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The new Nicaraguan seismic network

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RESUMEN
La red sismológica de Nicaragua, de 16 estaciones fue instalada en 1975 a raíz de la catástrofa sísmica de Managua en 1972. La red desapareció después de 1982 y ahora fue reconstruida y modernizada con base a un proyecto conjunto centroamericano. La nueva red tiene actualmente 9 estaciones telemétricas por FM con digitalización central. Los primeros 3 meses de operación sugieren que el umbral de detección es de magnitud 3.8 (el anterior era de 2.9), y que la resolución de profundidad es algo baja por la geometría de la red. Pese a una menor extensión, la red podría contribuir potencialmente en forma significativa a la sismología de Nicaragua y centroamerica, por ser digital y por formar parte de la red centroamericana. Su potencial es demonstrado mediante el modelado de un sismo profundo.

PALABRAS CLAVE: Sismos, redes sismológicas, Nicaragua.

ABSTRACT
The 16 station Nicaraguan seismic network was installed in 1975 as a consequence of the disastrous 1972 Managua earthquake. The network disappeared after 1982 and has now been partly rebuilt and modernized in a joint Central American effort. The new network currently has 9 FM telemetered stations, centrally digitized. The first 3 months of data shows that the detection threshold is now around magnitude 3.8 versus 2.9 for the old network, and that the depth resolution is somewhat low due to the current geometry. Despite the smaller size, the network has the potential to contribute significantly to Nicaraguan and Central American seismology by being digital and part of the Central American network. Some of its potential is demonstrated by modeling a deep earthquake.

KEY WORDS: Earthquakes, seismic networks, Nicaragua.

INTRODUCTION

Seismicity in Nicaragua is mainly caused by the Cocos plate subducting under the North American plate (e.g. Isacks and Molnar, 1971, Dewey and Algermissen, 1974), which generates earthquakes up to magnitude 8.0.

However, the more destructive earthquakes are the shallow inland events related to the graben structure (Kuang, 1971), although magnitudes do not exceed 6.0. The destructive 1972 Managua earthquake (December 24, mb=5.6, Brown *et al.*, 1973) was of this type and as a consequence, a seismic network was installed in 1975. It disappeared at the beginning of the eighties and has now partly been reinstalled and modernized. The purpose of this paper is to give a short history of the Nicaraguan seismic network, describe the past and current capabilities and give some initial results for the first few months of operation.

THE 1975-82 NETWORK

In 1975, a seismic network in the Pacific part of Nicaragua was constructed in a cooperative project between the US Geological Survey (USGS) and the Nicaraguan government. The network consisted of 16 short period stations (Figure 1) telemetering to the central site at Instituto de Investigaciones Sísmicas (IIS) (now called Instituto Nicaragüense de Estudios Territoriales (INETER)) in Managua, where recording was done on 16 mm film (Develocorder). Three of the stations (JIG, RTN and MMO, Figure 1) were 3-component and the 6 horizontal components were recording on paper. This network functioned until 1982 when, due to the political and social problems in the country, no more spare parts and funds were left for the operation. The network thus disintegrated and in 1985, when there was important seismic activity in the SE of the country (Segura, 1986), there was no capability left for locating the seismicity. During its 8 years of operation, it located a total of 15 000 earthquakes (Figure 2). Of these, 232 were magnitude 5 or larger, see Figure 2. As it can be seen, the majority of the larger events located by the Nicaraguan network are outside the country, and the network thus contributes significantly to the definition of the central American seismicity. It is also seen that the local network defines the subduction zone quite well.

THE NEW NETWORK

In 1988, a cooperative project in disaster prevention between all Central American countries was started with funds from the Swedish Development Agency (ASDI) coordinated through CEPREDENAC (Centro de Prevención de Desastes Naturales en Centro América) of Guatemala. The most important component the program was seismology and for Nicaragua, a reinstallation of part of the network (6 stations) was planned. In 1991, the Norwegian Development Agency (NORAD) joined the project with funds for digitalization of all the Central American networks. The rebuilding of the network

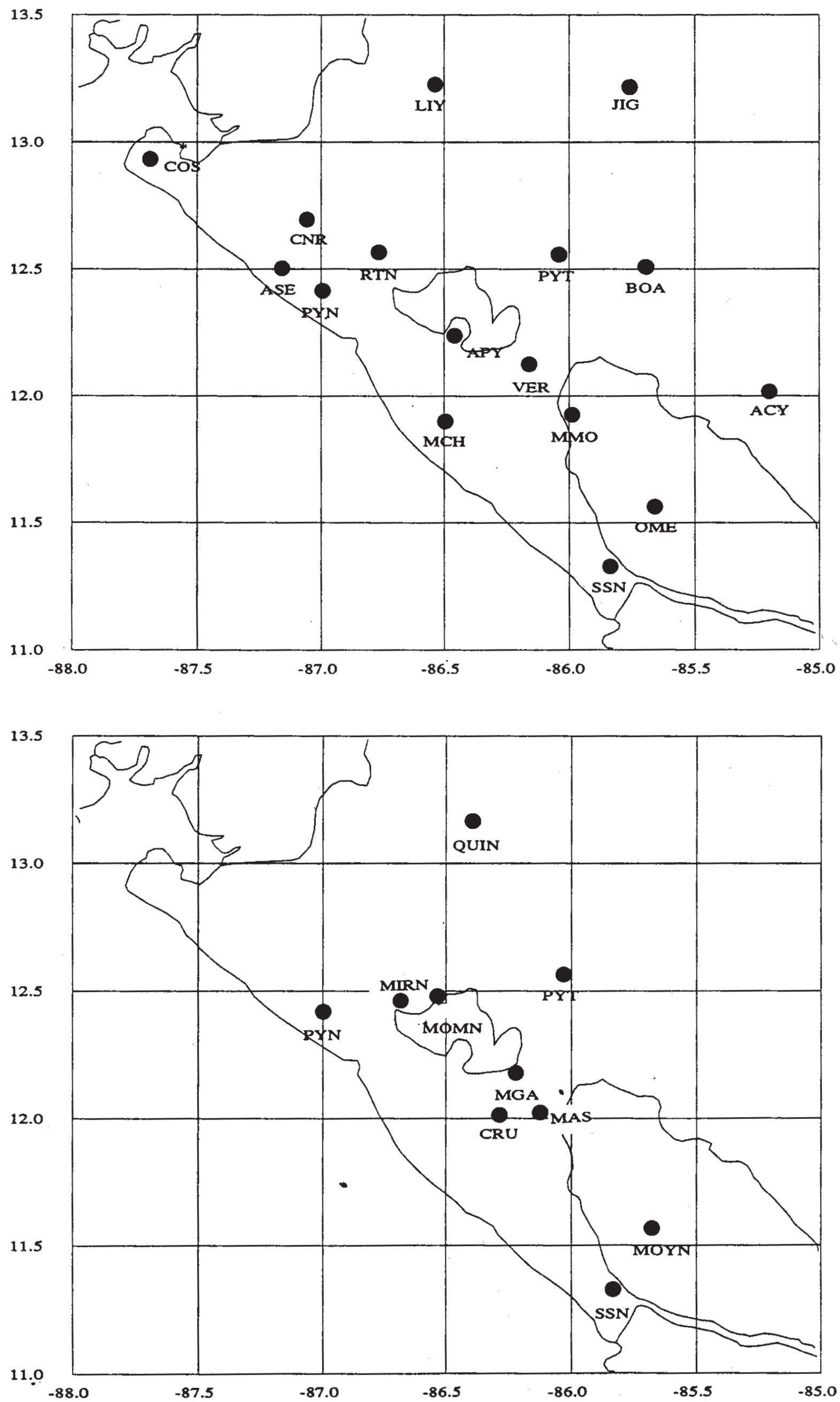


Fig. 1. Seismic stations in Nicaragua. At top is shown the old network and at bottom the current (of March 31, 1993) network. The stations are marked with their station codes.

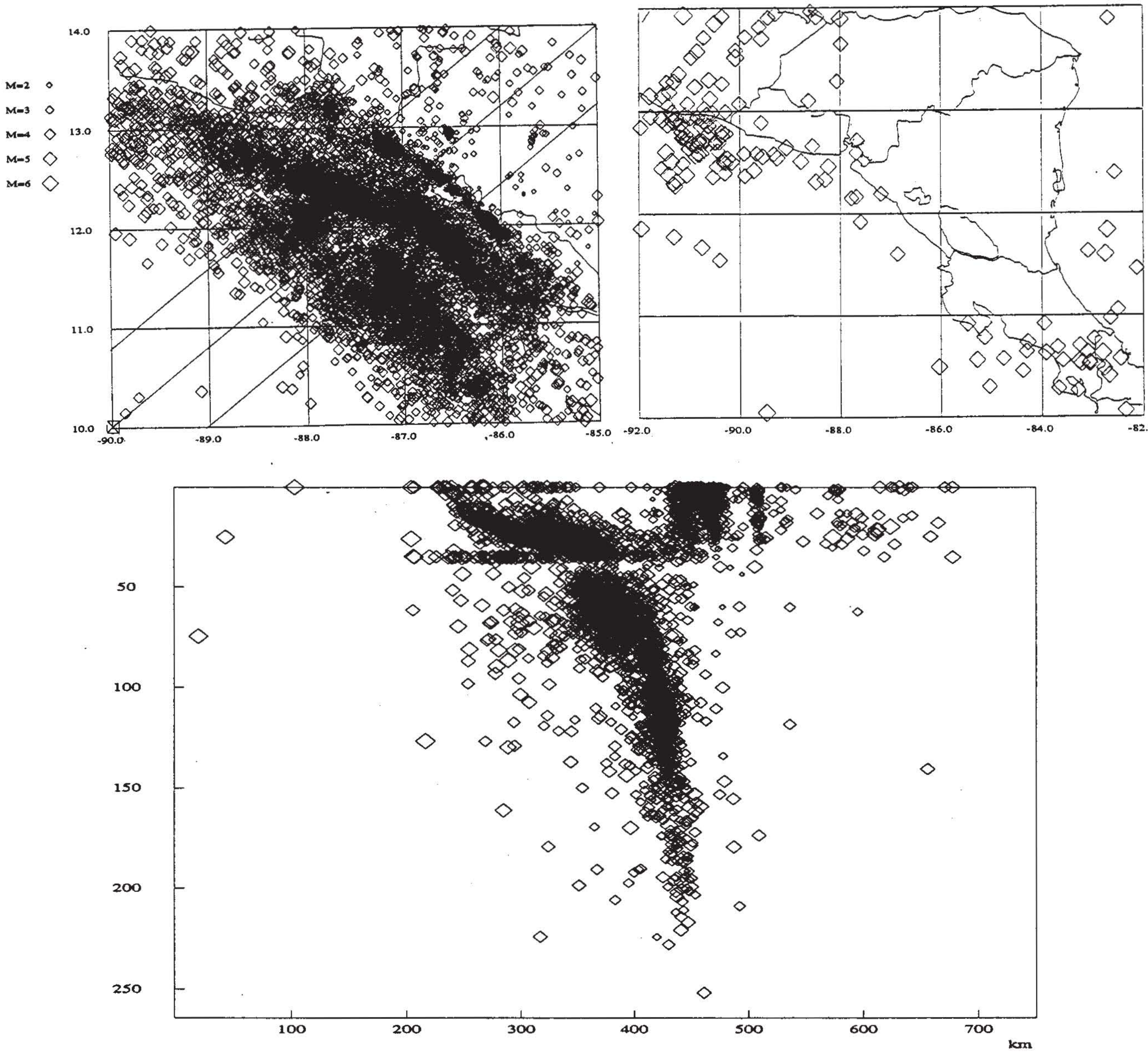


Fig. 2. Seismicity of Nicaragua. Top left shows all events near Nicaragua located with the old network in the period 1975-82. Top right shows the largest events (magnitude larger than or equal to 5.0) for the same time period in Nicaragua and neighboring countries. The bottom figure shows the depth profile with events selected between parallel lines as shown on the top left figure, with distances measured from lower left-hand corner.

in Nicaragua started in 1992, a year when several natural disasters stuck Nicaragua, underlining the need for a seismic network. In April of that year, a short violent eruption occurred at the Cerro Negro volcano and although there were no casualties, the impact on the environment and the economy was disastrous (Segura, 1993). In September, a magnitude Ms=7.0 earthquake struck the Pacific coast. Although there was little damage, 150 people were killed in the tsunami caused by this unusual earthquake (Satake *et al.*, 1993, Kanamori and Kikuchi, 1993, Byrne *et al.*, 1993).

In November 1992, the first 3 telemetered stations were recording digitally plus 9 sensors at the central recording site, and by the end of March, 1993 6 more field stations were installed, of which two were contributed by France in a special program to monitor the Momotombo volcano. The new 10 station network (Figure 1, Table 1) does not cover as large an area as the old network; however, the plan is to install 6 more stations.

At the central recording site at INETER (Figure 3) the sensors consist of 3 short period L4C seismometers, a 3 component FBA23 accelerometer and an intermediate period TSJ-10 seismometer produced by, and on loan from, the Central Institute of Earth Physics in Potsdam, Germany. The many sensors at the central recording site thus cover a wide frequency range, and at least one set of sensors will remain unsaturated. Figure 4 shows an example

Table 1

Current (April 1, 1993) seismic stations in Nicaragua. All stations except Managua have single-component vertical short-period seismometers. Managua has a 3 component short-period sensor, a medium-period 3 component seismometer and a 3 component accelerometer.

Name	Code	Latitude (N)	Longitude(E)	Height(m)
Quiabu	QUIN	13 07.5	86 25.0	1605
Momotombo	MOMN	12 24.5	86 32.4	500
Miramar	MIRN	12 26.4	86 42.7	280
Moyogalpa	MOYN	11 32.1	86 41.7	50
Masaya	MAS	12 00.0	86 08.9	150
Poneloya	PYN	12 22.9	87 01.3	50
Playita	PYT	12 32.3	86 03.5	460
Managua	MGA	12 08.8	86 14.8	80
Crucero	CRU	11 59.6	86 18.5	930
San Juan del Sur	SSN	11 17.3	86 51.0	415

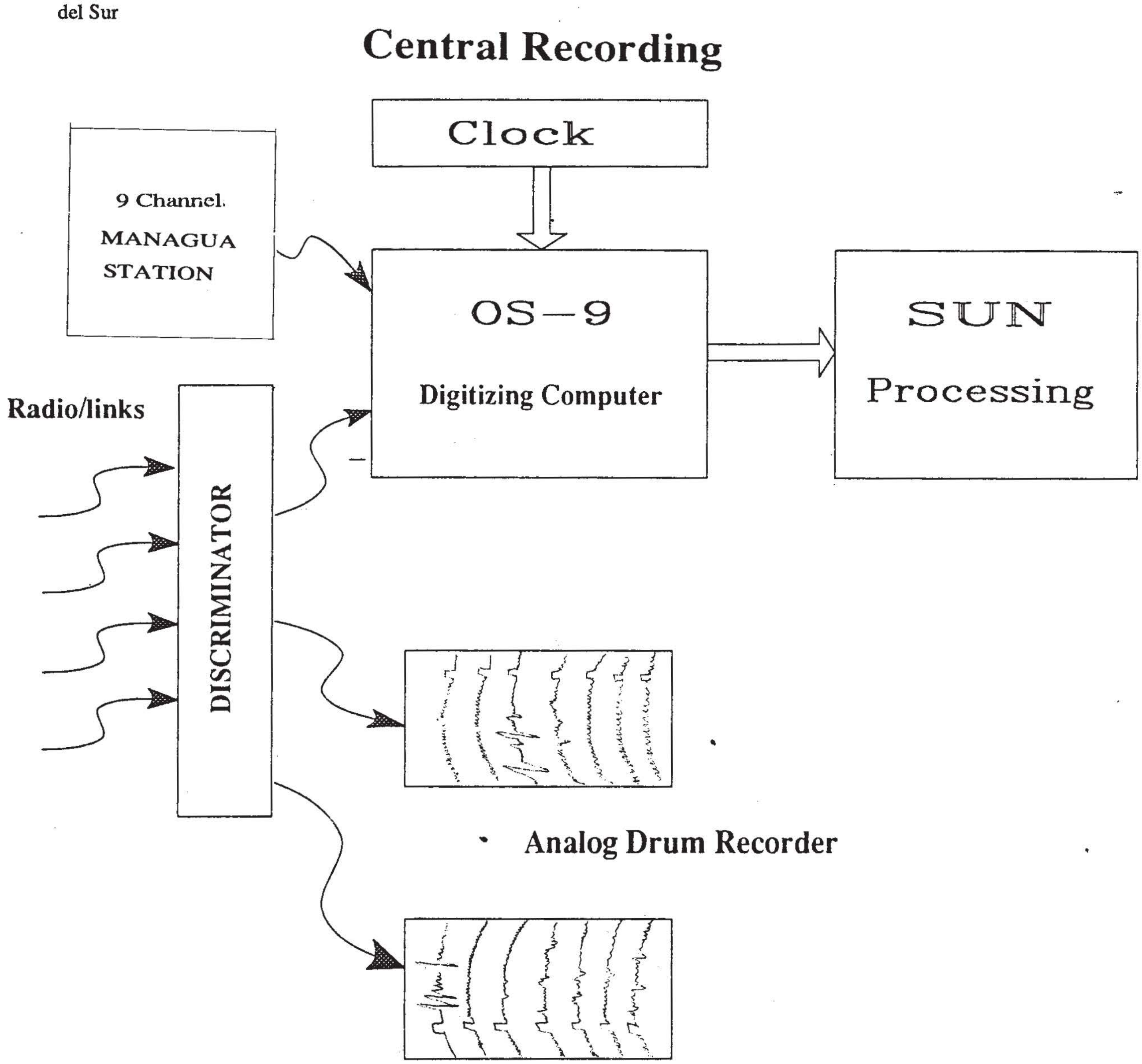


Fig. 3. Nicaraguan seismic system. The central recording is located in Managua and receives radio-transmitted signal from 9 field stations. The central clock is Omega synchronized and keeps the clock of the digitizing computer synchronized. The link between the OS-9 and Sun is by ethernet.

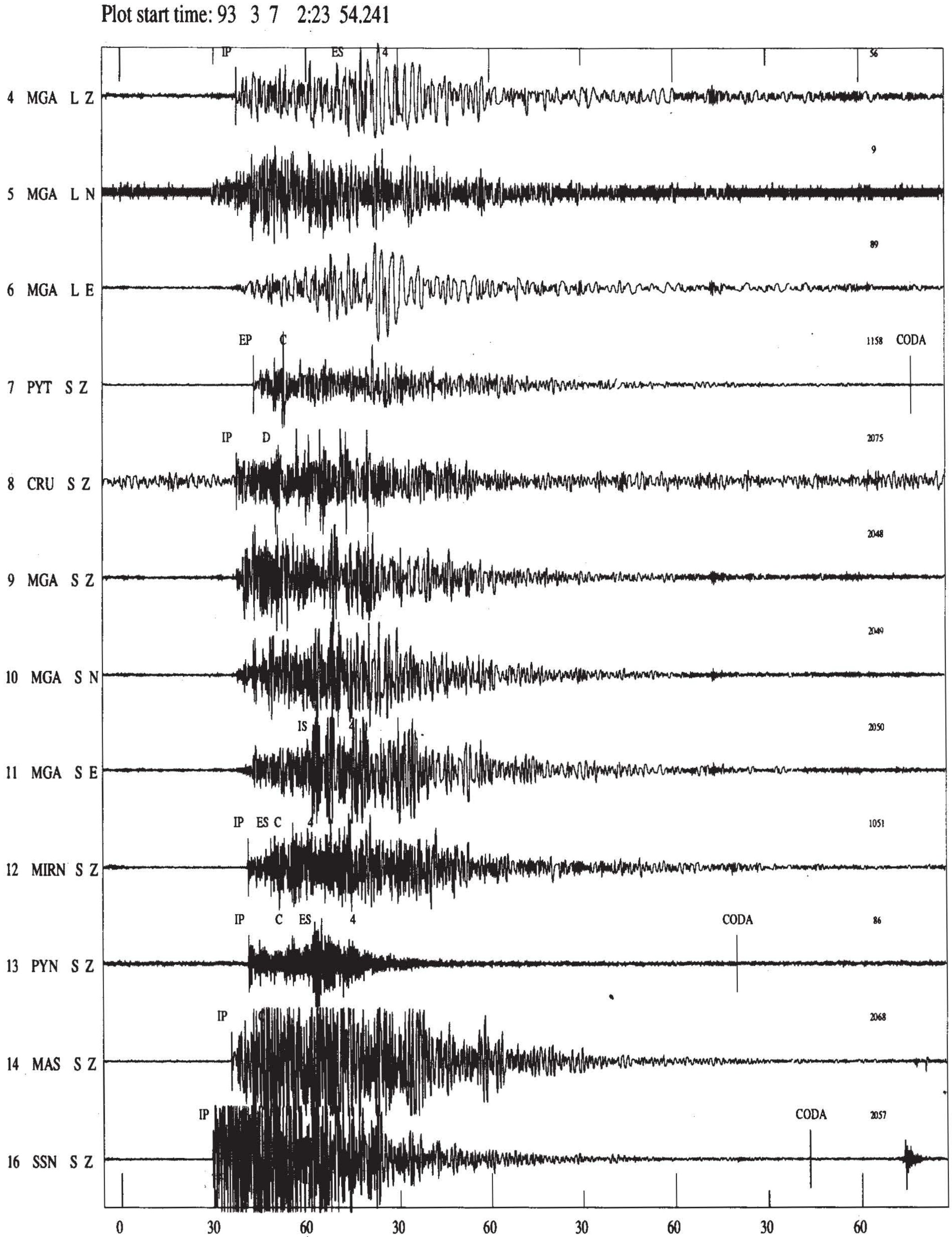


Fig. 4. An example of a seismogram with recordings on 7 stations, each channel is indicated by channel number, station code and component. The picked phase arrivals and coda durations are indicated on the traces with both polarity and weight (Hypo71 style) shown. The numbers to the left above the traces are maximum amplitudes (counts). The time scale below is in seconds. Note the clear surface waves on channel 4.

of seismic recording of a shallow event. Note the clear surface waves on the medium-period sensor. These are clearly absent on deep events, and using the medium-band sensor makes it simple to distinguish between deep and shallow events.

The data is sent from the field stations by radio using conventional FM modulation. At the central recording site the signals are demodulated and passed on to the SEISLOG data acquisition system using a 68030 processor and OS9 operating system (Havskov and Utheim, 1992) and 6 of the channels are at the same time recorded on paper. The timing is done with a Radiocode Omega clock. From the SEISLOG system, the data is transferred to the SUN computer via ethernet for further processing.

DATA PROCESSING

All detections from the SEISLOG system are manually transferred to the SUN at regular intervals (every 4 hours). Here all detections are manually checked and real events are registered into the data base for further processing while false detections are deleted. The data is processed (phase picking, location, hard copy etc) using the SEISAN analysis system (Havskov and Utheim, 1992, Havskov and Lindholm, 1992). The location program is the modified HYPOCENTER (Lienert, 1988, 1991) capable of using the crustal phases Pg, Pn, Sg, Sn, Lg in addition to P and S as well as azimuth information obtained from the 3 component stations. It is thus possible to locate with just the Managua station. The crustal model used is as follows:

P-velocity (km/sec)	Depth to interface (km)
3.5	0.0
5.0	1.0
6.0	6.0
6.8	13.0
8.0	35.0
8.3	200.0
8.5	300.0

This model was found to be the most appropriate around 1980 when the initial network had been in operation for some years. The 1.0 km top layer takes into account the pyroclastic layer.

The coda magnitude Mc (Lee *et al.*, 1972) is

$$Mc = -0.87 + 2 * \log(T) + 0.0035*DIST$$

where T is coda duration (sec) and DIST is epicentral distance (km). Although a new scale has been developed for Central America (Maroquin and Arriola, 1992) the old scale has been used in order to be able to compare with results from the old network. Local magnitudes Ml were calculated using the following preliminary scale (Arriola and Marroquin, 1992)

$$Ml = \log(A) + 1.93*\log(R) - 0.004*R - 3.1$$

where A is the maximum ground amplitude in nm and R is the hypocentral distance (km). The amplitude has been measured on a simulated Wood-Anderson seismogram using the SEISAN system.

The processing takes place routinely every 4 hours, and in case of an emergency an epicenter can be calculated within minutes of the occurrence of an event. The new seismic system thus gives a good real time capability.

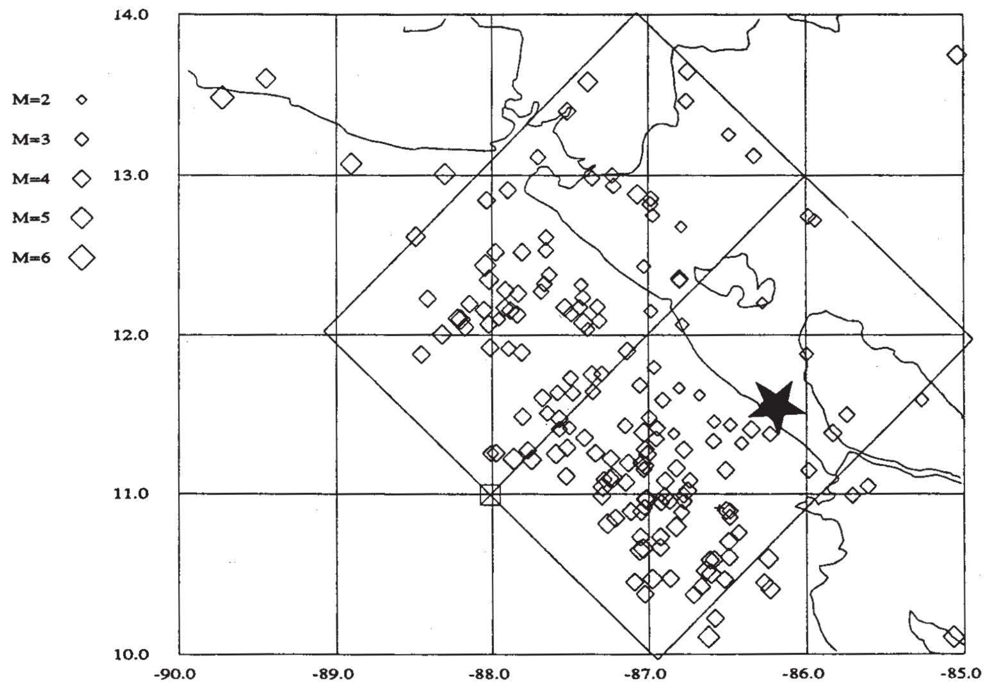
All data from the network (waveforms and readings) are sent to the Central American Seismic Database in Guatemala (at INSIVUMEH) where all Central American data are processed together after which the complete data set is returned to each Central American country.

SEISMICITY

The new network is considered operational from January 1, 1993 and here the first 3 months of seismicity are presented (Figure 5). In order to compare the current network with the old network, the 3 first months of seismicity from 1976 have also been processed in the SEISAN system in an identical way (Figure 6). For the two periods (1976 and 1993), 452 and 266 events were located, respectively and the numbers for March were 146 and 117 respectively, which can be compared to a monthly average of about 150 events located in 1976. The magnitude distribution for the two periods is shown in Figure 7. It can be seen that the detection threshold in 1976 was about 2.9 while in 1993 it was 3.8. Above the current detection threshold of 3.8, the two networks detect about the same number of events, which shows that the digital system triggers on a reasonable amount of earthquakes assuming that the rate of seismicity is similar in 1993 and 1976. The b-values are quite different. This could be caused by systematic differences in reading coda length on analog and digital seismograms.

The reason for the higher detection threshold now is probably the lower station density, especially considering that stations QUIN and MOMN (installed at the end of March) (Figure 1) practically did not contribute to the 3 months of data analyzed.

The seismicity with corresponding depth profiles are shown in Figures 5 and 6. The seismicity distribution is quite similar near the network, however more events are seen north and south of Nicaragua in 1976 than in 1993, which again probably is caused by the smaller current network. The depth profile shows a well-defined Benioff zone with the 1976 data, while the 1993 data does not resolve the hypocentral depths too well. Comparing the station distributions (Figure 1), this is not too surprising and when more stations are installed, the depth location ability should be improved.



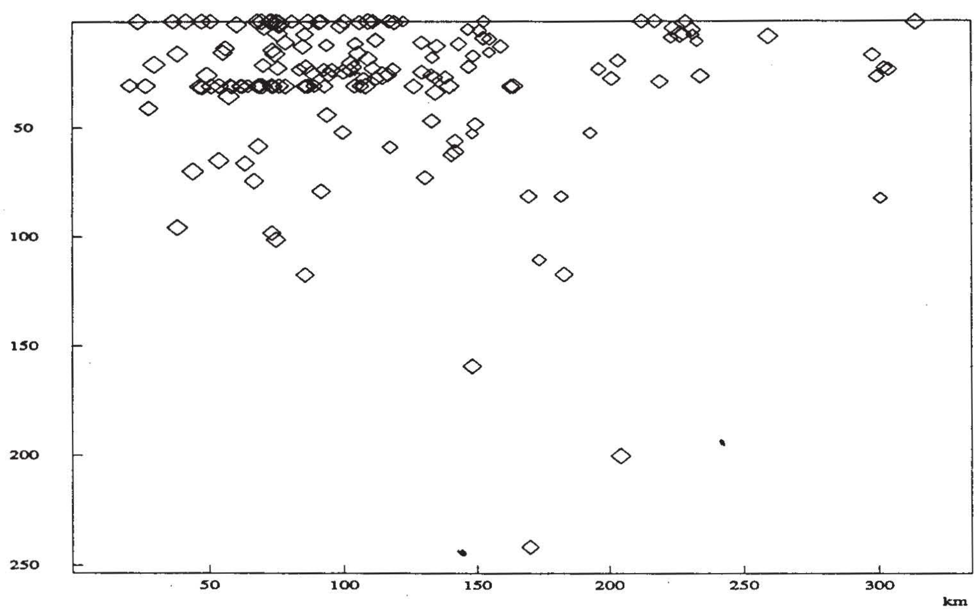


Fig. 5. Earthquakes located by the new seismic network in Nicaragua, January 1, 1993 to March 31, 1993. The top figure shows the epicenters and the bottom figure the depth profile within the rectangle shown in the top Figure. The star on the epicenter plot indicates the deep event, which was modelled. Distances are measured from the diamond. See also Figure 6.

In conclusion, the new network will detect most events larger than magnitude 3.8 and can be expected to give a reasonable epicenter location. However, the depth remains uncertain, especially for shallow coastal events.

A MODELLING EXAMPLE

Although the current Nicaraguan network clearly lacks location capability due to the limited number of stations,

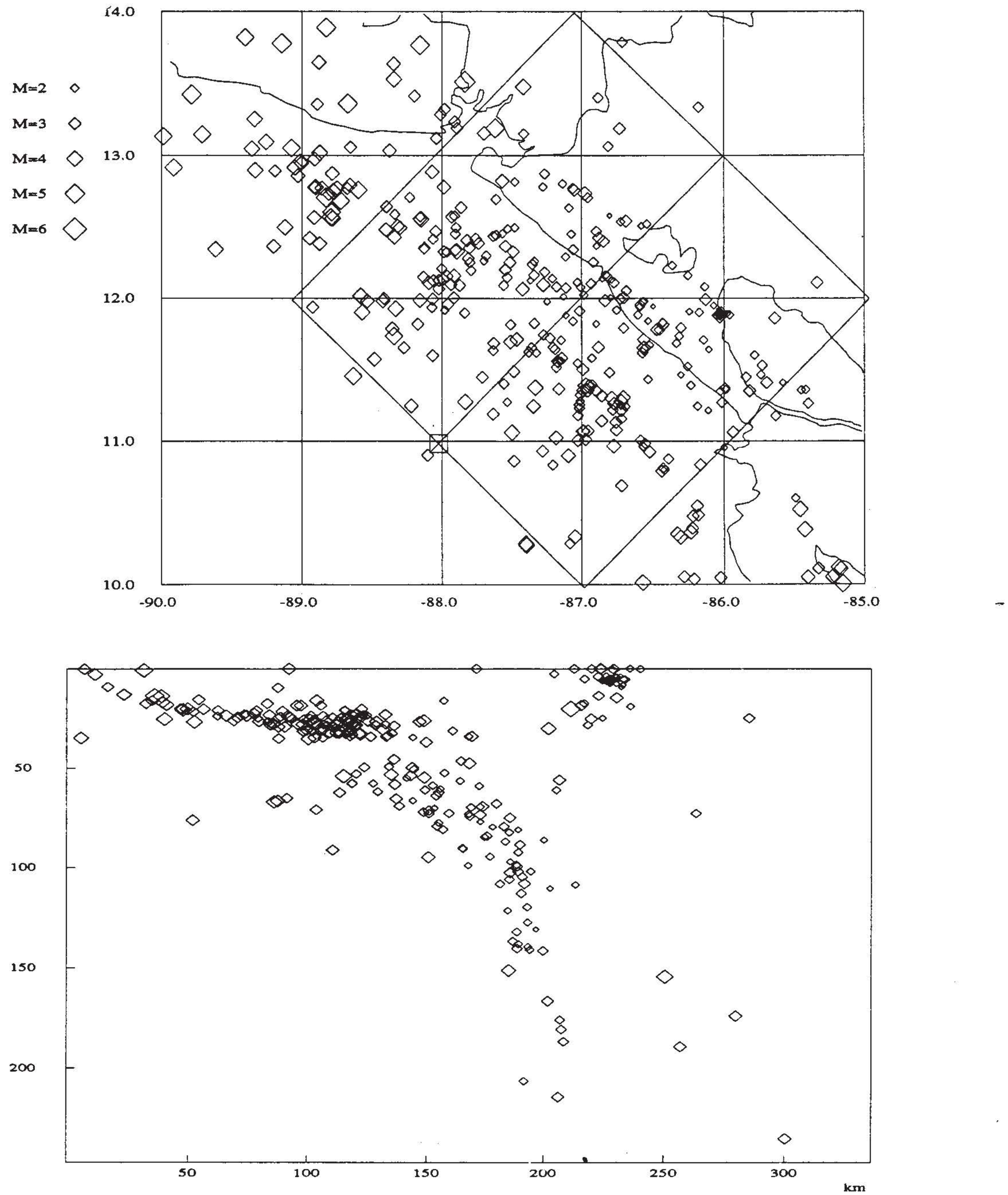


Fig. 6. Earthquakes located by the old seismic network in Nicaragua, January 1, 1976 to March 31, 1976. The top figure shows the epicenters and the bottom figure the depth profile within the rectangle shown in the top figure. Distances are measured from the diamond. See also Figure 5.

it is still possible to do more analysis due to the availability of digitally recorded data. In the following, the ability to obtain fault plane solutions will be demonstrated using synthetic modelling techniques.

The dynamic range of the field stations is limited by the FM transmission and the 12 bit A/D converter and there are therefore relatively few events with good signal to noise ratio which are on scale at all stations, and only a few events were good candidates for modelling. Additionally, in order to simplify the modeling a well-located deep event with a short epicentral distance was chosen:

Origin time: March 7, 1993 10:13.46
Coda magnitude: 3.6
Local magnitude: 3.7
Hypocentral depth: 94 km

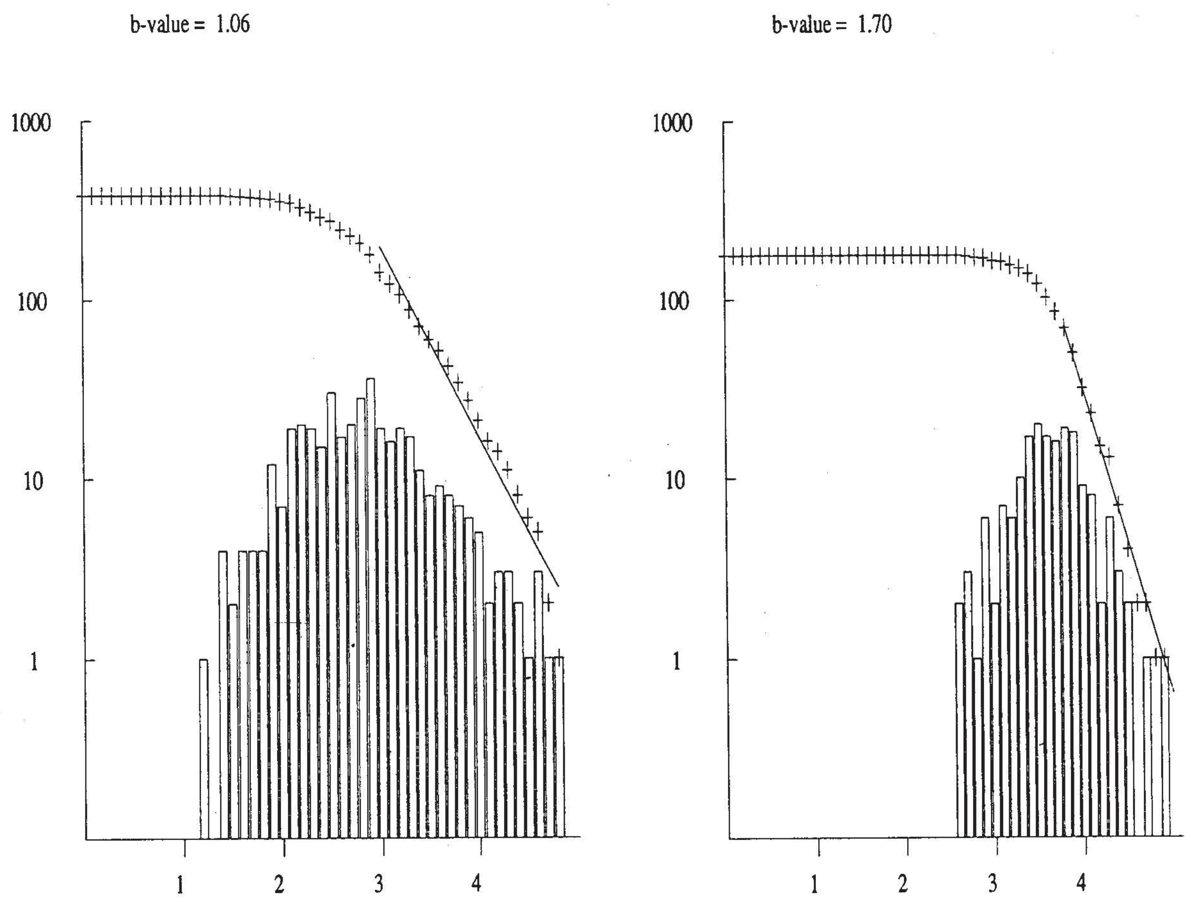


Fig. 7. Earthquake statistics for January to March, 1976 (left figure) and 1993 (right figure) as shown in Figures 5 and 7 respectively. The plots show number of events (bars) and accumulated number of events as a function of coda magnitude. Note the larger number of small events in the 1976 data.

The location of the event is shown on Figure 5. The reliability of the depth was tested by fixing the depth at values in the range 50 to 130 km, which showed that the location was at a true RMS minimum. With the depth fixed, one parameter less is needed in the modeling. The event had clear first arrivals; however, with the few stations available, it was not possible to get a fault plane solution (Figure 8). The fault plane solution program (originally written by A. Snoke) within SEISAN selects all possible solutions searching on a grid. With a grid size of 30 deg, 8 possible solutions were available (Figure 8) and each was tested with the modelling program.

For modelling, the Bouchon (1981) program was used. This program uses wavenumber integration and gives a full wave solution. The following simplified crustal model was employed:

P-velocity (km/sec)	Layer thickness (km)	Density (g/cm*cm)
6.8	35.0	3.8
8.0	165.0	4.0
8.3	100.0	4.2

All 8 of the possible fault plane solutions were tested using the best 3 stations. Before comparing the original and synthetic trace, all traces were narrow band filtered between 0.2-0.6 Hz. The results of Figure 8 show that two solutions are equally good. Although no unique solution was found, it has been demonstrated that a simple modeling method can eliminate many possible solutions, and one or two well-placed stations would probably have been enough to pin down the solution.

CONCLUSIONS

The development of seismology in Nicaragua looks promising. The capability of the new network is in many aspects superior to the old network, and with more stations to be installed, it should perform even better. Clearly seismology in a small country like Nicaragua cannot be isolated from Central American seismology; and for complete analysis of Nicaraguan seismicity and tectonics, data is needed from neighboring countries. With the coordinated efforts in seismology in Central America, where identical formats and identical processing systems will be used in all countries, both Nicaraguan and Central American seismology should be able to make significant progress.

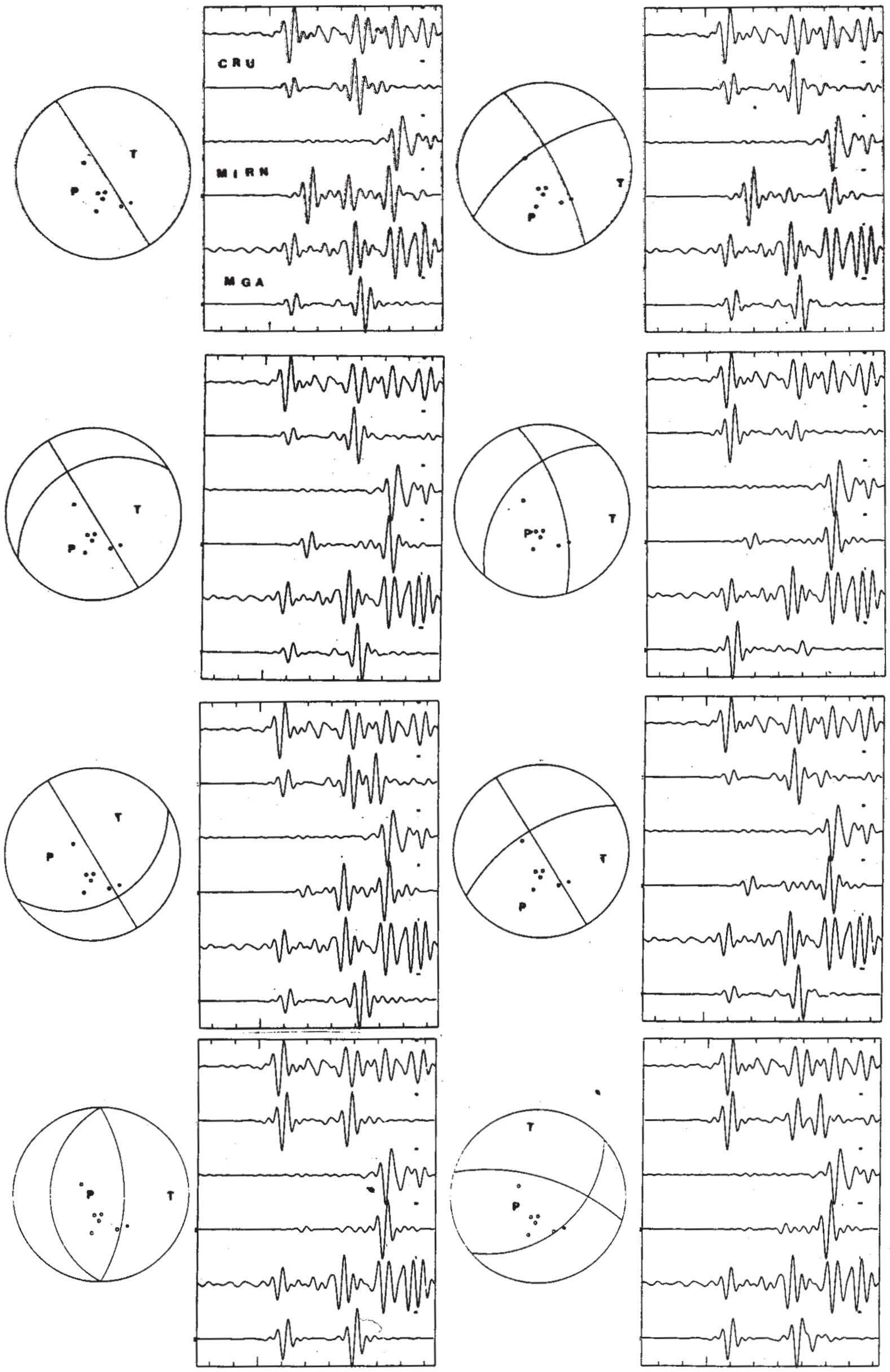


Fig. 8. Modelling a deep earthquake. The figure shows the 8 most likely fault plane solutions and the corresponding synthetic seismograms (bottom traces) compared to the real data (top traces) at stations MGA, CRU and MIRN. The traces are bandpass filtered between 0.2 and 0.6 Hz . The two most prominent phases on the seismograms are the P and the S- phases. The fault plane solutions show the lower focal hemisphere and P and T are the compressional and tensional axis respectively. The distance between time marks is 10 s.

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