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DETERMINING THE PARAMETERS OF EARTHQUAKE SOURCES IN SOUTH AMERICA FROM MACROSEISMIC INTENSITY DATA (CERESIS DATABASE)

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ABSTRACT

In the past decades many different procedures have been made to handle the historical data for the determination of the earthquake source parameters. This has been only possible dealing with historical data interpreted and compiled as Intensity Data Points (IDP).
One of the most interesting tools is the *Boxer* algorithm, a parameterisation method that computes the parameters of the earthquake source in terms of latitude and longitude of the epicentre, magnitude of the event, length, width and azimuth of the *box*, which represent the surface projection of the sismogenic source. Applying the Boxer algorithm we have used intensity data points available from the CERESIS database (earthquakes with $I_0 \geq 8$MM) to obtain a preliminary idea of the possible sources of some historical earthquakes of the South-American region. At a first approach to the South-American historical seismicity we generally can affirm that our results agree fairly well with seismological data and geological background as reported in literature.

Key words: Earthquake source parameters, intensity data points, parameterization techniques, South America.

RESUMEN

En pasadas décadas han sido desarrolladas diferentes metodologías para determinar parámetros de fuentes de terremotos a partir de datos macrosísmicos. Esto ha sido posible usando los datos históricos interpretados y compilados como Datos Puntuales de Intensidad.
Una de las más interesantes herramientas es el algoritmo *Boxer*, un método que calcula parámetros de la fuente del terremoto en relación con la latitud y longitud del epicentro, magnitud del evento, longitud, ancho y azimut del «rectángulo» que representa la proyección en superficie de la fuente sismogenética. Datos de intensidad con $I_0 \geq 8$MM, disponibles en la base de datos del CERESIS, han sido usados para obtener una idea preliminar de las posibles fuentes de algunos terremotos en Suramérica. En esta primera aproximación para la sismisidad histórica suramericana, los resultados obtenidos son discretamente acordes con datos sismológicos y geológicos encontrados en la literatura.

***Palabras clave*:** Parámetros de fuentes de terremotos, puntos de intensidad, técnicas de parametrización, Suramérica

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INTRODUCTION

Macro seismic data are frequently used for parameterisation of the sismogenic sources and evaluation of seismic hazard. Consequently, several seismological institutions have formalised their historical data into homogeneous macroseismic databases and have developed online databases to increase the dissemination of data through the web (Rubbia, 2004).

The increased availability of historical data interpreted in terms of IDP has stimulated seismologists to develop standard and repeatable procedures to determine earthquake source parameters, in order to lower the level of subjectivity they are usually determined upon. The Boxer program (Gasperini et al., 1999) is an example of these new procedures. The algorithm computes the parameters of the earthquake source from IDP; it provides the seismological parameters (latitude and longitude of the epicentre, moment magnitude) and a geometric model of the source through a *box* that represents the surface projection of the modelled sismogenic source. The program represents each source as the surface projection of a fault dipping 45° towards a perpendicular direction to the fault strike (Gasperini et al., 1999); the original version is designed only for dip-slip faults and initially calibrated for Apennines earthquakes (in most cases shallow events). The projection width constrains the fault at depth.

The procedure was largely tested in Italy (Valensise and Pantosti, 2001; Mirto et al. 2001) and Europe, in the frame of the EC project FAUST (Faults as a Seismologist's Tool, http://faust.ingv.it), whose goal was to determine the source parameters (Leschiutta and Mirto, 2000; Stucchi et al., 2000) of some European earthquakes using the European Mediterranean Intensity Database (EMID).

In this paper we applied the Boxer program to some earthquakes of the South-American region, using the data provided by CERESIS database available through http://www.ceresis.org. We are perfectly aware that in South America earthquakes are chiefly deep, crustal or due to subduction processes, and the structures are often strike-slip faults. Nonetheless, we applied the Boxer method to some large earthquakes (above the threshold of Io ≥ 8) trying to respect the applicability limit of Boxer to dip-slip faults and without considering that the attenuation of earthquake intensity in the algorithm is assessed for the Italian territory. As such, our results represent a very preliminary attempt of determining source parameters for some large South American earthquakes.

THE CERESIS DATABASE: CHARACTERISTICS AND APPLICABILITY

The CERESIS database is the main source of Intensity Data Points (IDP) for South America, it contains 16,318 IDP (Fig. 1a) related to 3,183 events (Fig. 1b) that occurred from 1471 to 1985 in eight South American countries and one Caribbean country (Table. 1).

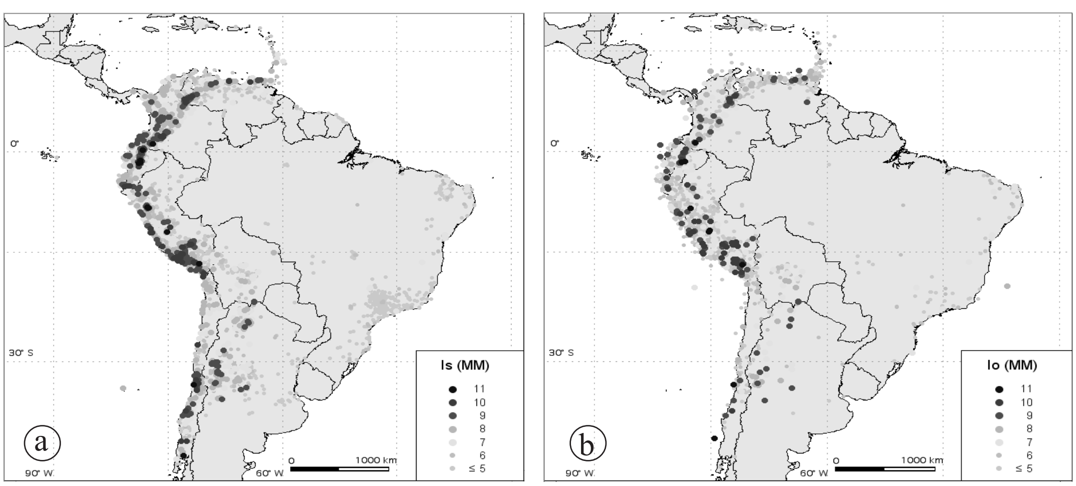

Figure. 1. a) IDP distribution from the CERESIS database. *b)* Epicentre distribution from the CERESIS database.

Table 1. TIME-WINDOWS, NUMBER OF EARTHQUAKES AND RELATED IDP IN THE CERESIS DATABASE

Country	Time-Window	Nº of Earthquakes	Nº of IDP
Argentina	1692 - 1985	45	703
Bolivia	1650 - 1981	45	208
Brazil	1767 -1981	114	431
Chile	1730 - 1977	61	816
Colombia	1566 - 1981	188	2097
Ecuador	1541- 1980	153	1416
Perú	1471 – 1981	2023	8354
Trinidad & Tobago	1825 – 1981	23	78
Venezuela	1530 - 1981	531	2215
Total		3183	16318

Table 2. EXAMPLE OF CERESIS DATABASE FORMAT. EXAMPLES OF DUPLICATE RECORD, AS FOR DIFFERENT "INTERPRETER" (I.E. CALLAO: DH OR UTLO) OR UNCERTAINTIES IN THE INTENSITY ASSIGNMENT (I.E. CALLAO I=8/9), ARE REPORTED

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Cou Code    Ye   Mo Da Ho Mi Se  ILat    ILon    MLat    MLon       Dph      Ms     Io           Ne
HYP PE  120 1586 07 10 00:30:00                  -12.300 -77.700    60              10M          12
 PE LIMA                                          -12.10 - 77.00  100   76         81  8K DH   421
 PE CALLAO                                        -12.05 - 77.15   32   62         74  8K DH   421
 PE CALLAO                                        -12.04  -77.09   20   10   41  319  8K UTLO 411
 PE CALLAO                                        -12.04  -77.09   20   10   41  319  9K UTLO 411
 PE CARAVELI                                      -15.77  -73.36 1779  567  568  136  3K UTLO 411
 PE CUZCO                                         -13.52  -71.97 3326  571  573  106  3K UTLO 411
 PE HUANUCO                                        -9.92  -76.23 1894  257  261   20  3K UTLO 411
 PE ICA                                           -14.07  -75.72  439  259  262  147  5K UTLO 411
 PE ICA                                           -14.07  -75.72  439  259  262  147  6K UTLO 411
 PE LIMA                                          -12.05  -77.05   32    7   41  333  9K UTLO 411
 PE LIMA                                          -12.05  -77.05   32    7   41  333  8K UTLO 411
 PE TRUJILLO                                       -8.10  -79.03   51  495  496  333  3K UTLO 411

Cou Code    Ye   Mo Da Ho Mi Se  ILat    ILon    MLat    MLon       Dph      Ms     Io           Ne
HYP PE19795 1960 11 20 22:01:56  -6.800  -81.000                    55      6.8Ms   6M            2
 PE PIURA                                          -5.20  -80.62   35   54   81   35  6K UTLO 411
 PE PIURA                                          -5.20  -80.62   35   54   81   35  5K UTLO 411
```

The format of the CERESIS database includes two types of record as shown in Table 2. For each event, the first line provides the earthquake parameters (i.e., epicentral co-ordinates, epicentral or maximum intensity, magnitude, and depth, number of related IDP - although this is not always reported); in the following lines, the IDP related to the earthquake is listed.

All intensities are given in either MM (Modified Mercalli) or MSK (Medvedev-Sponheuer-Karnik) macroseismic scales. The investigator who assigned the intensity value is identified as "interpreter" ("DH" or "UTLO" in Table 2). A more detailed description of the catalogue format is given in vol. 1 of CERESIS (1985), including the list of the "interpreters" and the references they used. The database contains some cases of duplicate records for the same events and/or localities. This is either due to different interpreter/source or to uncertainties in the intensity assessment. For instance, if the "interpreter" assess an I=7/8 for a given locality, two records are present in the database, one with I=7 and another with I=8.

With the aim of determining source parameters using the Macroseismic data provided by CERESIS database we focused on large events. As a first input 201 earthquakes above the threshold of Io ≥ 8, are considered in this study. Figure 2 shows the distribution of earthquakes and number of IDP for 50-year time windows, for the 201 selected earthquakes.

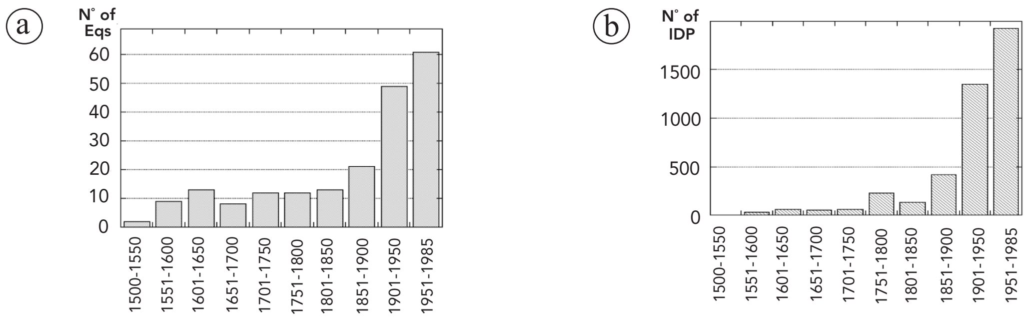

Figure 2 a) Number of earthquakes per 50-year time-windows. *b)*. Number of IDP per 50-year time-windows.

Table 3. NUMBER OF RECORDS IN THE CERESIS DATABASE FOR EARTHQUAKES WITH $I_0 \geq 8$

	CERESIS data base Io ≥ 8			This study Io ≥ 8
Country	Time-Window	N° of Earthquakes	N° of IDP	N° of IDP used
Argentina	1692 - 1985	17	483	480
Bolivia	1650 - 1947	6	30	30
Brazil	1955	1	10	10
Chile	1730 - 1976	13	382	330
Colombia	1644 -1981	43	1287	921
Ecuador	1541- 1980	29	912	871
Perú	1471 - 1974	63	1775	990
Trinidad & Tobago	1825	1	14	14
Venezuela	1530 - 1975	28	622	599
Total		201	5515	4245

Table 4. RECORDS FROM 201 EVENTS WITH $I_O \geq 8$.

Criteria	N° of earthquakes eliminated
Number of IDP <10	89
Focal Depth 30 >km	45
Off shore events	18
Subduction events	11
Incoherent IDP distribution	1
Total events eliminated	164

In some of the studied cases, the CERESIS database contains for an individual earthquake duplicated intensity values assessed at the same place. Since the *Boxer* program accepts one intensity value only for each place, an "a-priori" choice has been made. Both in case of different interpreters and of uncertain intensity, the highest intensity value has been adopted. The number of IDP in the CERESIS database for the 201 events with Io ≥ 8 is 5515, while those used in this study are 4245 only (Table 3). Out of the 201 events above the threshold (Io ≥ 8) a more detailed selection was carried out considering the characteristics of the *Boxer* program (Table 4). Therefore only events with an appropriate number of IDP (n° ≥ 10) have been considered; all the earthquakes with a focal depth ≥ 30 km have been disregarded as well as the offshore and subduction events. The identification of the subduction events was supported by the available literature. Dorbath et al. (1990) assessed the size of large and great historical earthquakes in zones along the trench in Peru. These zones correspond roughly to segmentation defined by the geometry of the subduction zone. Other authors, such as Lomnitz (1970), Kelleher (1972), Pennington (1981), Kanamori and McNally (1982), Nishenko (1985), Comte and Pardo (1991), Monge (1993), Tavera and Buforn (1998), Tavera (2002) and Carpio and Tavera (2002) listed the major earthquakes along South

American subduction zone. They are the 1746, 1868, 1912, 1913, 1970 earthquakes in Peru and the 1730,1751,1822,1868, 1877, 1928, 1966 earthquakes in Chile. These events are not considered by this study. Adopting the above described criteria only 37 events have been processed with the method proposed by Gasperini et al. (1999). In Figure 3, *boxes* representing the source dimension, size and location obtained from macroseismic data are shown.

Table 5 gives the CERESIS parameters, the parameters computed by *Boxer* and a comparison between them. In general, the moment magnitude calculated by *Boxer* program is smaller than the magnitude Ms reported by CERESIS.

Table 5. PARAMETERS FOR THE 37 INVESTIGATED EARTHQUAKES IN SOUTH AMERICA.
ΔEPIC. IS THE DISTANCE BETWEEN EPICENTRE GIVEN BY CERESIS AND EPICENTRE COMPUTED BY BOXER PROGRAM

ID Box	CERESIS (1985)						This Study								
							Parameters computed by Boxer program						Comparison of parameters obtained by Boxer program with CERESIS data		
	Date	Country	__	Sc	Depth (km)	Ms	Nº IDP Used	__	Mw	Fault Length (Km)	Fault Width (Km)	Fault Azimuth	___	Mw-Ms	_Epic (Km)
1	1698-06-20	Ecuador	10	MSK			14	10	6.3	20.3	10.5	009±053	00		30.8
2	1766-10-21	Venezuela	9	MM		6.0	3	8	5.6	7.7	6.2	027±000	-1.0	-0.4	13.1
3	1785-07-12	Colombia	8	MM		6.5	17	8	6.3	20.0	10.5	138±048	0.0	-0.2	37.3
4	1797-02-04	Ecuador	11	MSK			86	11	7.3	70.3	20.7	067±001	0.0		7.3
5	1812-03-26	Venezuela	9	MM	6	6.3	40	9	7.2	62.5	19.4	056±009	0.0	0.9	294.0
6	1834-01-20	Colombia	11	MM		7.0	11	10	6.3	20.3	10.5	034±000	-1.0	-0.7	16.2
7	1859-03-22	Ecuador	8	MSK			20	8	6.2	17.5	9.7	018±029	0.0		14.4
8	1868-08-15	Colombia	8	MSK		7.0	10	10	6.3	18.4	10.0	068±018	0.0	-0.7	34.8
9	1868-08-16	Ecuador	10	MSK			52	10	6.7	32.3	13.5	008±016	0.0		7.4
10	1875-05-18	Colombia	10	MM	20	7.3	30	10	7.0	45.5	16.3	093±016	0.0	-0.3	9.0
11	1878-04-13	Venezuela	8	MM	13	5.9	18	7	5.3	5.2	5.0	096±024	-1.0	-0.6	4.8
12	1894-04-29	Venezuela	9	MM	20	7.1	71	9	6.8	38.9	15.0	060±016	0.0	-0.3	12.0
13	1894-10-27	Argentina	9	MM	30	8.0	44	9	7.1	53.8	17.9	167±011	0.0	-0.9	215.0
14	1913-11-04	Peru	10	MM	20		23	9	6.3	19.7	10.4	106±058	-1.0		4.3
15	1914-12-02	Peru	10	MM	15		18	10	6.3	19.3	10.2	073±217	0.0		16.6
16	1928-04-09	Peru	9	MM	30	6.9	11	7	6.0	12.7	8.2	101±000	-2.0	-0.9	137.8
17	1928-05-14	Peru	10	MM		7.3	16	9	6.9	45.6	16.3	136±143	-1.0	-0.4	91.3
18	1932-03-14	Venezuela	9	MM	25	6.8	58	9	6.8	35.8	14.3	114±048	0.0	0.0	32.3
19	1934-06-11	Argentina	9	MM	30	6.0	13	8	6.1	14.0	8.6	-	-1.0	01	28.8
20	1938-08-10	Ecuador	9	MSK			23	9	5.8	9.5	7.0	090±015	0.0		1.2
21	1942-12-26	Colombia	8	MM		6.5	12	8	6.5	24.9	11.8	056±042	0.0	0.0	86.2
22	1944-01-15	Argentina	9	MM	30	7.4	39	9	6.9	41.6	15.5	076±165	0.0	-0.5	12.6
23	1946-11-10	Peru	11	MM		7.3	34	11	7.3	70.8	20.7	132±016	0.0	0.0	21.1
24	1947-07-14	Colombia	9	MM	10	5.5	59	9	5.9	11.3	7.7	159±115	0.0	0.4	36.4
25	1950-08-03	Venezuela	8	MM	8	6.4	55	8	6.2	15.7	9.2	043±044	0.0	-0.2	34.6
26	1952-06-11	Argentina	8	MM	30	7.0	15	8	6.0	12.2	8.0	177±016	0.0	-1.0	23.9
27	1955-05-11	Ecuador	8	MSK		6.8	22	7	5.4	5.3	5.1	051±021	-1.0	-1.4	35.0
28	1957-04-21	Colombia	8	MM		6.6	18	8	7.0	45.5	16.3	036±037	0.0	0.4	90.3
29	1961-04-08	Ecuador	8	MSK	24		29	8	5.7	7.9	6.3	155±023	0.0		20.2
30	1966-09-04	Colombia	8	MM	8		10	7	5.2	4.1	4.4	121±076	-1.0		19.7
31	1969-10-01	Peru	9	MM			20	7	5.3	4.6	4.7	036±009	-2.0		9.7
32	1970-09-26	Colombia	8	MM	8	6.6	13	7	6.0	12.0	7.9	000±000	-1.0	-0.6	21.6
33	1974-04-18	Colombia	9	MM	24	4.5	10	8	6.3	20.2	10.5	151±158	-1.0	1.8	14.6
34	1974-07-13	Colombia	8	MM	12	7.3	17	8	7.0	47.0	16.6	006±042	0.0	-0.3	57.9
35	1976-04-09	Ecuador	8	MM	19	6.7	67	7	5.8	5.7	5.3	017±032	-1.0	-0.9	15.4
36	1977-11-23	Argentina	9	MM	4	7.4	132	9	6.9	40.2	15.3	108±031	0.0	-0.5	86.4
37	1985-01-26	Argentina	8	MM	12		22	8	5.8	9.5	7.0	064±050	0.0		24.4

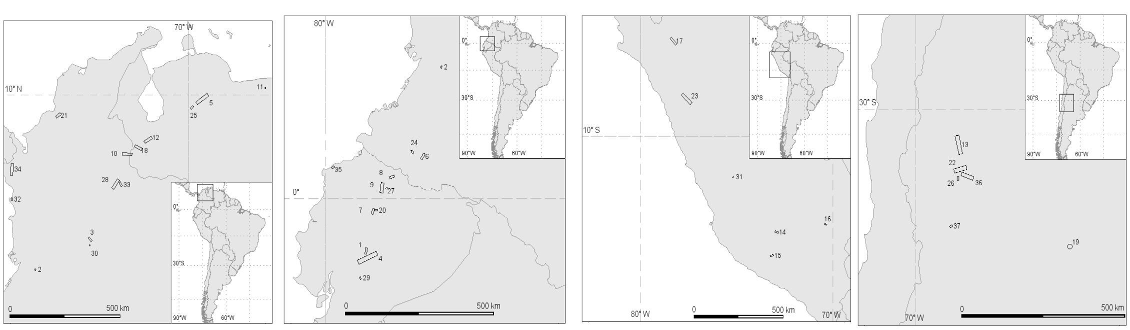

Figure. 3. Location of 37 intensity-based sources (box) quoted in table 5. The adjacent number to each box corresponds to ID Box (table first column).

The epicentral intensities are essentially similar. Table 5 lists also “ΔEpic.” that is the distance between the CERESIS epicenters and the macroseismic ones computed by the *Boxer* program. This comparison between epicenters shows some cases with distance greater than 150km.

The only justifiable difference is the one concerning 9 April 1928, Peru earthquake, because in this case CERESIS gives the instrumental localization. For the other two events (26 March 1812 Venezuela and 27 October 1894 Argentina earthquakes) a more detailed analysis would be necessary (but it is out of the scope of this study).

EXAMPLES:

The Earthquake of 1894, April 29th, in the Venezuelan Andes

The 1894 event is one of the largest historical earthquakes in Venezuela. It is known as the Great Earthquake of the Venezuelan Andes and it ruined almost completely the towns of Santa Cruz de Mora, Zea, Mesa de Bolívar, Tovar, San Juan de Lagunillas, Chiguará and Mérida (Audemard, 1998). Altuve (1998), Rengifo and Laffaille (1998) and Rivera de Uzcátegui and Torres (1998) investigated and collected historical sources on this event. CERESIS (1985), on the basis of the historical work by Grases (1979), gives the epicenter as 8.50°N, 71.70°W, at a 20 km depth, magnitude Ms = 7.1, and maximum reported intensity IX (MM).

Also the epicenter given by Rengifo and Laffaille (1998) is similar: 8.55° ± 0.05°N, 71.69° ± 0.05°W, but with a focal depth estimated in 14 ± 2 km, and a magnitude ranging between 7.1 and 7.4. Recently this event has been directly associated to the southern section of the Bocono fault through paleoseismological investigations (Audemard, 1997; Audemard, 1998, Audemard et al., 1999) and its magnitude has been estimated between Ms 7.1 and 7.3.

Based on the 71 macroseismic data reported by CERESIS (Figure 4a), the macroseismic epicenter (8.39°N, 71.70°W) and the moment magnitude (Mw = 6.8) were obtained through the *Boxer* program.

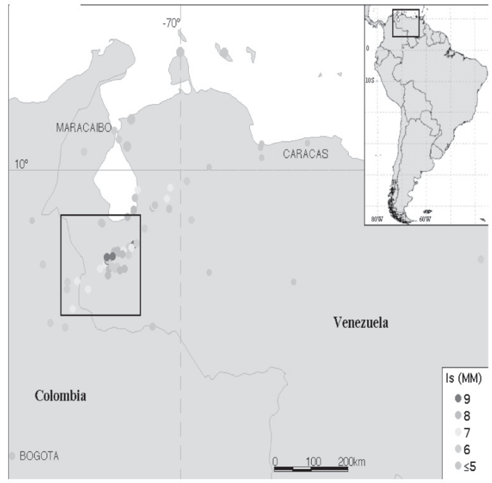

Figure 4. a) The 29 April 1894 earthquake in Venezuela: 71 intensity data points reported by CERESIS (1985).

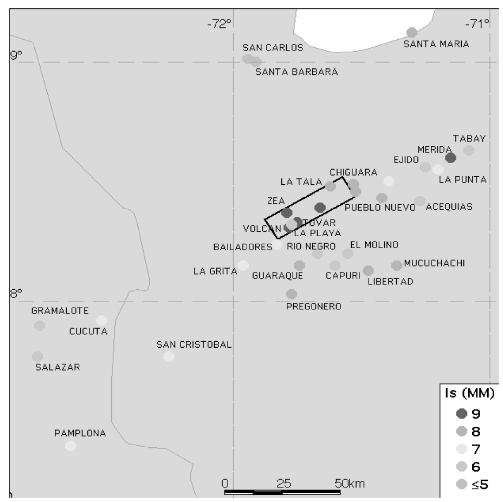

Figure 4. b) The box represents the source dimension, size and location obtained from intensity data following the method proposed by Gasperini et al. (1999)

Table 6. EARTHQUAKE OF 1894, APRIL 29TH: COMPARATIVE TABLE OF THE EARTHQUAKE PARAMETERS.

AUTHOR	Epicentre		Magnitude
	Latitude (N)	Longitude (W)	
CERESIS (1985)	8.50°	71.70°	7.1 Ms
This study	8.39°	71.70°	6.8 Mw
Rengifo and Lafaille (1998)	8.55°	71.69°	7.1-7.4 Ml
Audemard et al (1997)	-	-	7.1-7.3 Ms

The moment magnitude calculated by the *Boxer* (Table 6) is smaller than the magnitudes reported by the CERESIS catalogue (Ms 7.1), by Rengifo and Lafaille (1998) and by Audemard et al. (1997).

As shown in Figure 4b, the *Boxer* program suggests that the 1894 earthquake ruptured a source with a length of 39 km and an azimuth of N60°E. This result can be considered consistent with the regional tectonic trend, and it is further supported by the conclusions drawn by Audemard et al. (2000) (Figure 4c). In fact, they mention this earthquake as an event related to historical movement (sense of movement: dextral-normal) of the South of Mérida Section of Bocono fault system, in Venezuela.

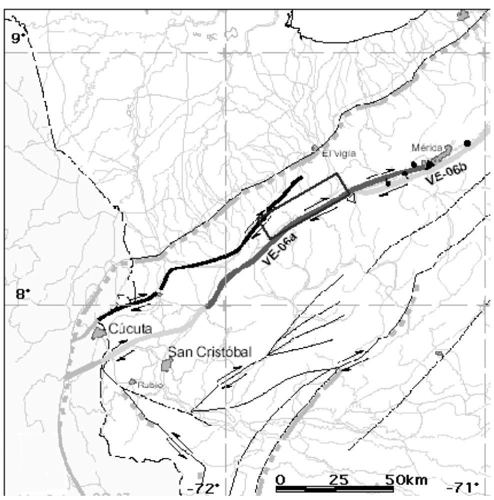

Figure 4. c) Box of the 1894 event (blue box), in comparison with the "Map of Quaternary Faults" as published by Audemard et al. (2000), modified.

The Earthquake of 1946, November 10th, in The Peruvian Andes

This earthquake is known as the Ancash earthquake, in the Northern Peru and partially destroyed the towns of Pallasca, Pomabamba and Quiches in the "Departamento di Ancash".

The "Instituto Geofisico del Peru" (www.igp.gob.pe) locates the event at 8.333°S, 77.833°W, assess maximum intensity IX-X (MM), focal depth 30-40km and magnitude 7.2 (m_b) and indicates that this earthquake mainly affected the towns Mayas and Quiches. It also gives information about isoseismic map, quotes historical sources and associates this event with the Quiches fault. Doser (1987) re-evaluated first-motion data and concluded that the epicenter was located at 8°.28.4'S, 77°.51.6'W, the focal depth was 15 to 17 km, and the magnitudes were 6.3 to 6.5 (Ms), 6.5 to 6.9 (m_b), and 6.8 (Mw). Bellier et al. (1991) say the 1946 Ancash earthquake produced a surface faulting along the Quiches normal fault and given a moment magnitude Mw = 7.0 ± 0.1, which is close to the value of Mw = 6.8 given by Doser (1987).

The epicenter coordinates of the event given by CERESIS (1985) are 8.5°S, 77.5°W, without information about depth; maximum intensity XI (MSK), magnitude Ms = 7.3 and the IDP are quoted from historical compilation by Silgado (1978).

This earthquake has a good distribution of IDP (34 localities, Figure 5a and Figure 5b). In such cases the *Boxer* program is rather stable, therefore the results obtained, macroseismic epicenter (8.340°S, 77.603°W), moment magnitude (Mw7.3), relative fault length (71 km) and azimuth (N132) are highly valuable to be compared with the ones in literature (Table 7 and Figure 5c). The moment magnitude computed through the *Boxer* program is similar to the instrumental one (Ms7.3) quoted by CERESIS. Also, in this case, the azimuth of the inferred sources (N132º) is consistent with the strike of Quiches fault reported by Macharé et al. (2003), located west of the Marañon River and north-east of the Western Cordillera in Peru (Figure 5c). The author quotes this fault was active during the 1946 Ancash earthquake (sense of movement: normal).

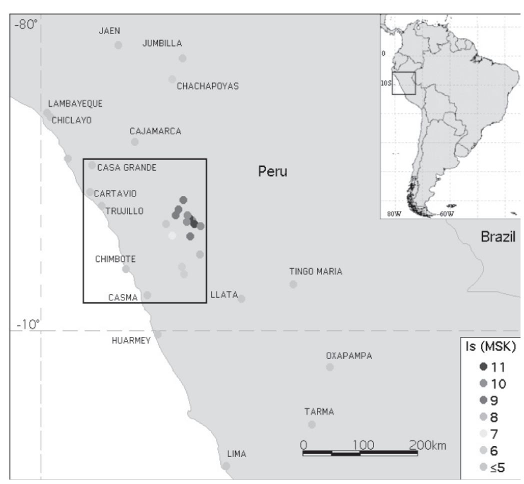

Figure 5. a) The 10 November 1946 earthquake in Peru: 34 intensity data points reported by CERESIS (1985).

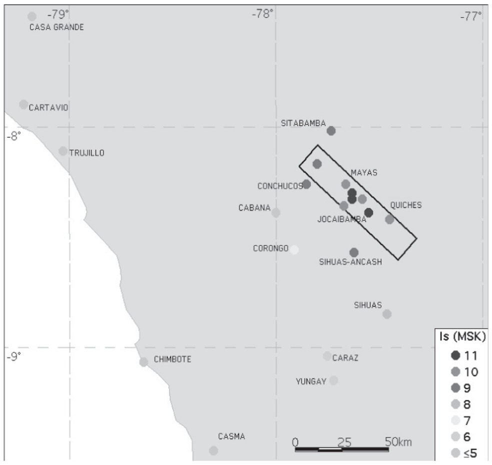

Figure 5. b) The box represents the source dimension, size and location obtained from intensity data following the method proposed by Gasperini et al. (1999).

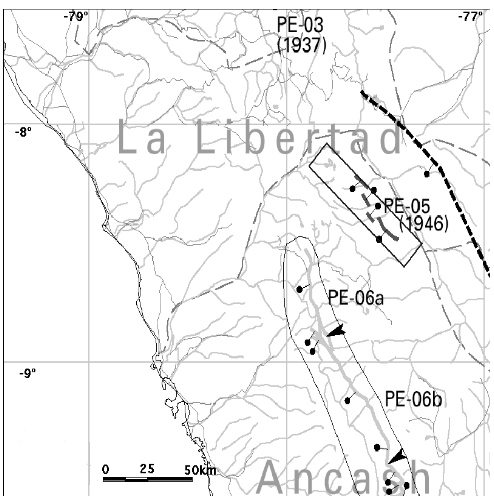

Figure 5. c) Box of the 1946 event (blue box), in comparison with the "Map of Quaternary Faults" as published by Macharé et al. (2003), modified.

Table 7. EARTHQUAKE OF 1946, NOVEMBER 10th: COMPARATIVE TABLE OF THE EARTHQUAKE PARAMETERS.

AUTHOR	Epicentre		Magnitude
	Latitude (S)	Longitude (W)	
CERESIS (1985)	8.50°	77.50°	7.3 Ms
This study	8.34°	77.60°	7.3 Mw
Instituto Geofísico del Perú	8.33°	77.83°	7.2 mb
Doser (1987)	8.47°	77.86°	6.8 Mw
Belhier et al. (1991)	-	-	7.0 Mw

CONCLUSIONS

A recently developed application, which processes macroseismic data (*Boxer*, Gasperini et al., 1999) and was originally tested in Italy and Europe, has been adopted in this study. Even though this application should be carefully applied, given the nature of the South-American catalogues, which include both shallow and subduction earthquakes, the results we achieved are to some degree conformable.

As a first approach to the South-American historical seismicity we generally can affirm that our results agree fairly well with seismological data and geological background as reported in literature.

In particular in the examples we presented in this paper we have observed that the strike of the sismogenic sources inferred from macroseismic data is compatible with the tectonic structures or surface faulting evidence available for large historical earthquakes.

Indeed the procedure we adopted can be taken as stable for a limited number of large magnitude events due to the source characteristics, that in South America are strongly different from the ones for which the algorithm was initially calibrated. Therefore to conclude, we emphasize that more efforts are needed to develop methods that make use of macroseismic intensity data to constrain the essential characteristics of the seismic sources for South America.

REFERENCES

Altuve, F. (1998): El gran terremoto de los Andes venezolanos y las juntas de socorro. Revista Geográfica Venezolana, 39, 1-2, 163-178.

Audemard, F. (1997): Holocene and historical earthquakes on the Boconó fault system, southern Venezuelan Andes: trench confirmation. Journal of Geodynamics, 24,1-4, 155-167.

Audemard, F. (1998): Contribución de la paleosismología a la sismicidad histórica: Los terremotos de 1610 y 1894 en los Andes venezolanos meridionales. Revista Geográfica Venezolana, 39, 1-2, 87-105.

Audemard, F., D. Pantosti., M. Machette, C. Costa, K. Okumura, Cowan, Diederix, H. Ferrer, C. and participants of the South American Field Workshop on Paleoseismology (1999): Trench investigation along the Mérida section of the Boconó fault (central Venezuelan Andes), Venezuela. Tectonophysics, 308, 1-2, 1-21.

Audemard, F. A., Machette, M. N., Cox, J. W., Dart R. L and Haller K. M. (2000): Map and Database of

Quaternary Faults in Venezuela and its Offshore Regions. A project of the International Lithosphere Program Task Group II-2, Major Active Faults of the World, U. S. Geological Survey, Open-File Report 00-018, 78pp.

Bellier, O., J. F. Dumont, M. Sebrier and J. L. Mercier (1991) Geological constraints on the kinematics and fault-plane solution of the Quiches fault zone reactivated during the 10 November 1946 Ancash earthquake, northern Peru. Bulletin Seismological Society America, 81, 2, 468-490.

Carpio, J. and Tavera H. (2002) Estructura de un catálogo de tsunamis para el Perú basado en el catálogo de Gusiakov. Boletín de la Sociedad Geológica del Perú. Vol. 94, pp. 45-59.

CERESIS, Centro Regional de Sismología para América del Sur (1985) Catálogo de terremotos para América del Sur. Programa para la mitigación de los efectos de los terremotos en la región andina, Proyecto SISRA, Vol. 1-14, edited by B. Askew and S.T. Algermissen.

Comte, D. and Pardo, M. (1991) Reappraisal of great historical earthquakes in the northern Chile and southern Peru seismic gaps. Natural hazards 4, 23-44.

Dorbath, L .A., Cisternas, and C. Dorbath, (1990) Assessment of the size of large and great historical earthquakes in Peru. Bulletin Seismological Society America, 80, 3, 551-576.

Doser, D. I. (1987): The Ancash, Peru earthquake of 1946 November 10: Evidence for low-angle normal faulting in the high Andes of northern Peru. Geophysical Journal of the Royal Astronomical Society, 91, 57-71.

EMID: Euro-Mediterranean Intensity Database. http://emidius.mi.ingv.it/EMID/

FAUST: Faults as a Seismologist tool. http://FAUST.ingv.it

Gasperini, P., Bernardini, F. Valensise, G. and Boschi E. (1999): Defining seismogenic sources from historical felt reports. Bulletin Seismological Society America, 89, 94-110.

Grases, G. J. (1979): Investigación sobre los sismos destructores que hayan afectado el oriente de Venezuela, delta del Orinoco y regiones adyacentes. Proyecto Instituto Tecnológico Venezolano del Petróleo, 2 vol.

Kanamori, H. and Mcnally K. C. (1982) Variable rupture mode on the subduction zone along the Ecuador. Bulletin Seismological Society America, 72, 1241-1253.

Kelleher, J. (1972) Rupture zones of large South American earthquakes and some predictions. Journal of Geophysical Research, 77, 11, 2087-2103.

Leschiutta, I. and C. Mirto (2000) Using historical earthquake data for the determination of the source parameters of some European earthquakes. Proc. of the ESC WG «Historical Seismology» Workshop, 1-5 September, Macerata (Italy), pp. 54-59.

Lomnitz, C. (1970) Major earthquakes and tsunamis in Chile during the period 1535 to 1955. Geologisct Rundschschau, 59, 938-960.

Macharé, J., C. Fenton, M. Machette, A. Lavenu and R. Dart (2003): Database and Map of Quaternary Faults and Folds in Peru and its Offshore Region. A project of the International Lithosphere Program Task Group II-2, Major Active Faults of the World, U. S. Geological Survey, Open-File Report 03-451, 50pp.

Mirto, C., E. Ercolani, I. Leschiutta, F. Mosciatti e G. Rubbia Rinaldi (2001): I database macrosismici on-line dei terremoti italiani ed europei e il loro utilizzo per la determinazione dei parametri di sorgente dei terremoti. Atti del VI Workshop GIAST, Sansepolcro (Arezzo, 14-16 settembre 1999), pp. 77-89.

Monge, J. (1993): Estudios de Riesgo de Tsunami en Costas Chilenas. Jornadas Chilenas de Sismología en Ingeniería Antisísmica. pp. 3 - 22, V.2, Santiago, Chile.

Nishenko, S. (1985) Seismic potential for large and great interplate earthquakes along the Chilean and southern Peruvian margins of South America: a quantitative reappraisal. Journal of geophysical research, 90, No. B5, 3589-3615.

Pennington, W. D. (1981) La subducción de la cuenca oriental de Panamá y la sismotectónica del noroeste de Sur America. En Investigacioness geofísicas sobre las estructuras océano-continentales del occidente colombiano, Bogotá: Instituto Geofísico, Universidad Javeriana. p. 97-137

Rengifo, M. and Laffaille, J. (1998) El terremoto del año 1894 en los Andes venezolanos. Revista Geográfica Venezolana, 39, 1-2, 141-161.

Rivera De Uzcátegui, A. and Torres, R. (1998): Estudio de daños originados a las iglesias de la ciudad de Mérida por la acción de los terremotos de 1812 y 1894. Revista Geográfica Venezolana, 39, 1-2, 219-256.

Rubbia, G. (2004): A review of intensity data banks online. Annals of Geophysics, in printing.

Silgado, E. (1978) Historia de los sismos más notables ocurridos en el Perú (1513-1974). Instituto Geología y Minería, Boletín No. 3, Lima.

Stucchi, M., Leschiutta, I. and Mirto, C. (2000) On the influence of the uncertainties of historical data on the determination of earthquake parameters. XXVII General Assembly of The European Seismological Commission (ESC), WSA-1. Lisboa 10-17 September 2000, abstract, p. 115.

Tavera, H. and E. Buforn (1998) Sismicidad y sismotectónica de Perú. En Física de la Tierra, edited by E. Buforn and A. Udias (Servicio de Publicaciones Universidad de Complutense), No. 10, pp. 187-219.

Tavera, H. (2002) Historia de un terremoto anunciado para la región sur del Perú. Centro Nacional de Datos Geofísicos, Instituto Geofísico del Perú, pp. 11-18.

Valensise, G. and Pantosti D. (eds.) (2001) Database of Potential Sources for Earthquakes Larger than M 5.5 in Italy. Ann. di Geofisica, Suppl, 44 (4): 180, with CD-ROM.