U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

VOLCANOLOGIC INVESTIGATIONS IN THE COMMONWEALTH OF THE NORTHERN MARIANA ISLANDS, SEPTEMBER-OCTOBER 1990

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U.S. Geological Survey

Open-File Report 91-320

Prepared in cooperation with the Office of Civil Defense, Commonwealth of the Northern Mariana Islands

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ABSTRACT

U.S. Geological Survey volcanologists visited four volcanic islands (Anatahan, Alamagan, Pagan, and Agrigan) in the Northern Marianas during September-October 1990, at the request of the Office of Civil Defense (CD) for the Commonwealth of the Northern Mariana Islands (CNMI). A shallow earthquake swarm on Anatahan in March-April 1990 and reports of possible new fuming on Agrigan in August 1990 had prompted CD to evacuate all inhabited islands north of Saipan.

Permanent seismic stations were installed on Anatahan, Alamagan, and Pagan; data are radio-telemetered to Saipan and recorded at Civil Defense headquarters. No significant local microearthquakes or volcanic tremor have occurred on Anatahan, Alamagan, or Pagan since installation of the permanent stations. Seismographs operated for four days at temporary stations on Agrigan recorded no sustained microearthquake activity or volcanic tremor.

The team established a new EDM (electronic distance measurement) network on Agrigan. Remeasurement of EDM networks on Pagan and Anatahan showed no significant changes in line lengths, in accord with the lack of local seismicity.

The team conducted geologic studies on the floor of Agrigan's caldera and discovered a boiling hot spring, associated terrace deposits, and solfataras. These features may have started to form soon after Agrigan's most recent eruption in 1917. Temperatures of 25 solfataras and the hot spring water were 98°C. Water from the hot spring had a pH of 2.0. Abundances of gases emitted by the solfataras were 200-320 ppm HCl, 0-3 ppm CO, >3% CO_2, 1,900->2,000 ppm H_2S, and >400 ppm SO_2, but atmospheric dilution may have occurred.

We conclude that the low levels of local volcanic seismicity, deformation, and fuming indicate that the threat of eruptions in the immediate future on Anatahan, Pagan, and Agrigan is much reduced. However, a new surge in magmatic activity, such as apparently occurred on Anatahan in March-April 1990, could begin sometime in the future and once again increase the possibility of eruption.

INTRODUCTION

Seven U.S. Geological Survey volcanologists visited the Northern Marianas (fig. 1) September 24-October 6, 1990, at the request of the Office of Civil Defense for the Commonwealth of the Northern Mariana Islands. The team had two major goals: 1) assessment of the probability of eruption, mainly on Anatahan, Pagan, and Agrigan, and 2) installation of permanent seismometers on Anatahan, Alamagan, and Pagan.

Inhabited islands (Anatahan, Alamagan, Agrigan, and Asuncion) north of Saipan were evacuated earlier in 1990 because of a shallow earthquake swarm on Anatahan in March-April 1990 and reports of possible new fuming on Agrigan (also spelled Agrihan) in August 1990. Pagan Island has been evacuated since the major eruption of Mount Pagan on May 15, 1981 (Banks and others, 1984).

The Mariana Trench (fig. 1), about 200 km east of the Mariana island arc, is a seismically active subduction zone. The most recent sizable earthquakes (M 7.5 and 6.2) there occurred in April 1990. The subduction zone dips west and passes about 125 km beneath the island chain.

No volcanoes from Anatahan to Agrigan erupted during the visit. Five (Farallon de Pajaros, Asuncion, Agrigan, Pagan, and Guguan) have erupted since A.D. 1900 (Kuno, 1962). Farallon de Pajaros (Uracas), at the northern end of the island chain, has been intermittently active for more than a century (Tanakadate, 1940). Photographs taken by Civil Defense personnel in early August 1990 from a fixed-wing airplane show vigorous fuming on Farallon de Pajaros, but no further information is available.

This report summarizes the results of our visit and makes several recommendations to CD about maintenance of the seismic systems and future seismic, geologic, and volcanic deformation studies. A short summary of this report was published in the Bulletin of the Global Volcanism Network, v. 15, no. 10, October 31, 1990.

SEISMIC STUDIES

Agrigan

A revolving drum seismograph was installed in a building in Agrigan village (fig. 2) on September 28 and operated continuously until October 1. In conjunction with the continuous monitor, a portable chart-recording field seismograph was operated at numerous locations on the caldera floor for about five hours on September 28-29. Seismic records from these instruments indicated very weak and localized tremor near a boiling hot spring, but no seismicity to indicate an immediate threat of volcanic activity on Agrigan.

Pagan, Alamagan, Anatahan, and Saipan

The islands selected for installation of seismometers in the Northern Mariana Islands are widely separated: Saipan is about 126 km from Anatahan; Anatahan is about 124 km from Alamagan; and Alamagan is about 51 km from Pagan. Thus, the team needed to determine whether it was possible to telemeter seismic signals by radio to Saipan from the islands to its north, using relay stations on Alamagan and Anatahan. The experiment was successful, and three vertical component short-period seismic systems powered by solar panels and storage batteries were installed on South Pagan, Alamagan, and Anatahan. The seismic sensors were linked by radio to Saipan and continuously transmit signals for detection and selective recording at CD headquarters. Figure 3 gives technical specifications for the radios, seismometers, and electronic packages for the stations at Anatahan (ANA), Alamagan (ALA), and Pagan (PAG). Figures 4-6 show the locations of the seismic stations.

Data telemetered to Saipan show no significant shallow microearthquake activity on Pagan, Alamagan, or Anatahan since installation of the new stations.

Seismograms collected from a temporary seismograph station (SPN) installed at CD headquarters on Saipan from June-September 1990 were read and filed as an initial data set for seismic studies in the Northern Marianas. Sample seismograms of small earthquakes recorded in Saipan, at epicentral distances of slightly more than 100 km as indicated by their time separation of P and S waves, are shown in figure 7.

Station SPN is located at latitude 15.207°N and longitude 145.748°E; its elevation is 250 m. SPN detected 212 earthquakes, of which 75 were well recorded and picked for accurate timing. The records indicate a high level of earthquakes from the active subduction zone about 200 km east of the Northern Mariana Islands.

Regional distribution of moderate-sized earthquakes (M>5) from January-August 1990 reported by the U.S. Geological Survey's National Earthquake Information Center mainly outlines the concentration of aftershocks from the 7.5 magnitude earthquake in April 1990 about 100-200 km northeast of Saipan (figure 8a).

The frequency of major earthquakes of magnitude 7 or greater is high in the Northern Marianas. Data accumulated since 1902 indicate that 27 earthquakes with magnitudes of about 7.0 to 7.9 occurred in the region (figure 8b).

Recommendations to the Office of Civil Defense, CNMI

Installing the three permanent stations and linking them by radio to Saipan gives CD an opportunity to establish a system providing early warning of volcanic activity in the Northern Marianas. The network could be extended to other islands.

The three stations established for the test survey should be strengthened to withstand extreme weather conditions and supplied with power regulators for the solar panels so the batteries will last longer.

Figure 9 shows a suitable arrangement for a proposed seismological laboratory to house the data receiving system. The laboratory should be equipped with continuously operating seismic recorders for each of the transmitting field stations and should be designed to accommodate more instruments.

Training of local personnel is critically important for the success and long-term continuity of the seismic program. People with scientific capability and interest in volcanoes and seismic studies should participate in the development and maintenance of the seismic system and in scientific interpretation of the data.

GEOLOGY

Agrigan

New geologic studies during this visit centered on Agrigan Island, in an effort to evaluate the state of this volcano. Agrigan extends about 9 km north-south and 7 km east-west; it has two partly nested summit calderas about 2.2 and 1.5 km in diameter (fig. 2). The calderas apparently formed in the late Holocene as a consequence of voluminous (at least 2.2 km^3) pyroclastic eruptions of andesite (Stern, 1978). The outer caldera rim is remarkably narrow and, except on its northwestern side, is more than 400 m above the floor of the inner caldera. The outer caldera is elongated NW-SE; its northwestern part has collapsed the least and forms a shallow sector graben lower on the volcano's flank, to the northwest. The more circular inner caldera truncates part of the northwestern segment of the outer caldera and is partly coincident on its eastern side with the outer caldera. The nearly vertical walls of the inner caldera are 150-400 m high.

Agrigan most recently erupted in 1917; showers of basaltic scoria and bombs as large as 1 m in diameter buried most of the island to a depth of as much as 3 m (Tanakadate, 1940). The eruption probably was Plinian, on the basis of the great thickness and wide distribution of scoria and comparison of eyewitness reports in 1917 with those of the May 15, 1981, Plinian eruption of Mount Pagan (Banks and others, 1984).

We were transported by helicopter to the otherwise inaccessible inner caldera floor and believe that, based in part on statements by Stern (1978, 1979), we were the first geologists ever to work there. We present observations of the 1917 products and interpretations of eruptive events during that activity that differ somewhat from those of Tanakadate (1940) and Stern (1978). In contrast to the observations from the caldera rim by Stern (1978), we found that 1917 rootless flows, aa, and minor pahoehoe cover most of the inner caldera floor (fig. 2). Flows also bury basaltic scoria and cinders from early episodes of the 1917 eruption.

Voluminous eruption of spatter from a vent, now occupied by a solfatara field (see Geochemistry section), near the center of the caldera (fig. 2) built a low, broad hill elongated NE-SW and about 500 m long, 250 m wide, and 50-60 m high. No crater is present on the hill. The hill consists mainly of rootless flows of agglutinated spatter and is cut by deep (>15 m) northeast-trending cracks that we believe formed during partial flowage of the welded mass during the late stages of the eruption. Possibly, the cracks are tectonic in nature and postdate the 1917 eruption. However, the cracks do not cut 1917 lava on the caldera floor away from the base of the hill. A third possibility is that the hill was uplifted and cracked by unerupted magma either near the end of the 1917 eruption or at a later time.

Our interpretation of the 1917 eruptive sequence is: 1) initially gas-rich lava was violently expelled in Plinian eruptions of scoria, lapilli, and bombs that buried most of Agrigan; 2) as the lava became less gas-rich, continued voluminous Strombolian eruptions were directed to the northwest, where accumulation of spatter built the low, broad hill; 3) as the amount of gas in the lava continued to decrease, extrusion of spatter waned and voluminous flows became the dominant product; these flows eventually covered most of the caldera floor, including their source vent; 4) minor collapse (5 m or less) of the vent area occurred as the magma column subsided; 5) possibly soon after the eruption ended, a solfatara field developed in the vent area, as gases were liberated from the cooling magma; 6) sometime later, a boiling hot spring formed in the solfatara field.

We discovered a pre-1917 spatter cone, breached on its southwestern side, on the northeastern caldera floor at the base of the caldera wall (fig. 2). This cone, not previously recognized by Stern (1978), and the 1917 lava that covers most of the floor are the only known post-caldera deposits within the caldera, a further indication that the inner caldera is quite young. Possibly, however, pyroclastic deposits and lava flows from earlier post-caldera eruptions are buried by the products of these two most recent eruptions.

Pagan

Aerial and ground reconnaissance of Mount Pagan revealed numerous erosional gullies 1-15 m deep and 2-10 m wide. The gullies on the southwestern flank carried debris flows that, upon reaching the flatter terrain at the base of the volcano, spread out to form a large alluvial fan that buried almost all of the abandoned village.

Extensive areas of ash deposited intermittently from late May 1981-October 1988 (Subera and Banks, 1988) cover the northern and southern flanks of Mount Pagan. This younger ash is so deeply eroded that a reliable estimate of its thickness cannot be made.

The USGS team observed a prominent cloud of SO_2-bearing fume from Mount Pagan from September 28-October 3, 1990.

Anatahan

The lake, in the eastern crater, that was boiling in April 1990 (Sasamoto and others, 1990) had disappeared by June 1990 (Sako and others, 1990). The lake was full again on October 1, 1990, with water that was discolored but not boiling.

GEOCHEMISTRY

We discovered a 100-m-diameter solfatara field, which Stern (1978) recognized from the caldera rim as a fumarole, at the 1917 vent on the floor of Agrigan's caldera (fig. 2). A boiling hot spring and associated terrace deposits are near the southern edge of the solfatara field. We also observed steam at several locations near the base of the caldera wall, but we found no evidence of new fuming. Surface rocks in the solfatara field are chiefly degassed aa and minor pahoehoe that probably were the last extrusions of the 1917 eruption.

Temperatures, measured by thermocouple, of the boiling hot spring and 25 solfataras were 98°C. Water from the hot spring had a pH of 2.0. Chemical analysis of the water is in progress.

Several measurements using Kitagawa and Draeger tubes of the abundances of various gases emitted by the solfataras yielded the following results:

HCl	200-320 ppm
CO	0-3 ppm
CO_2	>3%
H_2S	1,900->2,000 ppm
SO_2	>400 ppm

Possibly, these abundances have been contaminated by an unknown amount of air.

The hot spring terraces, composed of siliceous sinter, cover an area of about 20 by 7 m downslope from the boiling hot spring. The terraces are now mostly dry, with current deposition of silica limited to a few m^2 adjacent to the hot spring, suggesting that activity was more vigorous sometime in the past. These features may have started to form shortly after the 1917 eruption. However, fluctuations in the volume of flow from the spring may occur as a result of seasonal variations in rainfall.

SEM analyses of the siliceous sinter (D.B. Yager, personal commun., 1990) show that it consists mainly of hydrated opaline silica, with minor amounts of native sulfur. Small X-ray peaks for K, Fe, and Ti suggest that a small amount of volcanic ash possibly was blown into the caldera from a distant source.

EDM SURVEYS

Agrigan

The team established a new EDM network (figs. 10-15, table 1) within the summit caldera. The network consists of a central station for the instrument (we used an infrared source) and five permanent reflectors, four of which are near the base of the caldera wall. Placement of permanent reflectors and the instrument station on the caldera rim was prevented by the narrowness of the rim, ruggedness of the terrain, frequent clouds enveloping the rim, and thick vegetation.

Reoccupation of the network should be possible for many years, if a helicopter is available, vegetation does not grow too rapidly, and no intracaldera eruptions occur. We hope to remeasure line lengths in 1991 to determine if any deformation of the volcano has occurred.

Pagan

Two of three reflector sites established in 1983 on the southwestern flank of Mount Pagan were located and measured from the instrument station, PAGAN 1 (fig. 16). The third site, which was the highest permanent glass station (STEEP), was destroyed by runoff from rainstorms that eroded deep gullies into the upper slopes of the volcano. Measurements from Pagan 1 to Station STEEP had shown the largest change between the 1983 and 1984 occupations (table 2). The latest measurements from PAGAN 1 to the two lower stations (RIDGE and NOSE) showed no significant changes in line lengths from 1984-90 (table 2).

The EDM monitor on the southern flank of Mount Pagan was not reoccupied. Data prior to 1983 are reported in Banks and others (1984).

Anatahan

Only two of the eight lines of the EDM network (fig. 17) established on Anatahan in April 1990 were measured. The other lines were blocked by vegetation, or the reflectors were full of water. The two lines measured, EC-1 to EC-5 and EC-5 to EC-4, cross the western part of the caldera. Both lines contracted since April, with the EC-1 to EC-5 line showing -2 cm of change (table 3; fig. 18). The absence of new data for lines across the eastern part of the caldera makes interpretation of the measured changes difficult. The contraction could result from minor inflation in the eastern part of the caldera.

ACKNOWLEDGMENTS

We thank Felix Sasamoto and the staff of the Office of Civil Defense for the Commonwealth of the Northern Mariana Islands for considerable logistical support, especially food, lodging, and transportation by ship and helicopter to the outer islands. Todd Hinkley and James Quick reviewed the manuscript.

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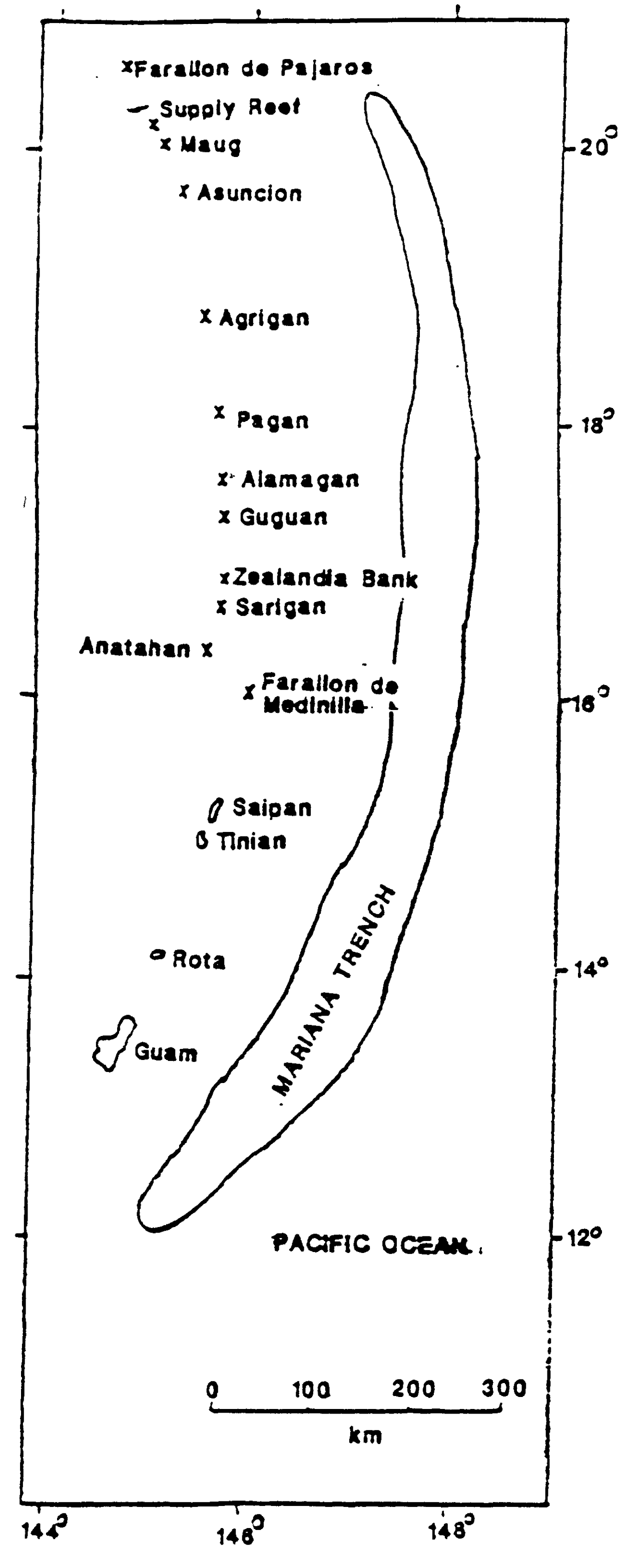


Figure 1. Index map of the Northern Mariana Islands. North is at the top.

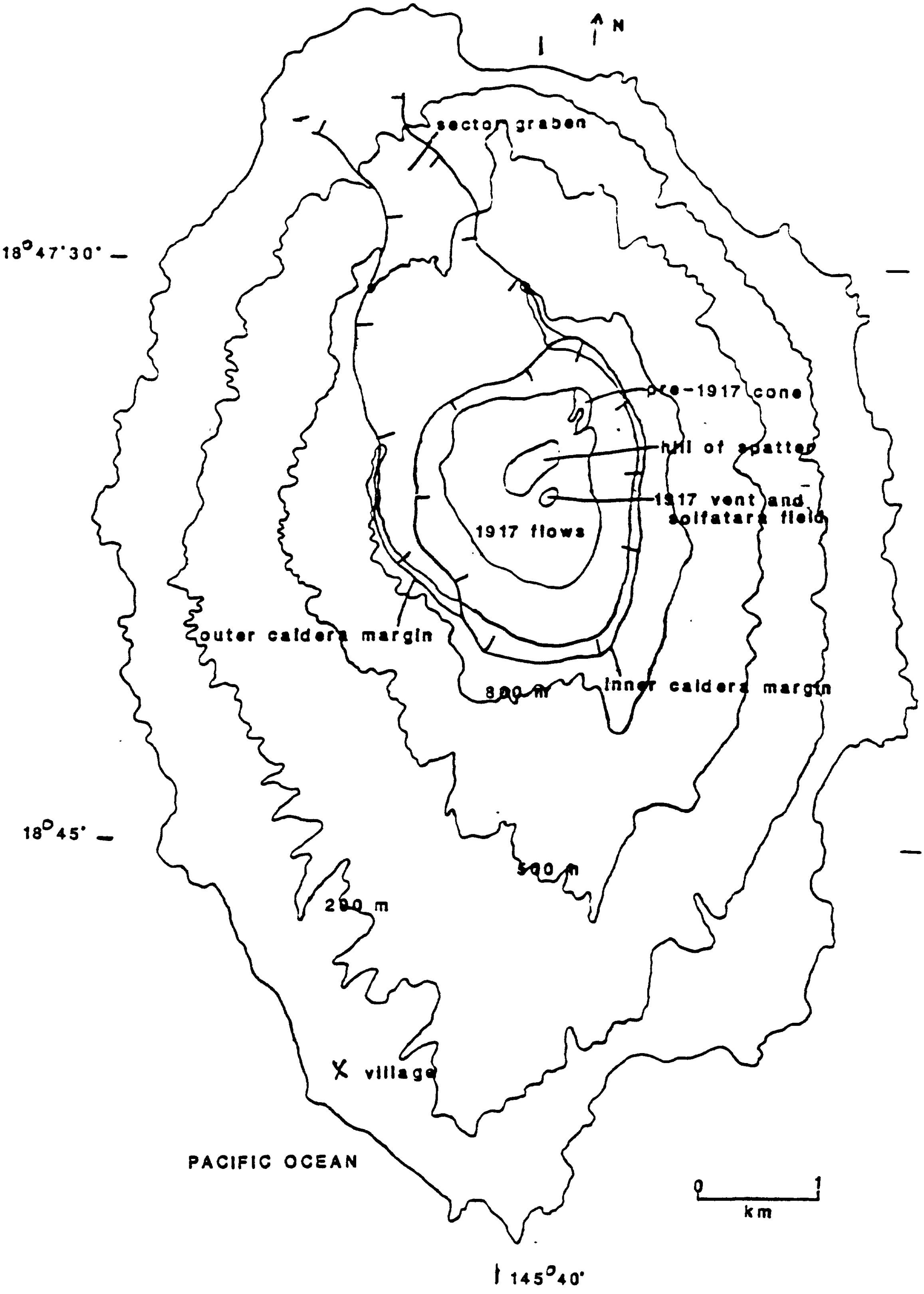
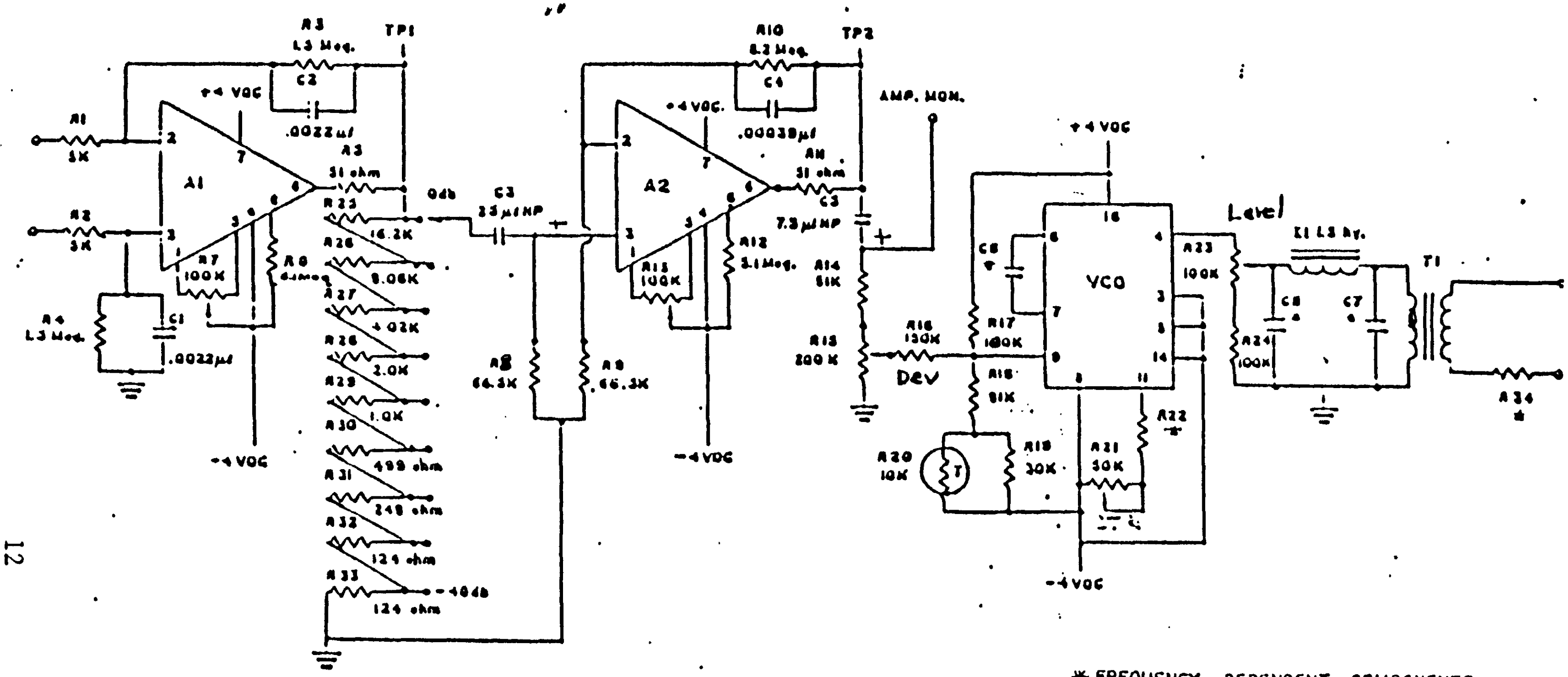


Figure 2. Map of Agrigan, showing location of the small village and various geologic features.

J302 *Preamplifier / Voltage Controlled Oscillator*



* FREQUENCY DEPENDENT COMPONENTS

NO.	STATION	MHZ	RF	TYPE	SUBCARRIERS	VCO	SEISMOMETER
0		data base	AW		10/1/90		
1	ANA/SAI	164.009375	3	MON	123	J302	L-4 #7682
2	ALA/ANA	166.659375	7	MON	23	J302	L-4 #7511
3	PAG/ALA/ANA	164.009375	3	DEV*	3	J302	L-4 #7509

* denotes 0.1 watt; others are 0.2 to 0.5 watt; all with horizontal Yagis

Figure 3. Technical specifications for radios, seismometers, and electronic packages used at seismic stations on Pagan, Alamagan, and Anatahan.

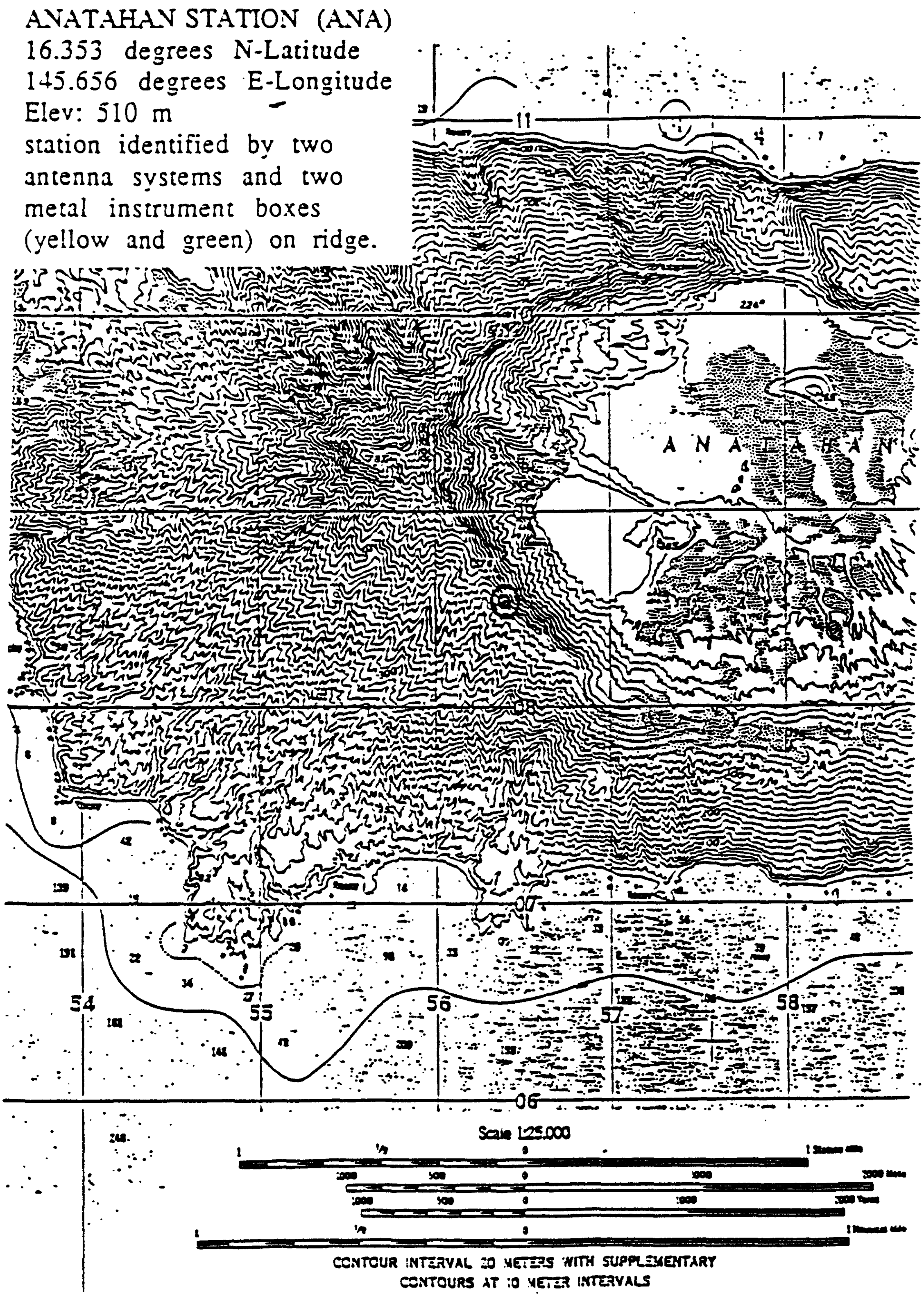


Figure 4. Map of Anatahan, showing location of the new seismometer.

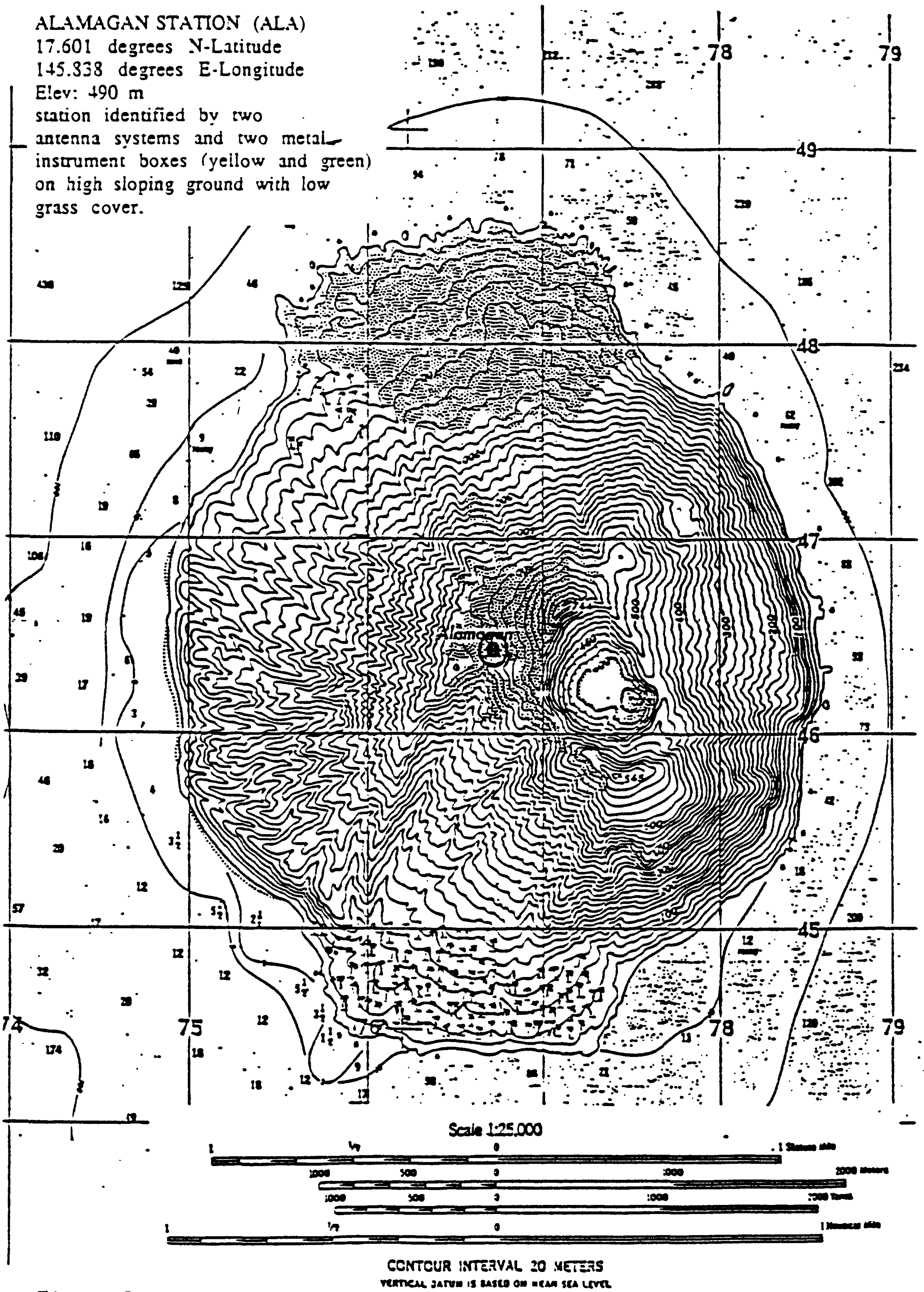


Figure 5. Map of Alamagan, showing location of the new seismometer.

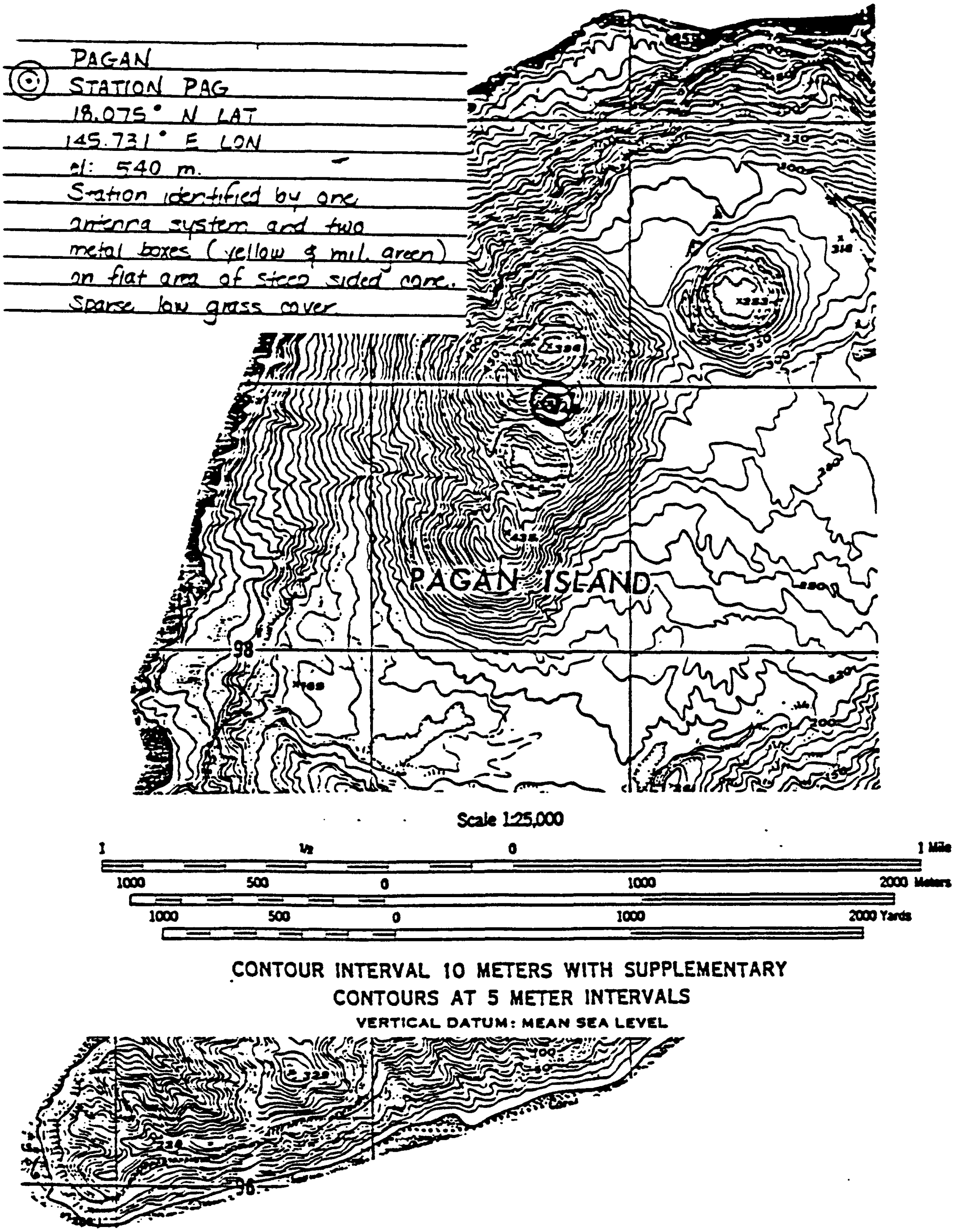
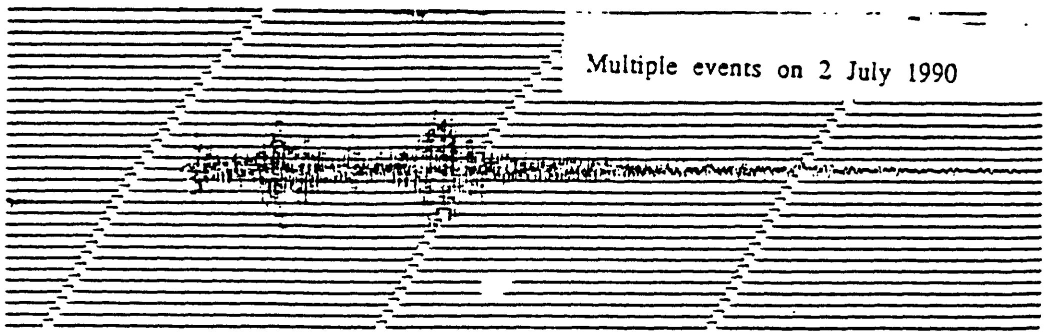
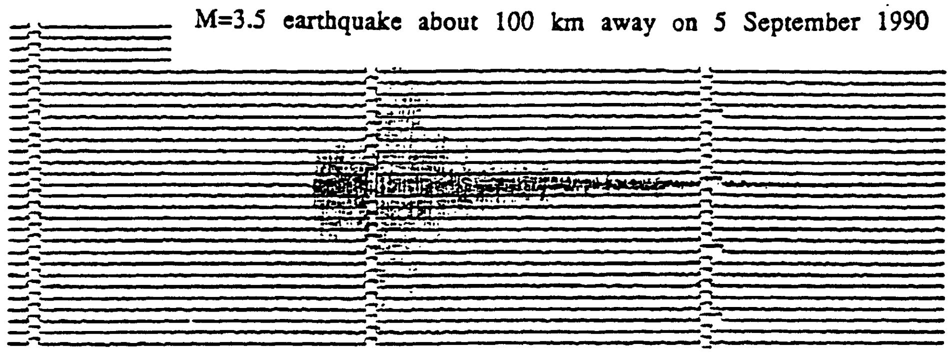


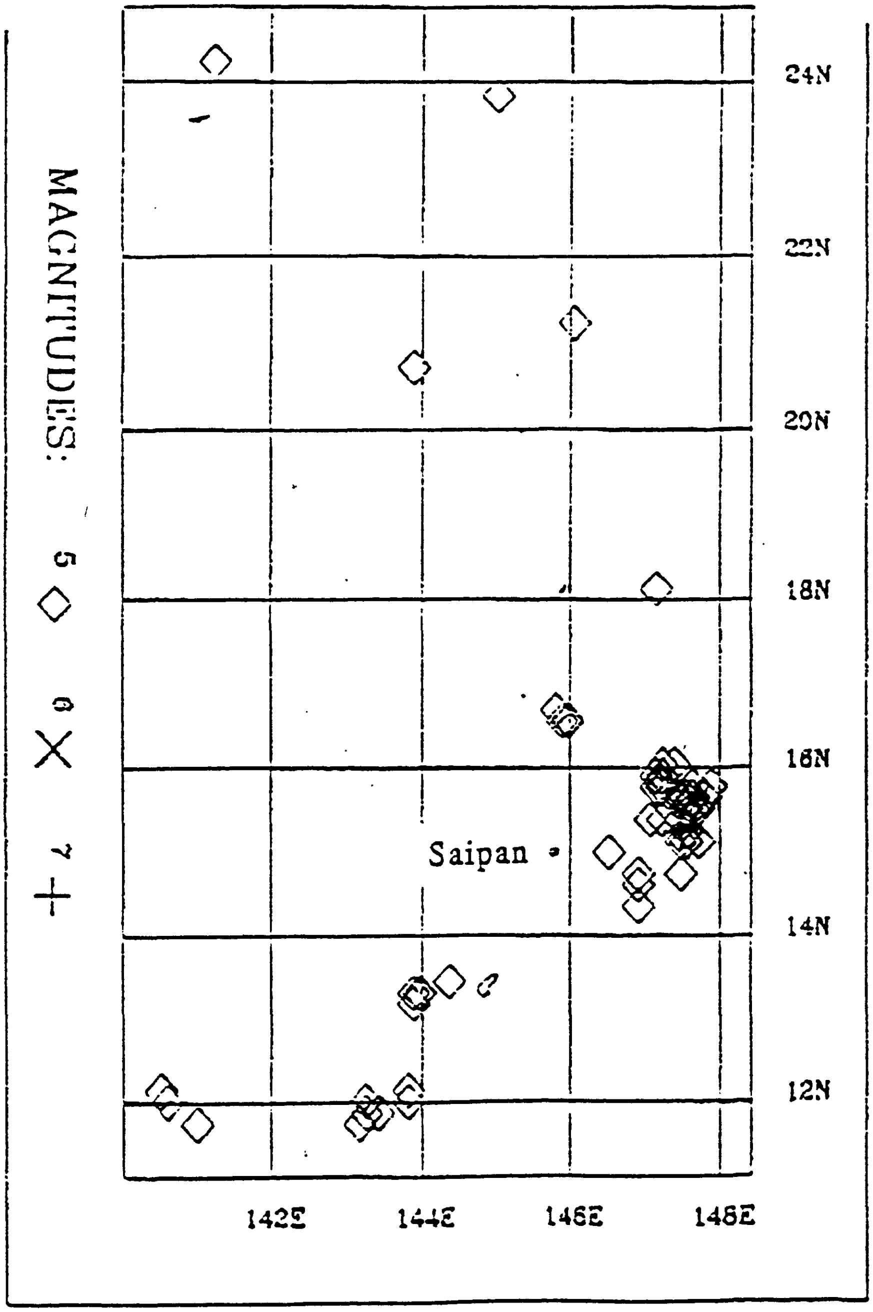
Figure 6. Map of Pagan, showing location of the new seismometer.





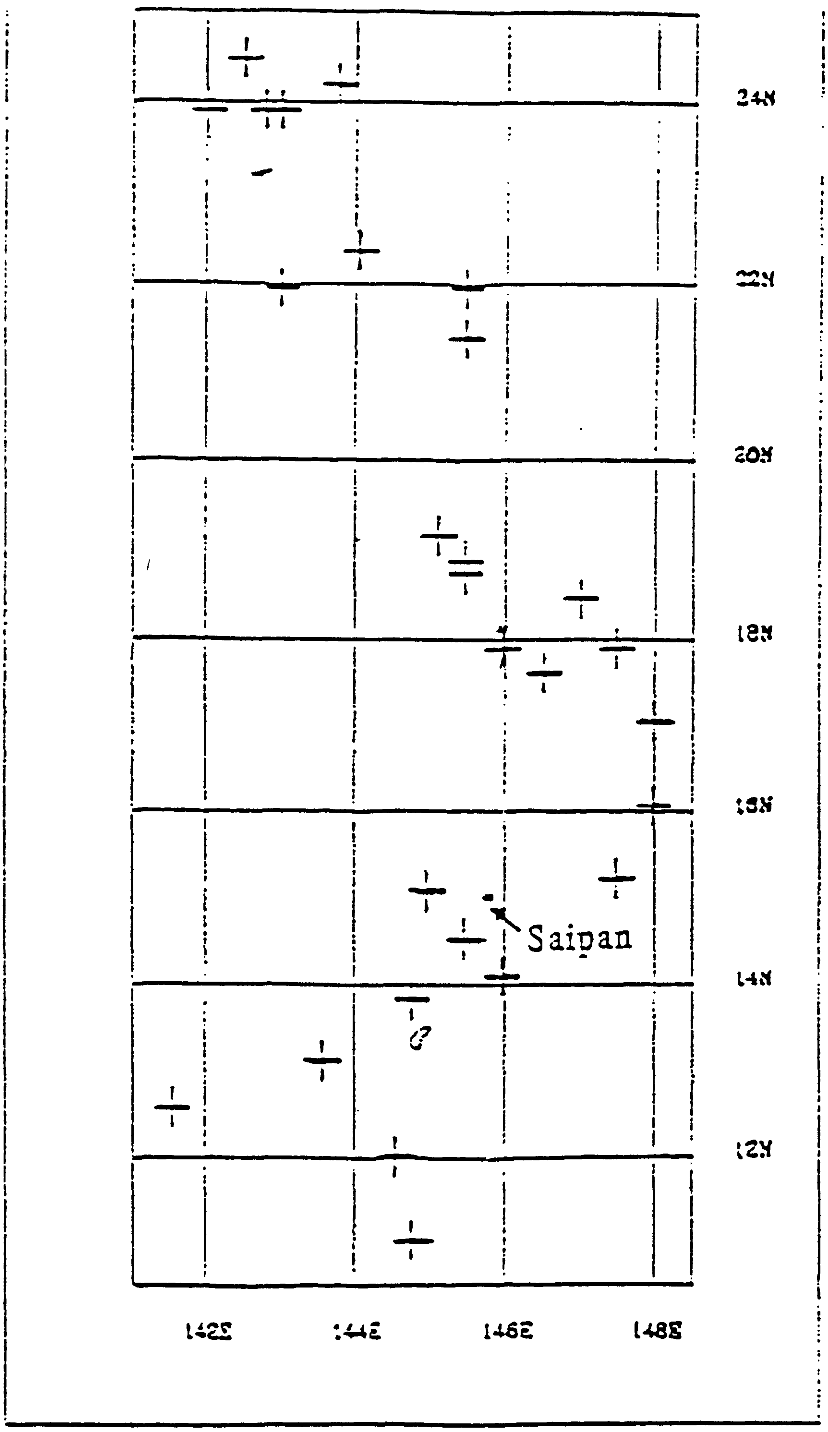
Seismograms of earthquakes from distances of >100 km recorded at temporary station in the CNMI Office of Civil Defense in Saipan. These events were too small to be detected and located by the worldwide seismograph network.

Figure 7. Seismograms of small earthquakes recorded in Saipan in 1990.



Computer graphics by Roger N. Hunter, Geophysicist

Figure 8a. Earthquake epicenters for earthquakes of magnitude 5.0 or greater in the Northern Mariana Islands region from 2 January to 31 August 1990. Data from the Earthquake Data Base System was compiled by the U.S. Geological Survey, National Earthquake Information Center. Most earthquakes recorded for this time period were near the lower threshold of detectable magnitude 5.0 to 6.0, as indicated by the large number of epicenter symbols in diamonds.



Computer graphics by Roger N. Hunter, Geophysicist

Figure 8b. Earthquake epicenters for major earthquakes of about magnitude 7 or greater in the Northern Mariana Islands region from September 1902 to September 1990. Data from the Earthquake Data Base System was compiled by the U.S. Geological Survey, National Earthquake Information Center.

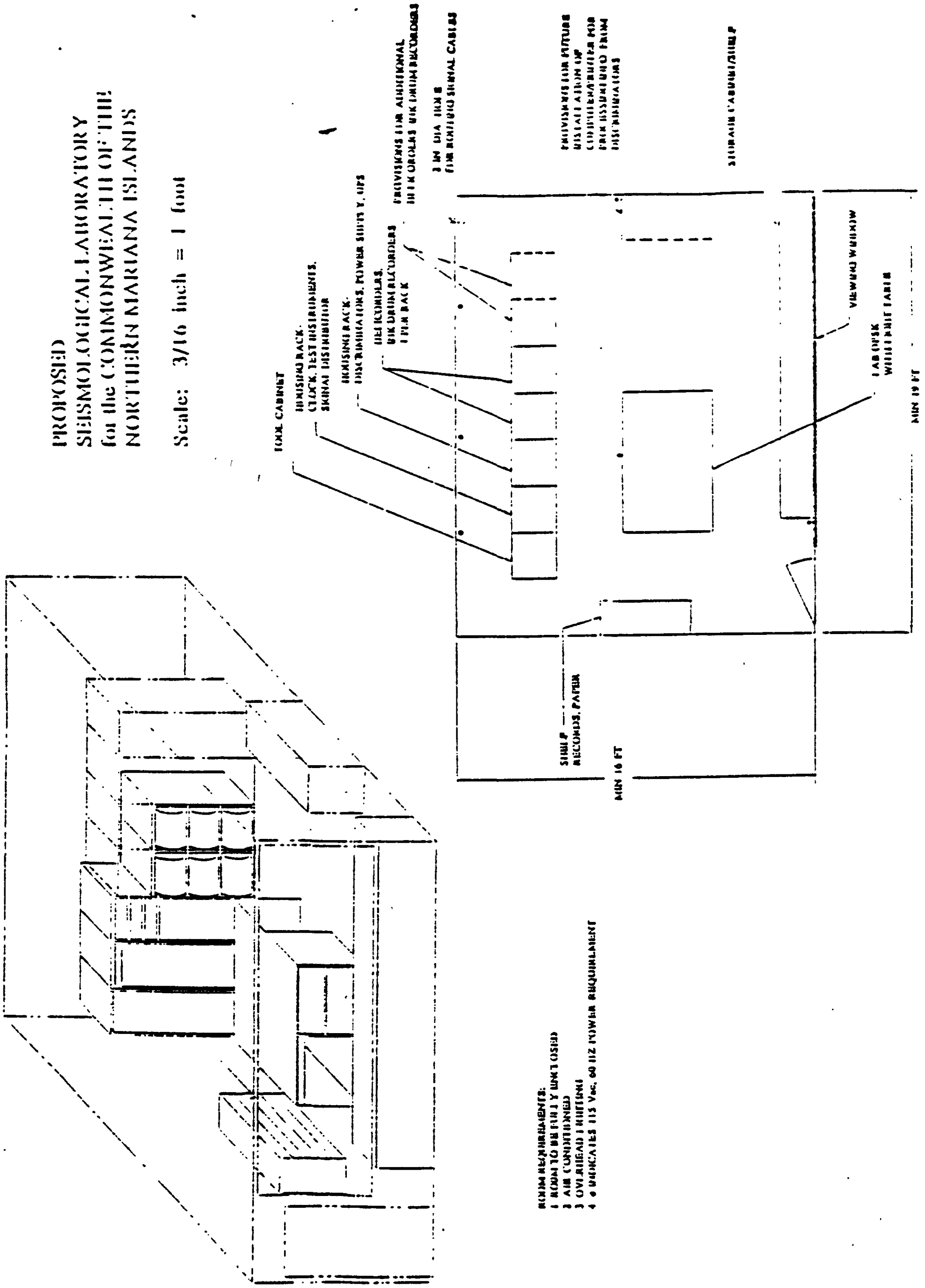


Figure 9. Diagram of a proposed seismological laboratory for the Commonwealth of the Northern Mariana Islands.

Station Name: Central Cone
Latitude: 18°46.57'N
Longitude: 145°40.04'E
Elevation: 545 m

Station Description: Central Cone is located on top of a large northeast-trending ridge near the center of Agrigan's inner caldera. The brush-covered ridge is 50-60 m high and consists mainly of welded spatter and rootless flows of the 1917 eruption. Possibly, movement along a series of northeast-trending cracks on the upper part of the ridge could cause problems with the measurements. The station is located between two of these cracks, which are about 7 m apart, and consists of a rebar pounded 1.22 m into aa. The operator should center the instrument on a punch hole in the middle of the rebar. A large area east of the station was cleared for a helipad. A machete is recommended for clearing the helipad and lines of sight to the reflector stations.

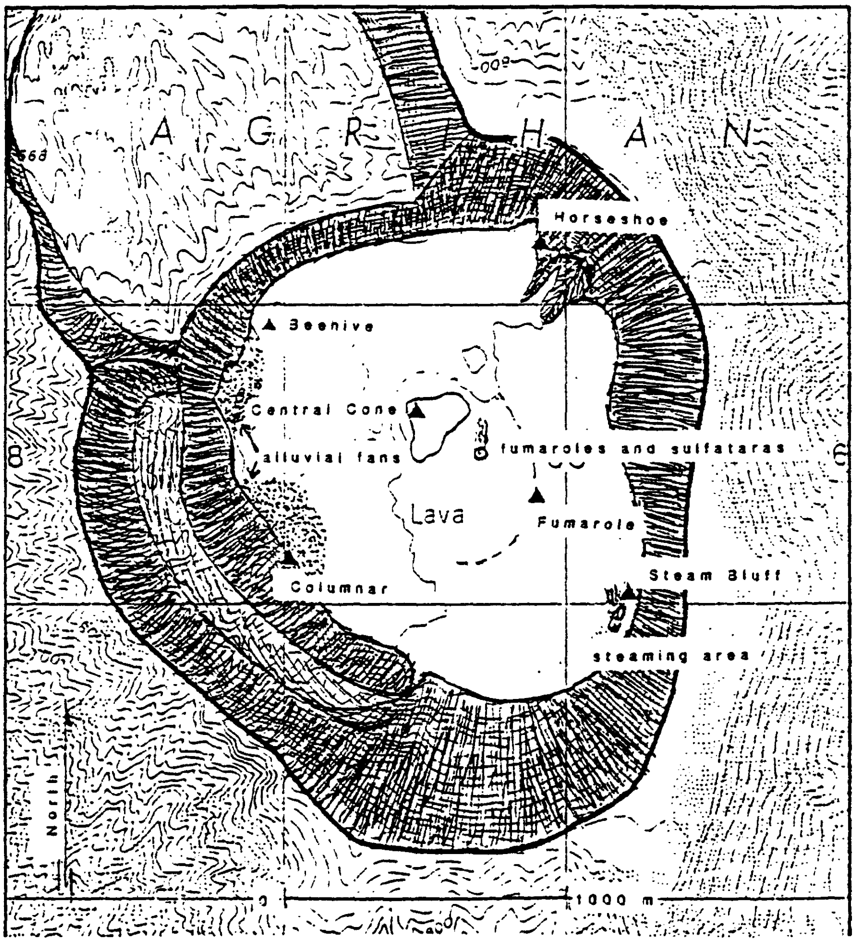


Figure 10. Location map of Central Cone and the reflector stations for the Agrigan EDM permanent glass monitor network.

Station Name: Fumarole
Latitude: 18°46.43'N
Longitude: 145°40.28'E
Elevation: 520 m

Station Description: Fumarole is located in a 2 x 1.5 m pahoehoe block at the rim of a low crater on the central caldera floor. The line of sight to the instrument station (Central Cone) is directly over a large fumarole and solfatara field. The station is a rebar with one attached permanent glass reflector. The rebar was pounded into a crack in the pahoehoe until refusal at 0.76 m depth. The station is easily accessible by foot from the helicopter landing site on the west side of the solfatara field.

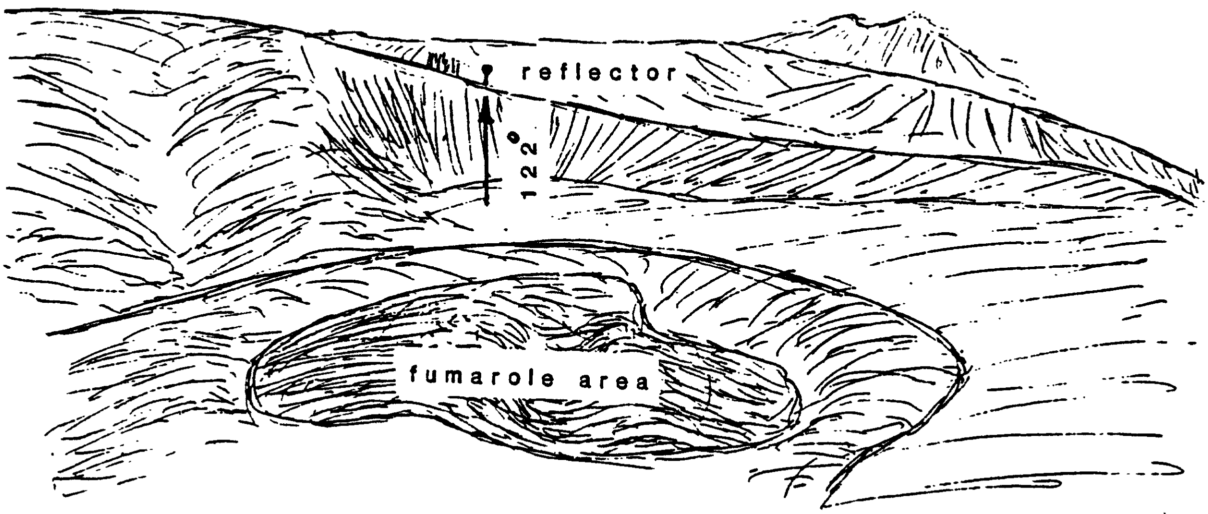


Figure 11. View from instrument station Central Cone looking toward reflector station Fumarole. Rough sketch is not to scale.

Station Name: Steam Bluff
Latitude: 18°46.26'N
Longitude: 145°40.46'E
Elevation: 510 m

Station Description: Steam Bluff is located on the southeastern side of the inner caldera, about 50 m from the base of the caldera wall and about 60 m north of a 30-m-thick flow on the wall. The station is in front of a large, black, 2 x 1.5 m boulder, which should protect it from alluvium and talus. The station is a rebar with one attached permanent glass reflector. The rebar was pounded into the ground until refusal at 0.46 m depth. The helicopter should land next to a large, cleared, steaming area near the caldera wall. A machete is recommended for clearing the line of sight to the instrument station.

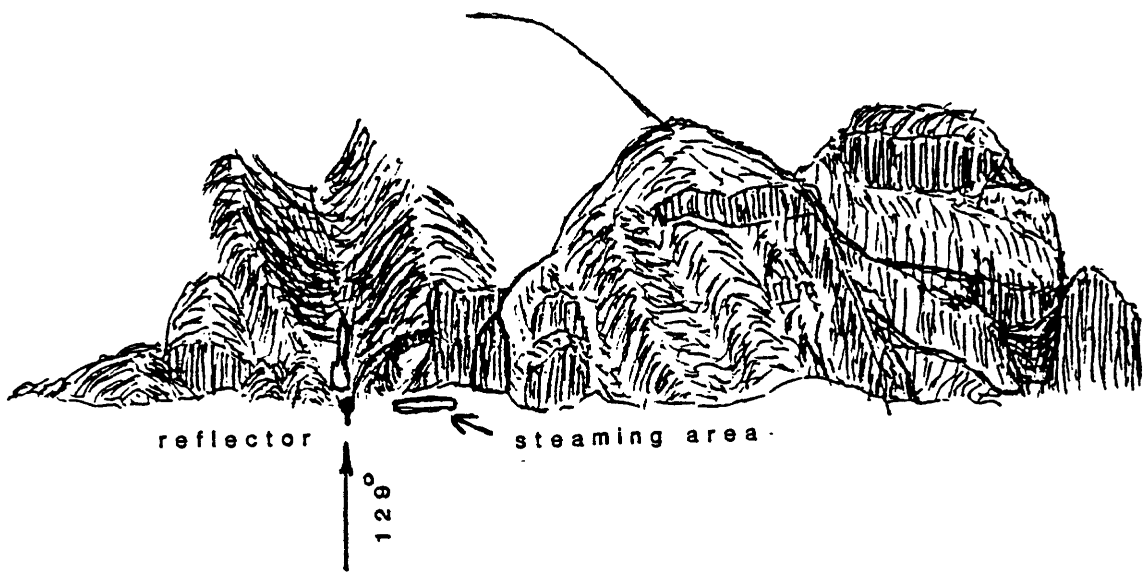


Figure 12. View from instrument station Central Cone looking toward reflector station Steam Bluff. Rough sketch is not to scale.

Station Name: Beehive
Latitude: 18°46.70'N
Longitude: 145°39.71'E
Elevation: 510 m

Station Description: Beehive is located near the breach in the outer caldera wall on the northwestern side of the inner caldera. The reflector site is about 50-60 m from the base of the caldera wall and 50-70 m northeast of the base of an alluvial fan. The station is a rebar with one attached permanent glass reflector. The rebar was pounded 0.92 m into a 1.5 x 0.75 m rock in an area of red soil. The helicopter should land at the base of the alluvial fan; there is a short hike to the reflector site. A machete is recommended for clearing the line of sight to the instrument station.

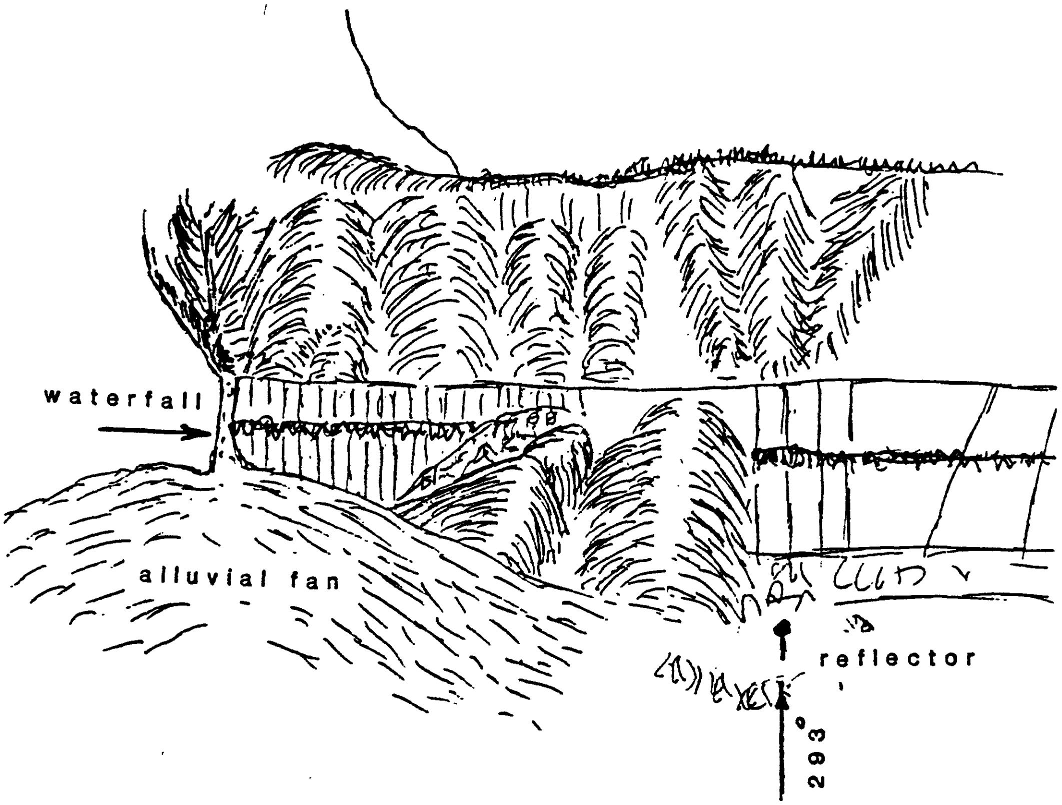


Figure 13. View from instrument station Central Cone looking toward reflector station Beehive. Rough sketch is not to scale.

Station Name: Horseshoe
Latitude: 18°46.89'N
Longitude: 145°40.25'E
Elevation: 510 m

Station Description: Horseshoe is located on the north-northeastern side of the inner caldera. It is 10 m above the caldera floor on the northwestern side of a horsehoe-shaped cone, breached on its southwestern side. The station consists of a rebar with one attached permanent glass reflector. The rebar was pounded 0.76 m into the ground. The helicopter should land in a large cleared alluvial deposit west of the cone. Banana and awa grow in the area. A machete is recommended for clearing the line of sight to the instrument station.

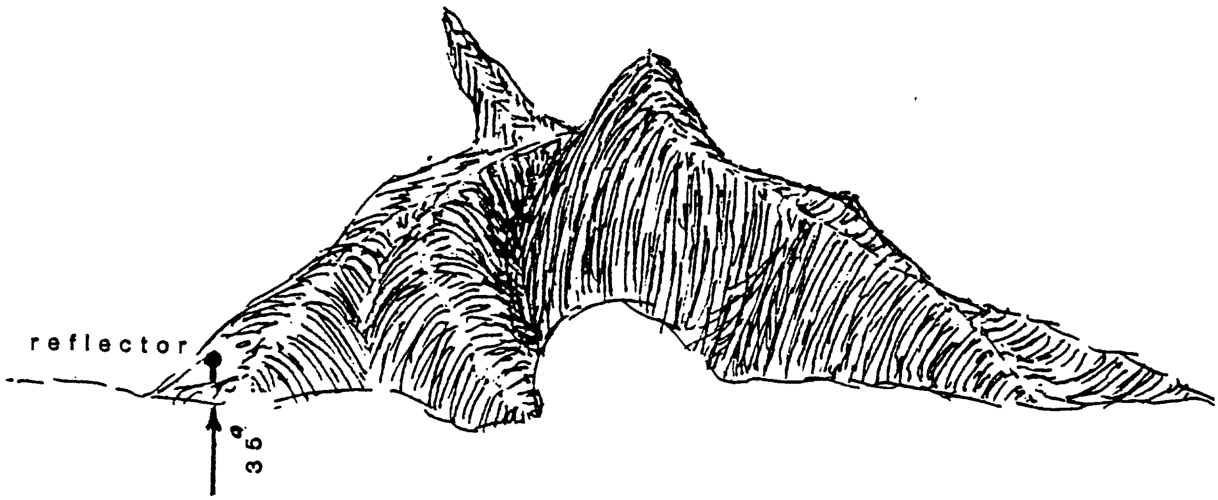


Figure 14. View from instrument station Central Cone looking toward reflector station Horseshoe. Rough sketch is not to scale.

Station Name: Columnar
Latitude: 18°46.31'N
Longitude: 145°39.77'E
Elevation: 510 m

Station Description: Columnar is located on the southwestern side of the caldera floor, about 25 m south of a large, intermittent waterfall. Alluvium deposited by the stream formed a large fan. The station is in rock about 5-7 m above the fan, just below the base of a 50-m-thick columnar-jointed lava flow. The station is a rebar with one attached permanent glass reflector. The rebar was driven 1.07 m into the ground. Awa and swordgrass cover much of the area. The helicopter should land on the lower part of the alluvial fan. A machete is recommended for clearing the line of sight to the instrument station.

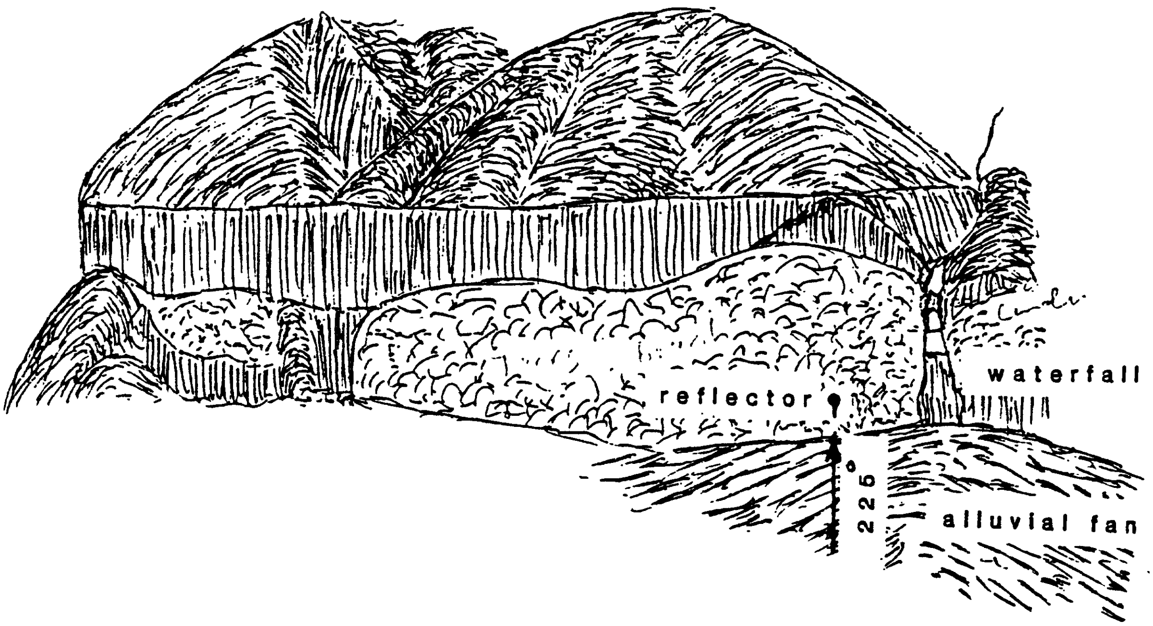


Figure 15. View from instrument station Central Cone looking toward reflector station Columnar. Rough sketch is not to scale.

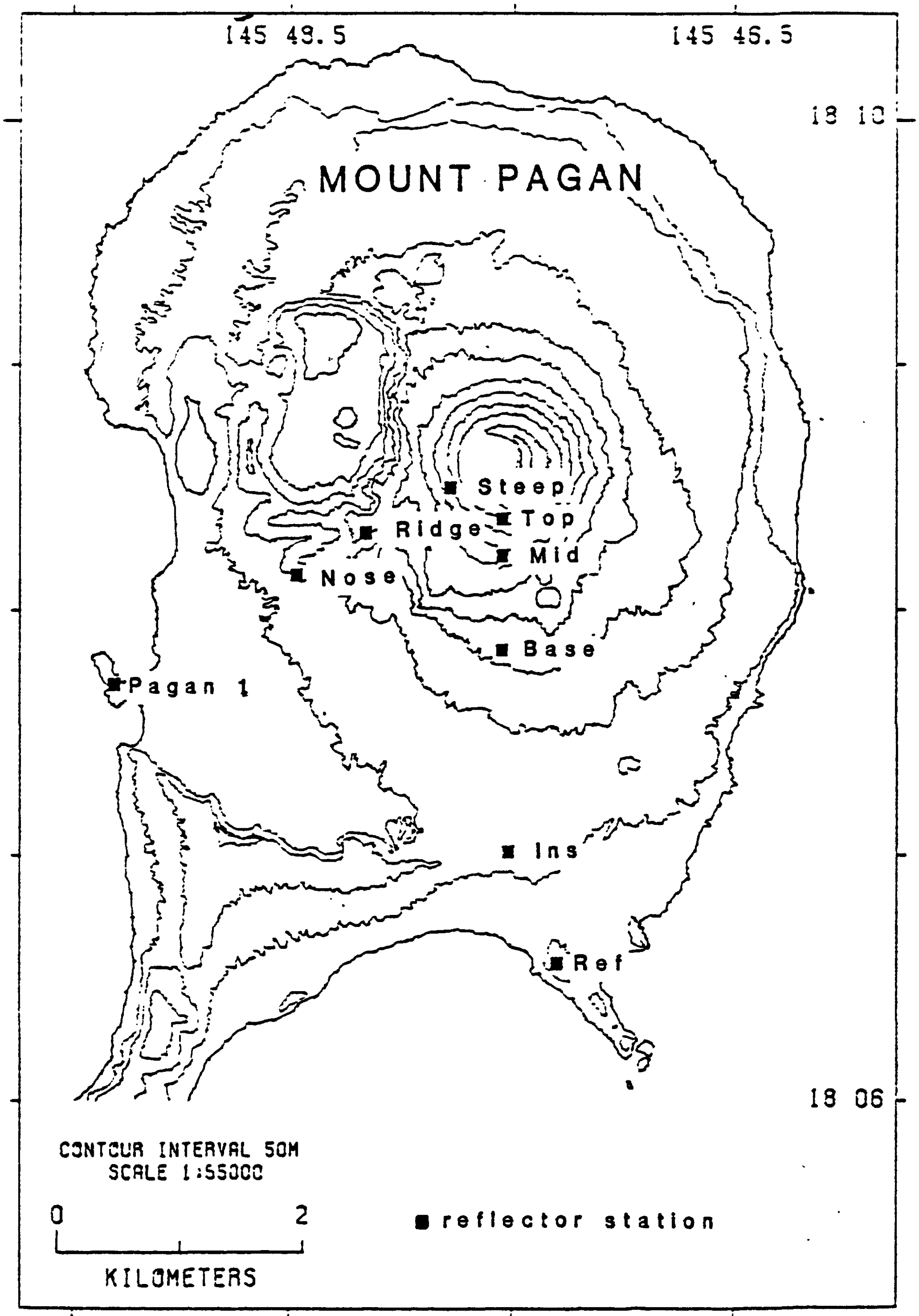


Figure 16. Location map of Pagan permanent-glass EDM networks.

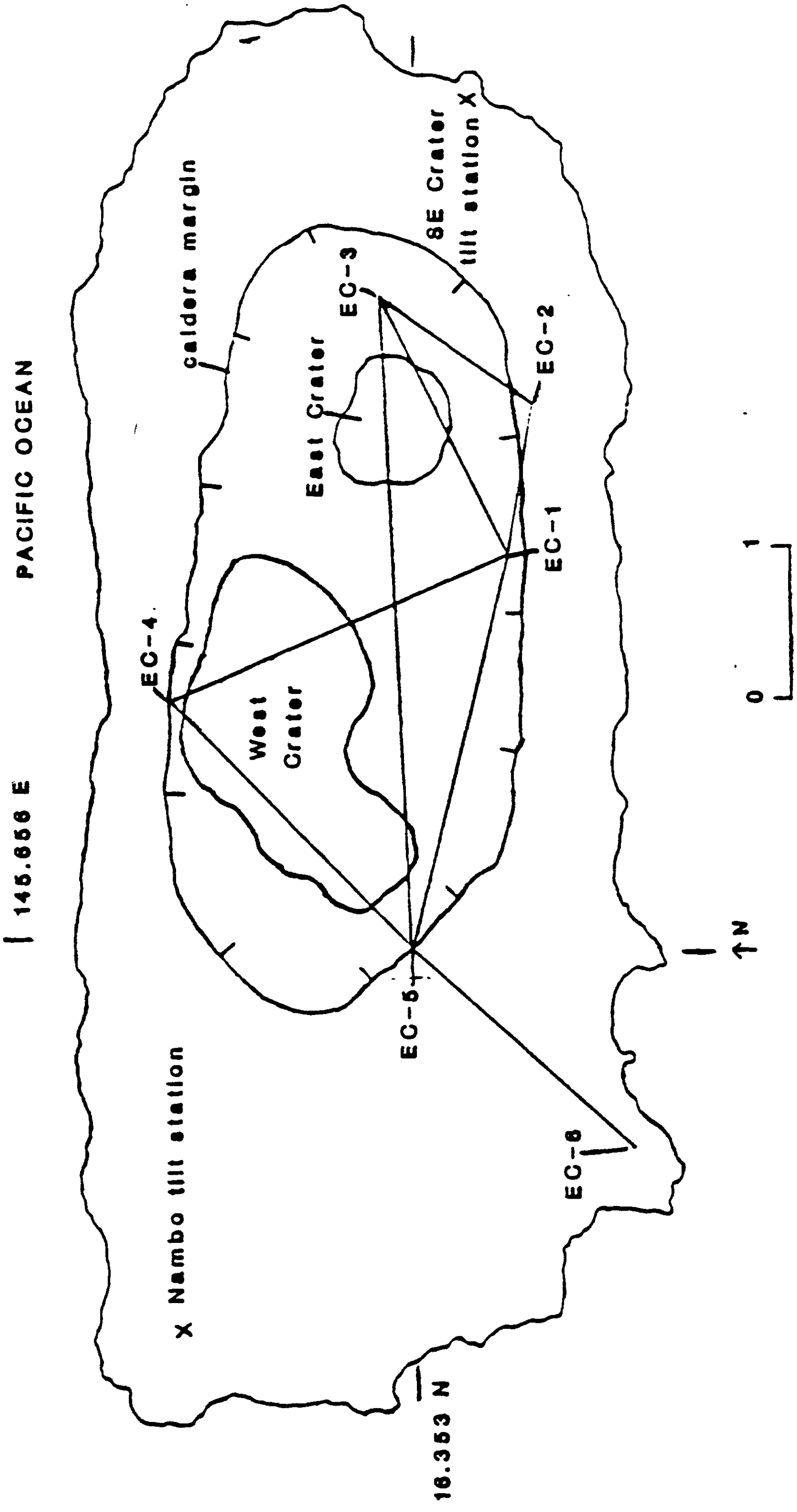
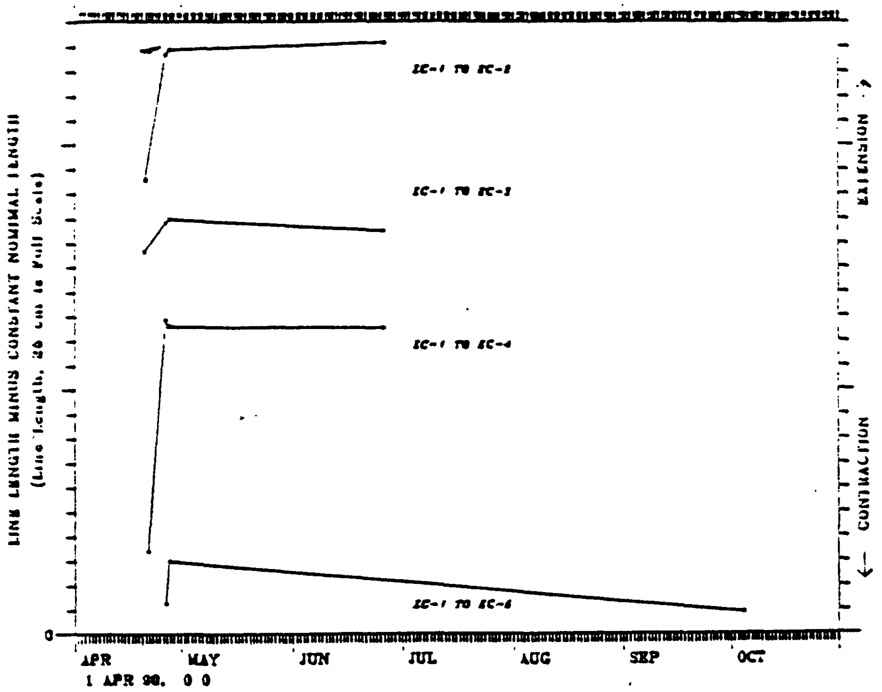


Figure 17. Map of Anatahan, showing location of the EDM network.

Anatahan Cross-Caldera Permanent Glass
EDM Monitor Line Length Changes (Plot 1 of 2)



Anatahan Cross-Caldera Permanent Glass
EDM Monitor Line Length Changes (Plot 2 of 2)

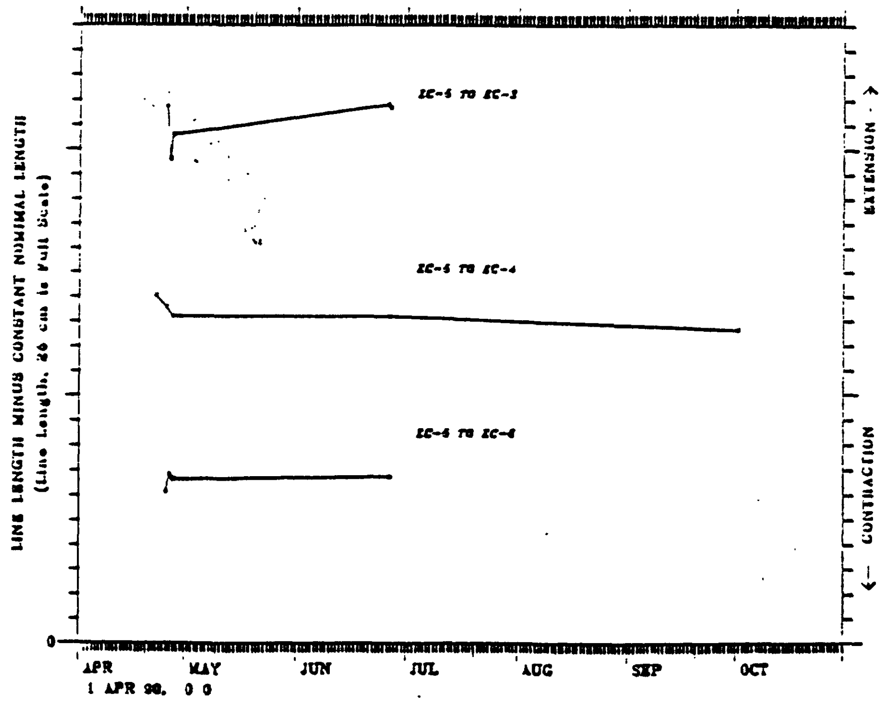


Figure 18. Line length changes in the Anatahan EDM network.

Table 1. Table of line length changes and cumulative differences for the permanent-glass EDM network on Agrigan, CNMI.

Ins. Stn.	Refl. Stn.	1st Survey Date	Dist. (m)	2nd Survey Date	Dist. (m)	Diff. (mm)	Cumulative Diff. (mm)
CEN	STM	09/29/90	967.872			0	0
CEN	STM	09/29/90	967.872	09/29/90	967.874	+2	+2
CEN	FUM	09/29/90	501.463			0	0
CEN	FUM	09/29/90	501.463	09/29/90	501.462	-1	-1
CEN	BHV	09/29/90	604.453			0	0
CEN	BHV	09/29/90	604.453	09/29/90	604.452	-1	-1
CEN	HSH	09/29/90	702.786			0	0
CEN	HSH	09/29/90	702.786	09/29/90	702.785	-1	-1
CEN	COL	09/29/90	660.099			0	0
CEN	COL	09/29/90	660.099	09/29/90	660.101	+2	+2

Central Cone = CEN; Steam Bluff = STM; Fumarole = FUM; Beehive = BHV;
Horseshoe = HSH; Columnar = COL

Table 2. Table of line length changes and cumulative differences for the permanent-glass EDM network on Pagan, CNMI.

Ins. Stn.	Refl. Stn.	1st Survey Date	Dist. (m)	2nd Survey Date	Dist. (m)	Diff. (mm)	Cumulative Diff. (mm)
PAGAN 1	STEEP	03/06/83	3060.901			0	0
PAGAN 1	STEEP	03/06/83	3060.901	03/06/83	3060.909	+8	+8
PAGAN 1	STEEP	03/06/83	3060.909	03/07/83	3060.917	+8	+16
PAGAN 1	STEEP	03/07/83	3060.917	03/07/83	3060.908	-9	+7
PAGAN 1	STEEP	03/07/83	3060.908	03/08/83	3060.913	+5	+12
PAGAN 1	STEEP	03/08/83	3060.913	03/09/83	3060.909	-4	+8
PAGAN 1	STEEP	03/09/83	3060.909	03/11/83	3060.895	-14	-6
PAGAN 1	STEEP	03/11/83	3060.895	03/12/83	3060.906	+11	+5
PAGAN 1	STEEP	03/12/83	3060.906	03/13/83	3060.910	+4	+9
PAGAN 1	STEEP	03/13/83	3060.910	03/14/83	3060.904	-6	+3
PAGAN 1	STEEP	03/14/83	3060.904	06/28/84	3060.753	-152	-149
PAGAN 1	RIDGE	03/06/83	2312.028			0	0
PAGAN 1	RIDGE	03/06/83	2312.028	03/07/83	2312.034	+6	+6
PAGAN 1	RIDGE	03/07/83	2312.034	03/07/83	2312.031	-3	+3
PAGAN 1	RIDGE	03/07/83	2312.031	03/08/83	2312.035	+4	+7
PAGAN 1	RIDGE	03/08/83	2312.035	03/09/83	2312.030	-5	+2
PAGAN 1	RIDGE	03/09/83	2312.030	03/11/83	2312.025	-5	-3
PAGAN 1	RIDGE	03/11/83	2312.025	03/12/83	2312.033	+8	+5
PAGAN 1	RIDGE	03/12/83	2312.033	03/13/83	2312.033	0	+5
PAGAN 1	RIDGE	03/13/83	2312.033	06/28/84	2312.025	-8	-3
PAGAN 1	RIDGE	06/28/84	2312.025	09/30/90	2312.038	+13	+10
PAGAN 1	RIDGE	09/30/90	2312.038	10/01/90	2312.042	+4	+14
PAGAN 1	NOSE	03/06/83	1685.879			0	0
PAGAN 1	NOSE	03/06/83	1685.879	03/07/83	1685.883	+4	+4
PAGAN 1	NOSE	03/07/83	1685.883	03/07/83	1685.878	-5	-1
PAGAN 1	NOSE	03/07/83	1685.878	03/08/83	1685.888	+10	+9
PAGAN 1	NOSE	03/08/83	1685.888	03/09/83	1685.888	0	+9
PAGAN 1	NOSE	03/09/83	1685.888	03/11/83	1685.885	-3	+6
PAGAN 1	NOSE	03/11/83	1685.885	03/11/83	1685.883	-2	+4
PAGAN 1	NOSE	03/11/83	1685.883	03/12/83	1685.888	+5	+9
PAGAN 1	NOSE	03/12/83	1685.888	03/13/83	1685.885	-3	+6
PAGAN 1	NOSE	03/13/83	1685.885	06/28/84	1685.872	-13	-7
PAGAN 1	NOSE	06/28/84	1685.872	10/01/90	1685.889	+17	+10
PAGAN 1	NOSE	10/01/90	1685.889	10/01/90	1685.891	+2	+12
INS	REF	03/07/83	924.866			0	0
INS	REF	03/07/83	924.866	03/13/83	924.870	+4	+4
INS	BASE	03/07/83	1446.382			0	0
INS	BASE	03/07/83	1446.382	03/13/83	1446.390	+8	+8
INS	MID	03/07/83	2192.578			0	0
INS	MID	03/07/83	2192.578	03/13/83	2192.579	+1	+1

Table 3. Table of line length changes and cumulative differences for the permanent-glass EDM network on Anatahan, CNMI.

Ins. Stn.	Refl. Stn.	1st Survey Date	Dist. (m)	2nd Survey Date	Dist. (m)	Diff. (mm)	Cumulative Diff. (mm)
EC-1	EC-3	04/20/90	2091.096			0	0
EC-1	EC-3	04/20/90	2091.096	04/26/90	2091.108	+12	+12
EC-1	EC-3	04/26/90	2091.108	04/27/90	2091.110	+2	+14
EC-1	EC-3	04/27/90	2091.110	06/25/90	2091.105	-5	+9
EC-2	EC-3	04/20/90	1456.202			0	0
EC-2	EC-1	04/20/90	1005.526			0	0
EC-1	EC-2	04/20/90	1005.526	04/26/90	1005.577	+51	+51
EC-1	EC-2	04/26/90	1005.577	04/27/90	1005.579	+2	+53
EC-1	EC-2	04/27/90	1005.579	06/25/90	1005.582	+3	+56
EC-4	EC-1	04/21/90	2562.984			0	0
EC-1	EC-4	04/21/90	2562.984	04/26/90	2563.079	+95	+95
EC-1	EC-4	04/26/90	2563.079	04/27/90	2563.076	-3	+92
EC-1	EC-4	04/27/90	2563.076	06/25/90	2563.075	-1	+91
EC-5	EC-4	04/22/90	2442.111			0	0
EC-5	EC-4	04/22/90	2442.111	04/25/90	2442.106	-5	-5
EC-5	EC-4	04/25/90	2442.106	04/27/90	2442.102	-4	-9
EC-5	EC-4	04/27/90	2442.102	06/26/90	2442.102	0	-9
EC-5	EC-4	06/26/90	2442.102	10/01/90	2442.097	-5	-14
EC-5	EC-3	04/25/90	4310.747			0	0
EC-5	EC-3	04/25/90	4310.747	04/26/90	4310.726	-21	-21
EC-5	EC-3	04/26/90	4310.726	04/27/90	4310.736	+10	-11
EC-5	EC-3	04/27/90	4310.736	06/25/90	4310.748	+12	+1
EC-5	EC-3	06/25/90	4310.748	06/26/90	4310.747	-1	-0
EC-5	EC-6	04/25/90	2431.981			0	0
EC-5	EC-6	04/25/90	2431.981	04/26/90	2431.988	+7	+7
EC-5	EC-6	04/26/90	2431.988	04/27/90	2431.986	-2	+5
EC-5	EC-6	04/27/90	2431.986	06/26/90	2431.987	+1	+6
EC-1	EC-5	04/26/90	2478.043			0	0
EC-1	EC-5	04/26/90	2478.043	04/27/90	2478.060	+17	+17
EC-1	EC-5	04/27/90	2478.060	10/04/90	2478.039	-21	-4