# The situation of the City of Mendoza, Argentina, in a Seismic Emergency

J.C. Castano[1,2], J.L. Zamarbide[2], E. Fernandez[3] and M.A. Bufaliza[1,2]

1. Instituto Nacional de Prevención Sísmica-INPRES
   Roger Balet 47-Norte - (5400) San Juan, Argentina
2. Universidad Nacional de San Juan
   Avda. Libertador Gral. San Martín 1109
   Oeste (5400) San Juan, Argentina
3. Centro Regional de Investigaciones Científicas y Tecnológicas -CRICYT
   Parque Gral. San Martín,
   (5500) Mendoza, Argentina

## Abstract

The development of the structure of land use in this city is analyzed since its creation up to now. Three well-defined stages are distinguished separated by two fundamental events:

1) The March 20, 1861, earthquake which stands out from the rest because it was the most destructive one in Argentina, destroying the city of Mendoza and killing 6,000 people out of a population of 18,000; and

2) The sudden urban growth in the 1950s which unified small surrounding urban centres with the original one, establishing the base of the present city called Gran Mendoza with 800,000 inhabitants.

The seismic hazard estimation was carried out considering the following aspects: seismicity, potential seismic sources, attenuation relations and local soil conditions, thus maximum acceleration maps with 10% probability of exceedance were obtained for different ranges of time.

Also, an inventory of the existing buildings in the area under study was made, surveying at the same time all the characteristics necessary to evaluate their vulnerability. The results show that 63% of the total constructions are earthquake resistant, whilst the non-earthquake resistant ones amount to 37%. The probable human and material losses for each district in every county were obtained.

Finally, an analysis was made of the distribution of the Gran Mendoza health care system which shows an inadequate concentration of hospitals and health care centres for the expected damage distribution and consequently for the victims that a destructive earthquake would cause.

Based on this critical situation, the locations of schools and sports facilities was analyzed, which would serve as alternative centres to provide a solution to the above mentioned situation.

## Location of the Study Area

The province of Mendoza is located between 32°S and 37.5 °S latitude and 66.5 °W and 70.5 °W longitude. It covers an area of 150,000 km$^2$ distributed in 18 counties. Its population is 1,400,000, which represents a population density of 9.3 inhabitants per square kilometre. Fifty percent of the population lives in an urban centre called Gran Mendoza which covers the whole or part of the Capital, Godoy Cruz, Guaymallén, Las Heras, Luján and Maipú counties (Figure 1).

In spite of the desertic conditions of the area, the fact that the water resources are abundant in it and the soils fertile, made possible the development of a large human settlement forming an irrigation oasis, which involves two basic uses: urban and rural. Every expansion of the city implied that the agricultural land was converted into urban use. The competition between both uses constitutes a relationship which rules the development of the oasis.

## Land Use and Future Development Trends

Gran Mendoza is located in an area morphologically characterized by the following elements: (1) mountain chains in the western part, which are the first Andean spurs, (2) an extensive alluvial plain, with a uniform slope predominantly directed to the northeast, and (3) the Mendoza river, to the south of the area under study, which traverses the middle portion of its basin. This river, which is the main water source of the territory, owes its origin to the melting of the snow in the mountains.

*First structure of urban land use in Gran Mendoza (1561-1861)*

Analyzing the development of the Gran Mendoza structures of land use between 1561 (when Mendoza was founded) up to now, a very important event stands out, that is the March 20, 1861 earthquake. That is the reason why this period (1561-1861) is considered as the original structure of land use in this area.

During the pre-Hispanic period the region was populated by the Huarpe Indians, who had a settlement of considerable importance next to what is now called Zanjón Guaymallén which is a branch of the Mendoza river, which was turned into a real fluvial channel by erosion.

This first structure of urban land use is characterized by a spatial pattern dispersed around spots of different importance, all of which were subordinate to the Capital (Figure 2).

The 1861 earthquake was a catastrophic event in the life of the city, since it caused total destruction and, consequently, the disruption of its first structure of land use.

*The March 20, 1861, earthquake*

This earthquake occurred at 11:00 p.m. Its epicentre was approximately located at 33.1°S and 68.9 °W, at a depth of 10 km, with an estimated magnitude, $M_s$=7.0.

This earthquake stands out from the rest because it remains the most destructive one in Argentina, destroying the city of Mendoza and killing 6,000 people out of a population of 18,000. From the analysis of the historic documentation, it can be concluded that the epicentre was very close to the populated zone, considering the earthquake started abruptly and almost without any interruption, the strong phase arrived and "the city was destroyed in just two seconds". There were many aftershocks, 19 of them occurring on the day after.

*Second structure of urban land use in Gran Mendoza (1861-1950)*

As a consequence of the earthquake, a new city was planned adjacent to the destroyed one, over terrains of the San Nicolás farm. This new city, located out of the first period urban zone, created a new growing centre west of the first one (Figure 3).

During this time, the infrastructure of urban services, such as potable water, electricity, sewage system, gas and telephone lines were installed as important parts of the new urban system, which already was showing the characteristics of a new modern city.

This period is characterized by a great increase in population and changes in the original structure due to the influence of the 1861 earthquake and to the construction of the railway.

The European immigration, on the other hand, determined a large increase in the extension of the cultivated land and a diversification in the activities of the population.

The structural configuration of the urban land during the period 1861-1950 was characterized by an expansion of the residential use in the area between the irrigation canals, from the Zanjón Guaymallén to the east to the Civit canal to the west. The greatest population concentration took place near the capital of the province, so that the integration between Godoy Cruz and the Capital city reached such a degree that both towns made up a single urban area by the end of this period. Even nowadays, the irrigation canals continue to be important structural elements, since they act as boundaries of stripes with different features.

*Destructive Earthquakes in Gran Mendoza between 1862 and 1950*

After the great 1861 earthquake, Gran Mendoza was shaken by many other earthquakes none of them as severe as the first one.

- The August 19, 1880, earthquake, was the first earthquake after 1861 that damaged some buildings in the city and surroundings and some walls and cornices collapsed; the intensity estimated was from VI to VII on the Modified Mercalli (MM) scale.

- The October 27, 1894, earthquake, whose epicentre was located north of the province of San Juan caused severe damage at several places, affecting also Gran Mendoza, mainly Las Heras county where the intensity reached VI on the MM scale.

- The August 12, 1903, earthquake, with epicentre located at 32.1°S and 69.1°W, $M_s$=6.0 and VII MM maximum intensity in the Capital and Las Heras.

- The July 27, 1917, earthquake, with epicentre located at 32.3 °S and 68.9 °W, $M_s$=6.5 and VII MM maximum intensity in the Capital and Las Heras. Many aftershocks were felt after this earthquake lasting about a month.

- The December 17, 1920, earthquake, with epicentre at 32.7 °S and 68.4 °W, $M_s$=6.0. The maximum intensity (VIII MM ) was reported in Lavalle, northeast of the city of Mendoza where the intensity was VI MM. Extensive liquefaction was reported in the epicentral area.

- The April 14, 1927, earthquake, with epicentre at 32.5 °S and 69.5 °W, at a depth of 110 km and $M_s$=7.1. The maximum intensity was VII MM in the Capital and Las Heras.

- The January 15, 1944, earthquake, with epicentre at 31.5 °S and 68.5 °W, $M_s$=7.4. This was the most destructive earthquake in this century, affecting the San Juan province where most of the buildings collapsed, and 5,000 to 10,000 were killed. In Gran Mendoza the maximum intensity was VI MM in Las Heras.

*Third structure of urban land use in Gran Mendoza (1950-1992)*

The formation of the Gran Mendoza urban area, which started between the expanding Capital and the nearby urban centres such as Las Heras, Godoy Cruz and Guaymallén, was consolidated during this period, which caused the disappearance of the structure of land use previously explained and its replacement by a new one (Figure 4).

The main reasons for these changes were: the construction of freeways, the massive construction of houses grouped into districts, the land subdivision law, the building codes, etc. The new mechanism of land settlement for urban use was based upon the acquisition of

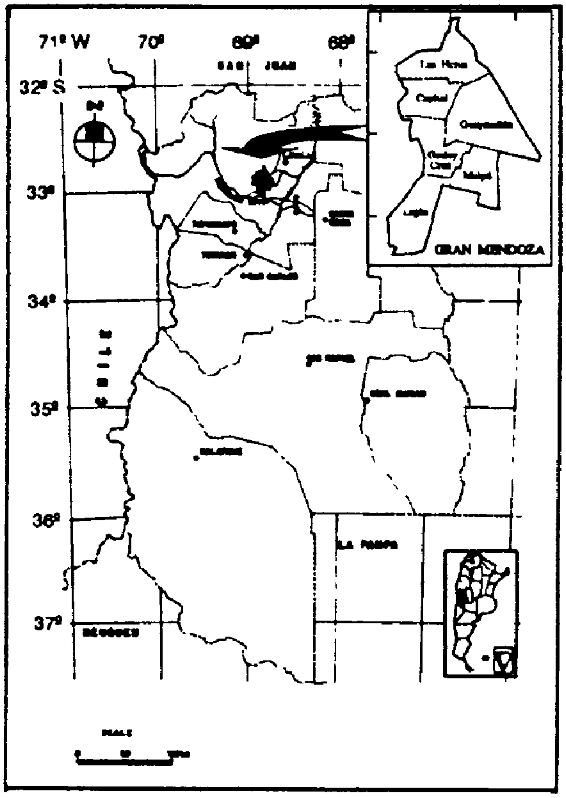



Figure 1: Location of the studied area in Mendoza province

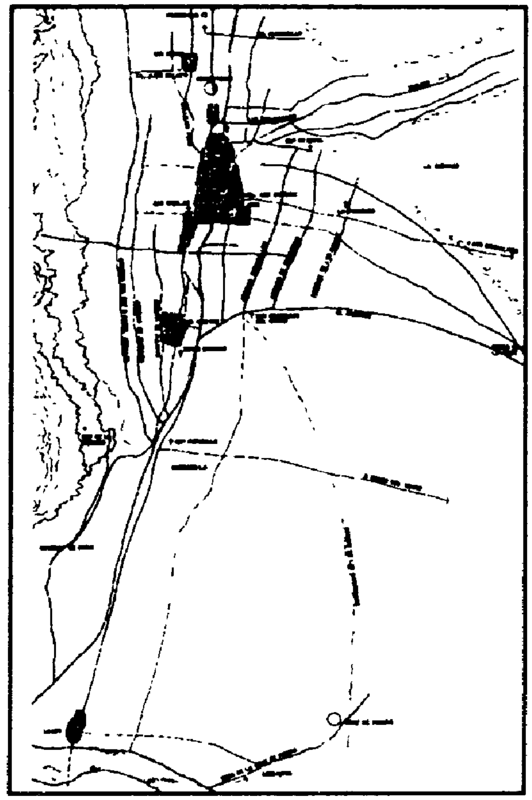


Figure 2: First Structure of urban land use in Gran Mendoza

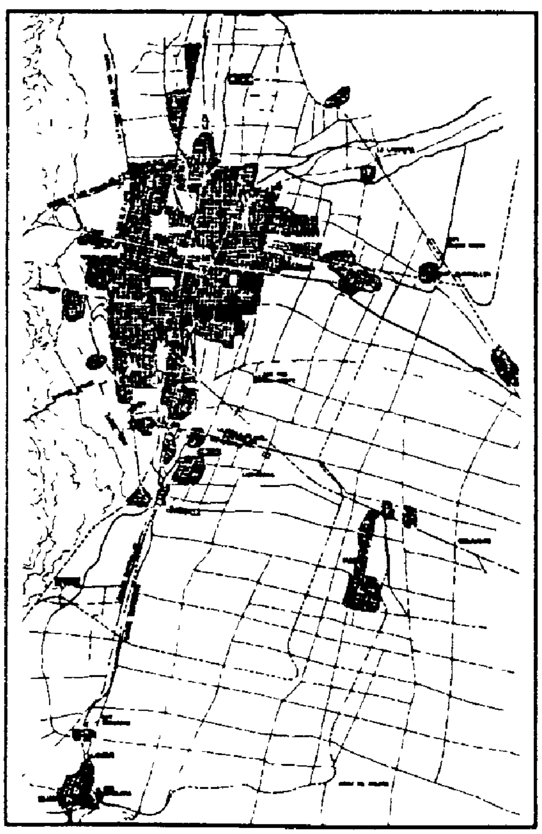


Figure 3: Second Structure of urban land use in Gran Mendoza

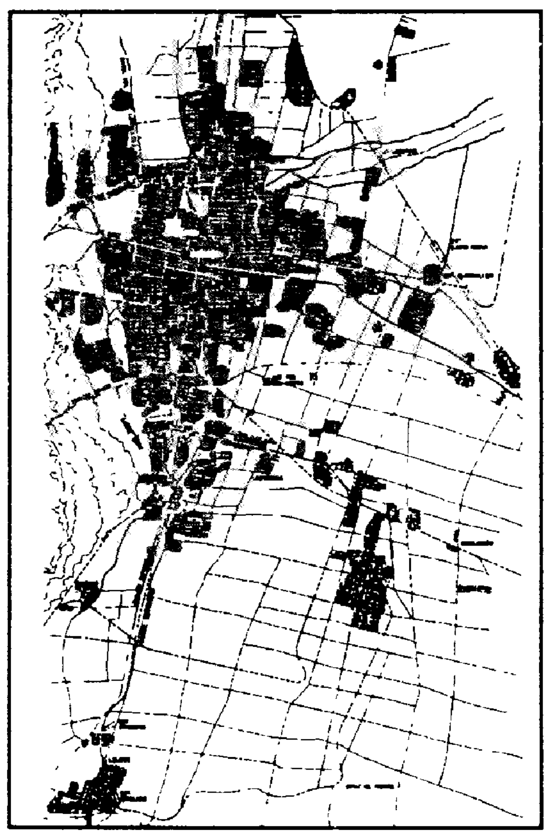


Figure 4: Third Structure of urban land use in Gran Mendoza

cheap land, originally devoted to agriculture, which was transformed into urban districts built as a unit with government financing. The repetition of this process in all the perimeter of the Gran Mendoza produced a real explosion of its margins, together with an accelerated competition between the urban and rural land use, as a result of which the latter became displaced and degraded.

Parallel to this process a notable multiplication of shanty towns took place in the piedmont area, as a conequence of the displacement of inhabitants from the rural zone and also due to a severe socio-economic crisis during the last decade.

Due to the lack of facilíties in the new districts, the demands of the marginal inhabitants and to the easy access to the capital of the province by the new turnpikes, a phenomenon of overburden was produced in the Capital on the demand of the functions and equipment centralized there, viz commercial, educational, entertainment, sanitary, etc. and this also produced permanent traffic jams during rush hours.

This urban evolution, which started from different origins, has led to the formation of a single city, where the different expanding centres evolved and were welded with one another until they were united in one total urban conglomeration.

All these aspects are of great importance for any emergency planning in case a destructive earthquake occurs.

*Destructive earthquakes in Gran Mendoza since 1950*

The April 25, 1967, earthquake, with epicentre at 32.7 °S and 69.2 °W , at a depth of 35 km had a magnitude of $m_b$=5.4. It caused moderate damage in the city of Mendoza where the intensity was VI MM.

The November 23, 1977, earthquake, with epicentre at 31.04 °S and 67.8 °W at a depth of 13 km had a magnitude of $M_s$=7.4. This earthquake damaged important counties east of the province of San Juan, especially Caucete where the intensity reported was IX MM. It caused around 70 deaths and 300 injuries. Gran Mendoza, located 150 km from the epicentre, suffered some damage especially in the northern part of the city where the intensity reported was VI MM.

The January 26, 1985, earthquake ($m_b$=6.0), had an epicentre located very close to the city of Mendoza, in the same area as the 1861 event. It caused only three deaths and few injuries, but produced extensive damage to the adobe construction. The distribution of the damage was not uniform. Gran Mendoza reached an average intensity of VII MM although there were small zones with greater values (MM= VIII).

For this earthquake, a detailed investigation was done using different sources: field observations, other reports of this event and government files (Castano et al., 1992). More than 36,000 inspection certificates were examined. These certificates were classified by district in every county, and thereafter by degree and type of damage, in order to determine damage indices for each zone. The damage index (DI) was defined as follows:

$$DI = \frac{\text{N}^{\text{o}}\text{. of adobe constructions totally or seriously damaged}}{\text{Total number of adobe construction}}$$

There is agreement between the intensity values obtained after quick observations made immediately after the earthquake and the damage indices determined by a detailed analysis of the damage surveyed case by case.

## Seismic Hazard Analysis

*Local and regional seismogenic sources*

There are two sets of seismic sources in the region under study: a) surface faulting, and b) the Benioff zone seismicity.

The shallow crustal sources consist of fifteen identified active faults in the region as well as a regional background source of smaller magnitude seismicity. Figure 5 shows the seismogenic sources which are closer to Gran Mendoza.

For each fault the maximum magnitude and its return period were estimated on the basis of field data which included the analysis of excavated trenches (INPRES, 1989).

*Gran Mendoza subsurface soil conditions*

Two distinct geologic units are present in this area: the coarse alluvial fan deposits of the Mendoza river and the finer sediments of the alluvial plain, to the north and north-east of the area, separated by a transition zone (Zamarbide et al., 1993).

The thickness of the silty materials overlying the Mendoza river alluvium is rather small, being generally of the order of 1 to 3 metres in the south of the study area. The thickness increases to the central and northern zones reaching between 5 and 20 metres in the transition zone, and between 20 and 70 metres in the alluvial plain.

The free ground water table is quite deep in most of this area, varying between 35 metres and more than 100 metres.

*Seismic hazard estimation*

A seismic exposure analysis was made and hazard maps for the area under study were obtained considering the potential seismic sources, the attenuation relationships and the local site conditions. The results are presented in terms of a contour map of mean peak ground acceleration corresponding to 10 percent probability of exceedance in 50 years.

Based on the results of the geological investigation, historical seismicity, the seismic hazard analysis for the probability of exceedance adopted, and on the estimated behaviour of the existing constructions in the area, the following amplitude ranges (in terms of peak accelerations) were adopted as the most adequate ones for representing the ground motion severity:

Range 1: less than 30% g
Range 2: from 30% to 35% g
Range 3: from 35% to 40% g
Range 4: more than 40% g

Figure 6 shows the seismic hazard distribution resulting from a combination of seismic sources, attenuation relations and different types of soil conditions.

## Vulnerability of the existing constructions

As part of the seismic microzonation study of Gran Mendoza (INPRES, 1989), a survey of the existing construction was performed to evaluate their vulnerability. Two distinct types of construction were defined:

1) Construction erected with earthquake resistant provisions: Most of them are one and two storey buildings, designed and built using masonry bearing walls as horizontal load resistant planes.

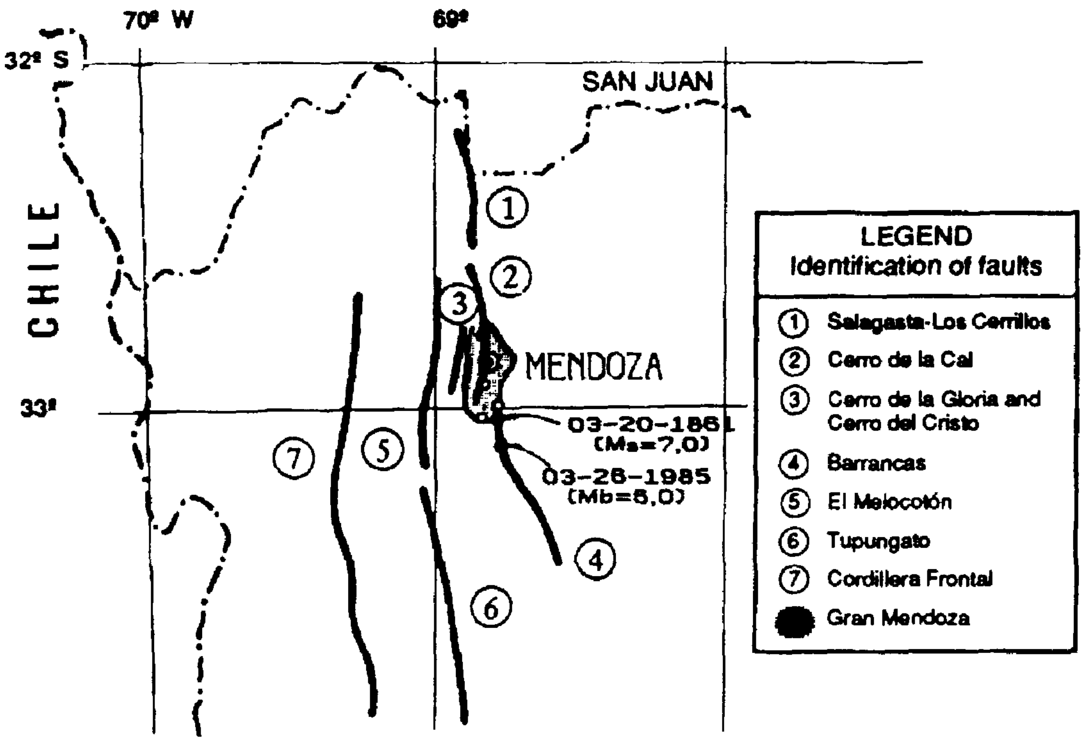



Figure 5: Active faults distribution and location of earthquakes in the studied region .

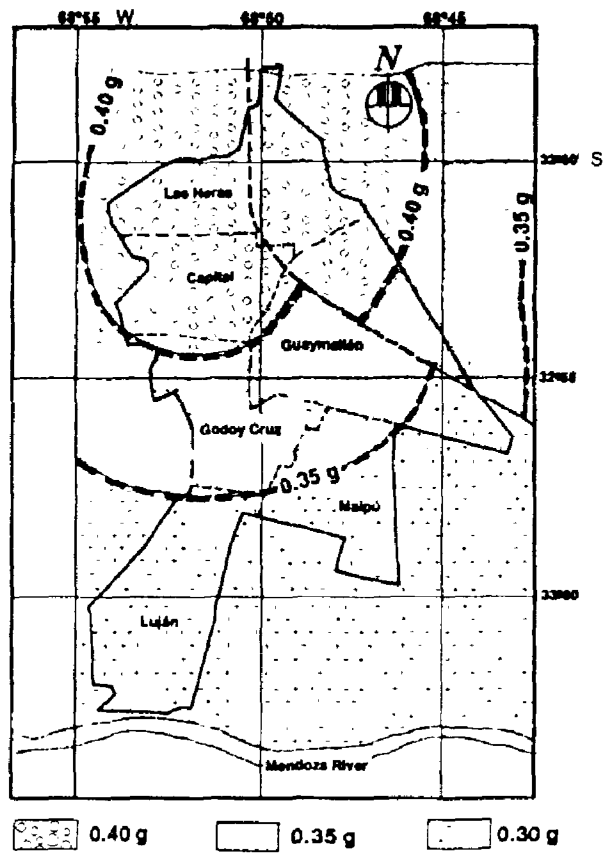



Figure 6: Ground motion characterization.

2) Construction without earthquake resistant provisions: The adobe construction make up the greater part of this type of buildings. A significant number of construction is of the mixed type with some walls built of adobe and other walls of solid bricks. These are one storey buildings, in which the facades have been built of solid bricks and the remaining walls of adobe.

   Unreinforced masonry was also included in this category, which is abundant in the zone under study.

The results show that 63% of a total of 132,000 buildings, are earthquake resistant, whilst the non-earthquake resistant ones amount to 37%.

## Damage potential evaluation and human loss estimation

The damage potential in this area was evaluated as an addition to the seismic microzonation study of Gran Mendoza. The results from the seismic hazard estimation were taken into account combined with those obtained from the determination of the vulnerability of the existing construction. The purpose of this evaluation was to provide necessary elements for emergency plans for disaster prevention. For this reason damage was associated with the total building collapse and/or partial collapse of structural elements. The damage was quantified by means of the damage index defined above, establishing a direct relationship between peak ground acceleration and the damage index on the basis of historical earthquakes, which resulted in a damage matrix as follows:

Ground Motion Range vs Percentage of Damaged Construction

| Type of construction | Ground motion range | | | |
|---|---|---|---|---|
| | Range 1 | Range 2 | Range 3 | Range 4 |
| Type I Non earthquake resistant | 30% | 45% | 55% | 70% |
| Type II: Earthquake resistant | 0 | 0 | 2% | 5% |

The following classification was adopted as regards the characterization of damage potential (Figure 7), in terms of total or partial collapse:

a) Low damage (LD): 0 to 5%

b) Moderate damage (MD):from 5% to 25%

c) Important damage (ID): from 25% to 50%

d) High damage (HD): from 50% to 75%

e) Very high damage (VHD): from 75% to 100%

A human loss ratio was defined as the mean percentage value of probable human casualties referred to the total number of inhabitants. To evaluate this ratio, previous destructive earthquakes in Argentina were considered, and also the fact that causative faults are around or within the populated area of Gran Mendoza.

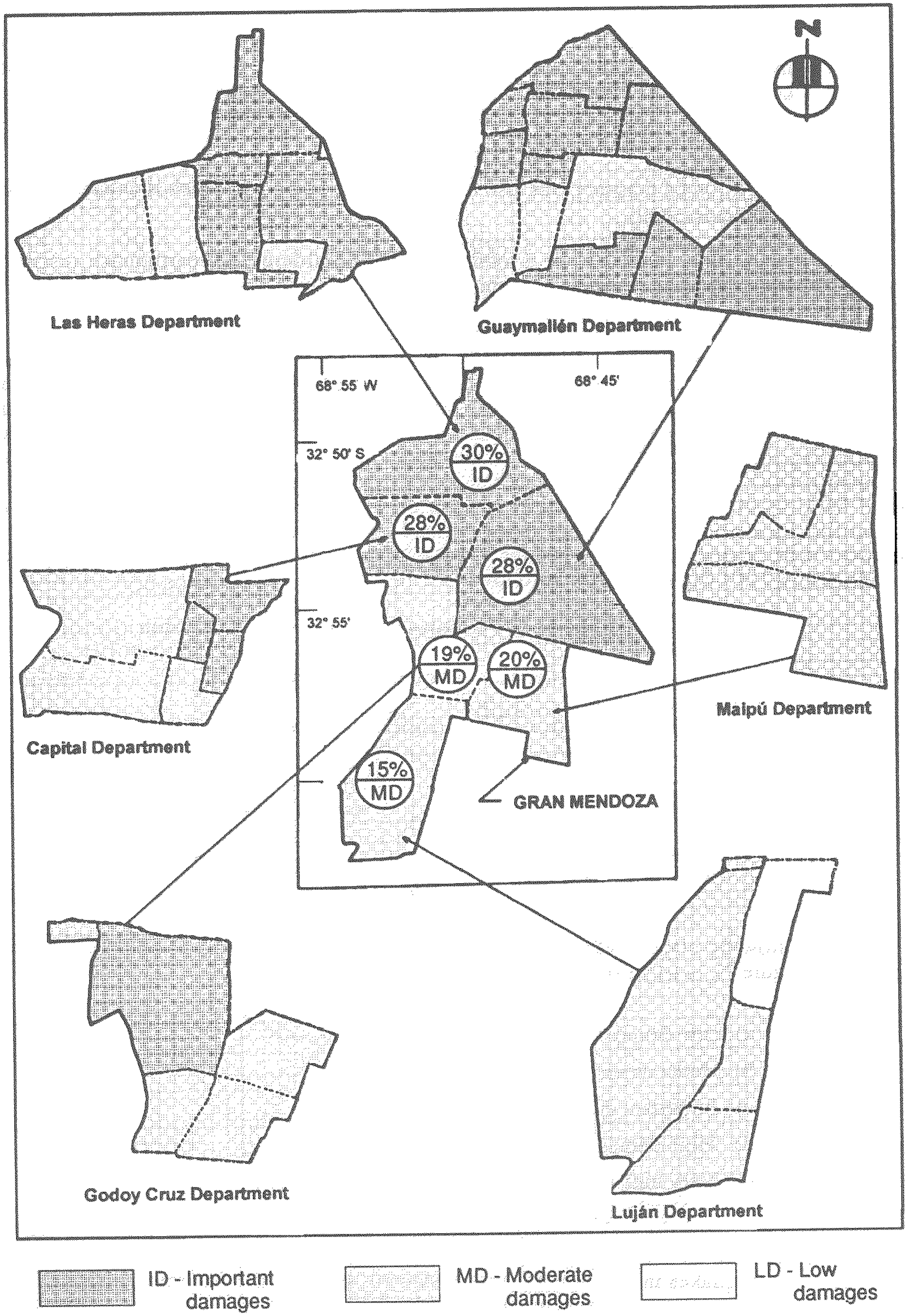



Figure 7: Gran Mendoza. Damage potential.

Each district of every county was analyzed considering: the probable range of the ground motion to which it would be subjected, the vulnerability of the existing construction and thedamage matrix, all to estimate the probable total number of human and material casualties. The results are shown in Figure 8.

An estimation of the amount of debris to be removed was also made. Adopting an average construction of 60 $m^2$ and considering 1/3 of it will collapse, about 1,000,000 tons of debris would have to be removed after the earthquake. The accumulation of this material will be directly related to the damage distribution and will constitute a severe difficulty for traffic movement.

## Gran Mendoza Health Care system: Its distribution and accessibility

As mentioned before, "an excessive demand occurred on the Capital". This, in particular, has led to a health care system which is inadequately distributed with respect to the Gran Mendoza population distribution. This can be observed in Figure 9 which shows the total amount of public and private hospitals and the number of beds. In the figure, it can be noticed that there is a strong concentration of these kinds of facilities in the central part of the area under study. On the other hand, three out of five of the biggest hospitals (more than 200 beds) are located west of the capital. In the case of the occurrence of a destructive earthquake causing the damage and casualties estimated and summarized in Figures 7 and 8, this inadequate distribution of health care buildings will make it very difficult for the emergency planning and operation to materialize, considering also that highways would be blocked by debris as was mentioned before.

## Emergency alternative centres

### *Schools*

In Figure 10, the distribution of schools in the Gran Mendoza area is shown. Although there are schools distributed in the whole area, once again a strong concentration of them in the central part can be noticed. All of the buildings will serve as alternatives in case of an emergency, but special attention has to be paid to some districts situated north and east of Guaymallén and Las Heras where, as shown in Figure 7, the most important damages will occur and there is an evident lack of school buildings.

### *Sports facilities and open-door spaces.*

Stadia, parks and other open-door spaces add another element to be considered in every emergency planning, as after the occurrence of a destructive earthquake they can also be used to install emergency housing and hospitals and food distribution centres (Figure 9).

## Conclusions

From the above mentioned, it can be concluded that the Gran Mendoza health care system does not match the population distribution and the damage and casualty distributions that would happen in the case of the occurrence of a destructive earthquake. This fact will have to be taken into account in any future developmental planning.

Also, the results obtained constitute guidelines that should have to be considered by the Mendoza authorities for an emergency planning project for the area. To this end, it would be necessary to add, on a second stage, other elements which have to do with seismic vulnerability such as: police and fire-station buildings, communication centres, life-lines, etc.

### *Acknowledgements*

The authors want to thank Mr Mario Romero, Mr. Hugo Pontoriero and Mr. Oscar Escudero for the drawings and typing of the manuscript.

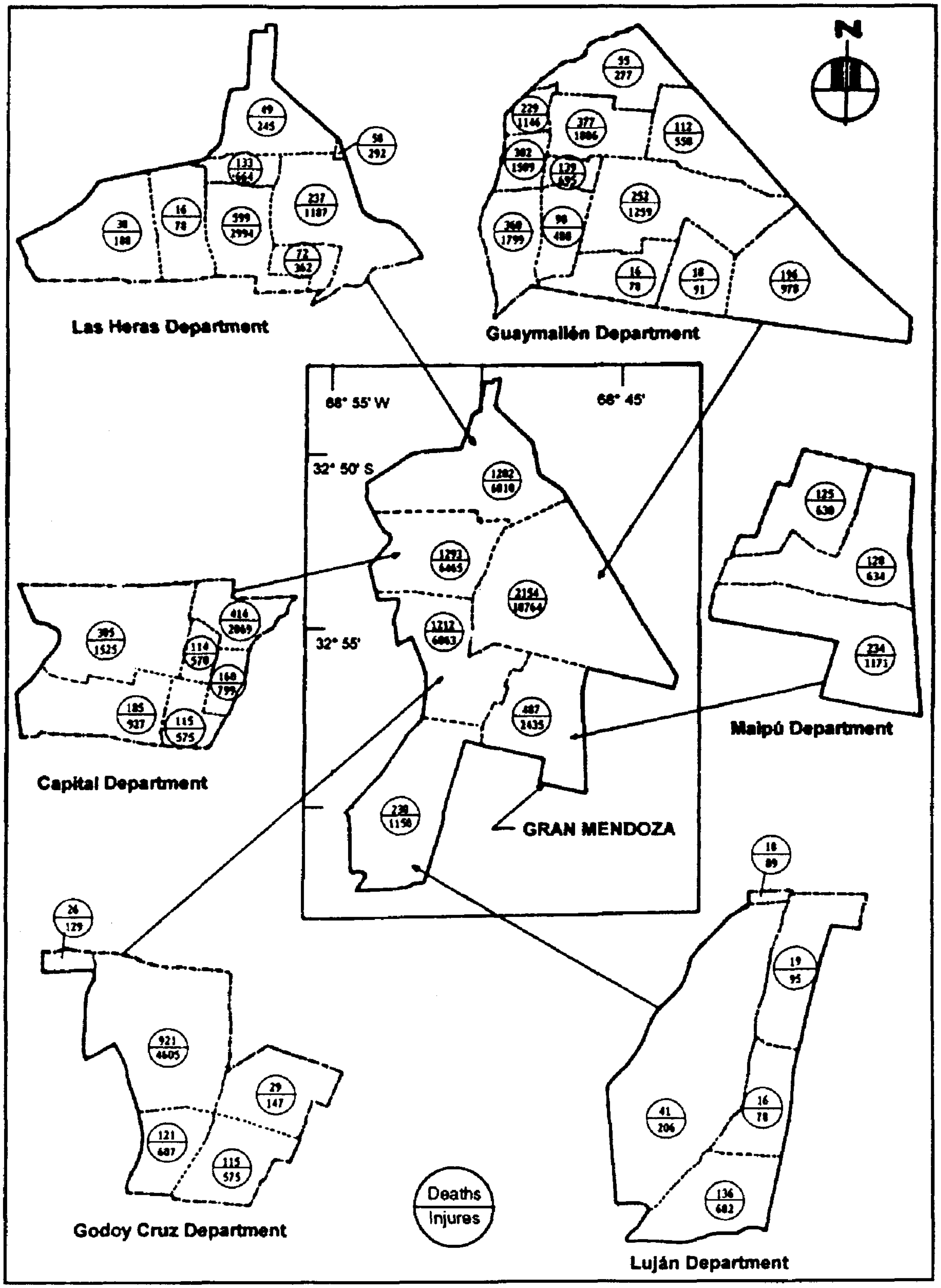
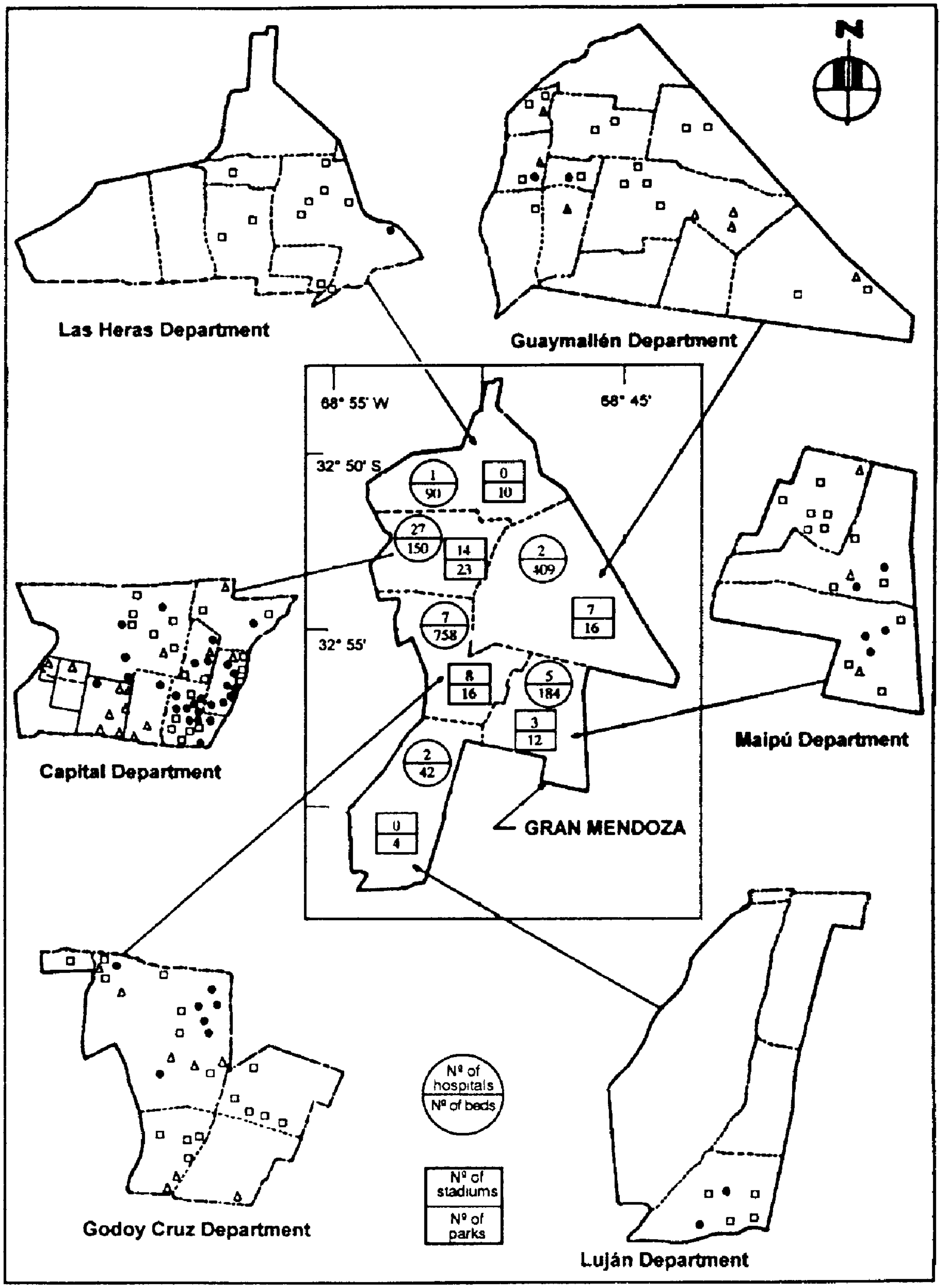



Figure 8: Probable human losses.




● Hospitals □ Parks △ Stadiums

Figure 9: Gran Mendoza health care system distribution. Sports facilities and open-door spaces.

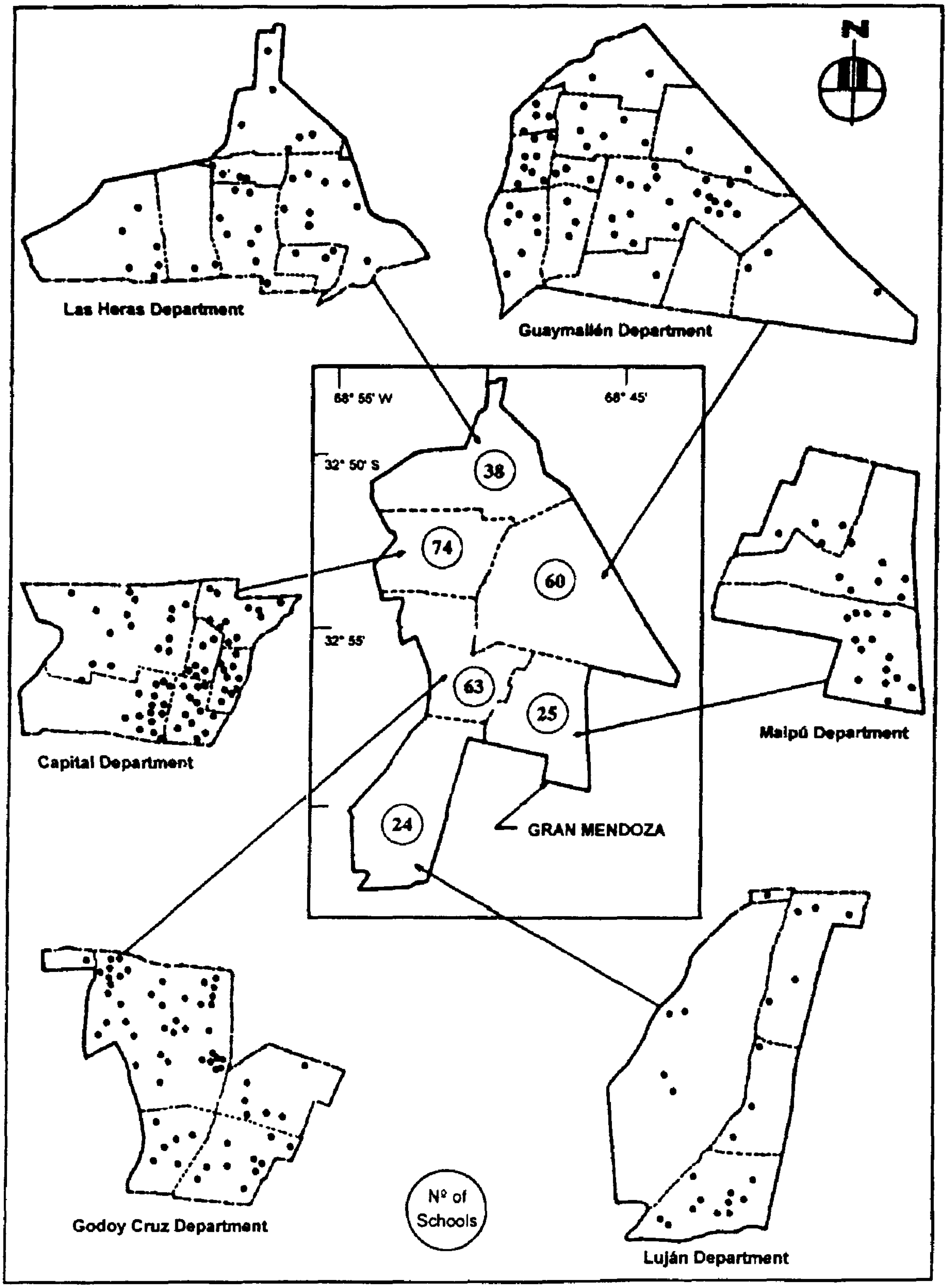



Figure 10: School distribution..

## References

Castano, J.C and Zamarbide, J.L. (1992). A seismic risk reduction programme for Mendoza City, Argentina. Proc. of the Tenth World Conference on Earthquake Engineering, Madrid, Spain, pp. 5953-5958.

INPRES (1989). Seismic microzonation of Gran Mendoza, Argentina. Instituto Nacional de Prevención Sísmica, San Juan, Argentina.

Zamarbide, J.L. and Castano, J.C. (1993). Analysis of the January 26th, 1985, Mendoza (Argentina) earthquake effects and of their possible correlation with the recorded accelerograms and soil conditions. Tectonophysics, 218: 221-235.