The Earthquake of January 13, 1993, and Implications for Earthquake Hazard in eastern Jamaica

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Abstract

On January 13, 1993, an earthquake of duration magnitude 5.4 and maximum Modified Mercalli Intensity VII occurred in Eastern Jamaica. The hypocentre was 15 km underneath the rural community of Woodford, in the southern Wagwater Belt. The latter is a fault-bounded, narrow, uplifted, northwest trending trough, separating the Liguanea Plains to the south, from the Blue Mountains to the northeast. The seismic activity of the Wagwater Belt was known from the numerous small earthquakes recorded by the Jamaica Network of Seismograph Stations over the past thirty years. However, the January 13 earthquake was the first earthquake of this size confirmed as having originated in the Belt. Hence, it was also seen as the first indication that the Wagwater Belt may be a source zone for larger Jamaican earthquakes.

First motion data indicate reverse faulting with a component of left-lateral strike-slip. This is consistent with the view of Mann et al. (1985) that the Wagwater Belt is a push-up restraining bend. Furthermore, the earthquake appears to have originated on a buried fault, which is not featured on current Geological Maps of the island. However, a fault having the same trend was mapped by Matley (1951) and more recently, it appears on maps by Mann and Burke (1990).

With the January 1993 event, new knowledge about the earthquake potential of land-based Jamaican faults has been gained. This has serious implications for earthquake risk in eastern Jamaica, particularly since Jamaica's capital city, Kingston, the island's seat of government and commerce, and home to nearly 800,000, is sited on the Liguanea Plain. Former hazard assessments were made with the belief that faults such as the Oriente Fracture Zone, the Northern Caribbean Plate Boundary which lies some 100 km off Jamaica's north coast, posed the major threat to Kingston, due to amplification of far source seismic waves in the alluvial sediments. It now seems plausible that the historic incidence of twenty damaging earthquakes per century reported by Shepherd (1971) could be the result of seismic activity on Jamaica itself.

Introduction

Except for damage observations, little is known about the nature of early Jamaican earthquakes. On June 7, 1692, an earthquake devastated the city of Port Royal, killing 2,000 inhabitants out of a population of 8,000 (Black, 1988). The intensity of that earthquake was X on the Modified Mercalli (MM) Scale (1956 version). The capital city was relocated across the harbour to Kingston. On January 14, 1907, 215 years later, Kingston experienced a high intensity earthquake (MM IX) in which 1,000 persons perished and tens of thousands were left homeless (Tomblin and Robson, 1977). Kingston was rebuilt in the same place and remains the largest city in the English-speaking Caribbean, with a population of close to 800,000. Neither the 1692 nor the 1907 earthquakes were repeated in the 325-year documented history of felt earthquakes in Jamaica (Tomblin and Robson, 1977). Nevertheless, eight other earthquakes with Modified Mercalli intensities of VII to VIII have affected eastern Jamaica (Table 1). The most recent of these occurred on January 13, 1993.

Table 1. Most damaging Earthquakes in Eastern Jamaica

Year	Date	Max MM Int.	Area Affected	Type of Damage
1667	unknown	VIII	East Jamaica	Landslide.
1688	March 1	VII	Port Royal	Houses and Ships in port damaged
1692	June 7	X	Whole Island	3000 dead, buildings collapsed, liquefaction, fissures, subsidence, landslides.
1771	September 3	VII	Port Royal, Kingston	Damage to structures, felt on boats in port.
1812	November 11	VIII	Kingston	Several people killed, walls fell, buildings damaged.
1824	April 10	VII	Kingston,Spanish Town, Old Harbour	Loud noise accompanied shock, some houses fell.
1906	February 27	VII	East Jamaica	Landslide, walls of buildings cracked, chapel lost ornamentation.
1907	January 14	IX	Kingston, Port Royal	1,000 dead, fires over 56 acres, most buildings collapsed, water mains broken, landslides and offshore slumps, damage put at 2M pounds sterling.
1914	August 3	VII	Eastern Jamaica	Buildings cracked, doors and windows out of plumb, clocks stopped, stocks in drug stores broken.
1993	January 13	VII	Eastern Jamaica	2 dead, items thrown off shelves in stores and homes, landslides, offshore slumps, weak buildings collapsed, reinforced engineered buildings suffered some damage.

(Sources: Tomblin and Robson, 1977; Sloane, 1809; EQU data, 1993)

Unlike earlier, high intensity Jamaican earthquakes, the January 1993 event was recorded by the Jamaican Network of Seismograph Stations. These records indicated that the earthquake originated in the Wagwater Belt, some 10 km north of downtown Kingston (Figure 1). It contradicted the earlier conclusion that the causative faults were the Oriente Fracture Zone and associated east-west faults off Jamaica's north coast (Figure 2) (Shepherd and Aspinall, 1980). The data from the January 13 event is presented in this paper.

This work is particularly important when considering seismic hazard in Kingston. The city is built on the abandoned alluvial flood plain of the Hope River, which now flows less than 10 km east of the city. The plain has a slope of one in 40 m, and a water table that shallows with proximity to the harbour. Some of the land bordering the harbour is reclaimed swamp; the sediments of the Liguanea Plain are fairly stiff but unconsolidated. In past earthquakes, these sediments exhibited liquefaction features, slumping near the coast, and the highest frequency of damage compared to the rest of Jamaica. It was commonly accepted that the high rate of damage was due to the soft-soil amplification of seismic waves from the offshore sources mentioned above (Shepherd, 1971). The ample local recording and analysis of the 1993 event provided, for the first time, a basis for comparing instrumental source parameters with macroseismic data for a significant eastern Jamaica earthquake. In addition,

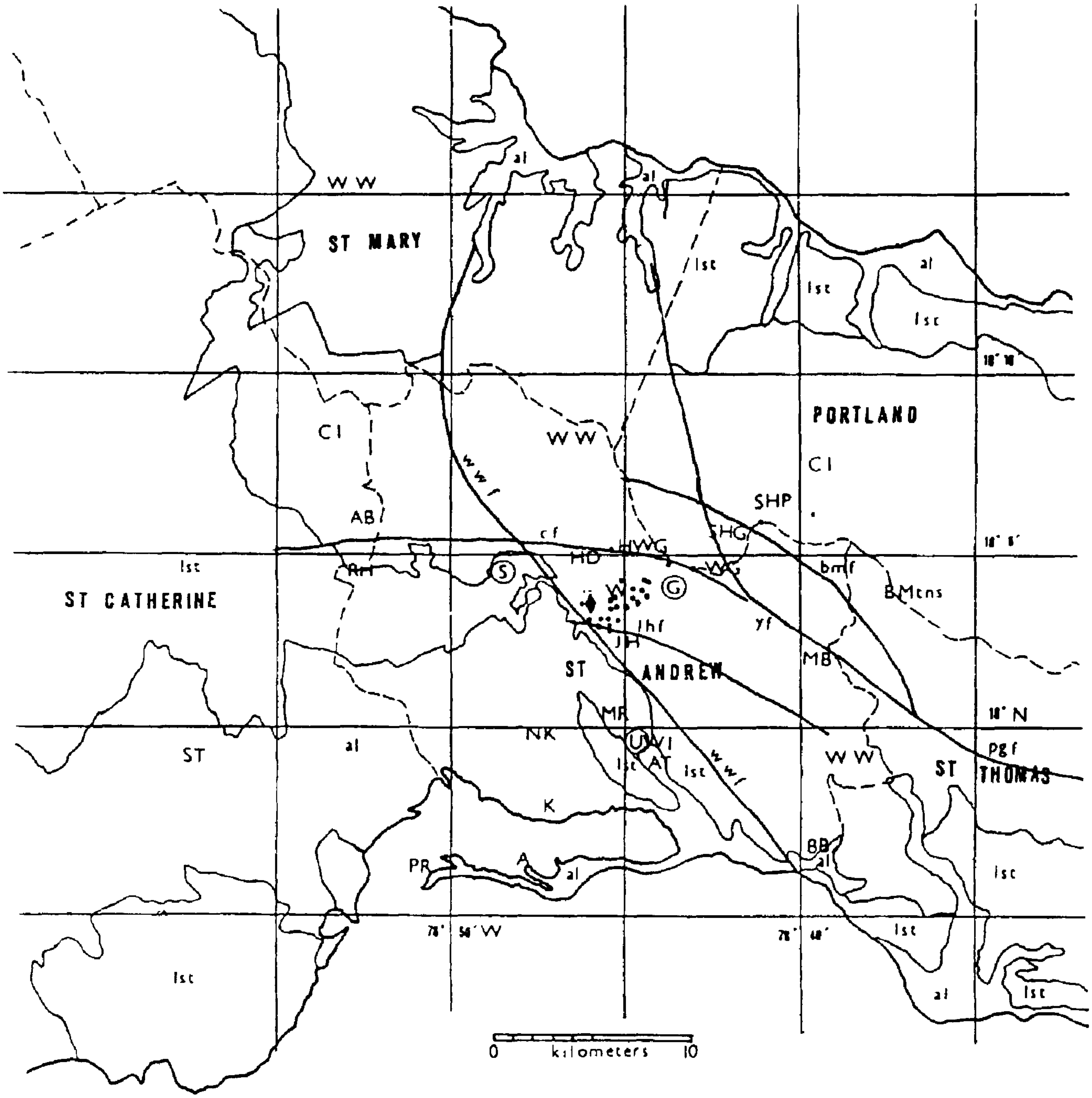


Figure 1. Location map showing the 5-Parish area affected most by the January 1993 earthquake. MD 5.4, MMI VII. Diamond = Epicentre of Main Shock; small solid circles - Epicentres of aftershocks; Circled S, G and U = stations in the Jamaica Seismograph Network; Towns and Places:- UWI = University of the West Indies - Mona Campus; AT = August Town; A = International Airport; PR = Port Royal; K = Kingston; NK = New Kingston; MR = Mona Reservoir; ST = Spanish Town; RH = Rock Hall; AB = Above Rocks; HD = Hermitage Dam; JH = Jack's Hill; BB = Bull Bay; MB = Mavis Bank; W = Woodford; HWG = Hardwar Gap; WG = Woodcutter's Gap; SHG = Silver Hill Gap; SHP = Silver Hill Peak; BMtns = Blue Mountains; Geology:- al = Alluvium and Coastal Group; lst = limestone; WW = Wagwater Belt and formations; CI = Cretaceous Inlier; Faults:- pgf = Plantain-Garden Fault; wwf = Wagwater Fault; yf = Yallahs Fault; bmf = Blue Mountain Fault; jhf = Jack's Hill Fault; cf = Cavaliers Fault. Parish names in bold uppercase letters.

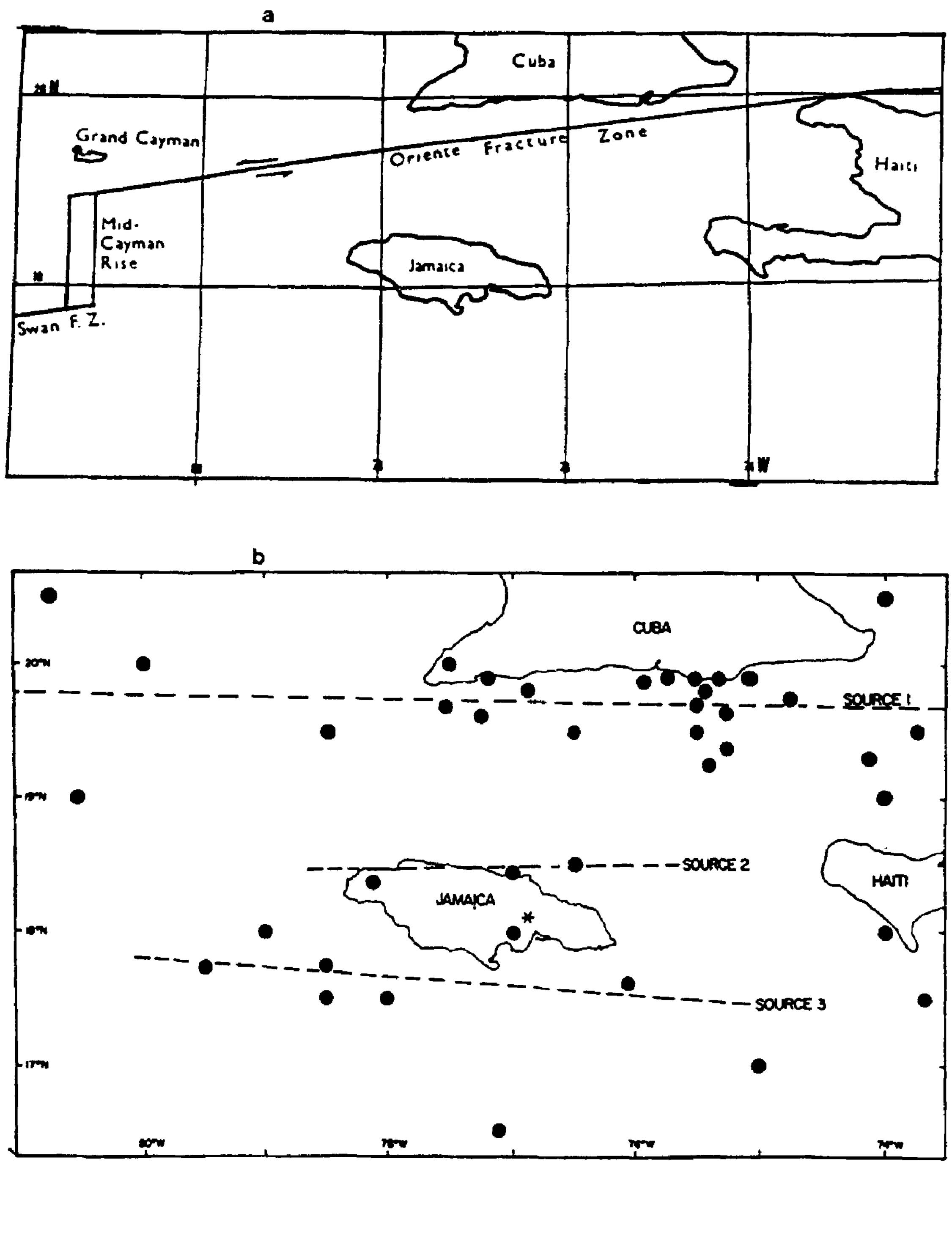


Figure 2: (a) Original concept of the North-Caribbean Plate Boundary (after Jordan, 1975); (b) Interpretation of Jamaican Seismic Sources (after Shepherd and Aspinall, 1980).

the comparison of the 1993 intensity map with intensity maps of earlier (hypocentre parameters unknown) events raises the very important issue of whether events such as the 1692 Port Royal earthquake and the 1907 Kingston earthquake may have been generated on land-based faults such as exist in the Wagwater Belt.

Geological and Tectonic Setting

The island of Jamaica is the site of an ancient island arc that was subjected since Cretaceous times to episodes of uplift and submergence, and even renewed volcanism (Jamaica-Geology, 1984). In eastern Jamaica, particularly the Wagwater Belt, this history is readily depicted in the strata (Kingston Sheet, 1984). Recent geological work has shown the Wagwater belt to be an area of transpression, a push-up restraining bend in a 600 km long fault, which runs form southern Haiti, through Jamaica, to meet the Swan Fracture at the southern end of the Cayman spreading centre (Figure 3) (Mann et al., 1985). This restraining bend is responsible for the marked elevation of the Blue Mountains, which is over 2,000 m high and is still said to be rising.

A rugged topographic high parallels this fault across the island from east to west. According to Mann and Burke (1990), the transpressive zone represents a linking of two east-west strike-slip faults, namely the Plantain-Garden Fault of southeast Jamaica and the Duanvale Fault of north Jamaica. Essentially, the Wagwater Belt is the zone where this link takes place, the proposed right-step forming the restraining bend. The trend of the Belt is northwesterly. It is bounded on the northeastern side by the Yallahs and Blue Mountain Faults and on the southwestern side by the Wagwater Fault. Northeast of this feature is the Blue Mountains. The Jack's Hill and Cavaliers faults are smaller cross-cutting nearly east-west faults which complete the picture of known faulting in the area and whose association in the structure of the area are not well understood.

Seismology and Hazard Review

Seismological and risk studies on Jamaica have been largely based on intensity data and the knowledge of the proximity of the Northern Caribbean plate boundary, the Oriente Fracture Zone (Shepherd, 1971; Tomblin, 1976). Without instrumental data to verify earthquake origins, it was logical that an effect-and-cause relationship developed between the two. Attempts by some authors to place epicentres at meisoseismal zones were dismissed on the grounds that land-based Jamaican faults were not long enough to generate the larger damaging Jamaican events (Taber, 1920). For example, the Wagwater Fault was described as consisting of a series of short segments bounding the Wagwater Belt and there was no corroborated evidence of any long surface breaks caused by damaging Jamaican earthquakes (Shepherd, 1971; Tomblin, 1976).

The high incidence of damage in Kingston especially was attributed to amplification of incident seismic waves from offshore sources by the deep alluvial sediments (Shepherd and Aspinall, 1980). Hence, it was perceived that long period energy was the main threat in the Kingston area.

Methods

In this work, another look was taken at the intensity data of larger historic Jamaican earthquakes (Figure 4). Much of this data came from the Tomblin and Robson (1977) catalogue and hence their interpretations of primary and secondary sources of data. Some original sources (Sloane, 1809; Rev. Kilburn's Diary, 1907) were made available to the author in the case of the 1692 and 1907 earthquakes and these were relied on heavily for the reinterpretation of intensity data.

A local telemetered seismograph network has existed in Jamaica over the past thirty years. Though the network consisted of between one and ten stations, for most of the time less than three stations operated. However, between 1983 and 1985 and again, from 1991 to

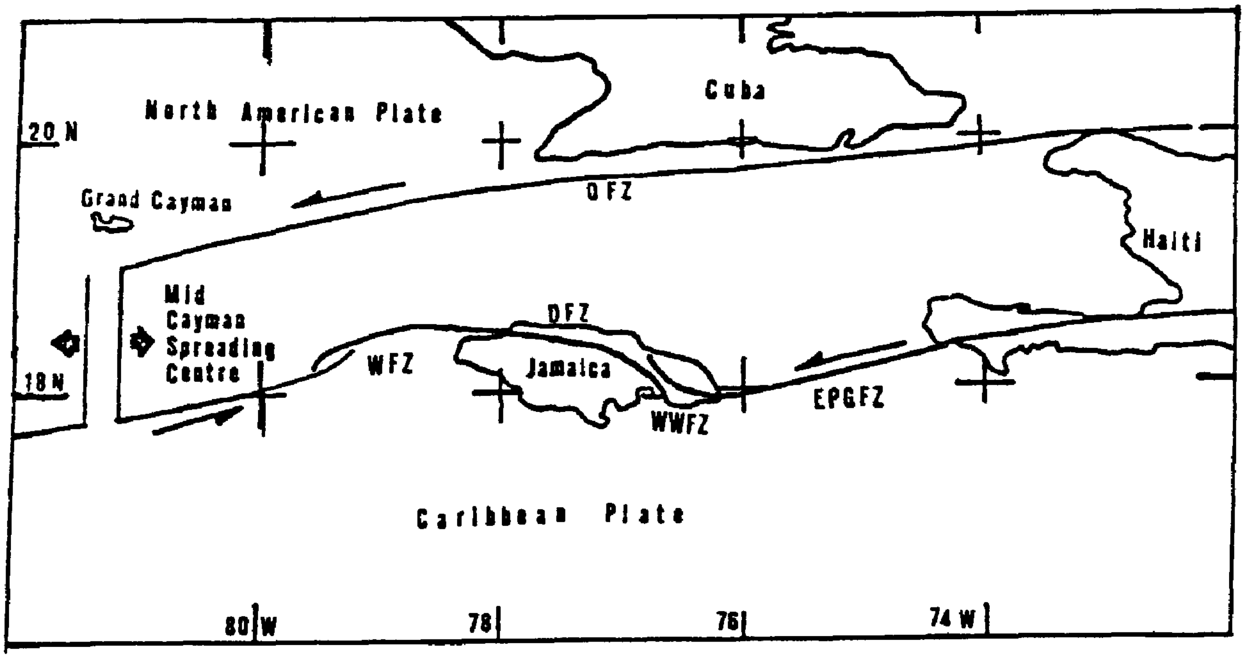
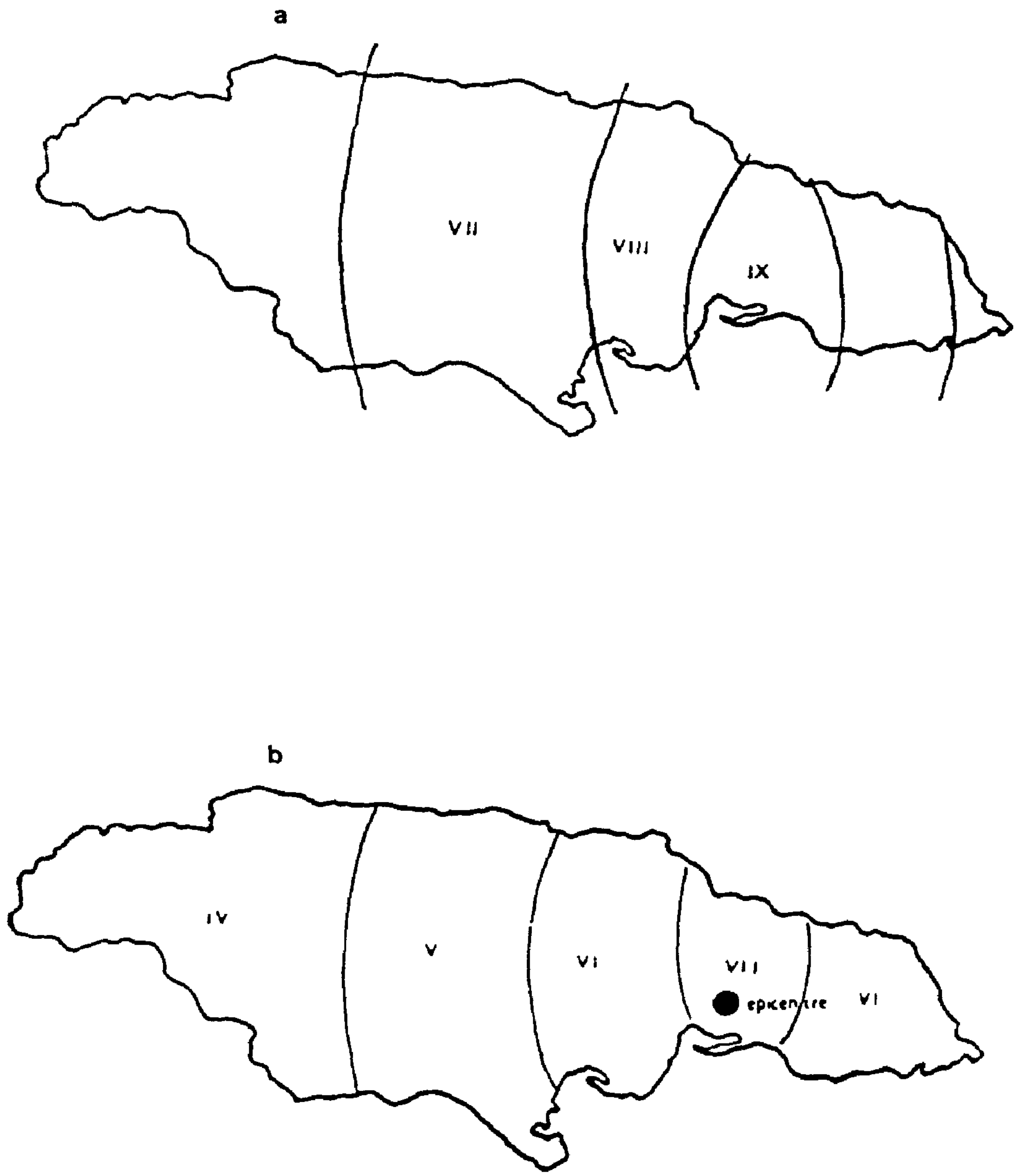


Figure 3: New Concept of the Northern Caribbean Plate Boundary showing the 600-km long Enriquillo-Plantain-Garden-Duanvale-Walton Fault. OFZ – Oriente Fracture Zone; EPGFZ = Enriquillo-Plantain-Garden Fault Zone; WWFZ = Wagwater Fault Zone; DFZ = Duanvale Fault Zone; WFZ = Walton Fault Zone (after Mann *et al.*, 1985; Mann and Burke, 1990).



MODIFIED MERCALLI INTENSITIES

(approximate boundaries)

Figure 4: (a) Isoseismal map of the 1907 earthquake, after Maxwell Hall, 1922; (b) Isoseismal map of the 1993 earthquake.

present, eight short-period vertical stations have formed the basic network. Since 1990 the network has benefited from digital data acquisition and processing with the Soufriere system developed by the Seismic Research Unit, UWI, St. Augustine. Data collected at the Earthquake Unit for the period 1991-93 formed the instrumental data set used in this study. Thirty-two aftershocks were located out of the 200 recorded for the January 13 event. These were used to estimate the rupture area and the orientation of the fault from their spatial distribution. A plot of the aftershock decay rate was also done (Figure 5), but is fairly meaningless at this time, having no previous Jamaican aftershock data for comparison. Hauksson and Jones (1989) mentioned that a rapid fall off in aftershocks might indicate high stress drops and completion of the rupture while prolonged sequences indicated lower stress drops in the initial rupture.

First motion data were obtained from the earthquake Data Reports (1993) published by the National Earthquake Information Center in Golden, Colorado, and from the Centre of Coordination for Prevention of Natural Disasters in Central America (CEPREDENAC). These were used to obtain a fault plane solution for the January 1993 earthquake. A number of ambiguities were found, and were excluded from the usable data, thereby reducing the number of stations used from 66 initially to 47.

The January 13 Earthquake

The earthquake of January 13, 1993, was located at 18.060 °N, 76.766 °W, 15.2 km deep in the Wagwater Belt of eastern Jamaica. Errors in the epicentral coordinates should not be more than 3 or 4 km, while the depth is expected to be much more accurate. These errors are not smaller because arrival times at Jamaican stations for the main shock were read from paper records. The duration magnitude was 5.4 and maximum intensities of VII on the Modified Mercalli Scale were reported within a radius of about 15 km around the epicentre. No surface rupture was apparent, but locations of 32 aftershocks indicated a rupture depth extending from 4 to 18 km. The aftershocks defined a fault with dimensions of 12 km in a northeasterly direction, and 4 km northwesterly (Figure 5).

The fault plane solution showed predominantly reverse faulting on a plane striking 60° from North, dipping 40° to the southeast, with a small amount of left-lateral strike slip movement (Figure 6). The epicentre of the earthquake coincided closely with the meeting point of the east-west trending Jack's Hill Fault with the northwest trending Wagwater Fault. The fault plane solution above matches the orientation of neither of these faults. Instead, it matches an un-named fault shown by Matley (1951) in an unfinished work. The trend of the aftershocks, starting from the Jack's Hill suburb, through Woodford, past Hardwar and Woodcutter's Gaps, and on to Silver Hill Gap, then Silver Hill Peak (Figure 5) also matches Matley's fault. This is entirely consistent with Mann and Burke's (1990) theory of an almost north-south compressive stress regime with east-west extension in the area under consideration. Mann and Burke (1990) went on to describe a conjugate pattern of faulting in Jamaica, with the northwest branches being more apparent. Two northeast trending faults were identified: the Cuffy Gully Fault which runs from Annotto Bay, St. Mary, on the north coast, to Vere in Southern Clarendon, and a fault which appears to be the same as Matley's fault, the fault which generated the January 1993 earthquake.

If Matley's Fault follows the trend of the Cuffy Gully Fault, then it is feasible that it continues southwest of Jack's Hill, through the bedrock underlying the Liguanea Formation, i.e., the city of Kingston. In fact, the data set from the Jamaica Network of Seismograph Stations consists of a number of small earthquakes having epicentres in the centre of the Plain. Moreover, the data from 1977 to 1985, which was originally interpreted to align with mapped northwest trending faults, can more easily be interpreted to align with lineaments such as Matley's Fault and the Cuffy Gully Fault (Figure 7).

The suggested scenario of movement on Matley's Fault conforms with the "blind thrust" described by Hauksson and Jones (1989) in a paper on the Whittier Narrows earthquake in California. Blind thrust faults, as the name implies, do not rupture the surface but cause

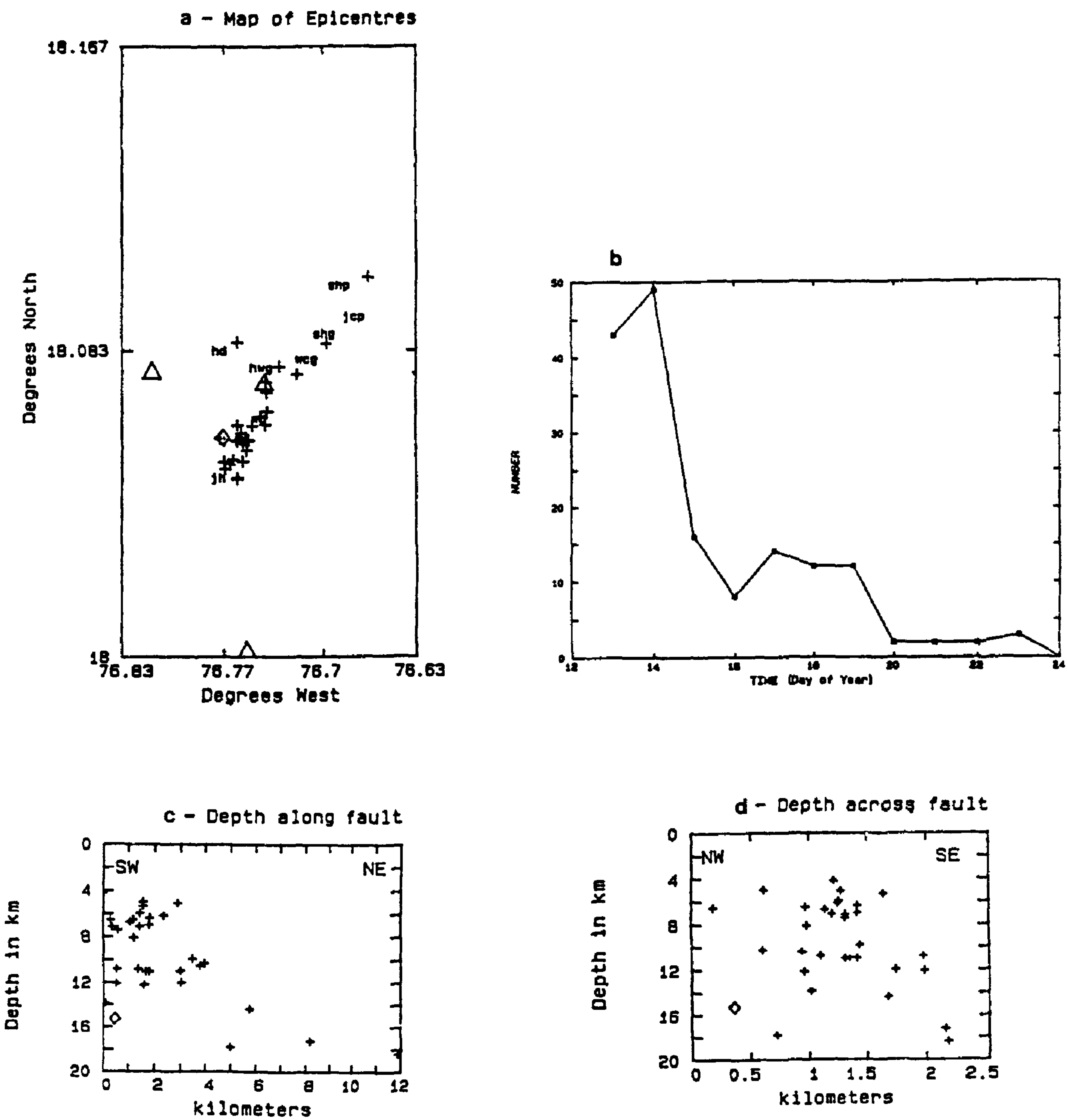


Figure 5: After shock data (a) Epicentres of Main Shock (Diamond) and aftershocks (pluses); (b) fall off in number of aftershocks versus day in January; (c) Depth distribution of main shock and after shocks along the fault; (d) Depth distribution of main shocks across the fault.

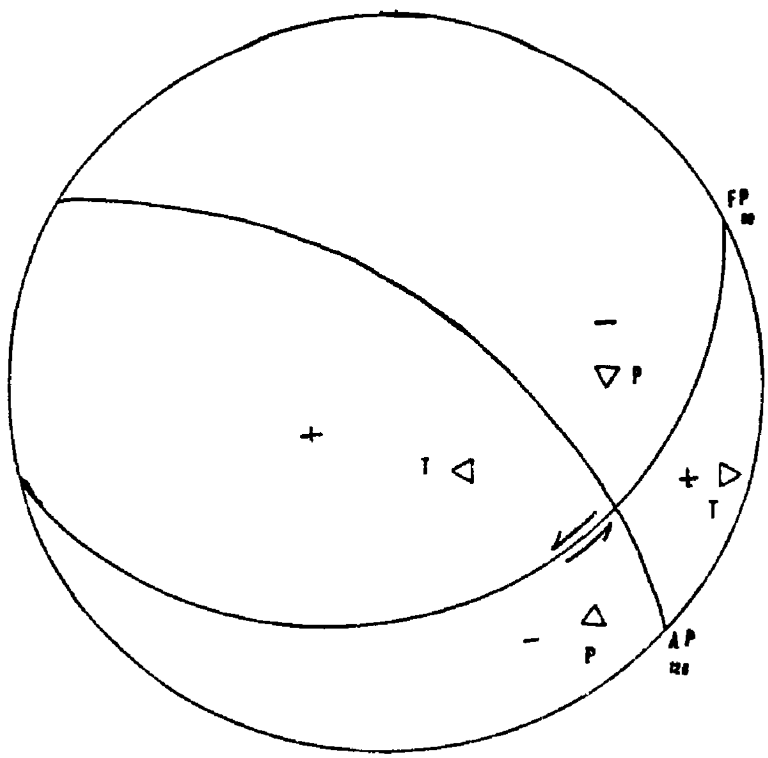


Figure 6: Fault Plane Solution of the Main Shock. Fault Plane N60 degrees, dip 40 degrees; Auxillary plane 126N degrees; dip 72 degrees; slip vector 215N; axis of maximum compression 10N; and maximum tension 256N. Represents reverse faulting with some left-lateral strike slip.

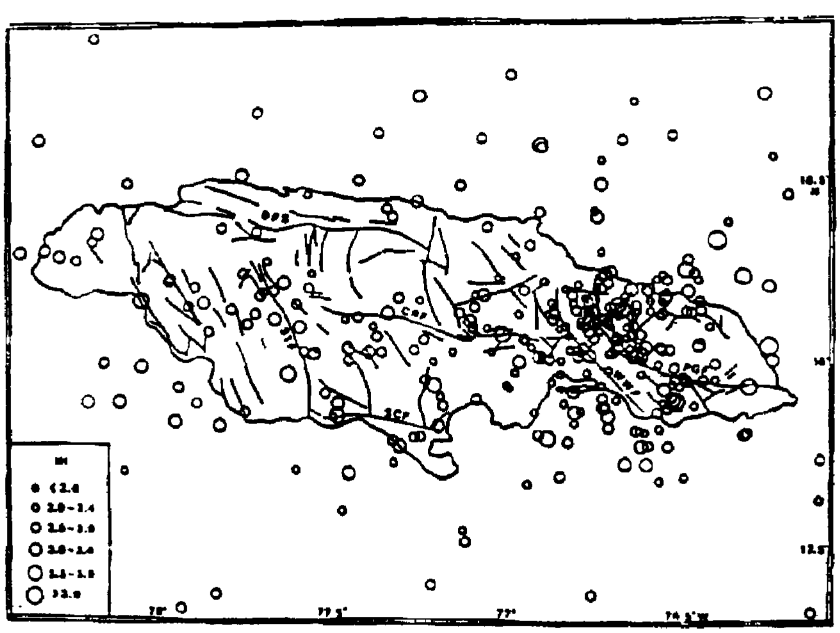


Figure 7: Epicentres from the Jamaica Network of Seismograph Stations from 1977 to 1985 (Shepherd, 1989).

anticlinal deformation and uplift. The uplift rate is then related to the slip rates on the buried fault plane.

The area of most intense damage was a fairly new concrete reinforced block and steel home in Jack's Hill, an upper middle class suburb of Kingston. The house was constructed of masonry and its destruction was extensive. Floors were cracked and shifted, a column split in two, water mains were broken, a pendulum clock stopped and thousands of dollars of non-structural damage resulted, china and ornaments were broken, and a heavy concrete slab garden table top was thrown off its pedestal. Also in Jack's Hill, one householder experienced the shearing off of both toilet bowls at their bases, while another reported that the upward force was so strong that the water from the toilet was splashed on walls of the bathroom. A school in the Woodford area reported that toilet tank tops were thrown off and all framed pictures on the walls were tilted to the north, while a store owner said that a large deep freeze had shifted, blocking a doorway. Two sizeable landslides blocked the roads in the Woodford and Newcastle areas, and a number of unreinforced weak masonry structures within the Woodford to Mavis Bank area collapsed nearly totally. Poorly built concrete structures in August Town suffered irreparable damage.

The damage pattern of the 1993 earthquake is alarmingly identical to that of the 1907 earthquake except that this time the extent of damage is smaller as one would expect from a smaller earthquake. Even the details of two breaks in submarine telecommunications cable to the south of Kingston which occurred in similar locations both in 1907 and 1993 and were believed to have been caused by submarine landslides is cause for concern.

Conclusion

The results suggest above all that the Wagwater Belt and its associated faults must be considered seriously in earthquake hazard assessment in Jamaica and in particular, Kingston. An enormous amount of instrumental based investigation is necessary if we are to properly assess and define the potential earthquake hazard and, hence, if we are to save lives from future earthquakes that will no doubt occur.

If the results of the focal mechanism are accepted, then reverse movement on Matley's fault is apparently a result of accommodation of at least some of the Caribbean Plate-North American Plate boundary slip, whose relative velocity is reportedly about 35 mm/year in a left-lateral sense. In other words the island of Jamaica indeed falls within a broad plate boundary zone perhaps 200 km in width (Burke et al., 1980) and Jamaica can continue to expect disastrous earthquakes as strain is accumulated and periodically released.

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