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WHY THE ATLANTIC GENERALLY CANNOT GENERATE TRANS-OCEANIC TSUNAMIS?

T.S. Murty*, N. Nirupama**, I. Nistor*, and A.D. Rao***

*Department of Civil Engineering
University of Ottawa, Ottawa, Canada
**School of Administrative Studies
York University, Toronto, Canada
***Centre for Atmospheric Sciences
Indian Institute of Technology Delhi, New Delhi

ABSTRACT

For the three oceans with major and concentrated population centers around the coastlines, namely, the Pacific, Atlantic and Indian Oceans, past events as well as numerical models appear to suggest that, while the Pacific and Indian Oceans can support trans-oceanic tsunamis, in general, the Atlantic Ocean cannot. There are seismological and physical oceanographic reasons for this difference in behaviour. It is not that the Atlantic Ocean does not give rise to tsunamis, but they are all generally local and do not impact the whole Atlantic Ocean. This local behaviour of tsunamis in the Atlantic Ocean needs to be taken into account in developing a tsunami warning system.

KEYWORDS: Tsunami, Atlantic Ocean, Lake Agassiz, Halifax Explosion, Canary Islands

INTRODUCTION

Even though, for administrative purposes, it may be convenient to have a global tsunami warning system, this is not feasible for scientific and also socio-economic reasons. The Indian Ocean is connected to the Pacific and Atlantic Oceans in the south through the Southern Ocean, and is not connected to the Arctic Ocean. The Arctic Ocean is connected to the Pacific and Atlantic Oceans in the north. Because of very low population density around it, at present, there is no priority for an Arctic Ocean tsunami warning system. For the Pacific Ocean, the tsunami warning system is in existence since 1948. Until now the Atlantic and Indian Oceans have no tsunami warning systems because tsunami events are rare in these two oceans, as compared to the Pacific Ocean.

For convenience, we will define the following three terms. First, a global tsunami is one which not only propagates throughout the ocean in which it was generated, but also into at least two of the three other oceans, albeit with small amplitudes. Second, a trans-oceanic tsunami is one that propagates throughout the ocean in which it is generated and could cause loss of life and damage even far away from the epicentral area. Third, an ocean-wide tsunami is one which propagates throughout the ocean in which it is generated, but the loss of life and damage are mostly confined to the epicentral area.

There are several major differences among the three oceans with reference to tsunamis. The Pacific Ocean generates major global and trans-oceanic tsunamis, as occurred, for example on the 1st of April 1946 (Aleutian tsunami), on the 22nd of May 1960 (Chilean tsunami) and on the 28th of March 1964 (Alaska tsunami). Even though tsunamis are much less frequent in the Indian Ocean, it is capable of generating global and trans-oceanic tsunamis, such as for example the ones that occurred on the 27th of August 1883 (tsunami from the eruption of the volcano Krakatoa) and on the 26th of December 2004. However, the Atlantic Ocean does not appear to be capable of generating global tsunamis, generally speaking.

There are several well-documented tsunamis in the Atlantic Ocean in historical times. We numerically modelled several of these tsunamis, as will be outlined with some details in the following sections. The numerical simulations of all these tsunami events have one thing in common. The Atlantic Ocean tsunamis generally do not propagate very far with large amplitudes, which is in contrast to the Pacific and Indian Oceans, where the tsunamis travel over trans-oceanic distances, and seem to suffer less dissipation. The reason for this could be that the fault zones in the Atlantic are smaller than those in the Pacific and Indian Oceans. Pacific Ocean, being large in extent, exhibits somewhat different tsunami characteristics from the Indian Ocean, which is much smaller. Reflected waves from distant boundaries do not contribute significantly to the total water levels associated with tsunami waves in the Pacific Ocean. On the other hand, in the Indian Ocean, one has to include boundary reflections to determine the tsunami heights. In the Atlantic Ocean, since most tsunamis occur close to the boundaries, the question of boundary reflections does not arise.

TECTONICS AND SEISMICITY OF THE ATLANTIC OCEAN

Figure 1 shows the major tectonic plates on the globe. The main tectonic feature in the Atlantic Ocean is the mid-Atlantic ridge, which is a divergent plate boundary where new ocean floor is created, but not tsunamigenic earthquakes. This tectonics is quite different from those in the Pacific and Indian Oceans, where there are tectonic converging plate boundaries.

Figure 2 shows the epicenters of tsunamigenic earthquakes in the Atlantic Ocean. There are far fewer tsunamigenic earthquakes here as compared to the Pacific Ocean (the epicenters in the entire Pacific are not shown here). Another interesting point is that the fault zones in the Atlantic are fewer and not as wide-spread as in the Pacific and also probably with less extension. This may explain the relative rarity of tsunamis in the Atlantic in general. The tsunamis that occur appear to be generally in the margins.

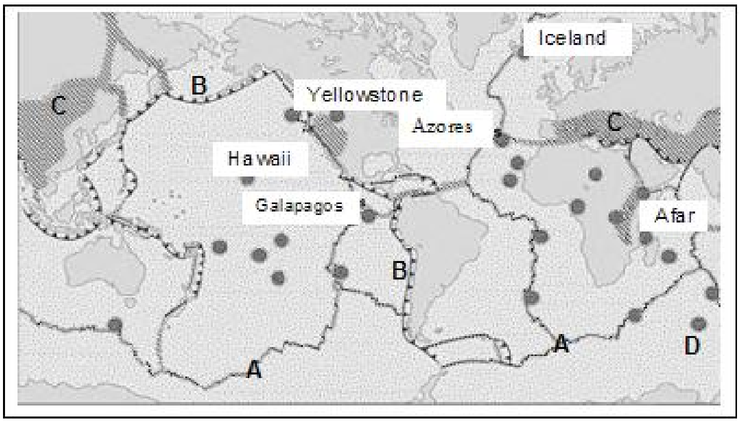

Fig. 1 Major tectonic plates on the globe; A: divergent plate boundaries; B: convergent plate boundaries; C: plate boundary zones in which deformation is diffused and boundaries are not well defined; D: selected prominent hotspots (adapted from http://pubs.usgs.gov)

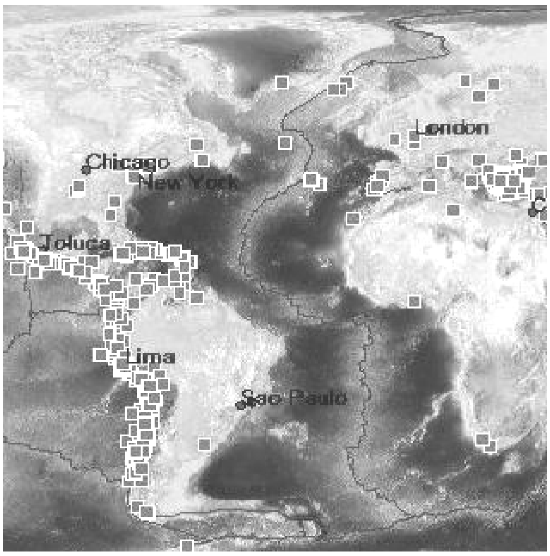

Fig. 2 Tsunamigenic earthquake epicenters in the Atlantic Ocean and part of the Pacific Ocean (map source: website http://map.ngdc.noaa.gov/website/seg/hazards/viewer.htm accessed on 11 September 2005)

TWO TSUNAMIS IN GEOLOGICAL TIME

We will briefly discuss here two tsunamis in geologic time, one in eastern Atlantic and the other in western Atlantic. We will first discuss the one in the north-western part of the Atlantic Ocean that occurred some 8,200 years B.P. At that time the Laurentide Ice Sheet, which had a maximum thickness of 3 km over the Hudson Bay was disintegrating rapidly. Shortly before the ice sheet finally and completely disintegrated, the glacial lake, Lake Agassiz, had become a super lake with a surface area of about 841,000 km^2. This is more than twice the size of the largest lake in the modern world, the Caspian Sea. At various times Lake Agassiz discharged very large volumes (thousands of cubic kilometres) of fresh water into the Labrador Sea through the mouth of the Hudson Strait. The largest of these outbursts occurred some 8,200 years B.P. and the volume was estimated to be in the range of 163,000 km^3. It appears that this outburst of flood occurred in a relatively short period of one-year duration and the average rate of discharge over that period was about 5.2 Sv (Sv is the abbreviation for Sverdrup, which is equal to one million cubic meters of water flow per second). In reality, the flow could have been somewhat higher than 5.2 Sv (Barber et al., 1999; Teller et al., 2002; Teller and Leverington, 2004; Clarke et al., 2004).

When such a large volume of water is discharged into a coastal sea like the Labrador Sea, a flood wave or a tsunami could have been generated. We could not find any references in the literature for tsunami generation from a sudden discharge of a large volume of fresh water (glacial melt). Using analogies to tsunami generation from ocean earthquakes and also from submarine landslides, the expected amplitude of the tsunami was estimated to be about 2 m (Murty, 2003). Directionality considerations (Iwasaki, 1997) as well as the effect of the Coriolis force in the Northern Hemisphere, suggest that the resulting tsunami probably travelled some 50-100 km along the west coast of the Labrador Sea, before being completely dissipated. It would be interesting if the tsunami-generated sedimentary deposits could be found on the west coast of the Labrador Sea in agreement with the results of the simulations (Figure 3). Even though until now the entire search for possible deposits from this tsunami was concentrated on the Greenland coast, our detailed paper on this event (Teller et al., 2005) created an interest in the geological community to search for the deposits on the Labrador coast. The main point to make here is that this tsunami was probably not trans-oceanic, in the sense defined above.

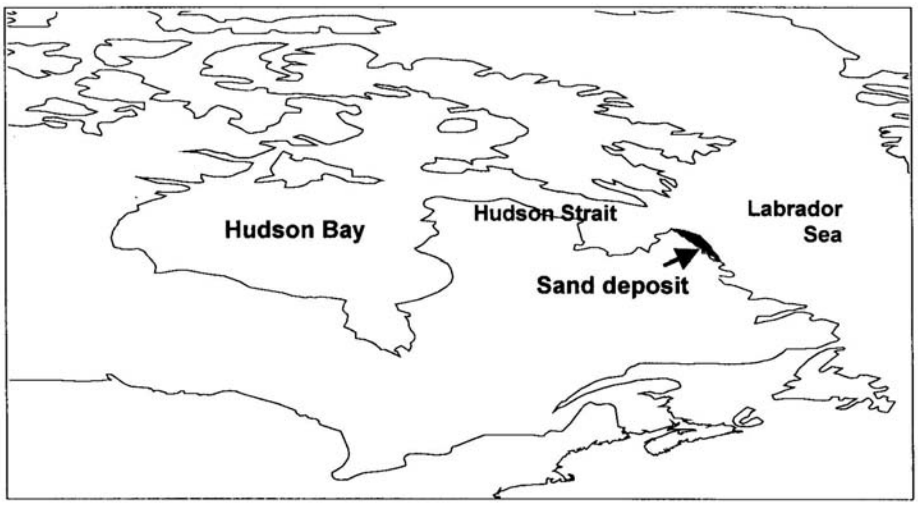

Fig. 3 Possible location of tsunami deposits in the western part of the Labrador Sea from a tsunami that probably occurred around 8,200 years B.P.

The second tsunami event in geologic time occurred in the North Sea. Henry and Murty (1993) numerically modelled the tsunami in the North Sea from the second Storegga Slide off the coast of Norway that occurred some time between 8,000 and 5,000 years B.P. Figure 4 shows sand deposits on the east coast of Scotland that could have resulted from this tsunami. These sand deposits were observed starting from north of Inverness southward up to Dunbar, a distance of some 500 km measured along the coastline. More recent and/or detailed data on this tsunami and tsunami simulations can be found in Smith et al. (2004) and in Bondevik et al. (2005).

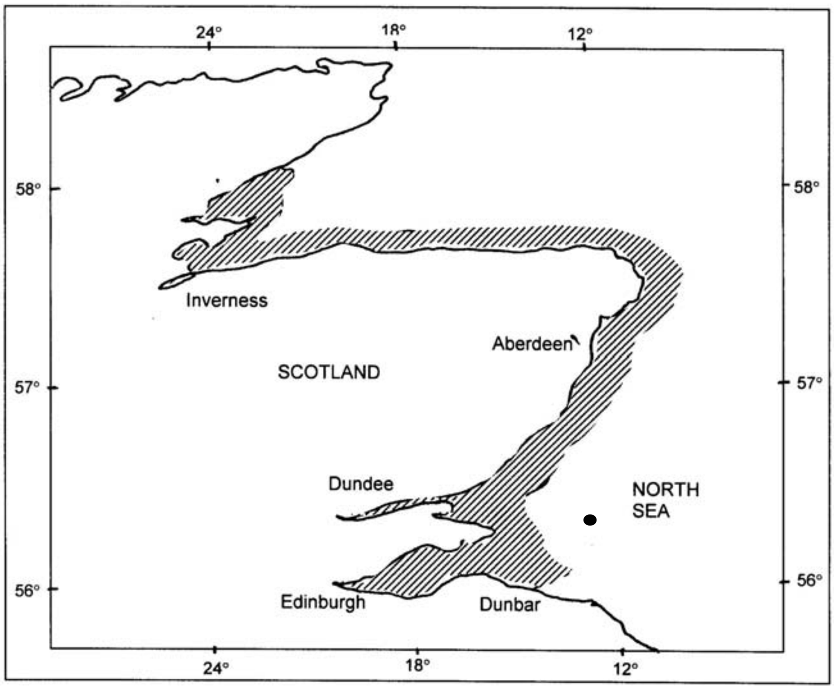

Fig. 4 Extent of coastline (shown hatched) including sites with sand sediments, possibly attributable to the second Storegga Slide tsunami (Henry and Murty, 1993)

TWO TSUNAMIS ON THE EAST COAST OF CANADA IN THE 20TH CENTURY

Greenberg et al. (1993, 1994) and Ruffman et al. (1995) numerically modelled the Halifax Harbour Explosion tsunami of the 6th of December 1917. Figure 5 shows a geographical map of the area. The explosion occurred close to the time of low tide in the Halifax Harbour and generated a tsunami that, according to the simulations, took about 18 minutes to enter the Atlantic Ocean.

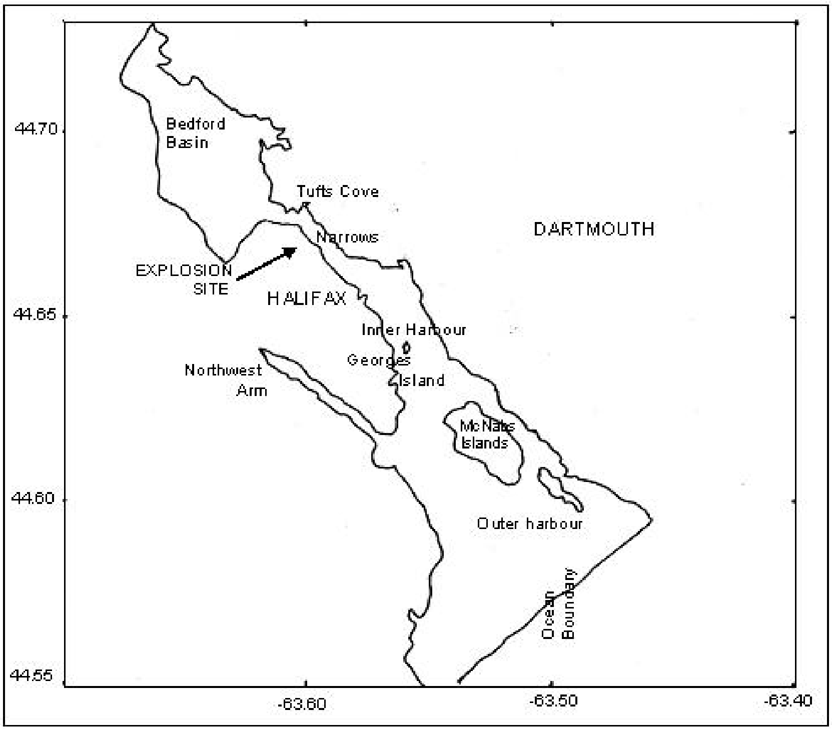

Fig. 5 Halifax Harbour location map (from Greenberg et al., 1993, 1994)

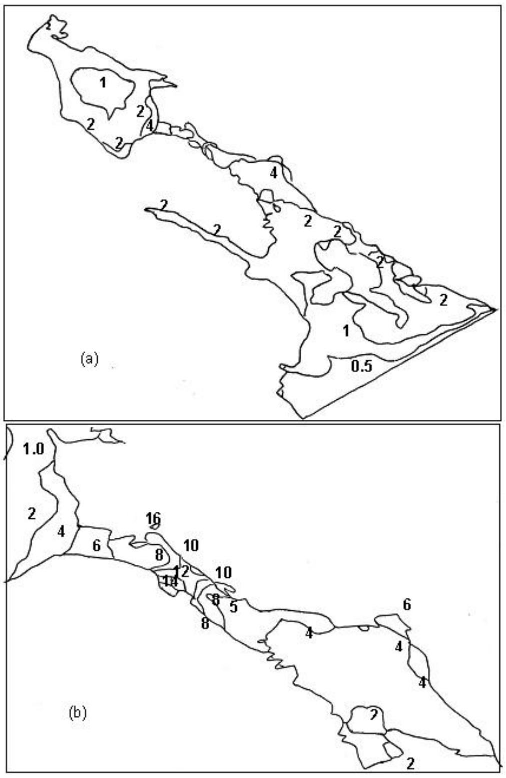

Fig. 6 Contours of maximum tsunami amplitudes (in m) for: (a) over the full domain, and (b) enlargement of the harbour and narrows (Greenberg et al., 1993, 1994)

Contours of the maximum amplitude of the tsunami are given in Figure 6 from which one can see that in the narrows the tsunami reached amplitudes up to 14 m.

Next, we consider the Grand Banks Earthquake tsunami of 18th of November 1929. An earthquake of Richter magnitude of 7.2 occurred at 44°30′N, 57°15′W, south of Newfoundland. The turbidity currents that were generated by this earthquake broke the Trans-Atlantic cables (for phone service to Europe from North America) on the ocean floor in a regular and coherent sequence. Murty (1977) numerically modelled the tsunami that killed 28 people. Figure 7 shows the tsunami travel time contours in minutes. Probably the tsunami energy predominantly propagated towards the south coast of Newfoundland and only little tsunami energy reached Nova Scotia, mainly because of extensive sand banks in between and also directivity of tsunami energy. Murty (1977) explained the large tsunami amplitudes in Lamaline Bay and surrounding area as mainly due to the quarter-wave resonance amplification. Notice that some recent studies on this tsunami are based on the alternative hypothesis that it was generated by a huge landslide that was triggered by the earthquake (see, e.g., Fine et al., 2005).

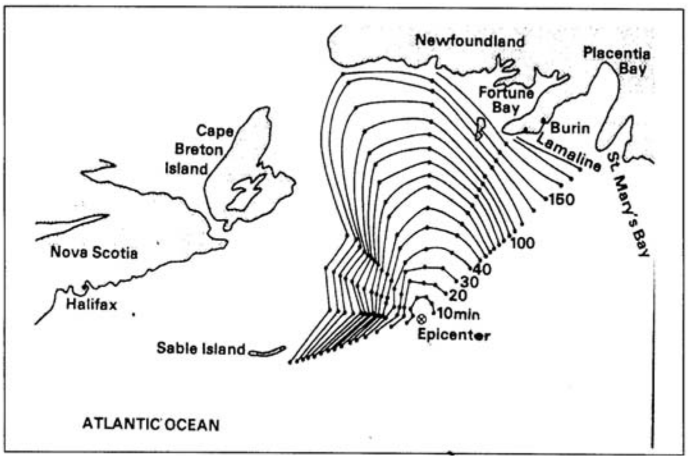

Fig. 7 Tsunami travel time contours in minutes (from Murty, 1977)

HISTORICAL TSUNAMIS ELSEWHERE

Many tsunamis have occurred in the Caribbean Sea; in 1530 in Venezuela, 1692 in Jamaica, 1755 in Martinique and Saba, 1867 in Virgin Islands, 1918 in Puerto Rico, and 1946 in the Dominican Republic (http://en.wikipedia.org/wiki/Tsunami). It has been suggested that during the past 150 years, more lives were lost to tsunamis (369) than by hurricanes in this area (O'Loughlin and Lander, 2003).

Probably the most important Atlantic ocean-wide tsunami in historical times took place 1755 off Portugal and caused destruction in Lisbon. Tsunami amplitudes of up to 6 m were observed in some Caribbean islands (O'Loughlin and Lander, 2003). This tsunami also had some effect at Cornwall in the United Kingdom. Some recent studies on the Lisbon tsunami were done by Gjevik et al. (1997) and by Baptista et al. (1998a, 1998b, 2003). A small tsunami occurred in Portugal in February 1969 (Moreira, 1970, 1988; Heinrich et al., 1994; Guesmia et al., 1998). It seems that other than the 1883 Krakatau event (Choi et al., 2003), there are no records of tsunamis in the South Atlantic Ocean in the historical times. Table 1 lists some tsunamis for the period 1531 to 1960 (Berninghausen, 1964).

The St. Lawrence Estuary region of Canada is also prone to tsunamis from earthquakes and landslides. Figure 8 shows the distribution of earthquakes and Figure 9 shows the locations of four hypothetical earthquake epicentres that were used in the numerical simulations of the tsunamis by Chasse et al. (1993) to study scenarios of tsunami impact. The travel times are short and are of the order of minutes to an hour and the maximum amplitudes could reach up to several meters.

The Mediterranean Sea gives rise to tsunamis, but since the Gibraltar Strait is too narrow, this sea is not considered as part of the Atlantic Ocean system.

Table 1: Tsunamis in the Eastern Atlantic, South of the Bay of Biscay, from 1531 to 1960 (from Berninghausen, 1964)

Date	Epicenter	Remarks
January 26, 1531	Near Lisbon, Portugal	Several Ships Destroyed by Waves; Flood on the Banks of Tagus River
July 26, 1591	Azores	Waves Damaged Several Ships
December 21, 1641	Azores	Inundation of Port Velas, Ilha de Sao Jorge
1653	Azores	Destruction on the Coast off Ilha Terceira
November 23, 1668	Azores	Calheta and Ilha de Sao Jorge Flooded
1676	Azores	Destruction of Praia da Victoria
May 6, 1706	Canary Islands	Tsunami Caused by Volcanic Eruption; Destruction at Garachico and Isla de Tenerife
December 26, 1746	Lisbon, Portugal	Tsunami Observed
April 28, 1752	Near Buarcos and Aveiro, Portugal	Tsunami Observed
November 1, 1755	38°N, 10°W	So-Called Infamous Lisbon Earthquake; 3 Tsunamis Waves from 4.6 to 12.2 m caused Destruction at Lisbon; at Cadiz Waves were 5.5 m, at Gibraltar 2.1 m; Large Waves at Tangier, Agadier, Madeira, Funchal, Azores
March 29, 1756	Lisbon	High Water in Tagus River
July 9, 1757	Azores	Large Waves on Coasts of Ilha de Sao Jorge, Ilha de Pico, and Ilha Graciosa
March 31, 1761	Off the Coast of Portugal	Tsunami at Lisbon 2.4 m; Tsunami also at Cabo Finisterre (Spain), Madeira, Ilha de Fayal, Ilha Terceira, Portorico, U.K., Barbados
December 27, 1772	Portimao, Portugal	Tsunami Observed near Cabode Sao Vicente
1787	Azores	Destructive Tsunami
January 23, 1792	Azores	Tsunami at Velas and Ilha de Sao Jorge
July 4, 1809	No Earthquake Listed	Sea Disturbed at Lisbon
December 4, 1809	Cape of Good Hope	Large Wave in Table Bay
February 17, 1855	Azores	Tsunami of 10 m Amplitude at Ilha Terceira
January 6, 1856	Azores	Large Tsunami at Velos and Ilha de Sao Jorge

August 27-28, 1883	Krakatoa (Volcanic Eruption in Sundra Strait, Indonesia	About 15.2 cm Amplitude Waves in Table Bay, English Channel
February 3, 1899	Azores	Destruction at Velas and Ilha de Sao Jorge; One Death
May 11, 1911	Gold Coast	Destruction at Lome
August 22, 1926	Azores	Tsunami of 60.9 cm Amplitude on Ilha de Fayal and Ilha de Pico
December 19, 1926	Lisbon	High Water in the Tagus River
November 19, 1929	40°N, 56°W	Tsunami at Azores due to the Grand Banks Earthquake
August 31, 1931	Azores	Destruction at Horta, Feteira, Ilha de Fayal
June 22, 1939	Gold Coast	Tsunami at Labadi and Tishi
February 29, 1960	Agadir, Morocco	Tsunami Existence Not Confirmed

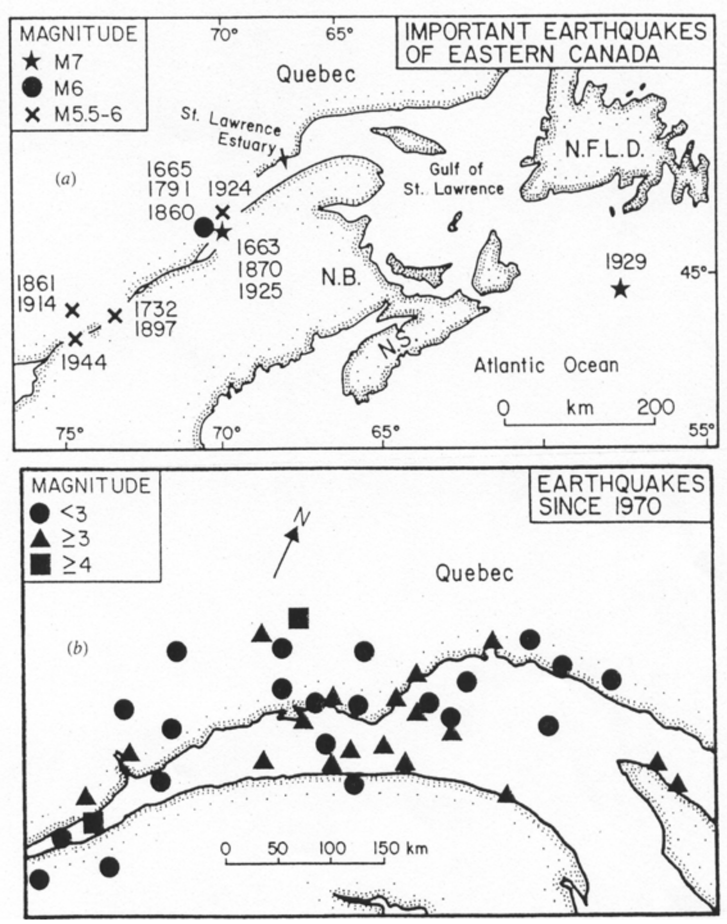

Fig. 8 (a) Major earthquakes of eastern Canada; and (b) Earthquakes that have occurred during 1970-1990 (from Chasse et al., 1993)

FUTURE TSUNAMIS IN THE ATLANTIC

There have been suggestions that Cumbre Vieja volcano in La Palma (Canary Islands) off the coast of Morocco could collapse into the ocean and cause mega tsunamis (Ward and Day, 2001), with amplitudes up to 100 m (see Figure 10). Mader (2001) and Pararas-Carayannis (2002) suggest that this is an exaggeration and much smaller waves can be expected. Other concerns are for events similar to the 1755 Lisbon tsunami and the 1867 Virgin Islands tsunami. Also, in recent years, cracks along the continental shelf off the Atlantic coast of Virginia and North Carolina were discovered. Cracks in the ocean floor on the continental shelf could be an indication of instability. It has been suggested that large pieces of the shelf could break loose and slide down the continental slope, generating a major tsunami (White, 1992).

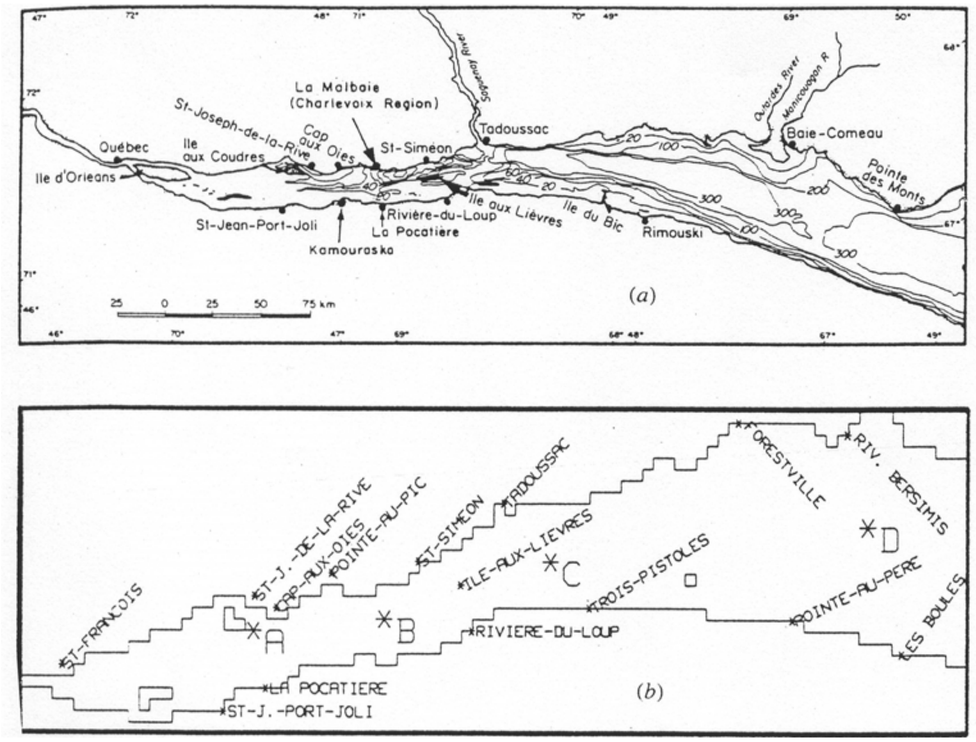

Fig. 9 (a) Map of St. Lawrence Estuary in eastern Canada; and (b) The four hypothetical earthquake epicenters used in numerical simulation (from Chasse et al., 1993)

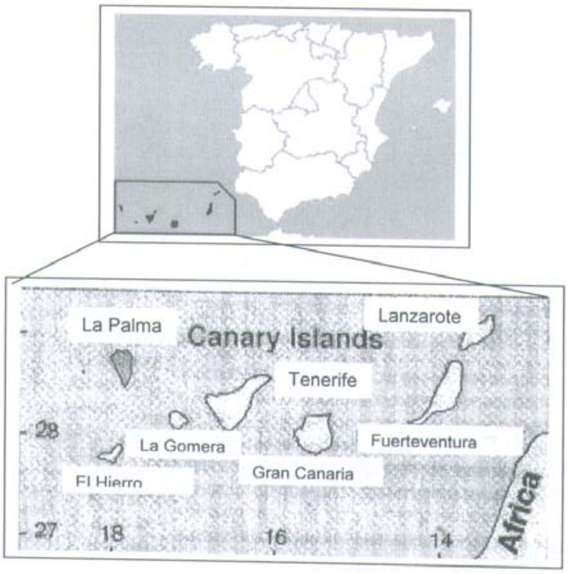

Fig. 10 La Palma and the other Canary islands (from Pararas-Carayannis, 2002)

CONCLUSION

With the possible exception of the 1755 Lisbon tsunami, which had some ocean-wide effects, there appears to be no trans-oceanic tsunami in the Atlantic Ocean in historical time. One of the reasons is the relative absence of major fault zones in the Atlantic as compared to the Pacific and Indian Oceans. The earthquakes associated with the mid-Atlantic ridge, which is a divergent boundary where plates move away from each other, appear to be deep and do not seem to have tsunamigenic potential.

The historical tsunamis and even those identified in geologic times are mostly at the margins of the Atlantic Ocean and not in the main part of the ocean itself. Even the 1755 Lisbon tsunami is not trans-oceanic in the sense defined in the introduction of this paper; it is rather an ocean-wide tsunami. It affected the Caribbean, but no other region far from the generation area. Even though there are no active margins in the Atlantic, the possibility of subduction-like tsunamis has been proposed by Gutscher et al. (2002) and Zitellini et al. (2004).

The conclusion is that it is a reasonably fair statement that there are usually no tsunamis travelling across the Atlantic Ocean; rather there are tsunamis in the relatively shallow waters at the margins of this ocean. This important point, that the Atlantic Ocean usually does not generate ocean-wide tsunamis, should be factored into the development of a tsunami warning system for the Atlantic Ocean. However, it should also be borne in mind that if a Lisbon 1755 type event occurred now, its consequences would be very significant in view of increased population and coastal infrastructure after 1755.

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