

## ENERGY QUANTIFICATION OF SEISMIC ACTIVITY ORIGINATED IN THE PROVINCE OF MENDOZA IN THE PERIOD 1956-1998

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### SUMMARY

It is quantitatively analyzed the energetic instrumental seismicity in the Province of Mendoza during 1956-1998.- Numerous superficial events led to adopt a criterion of classifying earthquakes according to focal depth into: **superficial** (from 1 to 20 km); **mild** (from 21 to 70 km) and **intermediate** (> 71 km).- All data correspond to U.S. Geological Survey; to Instituto Nacional de Prevención Sísmica and to the data base of **CEREDETEC** [Ref. 1, 10, 11] of events with epicentral coordinates between 31,9° and 37,5° South Latitude and 66,5° and 70,5° West Longitude.

### INTRODUCTION

The first step to establish the model of spacial and temporal frequency of seismic activity was to gather data of earthquakes occurred.- The seismic parameters taken into account were: 1) date; 2) origin time; 3) tridimensional coordinates of focus; 4) magnitude; 5) epicentral intensity.- All were taken from the above sources.

The low density of sismographic stations existing previously in the zone, affect negatively the precision of data included in seismic catalogues based on international information.- Numerous superficial events of small magnitude are not reported.- Another important indetermination is the event magnitude.- When regions of relatively low seismicity are studied, small variations in magnitude determination may significantly distort true values of energy liberation.- Epicentral coordinates are known with an error that extends from a few to a hundred kilometers.- Such an aspect may be of minor significance for deep focuses, but its impact is very important in superficial earthquakes with variations in the affected geographic area, in generated intensity, and in its variation related to distance.- Historical seismicity, with epicenters associated to the area of maximum intensity, indicates that the most destructive earthquakes in the region under study had their origin in very near and superficial focuses.- Nowadays the same conclusion is arrived at through instrumental seismicity, observation of field effects, studies of accelerographs and the experience of technicians.- The events of superficial focus are those which cause the greatest damage and destruction when compared to equal magnitude and epicentral distance but of a deeper focus.- Focus depth is a factor of great practical importance, that is why superficial earthquakes moderate magnitude may cause very high intensities in the epicentral area. Mendoza (1861), Agadir (1960), Managua (1972), Guatemala (1976), Mendoza (1985) and Kobe (1995) are valid examples.

### EPICENTRAL COORDINATES AND FOCAL DEPTH IN MENDOZA

Some local earthquakes are used as examples of the importance of indeterminations mentioned.- Localizations have been calculated separately with the same methodology from reliable seismic records obtained by the "Estación Sismológica Mendoza" [Ref. 1] based on time interval (**S-P**) and the seismoscopic records at ground level.- The difference between S and P time is very small, in most cases about 2 seconds, which proves that the events had very superficial focuses, Silva et al. [Ref. 3 -7, 10].- Seismoscope networks, proper amount of high technology instruments and a thorough study of macroseismic effects make local determinations very useful and of very low cost.-

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Table N° 1 - Summary Of Data From The Seismoscope Network

Nº	DATA	SÍS. C. max.	I.M.M. °, dec.	MAG.	DIST. Km	DEPTH km	DIREC.
1	24 mar 1980	0,038	5,4	4,5	9	10	SW
2	02 jul 1981	0,050	6,0	4,5	22	31	NW
3	01 dic 1982	0,029	5,1	4,5	8	10	NNW
4	06 mar 1986	0,046	5,6	4,7	9	38	SW
5	27 may 1987	0,046	5,6	4,3	11	18	NNE

In the map of **FIGURE 1**, international epicenters and those locally determined can be observed.

The seismic events of 24/03/1980, 01/12/1982 and 27/05/1987 caused several problems: energy blackouts, industrial steel furnaces off service and masonry cracking.

A typical example of this activity is the earthquake of January 26, 1985, now termed as "impulsive" with a magnitude  $m_b = 5,9$ ;  $h = 5$  km; duration of the main part = 2.5 seconds. In a Wilmot seismoscope and with a well defined VII intensity, a seismic coefficient  $C_s = 0.39$  was measured. The macroseismic epicenter of this earthquake was at about 500 m. to the West where the

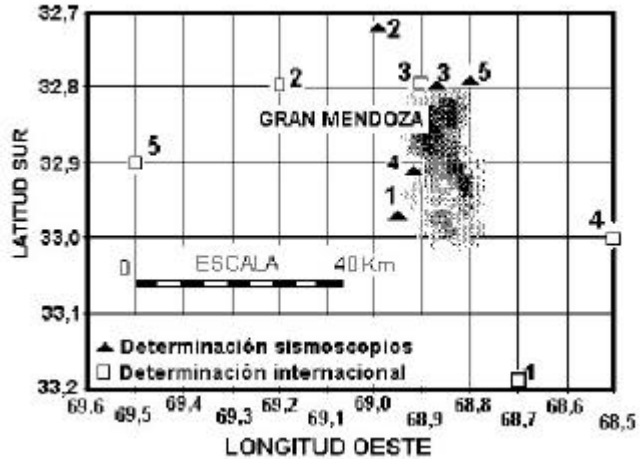


Figure 1 – Near Epicenters Map

intensity not only reached but exceeded degree VIII in the Modified Mercalli Scale with a seismic coefficient  $C_s = 0.42 - 0.50$ . This means that in a few hundreds of meters the seismic intensity had a variation of about 1 1/2 grades in the same scale.

### TEMPORAL ENERGETIC QUANTIFICATION OF ZONE SEISMIC ACTIVITY

Without going into considerations about event parameters and taking into account only the maximum intensities, affected area and magnitude from various sources, we drew the semilogarithmic graph (**FIGURE 2**) relating liberated energy with different periods in years. The aim is to show that seismic activity in the period 1956-1998 is considerably lower than in other historic periods when no instrumental data were available.



Figure 3 - Number Of Events In Catalogues



Figure 2 - Liberated Seismic Energy In The Province Of Mendoza

Figure 3 shows the number of events recorded in seismic catalogues used for various periods.

In activity qualification two factors are taken into account: depth of focus and geographic coordinates. In this paper the following classification is adopted due to the importance of antecedents related to focal depth, Sauter [Ref. 2].

Superficial earthquake	Focal depth	0-20 km
Mild earthquake	Focal depth	21-70 km
Intermediate earthquake	Focal depth	71-300 km

In energy quantification, accepted international relations have been used.

$$\text{Seismic energy} \quad \log E = 11.8 + 1.5 M_s \quad (1)$$

$$M_s \text{ Magnitude} \quad M_s = (m_b - 2.5) / 0.63 \quad (2)$$

TABLE 1 shows energy liberation calculated for each 5-year period in the area under study.

Tabla N° 1 - Periodic Liberated Seismic Energy

PERIOD Years	ENERGY / 10 <sup>13</sup> Ergios
1956-1960	1.261.914.688,96
1961-1965	2.179.487,61
1966-1970	15.968.054,80
1971-1975	7.524.902,11
1976-1980	8.336.495,31
1981-1985	23.389.953,70
1986-1990	10.116.887,90
1991-1995	1.174.925,94
1996-1998	2.568.293,39
<b>TOTAL</b>	<b>1.333.173.689,72</b>

When distribution of instrumental sismicity is studied, we observed that the greater part of activity is located in two zones: one in the North (31.9° - 33.9°) and the other in the South (34° - 37.5°) [Ref. 8].- Both were considered, but emphasis was placed on the first. Table 2 shows values and percentages.

Tabla N° 2 - Periodic Liberated Seismic Energy – North And South Zone

PERIOD YEARS	NORTH ZONE 31,9°-33,9° SOUTH		SOUTH ZONE 34,0°-37,5° SOUTH		OVSERV.
	ENERGY 10 <sup>13</sup> erg.	%	ENERGY 10 <sup>13</sup> erg.	%	
1956-1960	1.261.914.689	100	0	0,00	V.CONCL.
1961-1965	2.173.178	99,71	6.310	0,29	V.CONCL.
1966-1970	15.739.016	98,57	229.038	1,43	
1971-1975	7.433.648	98,79	91.254	1,21	
1976-1980	5.127.705	61,51	3.208.790	38,49	
1981-1985	22.152.398	94,71	1.237.555	5,29	
1986-1990	5.442.892	53,80	4.673.996	46,20	
1991-1995	822.147	69,97	352.779	30,03	
1996-1998	2.155.426	83,92	412.868	16,08	
<b>TOTAL</b>	<b>1.322.961.099</b>	<b>99,23</b>	<b>10.212.590</b>	<b>0,77</b>	

In Table 3, energy liberation is quantified between 31.9° S and 34° S for each 5 year period according to proposed focal depth.

Tabla N° 3 - Periodic Liberated Seismic Energy – North Zone (31,9° – 34° S)  
Superficial, Mild And Intermediate Earthquakes

PERIOD YEARS	SUPERFICIAL		MILD		INTERMEDIATE	
	ENERGY ergios/ 10 <sup>13</sup>	%	ENERGY Ergios/ 10 <sup>13</sup>	%	ENERGY Ergios/ 10 <sup>13</sup>	%
1956-1960	630.957.344	50,00	-----	-----	-----	----
1961-1965	1.625	0,07	343.479	15,76	1.834.383	84,17
1966-1970	180.590	1,13	7.443.061	46,61	8.344.404	52,26
1971-1975	375.824	4,99	329.372	4,38	6.813.397	90,54
1976-1980	1.984.346	23,80	447.199	5,36	5.904.950	70,83
1981-1985	14.204.275	60,73	133.138	0,57	9.052.541	38,70
1986-1990	4.692.886	46,39	82.223	0,81	5.341.779	52,80
1991-1995	503.359	42,84	133.400	11,35	538.168	45,80
1996-1998	108.804	4,24	158.675	6,18	2.300.815	89,59
<b>TOTAL</b>	<b>652.900.249</b>	<b>27,84</b>	<b>8.911.872</b>	<b>14,58</b>	<b>37.829.622</b>	<b>57,58</b>

From the qualitative point of view, special mention must be made to the influence of the earthquake of January 26, 1985. Its contribution in energy liberation was not significant, but all the same, it produced human casualties, numerous injured people and considerable damage due the important intensity produced by its superficiality and short epicentral distance which made of this earthquake the most significant seismic event in the last 70 years.

#### FOCAL DEPTH OF SISMIC ACTIVITY IN MENDOZA

**Southern Mendoza (South of parallel 34°):** Focal seismic distribution, **FIGURE 4**, shows superficial, mild and intermediate seismic activity from the Chilean border to meridian 68°. In this period, intermediate activity disappears eastwards and mild activity decreases. There are some superficial focuses in longitudes near San Rafael city.

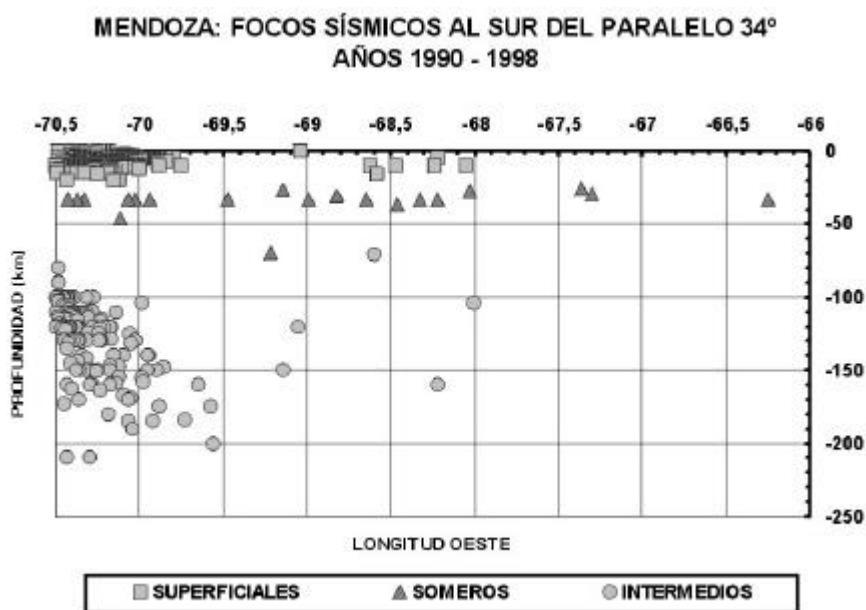


Figure 4 - Mendoza: Seismic Focuses, South Of Parallel 34° 1990-1998

**Northern Mendoza (Up to parallel 34°).** Figure 5 shows the introduction of Nazca Plate under the Southamerican Plate in a band of 220 km wide running from the Province of San Juan to the city of Tunuyán. It shows a tendency to horizontality from meridian 69° with a remarkable decrease of intermediate activity eastwards from meridian 68°.

A greater superficial seismic activity is concentrated in a narrower band of 110 km between 32.5° and 33.5° South latitude.- Greater Mendoza, (about a million inhabitants), is the most important socio-economic settlement located 20 km from the North border and 60 km from the South border.- In this location the Nazca Plate and the Benioff zone slide at an angle of about 16°.

This situation can be seen up to the meridian 69° where the activity diffuses and, apparently, tends to horizontalization. Superficial and mild seismic activity increases and intermediate activity decreases. This area extends from 68.3° to 69° West longitude. **FIGURE 6**

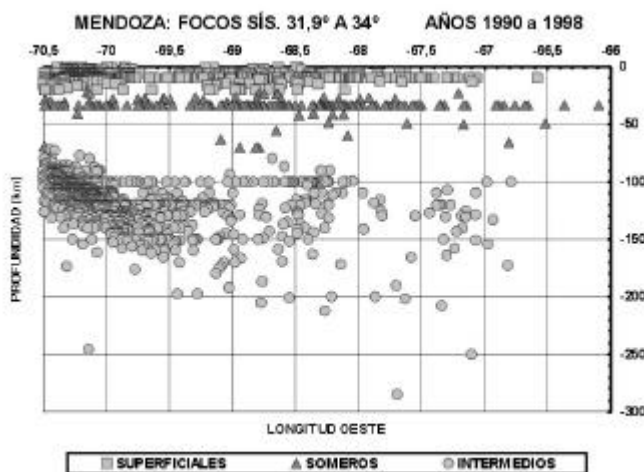
Figure 7 shows a meridianwise section comprising Greater Mendoza and its outskirts covering a North-South area of 120 km and extending for 100 km from East to West. It also shows seismic activity during 1990-98. There is an important superficial and mild seismic activity which increases from 32.6° to 33.8° parallels and slightly decreases in the direction North-South.

### EPICENTRAL DISTRIBUTION IN MENDOZA

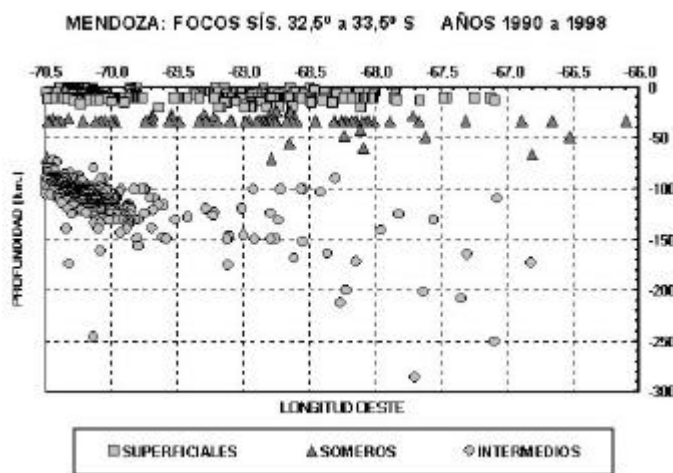
**General Seismic Activity:** As shown in map of **FIGURE 8**, the greater part of seismic activity is concentrated North of 34° S parallel and 68° W meridian.- In the rest of the territory a disperse activity is observed which decreased to the South and the East.-

**Superficial Seismic Activity:** It almost exclusively appears north of parallel 34° and especially between meridians 68° and 69° W and the parallels 32.5° and 33.5° S.- There are also other two epicentral concentration tending to join in the Chilean – Argentine border (**FIGURE 11**)

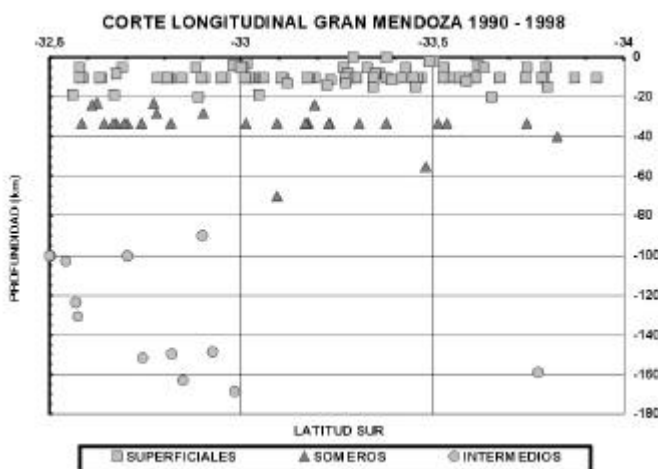
**Mild Seismic Activity:** It shows a more regular East-West distribution, mainly referred to the region between meridian 68° and 69° W and parallels 32.5° and 33.5° S (**FIGURE 9**)



**Figure 5 - Mendoza: Sismic Focos 31,9° - 34° South 1990-1998**

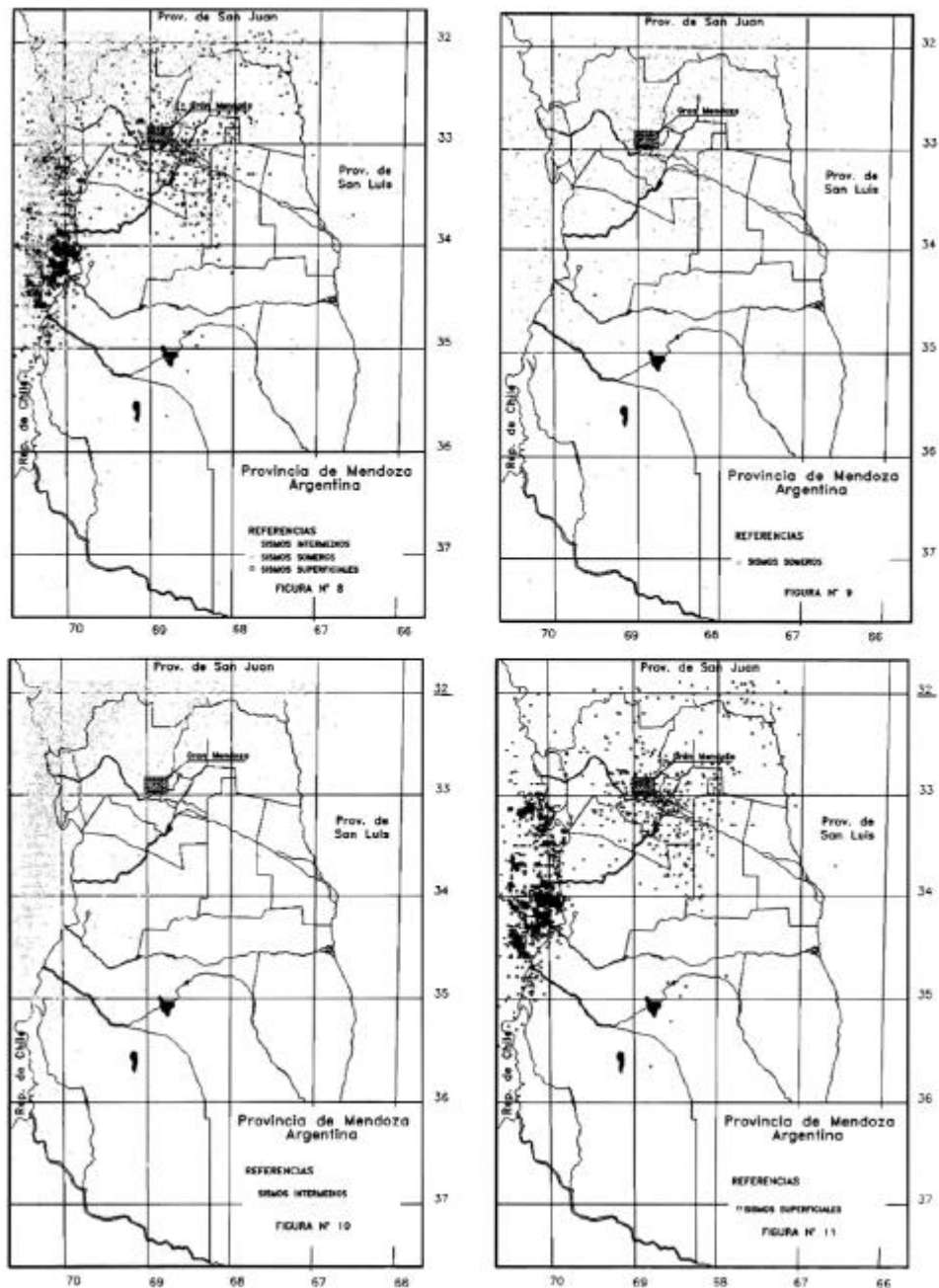


**Figure 6 - Mendoza: Seismic Focos 32.5° - 33.5° South 1990-1998**



**Figure 7 - Longitudinal Section Greater Mendoza 1990-98**

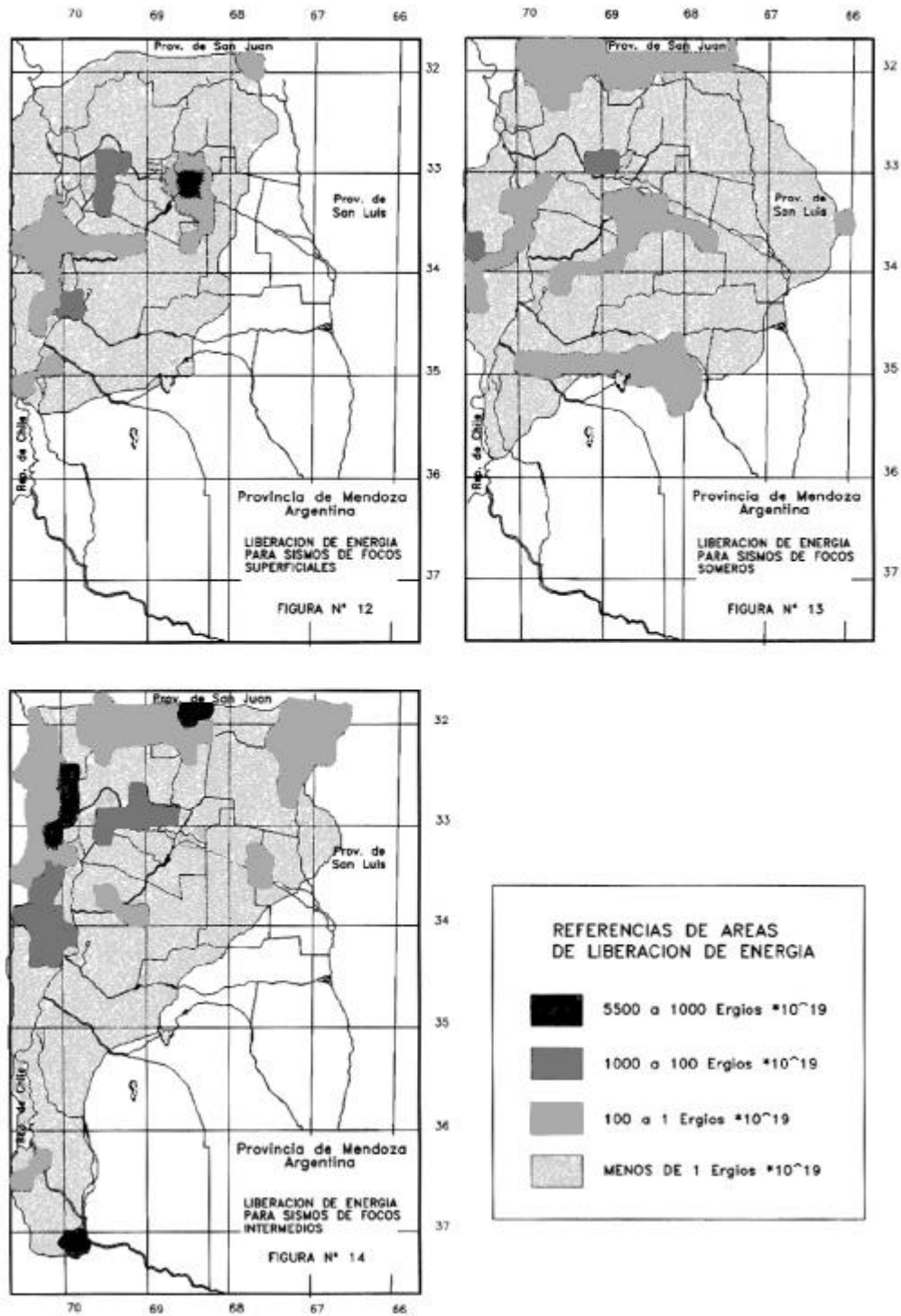
**Intermediate Seismic Activity:** Mainly concentrated in the Northwest and North of Mendoza showing a decrease in activity toward the interior area. (FIGURE 10)



**Mendoza Province – Epicenters 1956 – 1998 – All (Fig. 8); Milds (Fig. 9); Intermeddiates (Fig. 10) And Superficials (Fig. 11)**

**SEISMIC ENERGY LIBERATION; 1956 – 1998 PERIOD**

Maps of **FIGURES 12, 13 and 14** show areas limiting each of the four zones with similar liberated energy during the period under study based on the magnitudes given by various seismic catalogues ( $< 1$ ;  $1$  a  $100$ ;  $100$  a  $1000$  y  $1000$  a  $5500$  ergios  $\times 10^{19}$  ).- There exist coincidence between the areas of maximum energy liberation and epicenters of equal focal depth.- Variation continuity in energy liberation is not observed.-



**Seismic Energy Liberation 1956 – 1998**  
**Superficials (Fig. 12), Milds (Fig. 13) And Intermediates (Fig. 14)**

### CONCLUSIONS

- Due to zonal geotectonic characteristics and historical seismicity it is assumed that seismic activity maintains a certain level of permanent liberation of energy in the presence of historical earthquakes of higher magnitudes than those instrumentally registered since 1956.-
- Before 1970, international data do not allow to assess adequately seismic activity originated in Mendoza. This is due to the lack of accuracy in establishing epicentral coordinates, focal depths and magnitudes because of the

low density of local and global station networks or the lack of instrumental sensitiveness. To qualify and quantify energy liberation it is necessary to use historical seismicity so as to determine seismic parameters. This is applicable mainly to the early 30 years of the XX century when important earthquakes occurred.-

- With the help of modern instruments it has been possible to catalogue the area under study. There have been 3095 events in the period 1990-98 (9 years) against 1695 earthquakes between 1956-89 (34 years). In this latter period there were very important events such as those of 10-11-1966; 25-4-1967 and 26-01-1985 which, no doubt, must have originated aftershocks.-
- The importance of instrumental data given during 1990-98 together with those from previous periods and historical seismicity allow to qualify with precision the origin of seismic activity affecting the zone.-
- Between 32.5° and 33.5° S. Nazca Plate and Benioff Zone are seen sliding from West to East at an angle of about 16°. This situation is noticeable up to 69° meridian. At this point intermediate activity decreases and tends to horizontalize.- Superficial and mild activity increases.-
- It is convenient to keep an analysis of periodic energy liberation as well as its source. It might give signs of the proximity of a major seismic event.(Energy percentage from superficial earthquakes increased 9 years before the occurrence of an important event as that of January 26, 1985).
- From informatic data processing of seismic activity generated in the area, it is possible to infer that Greater Mendoza in general, and the city of Mendoza in particular, are situated in a zone where superficial and mild focuses concentrate.
- It is imperative the availability of dense local instrumental networks to qualitatively and quantitatively measure zonal seismic activity. This is because of the existing seismicity. In this area tectonic sources in the vicinity have produced, and no doubt, will produce important superficial focus earthquakes of highly destructive energy.- In this type of events intensity rapidly varies with distance.-
- Though the most important danger comes from superficial and mild seismic activity in the vicinity of Greater Mendoza, intermediate sources must not be overlooked.
- Investigation results open interesting perspectives not only for a better knowledge of local seismic activity, but also, as a source for future research concerning other scientific disciplines. This is the reason why the need of a depuration and, if need be, of completion and expansion of data is suggested as an important contribution to community.

#### ACKNOWLEDGEMENTS

We deeply thank the sound and sincere collaboration from our colleagues of CEREDETEC in the discussions and criticism held in the development of this investigation. We also thank the authorities of UTN and FAC.REG. MZA. for their trust and confidence in our work.

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