PRELIMINARY RESULTS OF MICROEARTHQUAKE SURVEY NORTHERN ADAK ISLAND, ALASKA

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by

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I. INTRODUCTION

Adak Island occurs in the central portion of the Aleutian Island chain. It is the largest island of the Andreauof Group and is centered roughly at latitude 51°47'N and longitude 176°40'W. It is approximately 1200 air miles from Anchorage.

The northwestern portion of Adak Island is occupied by the Adak Naval Air Station whereas the remainder of the island is maintained as a wildlife refuge. The present energy needs of the air station are supplied by electrical generators burning JP-5 fuel. The Navy is actively exploring the potential for geothermal energy as an alternate to the present system.

The northeast portion of the island is dominated by three volcanoes; Mt. Moffett, Andrew Bay volcano and Mt. Adagdak. Hot springs occur on the northwest shoreline of Andrew Bay volcano. These springs discharge waters of about 154°F (68°C). Geochemical thermometry of these spring waters suggest subsurface reservoir temperatures of at least 180°C (Miller et al., 1977).

a) Background

Geothermal exploration of Adak is being conducted by the Naval Weapons Center, Geothermal Power Group, China Lake, California. Under Navy contracts both the Colorado School of Mines (Butler and Keller, 1974) and the U.S.G.S. (1976) have conducted geophysical surveys on Adak. The U.S.G.S. primarily used electrical methods, namely, audio-magnetotelluric, telluric traverse, self-potential and EM-16R electromagnetic techniques to evaluate an area comprising Mt. Adagdak and Andrew Bay volcano. Complimenting these were gravity and aeromagnetic surveys.

Butler and Keller (1974) conducted a microearthquake survey over roughly the same area. They used seven Sprengnether Instrument Company MEQ-800-B portable seismic systems with Mark Products model LC-4, 1 hz natural-frequency vertical seismometers. Nine days of recording time between October 22 and November 1, 1974 were obtained. During this period two of the stations were relocated making a total of nine recording sites. Data from four NOAA stations, which were operated continuously as part of the permanent tsunami-warning network of NOAA, were also reported.

Twenty-six events were located off-shore northwest of Mt. Adagdak during the nine days of recording. A least-squares-fit solution was obtained from these events which suggested a fault plane striking N60E and dipping 70°NW. This fault plane when projected to the surface cuts through Mt. Adagdak and Andrew Bay Volcano.

b) Earth Science Laboratory Responsibility

In July, 1982 a contract was received by ESL from the Naval Weapons Center, China Lake, California, to expand the existing microearthquake survey of Butler and Keller in order to reaffirm the existence of their interpreted fault plane and to possibly identify other active fault planes in the general vicinity of Mt. Adagdak. The ESL survey was to consist of thirty days of recording time. Local events were to be identified and their approximate locations calculated using preliminary, in-the-field interpretation techniques. In addition, a map showing the location of the recording sites is to be provided.

c) Sub-Contractors Responsibility

ESL entered into a sub-contract with Mincomp Exploration Resources, Wheat Ridge, Colorado as a means to facilitate the microearthquake survey. Mincomp's responsibility included supplying 10 MEQ-800 portable seismic systems with all accessories. Recording sites were to be picked by Mincomp personnel. These sites in turn were to be surveyed by ESL and subsequently maintained and monitored for the duration of the field survey by a joint ESL-Mincomp team.

At the completion of the survey, Mincomp was to provide ESL with the smoked paper recordings from each site along with a report containing the preliminary locations of any local events identified on these records.

II. INSTALLATION AND STATION MAINTENANCE

Upon arrival at Adak it was discovered that only 9 seismic systems had been shipped. Because of the critical timing (September) of the survey and the potential for bad weather and because of the difficulty encountered in the shipment of the equipment on hand, the decision was made to forego any attempts to obtain a tenth MEQ-800. The nine seismic systems were emplaced on bedrock or in stable soil. Sites were chosen such that the area of interest would be covered and the previous survey of Butler and Keller could be checked. In selecting site locations it was necessary to maintain ease of serviceability by a two-man field crew. Five of the nine ESL sites were located in close proximity to a corresponding number of sites from the Butler and Keller survey. These ESL sites were Moffett, Rocky Point, Lahar, Clam Lagoon and Quonset corresponding to sites 1, 9, 6, 2 and 7 of Butler and Keller. The station locations are shown on Plate I, the geologic map of northern Adak Island (from U.S.G.S. Bull, 1028-C, Coats, 1956).

Two of the nine ESL stations were established by backpacking equipment into remote areas southeast of Mt. Adagdak and at Cape Adagdak at the extreme northern end of Adak Island. Recording speeds of the instruments at these two remote sites were set such that service was required every other day. The remaining seven sites were serviced on a daily basis.

III. SURVEYING RESULTS FOR RECORDING SITE LOCATIONS

The site locations for the ESL microearthquake stations were surveyed using a Hewlett-Packard 3820A electronic transit and standard traversing procedures.

a) Description of Survey Procedure

The station sites are all located with reference to benchmarks provided by the NAVSTA and NAVSECGRUACT engineering groups. Two benchmarks labeled AU8 and AU15, which are located along the Andrew Lake road at the southwest corner of this lake, were used to position the Rocky Point station. The remaining eight stations are referenced to benchmarks M8 and M9 which occur near Rawls road just south of the NAVSECGRUACT engineering groups office.

b) Precision and Accuracy

The transit employed was a Hewlett-Packard 3820A electronic total station. This instrument uses a solid state Ga As lasing divide (non-visible) light source and a series of reflecting prisms. Under ideal conditions this instrument has a range of 5 km (16,400 ft) with a slope distance accuracy of ± 0.016 ft ± 0.005 ft/1000 ft within the temperature interval of 15°F to 105°F. The angle resolution is one second with accuracy of ± 2 sec horizontally and ± 4 sec vertically. The instrument has an automatic level compensator and a digital display.

The General Development Map, NAVFAC Drawing No. 6016442, was provided to ESL by the NAVSTA engineering group. The northwest portion of this map has been reproduced as Plate II. This plate shows the major access roads and is the base map used to locate the microearthquake stations. Plate III is an overlay to Plate II and presents the results of the transit survey.

Several maps, all at different scales, exist for Adak Island. The survey traverses presented in this report indicate substantial distortion in some of the older maps, especially for the Cape Adagdak area and most seriously on the uncontrolled 1941 topographic map (discussed in detail below). Plate II results from more recent higher order surveys and appears to have the least distortion; hence its choice as the base map for the transit survey. The geologic map presented as Plate I appears to have limited, but minimal distortion. When an overlay of the transit data is constructed (Plate IV) at the scale of this map, it is noted that the Loran and Cape sites do not occur where they are known to be topographically. In establishing the respective station sites it became apparent that all stations except the Saddle site could be located within approximately 100 feet with respect to local topographic features. Therefore, because of the good agreement between Plates II and III, it is believed that distortion in the geologic map accounts for the apparent mislocation of the Loran and Cape sites. The transit survey and station locations presented on Plate IV were double checked and no errors were noted. However, because no latitude or longitude is given on Plate II, it was necessary to use the geologic map for this information using the position of the respective sites as determined by the transit survey and presented as Plate IV. This of course assumes that the latitude and longitude grid on the geologic map is not distorted.

Finally, one other map needs to be discussed. This is the topographic map at a scale of 1:25,000 entitled Andrew Lagoon copied by the Army Map

Service from the Adak Island 2, series Q831 of 1943. Using the topography on this map it is possible to topographically locate quite accurately each of the 9 recording sites. However, when an overlay of the transit data is prepared at a scale of 1:25,000 there is almost no correlation with the recording sites as determined from the topography. The ESL copy of the Andrew Lagoon sheet may have been distorted in reproduction or the original itself could be badly distorted. The map is based on older photographic data with limited survey control.

IV. MICROEARTHQUAKE RESULTS

The recording of microearthquake data began on September 5 and continued until October 4, 1982. Preliminary results of this survey are presented in Mincomp's report to the Earth Science Laboratory attached here as Appendices A and B.

a) Sub-contractors Results

During the recording interval, 190 events, recognizable on two or more station records, were identified by Mincomp personnel. Thirty-three of these were considered as local in origin; local being arbitrarily chosen for events having S-P arrival times less than 4 sec. Twenty four of the local events reportedly yielded reasonable hypocenters and origin times using a uniform earth model having a velocity of 5 km/sec. These results were obtained using a hand computer and a hypocenter program discribed in Appendix B.

When plotted, these hypocenters show much of the activity to occur on land beneath Mt. Adagdak instead of under the sea as shown by the Butler and Keller survey of 1974. The fault plane surface trace of Butler and Keller does however project through Mt. Adagdak hence there is agreement between the two surveys in this regard. It should be noted however that the velocity models used in the interpretation of the two surveys are not the same.

Mincomp obtained a fault trace passing through Clam Lagoon and the southern tip of Andrew Lake by projecting the hypocenters from the 1982 survey onto the vertical plane of Butler and Keller's fault trace and computing a least-squares plane through them. This fault trace has a dip of 49° NNW. This suggests that two or more fault zones may be active within the area of interest.

b) ESL Critique of Sub-Contractors Results

The 1982 survey was successful in that it produced data that completed the objectives stated in Section I (b) and (c). The equipment provided by Mincomp performed to expectations and produced records of approximately 190 microearthquakes. Mincomp provided ESL with preliminary hypocenter determinations. It appears in Mincomp's report (Appendix B, pgs. A8-A10) that these events were determined using only P-arrivals occuring on records at four or more stations. We are in general agreement with the recommendations set forth in the Mincomp report (Appendix A) for this stage of the data interpretation. Mincomp performed their contract responsibilities in both a timely and competent manner.

c) ESL Preliminary Hypocenter Determinations

It should be kept in mind that the results obtained by Mincomp from the 1982 survey and attached to this report as Appendices A and B are only preliminary. Arrival times were picked directly from the field records using an "eyeball and ruler" technique and hypocenters and focal depths were determined using a hand-held programable calculator and the P-arrival times at four stations. No sophisticated processing of the field records was attempted. In order to utilize the 1982 data to its fullest potential it is

ESL Hypocenters
Using Homogeneous Crust
V = 5.0 km/sec

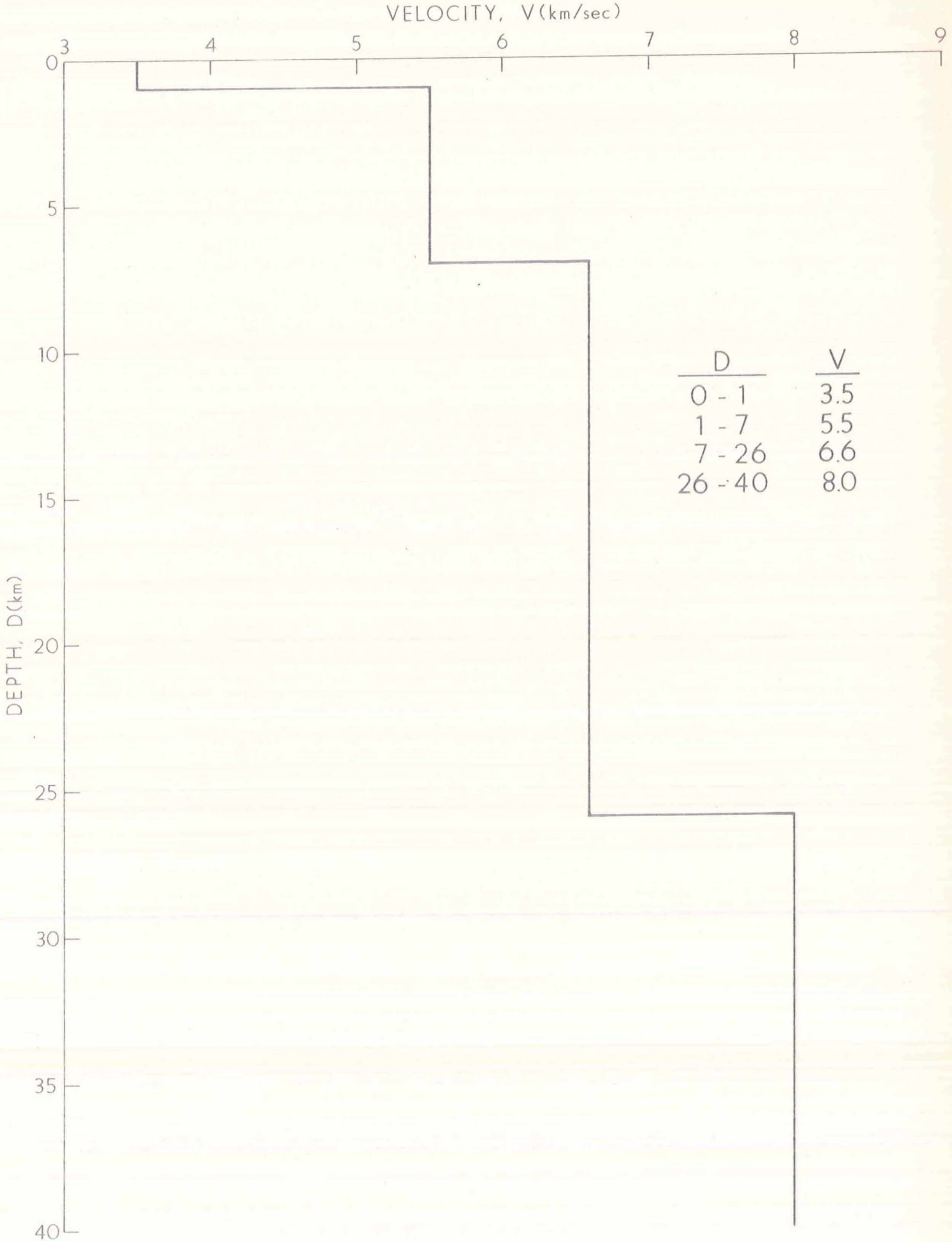
			Hypocenter					Error Ellipse (km)	
Event	Date	Origin Time	Lat.	Long.	Focal Depth (km)	No. of Arrivals	Gap	Horiz.	Vert.
1	82 9 11	0258 27.15	52 02.12	176 32.53	11.27	5	332	5.9	2.4
2	82 9 11	1929 59.86	51 52.28	176 48.03	11.95	12	337	3.1	3.1
3	82 9 12	0608 21.49	51 59.88	176 37.10	10.83	10	271	3.3	1.2
4	82 9 12	1640 46.10	51 58.03	176 45.36	8.56	8	337	4.6	5.1
5	82 9 14	1938 44.25	52 02.35	176 31.78	11.65	7	332	5.9	3.6
6	82 9 15	0438 22.63	51 59.05	176 37.44	11.40	7	305	3.8	1.6
7	82 9 15	0450 21.20	51 58.91	176 36.82	11.47	6	303	4.1	1.9
8	82 9 15	1007 45.32	51 58.80	176 39.64	12.88	6	285	4.6	1.9
9	82 9 15	1405 37.85	52 00.16	176 29.05	11.32	7	317	7.2	6.6
10	82 9 20	0615 33.77	51 59.02	176 38.02	11.54	6	238	4.8	1.4
11	82 9 20	1345 29.04	51 59.69	176 37.90	11.84	5	273	4.0	2.9
12	82 9 21	1735 37.55	51 54.50	176 44.27	16.84	7	327	4.3	3.8
13	82 9 25	0514 12.34	51 58.35	176 37.93	8.74	8	268	2.6	2.8
14	82 9 25	1057 01.89	52 01.36	176 40.36	15.18	11	333	4.4	1.3
15	82 9 25	1124 50.94	52 00.43	176 35.34	11.95	9	301	3.8	1.8
16	82 9 27	0456 00.46	52 02.05	176 34.89	11.86	7	329	5.7	3.4
17	82 9 27	0456 21.95	51 58.01	176 35.06	6.88	9	127	2.0	1.9
18	82 10 1	0637 04.37	51 59.85	176 35.38	10.75	7	277	5.3	1.9
19	82 10 2	0650 29.88	52 00.10	176 35.67	14.08	6	314	4.5	2.6
20	82 10 2	1524 16.49	52 00.19	176 29.70	11.60	9	316	3.6	2.7
21	82 10 2	2011 03.47	52 00.81	176 31.33	13.22	5	320	9.1	2.6
22	82 10 2	1531 38.63	51 59.99	176 37.22	5.63	8	286	1.7	2.6
23	82 10 3	0017 05.46	51 57.59	176 30.00	11.98	5	318	4.8	2.2
24	82 10 3	0642 29.44	51 58.64	176 31.57	13.75	9	282	2.9	2.3
25	82 10 3	2116 38.95	52 01.28	176 32.69	11.93	6	324	4.7	2.9
26	82 10 4	1912 02.19	51 58.79	176 39.42	13.64	11	318	3.1	1.2

Table 1

ESL Hypocenters
Using U.S.G.S. Layered Crust

			Hypocenter		Focal	No. of		Error Ellipse (km)	
Event	Date	Origin Time	Lat.	Long.	Depth (km)	Arrivals	Gap	Horiz.	Vert.
1	82 9 11	0258 27.20	52 01.01	176 33.44	10.77	5	322	5.1	2.6
2	82 9 11	1929 59.86	51 52.91	176 46.65	11.63	12	334	2.1	3.2
3	82 9 12	0608 21.37	51 59.61	176 37.01	10.21	9	256	2.5	1.3
4	82 9 12	1640 46.10	51 57.62	176 42.50	9.18	8	327	2.6	3.2
5	82 9 14	1938 44.26	52 01.41	176 32.43	11.17	7	326	4.5	3.4
6	82 9 15	0438 22.64	51 58.33	176 37.51	10.50	7	265	2.8	1.5
7	82 9 15	0450 21.11	51 58.40	176 37.05	10.82	6	292	3.6	2.0
8	82 9 15	1007 45.31	51 58.40	176 39.23	12.15	6	265	3.7	1.9
9	82 9 15	1405 37.88	51 59.53	176 29.92	9.83	7	307	4.0	7.2
10	82 9 15	1614 37.61	51 56.10	176 40.03	3.70	6	286	1.6	1.8
11	82 9 20	0615 33.74	51 58.58	176 37.66	10.63	6	201	3.7	1.9
12	82 9 20	1345 29.18	51 58.88	176 37.73	10.19	5	192	2.8	4.0
13	82 9 20	1534 56.97	52 00.73	176 32.69	5.22	6	318	2.3	3.4
14	82 9 21	1735 36.80	51 51.31	176 44.42	18.57	8	333	5.2	4.4
15	82 9 25	0514 12.07	51 58.00	176 37.44	8.87	7	252	2.1	3.2
16	82 9 25	1057 01.89	52 00.99	176 39.85	14.81	11	330	3.8	1.4
17	82 9 25	1124 50.89	51 59.86	176 35.56	11.40	9	277	2.9	1.6
18	82 9 27	0456 00.45	52 01.11	176 35.15	11.50	7	317	3.5	3.8
19	82 9 27	0456 21.92	51 57.65	176 35.36	4.71	9	88	0.9	1.4
20	82 10 1	0637 04.30	51 59.19	176 35.55	10.17	7	223	3.9	2.1
21	82 10 2	0650 29.85	51 59.60	176 35.91	13.67	6	290	3.8	2.8
22	82 10 2	1524 16.47	51 59.61	176 30.86	11.11	9	303	2.5	2.8
23	82 10 2	2011 04.78	51 57.40	176 35.53	8.26	7	205	1.8	2.3
24	82 10 2	1531 38.67	51 58.93	176 37.30	3.90	8	172	1.0	1.6
25	82 10 3	0017 05.47	51 57.48	176 31.40	11.37	5	304	4.0	3.0
26	82 10 3	0642 29.42	51 57.05	176 33.33	14.32	8	250	2.5	2.2
27	82 10 3	2116 38.91	52 00.49	176 33.39	11.68	6	314	3.4	2.9
28	82 10 4	1526 31.35	51 50.50	176 43.32	8.34	6	343	6.0	29.1
29	82 10 4	1912 02.04	51 58.71	176 37.20	14.23	7	279	4.0	2.0

Table 2



D	V
0 - 1	3.5
1 - 7	5.5
7 - 26	6.6
26 - 40	8.0

FIGURE 1

U.S.G.S. CRUSTAL VELOCITY MODEL ADAK REGION
(after Engdahl, 1974)

necessary to process the records in a more sophisticated manner.

ESl personnel independently completed hypocenter determinations for local events (< 4 sec.) identified on the MEQ records. Twenty-nine such events gave rational solutions on ESL's PRIME 400 computer system using a U. S. Geological Survey Program entitled "Hypoinverse" (Klein, 1970). Hypoinverse is a hypocenter inversion program that computationally uses the singular value decomposition (SVD) technique. The eigenvalues, eigenvectors, covariance matrix and error ellipsoid of the inversion are available as outputs. The SVD approach also permits eigenvalue truncation which prevents hypocenter adjustments in poorly constrained directions.

Hypocenter determinations were obtained from two earth crust models. Table 1 is a summation of ESL hypocenter determinations using a homogeneous earth having a velocity of 5.0 km/sec. This model is identical to that used by Mincomp is obtaining their preliminary hypocenter determination. Table 2 is a summation of ESL hypocenter determinations using the layered earth model developed by the U.S.G.S. (Engdahl, 1974). This model, taken from the Butler and Keller, 1975 report, is shown as Figure 1. We consider this earth model to be more realistic. The small error ellipses determined with either model show the importance of using event arrivals, both P-wave and S-wave, at all stations rather than from a selected four sites. Results shown in Tables 1 and 2 are presented in plan as Plates V and VI respectively.

Plates V and VI show many of the hypocenters to be on the northeast corner of the island. Least-squares-fits to the data suggests the events trend or strike N63°E and N75°E depending upon the model used. Both trends are, however, close to the alignment between Mt. Adagdak and the hot springs

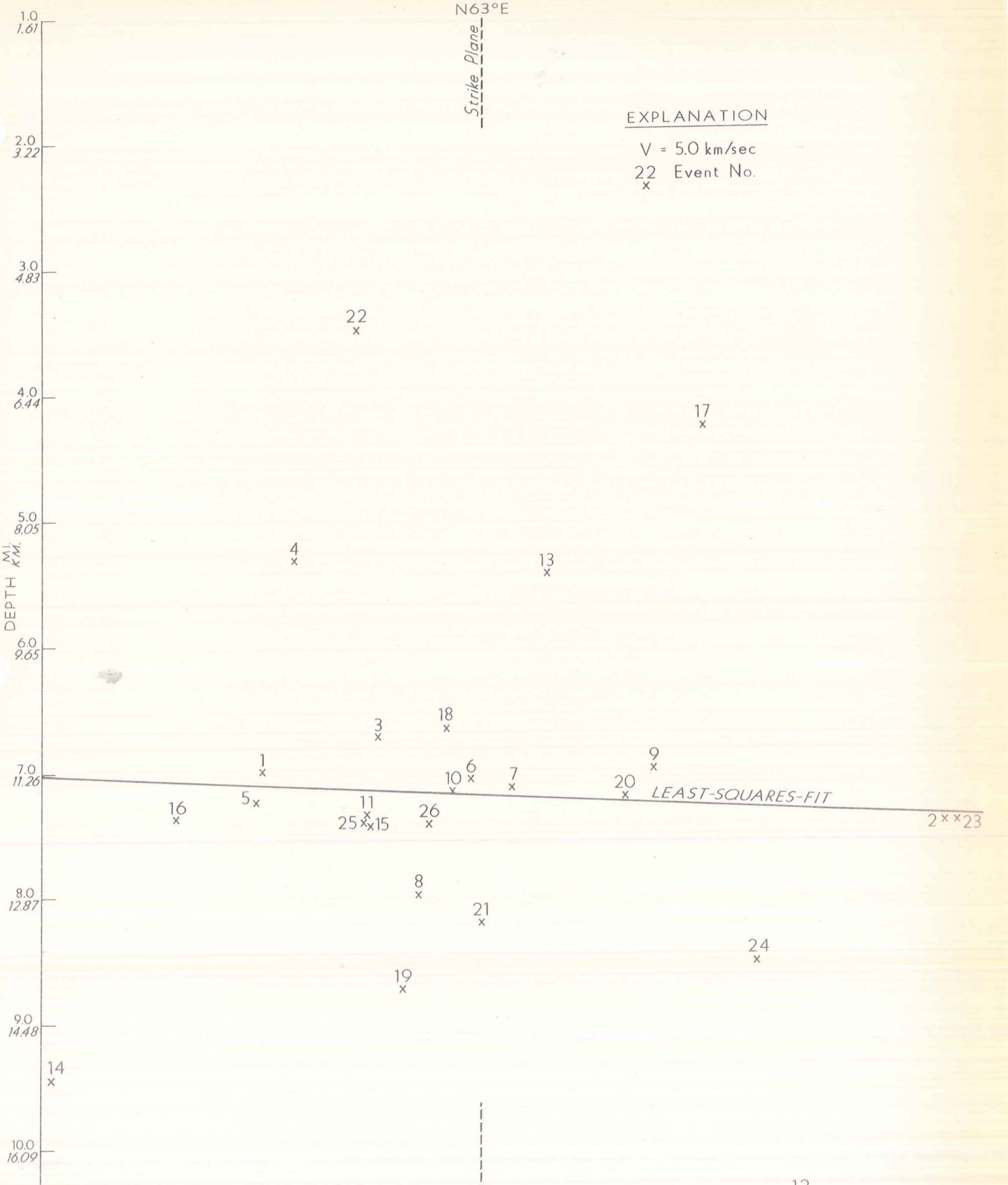


FIGURE 2

ESL FOCAL DEPTHS USING HOMOGENEOUS CRUST

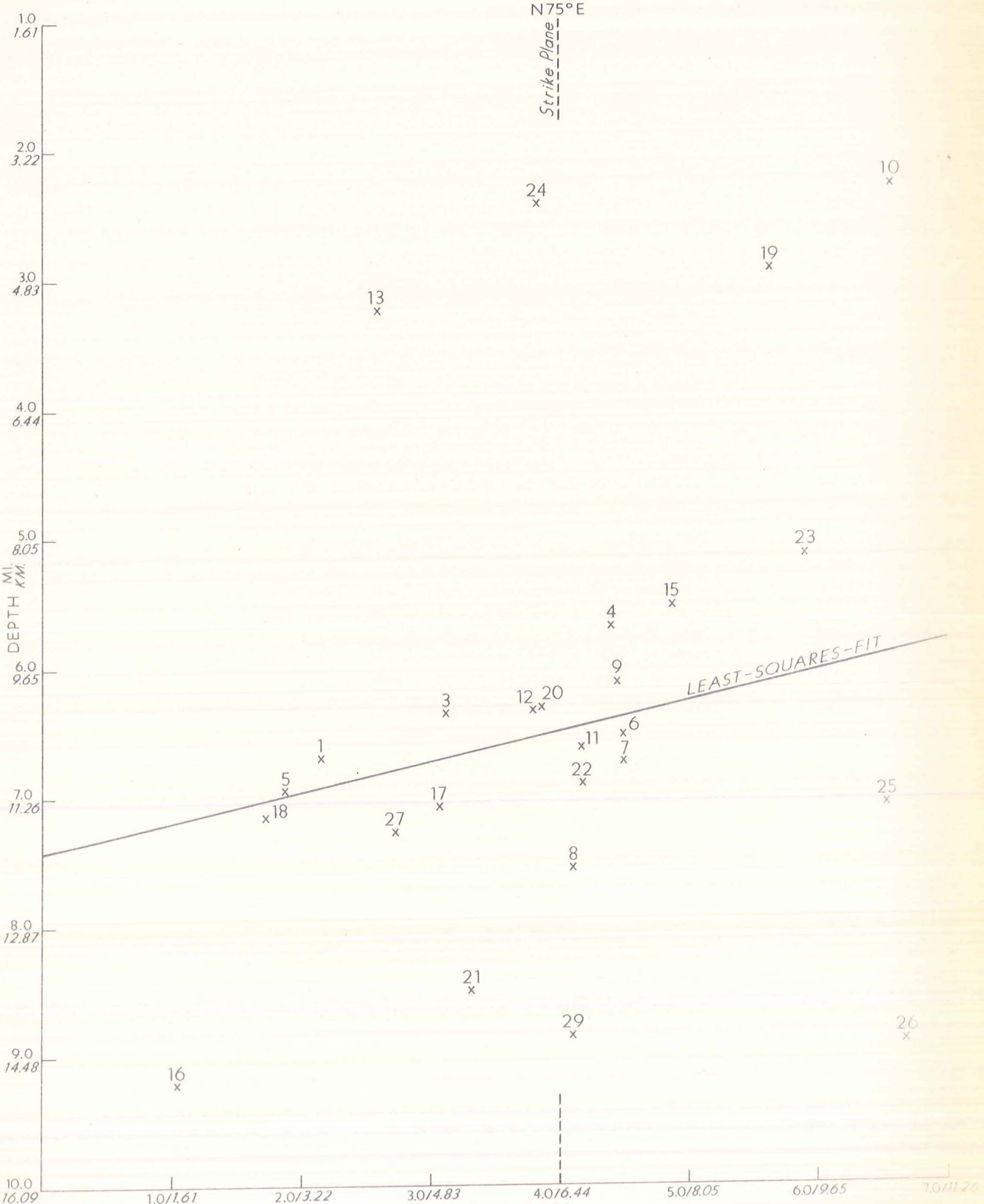


FIGURE 3

ESL FOCAL DEPTHS USING U.S.G.S. LAYERED CRUST located on the shoreline of Andrew Bay Volcano. No attempt has been made at this time to identify in detail other trends that appear to be present. For example, the cluster of hypocenter locations aligned along the eastern side of Andrew Bay Volcano (Plate VI) suggests there may be a north-south trending zone of crustal weakness.

Plots of focal depths are presented as Figures 2 and 3. These are constructed by taking sections normal to the strikes shown on Plates V and VI. Events are then projected onto these sections by location and focal depth. Figure 2 shows most of the events clustering at focal depths between 10 and 13 km when the homogeneous earth model is used. Figure 3 is constructed using data obtained from the U.S.G.S. model and shows the preponderance of the focal depths to occur between 8 and 10 km. A few events also occur both shallower (3-5 km) and deeper (13-15 km).

V. SUMMARY

Nine MEQ-800 portable seismic systems were emplaced and recordings taken during the 30 day period between September 5 to October 4, 1982. During this interval 190 events were correlated on two or more stations by Mincomp. Twenty four of these, seen on four or more stations and considered to be local in origin, yielded, according to Mincomp, reasonable hypocenters and origin times using a homogeneous earth model having a velocity of 5 km/sec. A plot of these hypocenters showed much of the microearthquake activity recorded during the survey to be located beneath Mt. Adagdak. This is different from the events located by the Butler and Keller (1974) microearthquake survey which placed hypocenters beneath the sea in Andrew Bay north and northwest of Mt. Adagdak. Butler and Keller did project a fault plane to the surface which would project southwest through Mt. Adagdak and Andrew Bay Volcano.

ESL hypocenter locations using the layered earth model show many of the identified events to occur on the northeast corner of the island at focal depths of 8-10 km. It is not obvious that the observed events are related to a single active fault. If so, the fault must be at a low dip angle as shown by the least-squares-fit to the data on Figure 3. Alternatively, the majority of the events occuring within a fairly restrictive range of focal depths may be more indicative of a magma chamber and the movement of magma. Further interpretation of the microearthquake data obtained during 1982 is, however, outside the scope of this report. The relatively small error ellipses for hypocenter locations, compared to the distribution of hypocenters shown on Plates V and VI lead us to question the validity of the projection of all hypocenters to define a single fault location and orientation. It is apparent that two or more structures could be indicated by the present data and that these structures intersect near the north end of Adak Island. The occurrence of most events in a narrow depth range would lead to considerable error in projecting a single fault plane to its surface intersection.

VI. RECOMMENDATIONS

It is apparent from the microearthquake surveys of 1974 and 1982 that Adak Island is in a zone that is seismically active. Events recorded during the two surveys do not, however, occur in the same areas. All the events of the earlier survey occur north and northwest of the island beneath the ocean. Many of the events in the recent survey occur on the island.

No additional microearthquake surveys utilizing the MEQ-800 systems are recommended. The deployment of this system becomes very restricted because of the limited access on Adak and because the MEQ's require almost daily service. If additional microearthquake data is warranted, the data should be obtained using digital event recorders and a telemetering system. This type of system could be deployed much more advantageously for a longer period of time and would be ideally suited for Adak.

Thermal waters are escaping at the surface as evidenced by the hot springs located on the northern shoreline of Andrew Bay volcano. The microearthquake data suggests faulting or magma movement to be fairly deep (∿ 10 km). The greatest potential for obtaining a useable geothermal resource would be in locating shallow permeable zones filled with thermal fluids. The hot springs indicate that such areas exist in proximity to the earthquake activity and may result from deep seated structures.

We recommend that the 1982 microearthquake data be processed and interpreted in much greater detail. This should include topographic corrections and fault plane solutions. A first motion study would identify direction of movement along fault planes. The calculation of Poisson's ratio would also be useful in identifying areas of anomalous fracturing with attendant high permeability. Obtaining data from calibration shots would aid the construction of a realistic velocity model to be used in hypocenter determinations. These recommendations are essentially the same as those proposed by Mincomp with the exception that during ESL's evaluation of the data, events were scrutinized under magnification resulting in the timing of arrivals good to 0.25 seconds. Furthermore, all arrivals are used in the Hypoinverse program to compute hypocenters.

Once the 1982 microearthquake data have been interpreted in additional detail, it would be desirable to integrate all available geophysical data to evaluate the geothermal potential of the northeast corner of Adak Island. This should lead to the definition of anomalous areas which may require detailed investigation using additional geophysical techniques prior to the selection of deep thermal gradient drill holes.

VII. ACKNOWLEDGEMENTS

Special thanks are given to Louise McPherson who provided the expertise in identifying and timing event arrivals at ESL. Her knowledge of the Hypoinverse program on the PRIME 400 computer system greatly facilitated the processing of the Adak microearthquake data.

Thanks are also given to Steve Olsen who provided the electronic expertise to maintain the MEQ-800 seismic system and for his assistance in surveying the station locations.

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