DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Permanent-Glass EDM Measurements on Mauna Loa, Hawaii From August 8, 1979 to August 5, 1987

by
R.Y. Hanatani

U.S. Geological Survey
Hawaiian Volcano Observatory
Hawaii National Park, HI 96718

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Introduction

Horizontal distance measurements using electronic distance measuring (EDM) instruments play an important part in the understanding of volcanic processes at the Hawaiian Volcano Observatory (HVO). EDM instruments accurately measure the length of a line between two points (the instrument station and the reflector station) by comparing the wavelengths of the outgoing laser beam and the reflected beam and then converting the phase difference to a slope distance. Repeated measurements of the line often reveals a change in the length of the line that can be related to volcanic activity.

At the summits of Kilauea and Mauna Loa, magma from the mantle is temporarily stored in a shallow magma chamber approximately 3 to 5 km below the surface. The pressure of incoming magma causes the summit area to inflate. This causes lines between points on the summit across the inflated area to increase in length. An eruption or intrusion on the rift zones releases the pressure on the summit area and causes it to deflate. The lines that previously lengthened now shorten in response to this deflation. A linear intrusion (dike) into a rift zone will produce a complex pattern of lengthening lines across the intruded area and contracting of lines away from the center of intrusion. All of these changes in line lengths, usually relatively small, can be measured with EDM instruments.

Background

The Hawaiian Volcano Observatory first measured horizontal distances with EDM instruments on Kilauea in 1964 and on Mauna Loa in 1965, using instruments (Tellurometer and Geodimeter) obtained by R.W. Decker on loan to HVO. These early measurements proved the superiority of the Geodimeter, which uses visible light, over the Tellurometer, which uses radio waves, and set the stage for the establishment of dense EDM trilateration networks on both volcanoes during the following decades. These networks have proven valuable in the quantitative understanding of the mechanics of a volcano during and between eruptions. EDM measurements have helped scientists to determine the location and size of magma chambers, and the volumes of magma injected into rift zones. This information helps HVO to better forecast future eruptions and intrusions.

EDM *trilateration surveys* are manpower intensive and usually requires a concerted effort by the staff at HVO to complete. These surveys are usually done bracketing a major volcanic or tectonic event and the data are modeled to obtain information such as that mentioned above. In order that the data gathered be

interpretable, the EDM measurements of a trilateration survey must be comprehensive, precise, and completed in a relatively short period of time.

On the other hand, using EDM measurements to *monitor* the current state of the volcano requires that more frequent periodic measurements be made, and the precision and density of the network need not be as great. These factors spurred the development of the "permanent-glass EDM" technique to measure horizontal distances with less commitment of time and manpower. This technique utilizes permanently installed reflectors, eliminating the need for a person to set up a reflector over a specific benchmark every time a measurement is made.

Permanent-glass EDM measurements were initiated on the summit of Mauna Loa in August 1979 by A.T. Okamura. These early measurents were done using the Geodimeter Model 8 laser instrument and highway reflectors. In March 1983, the highway reflectors were replaced by sealed, nitrogen-filled reflector prisms which are still in use at this writing. The Keuffel & Esser RangeMaster III and Ranger Va have, for the most part, replaced the Geodimeter instrument. Permanent-glass EDM measurements have become one of the primary ground deformation monitoring tools on Mauna Loa.

Purpose and Scope of Report

The purpose of this report is to present the results of the permanent-glass EDM measurements on Mauna Loa from the time the first lines were measured on August 8, 1979 to August 5, 1987. Data reported here are preliminary and subject to revision as refinements are made to data reduction procedures. Also included are station descriptions, station location maps, and documentation of equipment and procedures used to measure the lines of the permanent-glass EDM network on Mauna Loa. The data for HVO's EDM trilateration networks will be reported in other papers currently in progress.

Acknowledgements

I thank T.L. Wright and helicopter pilot W. Lacy for their help in installing the rift zone monitors; K. M. Yamashita, M.K. Sako, and A. T. Okamura for installing the summit monitor; and all deformation workers who have helped to measure the permanent-glass EDM network. I also thank T. English and P. Delaney for their support with computer programing and management of the data base. Finally, I thank C.C. Heliker and T.L. Wright for helpful reviews of this paper.

Mauna Loa Permanent-Glass EDM Network

The marks of the instrument stations on Mauna Loa are, either a standard U.S. Geological Survey or U.S. Coast and Geodetic Survey disk cemented into bedrock, or a steel rod (with an aluminum tag attached to it) driven and sometimes cemented into the ground. The EDM instrument is set up directly over the "+" on the survey disk or centered on the top of the steel rod using an optical tribrach.

The reflector station consists of a relatively inexpensive, sealed, nitrogen-filled reflector prism(s) attached to a steel rod that is embedded (sometimes cemented) in the ground. Appendix I contains station descriptions and Appendix II lists coordinates of the Mauna Loa permanent-glass EDM network stations.

The summit was the first area on Mauna Loa to be monitored with permanent-glass EDM in August 1979 in order to track the inflation/deflation cycles of Mauna Loa. This early summit monitor, installed by A.T. Okamura, K.M. Yamashita, and M.K. Sako, consisted of three lines that cross Mokuaweoweo Caldera, and was measured infrequently to March 1983 when the highway reflectors were replaced by sealed, nitrogen-filled reflector prisms. The reflector stations of the current monitor, plotted in figure 1, use the same steel rods that the highway reflectors were mounted on.

Permanent-glass EDM monitors were established on the northeast and southwest rifts (see figures 1 and 2) in May and August 1987 by R. Y. Hanatani, T.L. Wright, and W. Lacy. This was done to enable HVO to track any future horizontal ground deformation on the rift zones in a more timely manner and with less commitment of manpower and resources.

The *northeast rift zone monitors* consist of cross-rift lines at Puu Ulaula (10,000' elevation) and at Steam Cone (11,800' elevation). The lines are orthoganal to the axis of the northeast rift zone (except the line south from Steam Cone where a neighboring cone blocks the line of sight) and span distances of 6.8 km at Puu Ulaula and 3.7 km at Steam Cone. These monitors cross parts of the rift zone through which dikes associated with the 1984 eruption propagated.

There are three cross-rift monitors on the *southwest rift zone* at Puu O Keokeo (6,900' elevation), Bluebird (9,200' elevation), and Spatter (12,050' elevation). These lines are orthogonal to the axis of the southwest rift zone (except the lines west from Keokeo and southeast from Spatter where neighboring cones block the line of sight) and span a distance of 8.8 km at Puu O Keokeo, 5.0 km at Bluebird, and 2.9 km at Spatter. Monitoring the southwest rift zone has become very important because of the commercial and residential growth of areas downslope from the rift in recent years.

This factor combined with the historically sparse coverage on this rift zone, made establishing a permanent-glass EDM monitor there a high priority at HVO.

The permanent-glass EDM measurements on Mauna Loa can be done by two workers and requires only one helicopter trip per monitor line. The helicopter can stay at the instrument site (a critical advantage as bad weather often closes in quickly on Mauna Loa) instead of transporting reflector people to other points on the volcano. The monitors can usually be measured in a single day (starting at daybreak). The usual weather pattern on Mauna Loa has clear weather from daybreak to approximately midday and so it is important to get as early a start as possible.

We intend to measure all of the monitors at least three or four times per year. Major EDM trilateration measurements can then be planned using the permanent-glass EDM monitor results as a guide.

Equipment

We have used four different EDM instruments to measure the Mauna Loa permanent-glass EDM network. Of the four (Keuffel & Esser RangeMaster III, Geodimeter Model 8, Hewlett Packard 3808a, and Keuffel & Esser Ranger Va), the majority of the measurements have been done with the RangeMaster III and Ranger Va instruments. We plan to use the Ranger Va as the main instrument for measuring the network in the future because this instrument seems to be the best suited for the length of lines in the network and for the physical conditions on Mauna Loa.

We record the temperature and altitude measurements only at the instrument station while a specific line is being measured to correct for atmospheric effects on the line measurements. The temperature is measured with a Electro-therm TM-99 digital thermometer that has a shielded probe attached to the top of a telescopic pole 6 m above the ground surface. The altitude is measured using a Wallace and Tiernan altimeter.

Measurement Procedure

The procedure we use to measure a permanent-glass EDM line is listed below.

1. Set up EDM instrument over station mark and temperature probe on pole 6 m above the ground surface.
2. Allow EDM instrument to warm up for at least ten minutes.
3. Measure the height of the instrument. The height of the instrument above the ground is measured from the disk or top of the steel rod to the horizontal

axis about which the instrument rotates vertically. (The height of the reflector station is always assumed to be 50 cm).

4. Begin measuring the length of the line with the EDM instrument and recording temperature and altitude measurements for atmospheric corrections.
5. Record one temperature reading for every two line length measurements. Record two altitude measurements, one at the start and one at the end of a complete set of line length measurements.
6. After ten line length measurements are recorded, check to see that all readings are within 20 mm of each other. If they are, the set of line length measurements is complete.
7. If the readings are not within 20 mm of each other, take two more readings. Discard the high and low value of the set of twelve readings and if the remaining readings are within 20 mm of each other, the set of line length measurements are complete.
8. If they are not, take a minimum total of fifteen readings to complete the set of line length measurements.
9. Record the last altitude and temperature readings.

We reduce the raw line length and atmospheric correction measurements to a mark to mark slope distance using computer programs developed at HVO.

Results

The measurements of the current summit monitor's lines (2PA, 3PA, and 6PA) from March 3, 1983 to August 5, 1987 are listed in tables 1 to 3 and are plotted in figures 3 to 5 respectively. Table 4 contains the measurements of the earlier monitor on the summit. All of the distances in this report are mark to mark slope distances. The changes associated with two recent major events on Mauna Loa - the November 1983 magnitude 6.6 Kaoiki earthquake on the southeastern flank and the March 25 to April 15, 1984 summit and northeast rift zone eruption can clearly be seen.

The Kaoiki earthquake caused lines 2PA and 3PA to extend (0.024 m and 0.028 m respectively) and line 6PA to contract (0.032 m). The 1984 eruption had a major affect on all three permanent-glass EDM lines on the summit. The large extensions reflect the emplacement of a dike in Mokuaweoweo caldera that preceeded the initial eruption in Mokuaweoweo caldera. The subsequent contraction of all lines represents the deflation of the summit as magma drained from the summit magma chamber and exited underground to feed the eruption on the northeast rift zone. All lines have

extended since the end of the 1984 eruption, signaling reinflation of the summit caused by magma once again being stored beneath this area.

Tables 5 and 6 contain the measurements of lines on the northeast rift zone and the southwest rift zone, respectively from May 29, 1987 to August 5, 1987. There were no significant changes in line lengths during the short period of these monitor's existence.

Summary

Permanent-glass EDM lines have proven very useful in monitoring the summit of Mauna Loa. Timely measurements of the lines have successfully tracked the pre-eruption inflation, dike emplacement, and deflation related to the 1984 eruption. The summit has reinflated since the end of the eruption as evidenced by the extension of the three lines across the summit area. The rate of reinflation is one piece of important information used to evaluate when Mauna Loa could be primed for another eruption.

Since the rift zone monitors have been in operation for a short period of time, their effectiveness in tracking volcanic activity has not yet been established. We are hopeful that they will be as effective as the summit monitor. If they are, these measurements will give a better understanding of the current activity (or lack of it) in these areas, with a significant reduction in the amount of manpower and helicopter support required to obtain this data.

References

Lockwood, J.P., Dvorak, J.J., English, T.T., Koyanagi, R.Y., Okamuara, A.T., Summers, M.L., and Tanigawa, W.R., 1987, Mauna Loa 1974-1984: a decade of intrusive and extrusive activity, chap. 19, in Decker, R.W., Wright, T.L., and Stauffer, P.H., eds., Volcanism in Hawaii: U.S. Geological Survey Professional Paper 1350, v. 1, p. 537-570.

Figure 1. Location map of permanent-glass EDM stations on the summit and northeast rift zone of Mauna Loa.

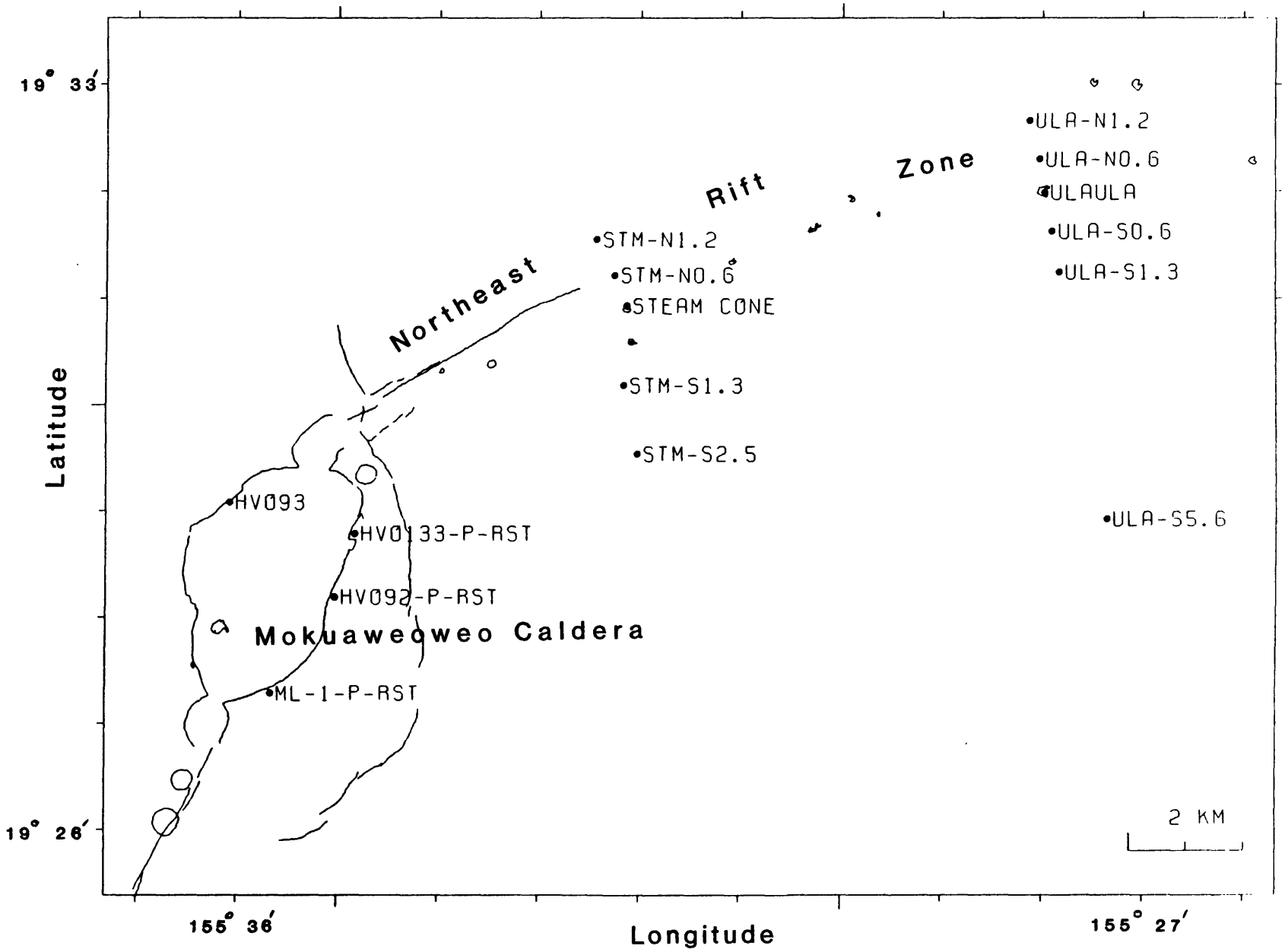

Figure 2. Location map of permanent-glass EDM stations on the southwest rift zone of Mauna Loa.

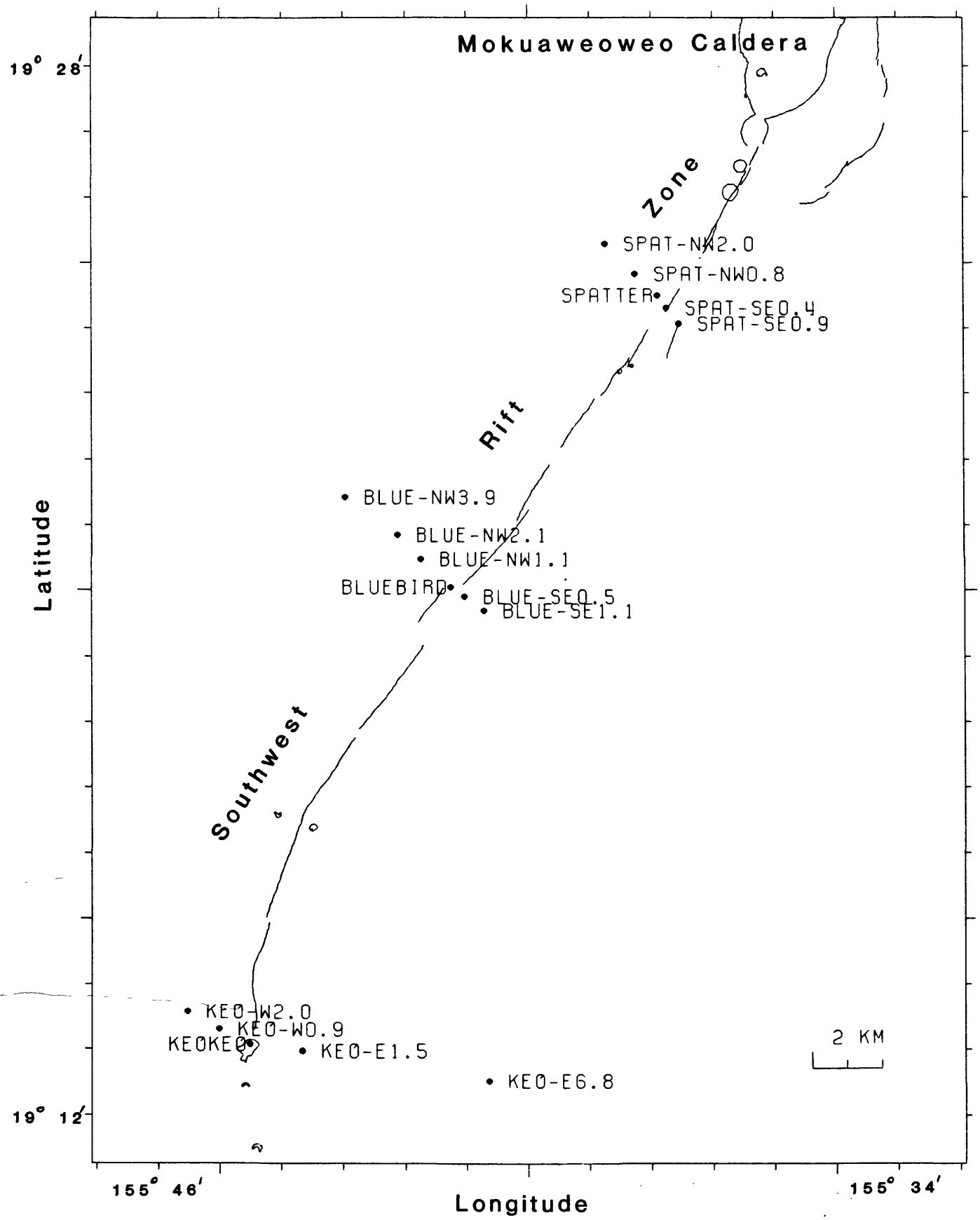

Figure 3. Timeseries plot of line lengths for line 2PA from March 23, 1983 to May 29, 1987.

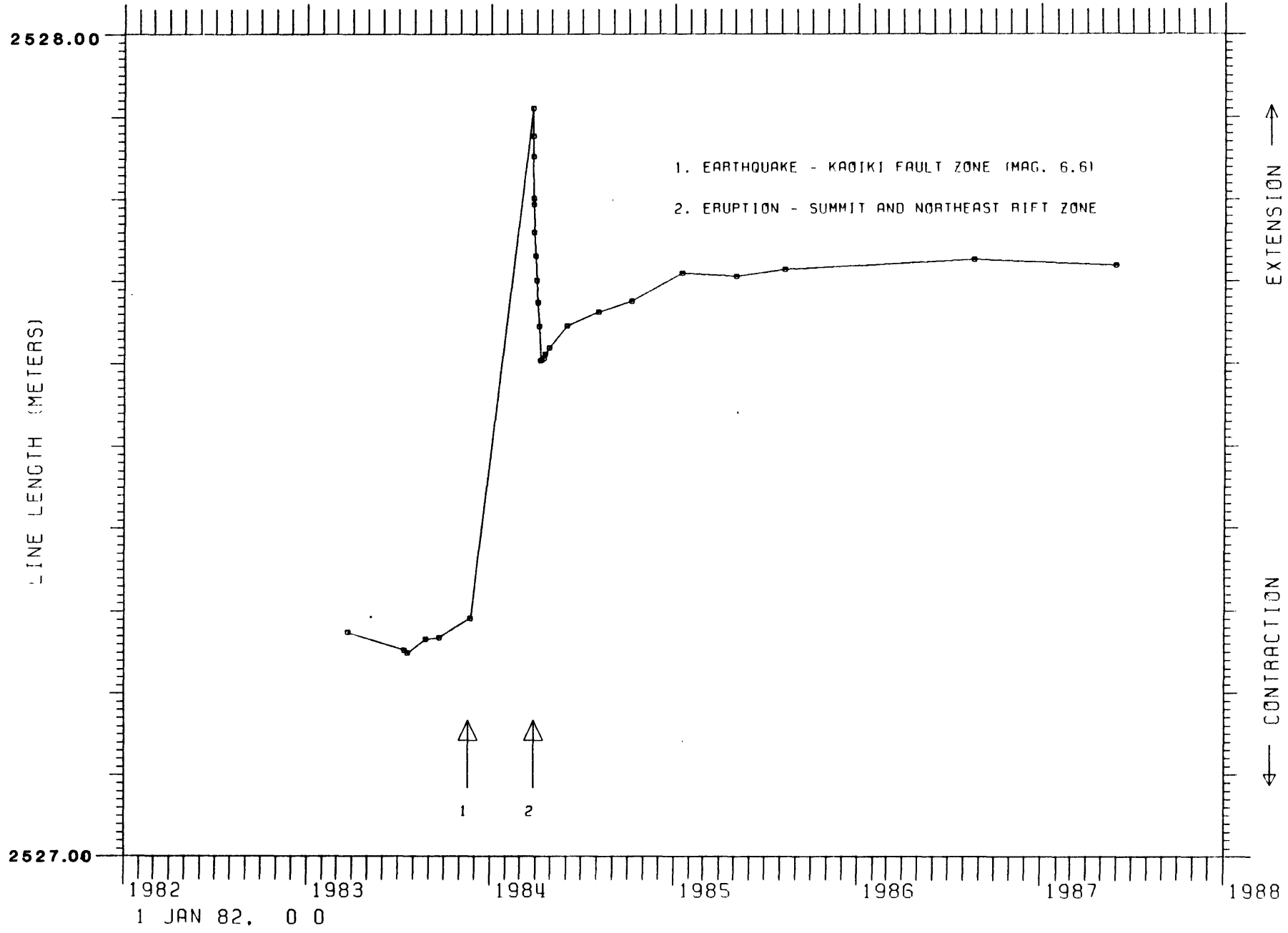

Figure 4. Timeseries plot of line lengths for line 3PA from March 23, 1983 to May 29, 1987.

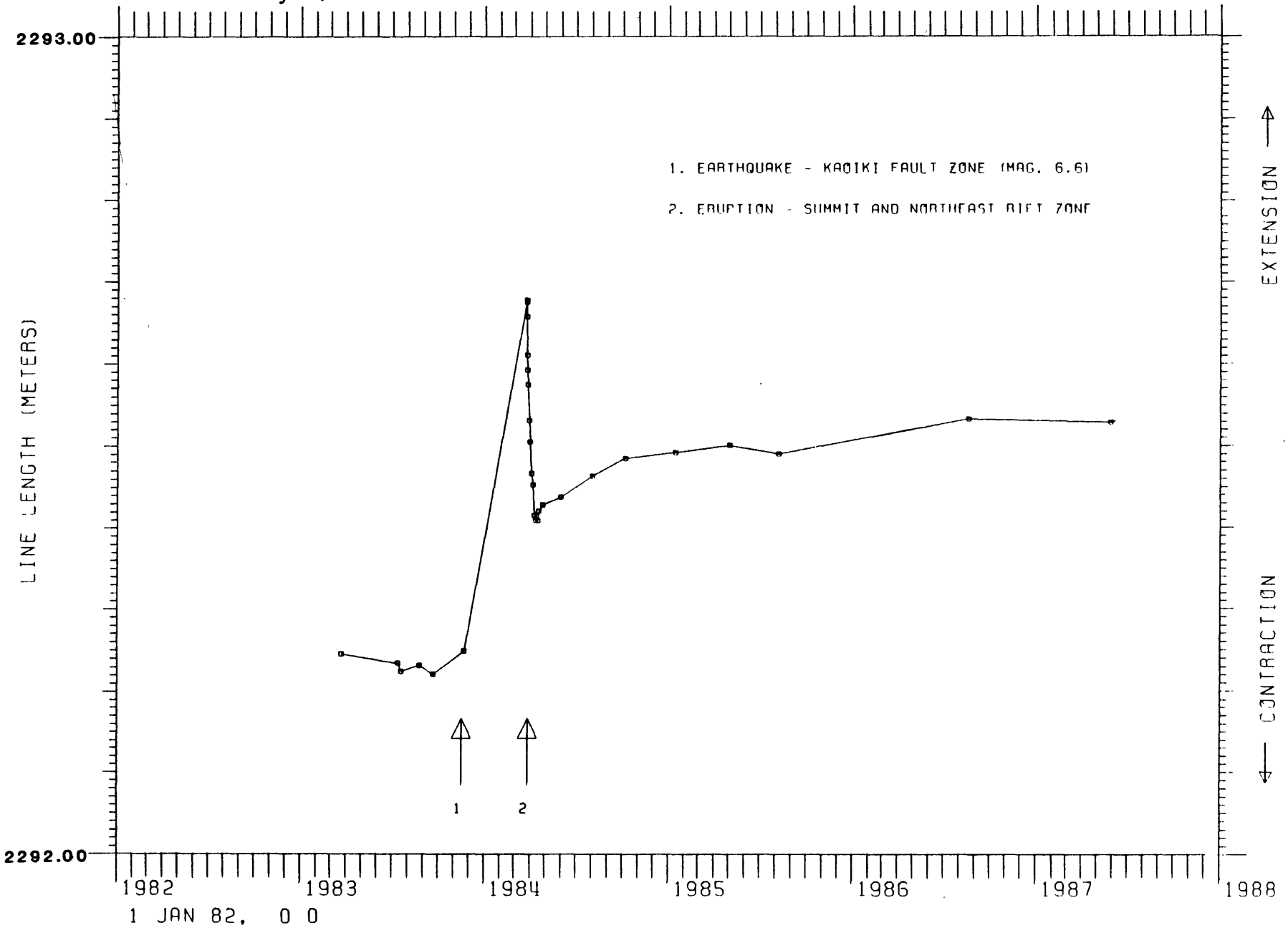

Figure 5. Timeseries plot of line lengths for line 6PA from March 23, 1983 to May 29, 1987.

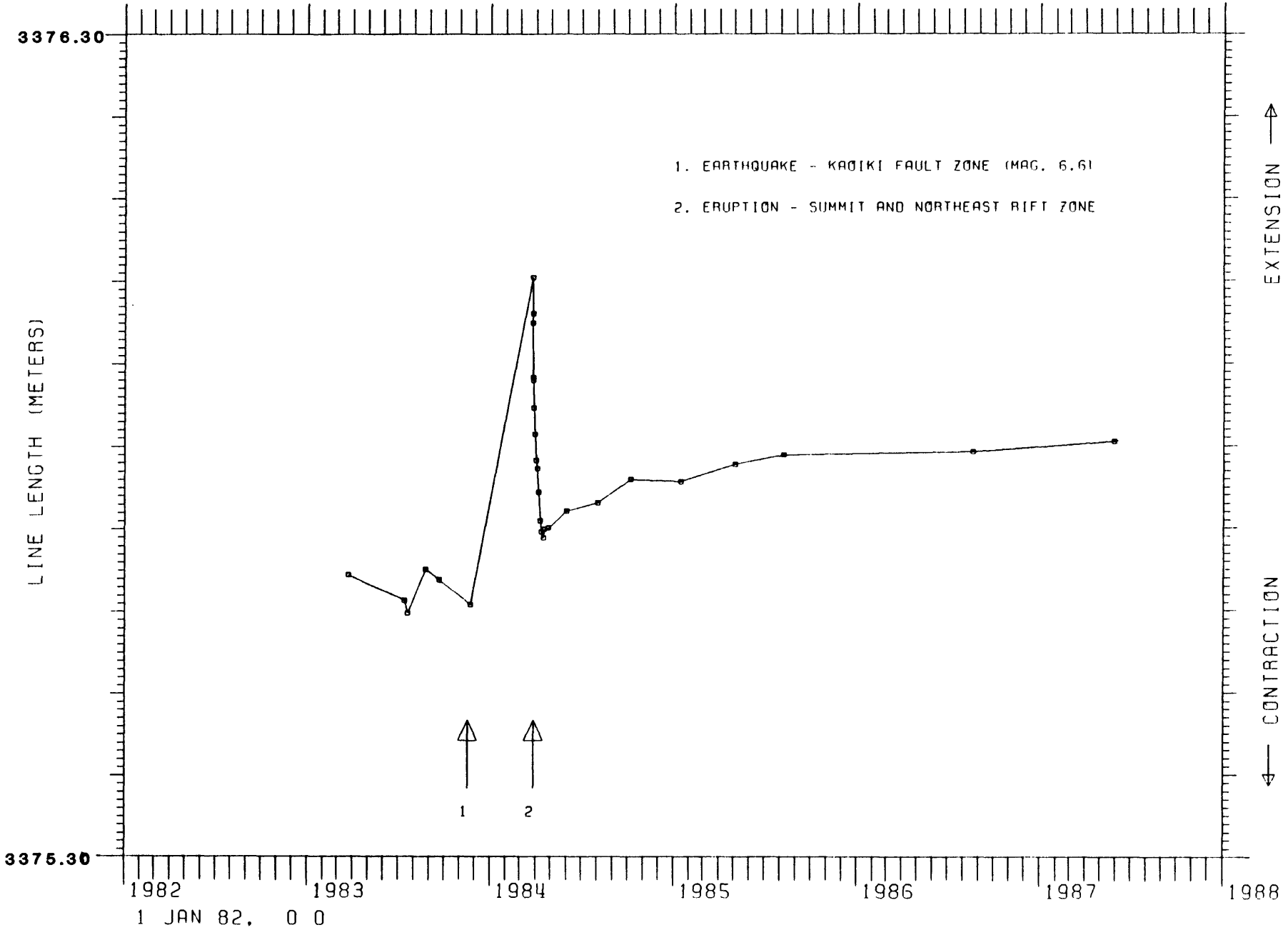

TABLE 1.

MAUNA LOA SUMMIT PERMANENT-GLASS EDM RESULTS

LINE 2PA HVO93 to HVO92-P-RST

Date	Time	Inst.	Slope Distance (m)
03/23/83	1115	RM	2527.274
07/13/83	1148	RM	2527.253
07/19/83	1026	HP	2527.249
08/24/83	1121	RM	2527.266
09/21/83	1027	RM	2527.268
11/22/83	1021	RM	2527.292
03/25/84	1133	G8	2527.910
03/25/84	1358	G8	2527.877
03/25/84	1532	G8	2527.852
03/26/84	0915	HP	2527.802
03/26/84	1136	HP	2527.794
03/27/84	1143	HP	2527.760
03/30/84	0907	RM	2527.731
04/01/84	1150	RM	2527.701
04/03/84	1502	RM	2527.675
04/06/84	1200	RM	2527.646
04/09/84	1040	RM	2527.604
04/12/84	0935	RM	2527.605
04/16/84	1110	RM	2527.607
04/18/84	1117	RM	2527.612
04/26/84	1033	RM	2527.620
06/01/84	1040	RM	2527.647
08/02/84	1043	RM	2527.663
10/06/84	1120	RM	2527.677
01/15/85	1055	RM	2527.710
05/ 2/85	1105	RM	2527.706
08/07/85	1557	RM	2527.715
08/20/86	1000	RM	2527.727
05/29/87	1144	RV	2527.720

RM = Keuffel and Esser RangeMaster III
HP = Hewlett-Packard 3808a
G8 = Geodimeter Model 8
RV = Keuffel and Esser Ranger Va

TABLE 2.

MAUNA LOA SUMMIT PERMANENT-GLASS EDM RESULTS

LINE 3PA HVO93 to HVO133-P-RST

Date	Time	Inst.	Slope Distance (m)
03/23/83	1222	RM	2292.246
07/13/83	1150	RM	2292.234
07/19/83	1013	HP	2292.225
08/24/83	1126	RM	2292.232
09/21/83	1200	RM	2292.221
11/22/83	1024	RM	2292.249
03/25/84	1108	G8	2292.678
03/25/84	1526	HP	2292.611
03/26/84	1157	HP	2292.593
03/27/84	1136	HP	2292.574
03/30/84	0911	RM	2292.532
04/03/84	1534	RM	2292.467
04/06/84	1150	RM	2292.453
04/09/84	1035	RM	2292.416
04/12/84	0941	RM	2292.409
04/16/84	1045	RM	2292.409
04/18/84	1110	RM	2292.421
04/26/84	1033	RM	2292.429
06/01/84	1050	RM	2292.437
08/02/84	1200	RM	2292.464
10/06/84	1110	RM	2292.485
01/15/85	1051	RM	2292.492
05/02/85	1100	RM	2292.501
08/07/85	1620	RM	2292.490
08/20/86	1011	RM	2292.533
05/29/87	1139	RV	2292.529

RM = Keuffel and Esser RangeMaster III
HP = Hewlett-Packard 3808a
G8 = Geodimeter Model 8
RV = Keuffel and Esser Ranger Va

TABLE 3.

MAUNA LOA SUMMIT PERMANENT-GLASS EDM RESULTS

LINE 6PA HVO93 to ML-1-P-RST

Date	Time	Inst.	Slope Distance (m)
03/23/83	1136	RM	3375.644
07/13/83	1145	RM	3375.614
07/19/83	1103	HP	3375.598
08/24/83	1116	RM	3375.651
09/21/83	1025	RM	3375.639
11/22/83	1018	RM	3375.609
03/25/84	1155	G8	3376.004
03/25/84	1350	G8	3375.961
03/25/84	1540	G8	3375.949
03/26/84	0925	HP	3375.884
03/26/84	1129	HP	3375.880
03/27/84	1209	HP	3375.847
03/30/84	0902	RM	3375.814
04/01/84	1145	RM	3375.783
04/03/84	1509	RM	3375.773
04/06/84	1205	RM	3375.744
04/09/84	1045	RM	3375.710
04/12/84	0931	RM	3375.696
04/16/84	1104	RM	3375.689
04/18/84	1122	RM	3375.699
04/26/84	1036	RM	3375.701
06/01/84	1030	RM	3375.722
08/02/84	1050	RM	3375.731
10/06/84	1125	RM	3375.759
01/15/85	1105	RM	3375.757
05/02/85	1110	RM	3375.778
08/07/85	1606	RM	3375.790
08/20/86	0944	RM	3375.793
05/29/87	1132	RV	3375.806

RM = Keuffel and Esser RangeMaster III
HP = Hewlett-Packard 3808a
G8 = Geodimeter Model 8
RV = Keuffel and Esser Ranger Va

TABLE 4.

MAUNA LOA SUMMIT (OLD NETWORK) PERMANENT-GLASS EDM RESULTS

LINE	DATE	TIME	INST.	SLOPE DIST. (m)
2PM (HVO93 to HVO92-P)	08/08/79	1200	G8	2527.231
2PM (HVO93 to HVO92-P)	10/04/79	1200	G8	2527.201
2PM (HVO93 to HVO92-P)	04/30/80	1200	G8	2527.256
3PM (HVO93 to HVO133-P)	10/04/79	1200	G8	2292.218
3PM (HVO93 to HVO133-P)	04/30/80	1200	G8	2292.236
6PM (HVO93 to ML-1-P)	08/08/79	1200	G8	3375.550
6PM (HVO93 to ML-1-P)	10/04/79	1200	G8	3375.558
6PM (HVO93 to ML-1-P)	07/08/80	1200	HP	3375.298

G8 = Geodimeter Model 8
HP = Hewlett-Packard 3808a

TABLE 5.

MAUNA LOA NORTHEAST RIFT ZONE PERMANENT-GLASS EDM RESULTS

LINE	DATE	TIME	INST.	SLOPE DIST. (m)
P38 (ULAULA to ULA-S5.6)	05/29/87	1000	RV	5663.459
P39 (ULAULA to ULA-S1.3)	05/29/87	1005	RV	1392.194
P39 (ULAULA to ULA-S1.3)	08/05/87	1319	RV	1392.211
P39 (ULAULA to ULA-S1.3)	08/05/87	1340	RV	1392.213
P40 (ULAULA to ULA-S0.6)	05/29/87	1010	RV	683.445
P40 (ULAULA to ULA-S0.6)	08/05/87	1321	RV	683.466
P40 (ULAULA to ULA-S0.6)	08/05/87	1342	RV	683.470
P41 (ULAULA to ULA-N0.6)	05/29/87	0957	RV	671.537
P41 (ULAULA to ULA-N0.6)	08/05/87	1327	RV	671.553
P41 (ULAULA to ULA-N0.6)	08/05/87	1338	RV	671.555
P42 (ULAULA to ULA-N1.2)	05/29/87	0950	RV	1277.251
P42 (ULAULA to ULA-N1.2)	08/05/87	1324	RV	1277.259
P42 (ULAULA to ULA-N1.2)	08/05/87	1335	RV	1277.259
P43 (STEAM CONE to STM-S2.5)	05/29/87	1042	RV	2532.690
P43 (STEAM CONE to STM-S2.5)	08/05/87	1208	RV	2532.700
P43 (STEAM CONE to STM-S2.5)	08/05/87	1236	RV	2532.696
P44 (STEAM CONE to STM-S1.3)	05/29/87	1047	RV	1384.149
P44 (STEAM CONE to STM-S1.3)	08/05/87	1211	RV	1384.155
P44 (STEAM CONE to STM-S1.3)	08/05/87	1240	RV	1384.159
P45 (STEAM CONE to STM-N0.6)	05/29/87	1054	RV	601.251
P45 (STEAM CONE to STM-N0.6)	08/05/87	1214	RV	601.279
P45 (STEAM CONE to STM-N0.6)	08/05/87	1233	RV	601.275
P46 (STEAM CONE to STM-N1.2)	05/29/87	1050	RV	1240.486
P46 (STEAM CONE to STM-N1.2)	08/05/87	1217	RV	1240.507
P46 (STEAM CONE to STM-N1.2)	08/05/87	1231	RV	1240.504

RV = Keuffel and Esser Ranger Va

TABLE 6.

MAUNA LOA SOUTHWEST RIFT ZONE PERMANENT-GLASS EDM RESULTS

LINE	DATE	TIME	INST.	SLOPE DIST. (m)
P47 (KEOKEO to KEO-E6.8)	08/05/87	0806	RV	6821.065
P47 (KEOKEO to KEO-E6.8)	08/05/87	0838	RV	6821.069
P48 (KEOKEO to KEO-E1.5)	08/05/87	0810	RV	1509.143
P48 (KEOKEO to KEO-E1.5)	08/05/87	0834	RV	1509.146
P49 (KEOKEO to KEO-W2.0)	08/05/87	0814	RV	2063.209
P49 (KEOKEO to KEO-W2.0)	08/05/87	0826	RV	2063.212
P50 (KEOKEO to KEO-W0.9)	08/05/87	0817	RV	970.585
P50 (KEOKEO to KEO-W0.9)	08/05/87	0829	RV	970.589
P51 (BLUEBIRD to BLUE-SE1.1)	08/05/87	0918	RV	1140.739
P51 (BLUEBIRD to BLUE-SE1.1)	08/05/87	0948	RV	1140.728
P52 (BLUEBIRD to BLUE-SE0.5)	08/05/87	0921	RV	527.564
P52 (BLUEBIRD to BLUE-SE0.5)	08/05/87	0950	RV	527.564
P53 (BLUEBIRD to BLUE-NW3.9)	08/05/87	0925	RV	3913.800
P53 (BLUEBIRD to BLUE-NW3.9)	08/05/87	0939	RV	3913.792
P54 (BLUEBIRD to BLUE-NW2.1)	08/05/87	0928	RV	2136.786
P54 (BLUEBIRD to BLUE-NW2.1)	08/05/87	0942	RV	2136.790
P55 (BLUEBIRD to BLUE-NW1.1)	08/05/87	0931	RV	1188.541
P55 (BLUEBIRD to BLUE-NW1.1)	08/05/87	0946	RV	1188.543
P56 (SPATTER to SPAT-SE0.9)	08/05/87	1040	RV	981.443
P56 (SPATTER to SPAT-SE0.9)	08/05/87	1103	RV	981.424
P57 (SPATTER to SPAT-SE0.4)	08/05/87	1041	RV	436.635
P57 (SPATTER to SPAT-SE0.4)	08/05/87	1105	RV	436.641
P58 (SPATTER to SPAT-NW2.0)	08/05/87	1043	RV	2080.843
P58 (SPATTER to SPAT-NW2.0)	08/05/87	1055	RV	2080.833
P59 (SPATTER to SPAT-NW0.8)	08/05/87	1046	RV	877.634
P59 (SPATTER to SPAT-NW0.8)	08/05/87	1057	RV	877.644

RV = Keuffel and Esser Ranger Va

APPENDIX I

PERMANENT-GLASS EDM STATIONS ON MAUNA LOA

Summit

HVO93 Instrument station (U.S. Geological Survey disk stamped "HVO93") located approximately 400 m south of the end of the 4-wheel drive summit road (13,570' elevation), 20 m northwest from the rim of Mokuaweoweo Caldera.

HVO92-P-RST Reflector station located on flat pahoehoe lava approximately 60 m northeast of the summit cabin, 2.52 km southeast of and bearing 130 degrees from the HVO93 instrument station. Located at 13,250' elevation and marked with a stone cairn with the top painted yellow. HVO92-P-RST station has two prisms mounted on a 1" diameter steel rod that extends approximately 0.5 m above the ground surface and is shot from HVO93 instrument station.

HVO133-P-RST Reflector station located on broken pahoehoe lava, 2.29 km east of and bearing 100 degrees from the HVO93 instrument station. Located at 13,245' elevation, between the trail to the cabin and the rim of Mokuaweoweo Caldera, next to the HVO133 EDM benchmark. Station is marked with a stone cairn with the top painted yellow. HVO133-P-RST station has two prisms mounted on a 1" diameter steel rod that extends approximately 0.5 m above the ground surface and is shot from HVO93 instrument station.

ML-1-P-RST Reflector station located on a broad pahoehoe tumulus, 3.37 km south-southeast of and bearing 165 degrees from the HVO93 instrument station. Located at 13,290' elevation, approximately 15 m southeast from the rim of Mokuaweoweo Caldera. Station is marked with a stone cairn with the top painted yellow. ML-1-P-RST station has two prisms mounted on a 1" diameter steel rod that extends approximatley 0.5 m above the ground surface and is shot from HVO93 instrument station.

APPENDIX I (cont.)

PERMANENT-GLASS EDM STATIONS ON MAUNA LOA

Northeast Rift Zone

ULAULA Instrument station (U.S. Coast and Geodetic Survey disk stamped "Puu Ulaula 2 1949 1967") located on the high point of Puu Ulaula (Red Hill) cinder cone (10,060' elevation), near the Red Hill cabin on the northeast rift zone of Mauna Loa. Caution: there is a U.S. Geological Survey benchmark approximately 1 m southeast of the station that should not be used when measuring the permanent-glass stations.

ULA-S5.6 Reflector station located on black pahoehoe lava, 5.66 km south of and bearing 167 degrees from the ULAULA instrument station. Located at 8,450' elevation, 100 m north of a brown a'a lava flow. The station is 3 m east of ELEIKI NEW EDM benchmark and is marked with large painted yellow circle and a white flag. ULA-S5.6 station has two prisms mounted on a 3/4" diameter steel rod that extends approximately 0.5 m above the ground surface and is shot from ULAULA instrument station.

ULA-S1.3 Reflector station located on a black pahoehoe lava pad, 1.38 km south of and bearing 167 degrees from the ULAULA instrument station. Located at 9,620' elevation, surrounded by red a'a lava flows and marked with large painted yellow circle and a white flag. ULA-S1.3 station has one prism mounted on a 3/4" diameter steel rod that extends approximately 0.5 m above the ground surface and is shot from ULAULA instrument station.

ULA-S0.6 Reflector station located on a black pahoehoe lava flow, 0.68 km south of and bearing167 degrees from the ULAULA instrument station. Located at 9,840' elevation, 50 m east of a prominant tumulus, 3 m south of a lava tube channel and marked with a large painted yellow circle and a white flag. ULA-S0.6 has one prism mounted on a 3/4" diameter steel rod that extends approximately 0.5 m above the ground surface and is shot from ULAULA instrument station.

APPENDIX I (cont.)

PERMANENT-GLASS EDM STATIONS ON MAUNA LOA

ULA-N0.6 Reflector station located on a black pahoehoe lava flow, 0.67 km north of and bearing 348 degrees from the ULAULA instrument station. Located at 9,910' elevation, 50 m north of a brown pahoehoe lava flow and marked with a large painted yellow circle and a white flag. ULA-N0.6 station has one prism mounted on a 3/4" diameter steel rod that extends approximately 0.5 m above the ground surface and is shot from ULAULA instrument station.

ULA-N1.2 Reflector station located on a brown spatter rampart, 1.27 km north (on the skyline) of and bearing 348 degrees from the ULAULA instrument station. Located at 9,800' elevation, surrounded by a black pahoehoe lava flow and marked with a large painted yellow circle and a white flag. ULA-N1.2 has one prism mounted on a 3/4" diameter steel rod that extends approximately 0.3 m above the ground surface and is shot from ULAULA instrument station.

STEAM CONE Instrument station (U.S. Geological Survey disk stamped "STEAM 1955") cemented in a pipe on a cinder cone on the northeast rift zone of Mauna Loa. Cinder cone is usually emitting steam and is at 11,790' elevation.

STM-S2.5 Reflector station located on brown pahoehoe tumulus, 2.53 km south (on the skyline) of and bearing 175 degrees from the STEAM CONE instrument station. Located at 11,640' elevation, 25 m south of a'a flow and marked with a large painted yellow circle and a white flag. STM-S2.5 station has one prism mounted on a 3/4" diameter steel rod that extends approximately 0.5 m above the ground surface and is shot from STEAM CONE instrument station.

STM-S1.3 Reflector station located on a black pahoehoe pad surrounded by a'a flows, 1.39 km south of and bearing 180 degrees from the STEAM CONE instrument station. Located at 11,720' elevation and marked with a large painted yellow circle and a white flag. STM-S1.3 station has one prism mounted on a 3/4" diameter steel rod that extends approximately 0.5 m above the ground surface and is shot from STEAM CONE instrument station.

APPENDIX I (cont.)

PERMANENT-GLASS EDM STATIONS ON MAUNA LOA

STM-N0.6 Reflector station located on black pahoehoe lava flow, 0.60 km northwest of and bearing 335 degrees from the STEAM CONE instrument station. Located at 11,630' elevation, 10 m south of a'a flow and marked with a large yellow painted circle and a white flag. STM-N0.6 station has one prism mounted on a 3/4" diameter steel rod that extends approximately 0.5 m above the ground surface and is shot from STEAM CONE instrument station.

STM-N1.2 Reflector station located on black phoehoe lava flow, 1.24 km northwest (on the skyline) of and bearing 335 degrees from the STEAM CONE instrument station. Located at 11,560' elevation, on the north edge of a large lava channel and marked with a large yellow painted circle and a white flag. STM-N1.2 station has one prism mounted on a 3/4" diameter steel rod that extends approximately 0.5 m above the ground surface and is shot from the STEAM CONE instrument station.

Southwest Rift Zone

KEOKEO Instrument station (1" steel rod with tag stamped "Tag 77-104") located on top of the east rim of broad low cinder cone complex.The station is at 6,890' elevation and is marked with a stone cairn painted white and a white flag.

KEO-W2.0 Reflector station located on red-brown prehistoric pahoehoe lava, 2.06 km west-northwest of and bearing 297 degrees from KEOKEO instrument station. Located at 6,500' elevation between two dark a'a lava flows of 1916 and marked with large yellow painted circle and a white flag. KEO-W2.0 station has two prisms mounted on a 3/4 " diameter steel rod that extends approximately 0.5 m above the gound surface and is shot from KEOKEO instrument station.

KEO-W 0.9 Reflector station located on the dark, a'a lava flow of 1916, 0.97 km west-northwest of and bearing 298 degrees from KEOKEO instrument station. Located at 6,680' elevation on east side of lava channel and marked with large yellow painted circle and a white flag. KEO-W0.9 station has one prism mounted on a 3/4" diameter

steel rod that extends approximately 0.5 m above the ground surface and is shot from KEOKEO station.

KEO-E 1.5 Reflector station located on the dark, a'a lava flow of 1916, 1.50 km east of and bearing 99 degrees from KEOKEO instrument station. Located at 6,520' elevation on the north side of a prominant lava channel and marked with large yellow painted circle and a white flag. KEO-E1.5 station has one prism mounted on a 3/4" diameter steel rod that extends approximately 0.5 m above the ground surface and is shot from KEOKEO instrument station.

KEO-E6.8 Reflector station located on a large tumulus covered by low shrub and tree growth, 6.81 km east of and bearing 99 degrees from KEOKEO instrument station. Located at 6,000' elevation and marked with a large painted yellow circle and a white flag. KEO-E6.8 station has two prisms mounted on a 3/4" diameter steel rod that extends approximately 0.5 m above the ground station and is shot from KEOKEO instrument station.

BLUEBIRD Instrument station (1" diameter steel rod with tag stamped "Tag 75-58") located on the northeast rim of oxidized cinder cone breached at downrift end with collapsed lava channel inside. The station is at 9,200' elevation and is marked with a stone cairn painted white and a white flag. There is a companion cinder cone approximately the same height 300 m to the west.

BLUE-SE1.1 Reflector station located on broken, brown pahoehoe, 1.14 km southwest (on the skyline) of and bearing 124.5 degrees from the BLUEBIRD instrument station. Located at 9,080' elevation, 50 m west of large skylight of lava tube system and marked with a large painted yellow circle and a white flag. BLUE-SE1.1 station has one prism mounted on a 3/4" diameter steel rod that extends approximately 0.5 m above the ground surface and is shot from BLUEBIRD instrument station.

APPENDIX I (cont.)

PERMANENT-GLASS EDM STATIONS ON MAUNA LOA

BLUE-SE0.5 Reflector station located on southern rim of a cinder cone (truncated by a lava flow), 0.53 km southeast of and bearing 124 degrees from the BLUEBIRD instrument station. Located at 9,200' elevation and marked with a large painted yellow circle and a white flag. BLUE-SE0.5 station has one prism mounted on a 3/4" diameter steel rod that extends approximately 0.5 m above the ground surface and is shot from BLUEBIRD instrument station.

BLUE-NW3.9 Reflector station located on dark pahoehoe lava flow, 3.91 km northwest (on the skyline) of and bearing 310 degrees from the BLUEBIRD instrument station. Located at 8,580' elevation between two prominant tumuli, approximately 20 m apart and marked with a large painted yellow circle and a white flag. BLUE-NW3.9 station has two prisms mounted on a 3/4" diameter steel rod that extends approximately 0.5 m above the ground surface and is shot from BLUEBIRD instrument station.

BLUE-NW2.1 Reflector station located on southwestern end of spatter-cinder rampart, 2.13 km northwest of and bearing 313 degrees from the BLUEBIRD instrument station. Located at 8,880' elevation approximately one half the distance to the top of the rampart and marked with a large painted yellow circle and a white flag. BLUE-NW2.1 station has one prism mounted on a 3/4" diameter steel rod that extends approximately 0.5 m above the ground surface and is shot from BLUEBIRD instrument station.

BLUE-NW1.1 Reflector station located on light-brown pahoehoe lava flow, 1.19 km northwest of and bearing 312 degrees from the BLUEBIRD instrument station. Located at 9,000' elevation, approximately 100 m south of a large skylight and marked with a large painted yellow circle and a white flag. BLUE-NW1.1 station has one prism mounted on a 3/4" diameter steel rod that extends approximately 0.5 m above the ground surface and is shot from BLUEBIRD instrument station.

APPENDIX I (cont.)

PERMANENT-GLASS EDM STATIONS ON MAUNA LOA

SPATTER Instrument station (1" diameter steel rod with tag stamped "TAG77-113") located on an old spatter rampart 3.0 km south-southwest of Pohaku Hanalei. SPATTER is located at 12,050' elevation and is marked by a stone cairn painted white paint and a white flag.

SPAT-SE0.9 Reflector station located on northwest edge of small spatter cone, 0.98 km southeast of and bearing 141 degrees from the SPATTER instrument station. Located at 11,880' elevation and marked with a large painted yellow circle and a white flag. SPAT-SE0.9 station has one prism mounted on a 3/4" diameter steel rod that extends approximately 0.5 m above the ground surface and is shot from SPATTER instrument station.

SPAT-SE0.4 Reflector station located on a black pahoehoe lava flow 0.44 km southeast of and bearing 141 degrees from the SPATTER instrument station. Located at 12,000' elevation and marked with a large painted yellow circle and a white flag. SPAT-SE0.4 station has one prism mounted on a 3/4" diameter steel rod that extends approximately 0.5 m above the ground surface and is shot from SPATTER instrument station.

SPAT-NW2.0 Reflector station located on the east side of a lava channel 2.08 km northwest (on the skyline) of and bearing 315 degrees from the SPATTER instrument station. Located on light grey pahoehoe channel overflow surrounded by red-black aa lava at 11,600' elevation and marked with a large painted yellow circle and a white flag. SPAT-NW2.0 station has one prism mounted on a 3/4" diameter steel rod that extends approximately 0.5 m above the ground surface and is shot from SPATTER instrument station.

SPAT-NW0.8 Reflector station located 10 m east of line of fissures, 0.88 km northwest of and bearing 315 degrees from the SPATTER instrument station. Located on black pahoehoe lava at 11,880' elevation and marked with a large painted yellow circle and a white flag. SPAT-NW0.8 station has one prism mounted on a 3/4" diameter steel rod that extends approximately 0.5 m above the ground surface and is shot from SPATTER instrument station.

APPENDIX II

COORDINATES FOR MAUNA LOA PERMANENT-GLASS EDM STATIONS

STATION	LATITUDE (DEGREES N)	LONGITUDE (DEGREES W)
HVO93	19.4847	155.6013
HVO133-P-RST	19.4797	155.5805
HVO92-P-RST	19.4698	155.5839
ML-1-P-RST	19.4546	155.5945
ULA-S5.6	19.4818	155.4561
ULA-S1.3	19.5208	155.4641
ULA-S0.6	19.5272	155.4654
ULAULA	19.5332	155.4665
ULA-N0.6	19.5384	155.4674
ULA-N1.2	19.5444	155.4690
STM-S2.5	19.4921	155.5338
STM-S1.3	19.5030	155.5361
STEAM CONE	19.5155	155.5357
STM-N0.6	19.5204	155.5377
STM-N1.2	19.5258	155.5406
SPAT-NW2.0	19.4215	155.6459
SPAT-NW0.8	19.4138	155.6377
SPATTER	19.4083	155.6317
SPAT-SE0.4	19.4051	155.6291
SPAT-SE0.9	19.4012	155.6258
BLUE-NW3.9	19.3570	155.7161
BLUE-NW2.1	19.3475	155.7021
BLUE-NW1.1	19.3414	155.6959
BLUEBIRD	19.3342	155.6876
BLUE-SE0.5	19.3317	155.6840
BLUE-SE1.1	19.3281	155.6786
KEO-W2.0	19.2262	155.7588
KEO-W0.9	19.2217	155.7501
KEOKEO	19.2179	155.7418
KEO-E1.5	19.2162	155.7277
KEO-E6.8	19.2086	155.6773