Geophysical Investigations I
Oceanographic Investigations of Bathymetry, Ocean Floor Discharge of Freshwater through the Ocean Floor and Sediment Distribution[1]

SUMMARY

Selective geophysical and hydrologic characterization of Amchitka Island and its nearshore vicinity was carried out to assist the field biological sampling efforts and to reduce uncertainty associated with previous groundwater contaminant fate and transport modeling of radionuclides from the test shots and related human health risk assessments. During preparation for the biological field sampling the following activities were completed:

1. Review of prior oceanographic data (bathymetry) to identify the ocean depths and locations of the areas that were most likely to have discharge of freshwater through the ocean floor originating from the test shots.
2. Review of prior geologic information to identify the locations of faults that potentially may serve as conduits for groundwater movement below the island.
3. New bathymetric measurements off-shore of the *Cannikin* and *Long Shot* sites.
4. Digitization and review of historic maps and aerial photography of Amchitka.

To assist in the reduction of uncertainty associated with contaminant transport modeling and human health risk assessments, the following geophysical questions were posed and evaluated:

1. Is there evidence of freshwater discharge through the ocean floor in the areas that were previously identified as most likely to have discharge emanating from the test shot sites?
2. Is there evidence of sediment accumulation on the ocean floor off-shore from the test shots?
3. What is the depth of the fresh-salt water interface at each test shot?
4. Would the use of more complex groundwater modeling approaches and newly available additional data on subsurface properties provide enhanced or alternative interpretations of contaminant transport from the test shots to the ocean floor?

Questions 1 and 2, posed above, are addressed in this chapter. Conductivity, density and temperature (CTD) measurements off-shore of the *Cannikin* and *Long Shot* sites and limited water sampling near the ocean floor were used to investigate freshwater discharge through the ocean floor. Sidescan sonar and limited sediment sampling off-shore of the *Cannikin* and *Long Shot* sites was used to evaluate the presence of sediment deposits. Questions 3 and 4 are addressed in Chapters 6 and 7, respectively.

The following conclusions are based on the results of the above investigations:

[1] The results presented in this chapter are a condensation of Appendix 5.A authored by Mark Johnson, University of Alaska, Fairbanks, Alaska, and Colin Stewart, Naval Undersea Warfare Center, Keyport, Washington.

1. 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 from the *Cannikin* and *Long Shot* test sites. Measurements at 6 locations indicated slight anomalies that may be the result of either freshwater discharge or measurement interferences that cannot be distinguished.
2. Significant regions of the ocean floor in the study area off *Cannikin* and *Long Shot* test sites have sediment accumulations. This is contrary to earlier assumptions that the ocean floor in these areas was devoid of sediment accumulations because of energetic ocean currents.

INTRODUCTION

Selective geophysical and hydrologic characterization of Amchitka Island and its nearshore vicinity was carried out to assist the field biological sampling efforts and to reduce uncertainty associated with previous groundwater contaminant fate and transport modeling of radionuclides from the test shots and related human health risk assessments. To assist the biological sampling efforts in the preparation for the field sampling and in identifying sampling locations, the following activities were completed:

1. Review of prior oceanographic data (bathymetry) to identify the ocean depths and locations of the areas that were most likely to have discharge of freshwater through the ocean floor originating from the test shots.
2. Review of prior geologic information to identify the locations of faults that potentially may serve as conduits for groundwater movement below the island.
3. New bathymetric measurements off-shore of the *Cannikin* and *Long Shot* sites.
4. Digitization and review of historic maps and aerial photography of Amchitka.

The sampling protocol and locations were designed to optimize the likelihood of identifying freshwater discharge locations. To assist in the reduction of uncertainty associated with contaminant transport modeling and human health risk assessments, the following questions were posed and evaluated:

1. *Is there evidence of freshwater discharge through the ocean floor in the areas that were previously identified as most likely to have discharge emanating from the test shot sites?* This question was addressed through the measurement of conductivity, temperature and depth (CTD) to determine salinity along transects off-shore from *Cannikin* and *Long Shot*. In addition, water samples were taken from near the ocean floor at selected locations. Evidence of freshwater discharge, if found, also would be used as input to selection of biological sampling locations.[1]
2. *Is there evidence of sediment accumulation on the ocean floor off-shore from the test shots?* This question was addressed by use of sidescan sonar and collection of sediment samples from selected locations. Earlier information had indicated that the ocean floor in areas surrounding Amchitka was free of sediment because of strong ocean currents. However, if present, sediments may serve to locally

accumulate radionuclides potentially discharged with groundwater through the ocean floor.[1]

3. *What is the depth of the fresh-salt water interface at each test shot?* This question was addressed through the use of magnetotelluric measurements on Amchitka to image subsurface porosity and salinity in the vicinity of the test shots. This question is important because transport of radionuclides in the freshwater or transition zones to the ocean floor would be substantially more rapid than would occur if the test shots were in the saltwater zone. The depths of the transition zone and saltwater zone were important uncertainties in previous groundwater contaminant fate and transport modeling of radionuclides from the test shots. Additionally, the following questions were asked using the MT measurements: Can subsurface features associated with nuclear testing be imaged with MT? Can faults be detected through their effects on groundwater flow*?* Discussion of the MT investigation is the subject of Chapter 6.
4. *Would the use of more complex groundwater modeling approaches and limited additional data on subsurface rock properties provide enhanced or alternative interpretations of contaminant transport from the test shots to the ocean floor?* This question was addressed by developing alternative groundwater transport model scenarios in the vicinity of the *Long Shot* test shot. Additional measurements were also made on porosity and diffusion rates in subsurface rock cores previously obtained from Amchitka. Discussion of these results is provided in Chapter 7

RESULTS AND DISCUSSION

Evaluation of Prior Data Sources

Evaluation of prior data included completing a literature search related to Amchitka Island, and collection and digitization of geologic charts and maps, bathymetry and aerial photography. A list of available information is provided in Table 5.1, which may be downloaded from either the CRESP (www.cresp.org) or University of Alaska web sites (http://www.ims.uaf.edu/research/johnson/amchitka/). Figure 5.1 provides a summary depiction of ocean depths, Amchitka Island's coastline and geologic fault lines. Figure 5.2 indicates the survey lines for aerial photos taken prior to and shortly after the nuclear testing.

Bathymetry

Our goal was to survey the bathymetry offshore of *Long Shot*, *Cannikin*, and *Milrow* from as near to shore as possible (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 estimated outer edge distance (99% CI) from shoreline for discharge through the ocean floor of radionuclides potentially transported with groundwater originating from the test shots (DOE, 2002). The proposed survey regions are bounded to the north and to the south by the location and direction of fault lines nearest to each blast site. Existing fault lines were visually extended offshore in a line parallel to the fault to define an area for detailed sampling. The highest priority was the survey at *Long Shot* and *Cannikin*, which was achieved. Surveying of bathymetry offshore of *Milrow* was not possible because of constraints imposed by field conditions and available ship time.

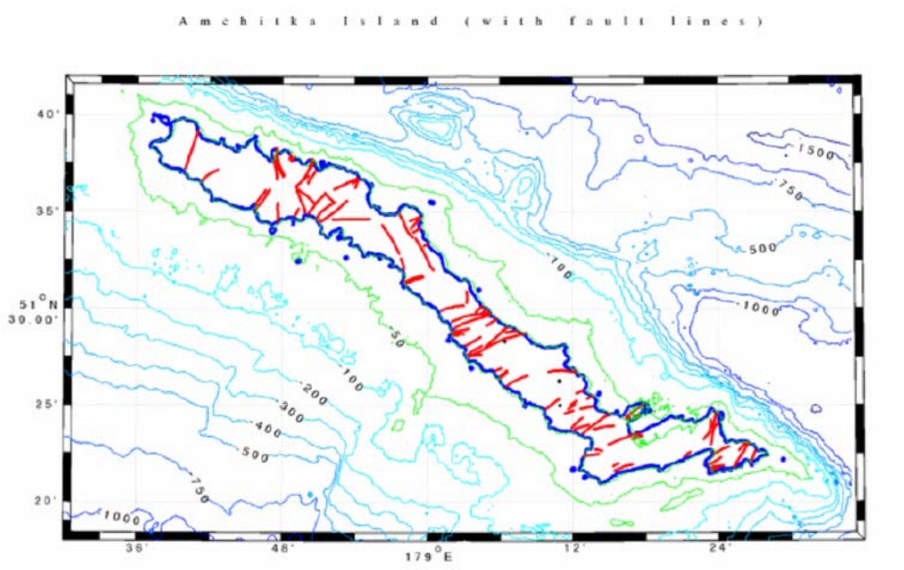

Figure 5.1. Contours of ocean depths, Amchitka Island coastline and geological fault lines.

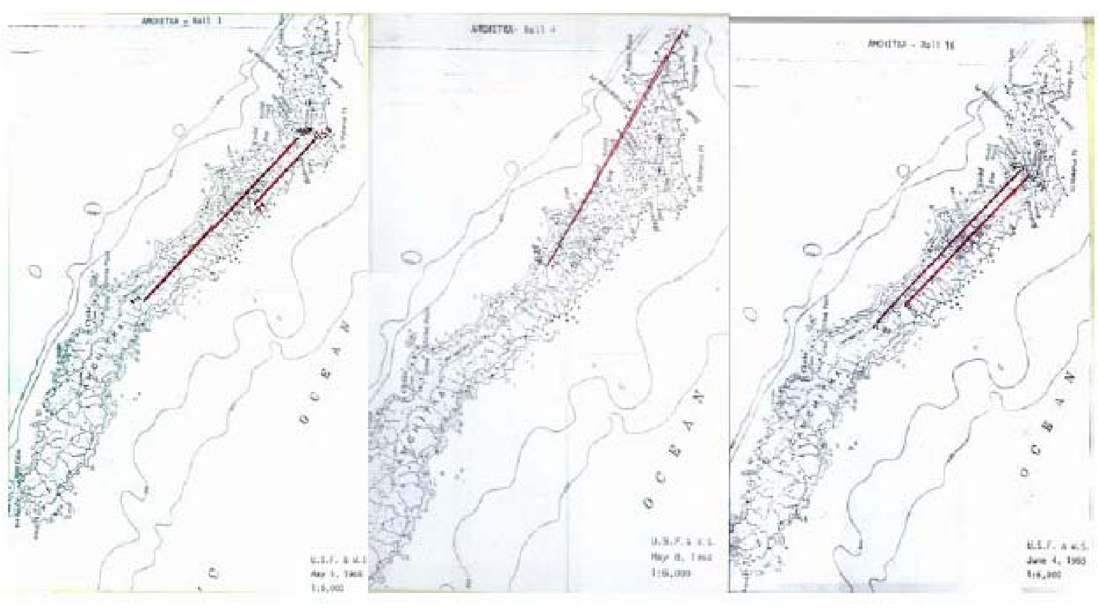

Figure 5.2. Scanned images of survey lines for aerial photos taken prior to and shortly after nuclear testing over southeastern Amchitka Island. Photos are archived at the University of Alaska Fairbanks.

Quality Integrated Navigation Systems (QINSy) software for Quality Positioning System (QPS) www.qps.nl, version 7.30 was used 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 multibeam echosounder. Ship positioning was recorded and logged using the Trackpoint II USBL with interrogation rates as follows: 3 second transmit and receive during CTD drops; 4 second during Side scan sonar operations.

The bathymetry to the north of Amchitka Island from about 20 m depth to the 100 m isobath offshore of the *Cannikin* and *Long Shot* test sites was mapped to 2 m resolution using a multibeam echosounder (SM2000). The SM 2000 multibeam echosounder 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. 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 for merging and gridding with Fledermaus, a 3D data viewer, or other software. The survey transects and resulting bathymetry are provided in Figures 5.3 and 5.44, respectively. Data files of the bathymetry (in ascii) are available at CRESP (www.CRESP.org) and University of Alaska web sites (http://www.ims.uaf.edu/research/johnson/amchitka/).

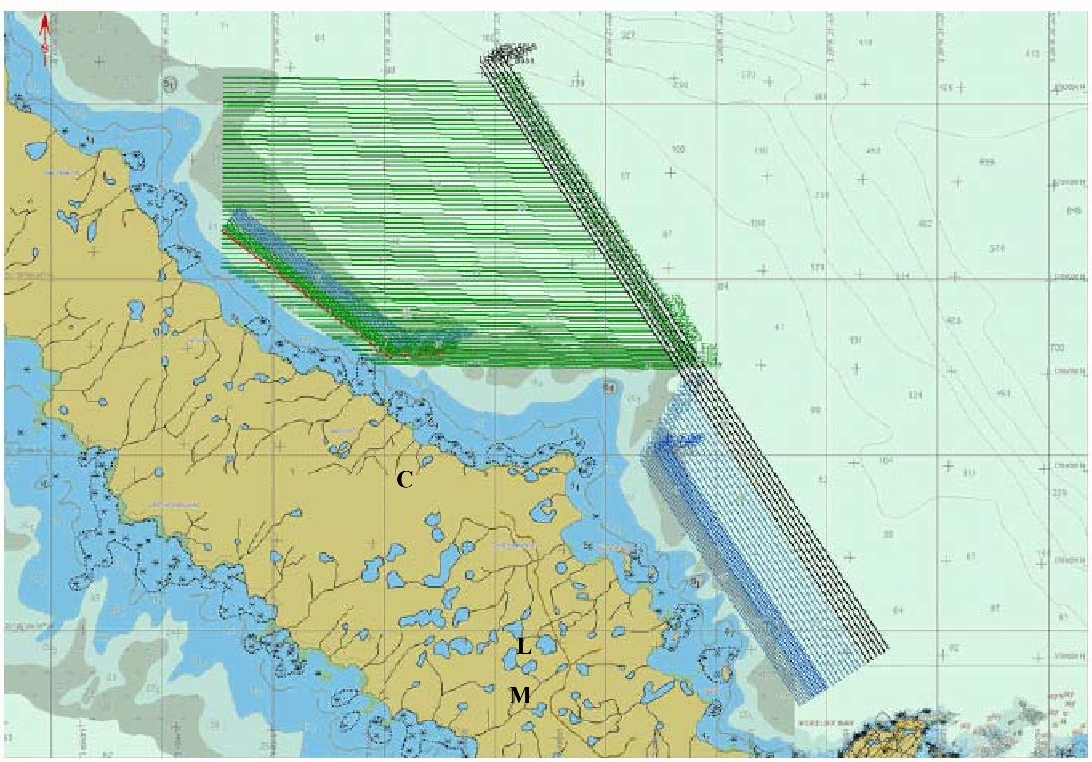

Figure 5.3. Survey lines for bathymetric survey. Approximate locations of test sites are shown.

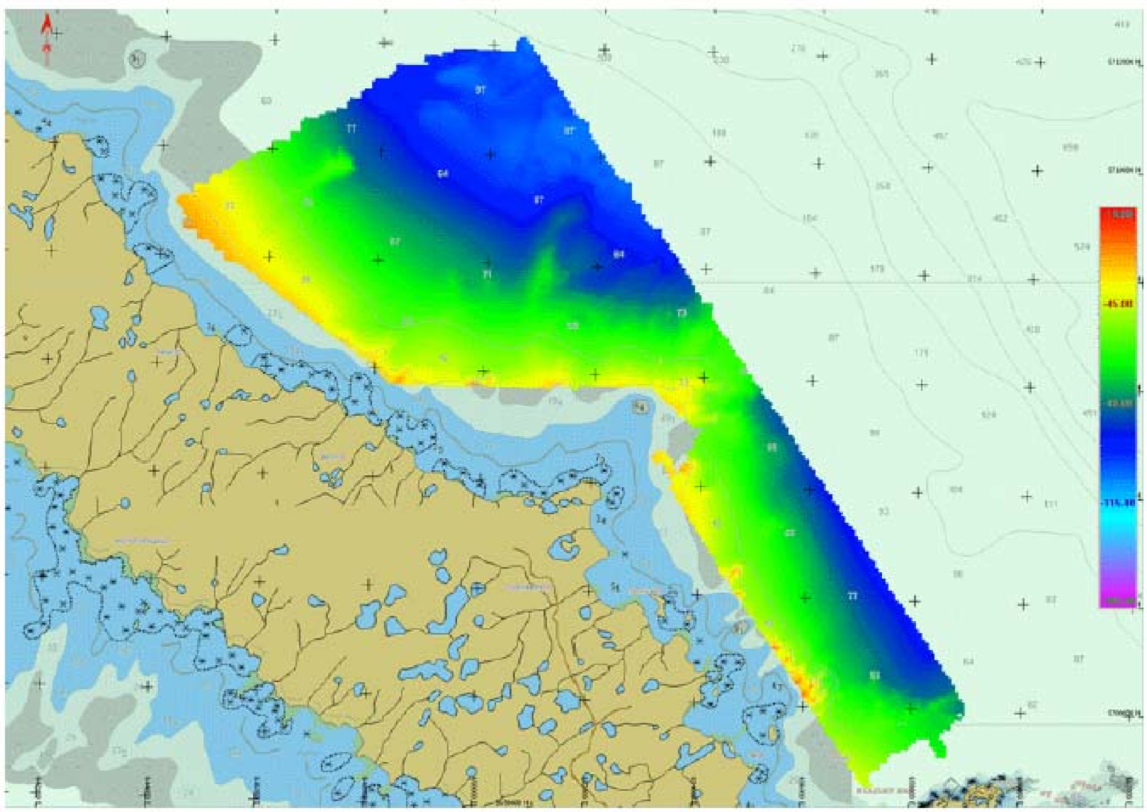

Figure 5.4. Contours of bathymetry from this study. For approximate locations of *Cannikin* (C), *Long Shot* (L) and *Milrow* (M) see Figure 5.3

Sidescan Sonar and Evidence of Sediments on the Ocean Floor

A Datasonics SIS 1000 sidescan sonar was used to map the bottom over the region of the bathymetry survey. The bathymetry survey was a prerequisite to ensure knowledge of the bottom so the sonar could be towed safely. It has a range scale of 200 meters which produces a 400 meter swath width. The survey transects and resulting sidescan sonar image are provided in Figures 5.5 and 5.6, respectively. Data files of the sidescan sonar (as jpeg images) are available at CRESP (www.CRESP.org) and University of Alaska web sites (http://www.ims.uaf.edu/research/johnson/amchitka/). Dark shaded areas indicate the presence of sediment deposits. Locations where sediment samples were obtained are indicated in Figure 5.7. Both fine and coarse grained sediment samples were retrieved and varied by location. Program resources did not permit characterization of these sediments for inclusion in this report.

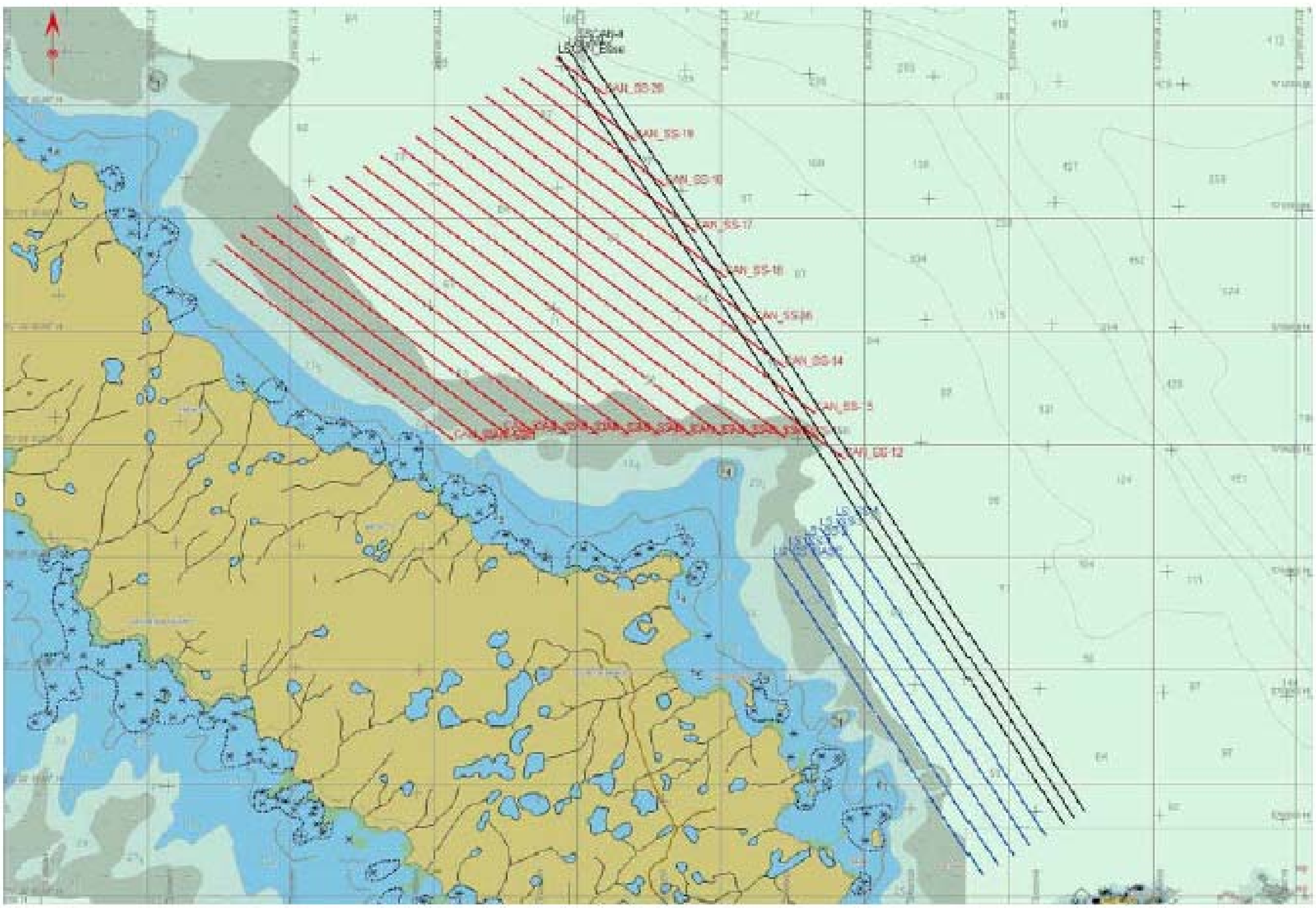

Figure 5.5. Transect lines for the side scan survey. For approximate locations of *Cannikin* (C), *Long Shot* (L) and *Milrow* (M) see Figure 5.3

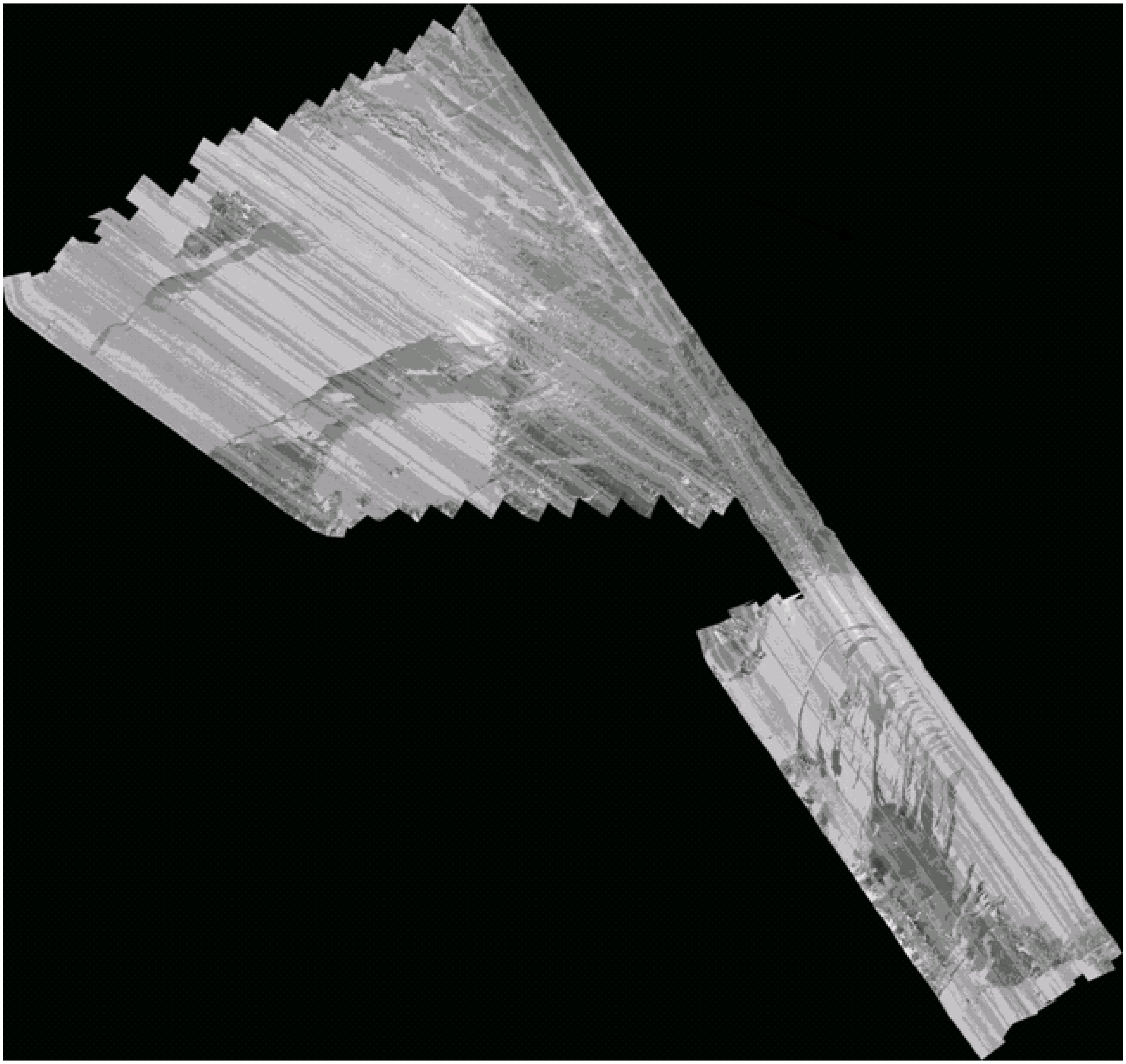

Figure 5.6. Side scan mosaic of all transect data. Note regions of apparent slumping offshore from the *Cannikin* site in the upper part of the frame, and almost parallel, curvilinear features off *Long Shot*. Benthic sites selected for the grab samples were based on this mosaic,

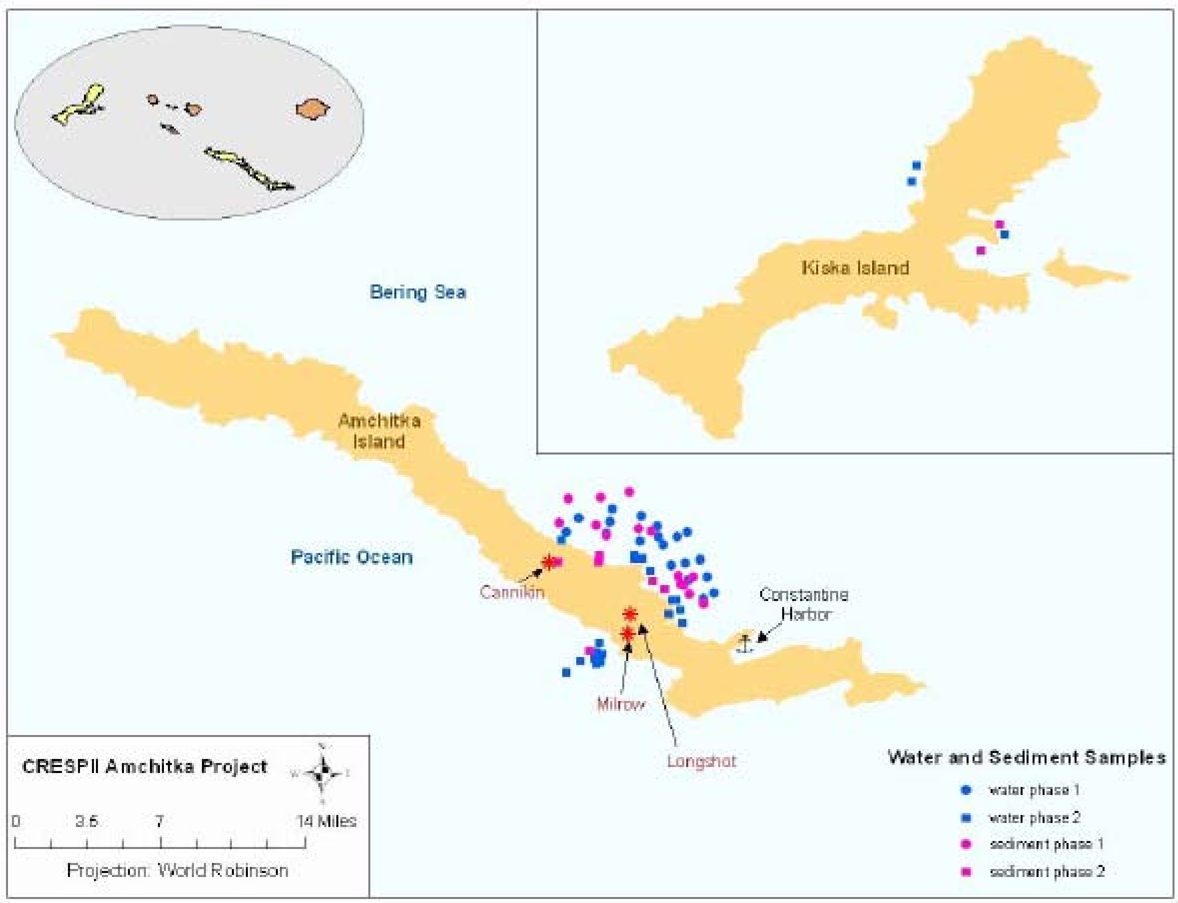

Figure 5.7. Locations of water (Niskin bottle) and sediment samples.

Salinity Measurements and Evidence of Freshwater Discharge through the Ocean Floor

Following the bathymetry and sidescan surveys, eighty oceanographic stations along twelve (12) transects running perpendicular to the bathymetric slope were occupied using a SeaBird 19 CTD (http://www.seabird.com/) to measure conductivity (salinity), temperature, and pressure (depth). The CTD was calibrated by Sea-Bird Electronics, Inc both before and after the cruise. Resulting salinity accuracy is about 0.001. Resulting temperature accuracy is about 0.01^{0}C. The CTD was lowered at no more than 30 m per minute until a 1-2 m altitude above bottom was reached, and then the CTD was held at 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 using an acoustic altimeter attached to the CTD with shipboard readout. CTD data were collected as 0.5 second averages. The temperature (degrees C) and salinity (dimensionless Practical Salinity Units) were aligned in time with pressure to correct for lags in the sampling stream. The sampling lines with station locations are shown Figure 5.8.

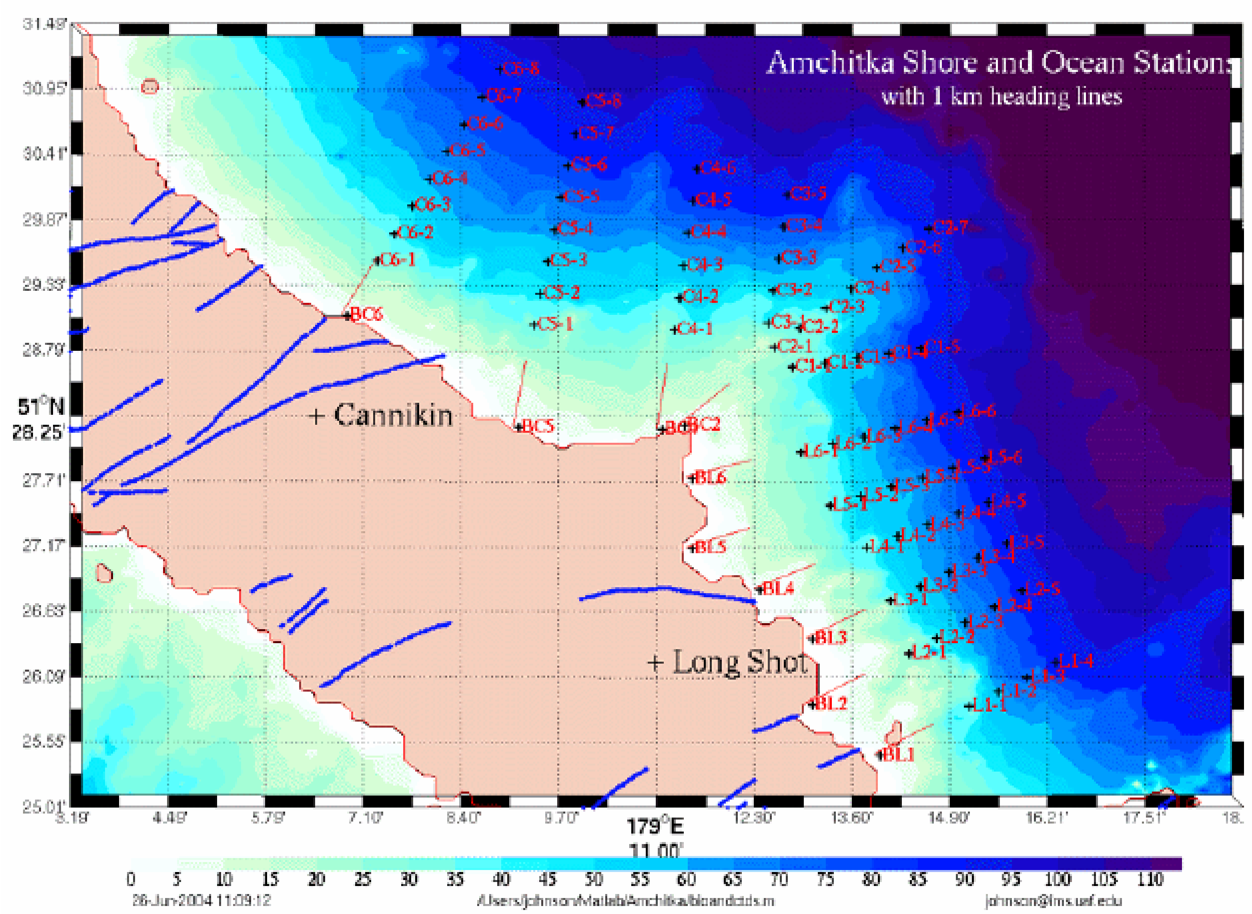

Figure 5.8. Sampling lines and CTD station locations. Blue lines over land show fault lines from historical maps as discussed above. *Cannikin* and *Long Shot* sites are shown. Stations near shore with heading location for sampling by divers are also shown.

Salinity data along the above transect lines, from L1 – L6 and from C1 – C6 were contoured as vertical sections. Three typical sections are provided as Figure 5.9; additional sections are provided in Appendix 5.A Each transect took several hours to complete, so the tidal signal is marginally aliased along each individual section. Each section can be viewed as a nearly synoptic snapshot of the ocean conditions at that time. Multiple sections took longer, so comparing sections introduces aliasing of the tidal signal. These vertical sections show no obvious evidence of broadly distributed freshwater at the bottom.

Small scale seeps have the potential to produce a freshwater CTD signal that would be revealed in individual profiles of salinity. To examine this possibility, vertical profiles at each station were produced. Each profile was reviewed 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 thick layer. This was done for both the CTD down cast and up cast. The standard deviation of the overlying salinity was computed. Data points indicating salinity near the ocean floor with a lower value than three standard deviations from the expected value is considered anomalous and potentially may be indicative of freshwater discharge. However, spurious salinity readings may have resulted from turbid bottom boundary layers, and from material entering the salinity pump (such as gelatinous zooplankton and similar material). There is no way of determining whether such anomalous measurements are from “contamination” or from freshwater discharge. CTD measurements at the following locations have the necessary conditions for freshwater anomalies near the bottom: C1-2, C3-4, C4-1, C4-4, C5-1, L2-2. These observations should be considered in the context of any future measurement efforts.

CONCLUSIONS

The following conclusions are based on the results of the above investigations:

3. 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 from the *Cannikin* and *Long Shot* test sites. Measurements at 6 locations indicated slight anomalies that may be the result of either freshwater discharge or measurement interferences that cannot be distinguished.
4. Significant regions of the ocean floor in the study area off *Cannikin* and *Long Shot* test sites have sediment accumulations. This is contrary to earlier assumptions that the ocean floor in these areas was devoid of sediment accumulations because of energetic ocean currents.

Appendix for Chapter 5 (See attached CD-ROM)

5.A Results from the Amchitka Oceanographic Survey Mark Johnson, University of Alaska, Fairbanks, Alaska and Colin Stewart, Naval Undersea Warfare Center, Keyport, Washington.

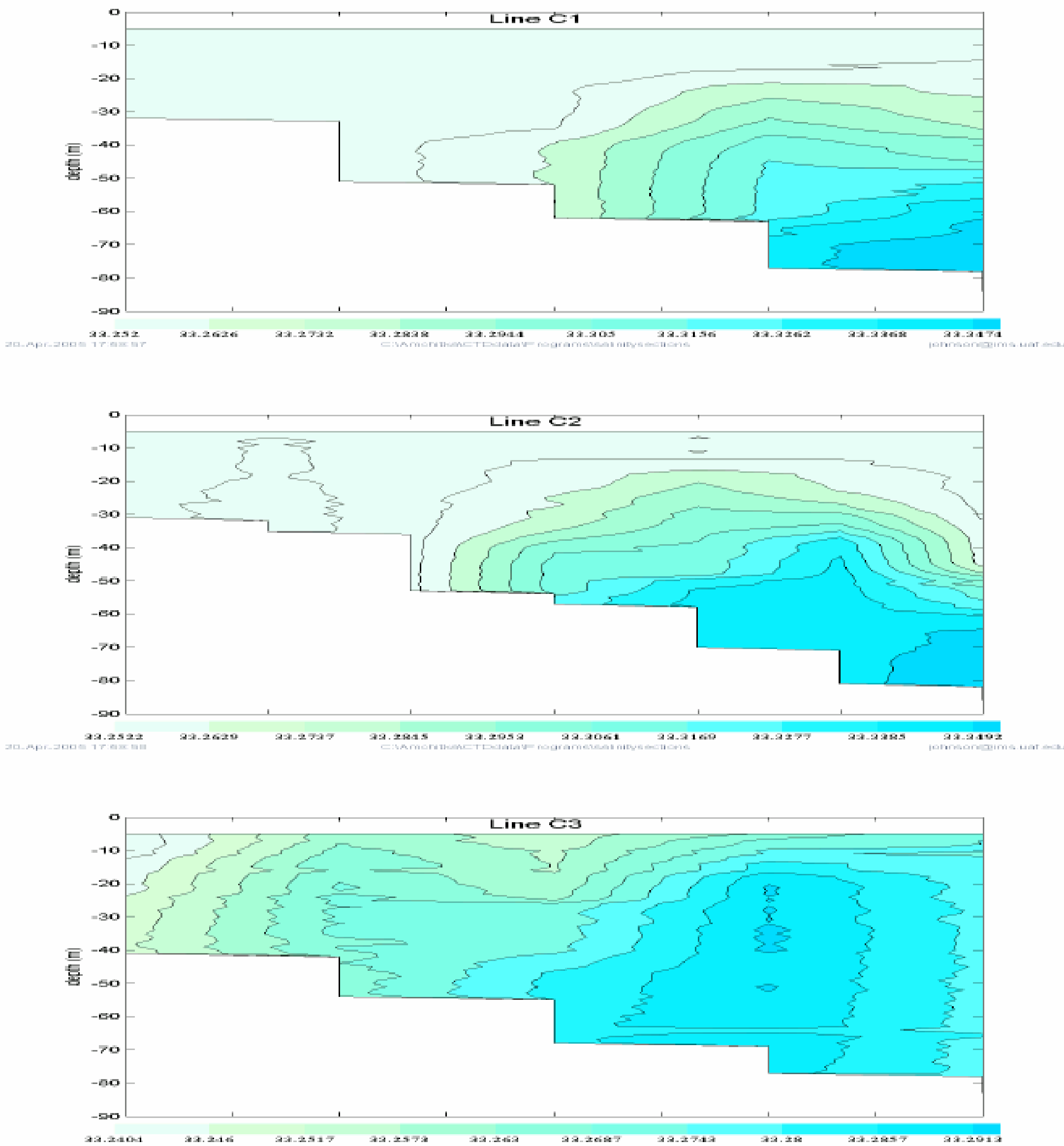

Figure 5.9. Typical vertical sections of salinity (along Lines C-1, C-2, C-3 from Figure 5.8). The section label is shown at the top and depth (meters) is at the left. Offshore is to the right. Note that the salinity scale changes for each section for better visualization. Generally, salty water intrudes onto the shallow shelf from offshore.

Table 5.1. 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	

Filename	Description	format	size	
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	Ascii	117 KB	*

Filename	Description	format	size	
	digitized from chart shown in AmchitkaGeology.tiff			
multibeam_1m_bathy_color.tiff	color contour of bathymetry from multibeam survey off *Cannikin* and *Long Shot*	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 RatIslandBathymetryREADME file for extracting data	text	22.1 MB	*
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	

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