TECHNICAL REPORT #3

10 June 1983

Pueblo Viejo-Quixal Seismograph Network
27 January 1983 through 6 May 1983

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CONTENTS

1. INTRODUCTION

Since the PUEBLO VIEJO-QUIXAL Seismograph Network was installed in February 1979, 52 months have elapsed. The results of data analyses and interpretation of the seismic data were submitted to INDE in the following reports:

Preliminary Report #1	25 April 1979
Preliminary Report #2	10 November 1979
Preliminary Report #3	29 July 1980
Technical Report #1	10 April 1981
Technical Report #2	22 October 1982

To enhance the real time monitoring capability, the Computerized Seismic Monitoring System (COSMOS) was installed at the Campamento for the Pueblo Viejo-Quixal Seismograph Network in January 1983. Meantime, following the completion of the construction, loading of the Pueblo Viejo reservoir started on 25 January 1983. Therefore, the purpose of this report is focused as follows:

(1) To describe the function of the newly installed COSMOS.

(2) To review the seismic activity in the vicinity of the Pueblo Viejo dam prior to impounding, and

(3) To describe the seismic activity during the period of water loading.

2. SUMMARY OF PREVIOUS WORK

In the preceeding reports, the regional and local seismic activities are summarized as follows:

A. Two major fault systems, the Motagua fault and Cuilco-Chixoy-Polochic fault, are proved to be active and comprise a complex plate boundary between the North American and the Caribbean plates. Due to the nature of plate boundary, potential for major earthquakes, probably up to magnitude 7.5, exists along these faults.

B. A prominent northwest-southeast trending lineation that passes through the vicinity of the dam site started to emerge during the study period of 11 March 1981 through 16 April 1982 (Figure 2A). This trend was not observed during the preceeding period. The dimensions of this active zone is tentatively measured at 92 km long. Based on Utsu's formula (1968), the greatest earthquake that may take place along this zone is estimated at 7.5 (Ms).

C. The composite fault plane solutions of the earthquakes in the area of Pueblo Viejo dam site are given as follows (Figure 2B):

Fault Plane #1	Strike N17°W	Dip 30°E
Fault Plane #2	Strike N48°E	Dip 35°NW

These solutions are approximately in agreement with the stress field comprising of north-south compression and east-west tension. This stress field is interpreted as the consequence of the regional plate motions; namely northward thrust of Cocos plate and westward movement of the Caribbean plate, or differential shear between the CCP fault and the Motagnua fault (Figure 2C).

D. The recurrence time of the regional earthquakes is estimated from both the NEIS earthquake data file and the data from Pueblo Viejo-Quixal Network. The recurrence time for magnitude (m_b) 7.5 are estimated at 501 years and 110 years respectively.

E. The strong motion accelerographs operated at the dam site since March 1978 registered the greatest maximum acceleration of 0.133g for the horizontal component and 0.050g for vertical. The peak (vertical) accelerations that could have been measured at the dam site for all the major earthquakes since 1963 were calculated using Estiva's formula (1973). The calculated peak acceleration associated with the 1976 Guatemala earthquake and one of the largest aftershocks at the dam site were 0.057g and 0.062g respectively. During the past 18 years, no earthquake exceeded the peak acceleration of 0.07g.

F. Surviving old church (said to have been constructed in 16th century) in San Cristobal Verapaz indicates that this area has not experienced the ground motion with the intensity greater than IX for nearly the past 400 years.

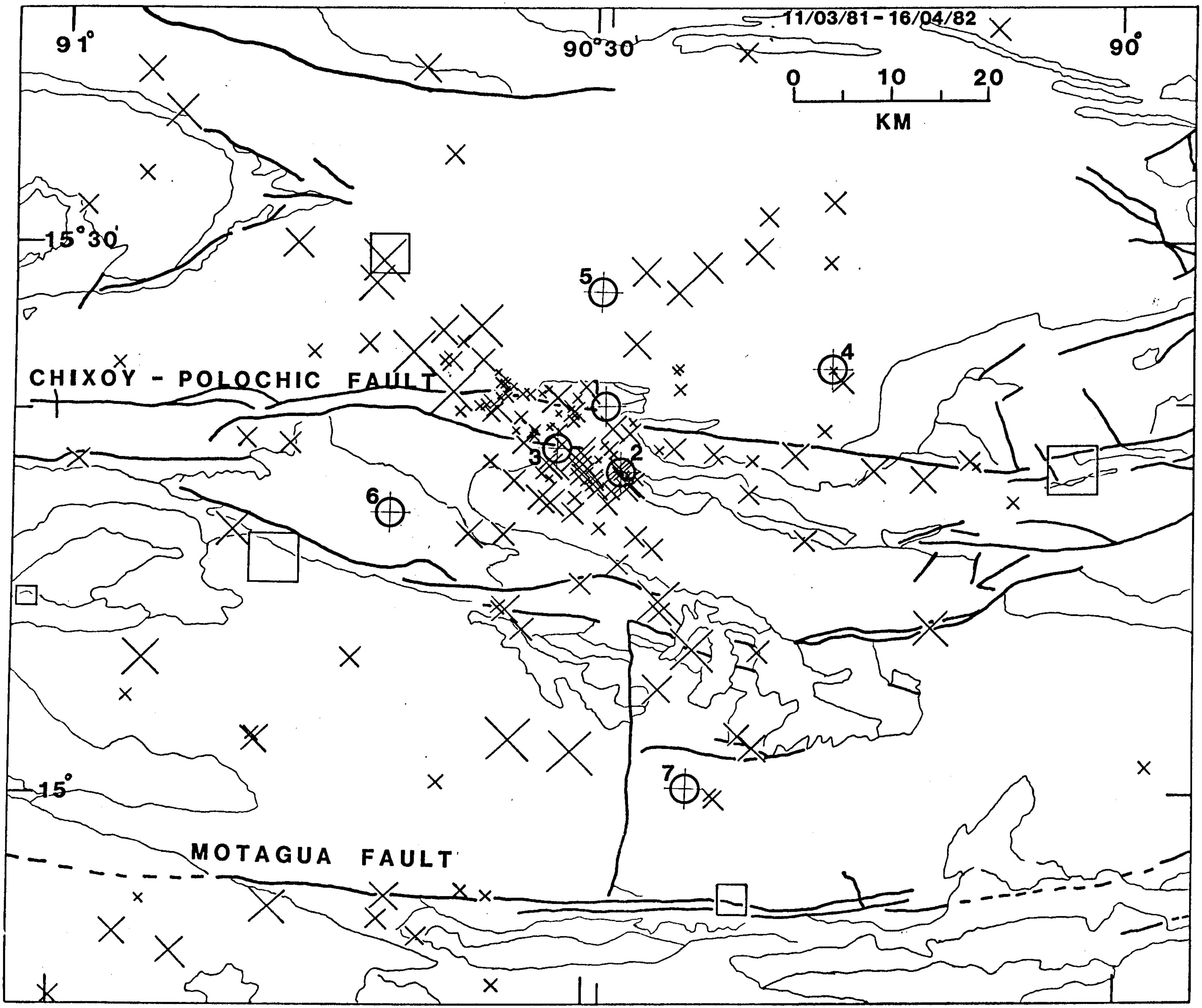

11/03/81 - 16/04/82
91°
90°30'
90°
0
10
20
KM
15°30'
15°
CHIXOY - POLOCHIC FAULT
MOTAGUA FAULT
1
2
3
4
5
6
7

FIG. 2A

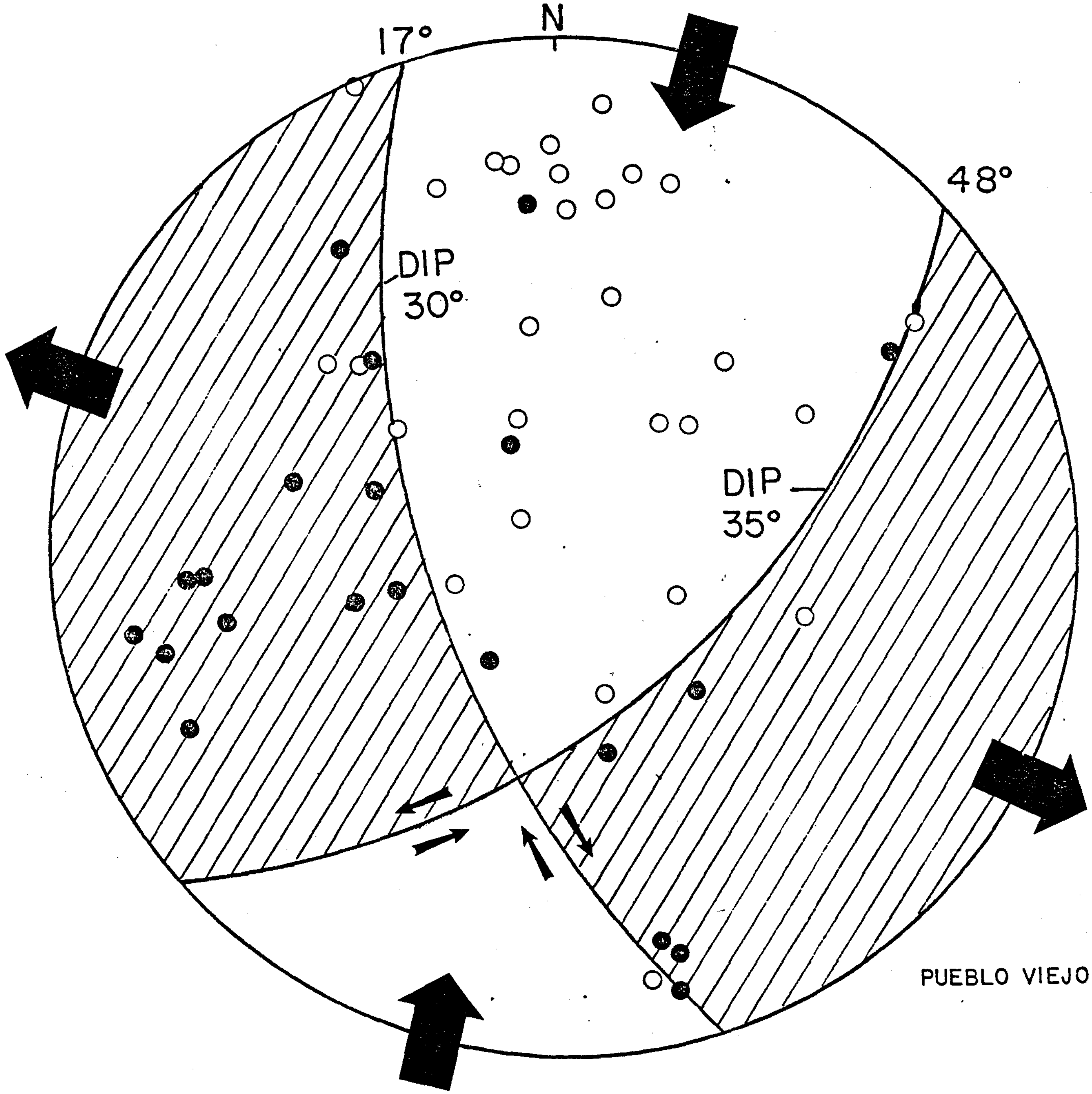


Figure 2B. Composite fault plane solution for the events in the vicinity of Pueblo Viejo Dam.

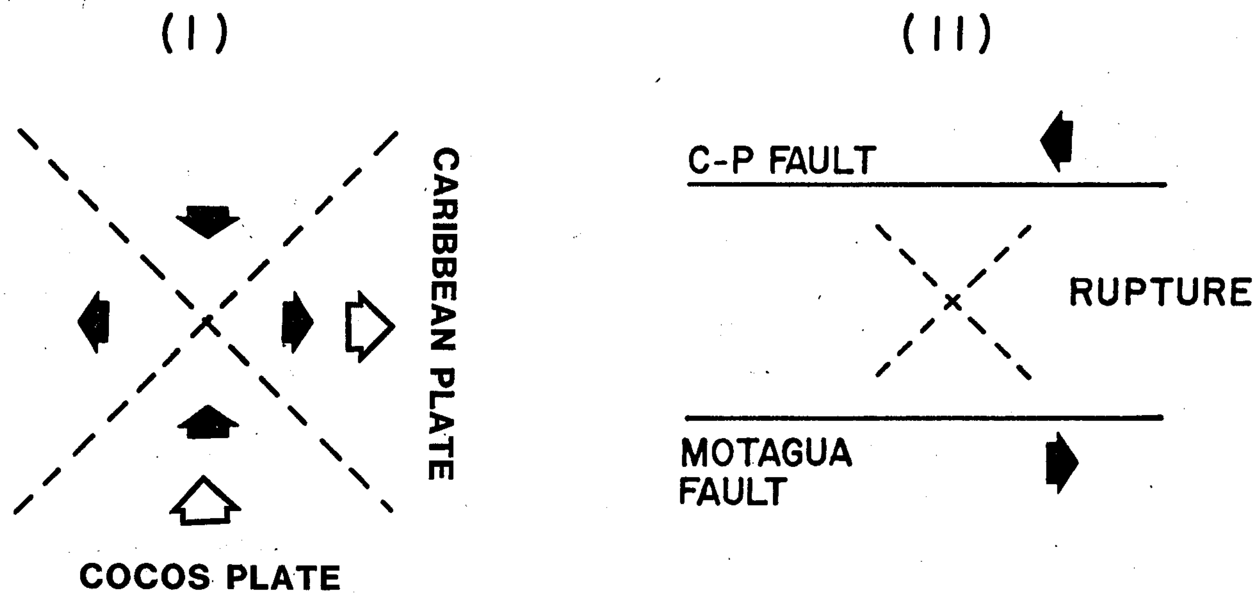


Figure 2C. Illustration of regional stress field.

(1) Stress field caused by the relative motion of Cocos and Caribbean plates.

(11) Stress field caused by the movements of the C-P and Motagua faults. The area between two faults is subjected to differential shear.

3. THE COMPUTERIZED SEISMIC MONITORING SYSTEM

3.1. Description of the Computerized Seismic Monitoring System

The Computerized Seismic Monitoring System (COSMOS) deployed in the Pueblo Viejo-Quixal Seismograph Network is the key element for the real time monitoring system by its capability of high speed plotting and automatic epicenter determination.

The chart of logical flow within the system is shown in Figure 3A. When the computer receives a seismic signal, the data is digitized through a 12 bit A/D converter at the rate of 40 HZ (25 milliseconds for each cycle). In each cycle, the computer examines the data quality, removes DC offset, reads the Binary time code (IRIG-C) and updates its internal clock. In addition, the computer examines the level of background noise (LTA: long term average) and the amplitude of input signals (STA: short term average), and if STA exceeds K*LTA, the computer tags that station as "triggered", where k is a constant to be adjusted by the nature of noise (usually $k = 4 \sim 8$. Once triggered, this condition is held for 10 seconds for that station.

If more than 3 stations are triggered simultaneously, the whole system is brought into "triggered" condition and plots the seismic signal for 90 seconds at the rate of 10 mm/sec (or longer if the signal amplitude is still large at the end of duplicating period). Before plotting, the signal is stored in the core memory for 20 seconds. Therefore, the signal is plotted with 20 seconds delay, which preserves the valuable P-arrivals from being lost. The functions described above comprise the routine scanning procedure of the data (called the real-time cycle) and are executed with the highest priority within the program.

When more than five stations are triggered within a certain time window (set of 20 seconds for the Pueblo Viejo-Quixal network), the epicenter determination program is activated and it starts computing the epicenter, depth, origin time and magnitude. This program however, is given a lower priority as compared to the real time cycle and occupies CPU only when the computer is idle between the real time cycles. Therefore, this epicenter determination program progresses concurrently with the real time cycles, but actual computation is divided into numerous fractions of time segments. The results of the epicenter determination is printed out onto the high-speed printer/plotter immediately after the PLOT made is completed.

This automatic epicenter program gives a prompt solution for an earthquake which is sufficiently large enough to trigger five or more stations. This real time capability is a powerful tool for real time monitoring of water induced earthquakes. However, this highly automated feature operates effectively only when necessary conditions are met. One who uses this system has to be well aware of these conditions and limitations:

3.1.1. When will COSMOS Trigger?

COSMOS is designed to start plotting when more than three stations are triggered simultaneously. Station 1N and 1E do not account for the triggering mechanism. Therefore, at least three stations with vertical components are required to be triggered before plotting.

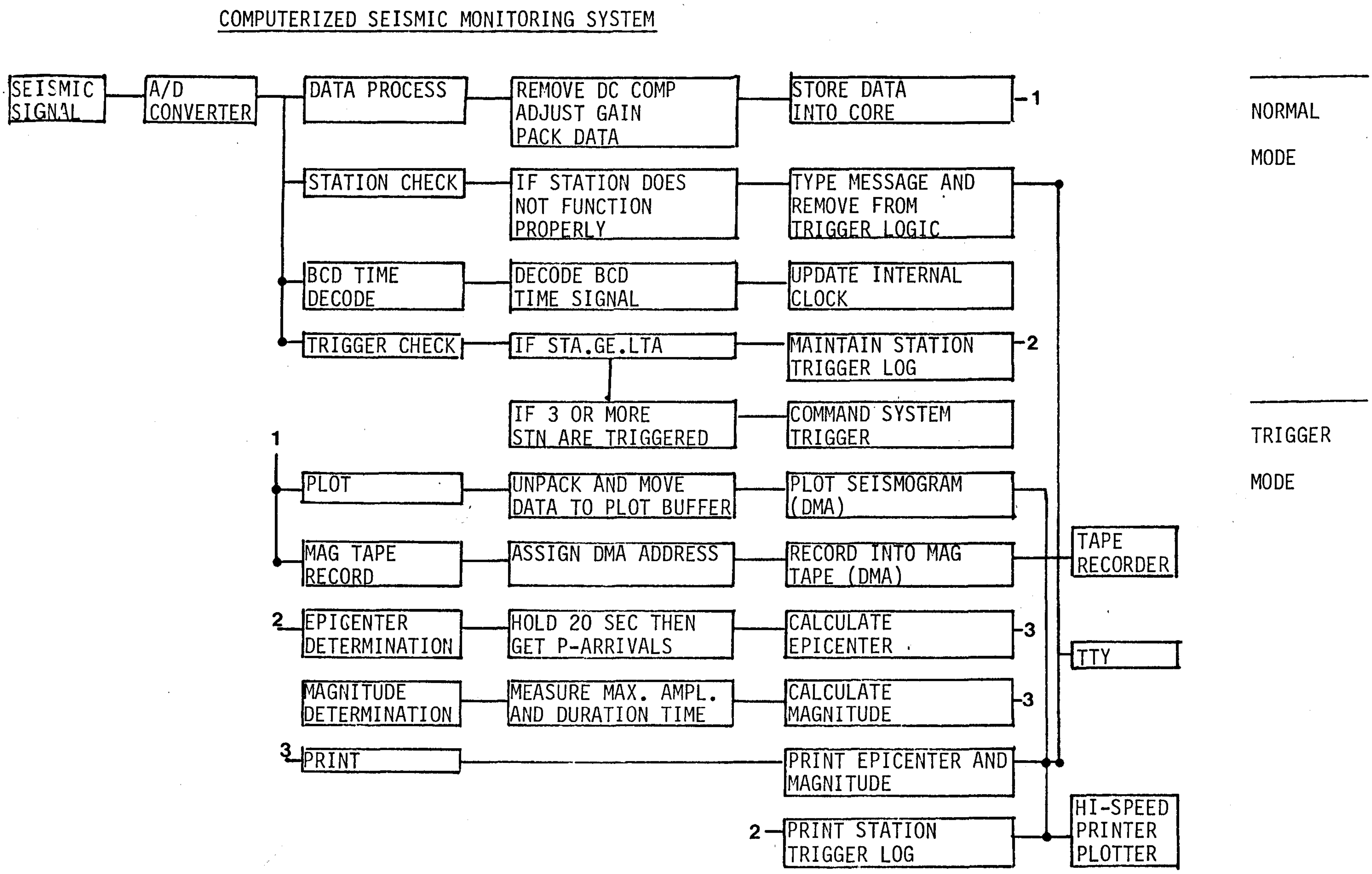


Figure 3A. Logical flow chart of the Computerized Seismic Monitoring System.

3.1.1. When will COSMOS Trigger? (Cont'd)

At least five (vertical components) stations are required to be in the triggered condition to summon the automatic epicenter determination program. Sometimes COSMOS rejects some of the "bad" readings (if the arrival times are logically not acceptable due to their order of arrival or to larger than acceptable time differences between them, it is a "bad" reading and is rejected automatically to avoid a large error in the epicenter calculation). Therefore, five stations are a bare minimum for an automatic epicenter determination and six to seven stations are usually required to utilize this feature effectively.

3.1.2. Accuracy of Epicenter Determination

The accuracy of the epicenter determination is significantly affected by the distribution of stations. For instance, if stations 3, 4, and 6 are not functioning properly, the rest of the stations 1, 2, 5, and 7 are distributed approximately on a straight line (see Fig. 4A) and the epicenter determined from this data is no longer trustworthy. There is a rather complicated pattern of error distribution as a function of station distribution (Flinn, 1965). Initially, the distribution of the remote stations for the Pueblo Viejo network was selected so that requirements of optimum distribution were fulfilled. If some of the stations fail to operate, however, the error distribution alters from the original pattern and special care must be taken to evaluate the precision of the epicenter determination. To maintain accurate epicenter determination, therefore, it is necessary to operate all the stations in good condition.

If an earthquake occurs at greater distance as compared with the size of the network, the epicenter determination usually bears a large error. This is similar to tri-angulating a distant object from a short base line. Similar conditions emerge for deep-focus earthquakes if the spread of the net work is not sufficiently large as compared to the depth of the events. In addition, predominance of a low-frequency component characterizes that the onset of the first arrival of a distant earthquake will be gradual and indistinguishable. In most of the cases, the readings of the first arrivals are far less accurate for distant earthquakes than those from near-by earthquakes which is usually characterized by a high-frequency, sharp onset.

3.1.3. Limitations of the Automatic Epicenter Determination Program

COSMOS provides the printout of the automatic epicenter determination without human assistance immediately after the completion of the PLOT phase. The results of this epicenter determination, however, are carried out under a number of limitations resulting from the capacity of the computer and from the simplified logic in the program. The main differences, between the computer logic and the human analysis (especially done by skilled personnel) are described below:

a) The COSMOS is unable to identify S-waves. To identify S-waves, more complicated recognition techniques are required which apparently exceeds the memory size and execution speed of this computer. Since the time difference between S-waves and P-waves gives a clue to judge distance, the epicenter determination without an S-wave significantly influences the location of events with great distances.

Flinn, E. A. "Confidence Regions and Error Determinations for Seismic Event Location", Rev. of Geophysics, 3: (1965), 157.

3.1.3. Limitations of the Automatic Epicenter Determination Program (Cont'd)

b) To identify the triggered condition, a technique to compare the short term average (STA) versus long term average (LTA) was used. This is the simplest and the fastest approach. On the other hand, this technique has some drawbacks. For instance, the P-arrival time is always selected 0.05 to 0.2 seconds behind the actual onset. As a result, this method retains a good accuracy for the events with sharp onset, but less accurate with a slow, gradual onset.

c) If the short term average exceeds the threshold defined by the long term average, the machine recognizes the station as triggered. The machine does not care if it was noise or true signal to trigger. As a consequence, the mistriggering increases under noisy circumstances. Some of the mistriggered stations are automatically rejected in the epicenter calculation. But if mistriggering occurs within the threshold of the rejection, this incorrect reading is utilized in the computation which is enough to disturb the results of automatic epicenter determination.

Due to these limitations, the results of the automatic epicenter determination are usually trustworthy for the events with a) sharp onset (high S/n ratio), b) located within the network, and c) recorded by at least 5 stations.

For the events with slow and gradual onset, low S/N ratio, greater distances, and recorded by fewer than 4 stations, the results of the epicenter determination given by the automatic epicenter program should be utilized only after careful inspection.

3.2. Installation of the Computerized Seismic Monitoring System

To enhance the Pueblo Viejo-Quixal Seismograph Network, the Computerized Seismic Monitoring System was shipped from the University of Texas on October 25, 1982. Due to the delay on the contractual procedures, however, the University did not approve the travel of our technician, Donald McGhee until January 1983.

Donald McGhee arrived in Guatemala and started to move the central recording station to the Campamato and to install the Computerized Seismic Monitoring System on January 15. Despite a complete checkout that had been done prior to the shipment, the power supply of the NOVA 3/12 computer (manufactured by Data General) failed only 6 hours after the computer was turned on. Fortunately the local representative of Data General was able to repair the power supply. However, the system still experienced mysterious interruptions which disrupted the program within a day or two of continuous operation.

The diagnostic program ran by the Data General local representative indicated that the problem may have been resulting from one or a combination of the following components.

1. CPU
2. Printer/Plotter, and its controller, or
3. The connecting cable between controller and Printer/Plotter.

Unable to fix the problems of intermittent interrupt, Donald McGhee returned to Texas on February 1st. However, COSMOS continued to operate.

3.2. Installation of the Computerized Seismic Monitoring System (Cont'd)

Tosimatu Matumoto arrived in Guatemala on February 8 equipped with a number of spare boards. He replaced CPU and the connecting cable to the printer/plotter. When he left Guatemala on February 13, COSMOS was performing event identification, triggering, plotting and epicenter determination but was unable to print the epicenter data due to the problem in the logic control board in Versatec high speed printer/plotter.

Matumoto returned to Guatemala again on March 23 and replaced Versatec input logic board. Also, he found that the main frame (chassis) of the computer was significantly twisted (probably during the transportation) and this hampered secure contact of some of the boards. This was the real cause of intermittent interruptions. After this repair, the COSMOS resumed normal operation.

3.3. Example of Seismograph

Figure 3B shows an example of COSMOS seismogram recorded by the Pueblo Viejo-Quixal network. Of 15 data channels, 8 channels were used (stations 4, 5 and 7 were not operating at this recording). The Binary Time Code (IRlG-C Code, shown on the second page) was recorded at the top of the recording channels. The vertical reference lines are drawn on each 5 seconds.

Four vertical (12, 2, 3, and 6) plus one horizontal (IN) stations were triggered about 18h 45m 40 sec on 25 May 1983. Due to the 20 second time delay, sufficient lead time was secured prior to the first arrivals and shown in the figure.

When the amplitudes of the seismic signal become too large, the computer automatically reduces the gain with 6db step and maintains plotting without saturating. The number of adjustments at 6db steps were shown by horizontal bars attached to each channel. Four adjustment lines shown in this figure signigy 4 x 6db = 24 db (or 24 = 16 times) of gain reduction.

Page 3 shows the printout of the epicenter, depth, origin time and magnitude. The epicenter was given in longitude and latitude (in degrees), but actual calculation and epicenter iteration was performed in terms of distances as measured from the dam site (X: eastward, Y: northbound distances).

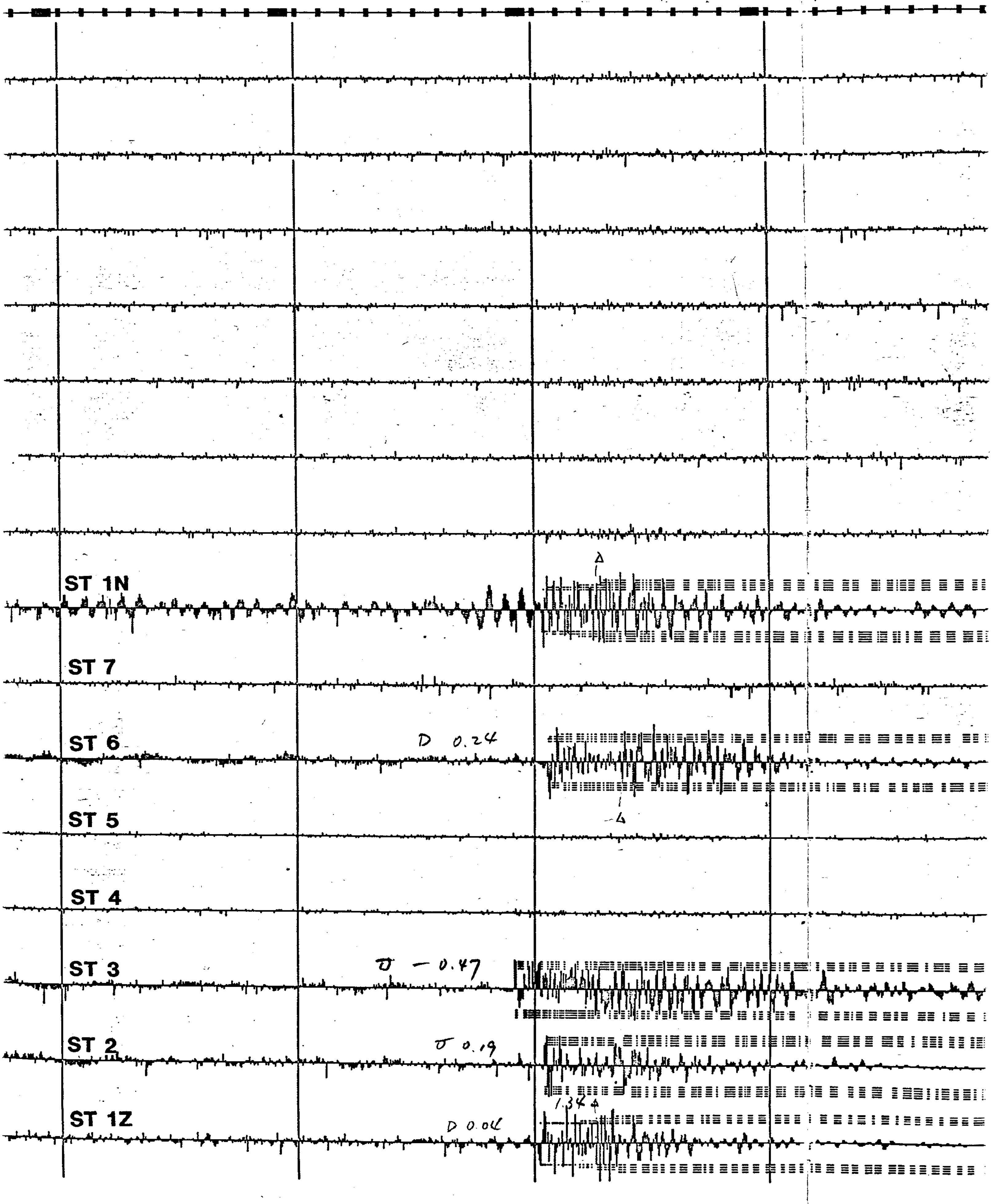
PUEBLO VIEJO-QUIXAL NETWORK

MAR 2 5 1983

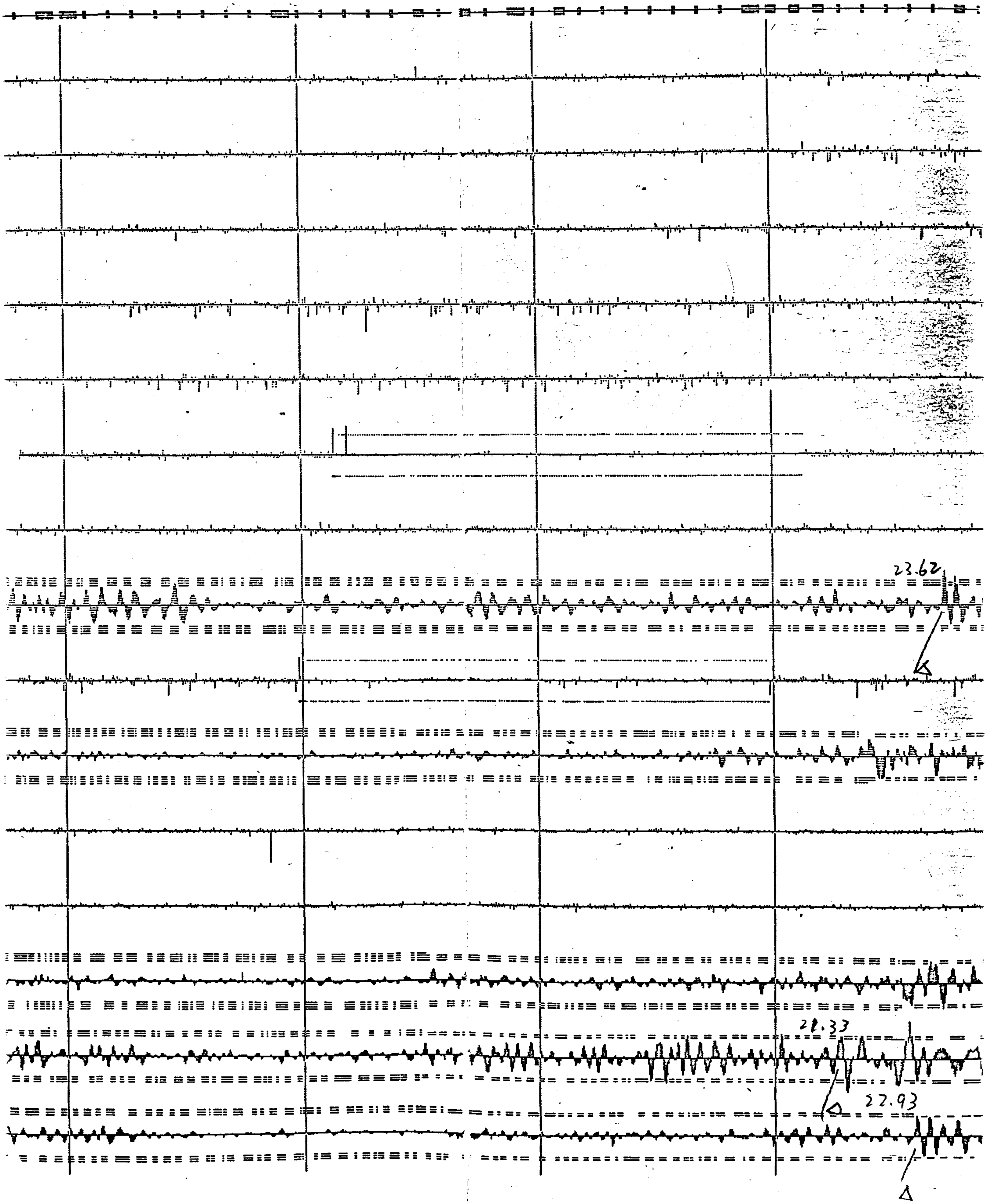
MAR 26 1983

Day 84 18:45:46

FIG 3B COSMOS SEISMOGRAM



BINARY TIME CODE



INDE NETWORK, VERSION 3, MOD MAR. 23,1983

AUTOMATIC EPICENTER DETERMINATION PRINTOUT

TRIGGERED TIME 83 84 18 45 40. 69

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	ST NO
40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	MV/MM
-0.13	-0.07	-0.70	0.00	0.00	0.00	0.00	-0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ONSET
2	1	1	0	0	1	2	2	0	0	0	0	0	0	0	ITRIG

U/D	-1	-1	-1	0	0	1	1	0	0	0	0	0	0	0	0
DIST(KM)	18.17	18.21	15.40	28.65	8.18	27.61	40.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MXAMP(MV)	88	5360	4020	0	0	4980	56	10220	0	0	0	0	0	0	0
MS	1.62	1.78	1.43	0.00	0.00	2.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ORIGIN TIME
83 84 18 45 40.59

EPICENTER	LONG(DEG)	LAT(DEG)
	-90.5311	15.4392
REF. PT. FOR X,Y	-90.4910	15.2798

	OT	X(KM)	Y(KM)	Z(KM)	DS	S
	-3.58	-4.39	17.63	5.00		
ST. DIV.	0.04	0.11	0.21	0.00		0.01

ITERATION

	OT	X(KM)	Y(KM)	Z(KM)	DS	S
1	-5.00	0.00	0.00	5.00	0.00	4.88
2	-3.35	2.59	6.74	5.00	7.22	1.53
3	-3.23	2.17	9.16	5.00	2.45	0.73
4	-3.30	1.75	10.94	5.00	1.84	0.35
5	-3.40	1.42	12.16	5.00	1.26	0.17
6	-3.48	1.21	12.91	5.00	0.78	0.08
7	-3.53	1.08	13.34	5.00	0.45	0.04
8	-3.56	1.01	13.57	5.00	0.24	0.02
9	-3.58	0.98	13.69	5.00	0.13	0.01
10	-3.58	0.96	13.75	5.00	0.06	0.01

4. EPICENTER DETERMINATION: 27 January 1983 through 6 May 1983

Utilizing COSMOS data returned from Guatemala, the location of the earthquakes were determined for the period from 27 January 1983 through 6 May 1983. Thirty-two earthquakes were located during this period (Table 1). Figure 4A shows the distribution of these epicenters (illustrated by ⊕).

Some of the stations (such as stations 4, 5, and 7) failed to operate properly through (or at least a part of) the period. Due to the insufficient number of stations, the COSMOS automatic Epicenter Determination Program was operated with the pre-fixed depth at 5 km through most of the period. Prolonged problems existed at station 7 throughout this period. Devoid of the data from station 7 cost an extremely expensive toll to the monitoring program. Due to lack of operating stations south of the dam site, the calculated epicenters located near the southern periphery (south of 15°20' latitude) sustained relatively greater errors. Also, the susceptibility (detection capability) of the network south of stations 2 and 3 was somewhat hampered by lack of station 7. This situation, however, has been improved and at least 6 stations are operating since late May.

In Figure 4A, the following active trends were observed:

A. Lineament located between stations 2 and 3 with westerly orientation and its possible extension towards northwest.

B. Events located north of and west of station 6.

Distribution of the events in Group A are approximately similar to those of the northwest trending active zone identified during the pre-loading period (Figure 2A). The activity located near station 6 (Group B), on the other hand, was never identified previously.

For more detailed examination, an expanded plot of epicenters in Group A was made and shown in Figure 4B. In this figure, an X represents events of the pre-loading period (11 March '81 - 16 April '82) and a symbol ⊕ signifies epicenters located after 27 January 1983. One can observe a lineament extending from the dam site through station 3 and possibly extending further northwest. A majority of the events in 1983 occurred along this line and seems to be filling a gap along this trend. A cluster of three events occurred northwest of station 2 and the events of the pre-loading period seems to delineate additional northwest trending lineaments which is en echelon and approximately 2.5 km apart from the former.

The composite fault plane solutions for the events in Group A are almost identical with those shown in Figure 2C. This fault plane solution indicates that the major component of the ruptures associated with Group A is the right-lateral strike-slip movement mixed with modes thrust component trending southwest, or the left-lateral strike-slip with minor thrust trending southeast.

As far as the spatial distribution and the fault plane solutions are concerned, there are no systematic changes between the seismic activities of pre-loading and during the period of impounding.

TABLE 1. LIST OF EARTHQUAKES (27 Jan. 83 - 6 May 83)

NO.	YR MO DY	HR MN	LATITUDE N	LONGITUDE W	DEPTH KM	MAG.	ERROR (RMS)
1	83 01 27	22 41	15°18'.69	90°38'.01	5.00	2.88	7.30
2	83 02 07	05 60	15°18'.69	90°38.01	5.00	3.49	5.72
3	83 02 13	18 21	15°59'.65	90°25'.35	14.04	2.55	0.61
4	83 02 23	21 45	15°17'.75	91°03'.73	5.00	2.54	16.02
5	83 02 24	23 05	15°17'.75	90°28'.60	5.00	3.07	14.46
6	83 02 25	06 57	15°29'.11	90°41'.09	2.50	3.63	29.95
7	83 02 29	15 48	15°22'.40	90°31'.18	4.50	2.85	5.52
8	83 03 01	15 33	15°22'.83	90°35'.14	4.00		3.34
9	83 03 01	17 23	15!18'.69	90°30'.45	5.00		29.57
10	83 03 02	01 50	15°18'.69	90°07'.39	5.00	2.91	21.19
11	83 03 02	14 13	15°18'.99	90°32'.49	5.00	3.10	14.45
12	83 03 02	18 33	15°28'.52	90°36'.11	2.25	2.75	20.96
13	83 03 03	14 41	15°20'.14	90°32'.93	5.00	3.02	23.19
14	83 03 08	12 35	15°18'.69	90°35'.91	1.25		24.14
15	83 03 08	20 33	15°18'.69	90°32'.16	2.50		26.66
16	83 03 09	00 52	15°39'.67	90°45'.51	5.00		23.95
17	83 03 09	03 37	15°17'.75	90°28'.60	5.00		22.91
18	83 03 25	18 45	15°21'.85	90°38'.03	4.50	1.97	19.97
19	83 03 26	06 10	15°18'.69	90°38'.01	5.00	2.65	15.63
20	83 03 26	07 48	15°10'.15	90°38'.01	2.50	3.55	11.64
21	83 03 26	17 06	15°18'.69	91°40'.89	2.50		5.44
22	83 03 26	17 18	15°18'.69	90°31'.24	4.00		2.53
23	83 03 28	02 49	15°17'.25	90°42'.30	1.25		27.20
24	83 03 28	10 40	16°05'.29	90°38'.01	5.00	2.83	13.74
25	83 03 28	17 04	16°05'.16	90°38'.01	5.00	3.43	19.02
26	83 03 28	18 00	15°33'.57	90°47'.32	5.00	2.96	25.35
27	83 04 01	07 03	15°18'.69	90°32'.06	2.50	2.71	26.87
28	83 04 01	08 46	15°18'.69	90°30'.85	2.50	2.11	15.15
29	83 04 01	10 27	15°18'.99	90°32'.49	5.00		13.80
30	83 04 27	04 17	15°26'.29	90°32'.43	1.25	2.13	26.53
31	83 05 06	03 35	15°13'.42	90°28'.60	6.93	3.98	19.14
32	83 05 06	03 55	14°53'.20	90°04'.16	5.00	3.51	13.79

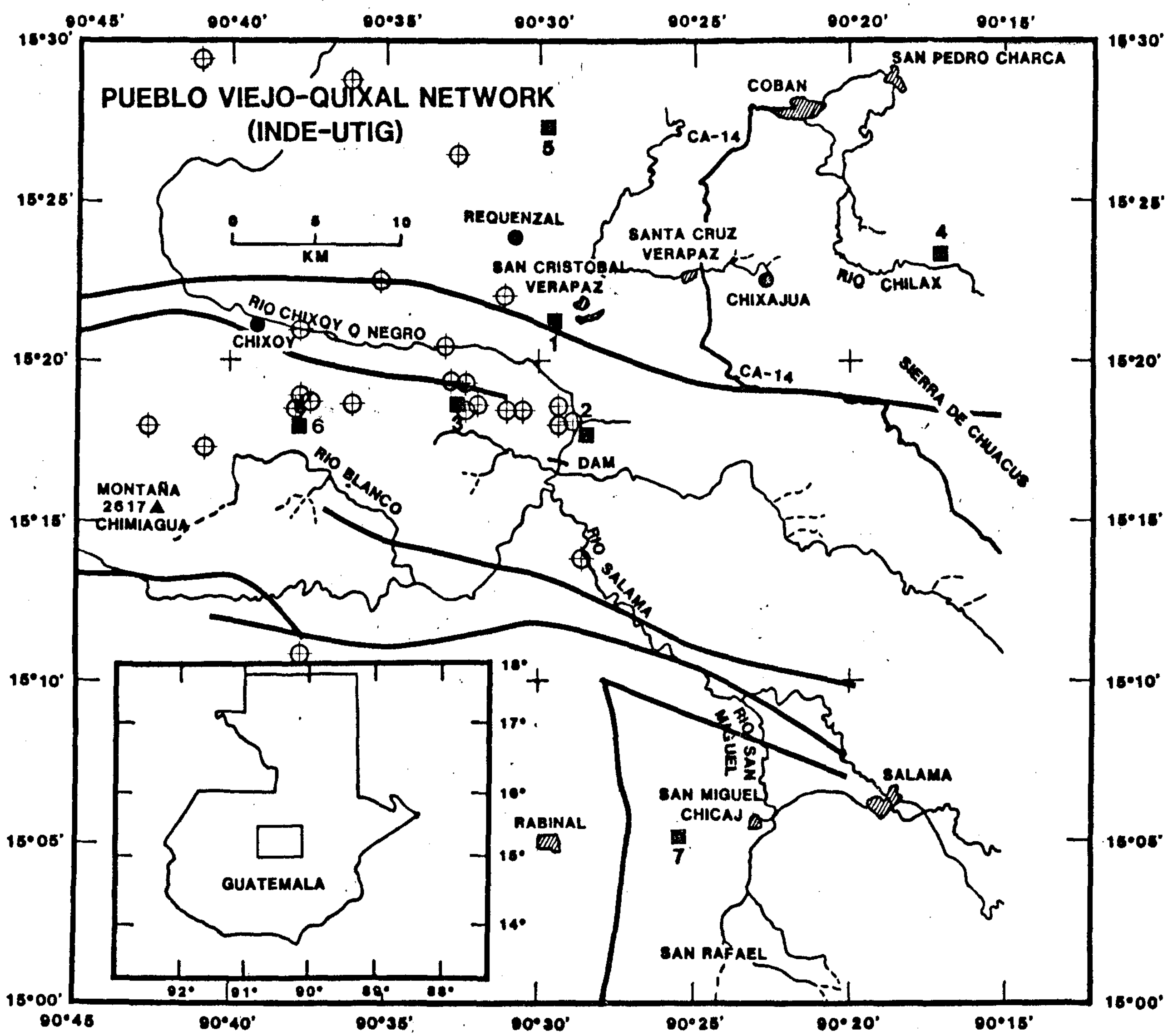


Figure 4A. Distribution of earthquakes: 27 January 1983-6 May 1983 ⊕ indicates an earthquake and ■ shows a remote station. Heavy solid lines are fualts mapped by Bonis et al. (1970).

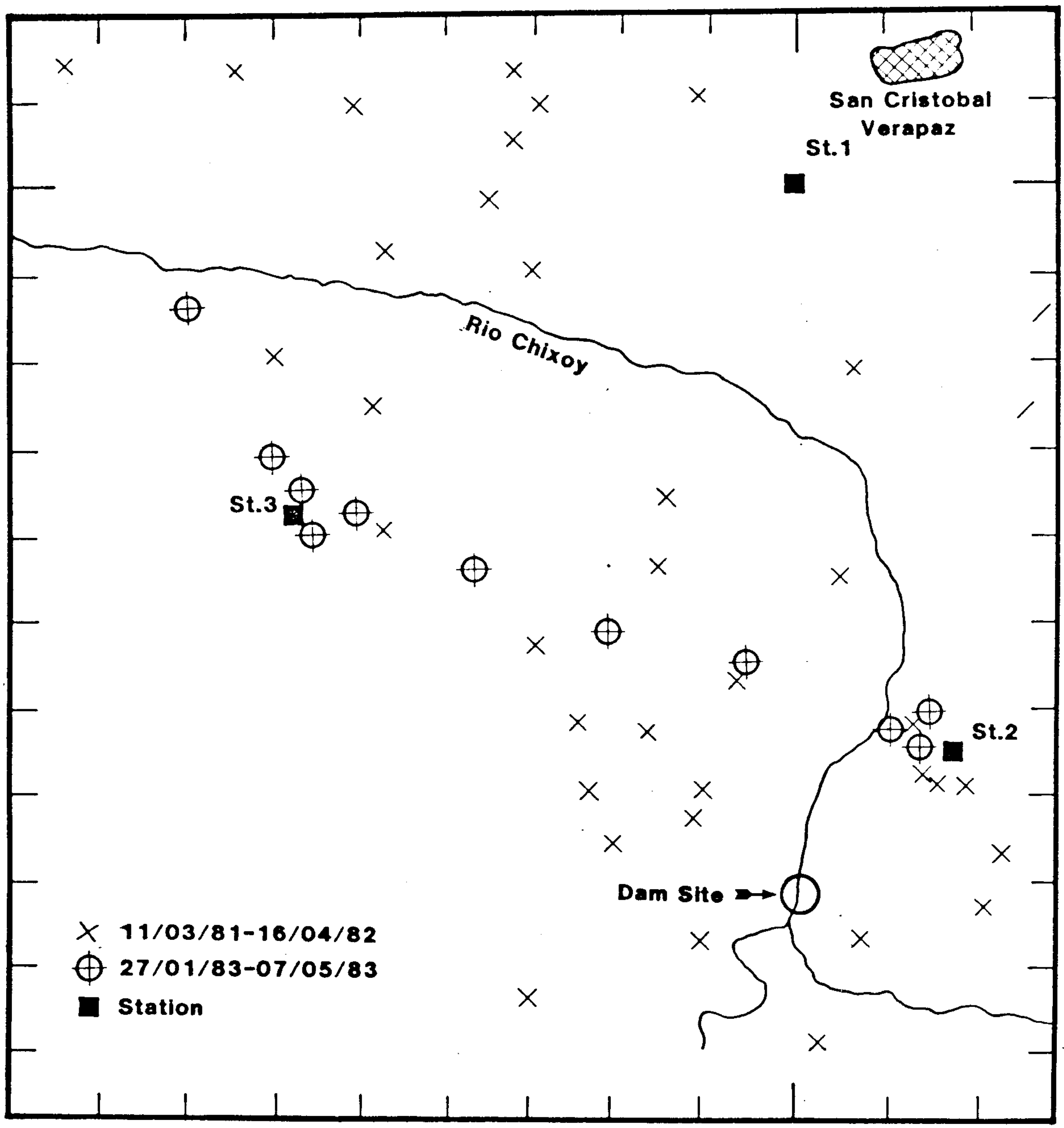


Figure 4B. Distribution of eathquakes in the vicinity of the Dam Site.

This does not mean, however, that no water-induced earthquakes are taking place during the loading period. Water-induced earthquakes usually show the identical focal mechanisms as compared to the pre-loading period, and accordingly, it is rather difficult to distinguish the water-induced earthquake based on the fault plane solutions and the spatial distributions.

5. EARTHQUAKES OCCURRING IN THE VICINITY OF THE PUEBLO VIEJO DAM

As shown in Figure 2A, a couple of active trends were identified during the pre-loading period in the vicinity of the Pueblo Viejo dam and these trends are explected to be active through the loading period. As described in the previous section, neither the spatial distribution nor the fault plane solutions provide clear clues to distinguish the events whether they are of tectonic origin or induced from water loading. Therefore, any changes in the seismic activity resulting from impounding the reservoirs need to be examined by statistical means.

For this purpose, earthquakes recorded on the drum recorders were examined and the events fulfilling the following criteria were chosen for further inspection:

1) Events occurring during pre-loading period (12 Feb. - 12 May 1982) and those during loading period (12 Feb. - 12 May 1983).

2) Events recorded by the inner cluster stations (stations 1, 2, and 3).

3) Events with S-P time interval shorter than 4 seconds.

The upper frame of Figure 5A shows the change of the water level in the Pueblo Viejo reservoir since the start of impounding on January 25, 1983. The elevation above the sea level was illustrated on the left-hand side and the depth of the reservoir was shown on the right-hand side of the figure.

The earthquakes fulfilling the above mentioned criteria are exhibited in the middle (1983) and the bottom (1982) frames in Figure 5A as the function of magnitude (measured from the duration time) and time of occurence. An open circle indicates an event with S-P time interval shorter than 4.0 seconds (within 32 km radius) and a solid circle shows an earthquake with S-P time interval less than 2.0 seconds (within 16 km radius).

One can observe that the seismicity in 1983 is significantly higher than those in 1982. To compare the level of seismic activities, the number of earthquakes (cumulative) as the function of magnitude was studied and shown in Figure 5B. Four different plots were exhibited in this figure: open circles are events within 32 km radius and recorded in 1983; open squares, within 32 km and in 1982; solid circle, within 16 km and in 1983; and solid square, within 16 km and in 1982, respectively.

In general, the relation between the number of earthquakes (N) versus magnitude (M) is given in the form of

$$\log N = a - bM$$

where a and b are constants. Applying this formula to the data, the following relations were obtained for each data set:

$$\log N = 1.89 - 0.46M \quad (32 \text{ km}, 1983) \qquad (1)$$
$$\log N = 1.69 - 0.48M \quad (32 \text{ km}, 1982) \qquad (2)$$

$$\log N = 1.65 - 0.59M \quad (16 \text{ km}, 1983) \qquad (3)$$
$$\log N = 1.38 - 0.49M \quad (16 \text{ km}, 1982) \qquad (4)$$

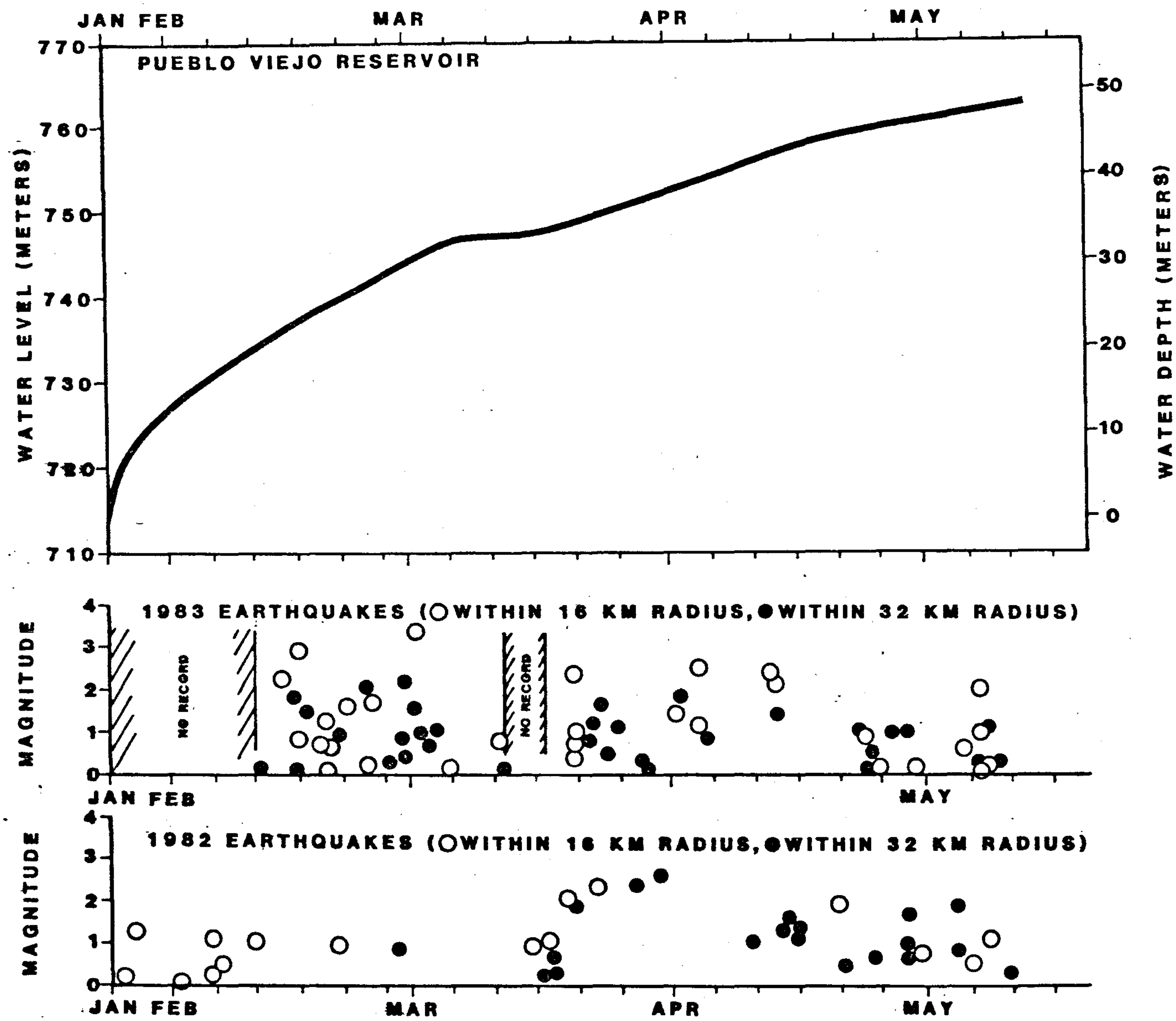


Figure 5A. Upper: Water level in the Pueblo Viejo Reservoir.

Middle: Earthquakes observed in 1983. An open circle indicates events within 16 km radius and a solid circle represents earthquakes within 32 km radius.

Bottom: Earthquake observed in 1982.

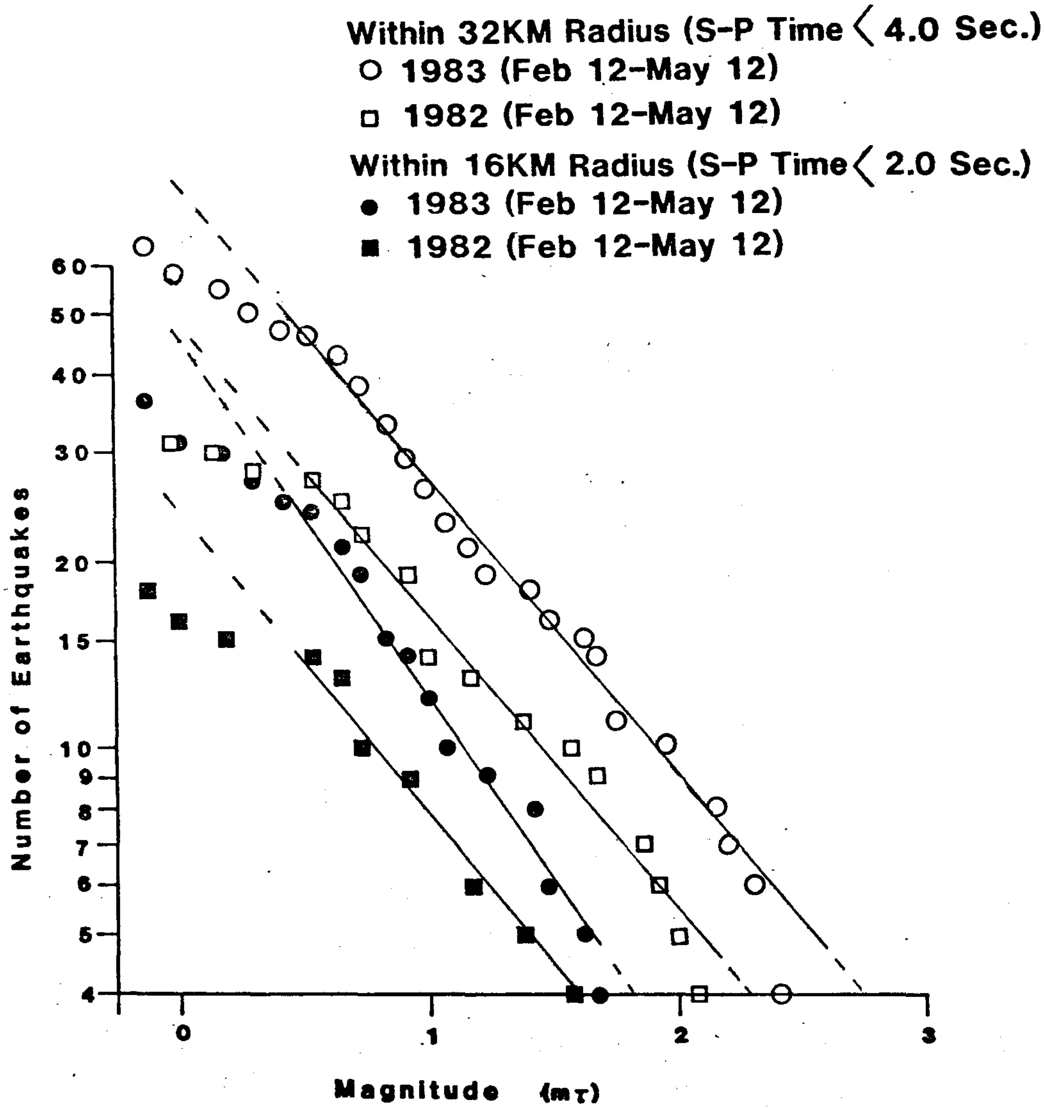


Figure 5B. Frequency-Magnitude Relation

The following conclusions can be extracted from these relations:

1) Comparing the three month period (12 February - 12 May), the seismicity in 1983 is 60% (within 32 km radius) to 100% (within 16 km radius) higher than those in 1982.

2) The slope (b-value) of the number-magnitude relation is almost equal each other for the equations (1), (2) and (4), but somewhat higher for the equation (3). This means that within 16 km radius, the increase of smaller events (magnitude range 0-1) is more significant than those of larger events (magnitude range 1-2) in 1983. Due to the size of the data set, however, the difference of b-value in equation 3 as compared to the other equations is small and well within the error range of statistics. Therefore, this change is not conclusive as yet.

The increase of seismicity during the loading period reflects the effect of increased surface load and increase of pore pressure. Devoid of epicenters in the immediate vicinity of the reservoir (with an exception of an event located along Rio Salama) and alignment of the recorded events along the extension of pre-loading active zones probably indicate that the additional surface loading is primarily responsible for the increase of the seismicity in 1983. But a possible change of b-value may indicate that the change of pore pressure already started to affect the statistical nature of rupture sizes in the immediate vicinity of the dam site.

6. SUMMARY AND RECOMMENDATIONS

6.1. Summary

6.1.1. Computerized Seismic Monitoring System was deployed and started to operate since 27 January 1983. The problem of occasional interruption was resolved by March 16.

6.1.2. Due to the insufficient number of stations operated, the capability of COSMOS system was somewhat hampered during a part of this recording period. The situation, however, significantly improved in the middle of May.

6.1.3. The distribution of earthquakes observed during the period of 27 January through 6 May 1983 was characterized as follows:

- Void of seismic activity within or the immediate vicinity of the reservoir.
- Dense distribution between the stations 2 and 3 (3 km north of the dam site) and its northwest extension.
- Spatial distribution and the composite fault plane solution did not show any significant difference between pre-loading period and loading time until 6 May 1983.

6.1.4. The frequency-magnitude relation, however, showed an increase of seismicity (60% increase within 32 km radius and 100% increase within 16 km radius) during the first three months of loading period as compared to pre-loading time.

6.2. Recommendation

6.2.1. It is important that all of the remote stations should be maintained and if a problem arises at any of the remote stations, the repair should be carried out as soon as possible. COSMOS does not operate properly with the stations fewer than five.

6.2.2. The University of Texas increasingly has become concerned about the payment schedule. Failure to meet the contracted payment schedule by INDE will result in more severe restrictions on expenditures including the computer time, purchase of equipment and supplies, and travel expenses. Without resolving this problem, our activity in maintenance and data analysis will be heavily impared.