A COMPREHENSIVE STUDY OF THE SEISMOTECTONICS OF THE EASTERN ALEUTIAN ARC
AND ASSOCIATED VOLCANIC SYSTEMS

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J.N. Davies, K.H. Jacob, J. Beavan, R. Bilham
L. House, J. Krause, M. Hamburger and P. Beck

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84

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TABLE OF CONTENTS

	<u>Page</u>
COVER PAGE	i
TABLE OF CONTENTS	ii
INTRODUCTION	1
SHUMAGIN ISLANDS SEISMICITY	2
CRUSTAL DEFORMATION IN THE SHUMAGIN GAP	4
Mean Sea-Level Meters	4
Geodetic Levelling	6
FOCAL MECHANISMS IN THE ALEUTIANS AND MAINLAND ALASKA	8
Aleutian Arc	8
Eastern Aleutian Arc and Mainland Alaska	9
P-WAVE VELOCITY STUDY OF THE ALASKA-ALEUTIAN SUBDUCTION ZONE	11
LONG-PERIOD SEISMIC DATA	15
PAVLOF VOLCANO GEOTHERMAL STUDY	17
FIELDWORK	21
Short-Period Seismic Stations	22
Long-Period Seismic Stations	25
Strong-Motion Station	26
Mean Sea-Level Meter Stations	26
Geodetic Levelling	27
PERSONNEL	30
REFERENCES	32
TABLES	34
FIGURES	42
APPENDIX I - Summary of Helicopter Operations	
APPENDIX II - Crustal Deformation Studies Field Report	
APPENDIX III - L-DGO Data Acquisition System	

INTRODUCTION

This progress report covers the work carried out by Lamont-Doherty Geological Observatory personnel during the contract year March 1, 1977 through February 28, 1978. The purpose of this work is to increase our understanding of the seismotectonics of the Aleutian arc and to evaluate a seismic method for delineating a magma chamber. To provide basic data for the studies described herein we have operated an extensive seismograph system and maintained a geodetic levelling program. The levelling program now includes the operation of five mean sea-level meters in the Shumagin Islands.

The ERDA supported seismotectonic and geothermal studies have again been augmented by a closely coordinated, NOAA sponsored study of the seismic hazards to the exploration for and development of petroleum products within the study area. One of the main contributions of the NOAA program to the ERDA work has been the provision of helicopter support for the maintenance of the remote stations.

In the following sections we describe: (1) Seismicity and deformation studies in the Shumagin seismic gap, (2) Studies of the structure of the Aleutian arc, (3) A study of the geothermal potential of Pavlof volcano and (4) The fieldwork and technological development work that supports the science.

SHUMAGIN ISLANDS SEISMICITY

We have continued to locate hypocenters of earthquakes within the Shumagin Islands network (Figure 1). The level of seismicity within this seismic gap region still remains at a low level with the exception of minor clustering of events in the vicinity of the aftershock region of the April 4, 1974 earthquake, southwest of Nagai Island and station (NGI). The map-view of seismicity covering the period July 1973 through April 1977 presented in Figure 2 shows little change from that shown in last year's progress report, covering the period July 1973 to June 1976. A total of about 40 events have been added for the ten-month period July 1976 through April 1977 (Figure 3). Ten months of seismicity for the western, central, and eastern Shumagins is plotted on 3 parallel vertical cross-sections which strike perpendicular to the trend of the island arc (upper half of Figures 4 through 6), and the cumulative seismicity for the entire period July 1973 to April 1977 is plotted on the same cross-sections (lower half of Figures 4 and 6). The new data are fully compatible with the previously observed features in all 3 cross-sections: (1) No events deeper than 200 km have been so far detected; (2) seismicity in the dipping Benioff zone at depths between 40 and 180 km is very well confined to a single, less than 20 km thick zone for the central cross-section, less confined in the eastern cross-section, and widens to a 40-km wide dipping band in the western cross section. This widening is either real and may indicate the existence of a double Benioff zone (Engdahl and Scholz, 1977), or may be artificial and related to the less accurate depth-control for events outside

the central portion of the seismic network. Two events in the eastern section, and three in the central section may also indicate a double Benioff zone. We will analyze the first motion patterns from events that constitute, respectively, the lower and upper family of events, to gain further insight into whether the existence of a double Benioff zone in the Shumagin Islands is real. (3) Above the Benioff zone and beneath the volcanoes very little seismicity occurs. (4) We were not able to detect any shallow seismicity close to the trench; this may be partly due to difficulties in locating events outside the network, but is at least in part also due to a low level of activity at the present, that is for the 4-year period of observation since July 1973.

CRUSTAL DEFORMATION IN THE SHUMAGIN GAP

Mean Sea-Level Meters

The geophysical reasons for measuring sea level using a dense array of instruments are set out in a paper by Bilham (1977) (DOE reference # COO-3134-13). A dense array enables one to average and to difference the signals from nearby instruments. Thus one can remove much of the "noise" signal caused by atmospheric and oceanographic variations, and hence isolate tectonic signals resulting from crustal tilting.

Two sea-level recorders were installed in the Shumagin Islands during the summer of 1975 and these were increased to five during 1976 (Figure 7). Several improvements have been made to the design of the instrument (Figure 8) since the start of the experiment; in particular the measurement of water level in the standpipe at each maintenance visit enables the absolute value of sea level to be obtained, so that the measurement baseline is not lost when instrument breakdowns occur. Reliability has been reasonable for an experimental instrument in a hostile environment; there has been less than 40% down time in the past year. The data obtained between August 1976 and June 1977 are plotted in Figure 9. The top two curves show atmospheric pressure measured on Popof Island and on Simeonof Island, and the remaining four curves show sea level in mm. There are several points to note about the plots. (1) The tides have been filtered by the instrument but no further filtering has been applied. (2) The sea level measured by the instrument has been related to nearby bench marks, so all instrumental drift has been eliminated from the records (an exception to this is the first three months of the SMM record, whose absolute level is unknown). (3) The absolute level of the records has been shifted on the plot simply to reduce overlapping

of traces. (4) The initial filling curve of the instruments is very noticeable both after installation in August 1976 and to a lesser extent after a maintenance visit in November 1976. The time constant of this curve is of the order of 4 days but varies from instrument to instrument.

(5) On most of the records the amplitude of the tide decreases with time. This is due to the instrumental problem that the syphon slowly fills with air exsolved from the sea water under low pressure. A possible remedy to the problem was introduced in June 1977 with the addition of air traps.

(6) There is obvious coherence between the atmospheric pressure and the sea level. Phase differences between air pressure and sea level are due partly to the long time constant of the sea level gauges.

Due to the problems with air in the syphon, the present sea level results are good to only ± 5 mm. However, over a 50 km baseline this corresponds to $\pm 10^{-7}$ radians which is more than an order of magnitude better than the accuracy which has so far been obtained from levelling lines ($\sim \pm 2 \times 10^{-6}$ rads). We are confident that as the air trap problem is solved the instruments will approach their design accuracy of ± 1 mm. The present results indicate an apparent NW-SE tilt of $\sim 4 \times 10^{-6}$ radians over the past year, with the NW end rising, between Simeonof and Popof Islands. Most of the tilt occurs between February and April 1977. However, this result is based on measurements from only three instruments and no oceanographic factors have yet been taken into account. An intermediate reading on Nagai Island would have been very valuable in interpreting these data, but the single instrument there was down for the entire year.

Geodetic Levelling

A north-south 1 km level line was set up at Sand Point, Popof Island in 1972 and has been measured every year since. The line has shown no statistically significant tilt greater than 4×10^{-6} radians since its inception. Figure 10 shows the level line results since 1972. The high value results from 1974 and 1976 can be disregarded as they are more than 2 s.d. above the mean of all the measurements. The mean and s.d. are then 2.0309 ± 0.0043 m; hence, our assertion that there has been no tilt greater than 4×10^{-6} radians. The measurements from 1972, 1975, 1976 and 1977 are considerably more accurate, having a mean and s.d. of 2.0303 ± 0.0017 m. The measurement accuracy should continue to be close to or better than 10^{-6} radians in the future due to the introduction during 1977 of semi-permanent intermediate markers rather than turning points.

A 700 m NW-SE level line was installed at Squaw Harbor, Unga Island in 1972 and has since been remeasured three times (Figure 11). This shows an apparent tilt of 2×10^{-6} rads in 5 years with the tilt up to the NW. This is the same direction as the tilt observed by the sea-level meters, but of much smaller magnitude; this is not necessarily inconsistent since the Squaw Harbor level line is close to the hinge line of the trench where tilts may be expected to be smaller. The Squaw Harbor level line tilt is not substantiated by the results from the Squaw Harbor dry tilt figure (Figure 12 and Table 1) which shows, if anything, an opposite tilt, nor by the Sand Point level line, though, as mentioned above, the noise on this line

has been too high to detect tilts less than a few microradians. Results from the Sand Point dry tilt figure (Figure 13 and Table 2) are confirming.

Additional level lines were installed in June 1977, one north-south at Sand Point airfield, Popof, and one NW-SE on Simeonof Island, closer to the trench axis. The 1100 m line on Simeonof employs fixed bench marks at ~ 70 m spacing so greater accuracy (up to $3 \cdot 10^{-7}$ radians) can be obtained than on the old lines which use temporary intermediate markers. The 1977 Simeonof measurements had a s.d. of 10^{-6} radians.

In summary, we believe that the Shumagin crustal deformation measurements are beginning to show meaningful results. The recent improvements in the level lines and their extension closer to the trench will enable much smaller tilts to be resolved. Initial results from the sea-level meter array are very encouraging but more time and an increase in the size of the array are necessary for a definitive interpretation of the results.

STUDIES OF FOCAL MECHANISMS AND TECTONIC STRESS
ORIENTATION IN THE ALEUTIANS AND MAINLAND ALASKA

We have intensified our seismic focal mechanism studies in the Alaska-eastern Aleutian regions. Two separate studies were carried out. One study is concerned with fault-plane solutions in the subduction zone of the eastern Aleutian arc with emphasis on the Shumagin Islands region, and is a continuation of work previously reported by L. House. The other study, by O. Perez and K. H. Jacob, is concerned with the regional stress pattern in the Gulf of Alaska and central Alaska regions using mostly shallow (crustal) and a few intermediate-depth earthquakes. The latter study is complementary to the work by Nakamura et al. (1977) in which we used volcanic features and fault patterns instead of earthquakes as regional tectonic stress-field indicators. We briefly summarize the results of these two studies, of which preliminary results were presented by L. House and by O. Perez, respectively, during the AGU Annual Meeting in Spring 1977 in Washington, D.C.

Aleutian Arc

Ten new fault-plane solutions were determined for moderate-sized (m_b 5.7 to 6.0) earthquakes which occurred between 1967 and 1974 in the eastern Aleutian arc between 158°W and 170°W, as well as a solution for the western Aleutian earthquake of February 19, 1977. Most solutions, including that for the February 19 earthquake, are similar to those pre-

viously determined for non-trench earthquakes throughout the Aleutians. Those solutions have nodal planes striking NE-SW with one plane steeply dipping to the southeast, the other, shallowly to the NW. This type of mechanism is consistent with the general pattern of mechanisms for earthquakes at subducting margins which lack deep seismicity. However, one earthquake, at a depth of approximately 150 km, had a mechanism completely opposite; the fault planes had nearly the same orientation, but the polarity of first motions was reversed. Other mechanisms had varying nodal plane orientations, but the small scatter of P axis might indicate horizontal compression along the strike of the arc.

These mechanisms suggest a variation in stress orientation within the subduction zone, and provide information about details of the subducting process, particularly in connection with relocation of many of these events. Exact location may reveal differences in stress patterns across the slab at any given depth, which could be related to plastic/elastic unbending during slab subduction.

Eastern Aleutian Arc and Mainland Alaska

Twenty-one new fault-plane solutions (Figure 14) were determined for shallow and intermediate-depth earthquakes in this region. Solutions for shallow foci in the Gulf-of-Alaska region are consistent with thrust motion on shallow-dipping faults whose strike varies from nearly east-west near Kodiak Island to northwest-southeast as one approaches the transform segment of the North American and Pacific plate boundary in the eastern Gulf of Alaska. The

horizontal component of the P-axis for these solutions strikes from N25°W near Kodiak Island to N20°E near the eastern Gulf of Alaska, and is, on the average, parallel to the directions of relative motion between the North American and Pacific plates, assuming a pole of rotation at 50°N, 85°W. These solutions are consistent with the orientation of tectonic stress recently deduced from volcanoes (Nakamura, Jacob and Davies, 1977). Mechanisms for events with intermediate depth beneath the eastern Aleutian arc indicate a strong component of down-dip tension within the descending slab. Single and composite mechanism for shallow events in the Alaskan interior indicate strike-slip motion, and normal faulting near the Seward Peninsula. The stress pattern inferred from these and other existing mechanisms suggests: a) a compressional stress field along the consuming plate boundary with the horizontal component of P-axes-nearly parallel to the direction of relative motion between the North American and Pacific Plates, and northeasterly oriented along the transform segment of the plate boundary in the eastern Gulf of Alaska. b) P- and T-axes become essentially horizontal in Central Alaska. In this region the maximum horizontal stresses are oriented southeast-northwest. c) towards the Seward Peninsula, P-axes become nearly vertical, and T-axes southwest-northeast, indicating an extensional regime.

These two focal mechanism studies almost completely exhaust the teleseismic WWSSN data-set presently available for the eastern Aleutians and continental Alaska. Further focal mechanism studies must either await future moderate to large events or must use local network data for smaller events.

P-WAVE VELOCITY STUDY OF THE ALASKA-ALEUTIAN SUBDUCTION ZONE

The purpose of this ongoing study is to use P travel time residuals for teleseismic and local events to stations along the Aleutian arc and in Alaska, in conjunction with the technique of seismic ray tracing developed by Jacob (1970), to refine velocity models for the crust and upper mantle in the Aleutians-Alaska area, to locate the position of the descending slab in the Gulf of Alaska corner, and to investigate the effect of the slab on transmission of seismic energy. Also, volcanism and volcanic features, if associated with sufficiently large volumes of magma beneath the arc, may affect the transmission of S-waves. Eventually we will incorporate geothermal and gravity data into an integrated analysis with the final goal to make inferences on the dynamics and geochemistry of the Alaska-Aleutian subduction zone.

Rowlett and Jacob (1972) found that P residuals from the nuclear explosions Cannikin, Milrow, and Longshot to stations distributed along the Aleutian arc, Gulf of Alaska, and into central Alaska were earlier than expected by as much as 4-7 seconds in southern Alaska and the Gulf of Alaska. They interpreted these results as due to rays being refracted along the surface of the descending lithosphere, which represents a path of higher velocity than the great circle path in a normal, laterally homogeneous earth. They used the P arrivals from Cannikin to derive a compressional-velocity profile under the Aleutian ridge to a depth of 90 km by assuming flat layers and fitting straight lines through the travel time data.

Jacob and Hamada (1972) used Rayleigh wave dispersion data to derive a shear-velocity model for the upper 150 km beneath the Aleutian ridge.

Jacob (1972) used the technique of three-dimensional ray tracing to interpret the observed pattern of negative P residuals in the Aleutians and Alaska from the nuclear explosion Longshot. He found that rays were refracted along an 80 km-thick slab of lithosphere which descends to a depth of 250 km beneath the Aleutian arc, with an average P velocity 7-10% higher than that of the surrounding mantle.

In the time since these studies were made, many more stations have been installed in the Alaska-Aleutian area as part of local seismic networks. In the light of the new data available, we feel that the time is ripe for a refinement of earlier results.

We are presently using P travel time residuals for teleseismic and local events to all available stations in the Alaska-Aleutian area, in conjunction with three-dimensional ray tracing, to derive a velocity model for the crust and upper mantle beneath the eastern Aleutian arc and Gulf of Alaska, where the behavior of the descending lithospheric slab appears to be more complicated than in the central Aleutians. We also intend to refine models already developed for the central Aleutians.

We have chosen, thus far, approximately 25 well-located teleseismic and local events to determine P residuals for different distances and azimuths, to all available stations (Table 3). Among the teleseismic events we have chosen are six Russian nuclear explosions from the Novaya Zemlya and Semipalatinsk test sites. Nuclear explosions generally are good sources for a residual study because they provide sharp first arrivals (Figure 15) and are usually well located. The local events were located by networks in the central Aleutians (R. Engdahl, CIRES) and Shumagin Islands (Lamont). Other events

were chosen from ISC catalogues. Most of the data are recorded by short-period vertical seismometers and read from develocorder film. Whenever possible, data from the long-period instruments maintained by Lamont at Sand Point (Shumagin Islands), Dutch Harbor (eastern Aleutians), and Saint Paul (Pribilof Islands) are also used. Arrival times are read on short-period records to an accuracy of about 0.05 seconds. Stations in the Alaska-Aleutian area are maintained by Lamont, NOAA, USGS, and the University of Alaska.

Teleseismic residuals are presently obtained by using a relocation program originally developed by Bolt and modified at L-DGO (Sykes 1963), based on the Jeffreys-Bullen travel-time tables, and corrected for the ellipticity of the earth. Residuals for Aleutian events are obtained by a relocation program based on the Herrin (1968) P68 tables.

Figure 16 shows some initial results of residuals from Novaya Zemlya and Semipalatinsk nuclear explosions at NOAA-operated stations. Distances to the epicenters are given in Table 4. As yet no attempt has been made to interpret these residuals in terms of near-surface geologic structures, or to assess possible errors in station locations. However, the unusual residual pattern in the Cook Inlet area may reflect either some deep structures connected with the Benioff zone, or a combination of the former and shallow structures in the Cook Inlet region. Figure 17 shows the residuals obtained by Rowlett and Jacob for the Amchitka nuclear explosions. It appears that rays from Aleutian explosions, which were refracted along the higher-velocity slab, give much more negative residuals than those from the

Russian explosions, which traversed the slab in an upward direction for only a small portion of their total path.

Van Wormer, Davies, and Gedney (1974) report that earthquake magnitudes determined at the NOAA Palmer Observatory are higher than magnitudes reported by the University of Alaska. This effect may be due to the low attenuation of body waves travelling up-dip along a descending piece of lithosphere to the station at Palmer. They also hypothesize a deep-seated structural anomaly in the Yentna River region, which they call the "Yentna River lineament", which may represent a break in the subducting slab. It is too early in our study for us to say whether the positive residuals at station SVW, as compared with the negative ones at PMR and PWA, reflect this structure. If the slab is descending under south-central Alaska, then the rays from Russian explosions at stations GMA, IMA, GIL, and FYU would not be expected to cross any part of the slab, and should not give strong negative residuals. In fact, positive residuals are observed. However, these raw data need further analysis and interpretation to separate the respective contributions from deep and shallow structures.

The work that has been done so far represents only a small portion of the total amount of time expected to be spent on this project. We are presently using P residuals and seismic ray tracing to derive a velocity structure for the slab and crust and upper mantle in the Alaska-Aleutian area, but we intend to incorporate geological and other geophysical data in studying the dynamics of the Aleutian subduction zone.

STUDIES OF LONG-PERIOD SEISMIC DATA

During the past year we continued to collect and prepare data for two studies which utilize data from four long-period seismic stations operated by L-DGO. These stations are Amchitka Island (AMC) (discontinued in 1972), Saint Paul (SNP), Dutch Harbor (DUT), and Sand Point (SDP). Both studies use observations of dispersion of surface waves to derive upper-mantle and crustal velocity structure. For the first study we have selected events whose ray paths to the Aleutian stations traverse the North Pacific. The purpose of this study is to determine the effect of the age of the lithosphere on its velocity structure. For the second study we have selected events whose ray paths to the stations either have great circles along certain Aleutian regions or where the great circles include two Aleutian stations. The purpose of this study is to improve our knowledge of the deep velocity structure of various Aleutian regions, viz., the island arc, the Aleutian basin, the Bering shelf, and the continental arc. The advantage of the circumstance where two stations are included in the great circle ray path is that much of the effect of the source mechanism can be differenced out.

For these studies we have digitized the two sets of events given in Tables 5 and 6. The digital data for an event are normalized in amplitude and sample frequency in preparation for a moving-window measurement of the phase and group velocities. Samples of seismograms thus prepared and re-plotted from the digital data are shown in Figure 18. The next step in processing these data awaits the conversion of computer programs to the format

of L-DGO's new PDP 11/70 computer system.

From the set of events selected for the second study, three have great circle paths which include two stations. The digitized but unnormalized seismograms for these events are shown in Figures 19 through 20.

These studies are being carried out in cooperation with Don Forsyth, formerly of L-DGO and now at Brown University in Rhode Island. Many of the computer programs used in these studies have been developed by him. We intend to complete the first study by the end of this contract period and the second early in the next.

PAVLOF VOLCANO GEOTHERMAL STUDY

A dense, 12 station seismic array was installed on the flanks of Pavlof volcano during the summer of 1976. This array is intended to be used in conjunction with the regional Shumagin Islands array to provide data with which to search for a magma chamber beneath Pavlof. During the past year the Pavlof array has only intermittently produced data and much of that is of poor quality. The reasons for this less-than-satisfactory performance are: (1) An unusually long period of high volcanic activity just after the array was installed, (2) The original design of the project called for only 4 months of data collection, (3) Loss of three stations due to weather. These circumstances were discussed in last year's progress report.

In spite of these generally poor conditions, 533 tectonic events were recorded during the period 1 August 1976 through 18 September 1977. Of these 77 have been classified as good arrivals and 43 have been located. Table 7 gives the date, origin time, source region and data source for these 43 events. Over half were located by the Shumagin Islands array, many by the USGS world-wide network and a few by the CIRES network around Adak Island. The analysis of these data awaits the final determination of the precise coordinates of the stations (see the description of the station survey in the Fieldwork section of this report). A very preliminary analysis of 3 of these events is somewhat encouraging, but leaves many questions unanswered.

In the meantime we have proceeded with the necessary calibrations of the system. Figure 22 shows the frequency dependent magnification of the overall system from seismometer to playback. The information contained in this plot is essential for the determination of magnitudes, and hence b-values. Figure 23 shows the time corrections for the period August through December 1976. These

corrections relate the local time to WWV. They show a linear drift of the local clock. The standard deviation of the individual measurements about the line whose equation is given in the figure is 0.04 seconds. Therefore absolute arrival times can be determined with an accuracy better than 0.1 seconds which is quite adequate for the purposes of the present study. Relative arrival times should be determined with a precision of about 0.05 seconds.

We have initiated two studies using the University of Alaska helicorder data from the regional station, PVV, located on Pavlof volcano. This station was installed in July 1973 and hence has a relatively long time base compared to the stations of the Pavlof array. It will be useful to examine the array data in the context of the longer time frame afforded by PVV.

The purpose of the first study is to accurately measure the activity of Pavlof. The first portion of these data has been plotted in Figure 24. The time period covered, October 1973 through January 1974, includes an eruption. During the eruption more than 2000 events per day were recorded. The events are divided into five classes, depending upon amplitude. These events are tabulated in Table 8. Figure 25 shows b-value plots for four time periods: (1) Pre-eruptive, 16 October to 13 November; (2) High activity, 14-22 November; (3) Post high activity, 23 November 1973 to 1 February 1974; and (4) the total period, 16 October 1973 to 1 February 1974. Table 8 also gives the data used in computing the b-values for these four sets of data. Somewhat surprisingly, the values, 4.78, 4.85, 4.43, and 5.04 are all essentially the same, indicating that the relative frequency of small events compared to large events does not change with time, before, during and after the period of very high activity associated with the eruption.

In the second study we are using tectonic events recorded at PVV to construct a coda-length magnitude scale. This scale will be used to provide uniform estimates of magnitudes for the Shumagin Island region array data. The PVV helicorder has been in operation since the inception of the array whereas the basic recording of the array data has changed from a tape system to a Develocorder system. The advantage of a coda-length magnitude scale is that it is not limited by the dynamic range of the seismograph system. Bandpass requirements usually severely limit the dynamic range of telemetered systems.

Figure 26 is a plot of Richter-type magnitude versus log coda length for about 100 events scaled from the PVV Helicorder record. The Richter-type magnitudes are computed using Richter's method (1958) except that hypocentral distances based on S-P times are used in place of epicentral distances. Also, a frequency-dependent conversion from Wood-Anderson to PVV magnification is used where the frequency is assumed to be a (weak) linear function of distance based on 20 observations from the PVV records. The x's are plotted using PDE magnitudes for some of the larger events. That the PDE magnitudes are close to our magnitudes gives us confidence that our calculations are reasonable. The increase in slope of the magnitude-coda length relation indicated here is a little puzzling. The magnitudes appear to be well determined. The coda lengths for most of the events are more than twice as long as the S-P times and only 3 are less than $3/2$ of the S-P time. So it doesn't seem that the S-P time is contaminating the coda lengths. The portion of the relation for $M < 3.5$ has an approximate slope of 1.95 which is quite similar to slopes obtained by other studies for this magnitude range (2.28, Pennington et al., 1977; 2.00, Lee et al., 1972). More work will be done on this relation before it is adopted.

Figure 27 is a similar plot for the Shumagin Islands array as recorded on the Develocorder. Here the magnitudes and coda lengths are averages for all of the stations recording a given event. The light crosses through the points represent the standard deviation of these averages. The straight heavy line is based on a linear regression of the magnitudes on the logarithm of the coda-lengths. The slope of this line is 1.68. Since the range of this data set is lower than that for Figure 26, this further suggests an increasing slope with increasing coda length. A possible explanation for this curvature has been given by Suteau and Whitcomb (1977). They derive a theoretical relation between magnitude and log coda-length that predicts an increase in slope with log coda length. Evaluation of this suggestion awaits further work.

FIELDWORK

Lamont-Doherty Geological Observatory (L-DGO) maintains an extensive field program in Alaska to provide basic data for seismotectonic studies of the eastern Aleutian arc. This field program now includes: 1) operation of 31 short-period seismic stations, 2) operation of 3 long-period seismic stations, 3) operation of 4 strong-motion accelerograph stations, 4) operation of 5 mean sealevel monitoring stations, and 5) the annual reoccupation of 4, 1-kilometer level lines and 2, 100-meter dry-tilt figures. The locations of these stations and levelling sites are shown in Figure 1.

The stations occupy a triangular region of about $80,000 \text{ km}^2$ in a fairly remote part of Alaska which is known for its difficult weather. Maintenance of the most remote stations is therefore limited to the summer months of June through August. For the past three summers the major portion of the logistic support has been provided by NOAA helicopter crews. Without this support the field program would have to be scaled down. A summary of the stations visited and tasks accomplished with NOAA helicopter support is given in Appendix I.

In addition to the logistic support (and other support for equipment and salaries described above) NOAA, in conjunction with the USGS, provided minimum support for the deployment of four ocean-bottom seismograph (OBS) instruments off Kodiak Island. One of these instruments did not seal properly and was not deployed. Of the three deployed, only one was recovered. Heavy foreign fleet fishing in the region may be the reason; however, instrument malfunction cannot be ruled out. ERDA funds were limited to providing two days of principal investigator time to help get the cruise under way from Kodiak.

Short-Period Seismic Stations

Seventeen seismometers are now recorded at Sand Point. Principal recording is done on the 20-channel Develocorder (16 mm film) with back-up on a 14-channel tape recorder.

The eight remote and three local Shumagin Island region stations have been the most consistently recorded and remain in their original configuration.

The six Cold Bay area stations were VHF telemetered to Cold Bay, transmitted to Port Moller on a phone line and VHF telemetered to Sand Point. This complicated telemetry link suffered from several problems, the most serious of which was icing of the antennas on the path over the mountains of the Alaska Peninsula from Port Moller to Sand Point. To avoid this problem and to simplify the system, these stations are now VHF telemetered directly to Sand Point along the south side of the Peninsula. In the present configuration (see Figure 1) BLH and FPS are transmitted to BAL. The mixed signal from BAL is sent to DRR where SNK is added and then sent to DLG. The six tones are then transmitted to Sand Point via a repeater-only station on Unga Island.

Akutan and Makushin volcano stations continue to be telemetered to Dutch Harbor where they are recorded along with the two local seismometers.

A single station is locally recorded at St. Paul.

The twelve stations of the Pavlof array remain in their original configuration.

Last year an effort was begun to upgrade the physical part of the remote seismic station installation. During the previous field season many of the

antenna guying systems were replaced with stronger ones. This effort paid off as none of the new systems failed and only two of the old systems did. This year we continued this project and carried it one step further. Because of the icing problem experienced at Pavlof and on certain other Alaska Peninsula stations it was decided to install fiberglass shields around the antennas. These shields require even stronger guying systems. Therefore all new station installations and all of the Pavlof stations were fitted with four aluminum, U-channel guy-bars to replace the six guy wires used in the past. This new guying system is much more rigid than the old one. The fiberglass shields were installed only on the north-side Pavlof stations, however, The remaining shields did not arrive until the end of the field season. They will be installed next year.

We will also have to address two other major problems next year. This summer we found three stations flooded, apparently due to snow melt water, and six Pavlof stations destroyed by bears. The flooding problem can be solved fairly easily. The bear problem is more difficult. As a temporary measure, at all of the stations where it was feasible, we buried the equipment in rocks. Many of the amplifiers were ruined beyond field repair. Adding insult to injury a bear also punctured the floats of our helicopter, delaying the work on the Pavlof stations by seven days while they were repaired. As a result, only six of the Pavlof stations could be made operational by the close of the summer field season. A second attempt to rejuvenate some of these stations is underway at this writing. However, the fundamental problem remains: how do we bear-proof these stations? A number of possibilities exist and are being evaluated for implementation next year.

Another problem which was addressed this field season is the determination of station coordinates. For FPS, SNK, ZKB, and all of the Pavlof stations, the only maps available are the 1:250,000 series. It is difficult to determine locations from topography using these maps. For purposes of the regional array they are barely sufficient; for the detailed residuals desired from the Pavlof array they are totally inadequate. Further, it was discovered that the coordinates given for the benchmark on the top of Black Hill (the location of BLH) plotted about 1.5 miles away from the topographic summit as shown on the 1:63,000 series map. Therefore, it was decided to survey the locations of as many stations as possible. Table IV, Appendix I, gives the preliminary results of surveys for the locations of 15 stations. The locations of Black Hill and Sanak Island stations were determined by chaining the distance to the station from a nearby benchmark and determining the azimuth with a magnetic compass. The location of the Zachary Bay station was determined using a tellurometer and sextant based on a benchmark about 6.8 km away. The Pavlof stations were surveyed using a laser geodimeter and theodolite. The northside station locations were based on benchmarks on Black Hill and Trader Mountain; southside, on Bluff Point and Tolstoi Peak. It should be emphasized that these coordinates are preliminary. The only check that has been made is to compare two independent determinations of the location for PN4. The two results are within 6.5 m of one another, indicating quite satisfactory agreement.

Figure 28 is a map of the old (solid circles) and new (crosses) locations of the Pavlof stations. For the northside stations the average new position is 267 m NW of the old position. This is well within the standard deviation of the new positions with respect to the old of 1010 m. There does not seem to be any significant bias of the new positions relative to the old. It should

be noted that in rechecking the old determination for PN2 a plotting error was found so that the disagreement is not as large as it appears in the figure. For the southside stations, the average new position is 862 m SE of the old position. This value is larger than the standard deviation of the new positions with respect to the old of 542 m so there may be a significant bias of the new locations with respect to the old. It is not known at this writing if this is due to an error in data reduction or in the topography upon which the old locations were based. Finally, note that there is a question about the relative position of PS2 based on an arrival time anomaly. These questions will be resolved in the near future.

In spite of the severe problems of Aleutian weather and wildlife, 28 of 35 short-period seismometers were being recorded at the end of the field season. An 80% success rate is reasonably good, but we hope to improve our coverage of Pavlof during the current trip.

Long-Period Seismograph Stations

We continue to operate long-period stations at Sand Point (3 component), Dutch Harbor and Saint Paul. All of these instruments were calibrated as usual with the addition of a direct measurement of the phase response over the period range 5 seconds to 200 seconds. This measurement will be used in an evaluation of the calibration information contained in the step-function pulses which are recorded daily on the records. One salutary effect which was obvious during the course of the calibrations is that the amplitude of the

pulse is strongly dependent upon the natural period of the seismometer.

Thus, this critical parameter will be well determined by the daily calibration pulse.

During the past year very few data were generated at Dutch Harbor due to operator problems. In spite of changing operators several times and many phone calls, we were unable to locate a reliable operator for this station. Eventually it may be necessary to move the Dutch Harbor recording center across the bay to the village of Unalaska. On the current field trip several potential operators in Unalaska will be interviewed with this possibility in mind.

Strong-Motion Stations

There are five strong-motion accelerographs in operation in the eastern Aleutians (see Figure 1). Four are maintained by L-DGO (DUT, CPS, SDP and PMA) and one by the USGS (Cold Bay). During the past year none of these instruments was triggered. Calibration signals were recorded on all of the L-DGO instruments during the past summer. Consult last year's annual report or USGS open file report no. 77-374 for site descriptions and coordinates.

Mean Sea-Level Monitoring Stations

By last summer five mean sea-level monitoring stations were in place. These stations have been described by Bilham (1977) and their locations are shown in Figure 7. During the period September 1976 through June 1977, SDP

operated September and October, PRC and SMH operated the whole period, SMW operated November through June, and EGH only operated for two weeks. The overall operation rate was 61%, which is reasonable for an experimental system in the Aleutian environment.

Several improvements in instrumental design were made this summer. Electronic clocks and multiplexing circuitry replaced the mechanical clocks used last year. The multiplexing capability will allow up to 4 signals to be recorded on the minigraph recorders. A toothed cable replaced the wire float cable. This eliminates worry that over time the wire might slip on its pulley causing an apparent change in mean sealevel. An air trap is intended to eliminate the problem caused by air exsolving from the seawater in the inlet tube. At all stations the water levels were measured with respect to the standpipes and the standpipes were releveled with respect to benchmarks located in nearby bedrock. By making these absolute measures of water level whenever the sites are visited any instrument drift can be detected and accounted for. A more detailed report of this summer's fieldwork on the mean sealevel meters is given in Appendix II.

Levelling Measurements

In 1972 L-DGO personnel established 1 km level lines and 100 m dry tilt figures on Popof and Unga Islands. These lines and figures have been re-occupied each summer since then. During the past summer permanent intermediate turning points were emplaced along most of the Popof level line. These turning points allow faster surveying and the possibility to recheck

questionable readings without resurveying the entire line.

This summer new level lines were established on Popof Island (800 m) and Simeonof Island (1100 m). The Popof line is along the airstrip. The levelling path is essentially flat so the line can be surveyed in about 1/2 the time of the original Popof line which traverses a deep valley. The Simeonof line is along the coast and employs brass cap turning points cemented into bedrock and spaced at about 70 m intervals. This line may be the most valuable of all because it is farther from the expected hinge line for tilt during a great earthquake.

Most of the work (excluding the OBS project) was carried out during June and August by the following L-DGO personnel:

Dr. John Davies, principal investigator

Dr. John Beavan, project scientist

Mr. Leigh House, graduate student

Ms. Janet Krause, graduate student

Mr. Laszlo Skinta, electronics technician

Mr. Michael Hambruger, field assistant

Mr. Phil Lelyveld, field assistant

Ms. Dee Breger, field assistant.

The total person-months required were 11.5. The actual effort was larger than this indicates because a typical day lasted 10 hours and weekends were ignored. To the effort of the L-DGO personnel must be added that of the NOAA helicopter pilots and mechanics without whom this volume of work would have been impossible.

In sum, the fieldwork involved maintaining or establishing 34 short-period and 5 long-period seismographs, 4 strong-motion accelerographs, 5 mean sealevel meters and 5 geodetic figures. The work was dispersed over 34 remote sites and 4 recording centers which range from St. Paul in the Pribilof Islands, through Dutch Harbor on Unalaska Island and Sand Point in the Shumagin Islands, to Port Moller on the Alaska Peninsula.

PERSONNEL

We had proposed to hire an electronics engineer during the past contract year. This engineer was to have addressed several technical problems associated with data collection in remote regions like the Aleutian arc. Among these problems were remote control of pre-telemetry gain and satellite data transmission.

During the past year the technical operation of seismic networks at L-DGO has undergone a significant managerial change. All of the networks have been brought under the supervision of a newly hired engineer. The purpose of this consolidation is to make more efficient use of the technical staff which had been spread over several projects, to take more full advantage of economies possible through standardization of equipment and to better learn from the varied experience of those working on the several projects.

Also during the past year, advances in hardware and software in digital data acquisition systems and the possibility of obtaining some or all of such a system from the USGS has forced a change in our priorities. These developments coupled with continuing severe problems with our data recording systems at Sand Point, Dutch Harbor and Port Moller have led us to identify a microprocessor controlled, event recording system as our first technical development priority. The main features of this proposed system are summarized in Appendix III. This system would increase the reliability of collecting data and speed the reduction of the data through automation. The technology developed for this system will be directly useful in the next step, which is to couple the event detector with the computer with a satellite link. There-

fore we have channeled our salary support for engineering into the technical management position and development of the digital event recording system.

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TABLE 1

SQUAW HARBOR DRY TILT FIGURE

Heights in mm of first named benchmark relative
to second

	B-A	C-B	A-C
1972	1460.1 $\pm$.1		-358.9 $\pm$ 4.6
1975	1459.8 $\pm$.1	-1103.7 $\pm$.1	-356.4 $\pm$.1
1976	1459.8 $\pm$.1	-1103.9 $\pm$.5	-357.1 $\pm$.3
1977	1459.9 $\pm$.1		-359.2 $\pm$.4

TABLE 2

SAND POINT DRY TILT FIGURE

Heights in mm of first named benchmark
relative to second

	1-B	2-B	3-B	4-B	5-B
1972	322.3 $\pm$.1	-192.5 $\pm$.1*	-1068.8 $\pm$.4	-238.3 $\pm$.3	
1973	323.9 $\pm$.1	-192.5 $\pm$.3*	-1069.4 $\pm$.3	-237.6 $\pm$.3	
1974	326.5 $\pm$.2	-179.4 $\pm$.2*	-1070.4 $\pm$.2	-238.4 $\pm$.2	
1975	325.1 $\pm$.2	-180.4 $\pm$.3*	-1070.4 $\pm$.1	-239.0 $\pm$.3	283.4 $\pm$.2
1976	324.9 $\pm$	-182.7 $\pm$	-1069.9 $\pm$	-239.0 $\pm$	283.6 $\pm$.1
1977	324.0 $\pm$.3	-182.5 $\pm$.3	-1072.1 $\pm$.9	-239.7 $\pm$.4	282.9 $\pm$.5

*Benchmark 2 was found to be loose while making the 1975 measurements.

TABLE 3. EVENTS CHOSEN FOR P RESIDUAL DETERMINATIONS

Local events	O.T.	Lat.	Long.	m_b	Depth (km)	Source
1972 7/30	21:45:14.1	56.83	-135.69	6.5	25.0	(ISC)
1973 7/01	13:33:34.7	57.85	-137.33	6.1	33.0	(ISC)
8/22	18:14:37.3	57.07	-154.11	5.9	38.0	(L. Huppert)
1974 4/06	03:56:01.9	55.13	-160.45	6.0	40.0	(L-DGO)
8/13	03:46:19.87	51.149	-177.869	5.8	14.94	(Engdahl)
1975 7/25	10:40:25.1	55.06	-160.38	5.8	17.0	(L-DGO)
1976 8/16	05:11:36.7	51.17	-178.38	5.1	39.82	(Engdahl)
8/28	02:30:09.9	52.19	-174.98	5.1	137.95	(Engdahl)
1977 6/29	08:47:14.64	51.409	-176.128	5.5	23.1	(Engdahl)
Teleseismic events						
1971 2/09	14:00:41.6	34.41	-118.40	6.1	13.0	(San Fernando)
1972 9/16	09:14:34.6	15.25	- 96.23	6.0	33.0	(Central America)
(explosion)						
8/26	03:46:56.8	49.94	77.81	5.3	0	(Semipalatinsk)
(explosion)						
9/02	01:26:57.8	49.91	78.85	6.1	0	(Semipalatinsk)
(explosion)						
12/10	04:27:07.6	49.97	78.95	6.0	0	(Semipalatinsk)
1973 10/18	10:49:37.6	19.39	-104.98	6.0	45.0	(Mexico)
9/10	07:43:32.3	42.48	131.05	5.8	55.22	(deep Kurile)
(explosion)						
9/12	06:59:54.6	73.32	54.97	6.8	0	(Novaya Zemlya)
(explosion)						
10/27	06:59:57.6	70.8	53.92	6.9	0	(Novaya Zemlya)
1974 7/13	01:18:22.9	7.76	- 77.7	6.4	12.0	(Panama/Colombia border)
1975 9/11	21:59:57.3	7.00	-104.28	6.4	33.0	(off Central America)
(explosion)						
10/18	08:59:5	70.8	53.72	6.7	0	(Novaya Zemlya)
1976 7/11	16:54:31.9	7.34	- 78.48	6.3	22.0	(Colombia)

TABLE 4

Distances to Selected NOAA Stations and Residuals for 3 Soviet Nuclear Explosions

Novaya Zemlya 9/12/73			Novaya Zemlya 10/27/75		Semipalatinsk 8/26/72	
lat = 73.32°N long = °E			lat = 70.80°N long = 53.92°E		lat = 49.94°N long = 77.81°E	
Epicenter J-B residual			Epicenter J-B residual		Epicenter J-B residual	
Distance			Distance		Distance	
Station	(Δ) (degrees)	(seconds)	(degrees)	(seconds)	(degrees)	(seconds)
GMA	39.45	+0.86	41.92	+0.84	56.34	+0.14
IMA	39.51	+1.21	42.03	+1.22	57.75	+0.09
GIL	41.15	+1.70	43.69	+1.65	60.16	-0.10
TTA	42.44	+1.06	44.93	+0.79	-	-
SVW	44.26	+1.33	46.75	+1.10	61.30	+0.80
TOA	44.10	+1.23	46.64	+1.19	62.95	-0.13
PMR	44.38	-0.25	46.91	-0.24	62.66	-1.23
PWA	44.38	-0.85	46.91	-0.84	62.66	-2.63
PMS	44.69	+0.43	47.22	+0.42	-	-
SIT	49.72	+1.20	52.28	+0.98	-	-
MID	46.74	+1.54	49.27	+1.15	-	-
KDC	47.88	-0.27	50.38	-0.14	64.98	-0.43
PMA	48.73	+0.55	51.16	+0.12	-	-
NIK	50.48	-1.34	52.80	-2.11	-	-
ADK	50.21	-1.64	52.41	-1.97	60.59	-0.62
SMY	47.60	-1.05	49.63	-1.54	-	-
FYU	-	-	42.28	+1.75	-	-

TABLE 5

Pacific Ray Paths

Year	Day	Region	Station
1970	Aug 11	New Hebrides Region	Amchitka
	Sep 29	New Hebrides Region	Amchitka
	Nov 2	Fiji Islands Region	Amchitka
	Nov 12	East New Guinea	Amchitka
	Dec 2	Solomon Islands	Amchitka
1972	Aug 30	North Coast of New Guinea	Amchitka
	Sep 5	New Hebrides Islands	Amchitka
	Sep 9	Tonga Islands	Amchitka
1973	Dec 30	New Hebrides Region	Sand Point
1974	Mar 14	New Hebrides Islands	Sand Point
	May 7	Fiji Islands Region	Sand Point
	Aug 23	N. Easter Is. Cordillera	Sand Point
	Sep 12	Off Coast of N. California	Sand Point
	Nov 10	Fiji Islands Region	Sand Point
1975	Apr 20	South Pacific Ocean	Sand Point
	May 10	Coast of Chile	Sand Point
	Oct 6	Santa Cruz Islands	Dutch Harbor
	Dec 9	Samoa Islands Region	Sand Point
1976	May 23	New Ireland Region	Sand Point
	Oct 5	New Britain Region	Sand Point

TABLE 6

Aleutian Ray Paths

Year	Day	Region	Station
1973	Dec 29	New Hebrides Region	SDP
	Dec 29	Komandorsky Islands	SDP
1974	Aug 7	Kodiak Island	SNP
	Aug 20	Rat Islands	SDP
	Sep 12	Off Northern California	SNP
	Sep 13	Near Kamchatka	SDP
	Sep 13	Near Kamchatka	SNP
	Oct 12	Kodiak Island	SNP
	Nov 11	Andreanof Islands	SDP
1975	Oct 17	Gulf of Alaska	DUT
	Oct 17	Gulf of Alaska	SDP
1976	Sep 15	Komandorsky Islands	SDP
	Sep 15	Komandorsky Islands	SNP
	Oct 22	Kodiak Island	SDP

TABLE 7

Located Events Detected by the Pavlof Array

Date	Origin Time	Region	Data Source*	Date	Origin Time	Region	Data Source*
22 Aug 76	0201	Cook Inlet	PDE	25 Oct 76	0636	Shumagin Is.	L-DGO
31 Aug 76	0104	Shumagin Is.	L-DGO	25 Oct 76	1110	Kodiak Is.	PDE
1 Sep 76	0411	Shumagin Is.	L-DGO	25 Oct 76	1506	Shumagin Is.	L-DGO
3 Sep 76	0544	Shumagin Is.	L-DGO	26 Oct 76	0104	Alaska Penin.	PDE
3 Sep 76	1012	Shumagin Is.	L-DGO	30 Oct 76	1937	Shumagin Is.	L-DGO
5 Sep 76	1033	Andreanof Is.	CIRES	8 Nov 76	0025	Shumagin Is.	L-DGO
5 Sep 76	1412	Shumagin Is.	L-DGO	10 Nov 76	1240	Shumagin Is.	L-DGO
8 Sep 76	1752	Shumagin Is.	L-DGO	11 Nov 76	0547	Shumagin Is.	L-DGO
11 Sep 76	0719	Shumagin Is.	L-DGO	16 Nov 76	1208	Shumagin Is.	L-DGO
11 Sep 76	0240	Andreanof Is.	PDE	18 Nov 76	2227	Shumagin Is.	L-DGO
11 Sep 76	1412	Shumagin Is.	L-DGO	26 Dec 76	1447	Shumagin Is.	PDE
11 Sep 76	1815	Shumagin Is.	L-DGO	6 Jan 77	1602	Andreanof Is.	CIRES
15 Sep 76	1000	Shumagin Is.	L-DGO	13 Feb 77	0551	Kamchatka	PDE
17 Sep 76	0411	Shumagin Is.	L-DGO	19 Feb 77	2234	Near Islands	PDE
22 Sep 76	0230	Andreanof Is.	CIRES	20 Feb 77	0702	Kodiak Is.	PDE
25 Sep 76	1551	Shumagin Is.	L-DGO	21 Feb 77	2003	Alaska Penin.	PDE
25 Sep 76	1926	Shumagin Is.	L-DGO	2 Mar 77	2311	Kamchatka	PDE
17 Oct 76	1933	Shumagin Is.	L-DGO	8 Mar 77	1636	Shumagin Is.	L-DGO
18 Oct 76	0714	Shumagin Is.	L-DGO	9 Mar 77	1435	N. Korea	PDE
22 Oct 76	1835	Kodiak Is.	PDE	15 Mar 77	1103	Rat Islands	PDE
23 Oct 76	0825	Fox Island	PDE	20 Mar 77	1347	Shumagin Is.	L-DGO
24 Oct 76	0418	Shumagin Is.	L-DGO				

*PDE: U. S. Geological Survey Preliminary Determination of Epicenters.

L-DGO: Lamont-Doherty Geological Observatory telemetered seismic network, Shumagin Islands region.

CIRES: Cooperative Institute for Research in Environmental Sciences, telemetered seismic network, Adak Island (Robert Engdahl, personal communication)

TABLE 8

Summary of B-Value Calculations for the November 1973 Eruption of Pavlof Volcano

Volcanic seismicity by amplitude, for events recorded at PVV, October 1973-February 1974. Magnitudes are calculated assuming a source directly beneath the volcano at 5 km depth. Bottom figures in each class are cumulative total of events for that time period. Counts are derived from daily totals normalized to a 24-hour period. A- and b-values for each time period are determined graphically from Figure 25.

Amplitude (min zero-peak)	Magnitude (m)	Pre-Eruptive (16 Oct-13 Nov 73)	High-Activity (14-22 Nov 73)	Post-High Activity (23 Nov 73-1 Feb 74)	Total (16 Oct 73-1 Feb 74)
< 2.5	-0.03-1.07	1.0	6.0	0.0	7.0
		1.0	6.0	0.0	7.0
2.5 - 5	1.07-1.37	8.0	82.1	0.0	90.1
		9.0	88.1	0.0	97.1
5 - 7.5	1.37-1.55	57.6	1134.5	10.6	1202.7
		66.6	1222.6	10.6	1299.8
7.5-10	1.55-1.67	744.8	4172.1	218.9	5135.8
		811.4	5394.7	229.5	6435.6
> 10	> 1.67	4368.7	5382.7	10576.8	20319.2
		5180.1	11777.4	10806.3	26754.8
b-value		4.78	4.85	4.43	5.04
A-value		1.33×10^8	1.53×10^9	1.19×10^7	3.30×10^9

FIGURE CAPTIONS

- Figure 1. Map of seismic station locations. The following abbreviations appear in the legend: SP, short-period; LP, long-period; SMA, strong-motion accelerograph; NOAA tsunami warning, stations of the Alaska-wide tsunami-warning network recorded in Palmer, Alaska, by the National Oceanic and Atmospheric Administration. The Shumagin network consists of those stations within the triangle formed by PVV, IVF and CNB.
- Figure 2. Epicenter map of earthquakes that have occurred within the Shumagin gap during the period July 1973 through April 1977. Epicenters are marked by numbers that give the depth of the event in kilometers. The locations of the seismic stations used to locate these earthquakes are marked by three-letter codes as given in Figure 1. The three dashed rectangles labeled "W", "C", and "E" delimit the surface projections of the respective volumes from which hypocenters were projected to form the cross-sections shown in Figures 4, 5, and 6.
- Figure 3. Epicenter map for the period July 1976 through April 1977. Details same as Figure 2.
- Figure 4. Western hypocenter cross-sections for the period July 1976 through April 1977 (upper section) and July 1973 through

April 1977 (lower section). The location of this section is shown by the dashed box labeled "W" in Figure 2.

Figure 5. Central hypocenter cross-sections for the periods July 1976 through April 1977 (upper section) and July 1973 through April 1977 (lower section). The location of this section is shown by the dashed box labeled "C" in Figure 2.

Figure 6. Eastern hypocenter cross-section for the periods July 1976 through April 1977 (upper section) and July 1973 through April 1977 (lower section). The location of this section is shown by the dashed box labeled "E" in Figure 2.

Figure 7. Mean sea-level meter locations: Sand Point (westernmost) and Pirate Cove on Popof Island, Eagle Harbor on Nagai Island, and Simeonof West and Simeonof Harbor on Simeonof Island. Simeonof Island is approximately midway between the volcano trend line and the trench.

Figure 8. Mean sea-level meter design. (A) Complete instrument configuration showing: 1) Inlet tube. Seaward end is anchored above the sea bottom and below lowest low tide, a copper-mesh filter inhibits algae growth in and around the end of the tube. 2) Capillary tube filter. This low-pass mechanical filter has a time constant of about 80 hours. It reduces the tidal amplitude in the standpipe by a factor of 20. 3) Standpipe assembly. The float/weight is attached to a 360° potentiometer gear by an

invar wire and low-temperature-constant plastic chain. The float position is recorded once an hour on a Minigraph recorder in the instrument head. The recording system will operate for more than a year on internal D-cells. (B) Water level is scaled to the top of the standpipe which is in turn referred to benchmarks in nearby rock outcrops. This procedure allows the elimination of any instrumental drift. (C) Detail of air trap and micropore filter (replaces capillary filter in newer models). Trap collects air exsolved from the seawater in the inlet tube.

Figure 9. Mean sea-level meter data. Bottom four traces are the sea-level data from stations Sand Point (SDP), Private Cove (PRC), Simeonof Harbor (SMH), and Simeonof West (SMW). Absolute levels are arbitrary.

Figure 10. Sand Point level-line data, 1972-1977. Annual results of levelling surveys using a Zeiss Ni-II automatic level are shown. The heights plotted are those of the south end of the level line (benchmark L-DGO 1971) relative to the north end (benchmark B of the dry tilt figure). These values are positive, indicating that the south end is higher than the north.

Figure 11. Squaw Harbor level-line data, 1972-1977. Annual results of leveling surveys using a Zeiss Ni-II automatic level are shown. The heights plotted are those of the NW end of the level line

(benchmark A) relative to the SE end (benchmark L). These values are positive indicating that the NW end is higher than the SE.

Figure 12. Squaw Harbor dry-tilt data, 1972-1977. Technique and sign convention same as for level lines. Relative positions of the benchmarks A, B and C are shown in the upper right corner.

Figure 13. Sand Point dry-tilt data, 1972-1977. Technique and sign convention same as for level lines. Relative positions of the benchmarks, B, 1, 2, 3, 4 and 5 are shown in the upper right corner.

Figure 14. Alaskan fault-plane solutions. Stereographic projections of the pattern of first motions for 21 earthquakes are shown for the lower half of the focal sphere. The shaded portion of the projection corresponds to compressional first motions. The directions of the implied compressional and tensional stress axes are indicated by the points labeled "P" and "T", respectively. Note that only one projection is given for very similar solutions obtained for two earthquakes located just outside of Cross Sound (58°N and 138°W). The stress field orientation derived from this data set is fully compatible with that reported by Nakamura, Jacob and Davies (1977) which was based on

volcanic and fault patterns only. Nine of these solutions were reported previously in the 1976/1977 progress report.

Figure 15. First arrivals to five NOAA-operated stations in Alaska for the Novaya Zemlya nuclear explosion of September 12, 1973. Note the sharpness of the first arrivals. Where the expected arrival precedes the picked arrival, the residual is positive. A positive residual indicates that the corresponding ray arrived at the station later than it would have, had it followed a "normal" path through a laterally homogeneous earth. Where the picked arrival precedes the expected, the residual is negative, and the ray is inferred to have followed a path of higher velocity.

Figure 16. P-residuals, using a Jeffreys-Bullen earth model, for three Soviet nuclear explosions to NOAA-operated stations in Alaska and the Aleutians. Positive residuals indicate that the first arrival was later than expected; negative residuals indicate early first arrivals. A blank indicates that the event was not recorded at that station.

The slightly negative residuals of some stations may indicate that the corresponding rays traversed the high-velocity clipping slab for only a small portion of their total path. Positive residuals at other stations may indicate that the corresponding ray path did not intersect the clipping slab at all.

- Figure 17. P-residuals, using a Jeffreys-Bullen earth model, for the nuclear explosions Cannikin, Milrow, and Longshot, detonated on Amchitka Island (Rowlett and Jacob, 1972). All residuals in this figure are negative. Rowlett and Jacob inferred from the early arrivals that the rays were being refracted laterally along the high-velocity dipping slab.
- Figure 18. Digitized and normalized records from three L-DGO Aleutian long-period seismograph stations: AMC, Amchitka, DUT, Dutch Harbor; and SDP, Sand Point.
- Figure 19. Surface waves recorded at two Aleutian stations along the same great-circle ray-path. The September 13, 1974 earthquake near Kamchatka was recorded at Saint Paul (SNP) and Sand Point (SDP). The traces are reproduced from a digital data file.
- Figure 20. Same as 19 for the 7 October 1975 earthquake in the Gulf of Alaska and recorded at Sand Point (SDP) and Dutch Harbor (DUT).
- Figure 21. Same as 19 for the 15 September 1976 earthquake in the Komandorsky Islands.
- Figure 22. Frequency dependent magnification of Pavlof seismograph system, based on calibration of 14 March 1977. Seismometer response was calculated from instrumental constraints. Sine-wave input

to tape recorder from Wavetek function generator. OAS tape recorder gain, 18 db; filter, 56 Hz low-pass; Crown playback recorder gain, 6 L-DGO units; tape speed, 15/32 ips, Siemens ink-jet playback system gain 3 V/cm. Dashed line indicates system response with OAS tape recorder filter at 25 Hz (low-pass), all other parameters identical.

Figure 23. Time corrections for the Pavlof seismograph system August-December 1976. The time correction is the difference between the local clock and the Coordinated Universal Time broadcast by the National Bureau of Standards radio station WWV or WWVH. Each correction plotted is the average of 4-10 measurements. The error bars represent one standard deviation. The standard deviation of the corrections about the regression line shown in the figure is 0.04 seconds.

Figure 24. Histogram of Pavlof volcano seismicity, from PVV helicorder records, October 1973 to February 1974. Daily seismicity is normalized to a 24-hour period. Eruption of volcano began at 0800 14 November 1973.

Figure 25. Volcanic seismicity vs. magnitude for events recorded at PVV, October 1973 to February 1974. Eruption of volcano occurred at 0800 13 November 1973. The average b-value, determined graphically, for the four time periods shown, is 4.78. A-value for the total period is 3.30×10^9 .

Figure 26. Coda-length magnitude plot from the Pavlof helicorder records, October 1973 to 26 February 1974. Crosses denote magnitudes from the Preliminary Determination of Epicenters Bulletins of the USGS. Queried points indicate earthquakes for which the S-P time is uncertain.

Figure 27. Coda-length magnitude relation from Develocorder records. Average Richter-type magnitudes are plotted against the average of the logarithm of the coda length in seconds for each earthquake. The light cross through each point represents one standard deviation about the averages. The straight line is based on a linear regression of the magnitudes against the coda lengths. The equation of this line is given in the upper left corner of the figure. The curved lines indicate the 3-standard-deviation limit of the points about the straight line.

Figure 28. Locations of stations of the Pavlof seismograph array. Solid circles indicate original locations. Crosses show locations based on this summer's surveys.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

SQUAW HARBOR DRY TILT FIGURE

Figure 12

Figure 13a

SAND POINT DRY TILT FIGURE page 2 of 3.

Figure 13b

SAND POINT DRY TILT FIGURE

page 3 of 3.

Figure 13c

Figure 14

$m_b = 6.8$

Figure 15

Figure 16

Figure 17

AMC 30 AUG 1972 10:54

OUT 06 OCT 1975 22:52

SDP 9 DEC 1975 09:44

Figure 18

SEP 13, 1974
NEAR KAMCHATKA

Figure 19

OCT 17, 1975
GULF OF ALASKA

Figure 20

SEP 15, 1976
KOMANDORSKY ISLANDS

Figure 21

Figure 22

Figure 23

PAVLOF VOLCANO SEISMICITY

Figure 24

Figure 25

Figure 26

Figure 27

Figure 28

APPENDIX I

SUMMARY OF HELICOPTER OPERATIONS

June and August, 1977

John N. Davies
Chief Scientist, Principal Investigator

RU #16

Lamont-Doherty Geological Observatory
of Columbia University
Palisades, New York 10964

Introduction. The work described in this report is in support of a project of Lamont-Doherty Geological Observatory of Columbia University. This project is entitled, "A seismotectonic analysis of the seismic and volcanic hazards in the Pribilof Islands - eastern Aleutian Islands region of the Bering Sea" (Contract no. NOAA 03-5-022-70). The purpose of this project is to monitor earthquake and some volcanic activity in this region to provide basic data for evaluating the seismic and volcanic hazards to petroleum exploration. To monitor this activity requires the maintenance of seismograph stations. Essential logistic support for the maintenance of these stations was provided by NOAA helicopter crews. Following is a brief summary of the tasks accomplished during June and August 1977 with the aid of NOAA helicopters.

Remote Island Stations. Some of the remote island stations were far enough from shore that the ship-based Bell 206 was used. Leg I of cruise RP4-SU-77B of the NOAA ship Surveyor was partially devoted to the maintenance of four of these stations. The stations, Sanak Island, Nagai Island, Big Koniuji Island, and Chernabura Island were serviced during the first two days of the cruise, thanks to good weather and the willingness of the ship's personnel to work long hours. Since this portion of the work was carried out with such dispatch, it was decided that the seismic crew would stay aboard during the hydrographic work in Pavlof Bay in the hope that several more stations in that vicinity might be serviced as time permitted. Unfortunately, weather and

TABLE I

Stations Serviced Using Ship-Based Bell 206

L-DGO personnel: John Davies, Chief Scientist
Mike Hamburger, Field Assistant

Embarkation: Cold Bay, June 10

Disembarkation: Sand Point, June 16

Station	Code	Tasks/Comments
Sanak Island	SNK	Replaced electronics and batteries. Chained distance from benchmark.
Nagai Island	NGI	Replaced batteries. Helo fuel leak; began in Boston whalers, finished with helo.
Big Koniuji	BKJ	Replaced batteries. Delayed by helo fuel leak.
Chernabura	CNB	Repaired station, replaced batteries.
Zachary Bay	ZKB	Repaired seis. cable, replaced batteries, removed amplifier for repair. Ship's survey crew surveyed station location with sextant and tellurometer from benchmark. Helo fuel leak forced use of Boston whalers.

TABLE II

Stations Serviced Using Sand Point Based UHIH

L-DGO personnel: John Davies, Chief Scientist
 Laszlo Skinta, Electronics Technician
 Janet Krause, Graduate Student
 Philip Lelyveld, Field Assistant
 Mike Hamburger, Field Assistant

Beginning: Sand Point, June 18

Finish: Sand Point, June 27

Station	Code	Tasks/Comments
Squaw Harbor	SQH	Replaced batteries, removed Nagai receiver to repair. Returned later to replace receiver.
Zachary Bay	ZKB	Replaced amplifier removed with 206.
Balboa Bay	BBB	Removed station.
Herendeen Bay	HNB	Removed station.
Pavlof volcano	PVV	Replaced batteries.
Ivanof Bay	IVF	Replaced batteries.
San Diego Bay	SGB	Replaced batteries, repaired antennae.
Black Hill	BLH	Replaced batteries, removed PR1,2 electronics. Chained distance from benchmark.
False Pass	FPS	Replaced batteries.
Cape Sarichef	CPS	Checked strong-motion accelerograph.
Akutan	AKN	Replaced batteries.
Makushin	MKN	Replaced batteries, Akutan receiver noisy, chartered commercial helo to return later.
Deer Island	DRR	Replaced batteries, installed new electronics. Returned to balance signals after adjusting SNK transmitter.
Sanak Island	SNK	Adjusted transmitter.
Dolgoi Island	DOL	Removed Station.
Dolgoi Island	DLG	Installed new station, batteries
Coal Harbor R.	CHR	Installed new repeater staion, batteries.

TABLE III

Pavlof Stations Serviced with the UHIH and 206-B

L-DGO Personnel: John Davies, Chief Scientist
 Laszlo Skinta, Electronics Technician
 Leigh House, Graduate Student
 Janet Krause, Graduate Student
 Mike Hamburger, Field Assistant

UHIH

Beginning: Port Moller, August 10
 Finish: Port Moller, August 15

206-B

Beginning: Cold Bay, August 22
 Finish: Cold Bay, August 29

Station	Code	Tasks/Comments
Pavlof North 1-8	PN1-8	Replaced batteries, transmitters and antennas. Repeat visits were necessary at all except 2 and 3.
Pavlof Repeater 1-2	PR1-2	Replaced batteries, receivers, and antennas, added extra batteries, installed shell for potential south side repeater. Due to volume of work several trips were required.
Pavlof South 1-4	PS1-4	Replaced batteries. All sites were revisited to replace repaired equipment.
Pavlof Repeater 3	PR3	Replaced batteries. Revisited once to repair and once to tune.

fuel leak problems forced the curtailment of helicopter operations so no stations could be serviced during the hydrographic work.

Shumagin, Cold Bay and Dutch Harbor Stations. Two days after disembarking from the Surveyor, the Lamont party was met at Sand Point by the UH1H helicopter. During the next ten days the remaining Shumagin Island stations, the Cold Bay area stations and the Dutch Harbor area stations were serviced. For the majority of this time the helicopter was based in Sand Point. However, several nights were spent at Cold Bay and one at Cape Serichef. Some 100-hour maintenance work was done at Cold Bay. During this time L-DGO personnel serviced the Baldy Mountain station by truck. This segment of the field work went very smoothly.

Pavlof Volcano Stations. L-DGO personnel met the UH1H at Port Moller on the 10th of August. In addition to replacing batteries at all of the stations we reguied all of the antennas, changed all of the north-side transmitters to UHF from VHF and surveyed in each of the stations. In previous years, we had had problems with the guy wires loosening and breaking. This summer we began replacing the old guy wires with rigid, aluminum U-channel. The result was a much more sturdy antenna mast. It is hoped that this will eliminate the loss of data due to failure of the antenna. The UHF antenna can be purchased with a fiberglass shield around it. The installation of these shielded antennas should eliminate loss of signal due to icing of the antennas. In additon, the UHF receivers were of higher quality than the VHF ones so it is hoped that mixing noise will be reduced at the repeater stations. Some portions of the USGS maps of the Pavlof vicinity have been found to be in error by more than a mile. It was therefore necessary to determine the loca-

TABLE IV

Station Coordinates

Preliminary results of surveys made during June-August, 1977

Station	Code	N. Latitude	W. Longitude	Elevation
Black Hill	BLH	55°42.15'	162°03.95'	390 m
Sanak Island	SNK	54°28.44'	162°46.52'	159 m
Zachary Bay	ZKB	55°18.66'	160°44.43'	183 m
Pavlof South-1	PS1	55°25.34'	161°44.18'	300 m
Pavlof South-2	PS2	55°24.40'	161°48.15'	459 m
Pavlof South-3	PS3	55°23.51'	161°49.02'	450 m
Pavlof South-4	PS4	55°21.23'	161°52.08'	520 m
Pavlof Volcano	PVV	55°22.45'	161°47.40'	164 m
Pavlof North-1	PN1	55°33.628'	161°57.118'	522 m
Pavlof North-2	PN2	55°30.482'	161°58.177'	344 m
Pavlof North-3	PN3	55°30.353'	162°00.495'	330 m
Pavlof North-4	PN4	55°28.819'	162°01.369'	434 m
Pavlof North-5	PN5	55°28.487'	161°53.524'	622 m
Pavlof North-6	PN6	55°27.118'	161°54.888'	814 m
Pavlof North-7	PN7	55°26.591'	161°56.781'	780 m
Pavlof North-8	PN8	55°26.623'	162°01.246'	605 m

tion of the stations by triangulation and trilateration from nearby benchmarks. In Table IV the new coordinates for these stations are given, along with those determined earlier for Black Hill, Sanak Island, and Zachary Bay.

The Pavlof portion of the summer's work had more than its share of the problems. Many days were lost in mid-August due to weather. Then in late August a week was lost because a bear clawed off the rear end of both floats of the UHIH. Bears had also damaged 6 of the 12 seismic stations, necessitating field repair of some of the electronics because spares were exhausted. In spite of these problems, all of the stations were eventually serviced and surveyed. However, at this writing, only six of the stations are being recorded due to: (1) the failure of 3 of the field-repaired amplifiers and (2) a problem at the repeater sites so that some working stations could not be received at the recording station. We plan a follow-up trip in late October - early November to try to rectify as many of these problems as possible. We are grateful to the Juneau project office for providing an extra week of 206 time to finish the servicing of this network. With the heavy work done, we are hopeful that the majority of the remaining problems can be solved with fixed-wing support.

Conclusion. Logistically we achieved 100% of our objectives. We serviced thirty-two remote seismic stations in 28 days of cumulative helicopter support-time, excluding down-time due to taking the UHIH to Anchorage to repair the floats. With the weather and bears taking their toll, our overall average was about one station per day. Scientifically, what is important

is how many stations are generating data. At this time, 28 of 35 short-period stations are fully operational; that is, an 80% success rate.

Even though this is reasonably good, we hope to improve this with the upcoming trip to the Pavlof array. Once again, enough cannot be said for the NOAA pilots and mechanics. We have been uniformly impressed with their judgement, skill and willingness to work hard under difficult conditions.

Much of the success of this operation is due to them.

APPENDIX II

A SEISMOTECTONIC ANALYSIS OF THE SEISMIC AND VOLCANIC HAZARDS
IN THE
PRIBILOF ISLANDS-EASTERN ALEUTIAN ISLANDS REGION OF THE BERING SEA

~~ERDA~~ Contract

~~FY 76-S-02-3134~~

Crustal Deformation Studies in the Shumagin Islands

Field Report - June 1977

John Beavan

This report describes: (1) the maintenance and updating carried out on the Shumagin Islands sea level monitor array during June 1977; (2) the installation of new levelling lines on Sand Point airstrip and Simeonof Island, and the upgrading of the original Sand Point levelling line by adding intermediate markers. All 1976 levelling results are included in an appendix.

See August 1976 and November 1976 reports for further details of the sea level monitor array.

A. SEA LEVEL MONITOR ARRAY

1. Upgrading of Instrumentation

The basic design of the instruments has remained unchanged but the following modifications have been made:

(1) The mechanical clocks which (a) switched the recorder motor on and off and (b) provided time marks have been replaced by an electronic clock, motor drive and multiplex unit. The multiplex unit enables up to 4 channels of information to be recorded on one minigraph recorder, the different channels being distinguished by having different length time marks.

(2) The wire and pulley arrangement, which may have been subject to slippage, has been replaced by a toothed cable and pulley which cannot slip.

(3) The capillary tube filter has been replaced by a micropore filter (Figure 1).

(4) Air traps have been added to the top of the syphon, to resist breakage of the syphon by accumulated air dissolved out of the sea water (Figure 1).

2. Installation Procedure

New instrument heads were taken to the Shumagins this summer, and the previous ones were replaced and brought back to Lamont for upgrading. The old capillary filters were discarded (except at PRC) and the new micropore filters and air traps installed in their place.

All the instruments were relevelled to their nearby benchmarks as a check against settling. This was previously done in August 1976.

Water levels in the standpipes were checked on all instruments, so that the relative height changes of the water in the standpipes can be related to

an absolute reference. This was first done in November 1976.

3. Sand Point SDP

27 February 1977

Visited 1130 local by Laszlo Skinta and found to be not operating correctly.

13 June 1977

Straight line since 27 February; electronics operating OK except for time-marks, but paper has been winding backwards on the chart for about 1 week; silica gel still quite blue.

1545 local. Water depth $61 \frac{11}{16}'' \pm \frac{1}{16}''^*$; temperature 56°F .

Installed new head (recorder #1), airtrap, micropore filter and toothed cable.

18 June 1977

Changed recorder; water depth $65 \frac{5}{8}''$, temperature 49°F .

20 June 1977

Levelling BM1 $\rightarrow$ sea level gauge⁺ $-308.0 \pm .5 \text{ mm}$

BM2 destroyed by rockfall.

*All water depth measurements are to the top of the standpipe unless otherwise stated

⁺All levelling is measured to the top of the upper baseplate on the sea level gauge, unless otherwise stated. Distance between top of standpipe and top of upper baseplate is $60.5 \text{ mm} \pm .2 \text{ mm}$.

22 June 1977

a.m. Air trap empty. Replaced it and pumped air out of all tubes.

Sealed all joints with RTV.

Changed instrument head; recorder has #4 gearbox. Water depth 56 9/16".

29 June 1977

1500 local air trap and filter refilled

water depth 55 3/16"

30 June 1977

1845 local air trap and filter refilled

water depth 55 13/16"; temperature 48°F.

4. Pirate Cove PRC

19 June 1977

2040 GMT water depth 105 9/16" before disturbing instrument; temperature 52°F

Instrument working perfectly. Replaced instrument head and installed toothed cable. Left capillary in place without inspecting it because it was working so well.

New recorder is #15; recorder has a #4 gearbox.

Levelling BM → top of standpipe -219.5 ± 0.2 mm.

Distance between bottom of lower baseplate and top of upper baseplate measured as 60.7 mm. Hence levelling from BM → top of upper baseplate gives $-158.8 \pm .2$ mm.

2235 GMT water depth 105 13/16"; temperature 52°F

5. Eagle Harbor, Nagai EGH

Instrument not working; paper had run out due to motor becoming jammed on; silica gel pink.

About two months of data were recorded before failure, but all but 3 weeks were of poor quality.

Installed new instrument head (recorder #8, #2 gearbox). This instrument records temperature as well as sea-level. Installed air trap, filter and toothed cable. Used two prefilters only in the filter.

2307 GMT water depth 100 9/16"; temperature 55°F

Leveling BM2 → sea level gauge $1727.8 \pm .2$ mm

BM1 → sea level gauge $632.4 \pm .2$ mm

Note: time written on start of record is 1100 GMT; it should be 2300 GMT.

6. Simeonof Harbor SMH

24. June 1977

~ 1600 local. Drawing a nearly straight line but still operating. Several inches of air in inlet tube. Silica gel blue.

0123 GMT water depth 105 7/32", temperature 55°F

Changed instrument head (recorder #1); installed air trap and micropore filter (used two prefilters plus 1 GS filter); installed toothed cable.

26 June 1977

Levelling (to top of upper baseplate)

BM2 → sea level gauge 1986.3 ± .2 mm

BM3 → sea level gauge 1975.0 ± .2 mm

BM1 was not located.

28 June 1977

0118 GMT water depth 106 29/32"; temperature 68°F

7. Simeonof West SMW

26 June 1977

Drawing a nearly straight line but still operating correctly. Silica gel pink.

2215 GMT. Water depth before disturbing instrument 90 5/16"; temperature 55°F.

Installed new head, air trap, micropore filter and toothed cable. Used two prefilters only in the filter.

Water depth 93" after installation.

Levelling BM → sea level gauge $17.4 \pm .5$ mm.

To locate the bench mark from the instrument, walk 270 m south along grass bank above beach. The mark is at the junction between the grass and the beach and is surrounded by orange paint.

8. Microbarographs

The Simeonof microbarograph was still operating, but the batteries were nearly flat. Delivery of a Weather-Measure temperature, pressure and humidity recorder was too late for the field trip.

A microbarograph was installed at the Sand Point Seismic Station last November and has been operating correctly since February.

B. LEVELLING LINES

1. Simeonof Island

A levelling line about 1100 m in length was installed on Simeonof Island on the WNW trending Pacific coastline directly east of the harbor. The trend of the line marks an angle of about 45° with the trench axis. 17 permanent brass markers were installed in the solid rock of the beach, using quick-set cement, at separations of approximately 70 m. The markers were stamped with the initials LGO, the year and a reference number; they were further marked with circles of orange-red paint which are easily visible from the cliff above the beach.

Figure 2 gives an approximate plan of the levelling line.

Marker 1977-50 is below high water mark.

Marker 1977-66 is close to high water mark.

Marker 1977-60 (?) is on a rock surrounded by sea for several hours around high water. It should be moved further inland next year.

2. Sand Point Airstrip

A levelling line about 800 m in length was installed along Sand Point airstrip. Permanent brass markers were installed in two groups, one at each end, but there was no solid rock in between so the line was measured using turning points.

Figure 3 gives a sketch of the positions of the brass markers at each end of the runway.

3. Sand Point Original Line

Three permanent brass markers were installed in the middle of this line on the concrete foundations of the water supply building. Intermediate markers were also installed, consisting of 1 m iron tubing driven into the ground and capped by brass markers held in position with epoxy.

An approximate plan of the line is given in Figure 4. Note that a temporary turning point is needed for the shot between markers 35 and 36.

Errata

August 1976 Field Report

page 19 Instrument is 633 ± 2 mm above BM2.

November 1976 Field Report

Figure 1 The separation of upper and lower baseplates is $1 \frac{3}{8}$ ", not 2".

LEVEL LINE RESULTS JUNE 1977

Date	End markers		Height difference	Notes
	From	To	mm	
<u>Sand Point original line (Figure 4)</u>				
16 Jun	A	1977-10	-40403.3 $\pm$.4	Errors are based on reading variations within the run.
20 Jun	1977-10	3a of dry tilt	36354.0 $\pm$.3	
16/20 Jun	1971	3 of dry tilt	-3103.1 $\pm$.5	
	1971	B of dry tilt	-2033.3 $\pm$.5	
21/22 Jun	3 of dry tilt	1977-10	-36358.1 $\pm$.2	do.
	1977-10	A	40403.4 $\pm$.3	
	3 of dry tilt	1971	3099.6 $\pm$.4	
	B of dry tilt	1971	2029.8 $\pm$.4	
<u>Sand Point airstrip (Figure 3)</u>				
23 Jun	1977-02	1977-01	111.4 $\pm$.3	north end
~28 Jun			112.0 $\pm$.2	measured when nearly dark.
23 Jun	1977-04	1977-03	1309.0 $\pm$.1	south end
~28 Jun			1309.4 $\pm$.3	south end
23 Jun	1977-05	1977-03	772.5 $\pm$.1	south end
~28 Jun			772.5 $\pm$.3	south end
23 Jun	1977-01	1977-03	995.8 $\pm$.3	errors based on reading variations within the run
~28 Jun	1977-03	1977-01	-992.8 $\pm$.2	
<u>Squaw Harbor</u>				
13 Jun	A	K	-1948.0 $\pm$ 1.1	poor readings, due in part to high winds
	K	A	1945.5 $\pm$ 2.5	
	B	K	-1225.0 $\pm$ 1.1	
	K	B	1222.5 $\pm$ 2.5	

SIMEONOF LEVELLING LINE JUNE 1977 (see Figure 2)

Shot	Distance (meters)	NW-SE run (10^{-4} m)	SE-NW run (10^{-4} m)	
50-51		3114.2 $\pm$.2	-3115.5 $\pm$.7	
51-52	69.3	-624.3 $\pm$.5	+627.8 $\pm$.8	
52-53	78.1	8840.3 $\pm$.3	-8841.0 $\pm$.3	
53-54	64.3	-5479.7 $\pm$.1	5485.8 $\pm$ 1.2	*
54-55	63.9	16191.8 $\pm$.3	-16191.1 $\pm$ 1.2	
55-56	69.6	-7806.4 $\pm$.3	7807.1 $\pm$.1	
56-57	77.9	4385.5 $\pm$.2	-4391.6 $\pm$ 1.1	*
57-62	79.2	11041.2 $\pm$ 1.2	-11042.4 $\pm$.1	
62-58	58.6	-13669.0 $\pm$.6	13657.2 $\pm$.5	*
58-59	78.8	-5101.0 $\pm$.6	5104.7 $\pm$.2	
59-60	72.0	-6535.5 $\pm$ 1.2	6527.0 $\pm$ 1.1	*
60-61		8979.0 $\pm$.3	-8975.0 $\pm$.6	
61-63	57.6	13555.8 $\pm$.5	-13554.0 $\pm$ 1.5	
63-64	60.3	-17363.6 $\pm$.4	17366.7 $\pm$.1	
64-65	58.5	-6961.6 $\pm$.9	6967.6 $\pm$.2	*
65-66	74.9	441.3 $\pm$.3	-438.3 $\pm$.1	
Total	$\sim$ 1100 m	3008.1 $\pm$ 2.4	-3004.8 $\pm$ 3.2	

NW-SE, with errors based on reading variations within the run: 300.8 $\pm$.2 mm
 SE-NW, with errors based on reading variations within the run: -300.5 $\pm$.3 mm

Mean, with errors based on differences between the runs: 300.6 $\pm$ 1.1 mm
 (most of this error is contributed by the shots marked with *.)
 These shots should have been repeated, but there was no time.)

DRY TILT FIGURE RESULTS JUNE 1977

Sand Point

.5 .1 .2
 .B
 .3
 .3A
 .4

Date	From	To	Height Difference mm	Notes
11 June	B	3A	-1071.9 $\pm$.9	Very poor readings
	B	2	-182.5 $\pm$.3	
	B	1	324.0 $\pm$.3	
	B	5	282.9 $\pm$.5	
	B	4	239.7 $\pm$.4	
	3	4	831.8 $\pm$.4	
	2	1	507.4 $\pm$.3	
	B	3	-1072.1 $\pm$.9	

Squaw Harbor

BAY

.A
 .B
 C. + turning point

Date	From	To	Height Difference mm	Notes
18 June	A	B	1459.9 $\pm$.1	
	B	TP1	-257.2 $\pm$.3	
	TP1	C	-102.0 $\pm$.2

Figure 1. Sketch of air trap and micropore filter arrangement in Shumagin Island sea level monitors.

Figure 2a. Sketch of Simeonof Island levelling line.

Figure 2b. Location of NW end marker of Simeonof levelling line.

Figure 3. Sketch of end marker locations on Sand Point airstrip levelling line.

Figure 4a. Sketch of intermediate markers on northern half of Sand Point levelling line. Markers 10, 11 and 46 are set in the concrete foundations of the water supply building. Markers 3 and 3a are part of the Sand Point dry tilt figure. The remaining markers are set on 1 m iron tubing driven into the tundra.

Figure 4b. Sketch of intermediate markers on southern half of Sand Point levelling line. A turning point is required at the position marked *.

L-DGO Data Acquisition System

Technical Memo/Cost Estimate

SUBJECT: Computer assisted data recording systems for network use.
(Ref. USGS seismic data systems)

BY: Douglas Johnson
Technical Manager, Seismology Group

DATE: 12 October 1977

Our requirements for the on-line data recording system portion of the proposed USGS seismic data system are somewhat different from those considered by USGS. While our total number of stations is fairly large (> 100), it consists of a number of networks, ranging in size from 12 to 30 stations. Furthermore, many of these networks are located outside the continental United States. As a result of these factors, an optimum on-line configuration would differ from the USGS configuration. In particular it would be designed to address these requirements:

- 1) A typical network size of 15 to 30 components, with expansion capability to 64.
- 2) Initial equipment cost must be lower than the ~\$45K USGS figure: \$20-25K seems to be a reasonable target.
- 3) The system reliability must be high, when operated in a minimum maintenance environment. Furthermore, system complexity must be minimized so as to allow relatively unskilled labor support.
- 4) It would be highly desirable to include a capability (existing or as a growth option) for non-real time data transmission to an appropriate U.S. center (such as LDGO). This would probably include some mechanism for data concentration/reduction.
- 5) The system should have some capability for network control, either by (software) program, or by remote input. In addition, a network status reporting capability is desirable.

From our viewpoint, it would therefore be desirable for the proposed USGS system to include these considerations:

- 1) Alternate compatible hardware and software configurations.
- 2) Standardization/specification of data format which would insure compatibility with the proposed off-line system.

With regard to item 2, we are less concerned with physical compatibility (i.e.: 1/2, 9 track magnetic tape) than with format compatibility (word size, block and file format, etc.).

We fully appreciate the potential pitfall of trying to do everything with the proposed on-line system, and consequently doing nothing (or doing most of it poorly). Consequently, while it would be desirable to have a relatively common hardware configuration with flexibility, it is more important to have a standardized data interface, thus permitting hardware flexibility.

Some specific system considerations are:

- 1) The computer should be both hardware and software compatible with minimum size systems. A minicomputer with a compatible microprocessor would be desirable (such as the T.I. 990 series or the Nova compatible unit from Fairchild).
- 2) The computer program should be capable of being loaded in a non-volatile form (ROM/EPROM, etc.).
- 3) The power requirements should be minimized; making it easier to provide backup power.
- 4) Enough solid state (RAM) memory capacity should be available to permit operation without a disc.
- 5) A built-in test program should be included.

Cost Estimate-Material-Multiprocessor System

32 Component/30 Second

1) System controller	
(1) System 80/20-4	\$ 1,895
(1) Analog I/O Board	\$ 700
(1) SBC 508 GP I/O Board	<u>\$ 350</u>
Total	\$ 2,945
2) Event detector	
(1) System 80/20-4	\$ 1,895
(1) SBC 310 Math Unit	<u>\$ 595</u>
Total	\$ 2,490
3) Pre-event memory	
(2) System 80/20-4	\$ 3,790
(6) 16 K Ram Board	<u>\$ 4,800</u>
Total	\$ 8,590
4) Tape recorder	
(1) Kennedy #9800 with NRZI Formatter	\$ 4,800
5) Control/display terminal	
(1) TI Model 743 KSR (or equivalent)	\$ 1,500
6) Console (BUD AGR-9303)	\$ 250
7) Power regulator (Sola 63-13-150)	\$ 210
8) Spares	<u>\$ 2,100</u>
 TOTAL MATERIAL	 \$22,885