Seismic Swarms at 16 and 21 hours GMT in Central Venezuela

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Abstract

Three independent seismic swarms which produce a great amount of periodic small earthquakes during 16 and 21 hours GMT (12 and 17 hours, local time), were found in Central Venezuela by applying a statistical study to the earthquake catalogue obtained from the analysis of the records collected by the FUNVISIS Seismological Network - RESVAC -. Magnitude for these shallow events oscillates between 2 and 3 on the Richter scale. The first swarm is located between the San Sebastián fault, the Tacagua-El Avila fault and the Macarao fault within an area of 4.5 km^2. The second swarm is limited by the Tacagua-El Avila fault, the Macarao fault and the La Victoria fault, occupying an area of 8.9 km^2. The third swarm is located south of the Rio Guárico fault and east of the city of San Juan de los Morros, with an area of 13.3 km^2. It is assumed that the events are triggered by gravitational effects (solar tides) acting on small quaternary fractures that lie between major active faults.

Introduction

In 1988, the Department of Seismology of FUNVISIS prepared a computerized earthquake catalogue that contains earthquakes registered in Venezuela and neighbouring regions from 1910. These data can be divided into three large categories according to their hypocentral errors. The first category groups the seismic events with the smallest hypocentral precision and that encompasses the period from 1910 to the 1960s. During this period, the number of seismological stations in existence was low, therefore the detection threshold was considerably high (magnitude greater than 5 mostly) and the precision in the hypocentre locations quite low (depths with errors greater than 30 km). This explains also the fact that most of the seismic events registered during this period may have unknown magnitude. Then with the establishment in the 1960s of the World Wide Standardized Seismic Network (WWSSN), the detection threshold decreased considerably, leading to an increase in the number of earthquakes located with better precision and an ability to assign magnitudes to most of them. In this way, the second seismic event category can be defined as those that occurred from the 1960s until 1980, when FUNVISIS began operating the National Seismological Station Network. With the establishment of this regional Network, which now consists of 20 short period stations, the earthquake detection threshold has decreased to about magnitude 2 for the national territory and to less than 1 for the earthquakes that occur in the central region, where the Network possesses its maximum density. Consequently, the third category encompasses the seismic events that occurred from 1980 until the present.

Once the Venezuelan earthquake catalogue was compiled, certain experiments could be easily accomplished. Among these projects was a plot of histograms of the hours of earthquake occurrence in the central region of Venezuela (9 to 11°N and 65 to 69 °W). It was found that for seismic events with magnitude between 2 and 3 approximately, there was a tendency for clustering at two particular hours. These two hours corresponded to 16 hours and 21 hours GMT (12 hours and 17 hours, local time). This fact motivated the study of this phenomenon in greater detail and the results are described below.

Data from the Earthquake Catalogue

The first phase of the study consisted in obtaining the occurrence histograms of earthquakes by hours of the day for the period between the 1960s and 1989, to identify the events whose origin times correspond to 16 hours and 21 hours GMT. Figure 1 shows the histogram that represents the number of earthquakes by hours of the day (GMT) for the central region of Venezuela without distinction of magnitude or depth. It can be appreciated that the bar that corresponds to the number of earthquakes for the hour 16 reports 55 earthquakes while the bar for the hour 21 indicates 60 earthquakes. The average number of earthquakes for the rest of the hours is less than 20. It is important to note that the central region of Venezuela possesses a lower level of seismicity than the eastern and western regions of the country. However, the central region is cut by many active geological faults (Soulas, 1986) and especially by the San Sebastián fault, which has produced large earthquakes in historical time. After proving the existence of two hours during which the number of earthquakes exceeds the daily average, other histograms were constructed to see the effects of magnitude and depth on the events associated with these two hours. Figures 2a, 2b, 2c show the histograms by range of corresponding magnitude to the depths of 0 to 50 km. From these diagrams it is clear that the activity peak for the hours 16 and 21 is concentrated between the magnitude 2 and 3, though there exists a small contribution from events of magnitude less than 2. For magnitudes greater than 3, these peaks are highly attenuated, oscillating about the average. The inspection of the data with depths between 50 and 200 km proves that for all magnitude ranges no anomalous occurrence of peaks of earthquakes for any hour of the day is observed. Consequently, it can be concluded that the anomaly in the occurrence of earthquakes for the central region of Venezuela has a superficial character. Once the ranges of magnitude and depths of the anomalous earthquakes had been identified, the study was divided into two parts: the earthquakes that correspond to 16 hours and the earthquakes that correspond to 21 hours GMT.

Seismic events at 16 hours GMT

Having identified the earthquakes in the catalogue whose occurrence hour corresponds to 16 hours (GMT), the seismological records in FUNVISIS were searched for other events that are not in the Seismic catalogue because they were recorded by less than four seismological stations. Only two additional events were found and locations for these were calculated from three P phases using the method described by Ramos and Mendoza (1990). Their corresponding magnitudes were also calculated and found to be between 2 and 3. A plot of the epicentres of the 57 events shows that most of the events are distributed throughout the San Sebastián fault, the Tacagua-El Avila fault, the La Victoria fault, the Macarao fault, the Tácata fault and the Rio Guárico fault with three geographical areas where the earthquakes tend to be concentrated. The first area of clustering is located at the confluence of the San Sebastián fault, the Tacagua-El Avila fault and the Macarao fault (named Swarm STM). The second area is located to the east of the first, among the Tacagua fault and the Macarao fault and the La Victoria fault (named Swarm TMV) and the third, to the south of the central part of the Rio Guárico fault (named Swarm G), nearby to the population of San Juan de los Morros. It is important to note that the earthquakes that belong to these swarms tend to be aligned in the North-South direction.

Figure 3 presents the geographical location of the earthquakes belonging to each of these three swarms. The swarm STM contains 12 earthquakes within the following coordinates: 10.3 to 10.7 °N and 67.0 to 67.1 °W. The area defined by the coordinates is about 4.5 km^2. The depth of these events is less than 10 km, with an average value of 5.4 km. The swarm TMV contains 8 earthquakes within the following range: 10.2 to 16.0 °N and 66.7 to 66.9 °W. The area of this region is 8.9 km^2. The maximum depth of the earthquakes is 12.1 km with an average value of 6.8 km. Finally, the swarm G contains 24

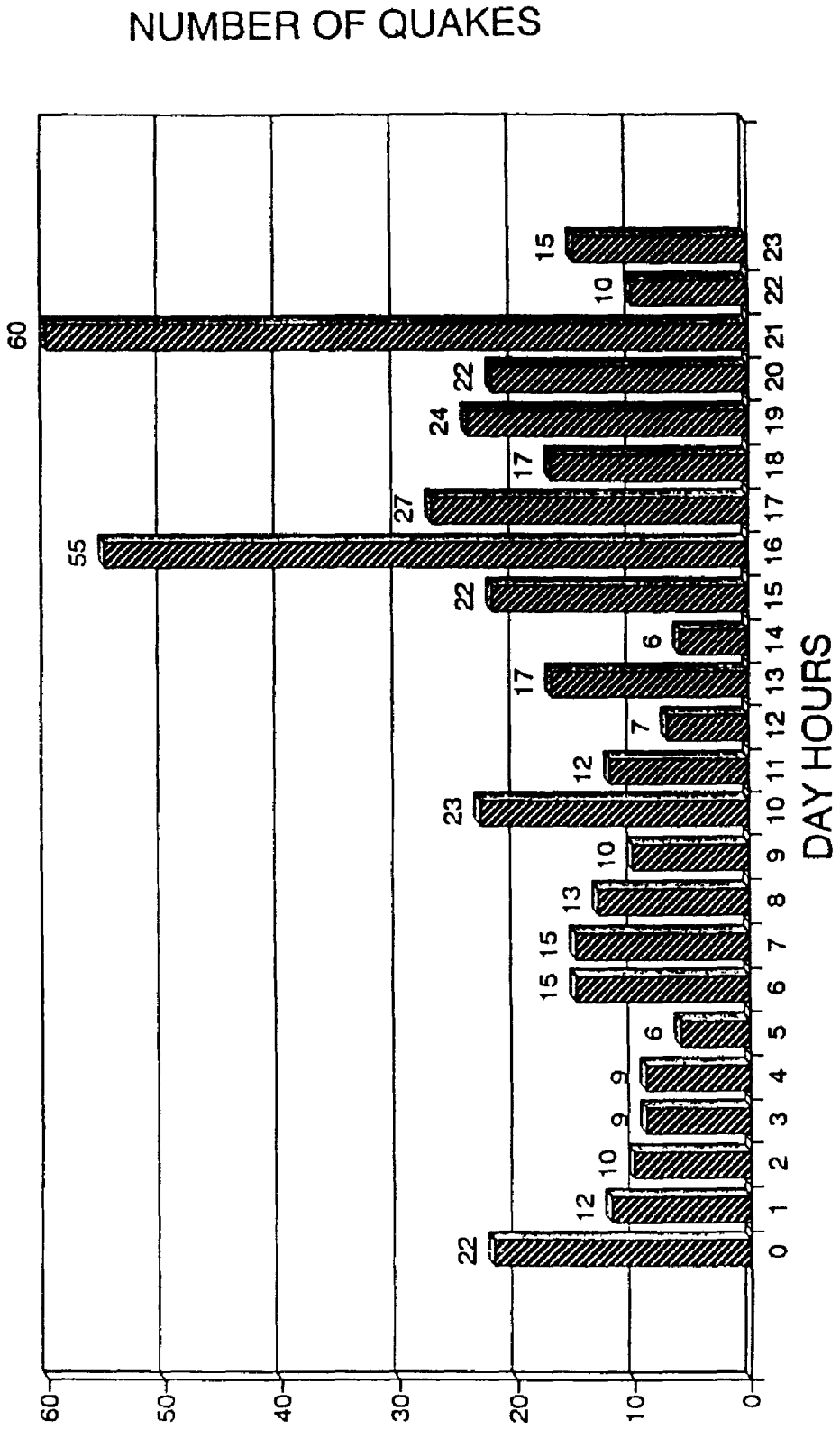

Figure 1: Histogram of occurrence frequency of earthquakes in the central region of Venezuela by hours of the day (GMT) for magnitudes of 1 to 9 and depths of 0 to 200 Km.

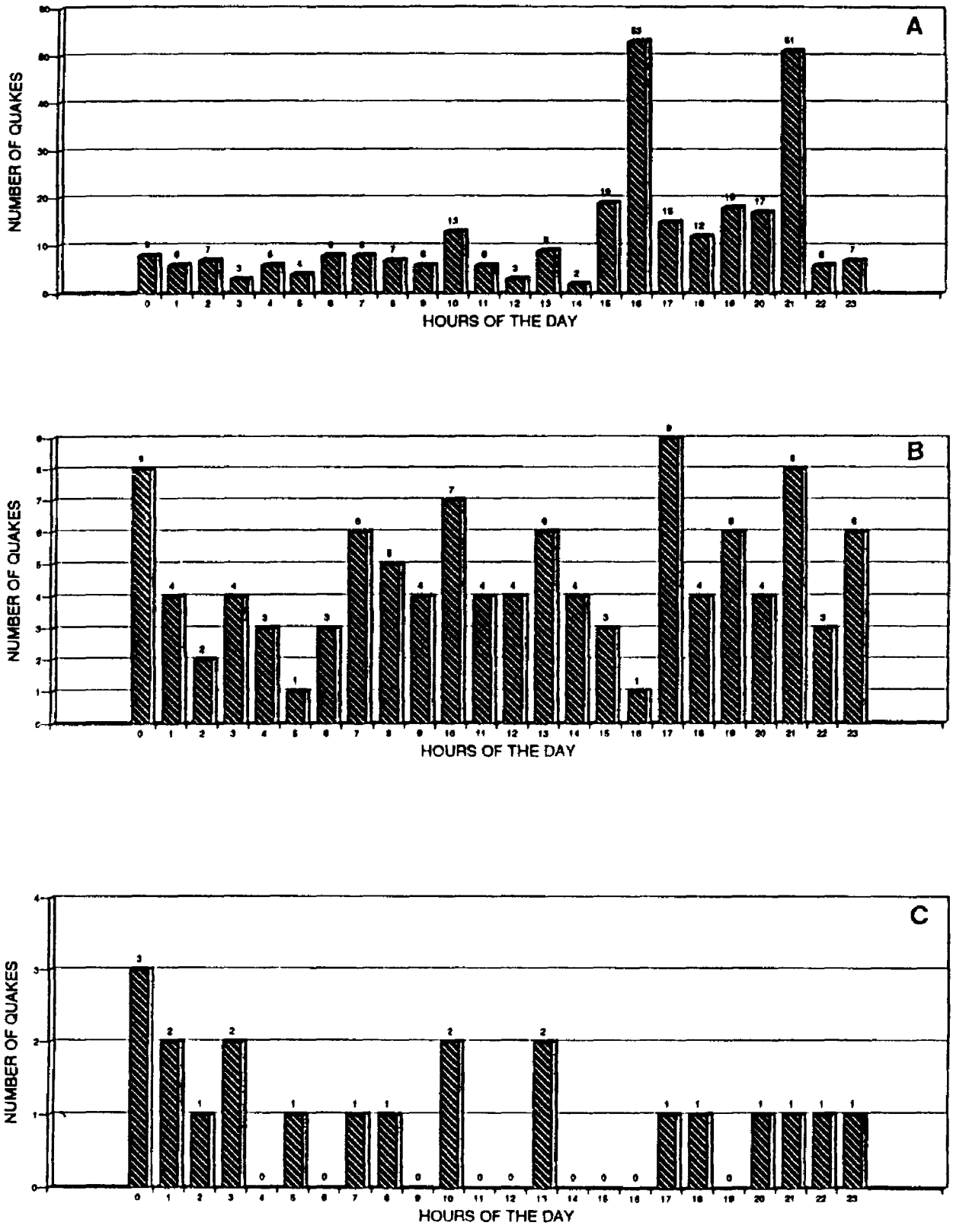

Figure 2: Histograms of occurrence frequency of earthquakes in the central region of Venezuela by hours of the day (GMT) for depths of 0 to 50 Km and a) for magnitudes of 1 to 3; b) magnitudes of 3.1 to 4 and c) magnitudes of 4.1 to 9.

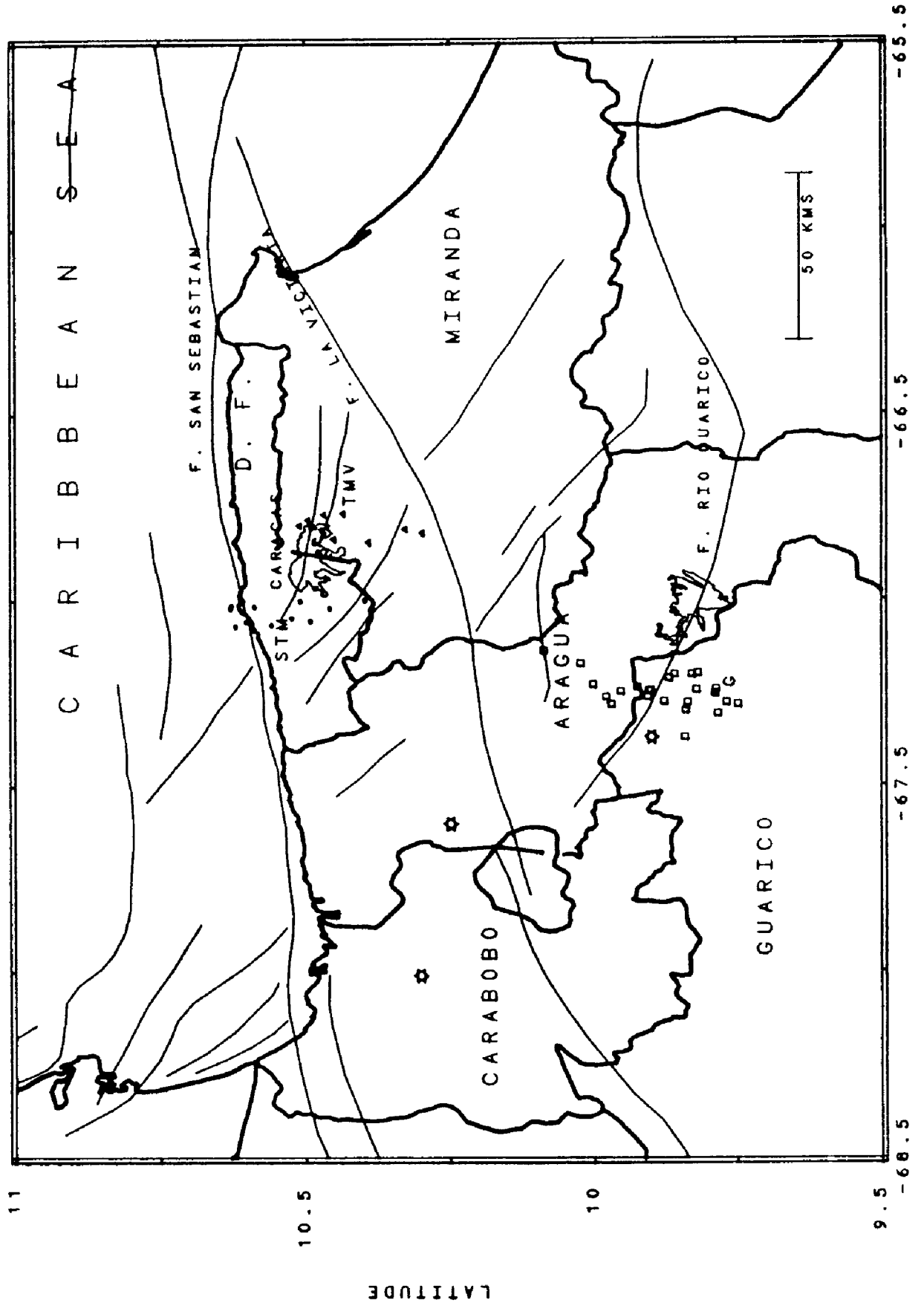

Figure 3: Faults map of the central region of Venezuela and the seismicity corresponding to the swarms STM (dots), TMV (triangles) and G (square) for the hour 16 (GMT). The stars represent capital of states (See base map)

earthquakes within the coordinates: 9.7 to 10.1 °N and 67.1 to 67.4 °W, corresponding to an area of 13.3 km^2. The maximum depth reached by the earthquakes in this swarm was 29.6 km and its average value was 12 km. The range of magnitudes for all these events oscillates randomly between 1.8 and 3.0. Of 57 events located in the central region whose origin times were 16 hours GMT, 44 belonged to the three swarms, corresponding to about 77% of the events. Within this 77%, 55% belong to the swarm G, 27% to the swarm STM and 18% to the swarm TMV. The study of the occurrence frequency by month of the earthquakes belonging to each swarm, reveals that only swarms TMV and G presented peaks. For the swam TMV, the peak occurs for the month of July with 4 events compared to an average of 2 earthquakes for the rest of the months, while for swarm G, peaks were found in the months of July and October with 5 and 6 earthquakes respectively above an average of about 2 earthquakes for the rest of the year. The analysis of the occurrence frequency by year of the earthquake swarms does not reveal any particular distribution, except for the swarm G for which the year 1986 produced 11 seismic events at 16 hours. This anomalous frequency coincides with strong seismic activity that occurred in the central part of Venezuela in that same year (FUNVISIS, 1986).

Seismic events at 21 hours GMT

60 events belonging to 21 hours GMT were taken from the seismic catalogue since it was not possible to locate in the seismological records other events that were probably recorded by less than four seismological stations. These data possess a dispersion greater than those corresponding to 16 hours GMT. However, it is possible to group 31 of them within the swarms STM and TMV defined for 16 hours GMT. Figure 4 represents the epicentral locations of these 31 earthquakes. As can be seen, these events tend to group the previously defined swarms of STM and TMV into one whose area is approximately 26.7 km^2 (10.1 to 10.8 °N and 66.7 to 67.1 °W. The maximum depth for the earthquakes belonging to this great swarm is 25 km with an average value of approximately 10 km. The study of the occurrence frequency by month of the earthquakes belonging to this swarm reveals that the distribution is quite uniform with minor peaks among the months of January (5 events), July (4 events) and September (4 events). With respect to the annual occurrence frequency, no particular distribution was found except for the year 1981 which produced 11 earthquakes of the swarm. This anomalous earthquake production coincided with the seismic storm of Guyagua of that same year, which was located very close to this swarm.

Discussion

In order to investigate if the identified seismic areas corresponding to 16 hours as well as to 21 hours GMT are also sources of other events that occur at times different from these two, the epicentres for the remaining hours were plotted (Figure 5). Also plotted in the same diagram are events for the swarms at 16 and 21 hours. It is observed that the swarms STM and TMV are also seismic areas for other hours, while the swarm G is an almost exclusive area for 16 hour GMT. The proportion of earthquakes in the swarms STM and TMV that occurred at 16 and 21 hours with respect to those that originated during the other hours is 51/44, that is to say, the proportion is slightly greater for these two particular hours. This is not the case for swarm G where the earthquakes have a tendency to occur only at 16 hours GMT.

The data shown previously indicate that in the central region of Venezuela, there exists three seismic areas of small dimensions which produce earthquakes within the hour 16 or the hour 21 GMT. As a first point of discussion, an analysis of the seismological records for the events in question was made to discard the possibility that these were explosions. The seismograms were found to present the typical appearance of an earthquake.

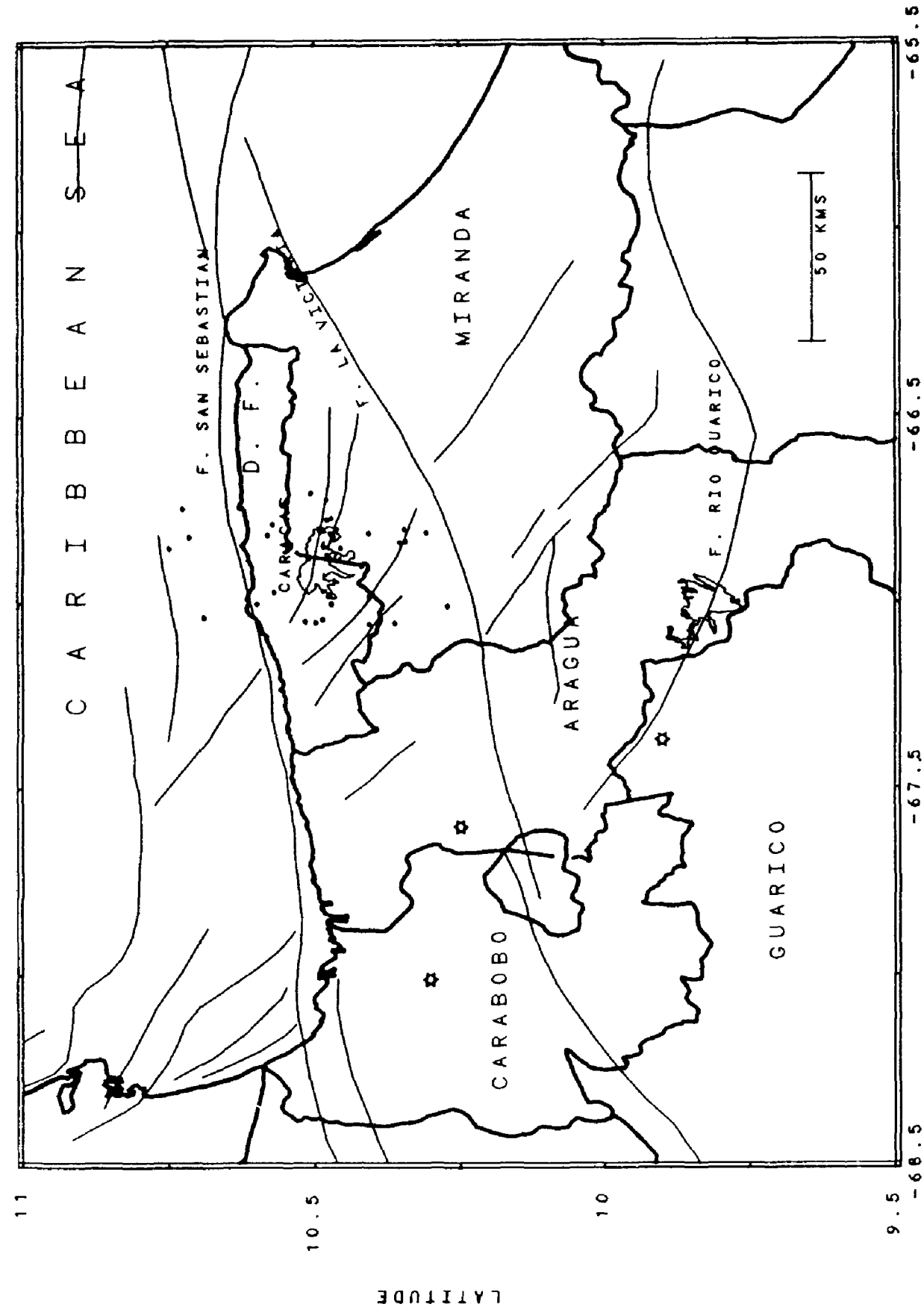

Figure 4: Faults map of the central region of Venezuela and the seismicity corresponding to the swarms STM and TMV (dots), for the hour 21 (GMT). The stars represent capital of states (See base map).

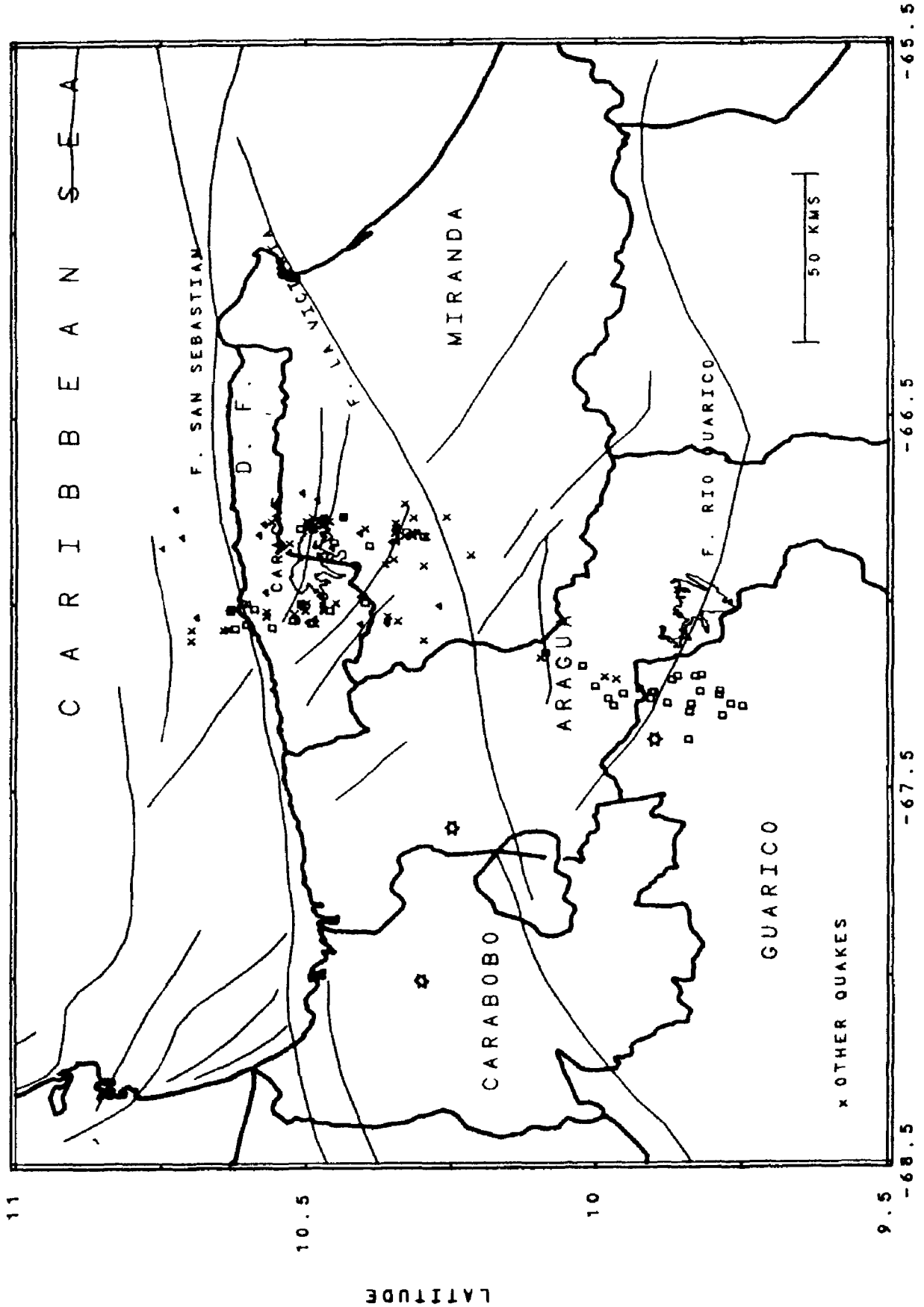

Figure 5: Fault map of the central region of Venezuela. The squares represent the seismicity registered to 16 hours (GMT), the triangles represent the seismicity registered to 21 hours (GMT) and the x represent the seismicity to other hours of the day. The stars represent capital of states (See base map).

Furthermore, the hypocentres of the events that correspond to 16 and 21 hours GMT were calculated from records obtained by four or more stations. Due to the significant distance among stations in the central region, it is very unlikely that a small quarry blast will be recorded by so many stations at the same time.

As a second point, it is possible to appreciate from Figure 5 that the swarm STM is limited within the geological faults of San Sebastián, Tacagua-El Avila and Macarao, to the west of the city of Caracas. This last fault has been named in this work as Macarao since it is not referenced in the literature and passes through the town of Macarao, located to the west of the city of Caracas. According to geological studies by Soulas (1986), the San Sebastián fault and the Tacagua-El Avila fault are right lateral strike slip faults, while the character of the Macarao fault is not known. However, it is not possible to directly associate the seismicity of these swarms with any of these faults, since the area occupied by the events is distributed among them. Site studies (Beltran, personal communication) indicate that the region delimited by the aforementioned faults must be highly fractured at the surface although this has not actually been observed. Due to the small magnitude of the events, it is difficult to evaluate the corresponding focal mechanisms and hence it is not possible to obtain a satisfactory conclusion on the geometric parameters from the seismic sources.

The swarm TMV is found to be limited by the Tacagua-El Avila fault, the Macarao and the La Victoria faults and is to the east of the city of Caracas. La Victoria is also a right lateral, strike slip fault (Schubert, 1988) and similarly to the swarm STM, the earthquakes cannot be associated directly with any of these three faults because of its diffuse character. It is worth pointing out that due to the arrangement of the Seismological Network for the central region (the events are located within the network) the location errors are quite small (about 1 km or less). For this swarm, it was also not possible to obtain a reliable focal mechanism. Also, it is important to note that the swarms STM and TMV are separated by the city of Caracas, where no seismicity has been detected. This is the main reason why we separated the swarm STM and the swarm TMV. The swarm G is located to the South of the Río Guárico fault and to the east of the city of San Juan de los Morros. The Río Guárico fault has been catalogued as a right lateral, strike slip fault (Audemard et al., 1990). However, the earthquakes tend to be disseminated within the area of the swarm and they cannot be associated directly with a particular fault. Of all the earthquakes analyzed, those belonging to swarm G possess the greater depths which could suggest that it is formed by near vertical faults. Furthermore, no events associated with occurrence times other than 16 hour GMT were observed. Since the earthquakes that correspond to 16 and 21 hours GMT and that belong to the three studied swarms do not occur in a particular month, it has not been possible to calculate the annual periodicity in them. It would have been interesting correlating the amount of rainfall but no reliable rainfall data is available. On the other hand, the earthquakes that occur at 16 hours cannot be interrelated with the earthquakes of 21 hours for the swarms STM and TMV. Until additional data is available on these swarms (focal mechanisms, rainfall data, geological data), the following generating mechanism is proposed: because the seismicity is shallow and diffuse in a small area of possible recent (quaternary) fracturing, limited by greater faults, elastic energy derived from the greater faults is accumulated and distributed quickly among these small faults, until saturating the capacity of energy storage of some of these fractures. Then the tidal effects produced by the sun when it reaches its zenith (16 hours GMT) on possible vertical faults or when the gravitational effects are almost horizontal (21 hours GMT), act as triggers for releasing of the accumulated energy. The earthquakes' occurrence is not periodic, probably due to the random captation rate and energy accumulation.

Conclusions

By analysis of the computerized data base of FUNVISIS, it was possible to find three areas or seismic swarms in the central region of Venezuela with a marked trend to produce shallow events between magnitude 2 and 3 at two specific hours: 16 hours GMT and 21 hours GMT. The seismic events do not present any periodicity with respect to the months or the years.

The first designated seismic swarm, STM, is limited by the San Sebastián fault, the Tacagua-El Avila fault and the Macarao fault with an approximate area of 4.5 km^2. The second designated swarm, TMV, is found to be limited by the Tacagua-El Avila fault, the Macaroa fault and the La Victoria fault, with an approximate area of 8.9 km^2. The third designated swarm, G, is located to the South of the Rio Guárico fault and to the east of the town of San Juan de los Morros. The area occupied by this swarm is about 13.3 km^2.

The earthquakes within the swarms STM and TMV occur at 16 hours as well as at 21 hours GMT and some events have been detected within these areas that occur at different hours of the day. The earthquakes within swarm G, are produced almost exclusively at 16 hours GMT and their depths are slightly greater than those of the other two swarms.

The low magnitude of the seismic events of the three swarms (between 2 and 3) indicates that they are probably associated with small geological faults that form a diffuse system within the corresponding areas. For that reason it was not possible to obtain a reliable focal mechanism.

We tentatively propose a gravitational mechanism (solar tides) acting as triggers of the earthquakes within the studied swarms.

References

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