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Damage associated with three early Eastern North American earthquakes

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ABSTRACT

Earthquakes in June 1638, February 1663 and September 1732 were felt widely in northeastern North America. Primary documents are analyzed for reports of their effects on and within structures. In 1638 damage in the Boston–Plymouth area was insignificant in kind and extent. Damage in 1663 consisted of a few fallen chimneys at Trois-Rivières and a few damaged chimneys plus a few examples of displaced furniture and light damage at Québec. In 1732 earthquake damage was confined to Montréal. Three large buildings were seriously damaged, one of which had been poorly maintained. While a number of houses were damaged, they may have been less numerous than previously thought. In all three earthquakes, population living near the epicentral area was large enough to be certain that all significant damage had been reported and that such information is still available today in archives or in printed documents.

INTRODUCTION

Engineering assessment of seismic risk for a particular project begins with evaluation of the seismic hazard at the site and in its vicinity. Such evaluation depends on two rather different types of information about earthquake activity, instrumental and historical. Since most of the larger earthquakes in eastern North America occurred before suitable instrumentation had been developed, historical records of earthquakes are very important in the evaluation of seismic hazard. Written accounts of earthquakes that occurred in previous centuries help us estimate the rate of earthquake activity and the maximum size of earthquake in each earthquake zone. The older earthquakes are seldom useful in defining zone boundaries, as their locations may be quite uncertain, sometimes by 50 or 100 km, or more.

Lacking instrumental data, estimates of earthquake location and size depend upon an interpretation of the effects of such earthquakes, principally on people and on structures. This paper treats three earthquakes that were reported felt in settled areas in the 1600s and 1700s and which caused some damage. These reported effects are examined in terms of population and types of construction at the time in order to determine what was typical damage.

HISTORICAL EXAMPLES

This paper focuses on the damage associated with the earthquakes of June 1638, February 1663 and September 1732; it will not discuss determination of their locations and magnitudes. All three earthquakes have been catalogued

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with maximum intensities of IX to X on the Modified Mercalli (MM) intensity scale, which were converted to magnitudes of the order of 7 (Smith 1962; Basham et al. 1979). These estimates of intensity and magnitude were based largely on non-representative damage, on accounts of landslides or on descriptive adjectives such as "great", "fearful" and "terrible" used in some of the original reports. When the damage caused by these earthquakes is isolated from these factors, then the three earthquakes would appear to have been smaller, considerably smaller in maximum intensity, perhaps somewhat smaller in magnitude. Aftershocks were reported felt in the weeks following each of these three earthquakes, but caused no further damage. Damage reports analyzed in this paper are drawn from primary documents written by persons having some first-hand knowledge of these earthquakes.

June 1638

The first earthquake in eastern North America for which a specific date can be unambiguously assigned occurred on Friday afternoon, 11 June 1638, somewhere in the vicinity of Boston, Massachusetts. About half a dozen documents still exist that were written by persons with first-hand knowledge of this event (Stevens and Gouin 1991), which was reported felt in New England in communities as widely separated as 150 km. It was also felt in the St. Lawrence valley, probably at one location near the settlement at Québec, at a distance of 500 km north of Boston. Based on recent experience, these distances suggest a magnitude not less than 5. Very minor damage was reported in the Plymouth colony, located on the Atlantic coast about 50 km southeast of Boston. In other communities, the historical documents describe the vibrations and the reactions of the populace, but say nothing about damage, from which we may assume that none occurred anywhere but Plymouth.

At Plymouth the following damage was reported (Bradford 1952 edition, page 302): " ... the earth began to shake and came at length with that violence as caused platters, dishes and suchlike things as stood upon shelves, to clatter and fall down." That is the total extent of the reported damage. In fact, "damage" is probably too strong a word; nevertheless it will be retained. We can accept as reliable this account of damage caused by the 1638 earthquake, since it forms part of a history written by William Bradford, who was governor of Plymouth colony for most of the years between 1620 and 1647. In another report written about 120 years later, but based on documents of the mid-1600s, some no longer available, Hutchinson (1760, page 90) added chimney tops to the short list of damage: " ... and the tops of chimnies [sic] in some places shook down ...." Note that no specific communities were named in this latter report. Comparing these effects with those of the Modified Mercalli intensity scale, a maximum intensity of MM V or VI could be assigned. This would be consistent with a magnitude of 5, although there is no satisfactory way to convert maximum intensity to magnitude. As already noted, this paper does not attempt to estimate magnitude for the June 1638 earthquake, but simply notes that its magnitude could not have been less than 5.

To place this reported damage in perspective, consider the size of the settlements at Boston and Plymouth and the type of house construction. A traveller from England arriving in Boston in July 1638 noted that it "was rather a village, than a town, there being not above twenty or thirty houses" (Josselyn 1674, pages 19-20). Later authors estimated the population of Boston in mid-1638 at about 1,500 persons, the entire European population of Massachusetts Bay at about 10,000 persons (Rutman 1965, page 179; Langdon 1966, page 44). Damage occurring in any of these communities would certainly have been noted and recorded, even if it had been as minor as fallen dishes. Plymouth and its surrounding communities were much smaller, with a population of several hundreds, rather than several thousands (Langdon 1966, pages 82–83,87).

Houses in the Plymouth and Massachusetts colonies in the mid-1600s were usually a simple 2-storey "frame structure covered with boards or shingles,

with a central chimney rising in its center" (Langdon 1966, page 146). Roofs were thatched, chimneys of wood daubed with clay (Rutman 1965, pages 31, 203). Several decades later, the 1692 Building Code for Boston (1699, pages 3–4) required new buildings more than eight feet in length or width and more than seven feet high to be constructed of stone or brick instead of timber and to be roofed with slate or tile instead of shingle to minimize the spread of fire. In addition, non-conforming wooden buildings constructed since 1688 were to be roofed with slate or tile. While these new measures reduced the fire hazard, they may not have improved earthquake resistance.

In considering the damage, or lack thereof, reported for the earthquake of June 1638, it is recognized that small wooden houses, including wooden chimneys, are inherently earthquake-resistant. However, widespread reports of fallen dishes throughout the Boston area would have been possible if the shaking had been strong enough. Since such reports were confined to the Plymouth colony, two explanations may be suggested for Boston – neither of which can be proved or disproved. First, the strong ground motion was not particularly strong – hence no damage, no overturned objects. Or, secondly, Boston was close enough to the epicentre that the strong ground motion was essentially high-frequency vertical motion, with weak horizontal components. A modern analogue might be the Miramichi, New Brunswick, earthquake of 09 January 1982, magnitude 5.7, which, although widely felt and causing some minor cracks inside buildings at about 100 km distance, did not disturb even dishes in cabins in the epicentral area (Stevens 1983). While historical documents of the 1600s contain sufficient information to permit estimates of location and magnitude of the June 1638 earthquake, as reported elsewhere (Stevens and Gouin 1991), the damage reports are too limited to draw any firm conclusions. Was the damage negligible because the horizontal components of strong ground motion were not very strong or because there was little to disturb in early New England buildings? This remains an open question.

February 1663

Twenty-five years later, a strong earthquake in the St. Lawrence valley early Monday evening, 05 February 1663, was widely felt in eastern Canada and the northeastern United States, to distances of over 500 km. For example, the main shock and several aftershocks were reported felt in Montréal (Mondoux 1942, pages 184–185) and in Boston. The earthquake and its long series of aftershocks, reported felt mainly at Québec and at Tadoussac, have been described by many writers in the intervening 300 years in both popular and scientific articles. The original and derivative accounts of the effects in New France were devoted largely to numerous examples of landslides and slumps discovered for several months thereafter, and to the superstitions of the frightened population. Sifting fact from fiction is not straightforward. The present paper focuses narrowly on damage reports and does not discuss location, except to note that the Charlevoix–Kamouraska area has generally been designated as the epicentral area, which is about 100 km and 200 km, respectively, northeast of Québec and Trois-Rivières.

The following information on damage emerges from the three primary documents, the annual report from the Jesuit missions in the colony of New France, the residence journal of the Jesuits at Québec, and a letter from the head of the Ursuline community at Québec. These documents included some first-hand experiences plus many second- and third-hand reports gathered from European and Indian travellers passing through Québec during the seven months from early February to the end of August 1663. In his covering letter dated 04 September 1663, Lalemant (1663) wrote that not one life had been lost, nor any earthly goods. In Chapter 2 of his annual report, he noted that they had not lost one child, not even one hair from the head. In his single reference to damage, he expressed amazement that only several chimneys had been demolished, but he did not indicate their location. His statement would imply that if other damage had occurred to buildings or contents anywhere in New

France, it must have been of much less importance than chimney damage. The Jesuit residence journal (Laverdière and Casgrain 1871), with monthly entries in 1663 also written by Lalemant, noted, in its February paragraph, that certain chimneys had been damaged and that there had been other light losses and damage. Since entries in this journal generally concerned Québec or Jesuit activities there, unless otherwise stated, we may assume that the journal entry referred to damage at Québec. These two damage accounts by Lalemant contrast sharply with the more dramatic description in the following document.

In a lengthy letter about the earthquake written to her son in France and dated August–September 1663, Marie de l'Incarnation (1663) emphasized the supernatural and unusual; in the final paragraph she noted that no one had perished, nor even been injured. Her letter included a few personal observations – overturned furniture, fallen stones, floors that separated, walls that were split. From the context, these observations were probably made at the Ursuline residence at Québec. Nothing was said subsequently about repair or the need for repair. On the other hand, the stone building must have been vigorously shaken, as thick dust spread out on all sides. From the Jesuit journal we know that the Jesuit fathers visited the Ursuline community regularly to say mass; they would certainly have known about any damage there. Movement of the specific items mentioned by Marie de l'Incarnation must thus have been confined to a few examples, and must not have been a general fall of stones and cracking of floors and walls, as might be concluded from her letter alone. Marie de l'Incarnation also quoted directly from a letter written from Trois-Rivières which said, in part, that as houses there were all of wood, damage had been confined to the fall of a few chimneys.

The total damage attributed to the February 1663 earthquake thus consisted of a few fallen chimneys in Trois-Rivières, a few damaged chimneys at Québec, and some overturned furniture and minor cracking at Québec. No damage occurred at Montréal. Lalemant's description in the Jesuit journal was brief and factual. The annual report of Lalemant and the letter of Marie de l'Incarnation devoted most of their space to landslides beyond the settlements and stories told by frightened persons, which implies that not much actual damage to buildings or contents had occurred; otherwise more than a few short sentences would have been devoted to it. As explained later, archival records of building contracts in 1663 should be examined for any evidence of earthquake-related repairs.

In 1663, the population in the region of Québec totalled 1,976 persons; settlement extended only about 40 km downriver (i.e. northeast) from Québec; the mission post at Tadoussac at the mouth of the Saguenay was occupied for only part of the year. The Montréal and Trois-Rivières regions had 597 and 462 inhabitants, respectively, for a total of about 3,000 persons in the St. Lawrence Valley (Trudel 1973, Chapter 18; Harris and Matthews 1987, Plate 46). Recall that the Boston area had achieved a population of 10,000 twenty-five years earlier. Despite the small population, there was regular correspondence within New France and beyond to France; any significant building damage would have been noted and reported. In the mid-1600s most houses had wooden roofs and stone chimneys and more than 10% of the houses in Québec and Montréal had stone walls. At Québec, settlement almost from the beginning had occurred both along the river in lower town and above the cliff in upper town, where both the Jesuit and Ursuline buildings were located (Harris and Matthews 1987, Plates 49 and 55; Trudel 1973, Chapter 18). It is not possible to say from the limited reports whether the effects in upper and lower town were markedly different.

As with the New England earthquake of 1638, the St. Lawrence valley earthquake of 1663 caused no significant damage, in part due to the small population, hence relatively few houses, and to the predominance of small wooden houses. A maximum intensity of MM VI would satisfy the damage observations at Trois-Rivières and Québec, which however are generally thought to have been some distance from the epicentre. Aftershocks were frequent during the first night and continued off and on for at least seven months, which suggests that the main

shock must have been fairly large in order to have spawned so many aftershocks, and hence its peak ground motions must have been fairly strong. We then can again ask why there were not more reports of fallen dishes and displaced furniture. The frequency range of the strong motions in the settlements was obviously not tuned to that necessary to displace household objects.

September 1732

The next widely-felt earthquake in eastern North America that caused some damage occurred in the late autumn of 1727, again in the Boston area. Since a similar shock occurred in Canada just a few years later, the Canadian earthquake is chosen for examination. The earthquake of Tuesday morning, 16 September 1732, near Montréal, Québec, had been catalogued for many decades as a major earthquake, which had killed one person and injured others. A re-examination by G. Leblanc (1981) proved from primary documents that previous interpretations had been greatly exaggerated. In particular, no one had been killed or seriously injured. He found a maximum intensity of MM VII to VIII compatible with damage reported in Montréal; he had available however only some of the damage information to be presented below. This new information would support a maximum intensity of not more than MM VII. Basing his magnitude estimate on the area and distances for which the earthquake had been reported felt, Leblanc concluded that a magnitude in the range 5.6 to 6.0 would satisfy these data. Damage was confined to the town of Montréal, if we overlook a report in two Boston newspapers that several articles there had fallen from shelves. No damage whatsoever was reported at Québec (Chaussegros de Lery, 1732) and there is no archival evidence of damage at Trois-Rivières.

Chaussegros de Lery (1732), chief engineer for the colony of New France, in an official report one month after the main shock, described the damage to houses and to the wall around the town, based on information that he had received from persons arriving at Québec from Montréal. He (1733a; 1734; 1733b) subsequently prepared itemized statements of repairs made to two large stone buildings and noted work done on a third. These last three documents have not been previously presented in connection with the 1732 earthquake.

For houses, he reported a good proportion of chimneys fallen, other chimneys split [cracked] and many walls of houses opened [cracked], but he gave no statistics. Two other reports cited figures of 567 chimneys (Lahaise 1973, page 38) and more than 300 houses (Duplessis 1732). These figures are compatible, since urban stone houses had at least two chimneys each. On the other hand, these figures, as well as some other details in these two documents, should be used with caution as they were mentioned, respectively, only in a history of Hôtel-Dieu of Montréal written some years later by Soeur Cuillérier, who had herself experienced the earthquake, and in personal correspondence written at Québec from second-hand reports. If these figures were to be accepted, then comparison with an estimated population of 3,000 in Montréal in 1732 (Miquelon 1987, page 145) would suggest that almost half of the houses did suffer some damage. In reviewing the exchange of official government correspondence between Québec and France [not all referenced herein], the effects of the earthquake seemed to be of little relative importance, which would suggest that very much less than 50% of the houses had been damaged. As thousands of building contracts in New France between 1640 and 1760 are still available in various archives (Moogk 1977, page 11), it should be possible to extract and analyze information on work done in Montréal between mid-September 1732 and the spring of 1733 and thus to determine the true extent of the damage.

In 1727, a comprehensive building code was issued for all the towns in the St. Lawrence valley, with the basic principle that construction was to be durable and safe (Moogk 1977, Chapter 3). Many of these regulations, including the requirement for urban stone construction, had already been issued for Montréal in 1721. By 1732, just over 50% of the houses in Montréal were made

of stone; virtually all chimneys were stone; roofing materials were planks or shingles (Harris and Matthews 1987, Plate 55; Moogk 1977, Chapter 3). Whether houses built in Montréal between 1721 and 1732 resisted earthquake damage better than earlier houses might make an interesting study.

The town walls in Montréal were under reconstruction in 1732, wood being replaced by stone. The town itself occupied a rectangular area about 1½ km by ½ km parallel to the St. Lawrence River (Harris and Matthews 1987, Plate 49). Chaussegros de Lery (1732) reported that alignment of the walls and their embankments had not been changed by the earthquake, which proves that no slumping nor liquefaction had occurred there. He noted the following minor damage, which had already been repaired for "60 livres". At the just completed Saint-Laurent gate several stones had shifted. In the masonry section of the wall, several parapet tops had shifted and several stones from the top of the gun slits had fallen. At the northern bastion a crack had developed, but closed again during an aftershock. Without estimating the purchasing power of "60 livres" in 1732, the context of this and other reports shows that this sum was not, in fact, considered very important.

Two of the large stone buildings in Montréal are known to have been damaged sufficiently to warrant requests to the King of France to pay for repairs, since they served the community. The first of these was the hospital complex, Hôtel-Dieu, which included an interconnected hospital, residence and church, plus some smaller outbuildings. The main buildings, each several hundred feet in length, were two to three stories in height (Mondoux 1942, Chapter 21). In the request for financial assistance, the head of Hôtel-Dieu noted that the monastery had been nearly completely ruined and she feared that its walls might completely collapse during the winter frosts (Le Vasseur 1732). All the chimneys had been toppled, walls were split [cracked] so as to show through daylight and part of the frame had moved out half a foot. The letter did acknowledge, however, that two previous fires [1695 and 1721] had weakened the walls. Extensive damage in the 1721 fire had caused the entire hospital complex to be temporarily relocated for 3½ years, lacking funds for immediate repairs (Mondoux 1942, Chapter 21). The requested assistance of "640 livres" was granted (Beauharnois and Hocquart 1734; Ducharme 1973), which was ten times the amount spent to fix the town walls. Repairs to the frame of the residence, reported above to have moved out half a foot, were itemized as only "60 livres", which makes that particular damage seem less severe than the written description alone would suggest. The repair costs were divided as follows (Chaussegros de Lery 1733a): rebuild or repair five chimneys, 36%; repairs to hospital, church and residence, 34%; repairs to other small buildings, 30%. The actual damage thus seems less dramatic than would be inferred from the partly objective, partly emotional descriptions by hospital staff who were reacting also to a further disruption to their hospital duties and to their living quarters.

The second damaged stone building in Montréal was the Récollets building. Their request, although acknowledged to be valid, was refused since the French government was short of funds (Beauharnois et Hocquart 1735). The total repairs estimated at "1884 livres", three times that for Hôtel-Dieu, were divided as follows (Chaussegros de Lery 1734): rebuild one chimney and parts of two walls, 53%; repair many ceilings where pieces had fallen, plus cracks in one chimney, 15%; general repairs to frame of building, 13%; other repairs, 19%. Chaussegros de Lery (1733b, folio 228v) entered additional information regarding earthquake damage in his 1733 financial statements for the colony of New France. Three masons and two labourers were paid a total of "120.75 livres" for 49½ person-days of work at the Montréal residence of "M. le Général", which suggests damage to a third large stone building. Some other details in this entry require clarification. Again, to put the damage to large stone buildings in perspective, town maps (Harris and Matthews 1987, Plate 49) show Hôtel-Dieu close to buildings such as Église Notre-Dame and Séminaire Saint-Sulpice, which were apparently undamaged or else suffered only minor

damage, as no details are recorded (Maurault 1929, Chapters 1 and 5). The Récollets were located several blocks further away. More archival research is necessary to determine the structural characteristics of these buildings and to find evidence for repairs.

Historians have paid very little attention to the 1732 Montréal-area earthquake, probably since its economic impact was considerably less than that of the large fires of 1695, 1721 and 1734 (Mondoux 1942, Chapters 19, 21, 22; Moogk 1977, Chapter 3). No comprehensive report of earthquake damage was published at the time. Summaries by Chaussegros de Lery (1732; 1733a; 1733b; 1734) and related correspondence provide the only objective information to date. With some effort, further information on damage or lack thereof could be extracted from various archives.

CONCLUSIONS

Most previous analyses of these three early earthquakes have concentrated on their more dramatic effects, assigning high maximum intensities and, by implication, large magnitudes. This paper has preferred to document the effects to structures and to note relevant population size and building types. When viewed in this context, the maximum intensities typical of a particular settlement are much reduced. Location and magnitude of these or any other earthquakes should not however be based on damage or maximum intensities, but on more representative parameters such as size of the felt area. As might have been expected, the damage recorded from the New England earthquake of 1638 and from the earthquakes near Québec and Montréal in 1663 and 1732, respectively, increased as the population of the settlements increased, being insignificant in 1638 and minimal in 1663. Inadequate maintenance was probably a contributing factor to the damage at the Hôtel-Dieu hospital complex in Montréal in 1732. Statements of repairs to this and two other large stone buildings in Montréal show what was repaired, but provide no details on why damage occurred. Chimney and other house damage in 1732 may have been less important than currently believed; an archival search for relevant building contracts in Montréal could document the true extent of such damage. A similar search might aid interpretation of the 1663 earthquake. Relevant details for all three earthquakes are too sketchy at present to identify any of the building damage with poor soils. While damage to structures was not in any sense catastrophic in these early earthquakes and while no one was even injured, one must not conclude that earthquakes of similar size near the same urban areas today would be of little consequence. Efforts must continue to improve the earthquake resistance of new and existing structures.

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