PRELIMINARY REPORT NO. 1

Tavera - Bao Seismograph Network

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INTRODUCTION

Seven remote stations of the Tavera-Bao Seismograph Network were installed by the Marine Science Institute, University of Texas, during the period of November 7 through November 28, 1979. The network started its full operation on December 13, 1979.

In this seismic monitoring system, the signals from the remote stations are transmitted back to the central recording station by VHF radio telemetry link. All the necessary power for a remote station is supplied from a battery and a set of solar panels.

At the central recording station, the signals from remote stations are continuously analysed by the Computerized Seismic Monitoring System (COSMOS). This system identifies a possible earthquake, triggers the recording system when an earthquake is detected, and plots the seismic signals without losing the first arrivals. In addition, when the sufficient number of stations are triggered, this system starts to calculate the location and magnitude of an earthquake without human assistance, and prints out this information when plotting of the seismic signal is completed.

Preliminary analysis of data covering the period from December 13 through December 28, 1979, was accomplished. The analysis indicated that:

1) Three events were located in the immediate vicinity of the Tavera-Bao project site with magnitude 1.0, 1.3 and 1.3 respectively. These events, however, were identified as those originated from explosions.

2) The closest earthquake to the project area was located approximately 5 km southeast of the Tavera Dam site with a magnitude of 2.2. No event distributed along the Tavera fault system was discovered during the 15 day recording period.

3) Distribution of the earthquakes exhibited a rather complicated regional pattern.

THE PURPOSE AND MECHANICS OF THE TAVERA-BAO SEISMIC NETWORK

The study of mecroearthquakes provides a rapid way of mapping active faults in regions of high seismic activity. Microearthquakes with magnitudes as small as 1 on the Richter scale can best be recorded by ultra-sensitive, high-frequency seismographs operated at distances of less than a few tens of kilometers from the earthquakes. More than 1000 microearthquakes may thus be detected in a region where only one earthquake has been recorded by the distant stations of the World Wide Seismograph Network during the same period.

The effectiveness of such a high gain seismic system is extremely useful for estimating the seismic risk within a limited time span. The crucial period of the seismological studies is divided in two different phases of the construction period of the dam. Data gathered at the early phase of the hydroelectric project provides essential design information such as the location of active faults, the expected maximum magnitude and acceleration, and duration of ground movement that the dam must be engineered to safely withstand. Even after the design is established, such information serves to confirm the design criteria.

The second phase begins as the reservoir is filled, as this is when water-induced earthquakes frequently occur. It is known that when the reservoir is being loaded, the surrounding pore pressure of the rock is increased. If faults do exist in the area, the increased pore pressure acts as a lubricant for existing faults and may cause a phenomena known as "water-induced earthquakes". This has happened in Zambia (Kariba earthquake, Sept. 23, 1963, m=6.3), Greece (Kremasta earthquake, Feb. 5, 1965, m=6.2) and India (Koyna earthquake, Dec. 10, 1967, m=6.4).

From Figure 1 and Table 1, we can see the general layout of the seismic network. There are 6 remote stations and 1 central recording station. A geophone has been placed at the central station to make a total of 7 monitoring points. Stations 1, 2 and 3 are within a 6 km radius of the dam, yielding very accurate measurements in the immediate construction site and stations 4, 5, 6 and 7 are on an outside circle of an approximate radius of 45 km.

Exact station locations are very carefully selected with priorities as follows:

1. Line of sight: Transmission of the seismic signal to the central station must be clear and unobstructed.
2. Background noise such as roads, cattle, footpaths and even wind must be low enough to accurately distinguish the seismic signal.
3. Accessability: The site must be easily reached for construction and possible future maintainance.
4. All stations together must provide an extended areal coverage for the comprehensive studies of local, regional and deep focus earthquakes.

Description of Remote Station Equipment and Function

Figure 2 is a simple illustration of the order of operation of the remote station and central recording station. The seismic signal is picked up by the geophone, amplified and modulated by the PA/VCO and then transmitted by a certain frequency transmitter to the central recording station. Each station consists of:

A) Geophone

B) PA/VCO

C) Transmitter

D) Antenna (directional)

E) Solar Panel

A) Geophone: (mark products 1 Hz vertical)

The geophone senses vertical ground movements and converts this mechanical energy to electrical impulses. These impulses travel down the geophone cable and into the PA/VCO. Both the Geophone and the cable are buried to prevent damage by inquisitive people or animals. The geophone is placed in a cement cylinder to further protect it and insulate it from extraneous noise.

B) PA/VCO: Pre-Amplifier/Voltage Controlled Oscillator (UT/MSI design)

Here the signal is amplified and converted to a modulating frequency by VCO for better transmission. Both the PA/VCO and transmitter are in small waterproof metal boxes. These two boxes are contained in a larger wooden box which also houses the 12V battery that supplies the power to each unit.

The Pre-Amp has a maximum of 90db gain with 8 adjustable steps of attenuation at 6 db each. The output of the VCO is a sine wave that varies in frequency following the amplifier output signal. There are 4 center frequencies being used: 1360, 1700, 2040 and 2380 Hz. Deviation about these center frequencies is maintained by the VCO. A ± 2.5 volt input variance will modulate the frequency ± 125Hz. Thus it follows that the larger the ground movement, the bigger the voltage impulse and the wider the frequency variation.

C) Radio Transmitter and Antenna:

The VCO output is fed into the transmitter and directional antenna for transmission back to the central recording station. The antenna possesses a 17^{o} dispersion angle of transmission but alignment of the antenna with the central station should be as accurate as possible. Each station has its own frequency of transmission. Transmitting frequencies vary between 140.750 and 144.750 MHz in increments of .5MHz.

D) Solar Panel:

Three solar panels occupy each remote station. Hooked in parallel to the battery, they can recharge the battery indefinitely, provided there is sufficient sunlight. The solar panels face the south in the Northern Hemisphere and are mounted at an angle of the station latitude plus 10^{o} for maximum sunlight.

Description of the Central Recording Station (Equipment and Function)

Upon reaching the central recording station, the signal is received and then demodulated by a discriminator and fed into the Computerized Seismic Monitoring System. Here possible earthquakes are detected through a triggering system and then located by a complex computer program. The central recording station consists of:

A) Receiver
B) Discriminator
C) COSMOS
D) Nova 312 Computer
E) Versatec Printer/Plotter
F) Time clock

A) Receiver and Antenna:

Six antennas are located close to the central station and are pointed in the direction of their respective transmitting stations. The cables from each antenna are run into the building housing the receivers and computer equipment. The receivers are all mounted on the wall together and numbered to the correct station for ease of service. The output from each receiver is a variable frequency tone matching the VCO output signal at the remote station.

B) Discriminators:

The output signal from each receiver is fed into a discriminator. This instrument converts the frequency modulated signal back into the amplified signal that was originally fed into the VCO at the remote station.

C) COSMOS (Computerized Seismic Monitoring System):

COSMOS is a fully automated computerized monitoring system which can handle input data from up to 30 seismic stations. On its own, COSMOS will:

--identify probable earthquake signals and plot these signals for all seismic stations beginning a few seconds prior to the first arrival of the signal.

--automatically determine the epicenter and magnitude of all probable events.

The basic idea behind the COSMOS computer program is the Delay Memory and Trigger Circuits. The output from each discriminator is fed into a digital memory unit where 20 seconds of data is stored. After 20 seconds, the data flows into a trigger identification circuit and a coincidence detector circuit. The trigger identification circuit compares the signal to the preceding 100 seconds of averaged background noise. If this signal exceeds the background noise level by a factor of 8, the trigger identification circuit for that station is set to the triggered mode for the next 20 seconds. The coincidence detector examines the number of stations that are in the triggered mode and if 3 or more stations are triggered, the earthquake location portion of the COSMOS program begins. If less than 3 are in the triggered mode, the system goes on as before, analyzing 20 seconds of memory stored seismic signals per station.

D) Nova 3/12 Computer:

This instrument is a computer with 32 k words of core memory through which the COSMOS program is executed. A/D signal converter, dual floppy disc drive, internal clock, and interface to peripherals (Printer/Plotter and Tele-type) are attached to this system. It stands next to the discriminator rack in the central station.

E) Versatec Printer/Plotter:

Next to the Nova 3/12, this high speed instrument prints out the located earthquake from COSMOS and also plots the seismic signal of all stations coinciding with this event.

F) Time Clock:

The Bureau of Standards broadcasts Coordinated Universal Time at 5, 10, 15, 20 and 25 megacycles or more commonly known as station WWV. We employ a Geotech WWV time clock for this purpose. This digital clock can be calibrated up to 1 millisecond by the standard WWV time signal. The COSMOS system records this time and a built-in subroutine continuously reads this time code and updates the internal clock in the computer.

G) Continuous Recording:

In addition to the COSMOS system, a drum recorder is continuously monitoring station 1. This drum recording system assures registering of small events that were not large enough to trigger the COSMOS system. The drum speed is set so that each revolution of the drum is 15 minutes and one sheet of drum paper records 24 hours of data.

The time code is also recorded on the drum paper as a small deflection of the pen each minute with large deflections at the hour and half hour marks.

All the electronic equipment for the central station is in a concrete house. This structure has been completely sealed off from any outside weather effects. An air conditioner keeps the room at a temperature and humidity that is ideal for the computer. Excessive humidity or extreme temperature changes could render the equipment inoperable.

PRELIMINARY ANALYSIS OF DATA, DECEMBER 13-28, 1979

The data covering the period from December 13 through December 28, 1979, was returned to the Marine Science Institute for detailed analysis. Up to date, only a preliminary analysis was accomplished.

For each event, the arrival times of P and S waves were carefully identified by a skilled operator. Comparison of the manual reading to the computer based automatic reading indicated that the latter was approximately identical to the manual reading when the onset of a P-wave was sharp and clear (within 0.1 to 0.2 seconds), but showed relatively greater error (up to 0.5 to 1 second) when an onset was slow and small. Also, the computer based reading is unable to identify the S-wave. Therefore, the automatic epicenter determination by the COSMOS system is valid only for local events with a sharp onset.

During the 15-day recording period, 81 events were identified and 51 epicenters were determined (Table 3). The magnitude (m_b) of the recorded events ranged from 3.9 to 0.6 with 62 percent of events falling between 1.0 to 2.9.

1. Regional Distribution.

Figures 5A and B show the regional distribution of the events located by the Tavera-Bao Seismograph Network. Events with the depth shallower than 50 km were illustrated by X's and those with the depth equal to or greater than 50 km were shown by open squares.

Most of the events determined by the Tavera-Bao network (Figure 5B) fall into the zone of epicenter distribution provided by the National Earthquake Information Service, U.S.G.S. (Figure 4). This shows a significant departure between the observed local seismicity and that depicted by the World Wide Seismograph Network.

In Figure 5B, one can observe that the shallow earthquakes are approximately distributed along the northern and southern boundaries of the Santiago Basin which extends roughly northwest-southeast between the Central Cordillera and the Northern Coastal Ranges.

The data from the Tavera-Bao network indicated the existence of intermediate and deep focus earthquakes, probably reaching up to the maximum depth of 200 km. This confirms the presence of a subduction zone beneath the eastern half of Hispaniola. The easterly movement of the Caribbean plate in reference to the North American plate predicts predominance of transform faulting along the east-west trending plate boundary. Elucidating the generation and evolution of the Benioff zone is quite important for the geodynamic process in this region.

2. Activity in the Vicinity of Tavera-Bao Project.

2.1. Explosion Earthquakes

Three events were located in the immediate vicinity of the connecting channel (Figure 6). These events occured on the following dates:

File #		Date	Time	Magnitude
2	1979	December 13	13^h27^m G.M.T. (09^h27^m Local time)	1.0
10	1979	December 16	18^h50^m G.M.T. (14^h50^m Local time)	1.3
33	1979	December 21	15^h27^m G.M.T. (11^h27^m Local time)	1.3

Only one of the events (No. 10) was identified as an explosion earthquake. However, all of them show quite identical seismic signatures which is characterized by all upward initial motion at all stations. Therefore, little doubt was left that the other two events could be identified as explosion earthquakes.

One question left open is the calculated loci were almost 2 km off from the actual explosion site (shown by a star * in Figure 6). Several possibilities are sought to explain the offset.

a). Mislocated station location:

At the time of installation, the location was plotted on the topo map (1:50,000) and the coordinates were calculated from the map coordinates. It is suspected that the location of station 2 may have been plotted incorrectly.

b). Station correction and velocity structure:

The assumed values of the crustal structure and the station correction (due to the difference of the substation structure) were tentatively employed. These values have to be calibrated by the use of explosion.

2.2. Local Earthquake

During the 15-day recording period, one event was registered. (File #55, December 25 07^h39^m G.M.T., 03^h39^m Local time, $m_b = 2.2$). This event was located approximately 5 km southeast of the Tavera dam site and approximately 2 km south of the Tavera reservoir. It is not known if this event is correlated with the activity of the Tavera fault system or caused as a water-induced earthquake or both. The preliminary inspection, however, indicates that the stress drop associated with this event may have been relatively low, which favors the water-induced origin.

RECOMMENDATIONS

1. Explosion events indicated that the determined foci were off approximately 2 km south of the actual explosion site. To resolve this discrepancy, the following measures were recommended:

   A. Measurement of the station coordinate by a surveyor, and

   B. Measurement of a "calibration explosion". By installing an additional, temporary station at the immediate proximity of the explosion site, any explosion for construction purposes can be utilized as a "calibration explosion". CDE already has all the necessary equipment for this installation, and will be able to carry out this measurement without any additional cost.

2. The road leading to the control recording station should be repaired to assure safety of access. This is especially important for the rainy season.

3. Any leak or crack in the building of the central recording station should be carefully monitored. An excess humidity will be very harmful to the computer system.

TAVERA-BAO SEISMOGRAPH NETWORK

Table 1. Location of Stations

NO.	X (km)*	Y (km)**	LONGITUDE (Degree,W)	LATITUDE (Degree, N)	ELEVATION (Meter)
1	0.	0.	70.69683	19.31066	505
2	-8.164	4.808	70.77367	19.35417	490
3	-7.901	-0.938	70.76775	19.27500	710
4	35.657	17.311	70.35942	19.46767	800
5	-16.999	35.932	70.85983	19.63483	660
6	-28.832	-10.999	70.99025	19.23350	870
7	9.584	-24.983	70.60517	19.08442	1200

* The distance measured from station 1, eastward plus

** The distance measured from station 1, northward plus

Table 2. VCO Frequency and VHF Transmitter Frequencies

No.	VCO Center Freq. Hz	Preamplifier Attenuation db	VHF Carrier Freq. MHz	Azimuth * Degree
1	1360	12	140.750	
2	1700	12	141.250	N 57.5^{o} W
3	2040	12	141.750	S 62.0^{o} W
4	2380	12	142.250	N 63.9^{o} E
5	1360	12	142.750	N 22.0^{o} W
6	1700	12	143.250	S 70.0^{o} W
7	2380	12	143.750	S 20.0^{o} E

* measured from station 1

Table 3. List of earthquakes recorded by the Tavera-Bao Seismograph Network

December 13, 1979 -- December 28, 1979
May 15, [illegible]

Column	Abbreviation	Description
1	NO	Identification number
2	YR	Year
3	M D	Month and Day
4	H M	Hour and minutes, G.M.T. (to calculate local time, subtract 4 hours)
5	S	Second of the origin time, a decimal point should be assumed between 2nd and 3rd digit
6	NP	Number of P-arrival reading
7	NS	Number of S-arrival reading
8	IQ	Quality number, ranging 1 through 5, 1 being the most accurate reading. 6 indicates a [illegible] 7 is events generated by an explos[illegible]
9	ITR	Number of iterations carried out during the epicenter calculations
10	MAG	Magnitude x10, magnitude is calculated based on the duration time
11	LONG	Longitude of epicenter (in degree)
12	LAT	Latitude of epicenter (in degree)
13	X	Distance measured from the central station (eastward positive)
14	Y	Distance measured from the central station (northward positive)
15	DEPTH	Depth; if a negative depth is obtained during the iteration process, the epicenter program automatically fixes the depth at 5.0 km and X, Y are calculated.
16	DX	Standard error for X (in km)
17	DY	Standard error for Y (in km)
18	DZ	Standard error for Z (in km)
19	S	Standard error for origin time (in sec.)

DR EQF

NO	Y	M D	H M	S	NP	NS	IQ	ITR	MAG	LONG (DEG)	LAT (DEG)	X (KM)	Y (KM)	DEPTH (KM)	DX (KM)	DY (KM)	DZ (KM)	S
1	79	1213	1136	3858	2	2	4	2	2.0	0.000	0.000	9.6	-25.0	5.0	1310.0	1310.0	0.0	9.84
2	79	1213	1327	3189	2	2	7	9	1.0	-70.732	19.287	-3.9	-2.6	3.8	14.5	24.8	0.0	0.78
3	79	1213	1329	2270	5	2	4	10	2.7	-69.347	18.807	147.8	-55.6	160.2	21.8	25.7	21.7	0.45
4	79	1214	1451	4948	2	1	5	1	1.6	0.000	0.000	9.6	-25.0	5.0	0.0	0.0	0.0	8.84
5	79	1216	728	1684	3	0	6	10	2.2	-70.768	19.142	-7.9	-18.6	5.0	0.3	0.1	0.0	0.01
6	79	1216	1254	3062	5	0	6	10	3.1	-70.974	19.148	-30.4	-17.9	16.8	5.6	1.6	8.9	0.13
7	79	1216	1840	413	5	2	4	10	2.7	-69.990	19.247	77.3	-7.0	19.6	6.8	3.7	4.4	0.32
8	79	1216	0	0	0	0	5	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
9	79	1216	0	0	0	0	5	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
10	79	1216	1850	4388	5	1	7	10	1.3	-70.740	19.293	-4.8	-1.9	7.1	0.7	1.0	0.6	0.14
11	79	1216	2108	3389	2	1	4	10	2.0	-70.362	19.793	36.6	53.4	5.0	0.4	0.5	0.0	0.01
12	79	1216	2121	5960	4	2	3	10	2.9	-69.942	19.225	82.6	-9.4	20.3	4.5	4.2	24.4	0.20
13	79	1217	307	2321	3	1	5	10	1.8	-70.505	19.616	20.9	33.8	5.0	2.8	11.8	0.0	0.39
14	79	1217	339	4650	4	1	4	10	2.9	-69.771	19.415	101.4	11.6	154.0	44.9	107.7	26.0	0.30
15	79	1217	430	758	2	2	5	2	0.6	0.000	0.000	730.6	1310.0	1310.0	1310.0	1310.0	1310.0	1310.00
16	79	1217	614	5345	3	0	6	10	3.4	-70.998	19.477	-33.0	18.5	5.0	0.0	0.1	0.0	0.00
17	79	1217	653	5312	4	2	3	10	1.3	-70.679	19.478	1.8	18.5	29.2	3.1	6.0	5.7	0.21
18	79	1217	701	1162	5	1	3	5	3.1	-70.749	18.276	-5.7	-114.4	21.6	12.7	17.4	37.0	0.52
19	79	1217	1102	1688	5	0	6	10	3.4	-70.985	18.797	-31.7	-56.7	29.0	3.0	5.4	7.2	0.03
20	79	1217	2139	3625	4	2	4	5	1.8	0.000	0.000	112.5	-142.3	111.2	162.2	226.4	182.0	6.82
21	79	1217	2253	4183	3	2	4	10	0.9	-70.250	19.267	48.9	-4.8	5.0	5.6	2.5	0.0	0.27
22	79	1218	0	0	0	0	5	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
23	79	1218	136	1231	3	1	5	10	2.2	-70.699	19.507	-0.3	21.8	40.5	0.1	0.3	0.3	0.00
24	79	1218	448	1882	3	1	4	10	2.0	-70.183	19.093	56.2	-24.0	111.4	1.1	1.2	0.8	0.02
25	79	1218	0	0	0	0	5	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
26	79	1218	1042	4469	2	1	5	10	2.0	-71.266	19.542	-62.4	25.6	5.0	0.7	0.4	0.0	0.02
27	79	1218	0	0	0	0	6	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
28	79	1218	0	0	0	0	5	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
29	79	1218	1313	4786	6	2	1	10	1.4	-70.682	19.577	1.6	29.5	33.6	2.5	4.3	6.5	0.33
30	79	1218	1445	3000	3	0	7	3	2.2	0.000	0.000	1310.0	1310.0	5.0	1310.0	1310.0	0.0	85.42
31	79	1218	1445	5251	3	2	5	5	1.3	0.000	0.000	2.8	-13.5	6.1	57.6	37.5	98.8	3.41
32	79	1218	1642	1713	3	1	5	10	2.3	0.000	0.000	191.6	-82.2	5.0	99.2	161.9	0.0	2.55
33	79	1221	1527	1855	5	2	7	10	1.3	-70.746	19.291	-5.4	-2.1	6.5	0.6	0.8	1.5	0.15
34	79	1221	0	0	0	0	6	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
35	79	1222	0	0	0	0	6	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
36	79	1222	302	1937	5	1	4	7	2.5	-69.372	18.591	145.0	-79.5	70.1	53.1	141.5	265.4	0.72
37	79	1222	559	5158	3	3	4	10	0.9	-70.597	19.123	10.9	-20.7	17.1	0.0	0.0	0.0	0.00
38	79	1222	700	1209	4	1	4	10	2.2	-70.307	19.958	42.7	71.6	73.0	12.8	20.1	19.2	0.19
39	79	1222	800	1625	4	1	4	10	2.2	-70.779	19.702	-9.1	43.3	56.6	10.6	17.3	21.9	0.31
40	79	1222	1004	2219	3	1	5	10	3.1	-69.170	18.665	167.1	-71.4	5.0	8.4	9.0	0.0	0.25
41	79	1222	1654	167	6	1	2	8	2.5	0.000	0.000	108.5	-25.1	47.3	74.0	61.0	421.9	2.55
42	79	1222	1659	4060	4	1	4	10	1.8	-70.230	19.759	51.1	49.7	5.0	11.0	9.3	0.0	0.40
43	79	1222	1823	5597	5	2	2	10	3.1	0.000	0.000	16.9	115.0	5.0	50.7	67.7	0.0	3.36
44	79	1222	2252	3402	3	1	4	10	1.6	-70.735	19.506	-4.2	21.7	70.7	1.2	1.3	0.7	0.01
45	79	1223	240	3589	5	2	3	10	1.8	-70.459	18.852	26.0	-50.7	85.5	6.5	6.7	5.1	0.20
46	79	1223	449	204	5	1	5	8	4.2	-68.231	19.339	269.9	3.2	63.0	83.7	164.5	328.2	0.51
47	79	1223	0	0	0	0	6	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
48	79	1223	1118	1971	6	1	2	10	1.8	-70.440	19.059	28.0	-27.7	30.0	3.0	4.4	5.7	0.27
49	79	1223	1119	4109	4	1	4	10	1.3	-70.564	19.088	14.5	-24.6	26.1	2.6	1.6	2.8	0.10
50	79	1223	1154	4158	5	1	3	10	3.9	-69.725	19.366	106.3	6.1	137.7	40.3	30.3	40.1	1.02

DR EQF

NO	YR	M D	H M	S	NP	NS	IQ	ITR	MAG	LONG (DEG)	LAT (DEG)	X (KM)	Y (KM)	DEPTH (KM)	DX (KM)	DY (KM)	DZ (KM)	S
51	79	1223	1613	2083	4	1	4	10	1.6	-70.838	19.202	-15.5	-12.0	13.8	0.9	2.1	4.8	0.18
52	79	1224	2300	3675	4	1	4	10	2.0	-71.120	19.587	-46.4	30.6	51.6	7.2	15.6	22.1	0.29
53	79	1225	404	2861	5	1	5	10	3.4	-67.706	17.607	327.4	-188.3	277.1	22.8	27.3	26.7	0.16
54	79	1225	0	0	0	0	6	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
55	79	1225	739	4669	4	0	5	10	2.2	-70.695	19.248	0.1	-6.8	16.1	0.1	0.0	0.1	0.00
56	79	1225	1311	5425	6	1	2	10	3.8	-71.415	19.116	-78.7	-21.5	62.6	6.8	5.6	4.7	0.20
57	79	1225	0	0	0	0	5	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
58	79	1225	1852	3270	5	1	3	10	1.8	-70.474	18.923	24.3	-42.8	82.4	2.8	5.1	4.3	0.14
59	79	1226	235	229	6	3	1	10	2.3	-70.668	19.662	3.1	38.9	5.0	6.3	14.3	0.0	1.06
60	79	1226	258	134	5	1	3	10	1.6	-70.926	19.459	-25.1	16.4	39.5	2.1	4.9	4.0	0.12
61	79	1226	628	2000	5	0	4	1	2.5	0.000	0.000	1310.0	-741.6	5.0	1310.0	1310.0	0.0	723.96
62	79	1226	928	4224	3	1	5	10	1.8	-70.825	20.071	-14.0	84.2	5.0	1.9	5.6	0.0	0.17
63	79	1226	1242	451	2	1	5	10	1.3	-70.271	19.271	46.6	-4.3	5.0	0.3	0.1	0.0	0.01
64	79	1226	1422	2805	4	1	4	10	1.8	-70.654	19.625	4.6	34.8	59.9	12.5	20.2	17.0	0.32
65	79	1226	1654	2178	4	1	4	10	1.8	-70.608	19.581	9.7	29.9	66.6	2.9	5.0	3.2	0.07
66	79	1226	1716	1360	6	1	2	10	2.7	-70.693	19.647	0.4	37.2	34.8	2.6	6.6	7.7	0.30
67	79	1226	0	0	0	0	5	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
68	79	1226	1900	3372	3	1	5	10	1.8	-70.249	18.913	49.0	-43.9	10.0	28.3	37.1	59.7	0.54
69	79	1226	0	0	0	0	6	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
70	79	1226	2100	3235	2	1	5	10	1.6	-71.338	19.486	-70.3	19.5	5.0	10.5	15.1	0.0	0.39
71	79	1226	2200	2644	4	1	4	10	1.6	-71.507	18.609	-88.8	-77.5	5.0	9.8	11.7	0.0	0.25
72	79	1226	0	0	0	0	6	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
73	79	1226	0	0	0	0	6	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
74	79	1226	2302	2363	3	1	4	10	2.0	-71.271	19.750	-62.9	48.7	88.6	0.4	0.4	0.6	0.00
75	79	1227	1444	4188	3	2	4	2	2.2	0.000	0.000	-1055.7	1310.0	1310.0	1310.0	1310.0	1310.0	1310.00
76	79	1227	1500	3706	3	1	5	10	1.6	-70.370	19.844	35.7	59.0	5.0	11.4	18.4	0.0	0.63
77	79	1227	1501	3243	5	2	2	10	2.0	-70.208	18.881	53.4	-47.4	7.6	3.3	4.1	86.0	0.23
78	79	1227	2022	4284	4	1	4	10	3.1	-70.108	19.952	64.4	71.0	108.5	28.5	58.0	26.2	0.37
79	79	1227	2222	2354	6	1	2	7	2.5	0.000	0.000	100.0	-22.5	31.7	250.7	193.0	73.6	7.51
80	79	1228	218	3337	5	1	3	10	2.9	-70.123	19.206	62.7	-11.5	19.9	9.9	5.2	4.1	0.35
81	79	1228	247	3500	5	0	5	10	3.0	-61.901	13.480	963.1	-644.9	826.4	1310.0	1310.0	1310.0	0.35

FIGURE CAPTIONS

Figure 1. Distribution of stations of Tavera-Bao Seismic Network

Figure 2. System diagram of Tavera-Bao Seismic Network

Figure 3. Schematic Tectonic map of the Caribbean region showing plate boundaries and late Cenozoic tectonic features (after T. Jordan, 1975).

Figure 4. Epicenter map of Puerto Rico - Dominican Republic region. Seismic data provided by the National Earthquake Information Service, U.S.G.S. An epicenter is shown by an X, an open circle, or a closed circle according to the depth (key at the bottom of the figure). A closed square shows the site of Tavera-Bao Hydrelectric Project.

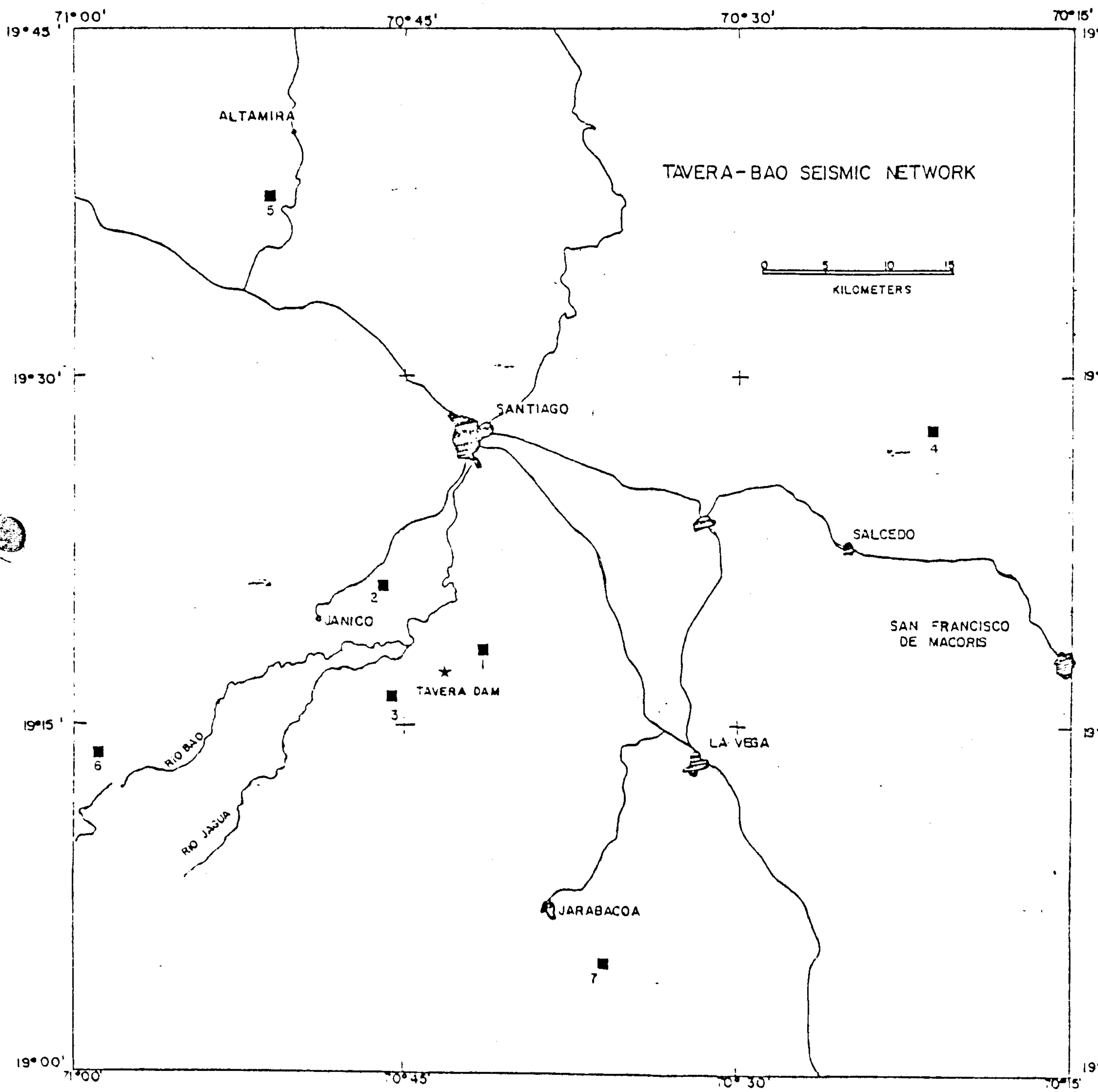
Figure 5. Regional distribution of earthquakes located by the Tavera-Bao Seismic Network during the period of December 13-28, 1979. An X shows an event shallower than 50 km, and an open square equal to or deeper than 50 km. An event originated from an explosion is indicated by a + sign.

Scale	Figure 5A	1:250,000
	Figure 5B	1:1,000,000

Figure 6. Location of three explosion events are shown by + signs. These events occured at:

1979, December	13	13 h 27 m G.M.T. (09 h 27 m local time) $m_b = 1.0$
	16	18 h 50 m G.M.T. (14 h 50 m local time) $m_b = 1.3$
	21	15 h 27 m G.M.T. (11 h 27 m local time) $m_b = 1.3$

The actual explosion site is indicated by a star * suggesting that the calculated epicenters are approximately 2 km off to the south.



TAVERA-BAO SEISMIC NETWORK
71°00'
70°45'
70°30'
70°15'
19°45'
19°30'
19°15'
19°00'
0 5 10 15
KILOMETERS
ALTAMIRA
SANTIAGO
SALCEDO
SAN FRANCISCO DE MACORIS
JANICO
TAVERA DAM
LA VEGA
JARABACOA
RIO BAO
RIO JAGUA
1
2
3
4
5
6
7

Fig. 2

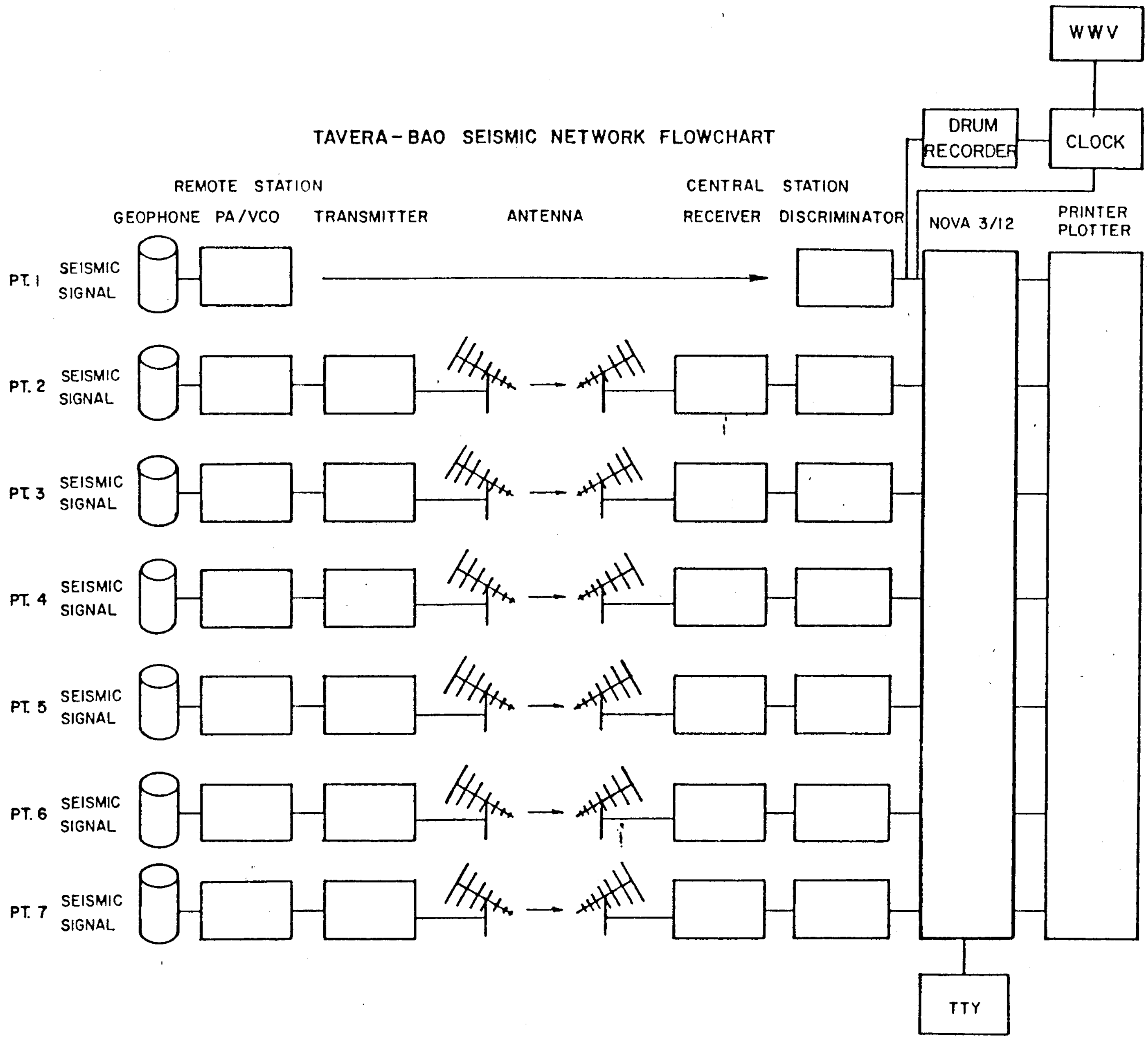
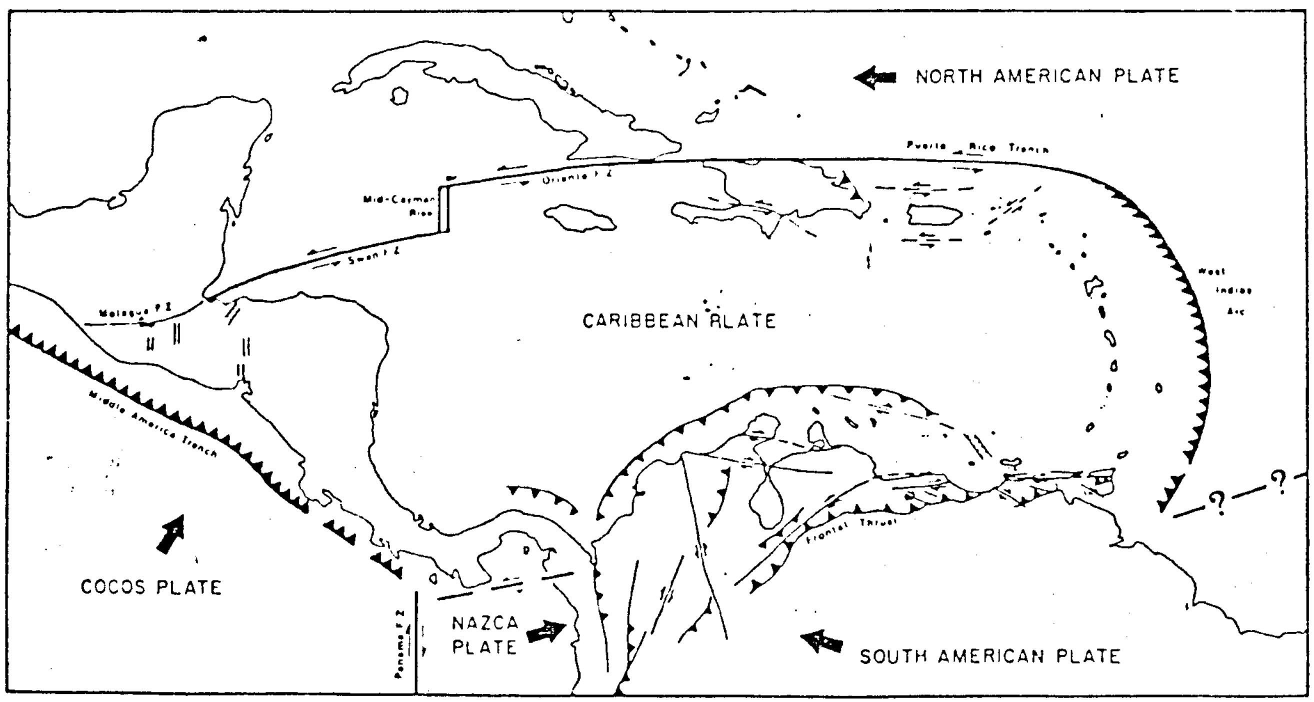
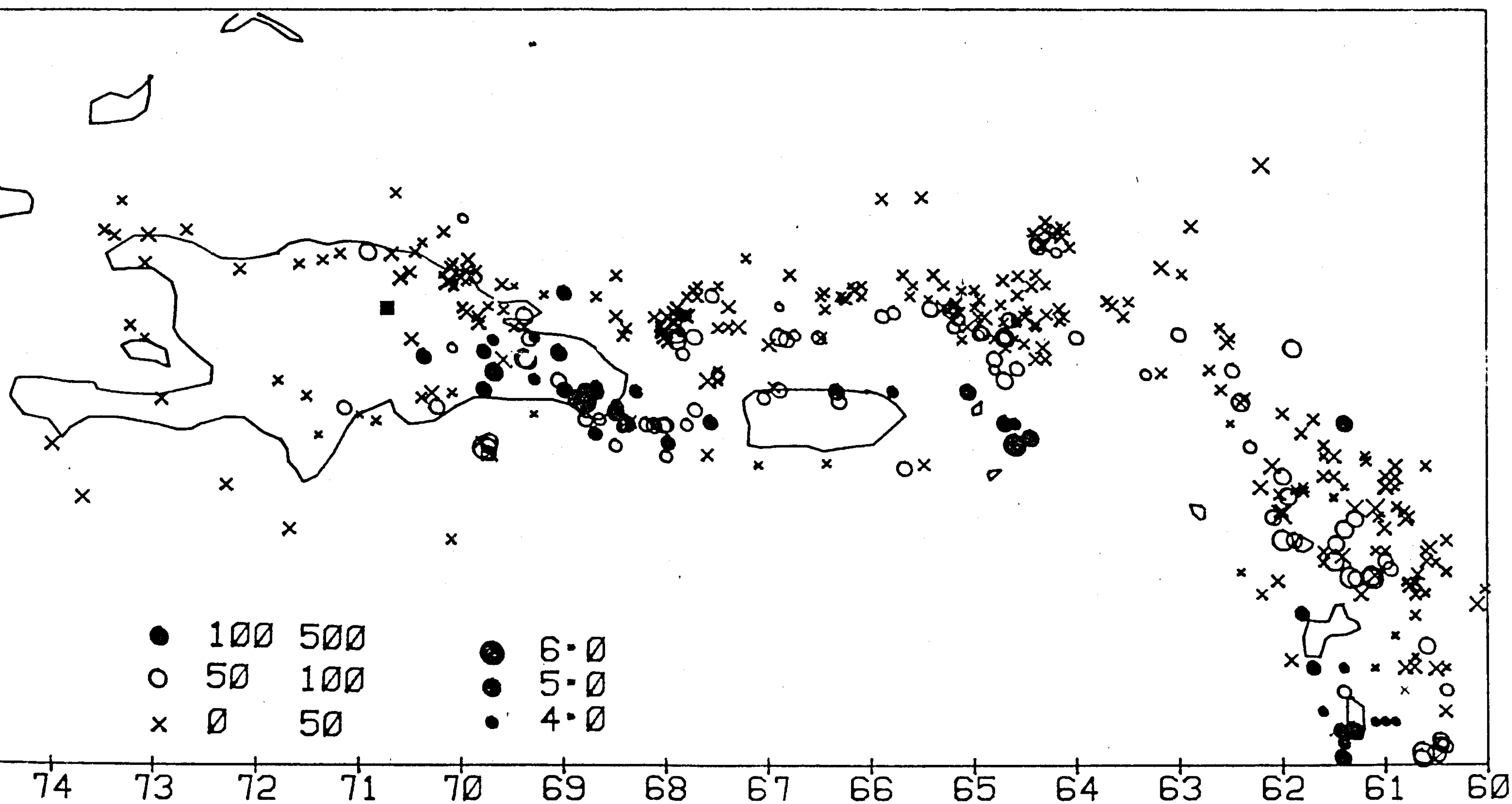

TAVERA-BAO SEISMIC NETWORK FLOWCHART
REMOTE STATION
GEOPHONE PA/VCO
TRANSMITTER
ANTENNA
CENTRAL STATION
RECEIVER
DISCRIMINATOR
NOVA 3/12
PRINTER PLOTTER
WWV
CLOCK
DRUM RECORDER
TTY
PT. 1 SEISMIC SIGNAL
PT. 2 SEISMIC SIGNAL
PT. 3 SEISMIC SIGNAL
PT. 4 SEISMIC SIGNAL
PT. 5 SEISMIC SIGNAL
PT. 6 SEISMIC SIGNAL
PT. 7 SEISMIC SIGNAL

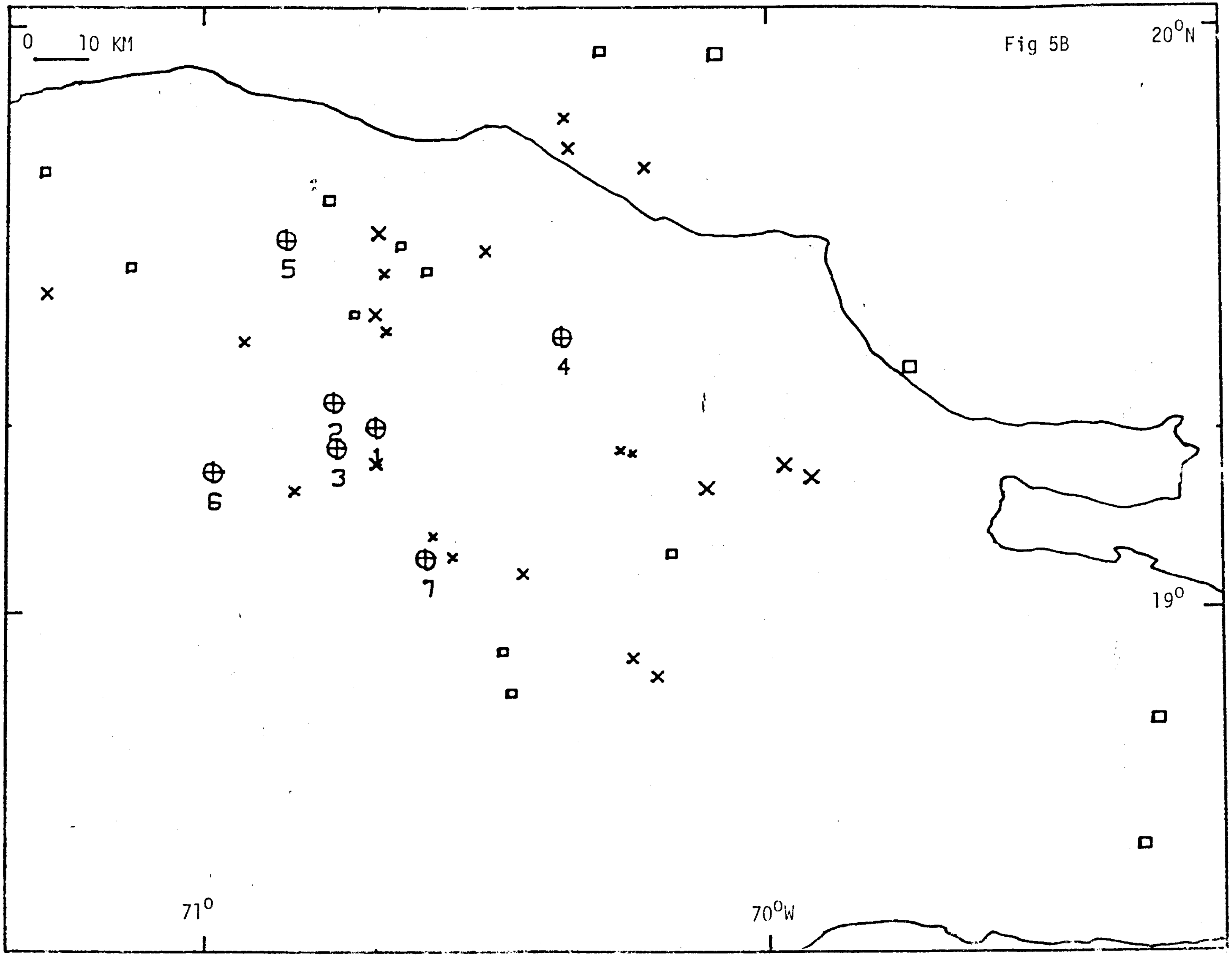
Fig 3


NORTH AMERICAN PLATE
Puerto Rico Trench
Oriente F Z
Mid-Cayman Rise
Swan F Z
Motagua F Z
West Indies Arc
CARIBBEAN PLATE
Middle America Trench
Frontal Thrust
COCOS PLATE
NAZCA PLATE
Panama F Z
SOUTH AMERICAN PLATE

63001-77303

Fig 4




0 10 KM
Fig 5B
20°N
19°
71°
70°W
1
2
3
4
5
6
7

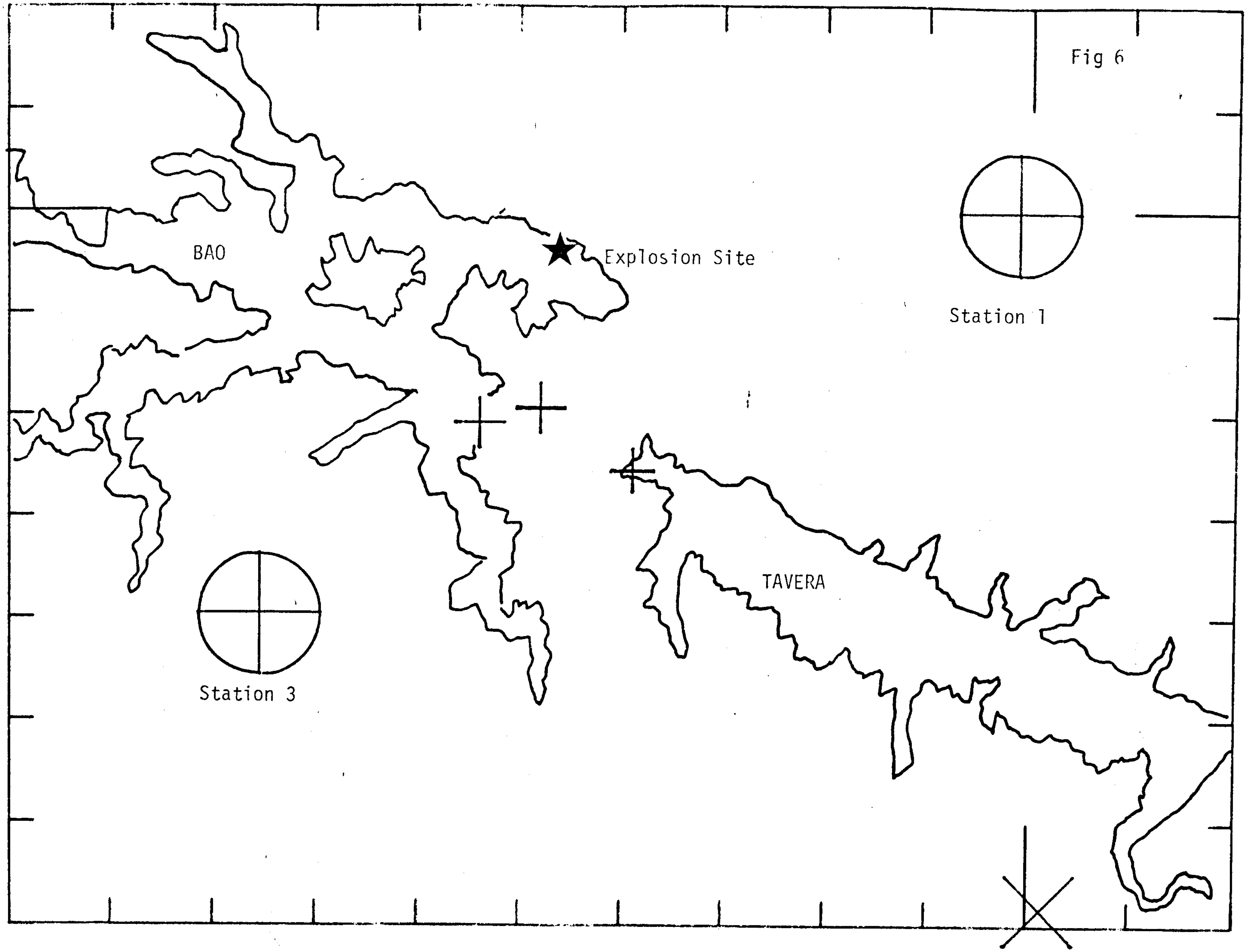


Fig 6
BAO
Explosion Site
Station 1
Station 3
TAVERA

PRELIMINARY REPORT NO. 1

Tavera - Bao Seismograph Network

January 11, 1980

Submitted to: Ing. Marcelo Jorge Perez, CDE

Submitted by: Dr. Tosimatu Matumoto
University of Texas

University of Texas Institute for Geophysics Contribution No. 561.

CONTENTS

INTRODUCTION

Seven remote stations of the Tavera-Bao Seismograph Network were installed by the Marine Science Institute, University of Texas, during the period of November 7 through November 28, 1979. The network started its full operation on December 13, 1979.

In this seismic monitoring system, the signals from the remote stations are transmitted back to the central recording station by VHF radio telemetry link. All the necessary power for a remote station is supplied from a battery and a set of solar panels.

At the central recording station, the signals from remote stations are continuously analysed by the Computerized Seismic Monitoring System (COSMOS). This system identifies a possible earthquake, triggers the recording system when an earthquake is detected, and plots the seismic signals without losing the first arrivals. In addition, when the sufficient number of stations are triggered, this system starts to calculate the location and magnitude of an earthquake without human assistance, and prints out this information when plotting of the seismic signal is completed.

Preliminary analysis of data covering the period from December 13 through December 28, 1979, was accomplished. The analysis indicated that:

1) Three events were located in the immediate vicinity of the Tavera-Bao project site with magnitude 1.0, 1.3 and 1.3 respectively. These events, however, were identified as those originated from explosions.

2) The closest earthquake to the project area was located approximately 5 km southeast of the Tavera Dam site with a magnitude of 2.2. No event distributed along the Tavera fault system was discovered during the 15 day recording period.

3) Distribution of the earthquakes exhibited a rather complicated regional pattern.

THE PURPOSE AND MECHANICS OF THE TAVERA-BAO SEISMIC NETWORK

The study of mecroearthquakes provides a rapid way of mapping active faults in regions of high seismic activity. Microearthquakes with magnitudes as small as 1 on the Richter scale can best be recorded by ultra-sensitive, high-frequency seismographs operated at distances of less than a few tens of kilometers from the earthquakes. More than 1000 microearthquakes may thus be detected in a region where only one earthquake has been recorded by the distant stations of the World Wide Seismograph Network during the same period.

The effectiveness of such a high gain seismic system is extremely useful for estimating the seismic risk within a limited time span. The crucial period of the seismological studies is divided in two different phases of the construction period of the dam. Data gathered at the early phase of the hydroelectric project provides essential design information such as the location of active faults, the expected maximum magnitude and acceleration, and duration of ground movement that the dam must be engineered to safely withstand. Even after the design is established, such information serves to confirm the design criteria.

The second phase begins as the reservoir is filled, as this is when water-induced earthquakes frequently occur. It is known that when the reservoir is being loaded, the surrounding pore pressure of the rock is increased. If faults do exist in the area, the increased pore pressure acts as a lubricant for existing faults and may cause a phenomena known as "water-induced earthquakes". This has happened in Zambia (Kariba earthquake, Sept. 23, 1963, m=6.3), Greece (Kremasta earthquake, Feb. 5, 1965, m=6.2) and India (Koyna earthquake, Dec. 10, 1967, m=6.4).

From Figure 1 and Table 1, we can see the general layout of the seismic network. There are 6 remote stations and 1 central recording station. A geophone has been placed at the central station to make a total of 7 monitoring points. Stations 1, 2 and 3 are within a 6 km radius of the dam, yielding very accurate measurements in the immediate construction site and stations 4, 5, 6 and 7 are on an outside circle of an approximate radius of 45 km.

Exact station locations are very carefully selected with priorities as follows:

1. Line of sight: Transmission of the seismic signal to the central station must be clear and unobstructed.
2. Background noise such as roads, cattle, footpaths and even wind must be low enough to accurately distinguish the seismic signal.
3. Accessability: The site must be easily reached for construction and possible future maintainance.
4. All stations together must provide an extended areal coverage for the comprehensive studies of local, regional and deep focus earthquakes.

Description of Remote Station Equipment and Function

Figure 2 is a simple illustration of the order of operation of the remote station and central recording station. The seismic signal is picked up by the geophone, amplified and modulated by the PA/VCO and then transmitted by a certain frequency transmitter to the central recording station. Each station consists of:

A) Geophone

B) PA/VCO

C) Transmitter

D) Antenna (directional)

E) Solar Panel

A) Geophone: (mark products 1 Hz vertical)

The geophone senses vertical ground movements and converts this mechanical energy to electrical impulses. These impulses travel down the geophone cable and into the PA/VCO. Both the Geophone and the cable are buried to prevent damage by inquisitive people or animals. The geophone is placed in a cement cylinder to further protect it and insulate it from extraneous noise.

B) PA/VCO: Pre-Amplifier/Voltage Controlled Oscillator (UT/MSI design)

Here the signal is amplified and converted to a modulating frequency by VCO for better transmission. Both the PA/VCO and transmitter are in small waterproof metal boxes. These two boxes are contained in a larger wooden box which also houses the 12V battery that supplies the power to each unit.

The Pre-Amp has a maximum of 90db gain with 8 adjustable steps of attenuation at 6 db each. The output of the VCO is a sine wave that varies in frequency following the amplifier output signal. There are 4 center frequencies being used: 1360, 1700, 2040 and 2380 Hz. Deviation about these center frequencies is maintained by the VCO. A $\pm$ 2.5 volt input variance will modulate the frequency $\pm$ 125Hz. Thus it follows that the larger the ground movement, the bigger the voltage impulse and the wider the frequency variation.

C) Radio Transmitter and Antenna:

The VCO output is fed into the transmitter and directional antenna for transmission back to the central recording station. The antenna possesses a 17^{o} dispersion angle of transmission but alignment of the antenna with the central station should be as accurate as possible. Each station has its own frequency of transmission. Transmitting frequencies vary between 140.750 and 144.750 MHz in increments of .5MHz.

D) Solar Panel:

Three solar panels occupy each remote station. Hooked in parallel to the battery, they can recharge the battery indefinitely, provided there is sufficient sunlight. The solar panels face the south in the Northern Hemisphere and are mounted at an angle of the station latitude plus 10^{o} for maximum sunlight.

Description of the Central Recording Station (Equipment and Function)

Upon reaching the central recording station, the signal is received and then demodulated by a discriminator and fed into the Computerized Seismic Monitoring System. Here possible earthquakes are detected through a triggering system and then located by a complex computer program. The central recording station consists of:

A) Receiver
B) Discriminator
C) COSMOS
D) Nova 312 Computer
E) Versatec Printer/Plotter
F) Time clock

A) Receiver and Antenna:

Six antennas are located close to the central station and are pointed in the direction of their respective transmitting stations. The cables from each antenna are run into the building housing the receivers and computer equipment. The receivers are all mounted on the wall together and numbered to the correct station for ease of service. The output from each receiver is a variable frequency tone matching the VCO output signal at the remote station.

B) Discriminators:

The output signal from each receiver is fed into a discriminator. This instrument converts the frequency modulated signal back into the amplified signal that was originally fed into the VCO at the remote station.

C) COSMOS (Computerized Seismic Monitoring System):

COSMOS is a fully automated computerized monitoring system which can handle input data from up to 30 seismic stations. On its own, COSMOS will:

--identify probable earthquake signals and plot these signals for all seismic stations beginning a few seconds prior to the first arrival of the signal.

--automatically determine the epicenter and magnitude of all probable events.

The basic idea behind the COSMOS computer program is the Delay Memory and Trigger Circuits. The output from each discriminator is fed into a digital memory unit where 20 seconds of data is stored. After 20 seconds, the data flows into a trigger identification circuit and a coincidence detector circuit. The trigger identification circuit compares the signal to the preceding 100 seconds of averaged background noise. If this signal exceeds the background noise level by a factor of 8, the trigger identification circuit for that station is set to the triggered mode for the next 20 seconds. The coincidence detector examines the number of stations that are in the triggered mode and if 3 or more stations are triggered, the earthquake location portion of the COSMOS program begins. If less than 3 are in the triggered mode, the system goes on as before, analyzing 20 seconds of memory stored seismic signals per station.

D) Nova 3/12 Computer:

This instrument is a computer with 32 k words of core memory through which the COSMOS program is executed. A/D signal converter, dual floppy disc drive, internal clock, and interface to peripherals (Printer/Plotter and Tele-type) are attached to this system. It stands next to the discriminator rack in the central station.

E) Versatec Printer/Plotter:

Next to the Nova 3/12, this high speed instrument prints out the located earthquake from COSMOS and also plots the seismic signal of all stations coinciding with this event.

F) Time Clock:

The Bureau of Standards broadcasts Coordinated Universal Time at 5, 10, 15, 20 and 25 megacycles or more commonly known as station WWV. We employ a Geotech WWV time clock for this purpose. This digital clock can be calibrated up to 1 millisecond by the standard WWV time signal. The COSMOS system records this time and a built-in subroutine continuously reads this time code and updates the internal clock in the computer.

G) Continuous Recording:

In addition to the COSMOS system, a drum recorder is continuously monitoring station 1. This drum recording system assures registering of small events that were not large enough to trigger the COSMOS system. The drum speed is set so that each revolution of the drum is 15 minutes and one sheet of drum paper records 24 hours of data.

The time code is also recorded on the drum paper as a small deflection of the pen each minute with large deflections at the hour and half hour marks.

All the electronic equipment for the central station is in a concrete house. This structure has been completely sealed off from any outside weather effects. An air conditioner keeps the room at a temperature and humidity that is ideal for the computer. Excessive humidity or extreme temperature changes could render the equipment inoperable.

PRELIMINARY ANALYSIS OF DATA, DECEMBER 13-28, 1979

The data covering the period from December 13 through December 28, 1979, was returned to the Marine Science Institute for detailed analysis. Up to date, only a preliminary analysis was accomplished.

For each event, the arrival times of P and S waves were carefully identified by a skilled operator. Comparison of the manual reading to the computer based automatic reading indicated that the latter was approximately identical to the manual reading when the onset of a P-wave was sharp and clear (within 0.1 to 0.2 seconds), but showed relatively greater error (up to 0.5 to 1 second) when an onset was slow and small. Also, the computer based reading is unable to identify the S-wave. Therefore, the automatic epicenter determination by the COSMOS system is valid only for local events with a sharp onset.

During the 15-day recording period, 81 events were identified and 51 epicenters were determined (Table 3). The magnitude (m_b) of the recorded events ranged from 3.9 to 0.6 with 62 percent of events falling between 1.0 to 2.9.

1. Regional Distribution.

Figures 5A and B show the regional distribution of the events located by the Tavera-Bao Seismograph Network. Events with the depth shallower than 50 km were illustrated by X's and those with the depth equal to or greater than 50 km were shown by open squares.

Most of the events determined by the Tavera-Bao network (Figure 5B) fall into the zone of epicenter distribution provided by the National Earthquake Information Service, U.S.G.S. (Figure 4). This shows a significant departure between the observed local seismicity and that depicted by the World Wide Seismograph Network.

In Figure 5B, one can observe that the shallow earthquakes are approximately distributed along the northern and southern boundaries of the Santiago Basin which extends roughly northwest-southeast between the Central Cordillera and the Northern Coastal Ranges.

The data from the Tavera-Bao network indicated the existence of intermediate and deep focus earthquakes, probably reaching up to the maximum depth of 200 km. This confirms the presence of a subduction zone beneath the eastern half of Hispaniola. The easterly movement of the Caribbean plate in reference to the North American plate predicts predominance of transform faulting along the east-west trending plate boundary. Elucidating the generation and evolution of the Benioff zone is quite important for the geodynamic process in this region.

2. Activity in the Vicinity of Tavera-Bao Project.

2.1. Explosion Earthquakes

Three events were located in the immediate vicinity of the connecting channel (Figure 6). These events occured on the following dates:

File #		Date	Time	Magnitude
2	1979	December 13	13^h27^m G.M.T. (09^h27^m Local time)	1.0
10	1979	December 16	18^h50^m G.M.T. (14^h50^m Local time)	1.3
33	1979	December 21	15^h27^m G.M.T. (11^h27^m Local time)	1.3

Only one of the events (No. 10) was identified as an explosion earthquake. However, all of them show quite identical seismic signatures which is characterized by all upward initial motion at all stations. Therefore, little doubt was left that the other two events could be identified as explosion earthquakes.

One question left open is the calculated loci were almost 2 km off from the actual explosion site (shown by a star * in Figure 6). Several possibilities are sought to explain the offset.

a). Mislocated station location:

At the time of installation, the location was plotted on the topo map (1:50,000) and the coordinates were calculated from the map coordinates. It is suspected that the location of station 2 may have been plotted incorrectly.

b). Station correction and velocity structure:

The assumed values of the crustal structure and the station correction (due to the difference of the substation structure) were tentatively employed. These values have to be calibrated by the use of explosion.

2.2. Local Earthquake

During the 15-day recording period, one event was registered. (File #55, December 25 07^h39^m G.M.T., 03^h39^m Local time, $m_b = 2.2$). This event was located approximately 5 km southeast of the Tavera dam site and approximately 2 km south of the Tavera reservoir. It is not known if this event is correlated with the activity of the Tavera fault system or caused as a water-induced earthquake or both. The preliminary inspection, however, indicates that the stress drop associated with this event may have been relatively low, which favors the water-induced origin.

RECOMMENDATIONS

1. Explosion events indicated that the determined foci were off approximately 2 km south of the actual explosion site. To resolve this discrepancy, the following measures were recommended:
   A. Measurement of the station coordinate by a surveyor, and
   B. Measurement of a "calibration explosion". By installing an additional, temporary station at the immediate proximity of the explosion site, any explosion for construction purposes can be utilized as a "calibration explosion". CDE already has all the necessary equipment for this installation, and will be able to carry out this measurement without any additional cost.

2. The road leading to the control recording station should be repaired to assure safety of access. This is especially important for the rainy season.

3. Any leak or crack in the building of the central recording station should be carefully monitored. An excess humidity will be very harmful to the computer system.

TAVERA-BAO SEISMOGRAPH NETWORK

Table 1. Location of Stations

NO.	X (km)*	Y (km)**	LONGITUDE (Degree,W)	LATITUDE (Degree, N)	ELEVATION (Meter)
1	0.	0.	70.69683	19.31066	505
2	-8.164	4.808	70.77367	19.35417	490
3	-7.901	-0.938	70.76775	19.27500	710
4	35.657	17.311	70.35942	19.46767	800
5	-16.999	35.932	70.85983	19.63483	660
6	-28.832	-10.999	70.99025	19.23350	870
7	9.584	-24.983	70.60517	19.08442	1200

* The distance measured from station 1, eastward plus

** The distance measured from station 1, northward plus

Table 2. VCO Frequency and VHF Transmitter Frequencies

No.	VCO Center Freq. Hz	Preamplifier Attenuation db	VHF Carrier Freq. MHz	Azimuth * Degree
1	1360	12	140.750	
2	1700	12	141.250	N 57.5^{o} W
3	2040	12	141.750	S 62.0^{o} W
4	2380	12	142.250	N 63.9^{o} E
5	1360	12	142.750	N 22.0^{o} W
6	1700	12	143.250	S 70.0^{o} W
7	2380	12	143.750	S 20.0^{o} E

* measured from station 1

Table 3. List of earthquakes recorded by the Tavera-Bao Seismograph Network

December 13, 1979 -- December 28, 1979

Column	Abbreviation	Description
1	NO	Identification number
2	YR	Year
3	M D	Month and Day
4	H M	Hour and minutes, G.M.T. (to calculate local time, subtract 4 hours)
5	S	Second of the origin time, a decimal point should be assumed between 2nd and 3rd digit
6	NP	Number of P-arrival reading
7	NS	Number of S-arrival reading
8	IQ	Quality number, ranging 1 through 5, 1 being the most accurate reading.
9	ITR	Number of iterations carried out during the epicenter calculations
10	MAG	Magnitude x10, magnitude is calculated based on the duration time
11	LONG	Longitude of epicenter (in degree)
12	LAT	Latitude of epicenter (in degree)
13	X	Distance measured from the central station (eastward positive)
14	Y	Distance measured from the central station (northward positive)
15	DEPTH	Depth; if a negative depth is obtained during the iteration process, the epicenter program automatically fixes the depth at 5.0 km and X, Y are calculated.
16	DX	Standard error for X (in km)
17	DY	Standard error for Y (in km)
18	DZ	Standard error for Z (in km)
19	S	Standard error for origin time (in sec.)

DR EQF NO	Y	M D	H M	S	NP	NS	IQ	ITR	MAG	LONG (DEG)	LAT (DEG)	X (KM)	Y (KM)	DEPTH (KM)	DX (KM)	DY (KM)	DZ (KM)	S
1	79	1213	1136	3858	2	2	4	2	2.0	0.000	0.000	9.6	-25.0	5.0	1310.0	1310.0	0.0	9.84
2	79	1213	1327	3189	2	2	7	9	1.0	-70.732	19.287	-3.9	-2.6	3.8	14.5	24.8	0.0	0.78
3	79	1213	1329	2270	5	2	4	10	2.7	-69.347	18.807	147.8	-55.6	160.2	21.8	25.7	21.7	0.45
4	79	1214	1451	4948	2	1	5	1	1.6	0.000	0.000	9.6	-25.0	5.0	0.0	0.0	0.0	8.84
5	79	1216	728	1684	3	0	6	10	2.2	-70.768	19.142	-7.9	-18.6	5.0	0.3	0.1	0.0	,0.01
6	79	1216	1254	3062	5	0	6	10	3.1	-70.974	19.148	-30.4	-17.9	16.8	5.6	1.6	8.9	0.13
7	79	1216	1840	413	5	2	4	10	2.7	-69.990	19.247	77.3	-7.0	19.6	6.8	3.7	4.4	0.32
8	79	1216	0	0	0	0	5	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
9	79	1216	0	0	0	0	5	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
10	79	1216	1850	4388	5	1	7	10	1.3	-70.740	19.293	-4.8	-1.9	7.1	0.7	1.0	0.6	0.14
11	79	1216	2108	3389	2	1	4	10	2.0	-70.362	19.793	36.6	53.4	5.0	0.4	0.5	0.0	0.01
12	79	1216	2121	5960	4	2	3	10	2.9	-69.942	19.225	82.6	-9.4	20.3	4.5	4.2	24.4	0.20
13	79	1217	307	2321	3	1	5	10	1.8	-70.505	19.616	20.9	33.8	5.0	2.8	11.8	0.0	0.39
14	79	1217	339	4650	4	1	4	10	2.9	-69.771	19.415	101.4	11.6	154.0	44.9	107.7	26.0	0.30
15	79	1217	430	758	2	2	5	2	0.6	0.000	0.000	730.6	1310.0	1310.0	1310.0	1310.0	1310.0	1310.00
16	79	1217	614	5345	3	0	6	10	3.4	-70.998	19.477	-33.0	18.5	5.0	0.0	0.1	0.0	0.00
17	79	1217	653	5312	4	2	3	10	1.3	-70.679	19.478	1.8	18.5	29.2	3.1	6.0	5.7	0.21
18	79	1217	701	1162	5	1	3	5	3.1	-70.749	18.276	-5.7	-114.4	21.6	12.7	17.4	37.0	0.52
19	79	1217	1102	1688	5	0	6	10	3.4	-70.985	18.797	-31.7	-56.7	29.0	3.0	5.4	7.2	0.03
20	79	1217	2139	3625	4	2	4	5	1.8	0.000	0.000	112.5	-142.3	111.2	162.2	226.4	182.0	6.82
21	79	1217	2253	4183	3	2	4	10	0.9	-70.250	19.267	48.9	-4.8	5.0	5.6	2.5	0.0	0.27
22	79	1218	0	0	0	0	5	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
23	79	1218	136	1231	3	1	5	10	2.2	-70.699	19.507	-0.3	21.8	40.5	0.1	0.3	0.3	0.00
24	79	1218	448	1882	3	1	4	10	2.0	-70.183	19.093	56.2	-24.0	111.4	1.1	1.2	0.8	0.02
25	79	1218	0	0	0	0	5	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
26	79	1218	1042	4469	2	1	5	10	2.0	-71.266	19.542	-62.4	25.6	5.0	0.7	0.4	0.0	0.02
27	79	1218	0	0	0	0	6	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
28	79	1218	0	0	0	0	5	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
29	79	1218	1313	4786	6	2	1	10	1.4	-70.682	19.577	1.6	29.5	33.6	2.5	4.3	6.5	0.33
30	79	1218	1445	3000	3	0	7	3	2.2	0.000	0.000	1310.0	1310.0	5.0	1310.0	1310.0	0.0	85.42
31	79	1218	1445	5251	3	2	5	5	1.3	0.000	0.000	2.8	-13.5	6.1	57.6	37.5	98.8	3.41
32	79	1218	1642	1713	3	1	5	10	2.3	0.000	0.000	191.6	-82.2	5.0	99.2	161.9	0.0	2.55
33	79	1221	1527	1855	5	2	7	10	1.3	-70.746	19.291	-5.4	-2.1	6.5	0.6	0.8	1.5	0.15
34	79	1221	0	0	0	0	6	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
35	79	1222	0	0	0	0	6	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
36	79	1222	302	1937	5	1	4	7	2.5	-69.372	18.591	145.0	-79.5	70.1	53.1	141.5	265.4	0.72
37	79	1222	559	5158	3	3	4	10	0.9	-70.597	19.123	10.9	-20.7	17.1	0.0	0.0	0.0	0.00
38	79	1222	700	1209	4	1	4	10	2.2	-70.307	19.958	42.7	71.6	73.0	12.8	20.1	19.2	0.19
39	79	1222	800	1625	4	1	4	10	2.2	-70.779	19.702	-9.1	43.3	56.6	10.6	17.3	21.9	0.31
40	79	1222	1004	2219	3	1	5	10	3.1	-69.170	18.665	167.1	-71.4	5.0	8.4	9.0	0.0	0.25
41	79	1222	1654	167	6	1	2	8	2.5	0.000	0.000	108.5	-25.1	47.3	74.0	61.0	421.9	2.55
42	79	1222	1659	4060	4	1	4	10	1.8	-70.230	19.759	51.1	49.7	5.0	11.0	9.3	0.0	0.40
43	79	1222	1823	5597	5	2	2	10	3.1	0.000	0.000	16.9	115.0	5.0	50.7	67.7	0.0	3.36
44	79	1222	2252	3402	3	1	4	10	1.6	-70.735	19.506	-4.2	21.7	70.7	1.2	1.3	0.7	0.01
45	79	1223	240	3589	5	2	3	10	1.8	-70.459	18.852	26.0	-50.7	85.5	6.5	6.7	5.1	0.20
46	79	1223	449	204	5	1	5	8	4.2	-68.231	19.339	269.9	3.2	63.0	83.7	164.5	328.2	0.51
47	79	1223	0	0	0	0	6	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
48	79	1223	1118	1971	6	1	2	10	1.8	-70.440	19.059	28.0	-27.7	30.0	3.0	4.4	5.7	0.27
49	79	1223	1119	4109	4	1	4	10	1.3	-70.564	19.088	14.5	-24.6	26.1	2.6	1.6	2.8	0.10
50	79	1223	1154	4158	5	1	3	10	3.9	-69.725	19.366	106.3	6.1	137.7	40.3	30.3	40.1	1.02

DR EQF

NO	YR	M D	H M	S	NP	NS	IQ	ITR	MAG	LONG (DEG)	LAT (DEG)	X (KM)	Y (KM)	DEPTH (KM)	DX (KM)	DY (KM)	DZ (KM)	S
51	79	1223	1613	2083	4	1	4	10	1.6	-70.838	19.202	-15.5	-12.0	13.8	0.9	2.1	4.8	0.18
52	79	1224	2300	3675	4	1	4	10	2.0	-71.120	19.587	-46.4	30.6	51.6	7.2	15.6	22.1	0.29
53	79	1225	404	2861	5	1	5	10	3.4	-67.706	17.607	327.4	-188.3	277.1	22.8	27.3	26.7	0.16
54	79	1225	0	0	0	0	6	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
55	79	1225	739	4669	4	0	5	10	2.2	-70.695	19.248	0.1	-6.8	16.1	0.1	0.0	0.1	0.00
56	79	1225	1311	5425	6	1	2	10	3.8	-71.415	19.116	-78.7	-21.5	62.6	6.8	5.6	4.7	0.20
57	79	1225	0	0	0	0	5	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
58	79	1225	1852	3270	5	1	3	10	1.8	-70.474	18.923	24.3	-42.8	82.4	2.8	5.1	4.3	0.14
59	79	1226	235	229	6	3	1	10	2.3	-70.668	19.662	3.1	38.9	5.0	6.3	14.3	0.0	1.06
60	79	1226	258	134	5	1	3	10	1.6	-70.926	19.459	-25.1	16.4	39.5	2.1	4.9	4.0	0.12
61	79	1226	628	2000	5	0	4	1	2.5	0.000	0.000	1310.0	-741.6	5.0	1310.0	1310.0	0.0	723.96
62	79	1226	928	4224	3	1	5	10	1.8	-70.825	20.071	-14.0	84.2	5.0	1.9	5.6	0.0	0.17
63	79	1226	1242	451	2	1	5	10	1.3	-70.271	19.271	46.6	-4.3	5.0	0.3	0.1	0.0	0.01
64	79	1226	1422	2805	4	1	4	10	1.8	-70.654	19.625	4.6	34.8	59.9	12.5	20.2	17.0	0.32
65	79	1226	1654	2178	4	1	4	10	1.8	-70.608	19.581	9.7	29.9	66.6	2.9	5.0	3.2	0.07
66	79	1226	1716	1360	6	1	2	10	2.7	-70.693	19.647	0.4	37.2	34.8	2.6	6.6	7.7	0.30
67	79	1226	0	0	0	0	5	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
68	79	1226	1900	3372	3	1	5	10	1.8	-70.249	18.913	49.0	-43.9	10.0	28.3	37.1	59.7	0.54
69	79	1226	0	0	0	0	6	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
70	79	1226	2100	3235	2	1	5	10	1.6	-71.338	19.486	-70.3	19.5	5.0	10.5	15.1	0.0	0.39
71	79	1226	2200	2644	4	1	4	10	1.6	-71.507	18.609	-88.8	-77.5	5.0	9.8	11.7	0.0	0.25
72	79	1226	0	0	0	0	6	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
73	79	1226	0	0	0	0	6	0	0.0	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.00
74	79	1226	2302	2363	3	1	4	10	2.0	-71.271	19.750	-62.9	48.7	88.6	0.4	0.4	0.6	0.00
75	79	1227	1444	4188	3	2	4	2	2.2	0.000	0.000	-1055.7	1310.0	1310.0	1310.0	1310.0	1310.0	1310.00
76	79	1227	1500	3706	3	1	5	10	1.6	-70.370	19.844	35.7	59.0	5.0	11.4	18.4	0.0	0.63
77	79	1227	1501	3243	5	2	2	10	2.0	-70.208	18.881	53.4	-47.4	7.6	3.3	4.1	86.0	0.23
78	79	1227	2022	4284	4	1	4	10	3.1	-70.108	19.952	64.4	71.0	108.5	28.5	58.0	26.2	0.37
79	79	1227	2222	2354	6	1	2	7	2.5	0.000	0.000	100.0	-22.5	31.7	250.7	193.0	73.6	7.51
80	79	1228	218	3337	5	1	3	10	2.9	-70.123	19.206	62.7	-11.5	19.9	9.9	5.2	4.1	0.35
81	79	1228	247	3500	5	0	5	10	3.0	-61.901	13.480	963.1	-644.9	826.4	1310.0	1310.0	1310.0	0.35

FIGURE CAPTIONS

Figure 1. Distribution of stations of Tavera-Bao Seismic Network

Figure 2. System diagram of Tavera-Bao Seismic Network

Figure 3. Schematic Tectonic map of the Caribbean region showing plate boundaries and late Cenozoic tectonic features (after T. Jordan, 1975).

Figure 4. Epicenter map of Puerto Rico - Dominican Republic region. Seismic data provided by the National Earthquake Information Service, U.S.G.S. An epicenter is shown by an X, an open circle, or a closed circle according to the depth (key at the bottom of the figure). A closed square shows the site of Tavera-Bao Hydrelectric Project.

Figure 5. Regional distribution of earthquakes located by the Tavera-Bao Seismic Network during the period of December 13-28, 1979. An X shows an event shallower than 50 km, and an open square equal to or deeper than 50 km. An event originated from an explosion is indicated by a + sign.

Scale		
	Figure 5A	1:250,000
	Figure 5B	1:1,000,000

Figure 6. Location of three explosion events are shown by + signs. These events occured at:

1979, December	13	13 h 27 m G.M.T. (09 h 27 m local time) $m_b = 1.0$
	16	18 h 50 m G.M.T. (14 h 50 m local time) $m_b = 1.3$
	21	15 h 27 m G.M.T. (11 h 27 m local time) $m_b = 1.3$

The actual explosion site is indicated by a star * suggesting that the calculated epicenters are approximately 2 km off to the south.

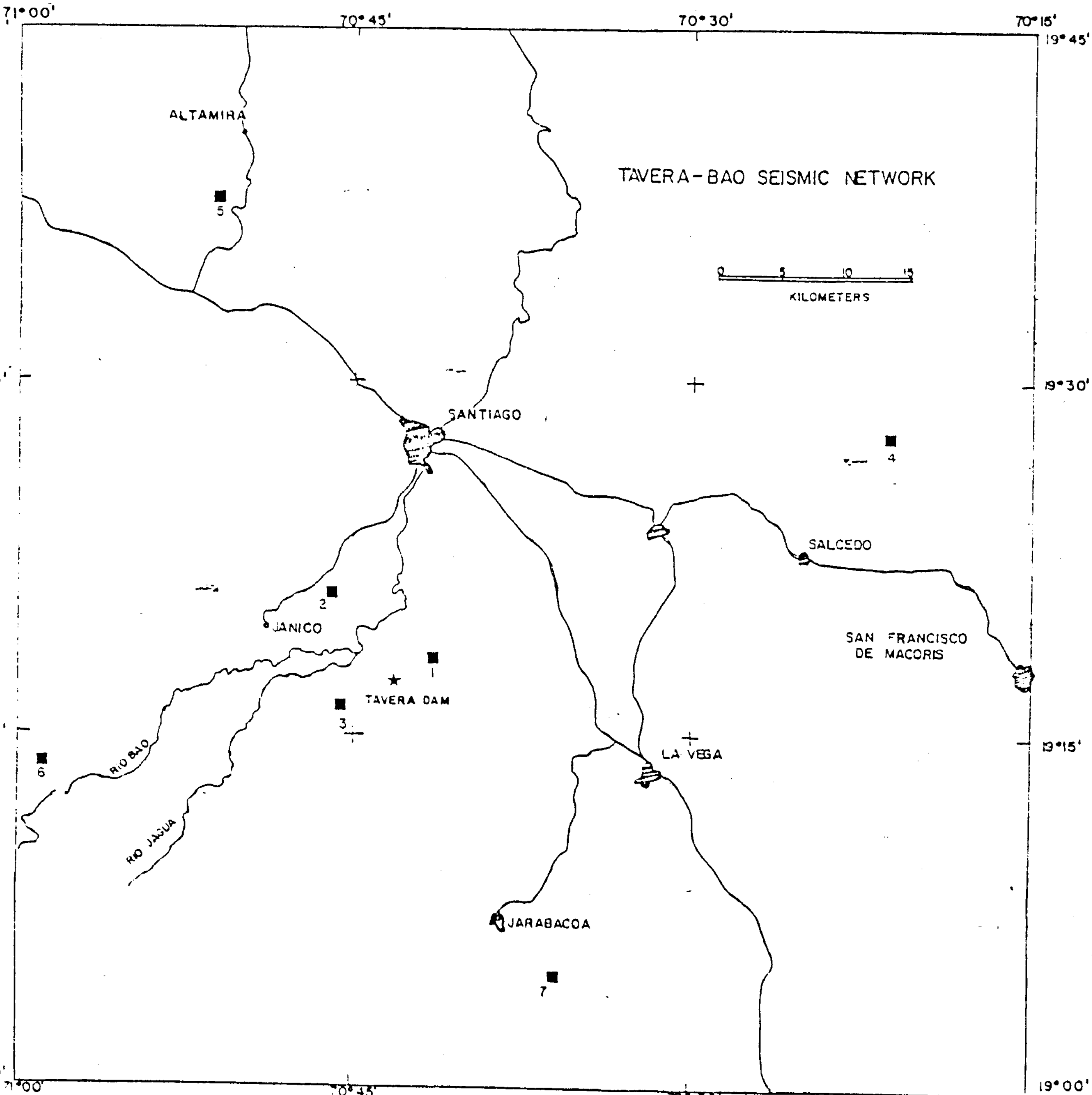

TAVERA-BAO SEISMIC NETWORK
0 5 10 15
KILOMETERS
71°00'
70°45'
70°30'
70°15'
19°45'
19°30'
19°15'
19°00'
ALTAMIRA
SANTIAGO
SALCEDO
SAN FRANCISCO DE MACORIS
JANICO
TAVERA DAM
LA VEGA
JARABACOA
RIO BAO
RIO JAGUA
1
2
3
4
5
6
7

Fig. 2

TAVERA-BAO SEISMIC NETWORK FLOWCHART

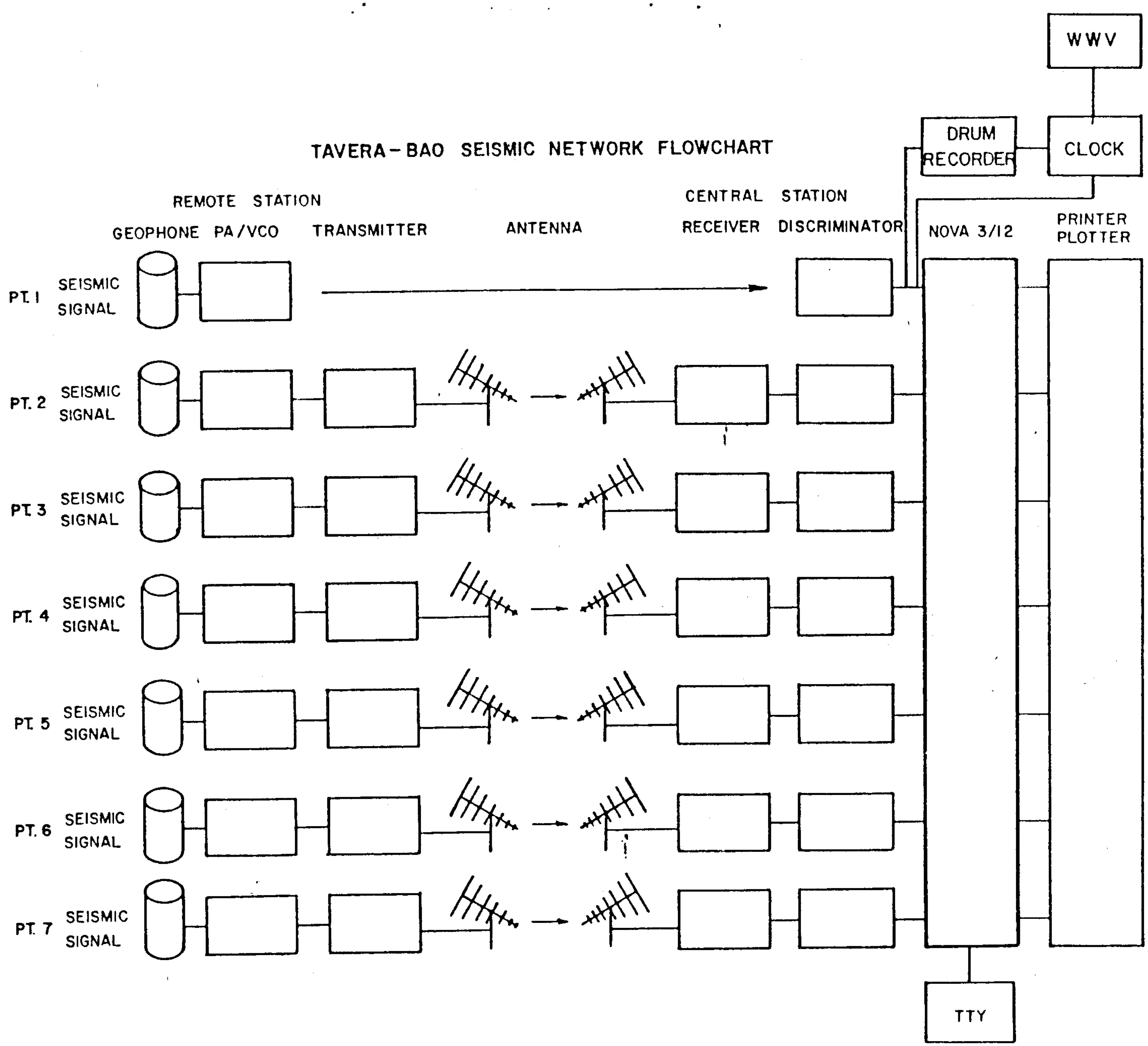


Fig 3

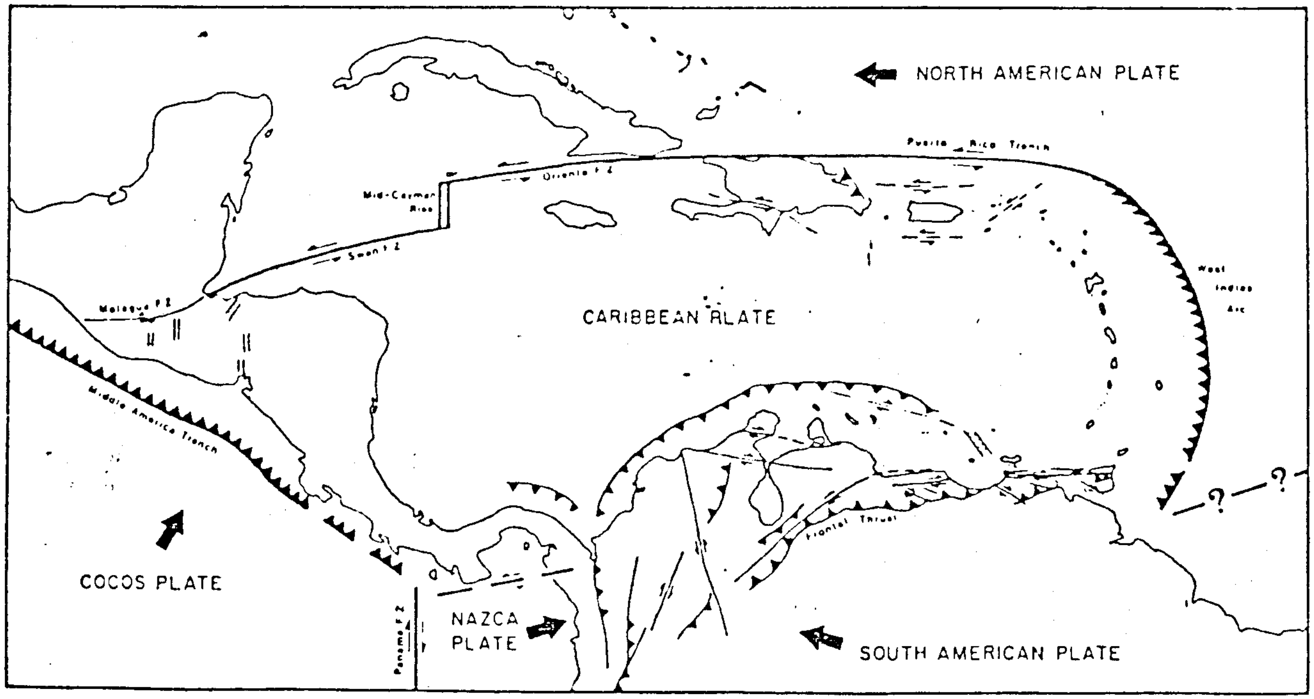
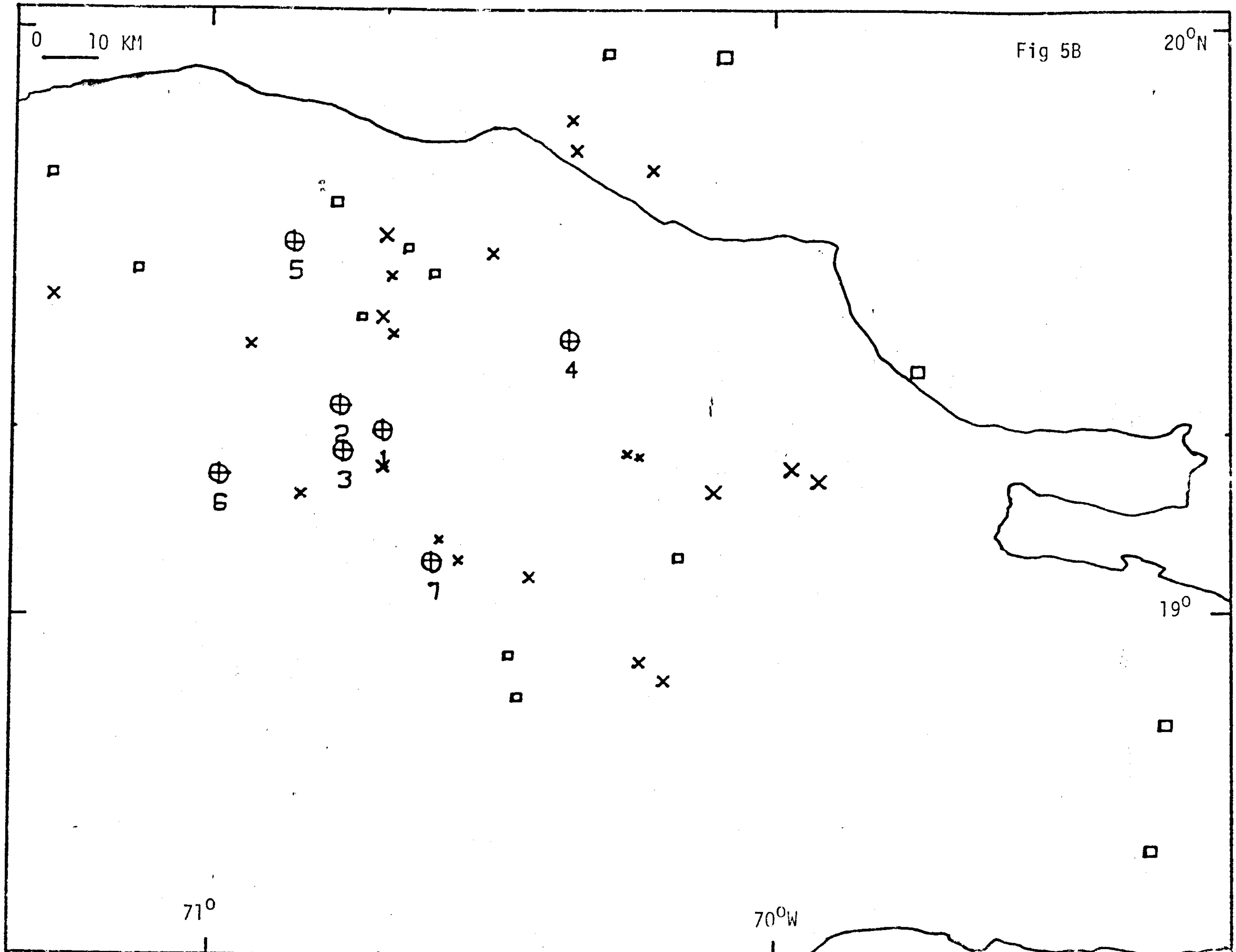

NORTH AMERICAN PLATE
Puerto Rico Trench
Oriente F.Z.
Mid-Cayman Rise
Swan F.Z.
Motagua F.Z.
West Indies Arc
CARIBBEAN PLATE
Middle America Trench
Frontal Thrust
COCOS PLATE
NAZCA PLATE
Panama F.Z.
SOUTH AMERICAN PLATE

Fig 5B



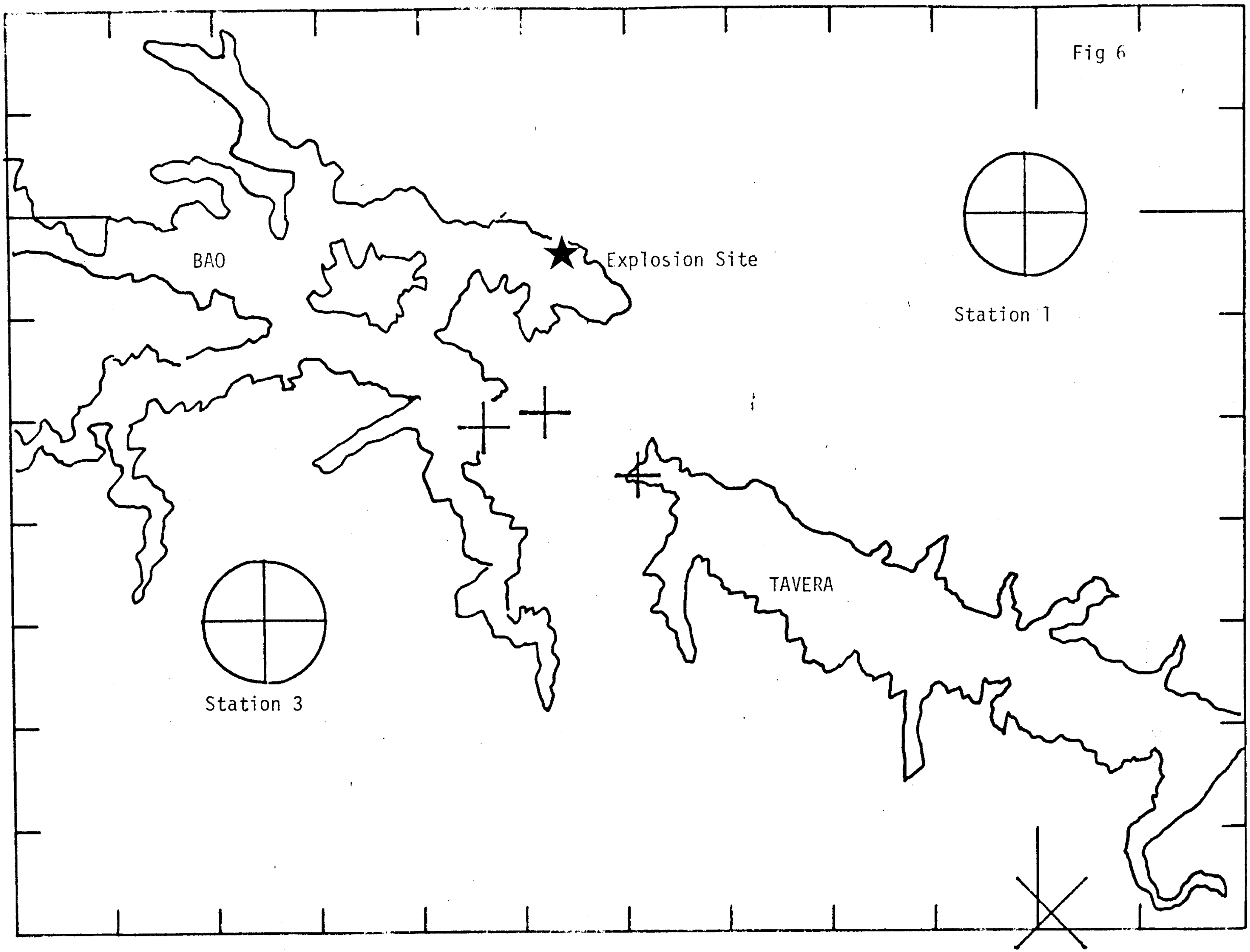
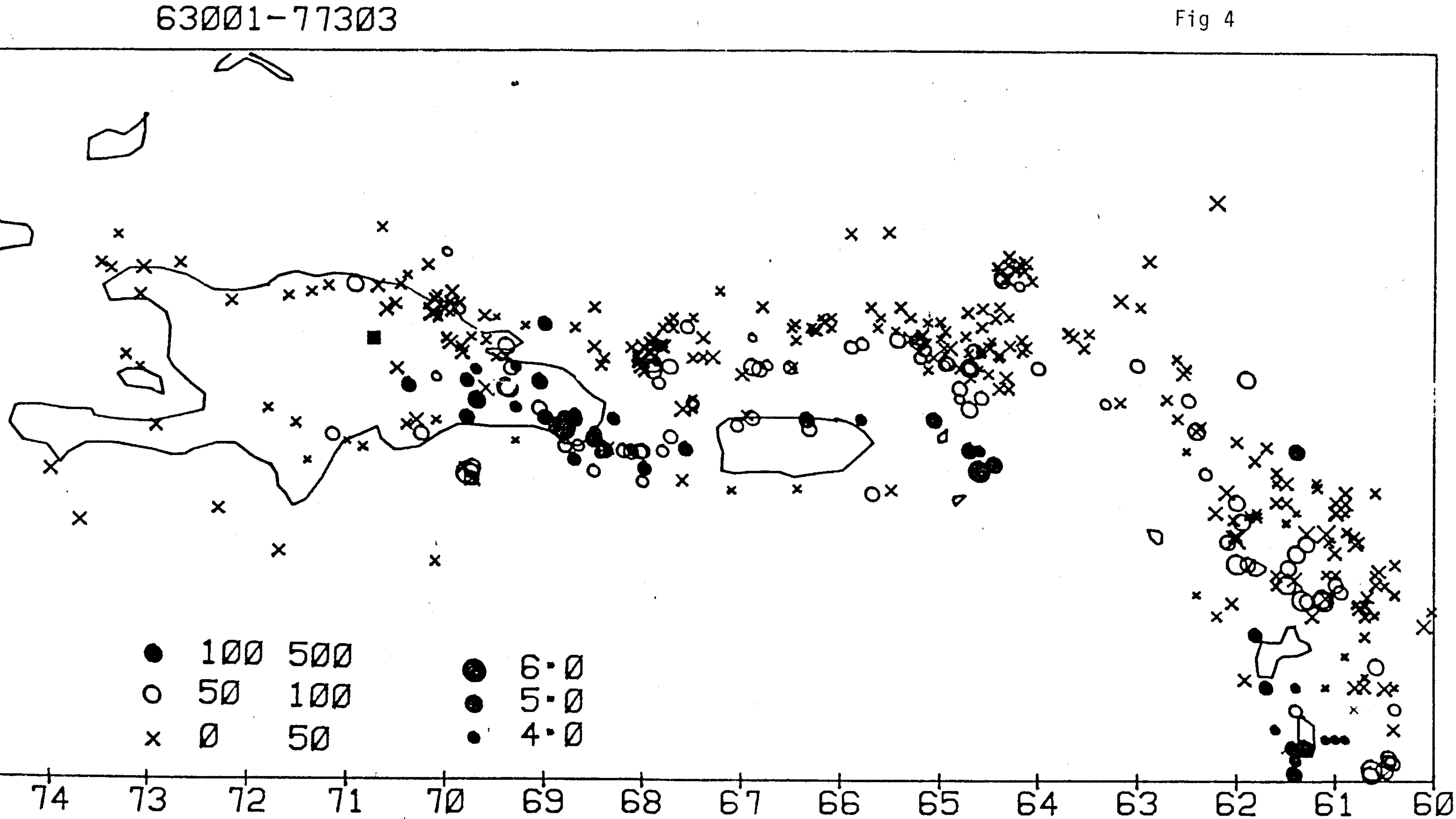


Fig 6
BAO
Explosion Site
Station 1
Station 3
TAVERA

Fig 4


63001-77303
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50 100
0 50
6.0
5.0
4.0
74
73
72
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