PRELIMINARY APPLICATION OF THE INQUA SCALE TO RECENT COLOMBIAN EARTHQUAKES

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ABSTRACT

The INQUA intensity scale was applied to ten of the most devastating Colombian recent earthquakes. The information related to the earthquake environmental effects is scarce in Colombia. It was not possible to establish an unique value of INQUA intensity for each event, nevertheless, the INQUA scale was consistent, and the assigned levels of intensity are comparable with the levels of intensity previously assigned in other scales, however in some cases the INQUA degree was greater.
A more detailed survey about environmental effects is needed in Colombia in order to apply the INQUA scale.

1. INTRODUCTION

The Subcommission on Paleoseismicity of the International Union for Quaternary Research, INQUA, has developed a scale for measuring the intensity of earthquakes based on seismically-induced ground effects in the environment. In order to have an active participation of Colombia in this Subcommission, a small group of Colombian researchers from different institutions formed a working group on paleoseismology. The initial research of this group focused in the application and calibration of the proposed INQUA intensity scale on the most devastating events of the recent Colombian seismic activity.

This report presents the preliminary results of this investigation in order to be presented in the meeting of the INQUA Subcommission of paleoseismicity to take place in Florence, Italy in August, 2004.

2. OBJECTIVES

To create a database of the environmental effects of the most important recent seismic events that have occurred in Colombia, in order to apply the INQUA intensity scale.

2.1 SPECIFIC OBJECTIVES

- Collect and analyze the information about the environmental effects of the recent significant seismic events in Colombia
- Present the intensity INQUA scale to the Colombian geological and seismological community and encourage its use
- Compare the results obtained from applying the intensity INQUA scale with the data reported from other intensity scales

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- Propose field parameters to be reported after the occurrence of an important earthquake in order to guarantee the necessary information for applying the INQUA intensity scale
- Demonstrate in Colombia the usefulness of this type of studies for seismic hazard assessments
- Encourage the active and continued participation in international investigation groups such as the INQUA Subcommission of Paleoseismicity
- Promote the creation of inter-institutional working groups in paleoseismicity, neotectonics, seismology, etc, in Colombia.

3. METHODOLOGY

The published and available information of ten of the most recent and devastating Colombian earthquakes was compiled and analyzed in order to extract their environmental effects.

These environmental effects were classified according to the different degree levels proposed in the INQUA scale, in order to obtain a INQUA intensity degree for each one of the selected earthquakes.

The INQUA intensity degree was compared with other intensity scales, previously determined for those particular earthquakes.

4. SELECTED EARTHQUAKES

Table 1 presents the general information about the selected earthquakes used to apply the INQUA scale. Figure 1 illustrates their location.

Table 1. Selected earthquakes for INQUA scale analysis

ID	Earthquake	Date	Magnitude	Depth
1	Bahia Solano	September 26, 1970	M_L 6.6	shallow
2	Tumaco	December 12, 1979	M 8.1	shallow
3	Popayán	March 31, 1983	mb 5.5	shallow
4	Murindó	October 17 and 18, 1992	Ms 6.7 and Ms 7.3	shallow
5	Puerto Rondón	July 21, 1993	mb 5.9	shallow
6	Páez	June 6, 1994	M_L 6.4	shallow
7	Tauramena	January 19, 1995	Ms 6.6	shallow
8	Calima	February 8, 1995	Ms 6.3	intermediate
9	Armenia	January 25, 1999	Mb 5.9	shallow
10	Juradó	November 8, 2000	Ms 6.4	shallow

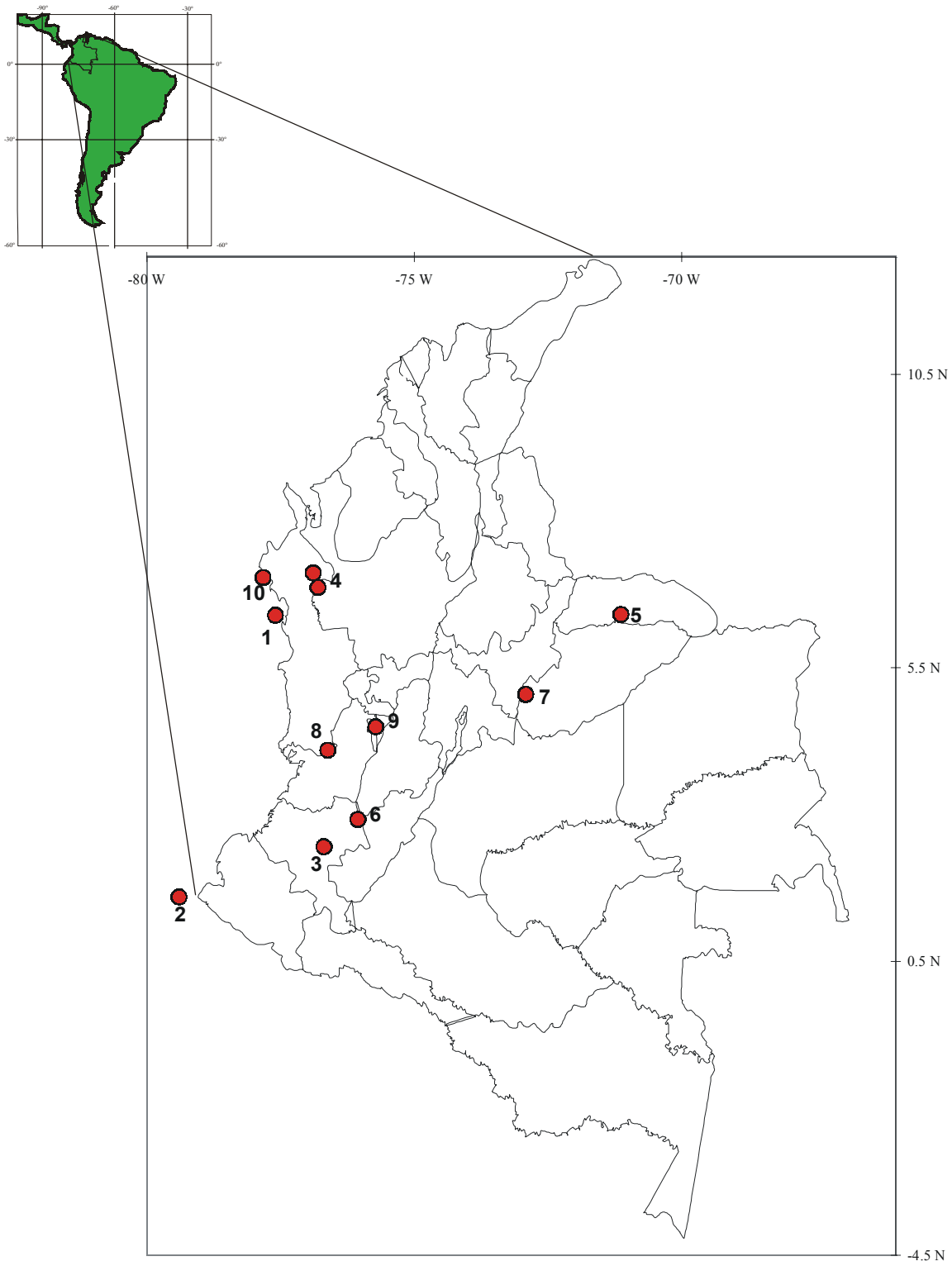

Figure 1. Location of the selected earthquakes

5. INQUA INTENSITY DEGREE FOR RECENT COLOMBIAN EARTHQUAKES

The environmental effects of the selected earthquakes reported by different authors are presented in Table 2. In this table, those effects directly usable to define an intensity degree are shown in italics. The third and four columns of Table 2 illustrate the INQUA intensity degree given to each earthquake and the intensity degree, previously reported in other scales, respectively.

6. DISCUSSION AND CONCLUSIONS

The studies of the consequences of Colombian earthquakes have focused, in general, on the effects of the earthquake in civil structures. Due to the economic situation of Colombia, when a significant earthquake occurs, every effort is focused on the affected population and on the evaluation of the affected buildings. In addition, in the most recent events, most of the studies are directly related to instrumental seismology in order to define aftershocks sequences and underground rupture area.

Therefore, only a few authors report the effects on the environment. This is in part because this type of studies do not take place immediately but after the emergency has passed and in a tropical country like Colombia environmental effects such as ground cracks, and sand blows can be easily destroyed by heavy rain. Consequently, the reported information is not, in many cases, enough for the assignation of a particular and unique INQUA intensity degree.

From the reviewed reports on the selected earthquakes was possible to determine that:

- Most of the earthquakes in Colombia do not have associated surface faulting
- Often, the same earthquake is associated with different geological faults
- There is a significant error in location due to poor covering of the national seismological network
- The reported earthquake intensity, mainly in Modified Mercalli scale, can vary for the same earthquake in different studies
- The INQUA intensity assigned here shows a correspondence with the intensity degree assigned previously in other scales, although, in some cases, the INQUA intensity degree is slightly greater
- With the available data, a unique INQUA intensity degree cannot be determined, although the scatter of the values is not wide
- A more detailed description of the environmental Colombian earthquake effects is needed in order to apply the INQUA scale
- Several Colombian earthquakes have been reported as related to the eruption of mud volcanoes; this effect is not contemplated in the INQUA scale
- Diapirism has been also related to Colombian earthquakes, which may be the cause of island elevation. Similar effects are not considered in the INQUA scale either.

Table 2. Environmental effects of the selected earthquakes and their intensity INQUA scale

EARTHQUAKE	**ENVIRONMENTAL EFFECTS (#) number that identify the author in the references who describes the environmental effect.**	**INTENSITY INQUA SCALE**	**OTHER INTENSITY SCALE REPORTED BY PREVIOUS AUTHORS (#) number that identify the author who assigned intensity**
BAHÍA SOLANO (SEPTEMBER 26, 1970)	Landsliding widespread along 10 km over the fault (19) *Surface ground cracks 3-5 cm wide* (19) Two fractures greater than 60 m in length through paved floors and roads (19) *An uplift of 63 mm was reported in Puerto Mutis* (19) *A subsidence of 73 mm was detected* (19) several landslides knocked trees down (19) Water pipe were broken (19) *Sandblows* (19) A temporary dam was formed (19) Big fissures in artificial fills along road (19) Water from the sea did not invade the land (19) Without significant fractures or ground cracks (17) Without earthquake dams (17) Landslides in some roads (17) *Small ground cracks in artificial embankments or over the lands that were recovered from the sea* (17). Not presented magmatic or tectonic factors that could be dangerous (24) There were not affection of the landscape, of the shores or of the land under sea level (24) There were not certainty about subsidence (24) There were not preferential direction that suggests that there were active faults (24) *Surface ground cracks in loose deposits (24)* Not tsunami in Buenaventura nor Tumaco (20) There were landslides and trees went down (20) Water pipes broke (20) *Sandblows together with new earthquakes (20)*	 VII VIII VIII VIII VI VI VIII	Not available

	Sound of detonations similar to cannon shots (20) Other main cause for the landslides: 45° of slope, the abundant rain in the area, presence of high plasticity clay, clearing of the forest trees, and the disturbance at the foothills by the opening of a new road (20) The greatest landslide had a possible extension of 700 m (20)		
TUMACO (December 12, 1979)	The epicentre located at the sea, 1.36°N 79.4°W and at 33 km deep (21) There were not previous events (21) The earthquake was followed by many aftershocks during at least two months. The magnitude of aftershocks were greater than 5.5 (21) *A tsunami took place a few minutes after the earthquake. It took place during the low tide and the waves were 5 to 6m high* *The second wave was 6 to 7 m high. There were a lot of dead fishes from different species and sizes. The water become muddy and black (probably by oil).* (21) All the beach present ground cracks (21) *At Guapi (Valle) village, three waves arrived to the beach. The first wave was 2m high; the second wave arrived 20 minutes later.* (21) (7) *At Guapi village, the subsidence was up to 1.6 m.* (7) At Gorgona island, 5 m high waves arrived to the beach. (21) *Liquefaction, subsidence, and ground cracks were present in the loose deposits in the Southwest part of Colombia* (21) (7) *Ground cracks (7) were up to 1 m wide* (21) *In San Juan de la Costa village, the ground cracks were 0.60 m wide and they had south to north trend* (21) Palms fell off Sandboils (7) up to two meters in diameter. Water flow out with sulphur smell (21) *High temperature water flow out of sandboils.* (21) *The subsidence was estimated in 0.50m using a rudimentary method.* (21) *The low tide were 0.40 m lower at Guapi village after earthquake.* (21) *Mosquera village had to be relocated because the place suffered a subsidence of 0.35 m* (21) At Tumaco place the islands had a subsidence up to 1.5m (21) A small island appeared 1.100 km north to Tumaco. This island had 30m	X X X X IX IX IX IX IX IX X	At El Charco VIII (MM) (21), IX (MM) (7) At Tumaco VII (MM) (21) , IX (MM) (7). At Guapi VI (MM) (21), VII (MM)(7) At Cali V (MM) (21) At Bogotá IV (MM) (21) At mouth of Patia River IX (MM) (7)

	long, 5m wide and 7m high. It appeared in the sea, 300m far to the coast. The island was green to gray plastic clay. The island appeared through ground crack that could saw in land with 0.02m wide. The island disappeared on January 9 of the next year. (21) *Lateral spreading and slumping* (7) Loose of bearing strength (7) *One exceptional large sand boil, partly submerged in a channel at the mouth of the Rio Patía , has a throat approximately 5 m in diameter and a cone 20 m in diameter* (7) *Fissures associated with slumps and lateral spreading (not continuous) in river banks as far as 50km from the coast. Displacements along fissures reached several metres in some places* (7) Rockfalls and rockslides in steep slopes. Some were reported as far as 150 km from the sea.	X IX IX or X	
POPAYÁN (March 31,1983)	Hundred meters long ground cracks in saturated soils (15) *Water in wells become muddy and water level change* (15) It was not produce a surface faulting. (15) This earthquake was produced by Rosas Julumito Fault. (15) There were not agree about epicenter location; USGS, NOAA and NEIS differ about their location. (15) (4)	VIII VII	Between II and VIII (MM) (15) IX (MSK) (4)
MURINDÓ (October 17 and 18, 1992)	The environmental effects were not evaluated completely. The access to the area was difficult. (14) The vegetation cover were totally destroyed (14) *In flat places trees fall* (14) Between 30 to 40% of the area were out of vegetation cover. (14) *Sediments came to the drainage; some temporally dams formed, the hydrological regime change and rivers temporally dam.* (14) Liquefaction in loose deposits and saturated soils (14) Fissuring parallel to river banks and open ground cracks (14) *Sandblows (14)* Mud extrusion at the Cacahual mud volcano. This mud volcano throw out 50.000 m3 of mud and gas. (14) A small island appear, 50m x 150m. There was not agree about the relation between the earthquake and the appear of the island. Some	XI IX or more	X (MCS) (14)

	people said that this island appear every 5 or 6 years. Other people said that the island appear by the earthquake. (14) The water table uplift. (14) *Landslides spread over the region. Cover 40km long to 10 – 12 km wide* (18)	 IX	
PUERTO RONDÓN (July 21,1993)	Right lateral strike slip fault (6) *The affected area was 7500 km2* (9) (23) *Artificial embankments collapsed* (9) *0.02 to 0.08 m wide ground cracks appear with 3 to 15 m long. (9) (23*) *Liquefaction* (9) *The sand that went out from the sandblows 0.15 to 0.20 m high (23)* The temperature of the sand at liquefaction places were high and there were a sulphur smell. (23) *Apparent water fountain in the river* (23)	 VIII or more VIII or more VII or more VIII or more VIII or more VIII or more	VIII (MM) (9) (23)
PÁEZ (June 6, 1994)	Landslides in the rivers basins (6) *Avalanche along Paez River generated by the material from landslides* (10)(16) Related to the Mora Fault (10) *Landslides around 40km of the epicentre*(16) Ground craks (16) The avalanche was 10 to 40 m high and it had speed of 50 to 60 km in the upper part of the basin and changed to 20 or 40km in the river mouth at Magdalena river. (16) The Huila Snow capped mountain is 10 km far to the epicentre but the glacier war not affected. (16) It may be related to the Cali Fault (16) This land had a lot of springs and it was highly susceptible to landslides. (16) *Ground cracks every 0.03m and with 0.08m wide* (16) *Liquefaction* (16) Landslides over the roads (16)	 IX or more IX VII VIII or more	VII (MM) 40km far of the epicentre (10) V to VI (MM) 100 km far of the epicentre (10)

TAURMENA (January 19,1995)	There were a lot of landslides (6) (11)° Associate to north segment of Guaicaramo Fault (11) It was not possible to identify surface fault rupture (11)	Insufficient information to assign an INQUA degree of intensity	VIII (MM) (11)
CALIMA (February 8, 1995)	There is not information related to environmental effects (12) (6) (13)	Insufficient information to assign an INQUA degree of intensity	VI (MM) (12)
ARMENIA (January 25, 1999)	Effects in 28 different localities (1) 11 landslides in Armenia city and 12 landslides in rural places (1) It was probably related to the Silvia Pijao Fault (6) Landslides before the earthquake were generated by rain (18) A lot of ground cracks and landslides in the epicentre area (18) There were a fracture north to south that was probably associated with the fault rupture (18)	Insufficient information to assign an INQUA degree of intensity	VII (MM) at Ibagué city (3)

Nevertheless, and despite of the poor information related to environmental earthquake effects in Colombia it was clear that the INQUA scale is consistent with other intensity scales and constitutes a good tool to evaluate the size of a seismic event.

It is recommended for Colombia that more detailed information is surveyed in order to apply the INQUA scale and to better describe earthquake effects. More detailed survey information to consider may include:

- Immediate survey of the epicentral area in order to describe liquefaction, ground cracks and their dimensions (longitude and width), their position with respect to other features such as drainage, other cracks and sandblows
- Measurement of the diameter of sand volcanoes, their height and the conditions of the expelled water
- Report changes in water levels in wells or water sources, temperature and general water conditions
- Definition of the area affected by landslides considering the stability prior to the event. Definition of the material affected by the landslides and report of the rain levels before and after the earthquake
- Study of the drainage to report temporal or permanent earthquake dams
- Analysis of still water and report of any changes. Inquiry with local inhabitants for any detected changes
- Survey of the roads and report of cracks (location, longitude and width). Also report of subsidence or elevation of the land and their dimensions
- Air photographs, if possible, in order to record most of the environmental effects before they are affected by other factors. These photographs may be the basis for detailed field work

7 REFERENCES

(1) Arango. J., Quintero, B., 2000. Diagnóstico de los procesos erosivos acelerados por el sismos del 25 de enero, 1999, en el municipio de Chinchiná, Caldas. En: *Revista Red Sismológica Regional del Eje Cafetero, Caldas y Tolima*, pp 46-52

(2) Bohórquez, O., Gil, F., Ospina, L., 2001. Sismo del Quindío del 25 de enero de 1999. Tensor de esfuerzos preliminar y estudio de réplicas. En*: Revista Horizontes Naturales* (revista de la Facultad de Ciencias Exactas y Naturales de la Universidad de Caldas, No 4, p 79-93

(3) Cárdenas, J.; Marquinez, G.; Acosta, C.; 2.000. Efectos del sismo del 25 de enero de 1999 en la ciudad de Ibagué. En: *Revista Red Sismológica del Eje Cafetero – Viejo Caldas y Tolima*, pp. 22-27

(4) Comunidad Económica Europea e Ingeominas (1992) Microzonificación sismotectónica de Popayán. Publicaciones especiales del Ingeominas, 208 p.

(5) Corporación Nacional para el Desarrollo del Chocó, 1971. El terremoto de Bahía Solano del 26 de septiembre de 1970. Ministerio de Agricultura, informes técnicos, 52 p.

(6) Escallón, J., 2000. La sismicidad Colombiana en la última década del siglo XX. En: *Revista Red Sismológica Regional del Eje Cafetero – Viejo Caldas y Tolima*, pp. 5-11

(7) Herd, D. G, Youd, T.L, Meyer, H., Arango, J. L., Person, W.J, and Mendoza, C. 1981. The great Tumaco, Colombia earthquake of 12 December 1979. Science, Vol 211, No 4481

(8) Ingeominas, Unicauca, Uniandes, Univalle, IGAC, CVC, ISA, SENA, Instituto geofisico de los Andes Colombianos. 1986. El sismo de Popayán del 31 de marzo de 1983. Ingeominas, 319 p.

(9) Ingeominas, 1993. El sismo de julio 21 de 1993 en Puerto Rondón (Arauca). *Boletín trimestral de sismos*, junio-agosto de 1993, 1, No 1, p 17-19

(10) Ingeominas, 1994. El sismo de Páez (Cauca) del 6 de junio de 1994. *Boletín Mensual de Sismos*, vol. 2, No 6, pp.13-25

(11) Ingeominas, 1995. El sismo de Tauramena (Casanare) del 19 de enero de 1995. *Boletín trimestral de sismos*. Enero – Marzo, Vol. 3, No 1, p. 33-40

(12) Ingeominas, 1995. El sismo de Calima (Valle del Cauca) del 8 de Febrero de 1995. *Boletín Trimestral de Sismos*, Enero Marzo, Vol. 3, No 1, p. 41-49.

(13) Jaramillo, J. O., 1995. El terremoto del 8 de febrero de 1995. En: *Boletín de Vías*, Universidad Nacional, XXII, no. 83, p.13-26

(14) Martínez, J. M.; Parra, E.; París, G.; Forero, C.; Bustamante, M.; Cardona, O. D.; y Jaramillo, J. D., 1994. Los sismos del Atrato Medio 17 y 18 de Octubre de 1992 Noroccidente de Colombia. Revista *Ingeominas* No 4, pp 35-76.

(15) Meyer, H., Duarte, J., Parafan, A. 1986. Características Físicas del sismo de Popayán, en El sismo de Popayán del 31 de marzo de 1983 (Capítulo 4). Ingeominas. Pp 119-147

(16) Mojica, J. 1996. Efectos del terremoto del 6 de junio de1994, en la región al oriente de Silvia (departamento del Cauca, Colombia). En: *Revista de la Academia Colombiana de Ciencias Exactas Físicas y Naturales*, vol. XX, No76, Santafé de Bogotá, pag 71-92.

(17) Montero, J., Celis, A., 1970. Inspección Ingeniero-geológica en Bahía Solano. El terremoto de Bahía Solano del 26 de Septiembre de 1970, Informes técnicos, pp 35-37

(18) Parra, E.; Mejía, I., 2.000. Efectos físicos del sismo del 25 de enero de 1999 en el sureste del departamento del Quindío. En: *Revista Sismológica Regional del Eje Cafetero – Viejo Caldas y Tolima*, pp. 17-21

(19) Ramírez, J. E (S.J). 1971. La catástrofe de Bahía Solano del 26 de septiembre de 1970. . El terremoto de Bahía Solano del 26 de Septiembre de 1970, Informes técnicos, pp 9-26

(20) Ramirez J. E (S.J) (1971) The destruction of Bahia Solano, Colombia, on September 26, 1970 and the rejuvenation of a fault. *Bulletin of the Seismological Society of America*, 61(4), 1041-1049

(21) Ramírez, J. E.; Goberna, J. R., 1980. Terremotos Colombianos noviembre 23 y diciembre 12 de 1979, Informe preliminar. Bogotá, 95p.

(22) Restrepo, H. (1971) Zona de falla de Puerto Mutis en Bahía Solano, En: El terremoto de Bahía Solano del 26 de Septiembre de 1970, Informes técnicos, pp 27-34

(23) Romero, J.; Martínez, J.; Avila, G.; Escallón, J.; 1994. El sismo del 21 de julio de 1993, Puerto Rondón, Llanos Orientales de Colombia, *Revista Ingeominas* No 4, p.15

(24) Suescún D. (1971) Bahía Solana permanece. El Colombiano, Medellín, dos de octubre 1970, en: El terremoto de Bahía Solano del 26 de Septiembre de 1970, Ministerio de Agricultura, Informes técnicos, pp 9-26