Statement of Work and Research Plan

Physical Environment June 12-22, 2004

In Two Parts

Part 1: Amchitka Island Oceanographic Survey p. 1-7

Part 2: Magnetotullerics and Audio-Magnetotullerics p. 8-17

Part 1: Amchitka Island Oceanographic Survey

BATHYMETRY Mark Johnson, University of Alaska Fairbanks

Objective: Complete a bathymetric survey of three areas offshore Long Shot, Cannikin, and Milrow from near shore to 4 km offshore for Long Shot, 6 km offshore for Cannikin, and 6 km offshore at Milrow. These distances are based on the DRI model estimates of the second edge distance from shoreline. The survey sites enclose the anticipated location of the nearest fault line from each blast site following a line offshore. Area coverage is approximately 10 km^2 for Long Shot, 15 km^2 for Cannikin, and 18 km^2 for Milrow. Of course, weather and the conditions found on site may cause us to modify this Science Plan.

Bathymetry survey will be done with a side scan sonar towed at 4 knots with 0.5 km horizontal spacing. Depth accuracy will be a function of the local sound speed. Side scan software (BathyPro) will allow surveyed data to be further mapped into a grid of bathymetric data. The newly acquired data will be compared with the 3 sec by 6 sec (lat v. lon) data we already have in hand.

FRESH WATER DETECTION IN MARINE ENVIRONMENTS through Conductivity Temperature Depth (CTD) Profiles Mark Johnson, University of Alaska Fairbanks

Objectives: Determine whether there are freshwater anomalies in the near bottom water in any of three selected sites around Amchitka Island.

We will collect conductivity (salinity) data using an SBE 19+ SEACAT Profiler, a self-powered mini-CTD that measures conductivity, temperature, and pressure up to 7000 meters (10,000 psia). It records data (4 Hz) in FLASH RAM memory, and comes standard with a pump. The SEACAT profiler has real-time data capability. It is accurate (0.005 in T, 0.0005 in C, and 0.1% in D) and meets typical oceanographic hydrographic standards.

Time and weather permitting, we expect to survey each of the three areas offshore Long Shot, Cannikin, and Milrow with 0.5 km spacing for the CTD survey. Our highest priority will be the survey from the 20m isobath (or closer to shore if possible) to 4 km offshore (or the 300 ft isobath, whichever is closer) at Long Shot followed by Cannikin. When these two sites are adequately surveyed, we will survey Milrow on the Pacific side of Amchitka.

Background: the University of Alaska Fairbanks (specifically Professor Mark Johnson) has been engaged to test certain aspects of the Desert Research Institute computer model (published as DOE/NV11508-51 and entitled Modeling and Groundwater Flow and Transport of Radionuclides at Amchitka Island's Underground Nuclear Tests: Milrow, Long Shot and Cannikin) that predict pathways for leakage of radionuclides from the Amchitka nuclear test sites.

The University of Alaska Fairbanks (specifically Professor Mark Johnson) to test certain aspects of the Desert Research Institute computer model (published as DOE/NV11508-51 and entitled Modeling and Groundwater Flow and Transport of Radionuclides at Amchitka Island's Underground Nuclear Tests: Milrow, Long Shot and Cannikin) that predict pathways for leakage of radionuclides from the Amchitka nuclear test sites. The independent assessment and verification of this model and reduction of risk uncertainty associated with the test shots were specifically requested to be planned and then executed by CRESP in a Letter of Intent developed between the Department of Energy and the State of Alaska signed in the summer of 2002 (See this LOI at page 164 of the Amchitka Independent Assessment Plan at www.CRESP.org).
In testing the DRI models, a side scan sonar will be used to survey the ocean bottom and software will be used to convert the raw data to a gridded bathymetric data set. The goal is to determine how well the sonar system penetrates into the sub-bottom and how well the DRI models predict, and the UAF software maps this information around Amchitka Island. This will enable comparison between the newly acquired data set with a digital data set we have acquired from USGS. The new bathymetric data will guide a salinity survey using a Seabird 19+ CTD capable of high precision measurements. A key feature for this testing work is the combination of the sonar and the CTD because this will allow us to track the CTD very close to the ocean floor using the sonar. Salinity measurements close to the bottom is an essential condition for our work. Additionally, the information gathered from these two techniques will provide contemporary confirmation/augmentation of the depiction of the marine environments around Amchitka that will materially aid in the identification of where biological sampling should occur and will similarly provide information that should significantly add to the definition and assurance of the safety of the environments in which diving and other sampling activities will occur further from the shores of Amchika itself.

1 Background and Objectives

1.1 Scientific operations

The bathymetric survey will be done using the vessel mounted SM200 Multibeam sonar. Subbottom profiling will be done using a Klein 3000 Side Scan Sonar and DataSonics SIS 1000 Side Scan Sonar/Sub Bottom Profiler and tracked from the research vessel using a USBL system to insure accurate positioning throughout the study. The multibeam unit will be mounted on a pole attached to the side of the vessel.

Survey equipment to be provided is shown in Table 1.

2 **Charter vessel:** The vessel from which this work will be done is the Ocean Explorer, a ship owned by B&N Fisheries of Seattle, Washington. The Ocean Explorer is the same vessel on

which Navy equipment has already this summer been loaded in order to support work done in the Aleutians by NOAA in the period immediately preceding its planned use in the this project.

2.1 Specifications

CRESP has chartered the *F/V Ocean Explorer* from B&N Fisheries Company of Seattle, WA. She is 155' LOA, with 36' beam, 16' draft and a 1764 hp main. The vessel will be provided with an experienced crew of six, consisting of captain, mate, engineer, two deck hands, and a cook. Berthing space for fourteen scientists is available in the form of three two-person and two four-person staterooms.

2.2. Mobilization (Seattle, Washington)

Mobilization and demobilization will be done at Dutch Harbor prior to June 10^{th} and a few days after June 22. The intinerary developed with the Ocean Explorer will have Navy equipment and crew returned to Dutch Harbor no later than June 25.

3. Responsibilities of UAF

IRM/CRESP and specifically its UAF researchers will have responsibility for overall project planning, coordination of at-sea operations. UAF and NAVY personnel will work together to complete data analysis to meet the needs of the IRM/CRESP goals. UAF will supply two persons and the Navy will supply 4 persons. In addition, CRESP researcher, Dan Volz will oversee a limited collection of both water and sediment samples at locations that may be indicated by the bathymetric evaluations and of CTD profiles. Determination about whether and if so these samples should be analyzed has not been made – and will probably be delayed until an evaluation of the total sample and data collection achieved by the expedition has been made and the final analytic prioritization is achieved in August, 2004.[a]

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[a] **Procedure for Taking Water and Sediment Samples During the Oceanographic Portion of the Amchitka Expedition**

1. Samples will be taken if salt-water/ freshwater anomalies are found in transects determined by Mark Johnson as a result of CTD scanning off shore from the Long Shot, Cannikin and Milrow blast sites.
2. The procedure for taking samples if an anomaly is found is as follows:
    - The GPS Location of the anomaly will be determined and logged.
    - Five (5) water and sediment samples (sample package) will be taken in the area where the anomaly is found.
    - One sample package will be taken in the area where the salinity difference is the highest, one package will be taken 20 yards downstream of the area of highest salinity difference, two (2) sample packages will be taken 20 yards downstream from the point of highest salinity difference, each at 45 degree angles to the line formed by the area of highest salinity difference and the downstream point and one sample will be taken 20 yards upstream from the area of highest salinity difference.
    - If a current direction cannot be accurately determined than one (1) sample package will be taken in the area of highest salinity difference. The remaining samples will be taken on the circumference of a circle at 4 equidistant compass points, all within 20 yards of the circles center.
    - If the salinity difference cannot be pinpointed and is diffuse, 5 or more sample packages will be employed in an attempt to characterize the water and sediment in that area, the distance between sample packages will be determined by site conditions in consultation with Mark Johnson.

4. Responsibilities of the U.S. Navy

The Navy will provide side scan sonar, multibeam echosounder and navigation services to complete the sub-bottom and bathymetric survey objectives in 2004. Manpower will be provided as necessary on an hourly basis, with a guaranteed workday of 16 hours while at sea and 12 hours during mobilization and demobilization. Actual workday length and hours will be determined by Johnson as Chief Scientist in consultation with the captain of the vessel and the leader of the Navy field team. The decision will be based on the type of activity expected (e.g. in port preparations), as well as on prevailing weather conditions and the Cruise Plan. The Chief Scientist has the final authority except in matters relating to safety of personnel, the vessel, and operation of its equipment, which are the responsibility of the vessel captain. The Navy has responsibility for prudent use of the Navy equipment. Essential equipment for accomplishing specific project objectives, with a goal of full redundancy, will be provided without charge as part of the Navy support package. Critical electronic equipment will be calibrated to manufacturer's specifications prior to and/or after the deployment for this project. In particular, the accuracy of the CTD will be assured.

Navy field team's responsibilities include: (1) advance preparation and coordination with the UAF team; (2) installation, operation and removal of USBL navigation system; (3) side scan

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3. Sample packages will also be taken in the ocean transects at Cannikin, Long Shot and Milrow if no saltwater anomalies are found. The sample packages will be taken along the midline of the transects as determined by Mark Johnson.
4. Sample Packages will be taken at our reference site Kiska. Five (5) sample packages will be in the Kiska area at similar depths to those taken at Amchitka.

Water Samples
Water samples will be taken using a Niskin sampler (which opens at the depth desired and closes immediately). The Niskin Sampler takes .7 liters of water on each grab. Since 2 liters of water are needed for analysis and the Nalgene sample bottles are 1 liter. Each water sample will be a composite of three grabs. The GPS location and depth of each water sample will be recorded.

Sediment Samples
Sediment Samples will be taken using a Van Veen Grab. At least 500 grams of sediment will be taken at each sampling location. The depth and GPS location of each sediment sample will be recorded.

Radiation Monitoring
All sediment and water samples will be scanned for radiation activity before being brought on the boat. Longer sampling count times will occur in the hold before sample packaging.

Sample Identification
Each water and sediment sample will be given a unique identifier. All samples will first be given a letter for where they are taken from. These will be Cannikin, C; Milrow, M; Long Shot, LS and Kiska, K. Numbers will be sequential in each location starting with 001. Finally the type of sample will be recorded in the identifier, Sediment, S and Water, W. Therefore the first sediment sample from our reference site, Kiska, will have the identifier K001S.

Data Entry
All data will be entered into a note book and than transferred to an Excel spreadsheet for transmission to CRESP headquarters at regular intervals.

sonar data acquisition, post-processing, groundtruthing, and mosaic preparation; (4) multibeam echosounder data acquisition, post-processing, groundtruthing and mosaic preparation, (5) general support services; and (6) preparation of a summary report and delivery of documented data products to UAF. Additionally, the Navy may be asked to participate in a debriefing soon after delivery of the final report and data products. In general, the Navy will work closely with the Chief Scientist to ensure that program objectives are met. Specific details of Navy responsibilities are provided below.

Advance preparation and coordination

Acquire available electronic bathymetric data sets in the Amchitka vicinity as available.

Installation, operation and removal of USBL navigation system

Precise positioning and navigation of the vessel (and sampling gear, e.g. towfish and CTD) is a critical element of the project. The USBL navigation system will provide real-time information to the helmsman on the location of sampling gear. In addition to the chartered vessel, telemetry and tracking will be provided for the following: (1) the side scan sonar towfish, 2), CTD casts, 3) multibeam echosounder. The Navy will inspect the Government-chartered vessel to determine positioning and design issues related to installation and optimum performance of the transducer pole and other Navy-supplied equipment.

Georeferencing standard.

The project will use the WGS-84 spheroid and a geographic projection for data acquisition. The Universal Transverse Mercator (UTM) zone 4 projection will be the standard projection used for navigational displays during field operations. Latitude and longitude will be formatted as degrees, minutes and decimal minutes to 6 places (as per the NMEA standard GGA telegram; or equivalent precision in decimal degrees), unless otherwise specified by the UAF chief scientist.

Install GPS and navigation displays.

The Navy will supply the necessary manpower and materials to install the portable GPS receiver plus spare, the associated cables and the antennas. The Navy will provide real-time navigation displays on the ship.

Install and calibrate the USBL navigation system.

The Navy will supply the necessary manpower and materials to install and calibrate the USBL tracking hardware, including (1) precise calibration of the primary and secondary portable survey grade gyro compasses using an accurate bearing determined from interconnected GPS receivers with measured offsets, (2) determine locations of vessel nodes associated with navigation and scientific sampling, including the USBL transducer mount, multibeam echosounder mount, GPS antennas, vessel transducers, determine any bias between the portable gyros and the charter vessel's gyro which may serve as a backup should the survey grade gyro(s) fail, and perform a dynamic box calibration of the USBL system and a static/dockside calibration during mobilization, unless directed otherwise by the UAF chief scientist.

Provide underwater tracking during field operations. The Navy will provide manpower and equipment for real-time underwater tracking of CTD and side scan sonar towfish. Range and bearing data from the USBL will be logged as well as computed positions. Output from all gyros and the VRU will be logged. As an aid to post-processing of navigation data, all the above mentioned navigation data will be logged and checked while at Dutch Harbor. CTD casts will be made as necessary to ensure use of appropriate sound velocities.

Removal of USBL tracking hardware (transducer pole, GPS and navigation systems*)*. Upon completion of field operations, the Navy will remove all Navy equipment and restore their workspace to near-original condition. The Navy will also supervise removal of the transducer pole to prevent damage to the vessel and the pole. It is recognized that certain residual effects related to welding and other methods of attachment are inevitable. Ultimately, this task should be completed to the satisfaction of the vessel captain, NMFS (regarding the USBL pole), and UAF. The NMFS will take possession of the pole after removal from the vessel.

Side scan sonar data acquisition, post-processing, groundtruthing and mosaic preparation
Side scan sonar data/images and groundtruthing are required to characterize sediment properties and bedforms within the study area. The Navy will acquire raw side scan sonar data (amplitudes) to provide reasonable coverage in each of the three study areas, unless directed otherwise by the UAF chief scientist. Continuous recording of side scan sonar data will be made during the survey passes using a 100 m range scale, unless directed otherwise by the UAF chief scientist. Consistent gain settings, towfish altitude, and other acquisition factors affecting images are required by the nature of the study. All towfish sensor data that can be recorded will be logged. As an aid to interpretation of the final data products, a detailed log of relevant observations (*e.g*., sea state, equipment settings, malfunctions/errors) shall be maintained at all times during data acquisition. As necessary, the Navy will provide input for determining sites for collection of CTD data and to aid in the interpretation of the side scan imagery.

Multibeam echosounder data acquisition, post-processing, groundtruthing and mosaic preparation

Multibeam echosounder data and groundtruthing are required to characterize bathymetry of the study areas. The Navy will acquire raw multibeam echosounder data to provide complete coverage in each of the three study areas, unless directed otherwise by the UAF chief scientist. Continuous recording of multibeam data will be made during the survey passes, unless directed otherwise by the UAF chief scientist. Consistent gain settings and other acquisition factors affecting images are required by the nature of the study. All sensor data that can be recorded will be logged. As an aid to interpretation of the final data products, a detailed log of relevant observations (*e.g*., sea state, equipment settings, malfunctions/errors) shall be maintained at all times during data acquisition.

General support services
The Navy will make regular backups and ensure safekeeping of data acquired at sea. Three (3) complete sets are required, one to be retained by the Navy and two to be delivered to UAF at

charter end in Dutch Harbor. Upon request of the UAF chief scientist, the Navy will provide electronic and mechanical support services related to successful completion of the project.

Deliverable data products and supporting documentation
To the maximum extent practicable, the Navy will process navigation, side scan sonar and other required data products while at sea. Those products not delivered at sea shall be delivered within 90 days of the end of the cruise. The Navy will deliver complete sets of navigation data including position fixes for the vessel and CTD sites. The intention is for UAF to have accurate knowledge of gear deployments relative to the specified sampling plan. Positions will be reported in both decimal degrees and UTM meters, with NMEA standard GGA equivalent precision. If post-processing will improve the accuracy of these data, both raw and post-processed data will be provided. If smoothing algorithms are applied during post-processing, these should be specified and clearly explained in the documentation.

Bathymetry data and imagery from the multibeam echosounder. Delivered data products should include 100% of the acquired raw data collected, with no corrections applied. All processed bathymetry data corrected for vessel motion, position, tide, draft and sound velocity will be delivered. Digital multibeam echosounder data will be provided in appropriate file format, as well as the post-processing configuration files. In addition, two (2) high quality hard copy mosaiced images for each study area will be provided. Digital images also are required and will be georeferenced and in a GIS-ready format such as Geo-TIFF. The map spheroid, datum and projection to be used will be specified by the UAF chief scientist. Sun-illuminated mosaics from projected from two angles will be delivered as digital images.

Digital side scan sonar data from the SIS1000 system as acquired and after post-processing will be provided in appropriate file format, as well as the post-processing configuration files. In addition, two (2) high quality hard copy mosaiced images for each study area will be provided sun-illuminated from two angles. Digital images also are required and will be georeferenced and in a GIS-ready format such as Geo-TIFF. The map spheroid, datum and projection to be used will be specified by the Chief Scientist.

All data used to calculate sound velocity profiles will be provided. This should include dates, times and positions of CTD casts, as well as times and dates where each profile was applied.

A report will be provided that includes the following information: 1) documentation of manufacture, model number and specifications of all instruments used for navigation, multibeam and sidescan sonar data collection, including descriptions of range scales, ping rate, number of beams, depth of water, line orientation and spacing, swath width, resolution, alongtrack coverage and quality assurance tools used during data acquisition, 2) descriptions of the computer hardware and software used for data acquisition and processing including all methods, procedures and parameters used, 3) documentation of sea states, weather, unusual oceanographic features that may influence data interpretation, and 4) methods used to determine, evaluate and apply tide or water level corrections to the data.

After the summary report has been issued by the Navy and reviewed by UAF, the Navy may be asked to debrief the chief scientist and provide recommendations for improvements in field protocols or equipment.

Table 1

Equipment	
Klein 3000 Side Scan Sonar	
Datasonics SIS 1000 Side Scan Sonar/Sub Bottom Profiler	
ISIS Sonar Work Station (3)	
Chase Side Scan Sonar Winch	
Simrad SM2000 Multibeam Sonar	
Trackpoint II+ USBL system with 6 Multibeacons	
QINSy Navigation System with 6 Monitors	
Seabird Seacat SBE-19 CTD Probe	
Scan 2000 Gyro Compass	
Trimble DSM132 WAAS Capable GPS Receivers (2)	
Side Scan Sonar Spare parts kit with a spare cable termination	
Deck Tool Locker	
Wireless Instrumented Sheave (spare)	
Desk top Computer and Monitor	
Deck Cameras with lights and Monitors (2)	
Digital Camera (Sony Mavica)	
HP OfficeJet d155xi color printer, copier, scanner, fax	
UPS for computer equipment (4)	
Technician Hand tools	
Electronic Test Equipment; Network Hub	
Laptop Computers (3)	
Office Supplies (CDs, Disks, Dat Tapes, etc)	

Part 2: Magnetotullerics and Audio-Magnetotullerics

MAGNETOTELLURICS (Martyn Unsworth, University of Alberta)

1. Objectives of the 2004 Amchitka magnetotelluric survey

To constrain the hydrogeology beneath Amchitka Island in the vicinity of the three shot cavities through remote sensing of electrical resistivity with surface magnetotelluric (MT) data. This should include the structure on transects from the Pacific Ocean to the Bering Sea, and enough measurements so that structures associated with the shot cavities can be distinguished from the normal background structure, unassociated with the underground nuclear tests.

2. Pre-survey analysis to determine optimal acquisition parameters

The magnetotelluric (MT) data to be collected comprise time recordings of electric and magnetic field variations at a number of measurement locations. MT images depth variations using the fact that high frequencies sample shallow structure and lower frequencies sample deeper structure.

To determine the frequencies that should be measured on Amchitka Island, a simple forward modeling exercise was undertaken in 2004. This assuming that resistivities above and below the salt water to fresh water interface are 300 and 30 ohm-m, based on observations of coastal hydrogeology elsewhere in the world. For example with the interface at 1 and 2 km, the frequency needed to image to these depths are 75 Hz and 18 Hz respectively. Frequencies above and below this frequency must be recorded to image the transition from high to low resistivity. Depth resolution to a low resistivity layer is likely to be around 10% of the depth with high quality data in the 1000-0.1 Hz band.

A more sophisticated modeling approach was also undertaken using 2-D numerical modeling in the Winglink software package. This included the ocean on each side of the island with known bathymetry. Similar results were obtained to those presented above.

Different types of MT system are available for recording different frequency bands. For Amchitka, the band should be at least 500-0.1 Hz (to bracket the frequency computed above). This is best achieved with a broadband MT system such as the Phoenix V5-2000 with MTC50 induction coils. The MT instruments owned by the University of Alberta that are being shipped to Amchitka Island are of this type.

The alternative choice would be to use the higher frequency audio magnetotelluric system (AMT) that records in the range 10,000-1 Hz. While this would give higher frequency data that would be useful for the upper 100-200 m, this system does not give low enough frequencies that are needed for imaging details in the saltwater layer. As a compromise, we are bringing some AMT sensors that will increase the upper frequency recorded to around 1000 Hz. Phoenix Geophysics have generously loaned these AMT sensors to the expedition at no cost.

3. Magnetotelluric survey during the Amchitka Expedition

3.1 Adak testing and training

The period 6-11th June on Adak Island will be used to :

(a) Test and calibrate all MT systems at a site a few miles outside the town. This will require a vehicle such as a pickup truck. Will also need to borrow local digging tools as ours are stored on the *Ocean Explorer*.

(b) A brief test of vehicles

(c) Ensure all batteries are fully charged.

(d) The time will also be used for training personnel so that we can work effectively as a group as soon as we arrive on Amchitka Island.

(e) Immediately upon arrival the contents will be checked and any missing or malfunctioning items can be sent from Phoenix Geophysics or the University of Alberta. Cargo schedules are planned so that both consignments arrive on June 6th flight. Arrival of cargo on June 10th would be less satisfactory.

3.2. Arrival and establishment of field party on Amchitka

This will be a critical time as camp will be established and MT fieldwork will begin. It is also vital that safe working practices are established and followed at the start of the survey. Participation of Dan Volz with the MT crew will be essential for most, if not all, of this phase.

3.3 Main MT data collection phase

The attached map shows the basic layout of the survey. Stations will be 500 m apart on profiles that cross the island. Terrain permitting, some profiles should cross from the Pacific Ocean to the Bering Sea. At minimum there should be an MT profile through each shot cavity (Cannikin, Milrow and Long Shot). Each shot cavity should be bracketed on at least one side by an MT profile. This will allow the effects of the explosion to be distinguished from the background (pre-existing) structure.

The depth sensitivity for MT exploration depends on the frequencies used, as described in the previous section. The best resolved parameter in MT exploration is the depth to a low resistivity layer. Thus the target beneath Amchitka Island (the salt water layer) should be well resolved. The other parameter to be investigated is lateral resolution. To a first approximation, a profile of MT stations should be as long as the maximum depth at which good lateral resolution is required. Clearly the 5 km width of the island is a limiting factor, but even with the Cannikin shot cavity, profiles will be long enough to give lateral resolution at the depths of the cavity. Note that this applies to both the cross-island profiles and the spacing between profiles.

The layout on the map takes advantage of existing roads, as working cross-country will be slower. Exactly straight profiles are not needed. Locations will be surveyed with hand-held GPS units and 10 m accuracy is adequate.

There are two types of MT station to be used on Amchitka Island. At a *3H-2E* station, both magnetic and electric fields are recorded. At a *2E* station, just electric fields are measured. 2E stations are much quicker to deploy. Thus we plan to move the *3H-2E* stations once a day and allow overnight recording. The *2E* stations will likely be moved several times a day, to maximize productivity. Remote reference recording will be used, as described in the QA/QC section. This will be achieved through a fixed *3H-2E* station.

We will have the following MT systems available on Amchitka Island

3H-2E 4 systems
2E 2 systems

Note that a *3H-2E* station can collect data in *2E* mode if needed.

In a typical day of MT fieldwork we could collect data at 9 MT stations as follows. Note that one *3H-2E* will be fixed as a remote reference station.

Movement	**Number of** *deployments*	**Number of** *stations*	**Recording time** *(hours)*	**Total number** *of stations*
3H-2E	1	3	18	3
2E	3+	2	2 / 2 / 12	6+

With 9 stations collected per day, and 10 days of acquisition, this would yield ~90 stations in total. However, technical and weather issues will likely restrict this plan. The basic plan on the map is for fewer stations and this is clearly feasible in the allowed time, allowing for the inevitable delays.

MT data can be influenced by shallow, small scale structures. These introduce so-called static shifts in the MT data. To address this issue, we will use an independent method to measure shallow resistivity structure at selected MT stations. This will be achieved with a standard direct current (DC) resistivity meter. This requires 4 metal electrodes to be inserted in the soil at various locations. Time per station around 30 minutes. We will only do this at a few sites where static shifts may be a problem.

Priority sequence

The duration of the proposed MT survey is short and a complete study of all three cavities will not be possible in 10 days. Thus a focused field plan is required to maximize the information that is obtained from the MT survey.

Profiles are named on the map and would be recorded in the following sequence.

Phase 1 : Basic coverage of Longshot and Millrow. Starting here is easiest as the time to drive back and forward to base camp is minimized. We will find a quiet remote reference site and experiment with length of recording times for *2E* stations (profiles L5,L6 and L7). This phase requires 28 stations that will take 3-4 days field work.

Phase 2 : Switch focus to Cannikin. Profiles L1,L2 and L3 with 21 stations. 3 days.

Phase 3 : Additional detail as required. Most likely this could include L4 and L8, but in field MT data analysis will determine the most important locations to make MT measurements.

Contingency plans

In the event that there are significant weather or technical delays the schedule could be accelerated as follows. This could also be implemented if it is discovered that a closer stations spacing is needed.

(a) Reduce recording time of all stations. Would require more effort from field crew.

(b) Not measure the vertical magnetic field. This requires a 1 m hole to be made with a post-hole digger and can be slow. Not collecting these data would compromise some aspects of subsurface resolution, but would speed up station installation. Another alternative would be to use an air loop sensor, and arrangements are being made with Phoenix Geophysics to include these in the rental agreement.

(c) Ideally each profile has 2-3 *3H-2E* stations and *2E* stations everywhere else. This is needed since magnetic fields vary from location to location. However, we could switch to a balance of a single *3H-2E* stations per profile, with *2E* stations elsewhere. This would increase productivity, with a hopefully minor loss of data quality.

(d) Daily schedules could also be altered to not move *3H-2E* stations each day and spend all effort moving 2E stations (e.g. 2 crews moving a 2E every 1 hour would give up to 16 stations a day. We could also leap-frog technique *i.e.* be installing a *2E* station while another records.

3.4 Post-expedition MT data analysis processing

Initial resistivity models will be obtained by MT data processing in tents on Amchitka Island. However extensive post-survey MT data analysis is needed to obtain a reliable resistivity model. This will involve application of the most modern (and reliable) techniques available and will include:

(1) Re-processing time series with other algorithms.
Time required : 1 month.

(2) Tensor decomposition and other approaches to understand the dimensionality of the MT data.
Time required : 1 month.

(3) Investigation of static shifts in data. DC resistivity data will be used as needed.
Time required : ½ month

(4) Detailed 2-D forward modeling and inversion. Both Martyn Unsworth and Wolfgang Soyer will work on this independently to understand the possible range of models that are consistent with the MT data.
Time required : 2 months.

(5) Development of a 3-D model incorporating the bathymetry around Amchitka Island. Seawater has a low electrical resistivity and influences onshore MT data. Thus the bathymetry must be included in all realistic analysis.
Time required : 1 month.

(6) 3-D modeling and inversion of the MT data. This stage is computationally slow and a single run of the inversion code will likely take several days of CPU time.

Time required : 2 months

(7) Synthesis and possible repetition of stages (4)-(6) as needed in light of hydrogeology modeling.
Time required : 1 month.

The above steps are standard for rigorous MT data analysis and have been implemented on a routine basis in my previous research. Adherence to the above sequence will result in a geoelectric model with associated uncertainties (i.e. a range of resistivity models will be developed and it will be clear what is required by the MT data). This will give a deliverable of high quality that can be trusted.

Quality assurance and quality control for 2004 Amchitka Expedition

MAGNETOTELLURICS (Martyn Unsworth)

1. Objectives

To constrain the hydrogeology beneath Amchitka Island in the vicinity of the three shot cavities through remote sensing of electrical resistivity with surface magnetotelluric (MT) data. This should include the structure on transects from the Pacific Ocean to the Bering Sea, and enough measurements so that structures associated with the shot cavities can be distinguished from the normal background structure, unassociated with the underground nuclear tests.

2. Overview of QC/QA[b]

Key areas that have been considered / will be considered include:

2.1 Pre-survey analysis to determine optimal acquisition parameters
2.2 In field quality check after each MT station is recorded
2.3 In field modeling to determine if additional MT stations are needed.
2.4 *Post-survey data analysis.*

The approaches outlined below represent standard operating procedures as used in both commercial and academic MT surveys. Note that Martyn Unsworth and Wolfgang Soyer each have extensive experience operating both the Phoenix V5-2000 MT system and other similar systems. Other field crew members will be trained on Adak Island and their role will primarily be to install and recover the electric and magnetic field sensors, batteries and V5-2000 units

2.1. Pre-survey analysis to determine optimal acquisition parameters

The magnetotelluric (MT) data to be collected comprise time recordings of electric and magnetic field variations at a number of measurement locations. MT images depth variations using the fact that high frequencies sample shallow structure and lower frequencies sample deeper structure.

To determine the frequencies that should be measured on Amchitka Island, a simple forward modeling exercise was undertaken in 2004. This assuming that resistivities above and below the salt water to fresh water interface are 300 and 30 ohm-m, based on observations of coastal hydrogeology elsewhere in the world. For example with the interface at 1 and 2 km, the frequency needed to image to these depths are 75 Hz and 18 Hz respectively (derived from the skin depth equation). Frequencies above and below this frequency must be recorded to image the transition from high to low resistivity. Depth resolution to a low resistivity layer is likely to be around 10% of the depth with high quality data in the 1000-0.1 Hz band.

A more sophisticated modeling approach was also undertaken using 2-D numerical modeling. This included the ocean on each side of the island with known bathymetry. Similar results were obtained to those presented above.

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[b] Items 2.1, 2.2 and 2.4 have been addressed, in whole or in part, in the Workplan that makes up the intial 5 pages of this document but are reiterated here to provide a whole and independent picture of the QA/QC process.

Different types of MT system are available for recording different frequency bands. For Amchitka, the band should be at least 500-0.1 Hz (to bracket the frequency computed above). This is best achieved with a broadband MT system such as the Phoenix V5-2000 with MTC50 induction coils. The MT instruments owned by the University of Alberta that are being shipped to Amchitka Island are of this type.

The alternative choice would be to use the higher frequency audio magnetotelluric system (AMT) that records in the range 10,000-1 Hz. While this would give higher frequency data that would be useful for the upper 100-200 m, this system does not give low enough frequencies that are needed for imaging details in the saltwater layer. As a compromise, we are bringing some AMT sensors that will increase the upper frequency recorded to around 1000 Hz. Phoenix Geophysics have generously loaned these AMT sensors to the expedition at no cost.

Lateral resolution is also important, and changes in horizontal resistivity structure can usually be distinguished to a depth approximately equal to the length of the profile. Thus a 5 km cross island profile will image to depths well in excess of even the Cannikin shot cavity.

MT survey layout

The attached map shows the basic layout of the survey. Stations will be 500 m apart on profiles that cross the island. Terrain permitting, some profiles should cross from the Pacific Ocean to the Bering Sea. At minimum there should be an MT profile through each shot cavity (Cannikin, Milrow and Long Shot) and each shot cavity should be bracketed on at least one side by an MT profile. This will allow the effects of the explosion to be distinguished from the background (pre-existing) hydrogeological structure.

The layout on the map takes advantage of existing roads, as working cross-country will be slower. Exactly straight profiles are not needed. Locations will be surveyed with hand-held GPS units and 10 m accuracy is adequate.

As the MT survey proceeds, it may be possible to add extra profiles, or to decrease the inter-station spacing where structure varies rapidly.

All modern MT surveys use the remote reference technique to cancel noise, and this will be applied on Amchitka Island. The most likely noise source is ground vibration from ocean waves and will be in the frequency band 1-0.1 Hz. To guarantee that a station is always running for remote reference, one 3H-2E station will be kept operational at an easily accessible location for the entire survey.

For the remote reference technique to be effective, noise must be incoherent at each site. Thus the distance between the remote reference and the production area will need to be determined in the field. Based on previous MT surveys1-2 km is expected to be adequate, but this issue will be carefully studied in the first days of the MT survey.

There are two types of MT station to be used on Amchitka Island. At a *3H-2E* station, both magnetic and electric fields are recorded. At a *2E* station, just electric fields are measured. 2E stations are much quicker to deploy. Thus we plan to move the *3H-2E* stations once a day and allow overnight recording. The *2E* stations will likely be moved several times a day, to maximize productivity.

We will have the following MT systems available on Amchitka Island

3H-2E	4 systems
2E	2 systems

Note that a *3H-2E* station can collect data in *2E* mode if needed.

In a typical day of MT fieldwork we could collect data at 9 MT stations as follows. Note that one *3H-2E* will be fixed as a remote reference station.

Movement	**Number of** *deployments*	**Number of** *stations*	**Recording time** *(hours)*	**Total number** *of stations*
3H-2E	1	3	18	3
2E	3	2	2 / 2 / 12	6

With 9 stations collected per day, and 10 days of acquisition, this would yield ~90 stations in total. However, technical and weather issues will likely restrict this plan. The basic plan on the map is for fewer stations and should be feasible in the allowed time, allowing for the inevitable delays.

2.2 In field quality check after each MT station is recorded: Data validation

Once an MT instrument is switched on at a station, field notes are written in the log book to record the location, time of recording, length of electric field lines and battery voltage. These are then used to confirm which data files were associated with each measurement site.

Once data recording is complete at an MT station, the MT data are recorded on a flashcard. This is transferred to a laptop PC at the end of the day for verification. A tent in the field area will allow us to do this as needed during the day. This involves careful examination of the time series for correct operation and initial processing to give frequency domain data. Data is copied to a

CD or DVD as soon as possible. Two copies of each time series are always in existence (i.e. the flashcard is not reused until copies are made to the PC hard-drive and burned onto a CD).

All V5-2000 MT systems (University of Alberta and the rental units from Phoenix Geophysics) will be calibrated on Adak Island prior to the MT survey on Amchitka Island. This is standard practice and will confirm that all units are functioning correctly.

In processing MT data, a smooth (noise free) variation of apparent resistivity is expected over the frequency band from 1000 – 0.1 Hz. If this is not obtained then the recording may be repeated the next day. The electrode holes will be marked with stakes and flagging tape to expedite this process. The processed data will be checked for phases being in the correct quadrants, as this will confirm that the north-south-east and west electrodes were connected to the recording unit correctly.

MT data can be influenced by shallow, small scale structures. These introduce so-called static shifts in the MT data. To assess this issue, we will use an independent method to measure shallow resistivity structure at selected MT stations. This will be achieved with a standard direct current (DC) resistivity meter.

2.3 In field modeling to determine if additional MT stations are needed

After initial time-series processing, the data are transformed into the industry standard EDI format, defined by the Society of Exploration Geophysicists. These EDI files can then be imported into a standard modeling package such as Winglink for viewing and interpretation. Winglink licenses will be available to the field party on Amchitka Island. This will include simple two-dimensional modeling in the field, and will allow us to optimize the location of subsequent MT stations. For example, if the initial MT station spacing is 500 m, and two stations show a major change in response, the gap may be filled. If responses are very similar then filling the gap will be a lower priority.

2.4 Post-expedition MT data analysis processing

While initial resistivity models will be obtained by MT data processing in tents on Amchitka Island, extensive post-survey MT data analysis is needed to obtain a reliable resistivity model. This will involve application of the most modern (and reliable) techniques available and will include:

(8) Re-processing time series with other algorithms.

(9) Tensor decomposition to understand the dimensionality of the MT data.

(10) Investigation of static shifts in data. DC resistivity data will be used as needed.

(11) Detailed 2-D forward modeling and inversion

(12) Development of a 3-D model incorporating the bathymetry around Amchitka Island. Seawater has a low electrical resistivity and influences onshore MT data. Thus the bathymetry must be included in all realistic analysis.

(13) 3-D modeling and inversion of the MT data.

(14) Repetition of stages (4)-(6) as needed in light of hydrogeology modeling.

The above steps are standard for rigorous MT data analysis and have been implemented on a routine basis in my previous research. Adherence to the above sequence will result in a geoelectric model with associated uncertainties (i.e. a range of resistivity models will be developed and it will be clear what is required by the MT data). This will give a deliverable of high quality that can be trusted.