PALEOSEISMOLOGY IN VENEZUELA: AN OVERVIEW.

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Paleoseismic studies in Venezuela actually have a rather long tradition despite the fact that Venezuela is among the "so-called" developing countries. The first venezuelan trench excavations ever carried out are celebrating their 32^{nd} anniversary at the time of this 31^{st} IGC (year 2000). In 1968, two trenches were excavated by the renowned american consultant company Woodward & Clyde –disappeared at present- across the western portion of the Oca fault, which was then well-mapped west of the city of Maracaibo in northwestern Venezuela. Cluff and Hansen (1969) proved the activity of that portion of the Oca fault with this evaluation by revealing the occurrence of an event in the last 2500 years. This assessment was performed for stability analyses of the coastal dykes along the eastern shore of the Maracaibo lake, after request of Maraven, S.A.

Since the very early 80's, all further paleoseismic studies have been performed by scientists belonging to the Earth Sciences Department of the Venezuelan Foundation for Seismological Research (*FUNVISIS*; government institution founded after the Caracas 1967 earthquake to carry out research on seismology, earthquake geology and seismic hazard assessment in order to produce and update the national seismic-resistant building code). The first attempts of this group were carried out during the construction of one of the largest hydroelectric projects of Venezuela –the Uribante Caparo- in the southern Mérida Andes where twenty two huge trenches were bulldozer-dug and studied, demonstrating the Upper Pleistocene-Holocene activity of the Uribante fault that was cross cutting the La Honda project dam site (Funvisis 1983; Soulas 1988). Except for this set of trenches requested and financed by the national power company (CADAFE) and two trenches on the Boconó fault (Morro de Los Hoyos – close to Apartaderos- and Buena Vista –near Barquisimeto-), all other trench studies have been solely requested by the Venezuelan oil industry (PDVSA or any of its former subsidiary companies: Intevep or Maraven).

A large number of trenches were essentially studied in western Venezuela, between 1986 and 89, under the coordination of Jean-Pierre Soulas and occasionally of André Singer, among which deserve mention (refer to Fig. 1 for relative location and Table 1 for more details): the Valera fault north of the Agua Viva reservoir and the Mene Grande fault at Mene Grande in 1986 (Funvisis 1987a; Soulas 1988; Soulas and Giraldo 1994), the Boconó fault at La Grita and Cordero in 1986 and 1987 respectively (Funvisis 1987b; Audemard and Soulas 1995; Audemard 1997), also the Boconó fault at Buena Vista (San Miguel) in 1987 (Beltrán *et al.* 1990) and the Northern Frontal Andes Thrust system at Alguacil in 1986 (Funvisis 1987b). All these trenches were rather large (> 2,000 m^3 and occasionally up to 5,000 m^3) since they were still dug by bulldozer. It is worth mentioning that the two Alguacil trenches were the unique that failed to cut the fault and explanation came out much later when more accurate seismic data acquisition showed that the thrust front was actually blind and the associated geomorphic features were just flexural scarps generated by triangular zones (unknown concept in the mid-80's). Due to logistic constraints (no access road), a first set of 5 trenches were excavated by hand above 3,000 m in elevation at the Páramo La Colorada in 1989 by Singer and Beltrán (Funvisis 1991a).

In early 90's, two trenches were dug across the Ancón and Oca faults, east of the Maracaibo lake, in 1990 and 1991 respectively (Funvisis 1991b; Audemard 1993, 1996). Bulldozer was still in fashion. However, in very early 1990, a set of 19 very modest (< 1 m^3), hand-dug trenches were opened to thoroughly study the liquefaction features induced by the Boca de Tocuyo m_b 5.7 and 5.0 earthquakes, along the east low coastlands of the Falcón state (Funvisis 1991c; Audemard and De Santis 1991). In 1990, another paleoseismic assessment is made; this time across the Urumaco fault, in the Falcón basin, but no excavation was needed since the fault was exposed on a natural outcrop –ephemeral channel bank- (Funvisis 1991b; Audemard *et al.* 1995, 1999).

Paleoseismic studies in the country resume in 1994 when attention is focused on eastern Venezuela for the first time, and the paleoseismic history of the El Pilar fault is assessed at Las Toscanas site (Funvisis 1994; Beltrán *et al.* 1996, 1999); for the last time with a bulldozer.

Following a request of the international PILOTO project, a new trench site –the fourth one- is chosen across the Boconó fault near Apartaderos, at Morro de Los Hoyos, where a paleoseismic school (SAWOP) took place in 1997 in order to introduce Latin American colleagues to the techniques of paleoseismic studies. Due to the good quality of acquired data and derived interpretations, this experience resulted in a publication (Audemard *et al.* 1999). Excavation size was substantially reduced for environmental reasons (located inside a national park) and trench was dug by a backhoe.

In 1998, eastern Venezuela, and particularly El Pilar fault, again deserved particular efforts because of the Cariaco 1997, Mw 6.9 earthquake and its rather well-expressed surface rupture. Three backhoe-dug trenches and an additional antropic outcrop (backyard cut) were studied. Final results are still under evaluation, but they seem much promising.

Perspectives

The future of this discipline in Venezuela heads to more trench excavations in order to give new insights on several unsolved problems, such as: seismic potential (repeat of maximum credible earthquakes) of known faults, fault segmentation, fault interaction as consequence of stress loading by stick-slip on contiguous faults, time-space distribution of seismic activity along a given tectonic feature, seismogenic association of historical earthquakes, among several others.

Conclusions

Despite all limitations of the paleoseismic approach which relies on the association of surface faulting with earthquakes, this technique has proved to be powerful in our onshore wrench setting, mainly because our instrumental seismicity catalog, even after being enlarged by historical seismicity studies, is still too short due to the long return periods (much longer than our 500 year-long history) of our largest and destructive earthquakes. The contributions of this approach refer to: Holocene fault activity, slip-per-event and average slip rate of a given fault (or segment), fault segmentation, size and recurrence of prehistoric earthquakes,

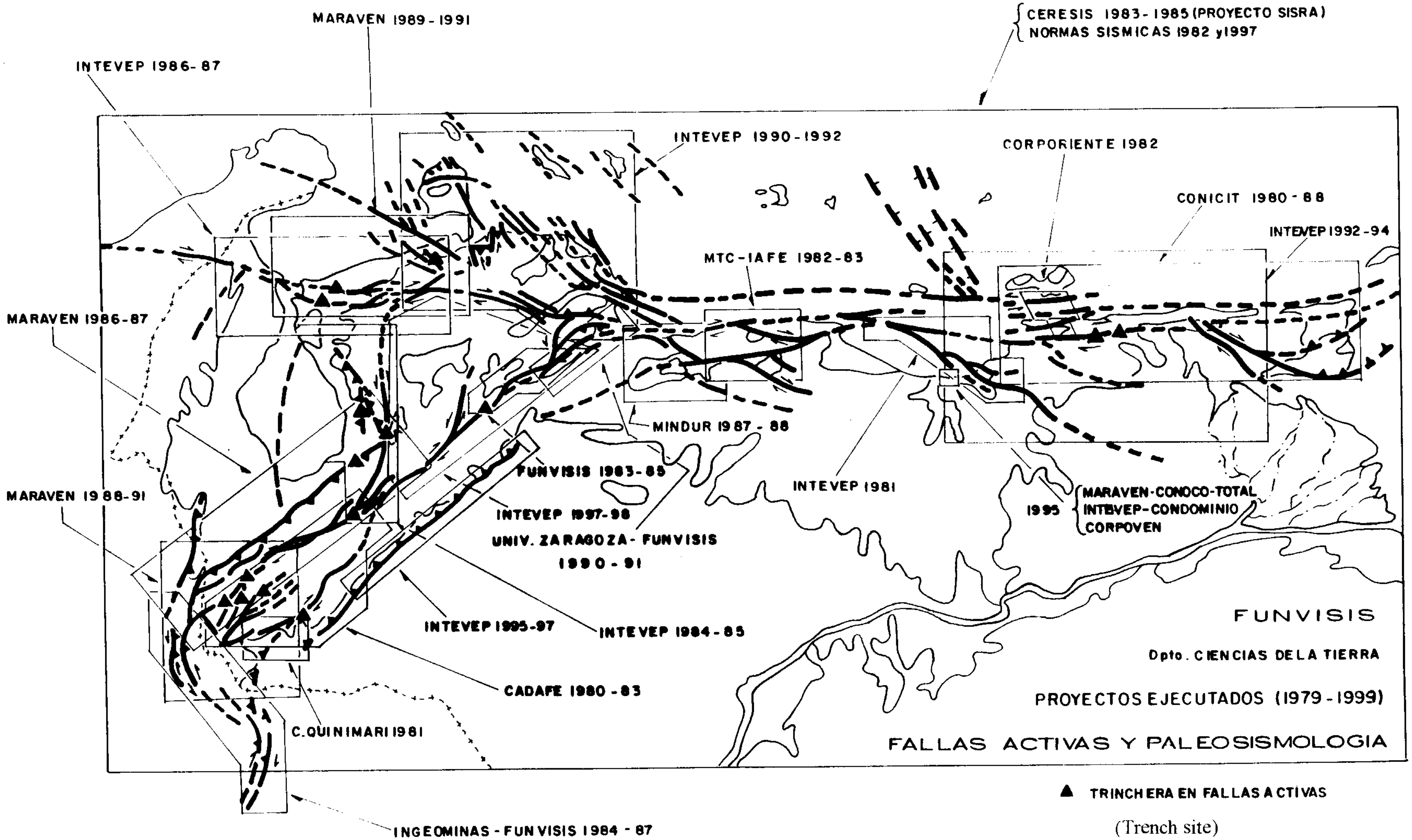

Fig. 1.- Simplified neotectonic map of Venezuela, showing relative location of paleoseismic studies carried out by Funvisis' Earth Sciences Department, between 1979 and 1999. It also shows coverage of individual contracts made by Funvisis (updated from Singer and Audemard, 1997).

Table 1

Paleoseismic Studies Performed in Venezuela Between 1968 and 1999

LOCATION	YEAR	TECTONIC FEATURE ASSESSED	NUMBER OF TRENCHES	MAIN RESULTS	PERFORMED BY (REF. N^0)
Sinamaica lagoon, Zulia state	1968	Oca fault; westernmost segment in Venezuela	2	Holocene activity confirmed. Latest event occurred in the last 2,500 years.	[12]
Uribante-Caparo region, Táchira state	1980-81	Uribante, Doradas and Caparo faults	22	Unpublished. Late Pleistocene-Holocene activity confirmed at La Honda y Borde Seco dam sites.	[13], [21]
Agua Viva, Trujillo state	1986	Valera fault	1	2,000 year return period for Ms 6.9 maximum credible earthquakes.	[14], [21], [22]
Mene Grande, Zulia state	1986	Mene Grande fault	1	Holocene activity confirmed. Thrust faulting confirmed. Slip rate: 0.1 mm/a	[14], [21], [22]
La Grita, Táchira state	1986	Boconó fault; southermost segment	1	Confirmation of two historical earthquakes: 1610 and 1894. Slip rate is 5.2±0.9 mm/y. Earthquakes of Ms 7.1-7.3 about every 300 y.	[3], [8], [15], [21]
El Aguacil (Caja Seca-Arapüey), Zulia state	1986	Andes Northern thrust front	2	Unpublished. No fault found.	[15]
Cordero, Táchira state	1987	Boconó fault; southermost segment	1	3 Holocene earthquakes revealed. Fault slip diminishes to the south (longer recurrence).	[3], [8], [15]
Buena Vista, Lara state	1987	Boconó fault; northernmost segment within the Andes.	1 + road cut	Holocene activity confirmed.	[9]
Páramo La Colorada, Táchira state	1989	;La Colorada-Macanillo fault; northern segment	5	Unpublished. 4 events as large as Ms 6.2-6.3 in the last 5,000 years (latest one may correspond to 1919 event).	[16]
Boca de Tocuyo and Tocuyo de la Costa	1990	Liquefaction features (sand blows and vents)	19	Pre-existing weak zones used by venting sand. Also, vented by cracks generated by lateral spreads in young flat alluvial plains.	[6], [18]
Hato La Pica, eastern Zulia state	1990	Ancón fault; segment east of Maracaibo lake.	1	Holocene earthquakes as large as Ms 7.4-7.5 every 4,000 years. Slip rate is about 1.45 mm/a.	[1], [2], [17]
El Mamón creek, north of Urumaco, Falcón state	1990	Urumaco fault; one strand of the eastern segment.	None (natural outcrop)	Two earthquakes of Ms 5.8-6.4 in the last 20,000 years.	[4], [5], [17]
Hato El Guayabal, western Falcón state.	1991	Oca fault; segment east of Maracaibo lake.	1	Latest event in the last 2,500 years.	[1], [2], [17]
Las Toscanas	1994	El Pilar fault; between Casanay and Río Casanay	1	Several earthquakes of Ms >7.0 every 900-1,200 years	[10], [11], [19]
Morro de Los Hoyos, Mérida state	1997	Boconó fault; segment north of Mérida	1	Several (6 to 8) earthquakes of Ms >7.0 every 1,100-1,500 years	[7]
Terranova-Guarapiche, Sucre state	1998	El Pilar fault; segment between Cumaná and Río Casanay	3 + antropic cut	Under evaluation.	---

seismotectonic association of historical earthquakes and landscape evolution on the short and long term. As a concluding remark, we desire to stress that the paleoseismic approach is more profitable when applied to regions where a comprehensive neotectonic mapping has already been carried out.

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