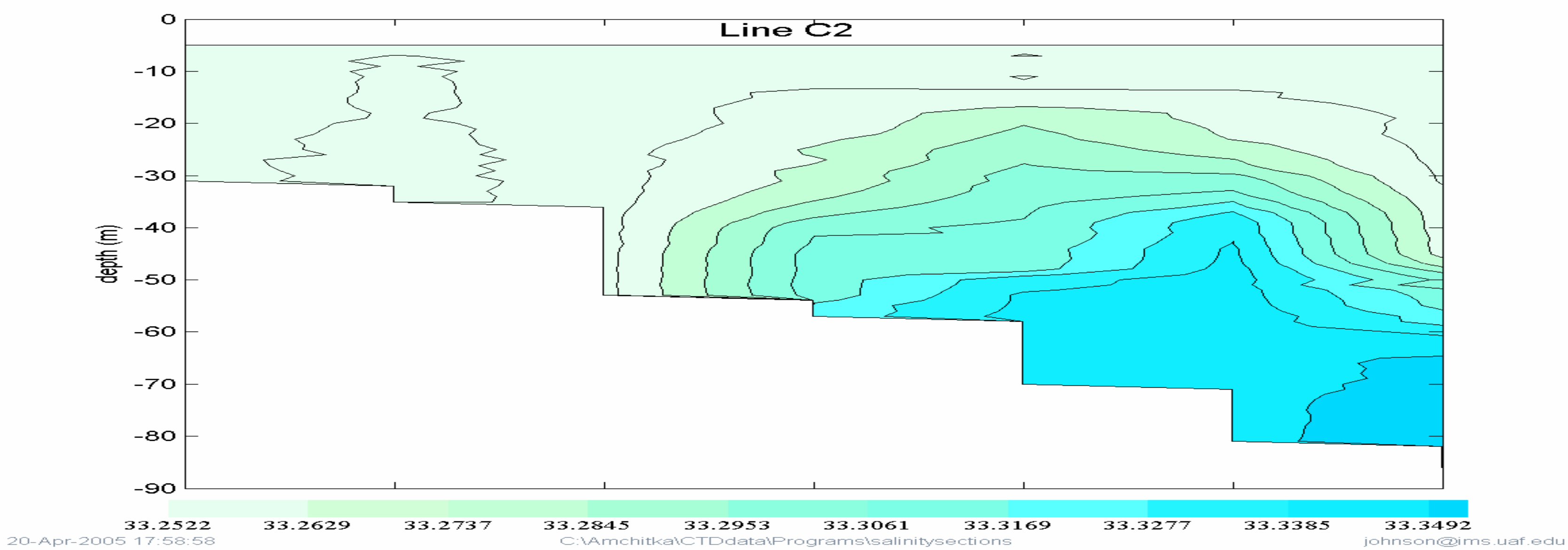
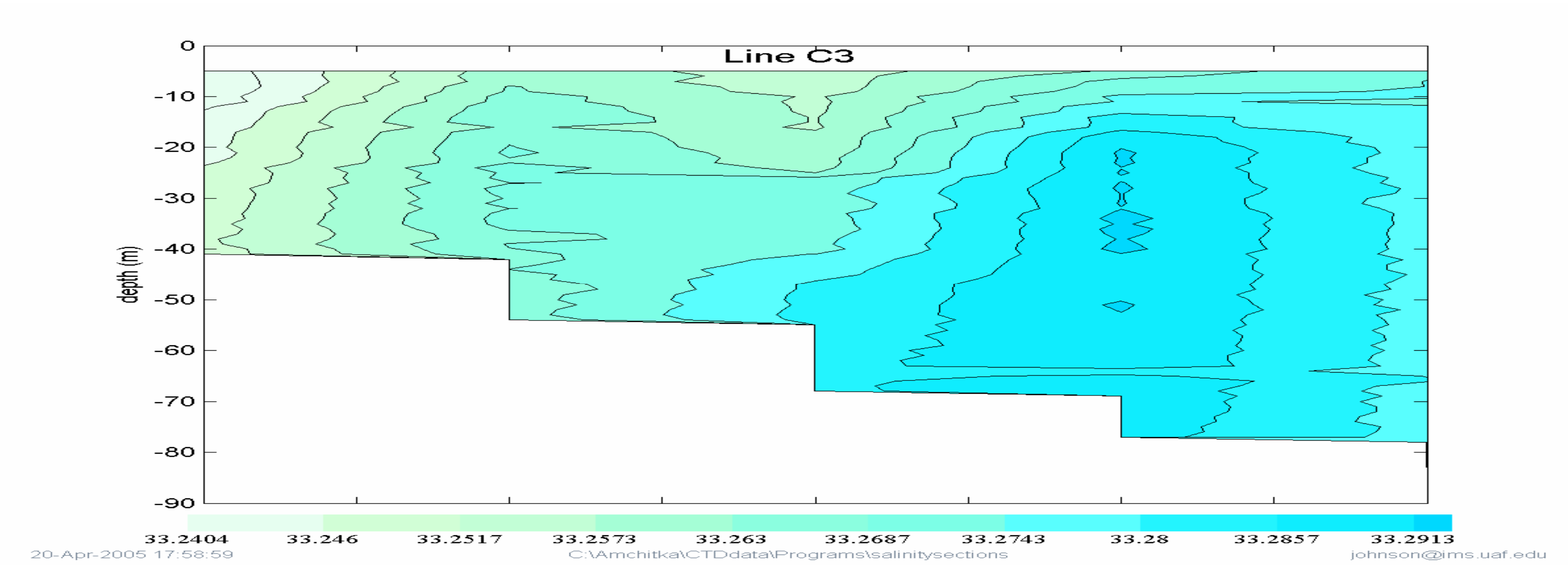


Figure 13. (G) Line C1. (H) Line C2. Note that the salinity scale changes.



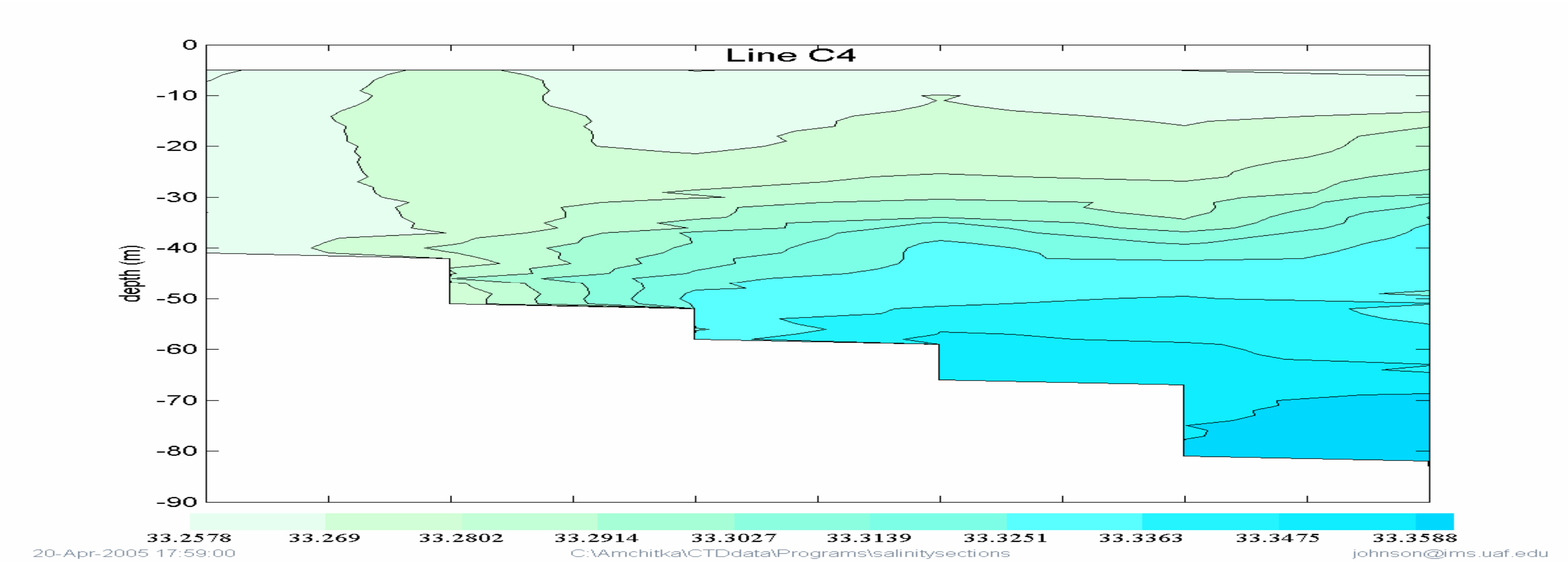
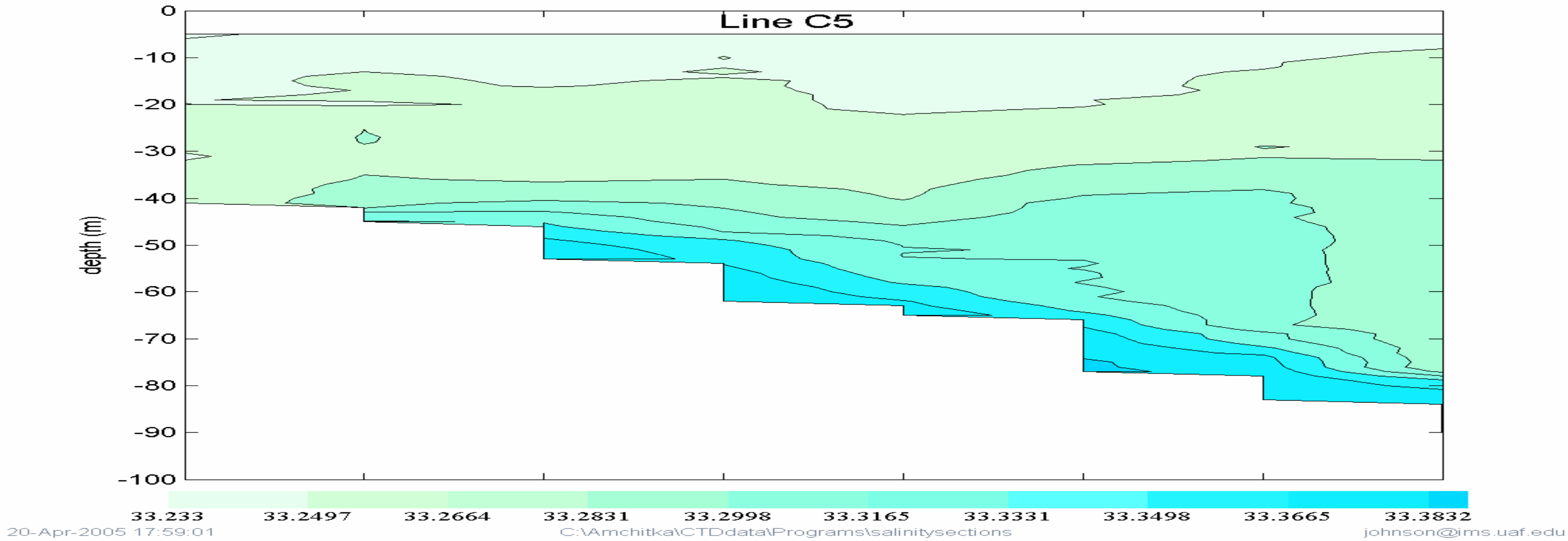


Figure 13. (I) Line C3. (J) Line C4. Note that the salinity scale changes



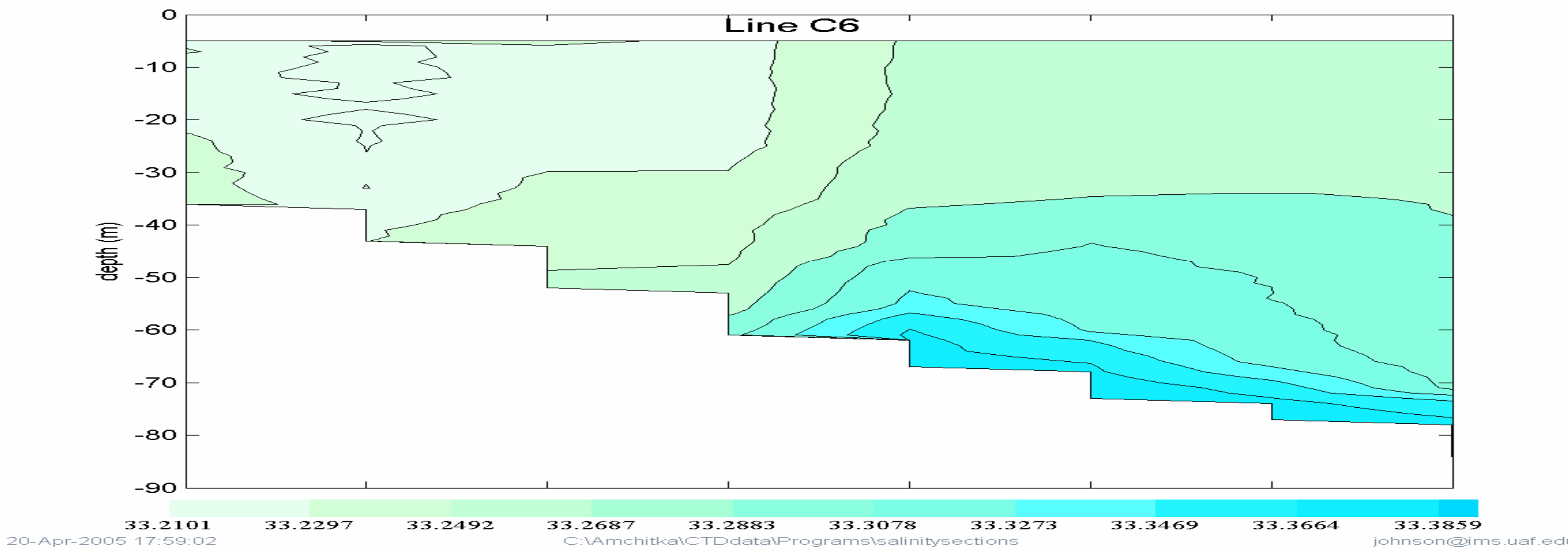


Figure 13. (K) Line C5. (L) Line C6. Note that the salinity scale changes.

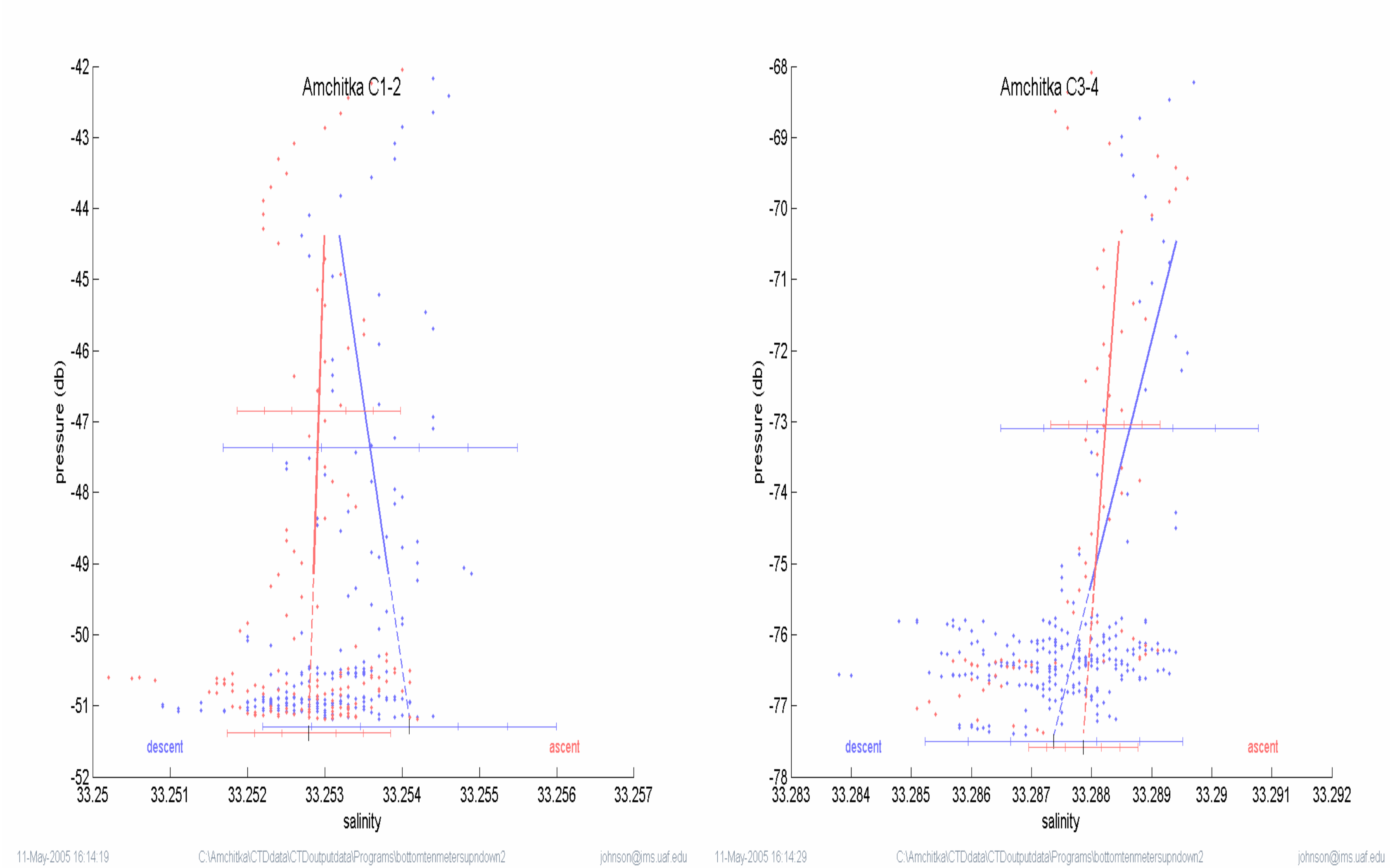


Figure 14. Bottom salinity for (left) C1-2 and (right) C3-4. CTD descent (blue) and ascent (red) are marked. The approximately vertical colored lines show the computed salinity-depth regression for the five meter layer above the deepest 2 m. Regression lines were projected (dashed lines) to the bottom. Horizontal colored lines are marked with one standard deviation ticks. Salinity values to the left of the lowest horizontal colored lines are 3std fresher than expected and may indicate anomalously fresh water.

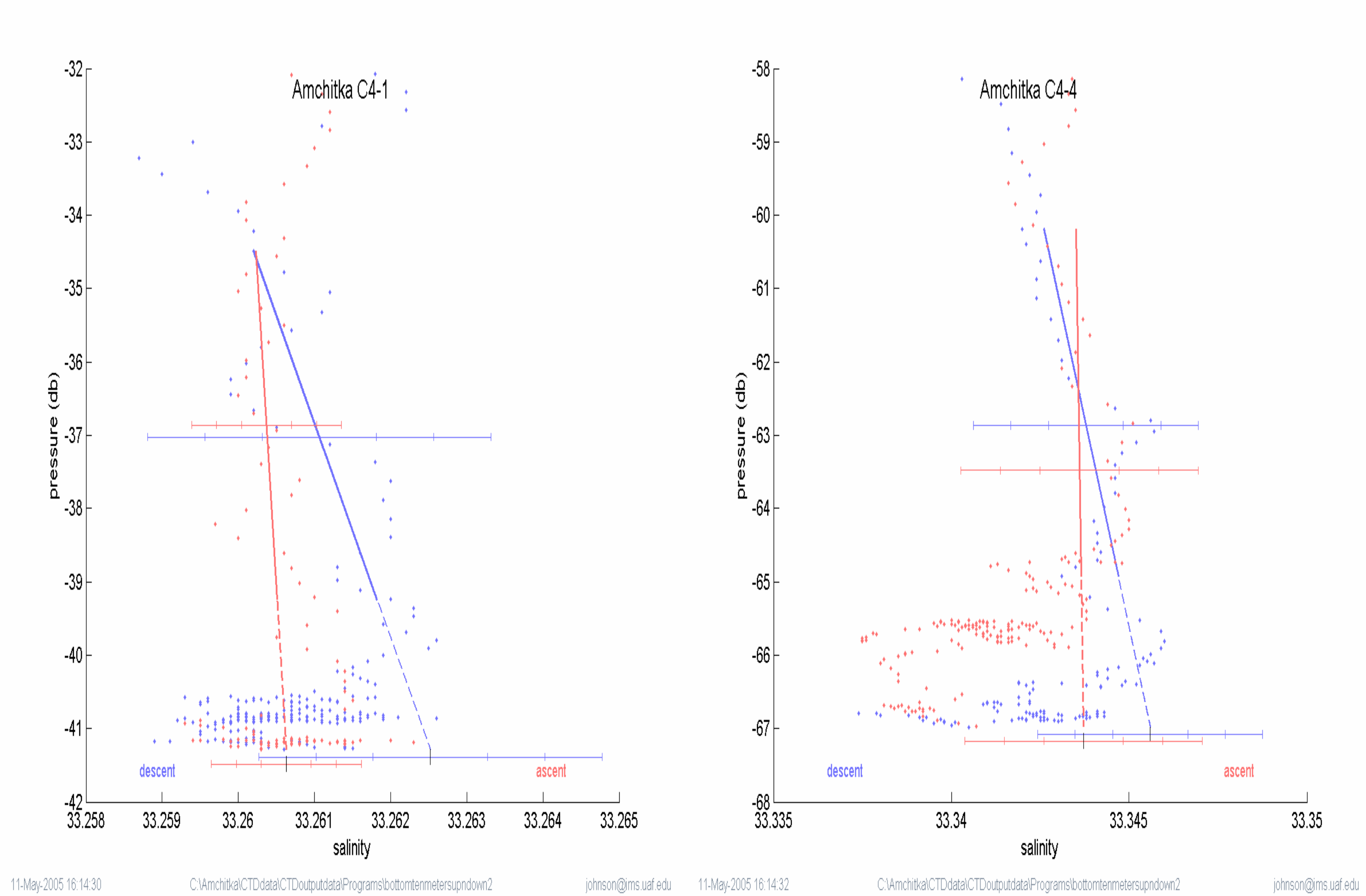


Figure 14. Bottom salinity for (left) C4-1 and (right) C4-4. CTD descent (blue) and ascent (red) are marked. The approximately vertical colored lines show the computed salinity-depth regression for the five meter layer above the deepest 2 m. Regression lines were projected (dashed lines) to the bottom. Horizontal colored lines are marked with one standard deviation ticks. Salinity values to the left of the lowest horizontal colored lines are 3std fresher than expected and may indicate anomalously fresh water.

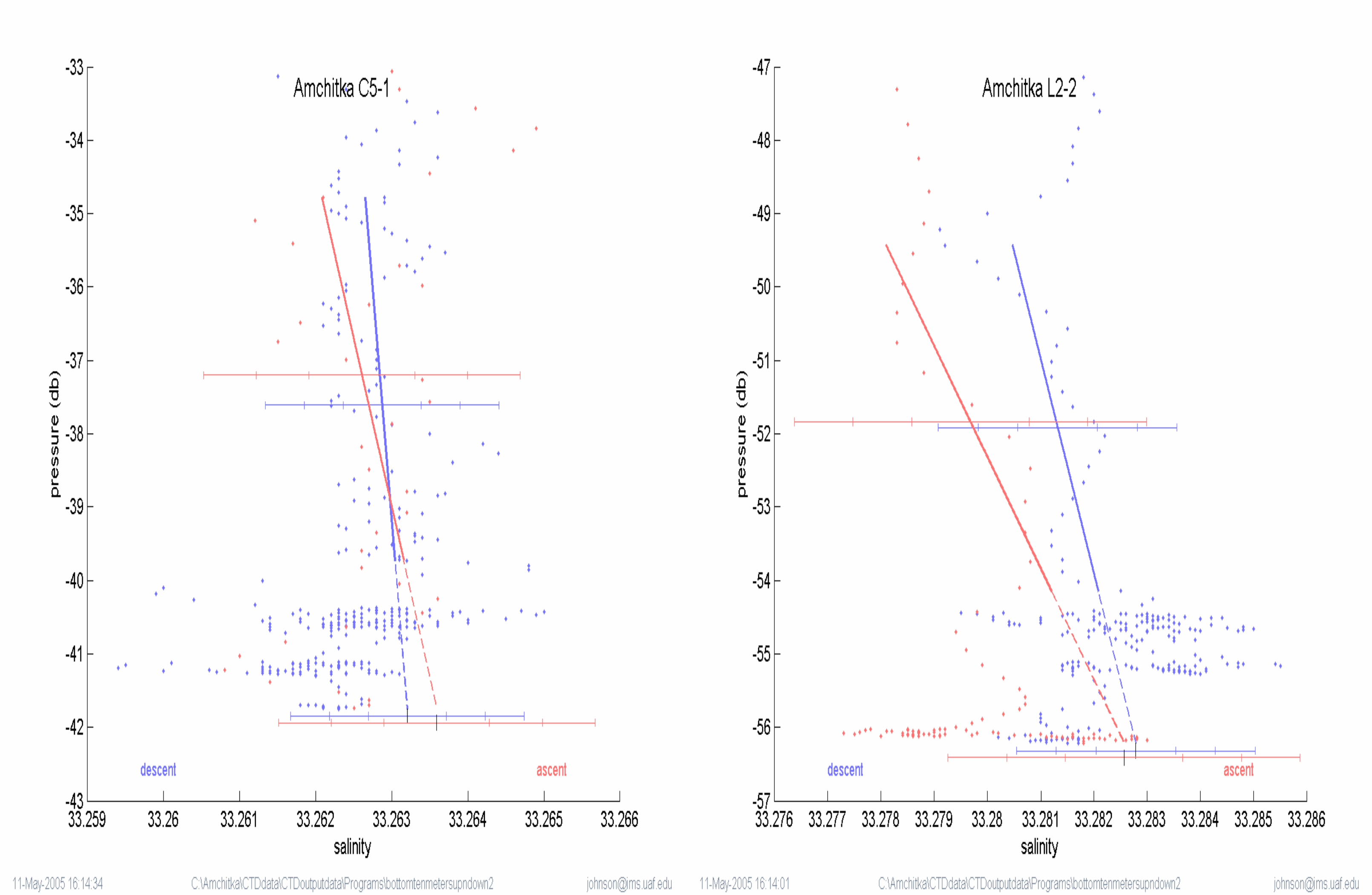


Figure 14. Bottom salinity for (left) C5-1 and (right) L2-2. CTD descent (blue) and ascent (red) are marked. The approximately vertical colored lines show the computed salinity-depth regression for the five meter layer above the deepest 2 m. Regression lines were projected (dashed lines) to the bottom. Horizontal colored lines are marked with one standard deviation ticks. Salinity values to the left of the lowest horizontal colored lines are 3std fresher than expected and may indicate anomalously fresh water.

References

Eichelberger, J, J. Freymueller, G. Hill, and M Patrick. 2002. Nuclear Setwardship: Lessons from a not-so-remote island. Geotimes. March, 2002.

DOE 2002. Screening risk assessment for possible radionuclides in the Amchitka marine environment. 2002. Nevada Environmental Restoration Project, Revision No.: 0, DOE/NV-857, October.

Lewis, Richard, Willis Nelson, Howard Powers. 1960. Geology of Rat Island Aleutian Islands Alaska: Investigations of Alaskan volcanoes. Geological Survey Bulletin, 1028-Q, pages 555-562.

Table 1. Name, date, depth, size, yield, and location of the three sites.

	Long Shot	**Milrow**	**Cannikin**
Date	Oct 29, 1965	Oct 2, 1969	Nov 6,1971
blast depth (ft. Engineering Chart)	2343	4002	6104
blast depth (m)	700	1220	1790
casing (inches. Engineering Chart)	32	36	54
GZ elevation (ft. Engineering Chart)			208
yield	80KT	~1MT	<5MT
Latitude (M. Unsworth)	51.43655	51.41559	51.46961
Longitude (M. Unsworth)	179.17976	179.17992	179.10335
UTM (from plaque on site)	N5700592	missing	N5704186
UTM (from plaque on site)	E651700	missing	E646322

Table 2. List of files available from http://www.ims.uaf.edu/research/johnson/amchitka. Scanned charts have the original citation in the image itself, files with an asterisk (*) were created from data collected in this study, and for all other images the citation is listed in ImageReferenceList2.doc.

Filename	Description	format	size	
Amchitka_All_SIS1000_SSS.jpg *	side scan sonar image	jpg	47.6 MB	*
AmchitkaAerialPhotosLine1.ppt	aerial photos over Line 1 (see Figure 7)	ppt	70.4 MB	
AmchitkaAerialPhotosLine16.ppt	aerial photos over Line 16 (see Figure 7)	ppt	70.4 MB	
AmchitkaAerialPhotosLine4.ppt	aerial photos over Line 4 (see Figure 7)	ppt	70.4 MB	
amchitkacoast.dat	Latitude and longitude data of coastline digitized from chart shown in AmchitkaGeology.tiff	ascii	30 KB	*
AmchitkaGeology.tiff	Color map with fault lines	TIFF	625 MB	
AmchitkaGeologyCloseup.pict	Same as AmchitkaGeology.tiff, but close up of text sites	PICT	17.0 MB	
AmchitkaIslandQuad.tiff	USGS Department of Interior Quadrangle with place names and bathymetry contours. B&W	TIFF	9.8 MB	
AmchitkaMultibeamBathymetry.jpg	Graphic of bathymetry from multibeam survey	jpg	86.9 KB	*
AmchitkaQuad.tiff	Same as AmchitkaIslandQuad.tiff	TIFF	15.5 MB	
bathymetrywithfaults.tiff	Matlab graphic with bathymetry contours and fault lines	TIFF	1.9 MB	*
biblio.doc	bibliography	MS Word	48 KB	*
biblio2.doc	bibliography with notes, keywords and abstracts	MS Word	2.2 MB	*
bioandctd2.tiff	Matlab graphic of CTD transect lines and nearshore diver stations	TIFF	2.9 MB	*
CDT_Data\RawCastData	raw profile data from CTD survey	hex	~22 KB per profile	*
CTD_Data\ProcessedData	processed profile data from CTD survey	ascii	~100 KB per profile	*
ctd_stations.tiff	Graphic of CTD stations locations	TIFF	4.8 MB	*
DM2m60N.asc	ascii file of 2m bathymetry	Ascii	429 MB	*
DOEfigure22.tiff	Figure 22 from DOE 2002 modeling report	TIFF	25.6 MB	
DOEfigure23.tiff	Figure 23 from DOE 2002 modeling report	TIFF	24.5 MB	
DOEfigure24.tiff	Figure 24 from DOE 2002 modeling report	TIFF	29.8 MB	
Figure1.tiff	Heart lake before blast	TIFF	3.3 MB	
Figure10.tiff	map of epicenters of tectonic events following Cannikin and Milrow	TIFF	4.6 MB	
Figure11.tiff	index map of Amchitka Island in UTM and lat-lon	TIFF	4.0 MB	

Figure12.tiff	map showing lakes where tilt was measured	TIFF	4.1 MB	
Figure13.tiff	map of streamflow and fluid-pressure monitor stations for Cannikin	TIFF	17 MB	
Figure14.tiff	map of directions of surface winds at detonation for Cannikin and Milrow	TIFF	429 KB	
Figure15.tiff	map of Cannikin site.	TIFF	15 MB	
Figure16.tiff	map of earthquake locations and size around Amchitka	TIFF	32.8 MB	
Figure17.tiff	map of earthquake locations and size around Amchitka	TIFF	32.8 MB	
Figure18.tiff	map of earthquake locations and size around Amchitka	TIFF	32.8 MB	
Figure19.tiff	map of earthquake locations and size around Amchitka	TIFF	32.8 MB	
Figure2.tiff	Heart lake after blast showing subsidence	TIFF	3.3 MB	
Figure20.tiff	map of earthquake locations and size around Amchitka	TIFF	32.8 MB	
Figure21.tiff	map of earthquake locations and size around Amchitka	TIFF	32.8 MB	
Figure3.tiff	Post shot fracture map, Milrow.	TIFF	4.5 MB	
Figure3Legend.tiff	Legend for above figure	TIFF	4.3 MB	
Figure4.tiff	map of eastern Amchitka with faults	TIFF	20.7 MB	
Figure5.tiff	map of central Amchitka with faults	TIFF	17.3 MB	
Figure6.tiff	map of eastern Amchitka with strain lines	TIFF	4.3 MB	
Figure7.tiff	map of Amchitka with place names	TIFF	4.3 MB	
Figure8.tiff	contours of underwater pressure and cavitation from Cannikin and Milrow	TIFF	17.7 MB	
Figure9.tiff	timeline of number of collapse events after Cannikin and Milrow	TIFF	3.8 MB	
ImageReferenceList2.doc	Source and reference list of scanned images Figures 1 – 24	MS Word	34.5 KB	*
links.doc	listing of interesting web links by category	MS Word	44 KB	*
mapofblastsites.tiff	map with blast sites labeled with fault lines from web	TIFF	1.9 MB	*
mapwithplacenames.tiff	map of whole island with location names from web	TIFF	1.9 MB	*
masterfault.dat	latitude and longitude of fault lines digitized from chart shown in AmchitkaGeology.tiff	Ascii	117 KB	*
multibeam_1m_bathy_color.tiff	color contour of bathymetry from multibeam survey off Cannikin and Longshot	TIFF	5 MB	*
multibeamlines.tiff	graphic of multibeam survey lines	TIFF	4.8 MB	*
RatIslandBathymetry.dat	ascii file of historical NOAA depths in meters. See	text	22.1 MB	*

	RatIslandBathymetryREADME file for extracting data			
RatIslandBathymetryREADME.txt	Describes depth file	text	1.35 KB	*
Table1(Figure12).doc	Table 1 from Figure 12. Pre-shot and post-shot water levels below top of rod, and average relative difference in water level.	MS WORD	26 KB	
Text1a.tiff	scanned page of text describing postcollapse events	TIFF	4.8 MB	
Text1b.tiff	next page of above	TIFF	3.2 MB	
Text2a.tiff	scanned page describing the earthquake location maps above	TIFF	36.1 MB	
Text2b.tiff	next page of above	TIFF	34.1 MB	

Table 3. Summary of model results from DOE radionuclide transport model

		Long Shot	Milrow	Cannikin
Small volume modeled plumes	release direction	Bering	Pacific	Bering
	shallowest (ft)	0	0	0
	deepest (ft)	180	300	300
	midpoint (distance from shoreline in km)	2	2	3
	horizontal range (km)	4.4	5.5	3.8
Groundwater (Tritium) Modeling	closest to shoreline(km) p. A-7	0.25	0.25	0.25
	farthest from shoreline (km) p. A-7	4.5	4.5	4.5
Extremes and statistical boundaries (Table A-2, page A-8)	distances from shoreline (m)			
	first edge (nearest)	530	240	1470
	first edge (5th %tile)	770	260	1470
	second edge (95th %tile)	3470	3704	4520
	second edge (farthest)	4170	5740	5320
CORMIX Model parameters	DRI estimate of groundwater discharge rate (m^3/d). p. A-21	24.3	24.8	72.5
	discharge depth (m). Table A-4.	30.5	23.5	68.6
	current speed (cm/s). Table A-4.	32	10 - 30	32