



# THE UNIVERSITY OF THE WEST INDIES

ST. AUGUSTINE, TRINIDAD AND TOBAGO, WEST INDIES

## THE SEISMIC RESEARCH CENTRE

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### A Sustainable Port of Spain in the Context of Seismicity in Trinidad & Tobago

by

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*Abstract:* Trinidad and Tobago lie at the south-east corner of the Caribbean plate in a tectonically complex regime, which generates damaging earthquakes. The largest known earthquake in the area, (estimated magnitude 7.5-7.9), occurred north of the Paria Peninsula on 21<sup>st</sup> November 1766 and caused catastrophic damage throughout Trinidad, destroying the then capital San José, and probably contributed to the relocation of the capital to Puerto de España. The most recent hazard analysis for the Eastern Caribbean estimates that accelerations of 0.55-0.6 g can occur on-land Trinidad, with the higher values expected in the Port of Spain area. As the country builds for now and the future, this hazard must be addressed in continuity and development plans.

### Introduction

The written history of the Eastern Caribbean islands began in the late fifteenth century with the arrival of Europeans. The islands were sparsely populated for the first three hundred years and the first definite account of an earthquake near Trinidad dates from 1766 when a major earthquake caused destruction throughout northern Venezuela and Trinidad. The population



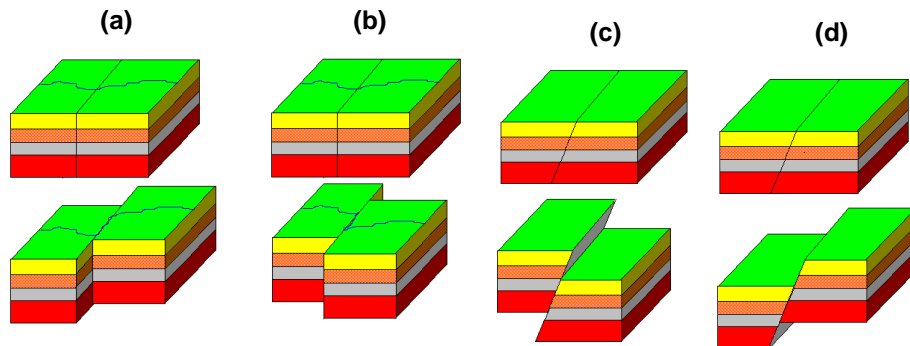
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began to increase rapidly at the end of the eighteenth century and the record of higher intensity shocks, i.e. greater than Modified Mercalli Intensity (MM) VI (Wood and Neumann, 1931), is probably complete from about 1820 when daily newspapers began to appear regularly in Trinidad and neighbouring islands. The general level of awareness of earthquakes was low in Trinidad until 1954 when an earthquake of body-wave magnitude (Fowler 1990) mb 6.5 caused extensive damage throughout Trinidad (Mocquet 2007; Shepherd and Aspinall 1983). Continuous instrumental monitoring began in 1952, which removed reliance on felt reports for recognising earthquake occurrence and lowered the observational magnitude threshold. This has revealed that the area is significantly seismically active. Some zones exhibit a high level of background earthquakes punctuated by the occurrence of strong (magnitude 6.0-6.9) and major (magnitude 7.0-7.9) events. Other zones, although apparently capable of earthquake magnitudes on that scale, exhibit deceptively low levels of background activity.

### **Faults and Seismogenic Zones**

The fault origin of earthquakes is now well accepted (Fowler 1990) and in many parts of the World much effort goes into identifying the faults in seismogenic zones (Topozada *et al.* 2002). In the Trinidad and Tobago area, while a few significant faults have been identified, seismic activity is generally described by way of zones of activity. There are three types of possible fault movements – strike-slip (left or right lateral), thrust and normal. Fig. 1 shows the three different types of movement during fault rupture.

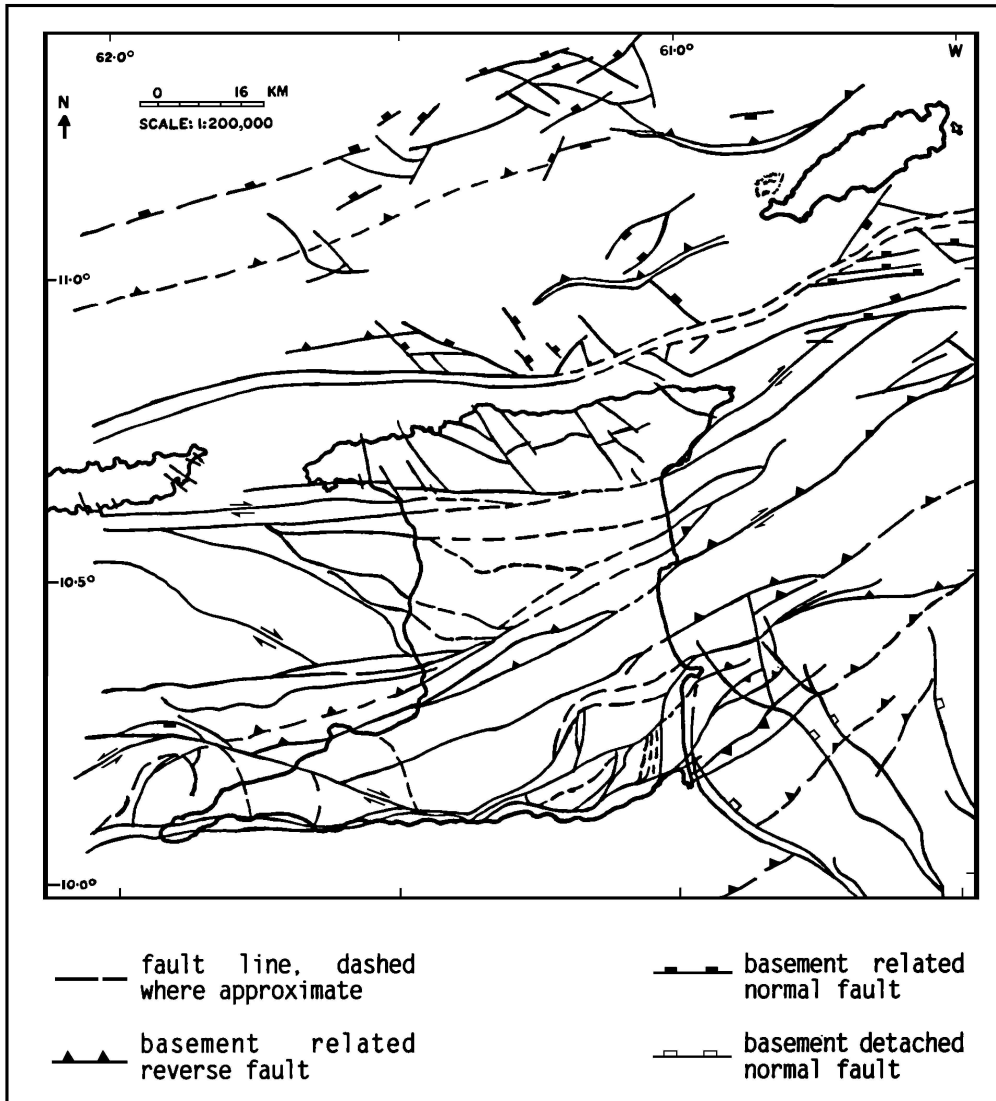
Trinidad and Tobago are located on the south-eastern boundary of the Caribbean plate, which is defined by a highly-complex pattern of faults (Persad, 1984). Fig. 2 shows a map of the faults identified in this area, constructed mostly from the results of commercial seismic reflection



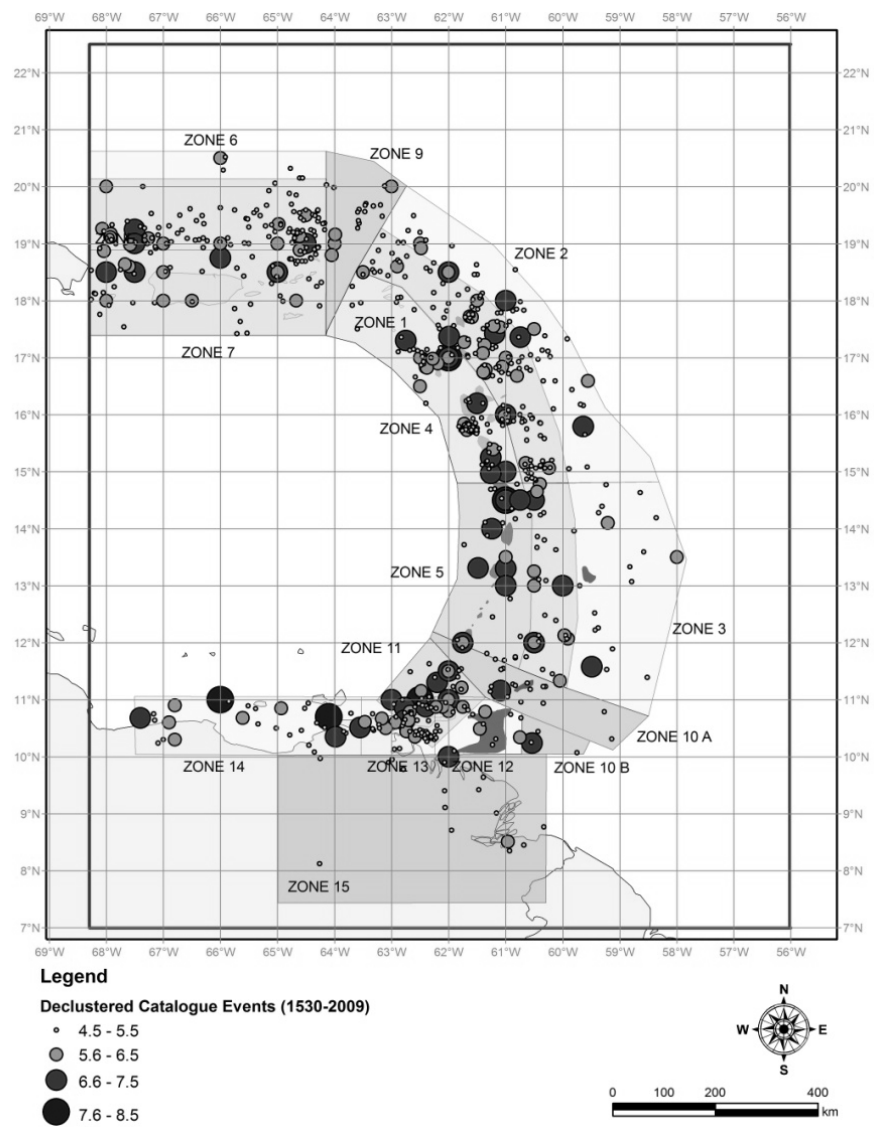
**Fig. 1: Schematic of movement during fault rupture (a) left-lateral strike slip (b) right-lateral strike slip (c) thrust (d) normal**

profiling. The main fault was once considered to be a continuation of the El Pilar fault crossing northern Venezuela into northern Trinidad and passing along the edge of the northern Range. However, Russo (1990) found no evidence of the El Pilar fault west of  $62.3^{\circ}\text{W}$ . More recent research suggests that the Central Range Fault constitutes that segment of the south-east corner of the Caribbean plate (Weber 2010; 2007). Other significant faults are the Los Bajos fault cutting the south-west peninsula in a N.W. – S.E. direction, El Soldado fault in the Gulf of Paria (Russo 1990) and the South-West Tobago Fault System in south-west Tobago (Snoke *et al.* 2001). The last of these is the only fault, with which earthquakes have been confidently associated (Latchman 1998; Morgan *et al.* 1988).

After more than 50 years of seismic monitoring in the Eastern Caribbean, identifying seismogenic zones has been recognised as being important in quantifying the seismic hazard. Fig. 3 shows the most recent partitioning of the region into zones with distinct characteristics.



**Fig. 2: Fault traces in the vicinity of Trinidad & Tobago (from Geologic-Tectonic Map, 1984 produced by Dr. Krishna Persad published by Robertson Research International Limited, (U.S.) Inc.)**



**Fig. 3: Boundaries of the 15 seismogenic zones identified in the Eastern Caribbean. Circles denote earthquake epicenters used in the analysis (after Bozzoni *et al.* 2011)**

In this arrangement, the Trinidad and Tobago area falls within Seismogenic Zones (SZ) 10A, 10B, 11, 12, 13-14 and 15.

*Seismogenic zone 10A: Vicinity of Tobago* was considered to be of low seismic hazard based on the low level, low magnitude output expression until 1982, when an earthquake sequence, in the south-west Tobago area, began in August and culminated on 20<sup>th</sup> September with an earthquake of mb 5.2. Aftershocks continued for many months thereafter. In the area west of Tobago there are episodic moderate magnitude earthquakes with the largest, during the instrumental era, occurring on 1997/04/02 with duration magnitude<sup>1</sup>, Mt 5.6. The depths are usually greater than 15 km. On the other hand, the area south of Tobago, while comparable with activity west of Tobago with regard to output pattern, earthquakes in this area occur, in general, at depths less than 15 km. The largest magnitude earthquake during the instrumental era was Mt 6.1 and occurred on 1997/04/22. This event caused at least TT\$18M worth of damage in Tobago (Latchman 2009; Weber 2009 and Burmester et al., 1996).

*Seismogenic zone 10B: East of Trinidad* was considered to be of low seismic hazard based on the low level, low magnitude output expression until 1988, when on 10<sup>th</sup> March, an earthquake with Mt 6.3 occurred east of Trinidad and effectively switched on that zone. Since that time, the zone has generated episodic moderate magnitude earthquakes. Earthquakes located in this zone are consistent with the detachment and bending-flexure of the South American slab which moves toward the collision zone (Russo and Speed, 1992). The zone is mainly characterized by normal faulting mechanism with ENE/WSW striking planes and strike slip faults with an average depth of 45 km.

*Seismogenic zone 11: North of Paria Peninsula* exhibits high level background seismicity and low magnitude earthquakes have been observed in the area from the earliest days of

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<sup>1</sup> The Seismic Research Unit uses a duration magnitude, Mt, which was derived to be consistent with body-wave magnitude, m<sub>b</sub>, (Shepherd and Aspinall, 1983). It is defined as:  $Mt = -0.705 + 2.073 \log_{10} \tau + 0.0018R$  where  $\tau$  is signal duration in seconds and  $R$  is hypocentral distance in km.

instrumental recording. The zone represents one of the most active seismogenic sources in the Eastern Caribbean (Russo et al. 1993; SRC, 2009). Historical accounts identify this zone as hosting the largest known magnitude earthquake in the Trinidad and Tobago area (Grases 1990) as noted earlier. This zone constitutes a subducting detached oceanic lithosphere with depth ranging from 50 to 300 km. The focal mechanisms indicate that normal faulting results from the initial flexure of the down going slab with a steeply NW-dipping of 60°. However, mixed-motion earthquakes with thrust and strike slip indicates bending of the subducting slab at greater depths.

*Seismogenic zone 12: Trinidad Faults.* This zone includes the faults mapped in Trinidad namely, the Northern-Range, Central Range, Darien Ridge, Arima and Los Bajos Fault. It manifested diffuse low level, low magnitude seismicity characterized by earthquakes with depths less than 50 km (SRC, 2009). This began changing from 2001 with the occurrence of a swarm of earthquakes in the Toco area; then in December 2004 an Mt 5.5 earthquake occurred near the east coast of Trinidad. This was followed in September 2006 by an Mt 5.8 event in north-west Trinidad, under the Northern Range. The historical accounts include an earthquake on 1825/09/20 that generated Modified Mercalli Intensity (MMI) VIII on land Trinidad (Robson 1964). The distribution of intensities for this earthquake suggests that this earthquake may have been located in Zone 12, on land Trinidad. Based on observations during the instrumental era, its magnitude would have been greater than 5.8.

*Seismogenic zones 13-14: El Pilar fault.* These zones comprise the boundary between the Caribbean and the South American plates. Earthquakes generated by the El Pilar fault in the northern coast of South America are shallow events, with depth less than 50 km and mainly characterized by right lateral strike slip mechanisms. The Caribbean plate is moving at about 20

mm/yr in an easterly direction relative to South America (Pérez et al., 2001). However, thrust focal mechanisms also take place in this region reflecting the oblique collision at crustal levels between the Caribbean and the South American Plates. A high level of seismicity characterizes SZ13, while a moderate seismicity level characterizes SZ14.

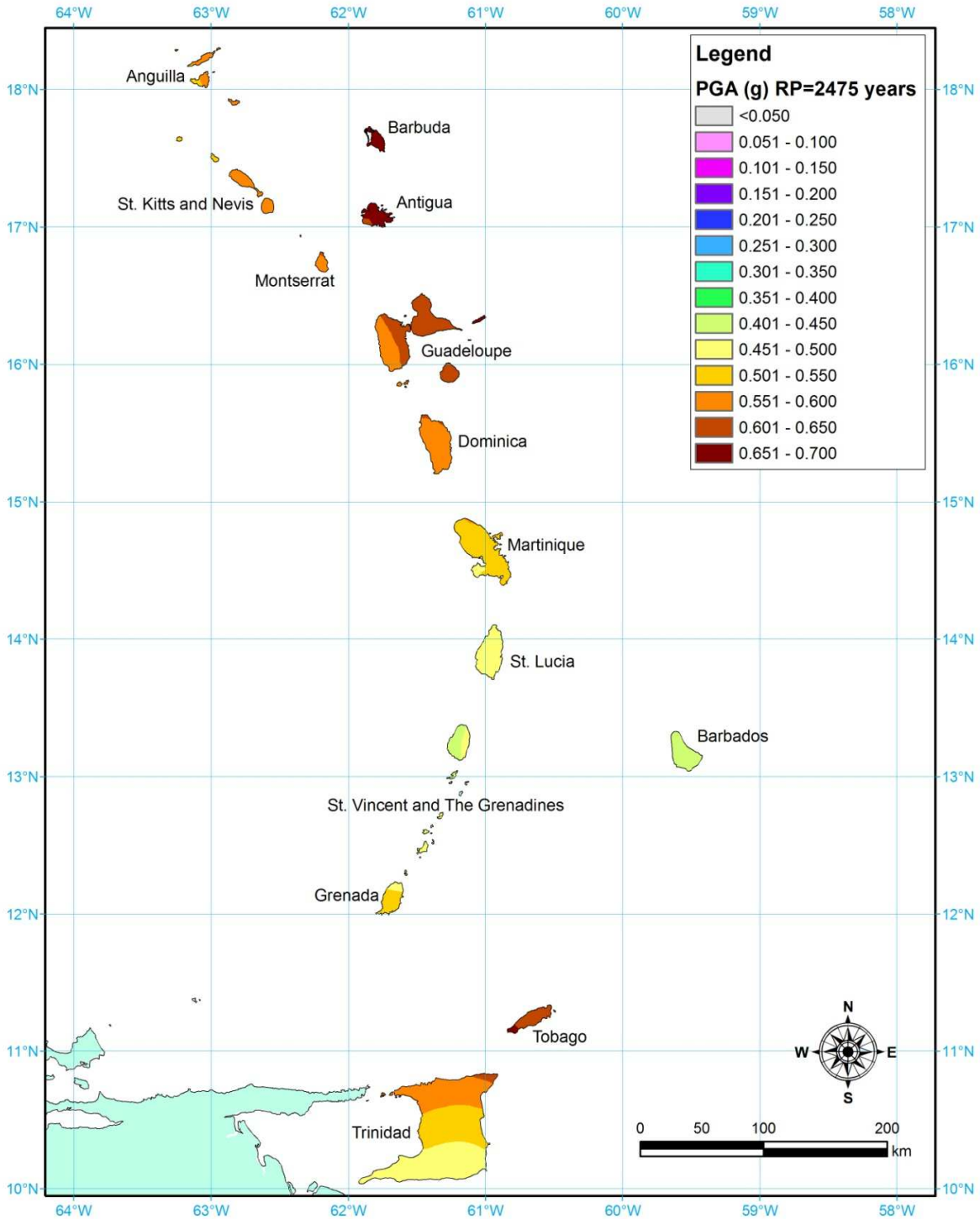
*Seismogenic zone 15: South of Trinidad* exhibits a low seismic output, with episodic moderate magnitude earthquakes. Russo *et al.* (1993) defined this zone as a passive margin in the north of South American continent. It includes events with strike-slip, mixed thrust and strike-slip and thrust mechanisms around the Orinoco-Delta region in Venezuela, with an average depth of 50 km.

### **Earthquake Hazard Analysis**

All of the data on the seismic activity in the Eastern Caribbean have been processed by an analysis technique that quantifies the highest level of shaking that a particular location may be subject to at a future time. The results are displayed by way of maps of expected Peak Ground Acceleration (PGA) within a defined Return Period (RP). Fig. 4 shows that accelerations of 0.55-0.60 g can occur on land Trinidad, with the higher values expected in the Port of Spain area.

### **Potential impact from accelerations of 0.55 -0.60 g in Port of Spain**

The built structures in Port of Spain fall into four main categories – wooden buildings, unreinforced masonry i.e. hollow clay blocks, reinforced concrete buildings and steel frames, which may be single storey structures, multi-storey facilities, and high-rise buildings. The City is home to residential buildings, business establishments, power generation facilities, hospitals



**Fig. 4 Map of PGA (g) for 2475 years return period for the Eastern Caribbean islands on rock sites conditions (after Bozzoni et al., 2011).**

and hotels. Vulnerabilities in these structures arise from the brittle connections and poor load bearing capacity. Given known construction practise past and current, expected impact would take the form of damage ranging from severe to catastrophic. Ground failure would be expected in much of the reclaimed areas leading to loss of function of structures located there.

### **Mitigation Measures**

Development in Trinidad and Tobago is in large measure being carried forward on the strength of a non-renewable, hydrocarbon resource. This means that in the event of a major disaster, previous development gains may be lost and never recovered. Therefore, it is essential that every effort to ensure continuity with minimum setback be made. This should take the form of site investigations to determine the strength of ground, assessing existing structures and retrofitting to necessary levels. This would require continuing training for small scale construction contractors and workers. These measures must be carried forward in the context of a legislated Building Code with enforcement thus ensuring that all new structures are constructed to be earthquake resistant based on the level of hazard identified in Fig. 4. Land use planning should guide all future development and in the case of critical facilities currently in vulnerable locations, a schedule for relocation would not be an excessive response.

### **Conclusions**

Much has been learned about earthquake hazards in the Eastern Caribbean since the written records began. Now, more than two centuries after an earthquake destroyed the first capital of Trinidad, we have sufficient information to adopt measures to mitigate the effects of a major earthquake, both individually and nationally. Implementation, with a well thought out

programme, will require effort and will involve costs that, in the current economic climate, may contribute to setting it at a low priority. However, ignoring the known hazards does not make them go away and the consequences of a major earthquake that affects Trinidad could far outweigh, based on figures from other parts of the World, the costs of implementation. The terrible devastation that can be wrought by earthquakes was recently seen in Haiti in January 2010 and in Japan in March 2011. Earthquakes will continue to occur every day somewhere in the world and one day, a major earthquake will occur close to one of our islands. If we are truly wise and preparing for our future, this reality must factor into all our development plans.

## REFERENCES

- Bozzoni, F., M. Corigliano, C. Lai; W. Salazar, L. Scandella, E. Zuccolo, J. Latchman; L.Lynch, R. Robertson. (2011). Probabilistic Seismic Hazard Assessment for the Eastern Caribbean Islands. *Bulletin of the Seismological Society America*.
- Burmester, R., M. Beck, R. Speed and A. Snoke (1996). A preliminary paleomagnetic pole for mid-Cretaceous rock from Tobago: further evidence for large clockwise rotations in the Caribbean-South American plate boundary zone, *Earth and Planetary Science Letters* **139**, pp. 79-90.
- Fowler. C.M.R. 1990. *The Solid Earth. An Introduction to Global Geophysics*. Cambridge: Cambridge University Press.
- Grases, J. 1990. *Terremotos Destruyentes del Caribe 1502-1990. Una contribución al Decenio Internacional para la Reducción de los Desastres Naturales*. Caracas: UNESCO - RELACIS.
- Latchman J.L. 1998. Seismic potential of the S.W. Tobago fault system. M.Phil thesis. St. Augustine. The University of the West Indies.
- Latchman J.L. 2009. Tobago and Earthquakes. Ph.D. thesis. St. Augustine. The University of the West Indies.
- Marshall, J.L. and R.M. Russo. 2004. Relocated aftershocks of the March 10, 1988 Trinidad earthquake: Normal faulting, slab detachment and extension at upper mantle depth. *Tectonophysics* 398: 3/4: 101-114.
- Morgan, F.D., G. Wadge, J. Latchman, W.P. Aspinall, D. Hudson and F. Samstag. 1988. The earthquake hazard alert of September 1982 in southern Tobago. *Bulletin of the Seismological Society America*. 78(48): 1550-1562.
- Mocquet, A. 2007. Analysis and interpretation of the October 21, 1766 earthquake in the southeastern Caribbean. *Journal of Seismology* 11: 381-403.
- Pérez, O. J., R. Bilham, R. Bendick, J. Velandia, C. Moncayo, M. Hoyer and M. Kozuch (2001), Velocity fields across the southern Caribbean Plate boundary and estimates of the Caribbean/South American plate motion using GPS geodesy 1994-2000, *Geophysical Research Letters* **28**, no. 15, 2987-2990.
- Persad, K. 1984. *Tectonic-Geologic map of Trinidad and Tobago*. Houston: Robertson Research International Limited, (U.S.) Inc.
- Robson, G.R. 1964. An earthquake catalogue for the Eastern Caribbean. *Bulletin of the Seismological Society of America*. 54(2): 785-832.

- Russo, R.M. 1990. Seismicity, Gravity Anomalies, and the Tectonics of the Southeastern Caribbean. Ph.D. Thesis. Evanston, Illinois. Northwestern University.
- Russo, R. M. and R. C. Speed (1992). Oblique collision and tectonic wedging of the South America continent and Caribbean terrains, *Geology* **20**, 447-450.
- Shepherd, J.B. and W.P. Aspinall. 1983. Seismicity and earthquake hazard in Trinidad and Tobago, West Indies. *Earthquake Engineering and Structural Dynamics* 11: 229-250.
- Snoke, A.W., D.W. Rowe, J.D. Yule and G. Wadge. 2001. Petrologic and structural history of Tobago, West Indies: A fragment of the accreted Mesozoic oceanic arc of the southern Caribbean. *Geological Society of America Special Paper*. 354: 54pp.
- SRC - Seismic Research Centre. (2009). Eastern Caribbean Earthquake Source Zones and *\*b*-values, The University of the West Indies, Trinidad and Tobago, W.I.
- Topozada, T. R., D. M. Branum, M. S. Reichle and C. L. Hallstrom . 2002. San Andreas Fault Zone, California:  $M \geq 5.5$  Earthquake History. *Bulletin of the Seismological Society of America*. 92:(7): 2555-2601.
- Weber, J. (2007): Neotectonics in the Trinidad and Tobago, West Indies segment of the Caribbean-South American Plate boundary. Occasional Papers of the Geological Institute of Hungary, Volume 204.
- Weber et al. 2010; *Geology*, doi: 10.1130/G30927.1 v. 38 no. 8 p. 675-678 ; Prehistoric earthquakes on the Caribbean-South American plate boundary, Central Range fault, Trinidad.
- Wood, H.O. and F. Neumann. 1931. Modified Mercalli intensity scale of 1931. *Bulletin of the Seismological Society of America*. 21:(4): 277-283.