Field Survey of Earthquake Effects from the Magnitude 4.0 Southern Maine Earthquake of October 16, 2012

By Amy L. Radakovich, Alex J. Ferguson, and John Boatwright

Open-File Report 2016–1071

U.S. Department of the Interior
U.S. Geological Survey

Cover—Damaged chimney and brick debris at the Taylor-Frey-Leavitt House Museum in East Waterboro, Maine, caused by the October 16, 2012, magnitude 4.0 southern Maine earthquake.

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Contents

Figures

Tables

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Abstract

The magnitude 4.0 earthquake that occurred on October 16, 2012, near Hollis Center and Waterboro in southwestern Maine surprised and startled local residents but caused only minor damage. A two-person U.S. Geological Survey (USGS) team was sent to Maine to conduct an intensity survey and document the damage. The only damage we observed was the failure of a chimney and plaster cracks in two buildings in East and North Waterboro, 6 kilometers (km) west of the epicenter. We photographed the damage and interviewed residents to determine the intensity distribution in the epicentral area. The damage and shaking reports are consistent with a maximum Modified Mercalli Intensity (MMI) of 5–6 for an area 1–8 km west of the epicenter, slightly higher than the maximum Community Decimal Intensity (CDI) of 5 determined by the USGS "Did You Feel It?" Web site. The area of strong shaking in East Waterboro corresponds to updip rupture on a fault plane that dips steeply east.

Introduction

At 23:12:23 UTC (7:12 p.m. EDT) on October 16, 2012, a moment magnitude (M) 4.0 earthquake that occurred in southern Maine, 35 kilometers (km) west of Portland, Maine, and 84 km east-northeast of Concord, New Hampshire, was felt throughout much of New England. The U.S. Geological Survey (USGS) Community Decimal Intensity (CDI) map based on "Did You Feel It?" (DYFI) reports is shown in figure 1.

The felt area extends somewhat farther to the south, into Connecticut and Long Island, than to the north, into northern Maine. This extended felt area (400 km versus ~75 km for an M4.0 earthquake in California) is characteristic of moderate earthquakes that occur in the Central and Eastern United States. Minor damage and strong shaking were reported near East Waterboro, Maine. The CDI intensities generally fall off to 3–4 at distances greater than15 km from the epicenter. The field survey described in this report was designed to complement the DYFI map by estimating intensities in the epicentral area from observations of damage and interviews with local residents. Our survey was motivated by the infrequency of earthquakes in this region. It is useful to fully catalog the minor damage and shaking effects from these moderate events in order to be able to predict the damage from larger, but less frequent, earthquakes on the eastern seaboard.

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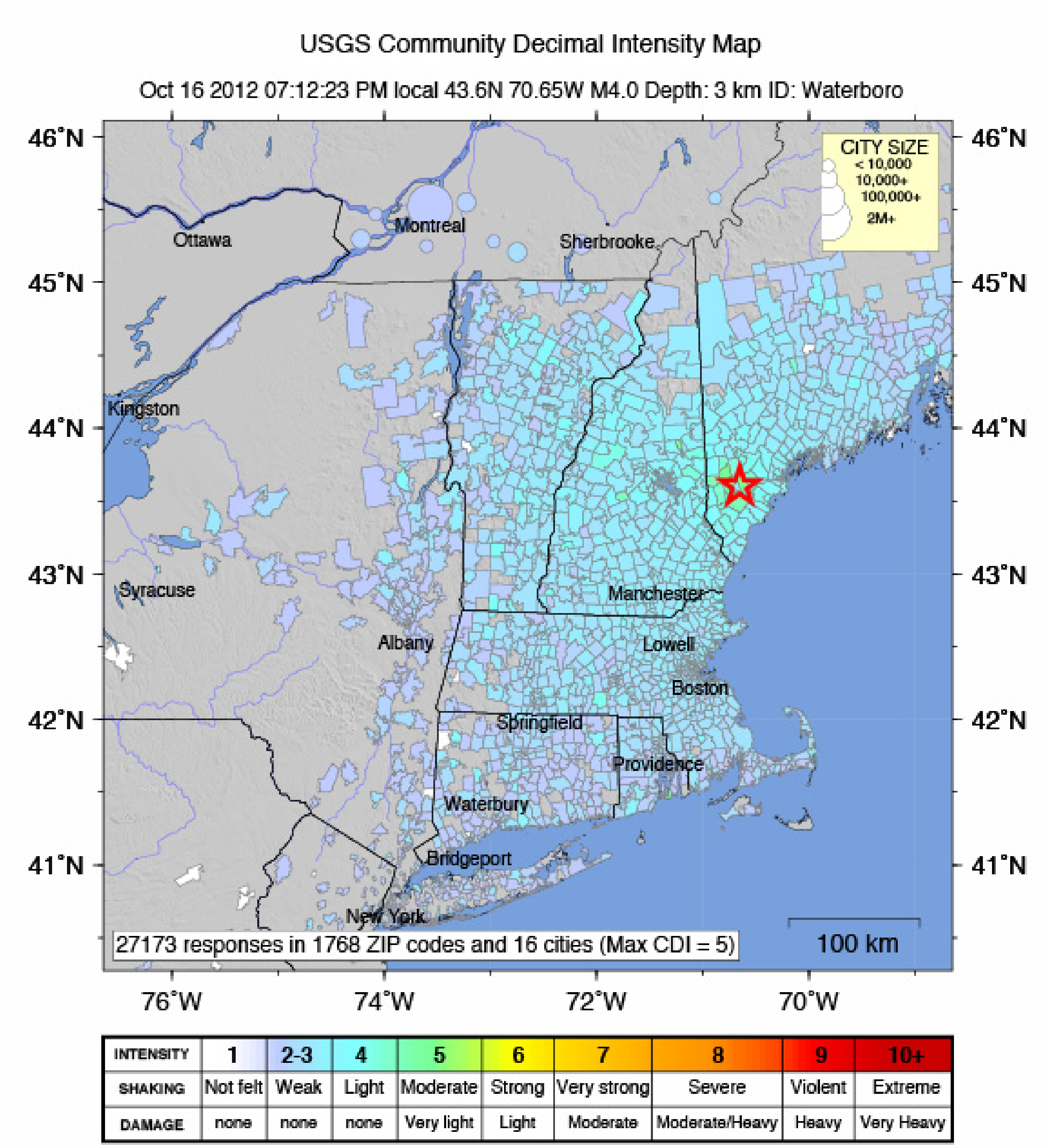

Figure 1. U.S. Geological Survey Community Decimal Intensity map for the southern Maine earthquake of October 16, 2012. Star, earthquake epicenter; M, moment magnitude.

Historical Seismicity and Seismic Hazard in Maine

Global seismicity is largely associated with tectonic plate boundaries, such as the San Andreas Fault in California and the Cascadia subduction zone that lies offshore of northern California, Oregon, and Washington. The eastern seaboard of the United States is far from the North American plate boundary and is much less seismically active than the west coast of the United States. Although the seismic hazard on the eastern seaboard is low as mapped by the USGS (Petersen and others, 2008), earthquakes occur there periodically. The Appalachian region of northeastern North America has a "low but steady rate of earthquake occurrence" (Berry, 2006). Some researchers have suggested that most earthquakes in this region occur where modern stresses are being released on faults that have been inactive since the Appalachian Orogeny 300 million years ago (Ma; Anderson and others, 1989; Osberg and others, 1989). Other researchers suggest that these earthquakes occur on reactivated rift faults from the opening of the Atlantic Ocean about 180–120 Ma (Van Lanen and Mooney, 2007). These infrequent earthquakes occur diffusely throughout the northeastern United States, and no mapped faults have been identified as active seismic sources.

The largest historical earthquake in Maine was the M~6 earthquake on March 21, 1904, in southeastern Maine, which was felt throughout most of New England, as well as in New Brunswick and Nova Scotia, Canada. The strongest shaking was consistent with a Modified Mercalli Intensity (MMI) of 7: chimneys were broken in Calais and Eastport, Maine. The M5.9 magnitude of the earthquake was estimated from the intensity distribution because accurate instrumental measurements were not yet available at that time. The largest instrumentally recorded earthquake in Maine was the M4.8 earthquake of June 21, 1973, that occurred in western Maine near the United States-Canada border. Most of the State of Maine felt the M5.8 Saguenay, Quebec, Canada, earthquake of November 25, 1988, and the M4.4 Cap-Rouge, Quebec, Canada, earthquake of November 5, 1997. The locations of the historical M≥4.0 earthquakes that have occurred in and around Maine since 1638, taken from a catalog compiled by Ebel (1990), are mapped in figure 2.

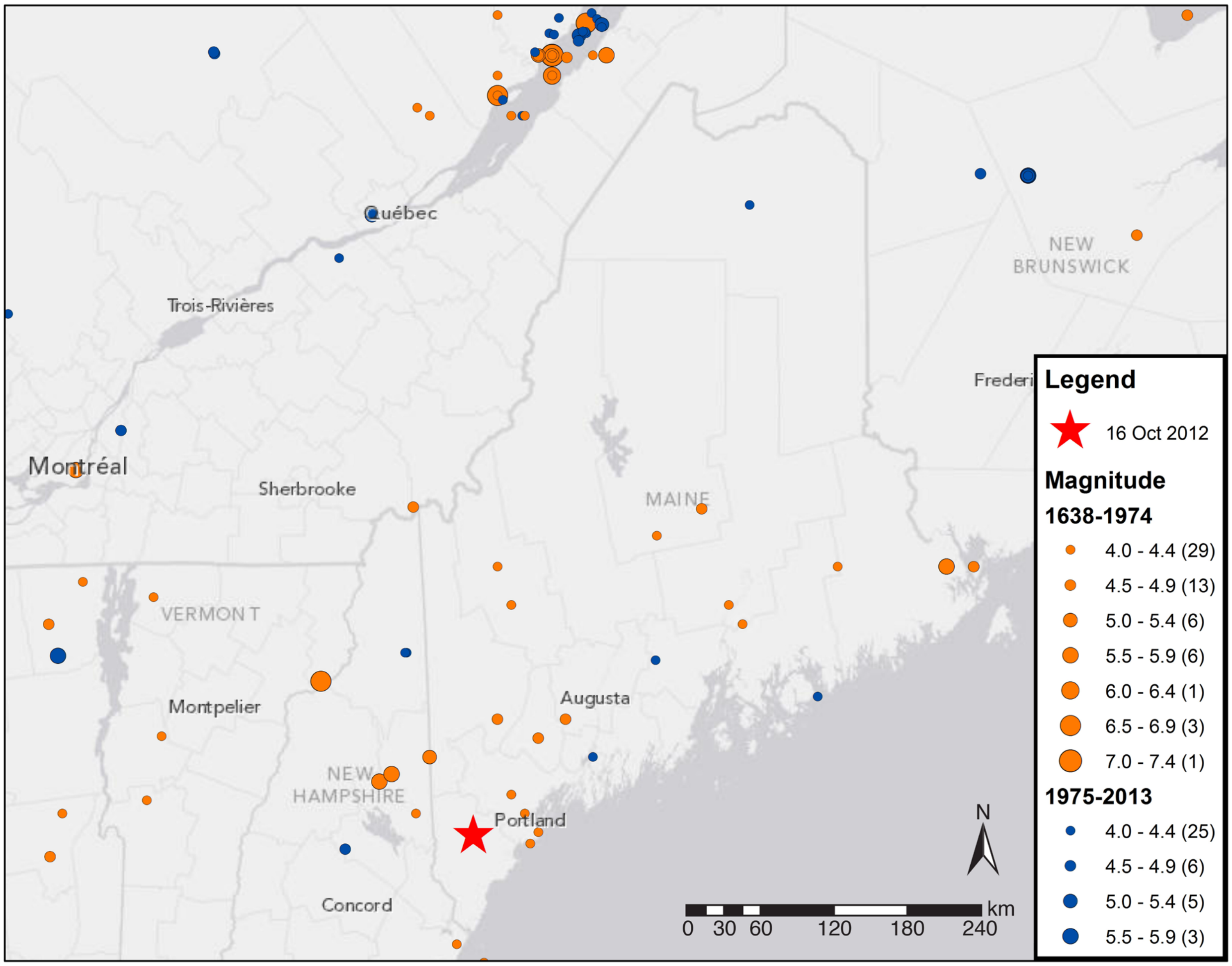

Figure 2. Maine and adjacent states, showing locations of historical M≥4.0 earthquakes since 1638. Orange dots, historical earthquakes (1638–1974); blue dots, instrumentally located earthquakes (1975–present). Earthquake data for 1638–1990 from Ebel (1990); earthquake locations and magnitudes for 1990–present from the Canadian National Seismic Network (Natural Resources Canada, 2013). Number in parentheses following magnitude is number of earthquakes of that size on map. Red star, location of southern Maine earthquake of October 16, 2012.

Small and moderate earthquakes have only been instrumentally located in Maine since 1975: the $M \geq 4.0$ earthquakes that have occurred since 1975 are also plotted in figure 2. These instrumentally located earthquakes are a crucial part of the dataset used to determine the seismic hazard zones shown in figure 3. The Charlevoix seismic zone (CSZ, fig. 3), centered in the Saint Lawrence Seaway to the north of Maine, is the most active seismic zone in northeastern North America. The 1988 M5.8 Saguenay earthquake and the 2005 M4.6 Rivière-du-Loup earthquake occurred in this seismic zone. The 2002 M5.0 Au Sable Forks earthquake in northern New York State and the 2010 M5.0 Val-des-Bois earthquake in southern Quebec are situated in the Western Quebec seismic zone (WQSZ, fig. 3).

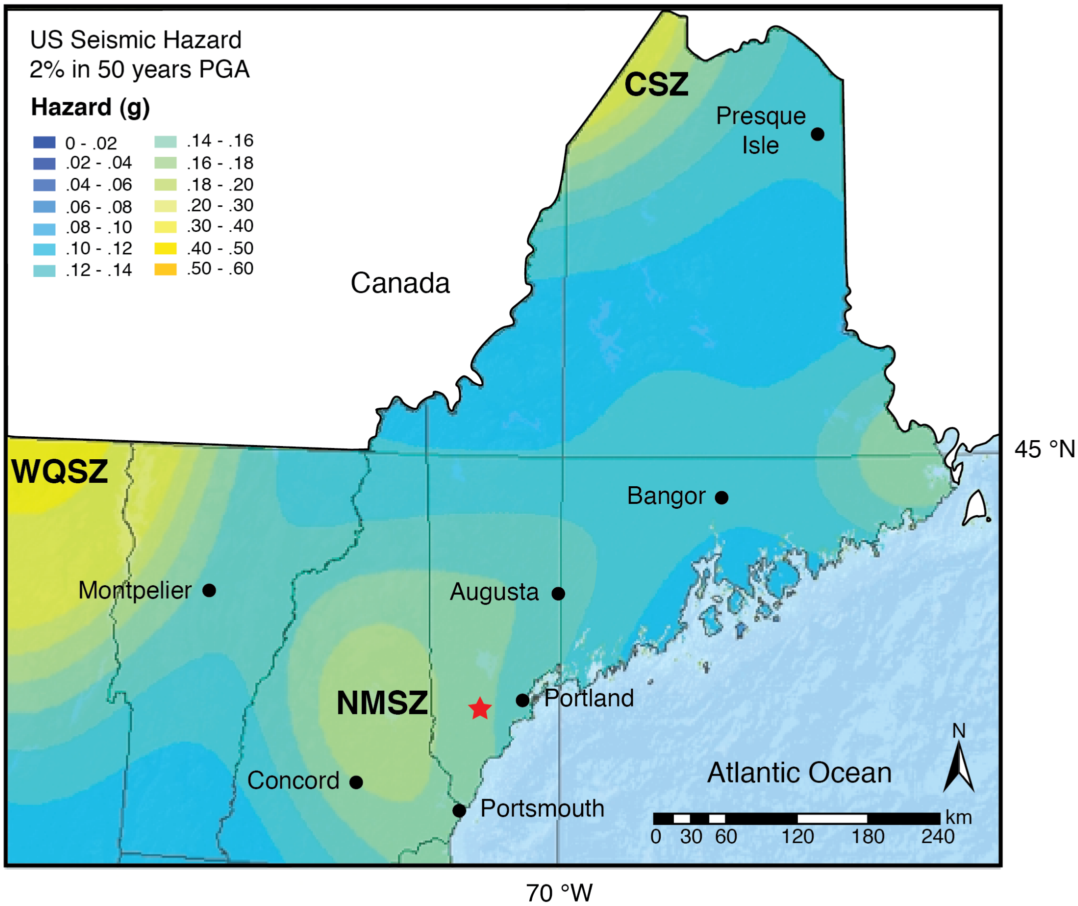

Figure 3. Seismic hazard map of Maine and nearby states (U.S. Geological Survey, 2008). Red star, epicenter of October 16, 2012, southern Maine earthquake. Three seismic zones discussed in this report are labeled: the Charlevoix seismic zone (CSZ), the Western Quebec seismic zone (WQSZ), and the Northeastern Massachusetts seismic zone (NMSZ).

The October 16, 2012, southern Maine earthquake was located within the less active Northeastern Massachusetts seismic zone (NMSZ, fig. 3), which encompasses parts of northern Massachusetts, southern New Hampshire, and southern Maine. On the basis of earthquakes that occurred from 1975 to 1983, Ebel (1984) anticipated that an M4.6 earthquake should recur in Maine every 24 years, an M5.0 earthquake every 52 years, and an M7.0 earthquake every 2,512 years. The M≥4.0 earthquakes listed in Ebel's (1990) catalog of historical (pre-1975) earthquakes suggest that the NMSZ extends eastward through coastal Maine, with a somewhat higher recurrence rate than indicated by the instrumentally located earthquakes.

Focal Mechanism, Centroid Depth, and Moment Magnitude

The October 16, 2012, earthquake epicenter was located at lat 43.60° N., long 70.65° W., 4 km west of Hollis Center in York County, Maine. The centroid depth was estimated at 6–7 km, and the moment magnitude at 4.0–4.1 (fig. 4). The earthquake has a nearly pure reverse-faulting mechanism, whereby one nodal plane dips shallowly west and the other steeply east.

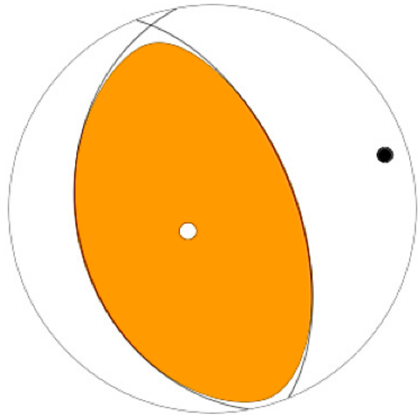

Figure 4. Focal mechanism for the October 16, 2012, southern Maine earthquake. White dot, minimum tension axis (T); black dot, maximum-pressure axis (P). Graphic by Harley Benz, U.S. Geological Survey.

The results from three different moment-tensor solutions for this earthquake, obtained by inverting either regional waveforms recorded within 700 km or surface waves recorded within 2,500 km, are listed in table 1. The Saint Louis University (SLU) and USGS waveform inversions differ only in the sets of stations analyzed. The waveform fits posted on the SLU Web site show a simple, highly compact source.

Table 1. Moment-tensor solutions for the October 16, 2012, southern Maine earthquake.
[USGS, U.S. Geological Survey; SLU, Saint Louis University; CEUS, Central and Eastern United States; km, kilometer; M, moment magnitude. SLU inversions by Robert Hermann of Saint Louis University]

	USGS waveform inversion (25 stations within 450 km)	SLU waveform inversion (54 stations within 700 km)	SLU surface-wave inversion (259 stations in CEUS)
Strike	170°	180°	170°
Dip	33°	30°	30°
Rake	100°	100°	90°
Depth (km)	7.0	7.0	6.0
M	4.03	4.03	4.16

The variation among the results from these three inversions indicates the uncertainty of the source parameters. The centroid depth and the dip are well constrained, but the strike, rake, and moment magnitude are somewhat less well constrained. Despite the moderate size of the earthquake, the focal mechanism, centroid depth, and moment magnitude are all very well determined. The epicenter and hypocentral depth, however, are poorly resolved because the closest seismic station that recorded the earthquake (NHFNK in Franklin, N.H.) is 83 km west of the earthquake. Thus, the difference between the hypocenter and centroid cannot be used to infer the fault plane for the earthquake.

Although no specific fault has been associated with the earthquake, we note that a shallowly east dipping reverse fault was mapped by Osberg and others (1985) in the epicentral area. The north-south-striking main trace of this fault is ~2 km west of East Waterboro, Maine. The strike of the mapped fault in this area agrees with that of the nodal planes calculated from the moment-tensor analysis. However, the shallow eastward dip of the fault inferred by Osberg and others (1985) is inconsistent with either of the nodal planes obtained by the moment-tensor inversions.

Postearthquake Intensity Survey

From October 20 to 24, 2012, we conducted a field survey of felt reports and earthquake damage, in addition to assisting a field team from Cornell University deploy an array of portable seismographs. We observed and photographed damage in Waterboro, Maine, and interviewed residents in the towns surrounding the epicentral area, including Waterboro, East Waterboro, Limerick, Limington, Lyman, Kennebunk, Biddeford, Westbrook, Alfred, and Sanford, Maine, and Rochester, N.H. Most of these interviews were conducted while we were installing the seismic array. We interviewed everyone available near these sites, talking with people who were outside in their yards and knocking on doors of houses that appeared to be occupied. We also sought to interview as many people as possible in areas farther from the epicenter, in order to provide coverage in all directions out to 30 km from the earthquake epicenter. This effort commonly entailed interviewing people in businesses as well as homes. No one we interviewed who was awake at the time of the earthquake reported that he or she did not feel the earthquake. The results of the 27 interviews are listed in table 2, and the correspondence table between shaking effects and assigned intensities is shown in table 3.

Table 2. Resident interview responses after the October 16, 2012, southern Maine earthquake.
[Locations are ordered north to south. Intensities are given in Roman numeral intensities. We used the Modified Mercalli Intensity (MMI) scale of Richter (1958) to assign intensities to these reports. Relevant descriptions of these intensity levels, as revised by Richter (1958) from Wood and Neumann's (1931) original MMI scale, are listed in table 3. We highlight specific effects within the MMI scale that correspond to the most frequent responses in our interviews]

Inter-view	Lat, N.	Long, W.	Location	MMI	Description
a	43.805°	70.813°	Cornish, Maine	5	"Sounded like a caravan of 18-wheelers came down the street." Some items fell off shelves. Lasted about 30 seconds.
b	43.731°	70.710°	Limington, Maine	4	Sounded like a big truck.
c	43.681°	70.440°	Gorham, Maine	4	Felt like a freight train moving through. Nothing fell off shelves. Shaking lasted 10 seconds.
d	43.676°	70.362°	Westbrook, Maine	3	Felt shaking like road construction. Not immediately recognized as an earthquake. Nothing fell off shelves.
e	43.671°	70.536°	Near Buxton, Maine	3	Shook the house. Nothing broken or knocked off shelves.
f	43.667°	70.725°	Lake Arrowhead, Maine	6	Felt like an explosion. A painting fell off the wall. The house shook.
g	43.610°	70.674°	Near North Waterboro, Maine	4	Sounded like a plane through the roof. No fallen objects.
h	43.610°	70.673°	Near North Waterboro, Maine	5	Sounded like an explosion, Lasted ~5 seconds. Plaque fell off a shelf. Crack in drywall extended.
i	43.599°	70.544°	East of Hollis Center, Maine	4	Loud explosion noise. House shook for ~10 seconds. Nothing fell off shelves.
j	43.590°	70.709°	East Waterboro, Maine	6	Sounded like an explosion. A picture fell off one wall, books toppled to the ground, china fell in a cupboard, and a ceramic plate fell from a stand. Crack developed in plaster wall. Felt in car while driving nearby.
k	43.589°	70.709°	East Waterboro, Maine	6	One chimney was topped. Reports of some internal damage and objects knocked off of shelves.

Inter-view	Lat, N.	Long, W.	Location	MMI	Description
l	43.586°	70.641°	Near Hollis Center, Maine		Epicenter.
m	43.581°	70.649°	Near East Waterboro, Maine	6	Sounded like an explosion. Picture knocked off wall, stack of logs knocked over. Cracks in chimney extended by earthquake.
n	43.576°	70.688°	East Waterboro, Maine	5	Heard a noise that sounded like metal scraping. House was shaking, and a few things fell off shelves.
o	43.576°	70.643°	Near East Waterboro, Maine	4	Well water was cloudy for several days. No damage.
p	43.567°	70.687°	East Waterboro, Maine	4	Sounded like a large truck. No items knocked off shelves.
q	43.558°	70.759°	Waterboro, Maine	4	A lot of shaking, but nothing knocked off shelves. Sounded like a truck. Wife slept through the whole thing.
r	43.540°	70.711°	Waterboro, Maine	4	Man lying in bed said “the bed rose a foot off the ground.” No items knocked off shelves.
s	43.538°	70.735°	Waterboro, Maine	5	Sounded like a semi truck passing. A picture fell off the wall, and small items were knocked off the shelves.
t	43.538°	70.839°	Shapleigh, Maine	3	Felt shaking but nothing fell off shelves. Reported that the “fridge was shaking.”
u	43.536°	70.715°	Waterboro, Maine	4	Employee at a restaurant heard a boom and thought something hit the building. All 15–20 people in the restaurant ran outside. Nothing fell off shelves.
v	43.533°	70.725°	Waterboro, Maine	5	Was outside at a soccer game. Ground appeared to ripple.
w	43.519°	70.679°	Between Waterboro and Lyman, Maine	5	Earthquake was very noisy. Some figurines fell off shelves.
x	43.504°	70.903°	Acton, Maine	5	Outside when the earthquake occurred. Ground appeared to ripple. His wife thought the furnace had exploded.
y	43.484°	70.492°	Biddeford, Maine	3	Thought something had hit the building. Some guests came down to the lobby to find out what was going on. Person on the ground floor did not immediately recognize it as an earthquake. No damage.
z	43.441°	70.779°	Sanford, Maine	3	Heard rumbling, and the building shook.
aa	43.438°	70.635°	Lyman, Maine	4	Man said his house was "wicked rockin’.” The house shook and sounded like a jet plane coming through. Heard rumbling. Nothing fell off walls. New cement sidewalk, which was poured that day, was not disturbed.
bb	43.305°	70.982°	Rochester, N.H.	3	Rumbling; nothing fell from shelves or counters. Does not remember how long it lasted, but knew right away that it was an earthquake because she'd been in one before.

Table 3. Modified Mercalli Intensity (MMI) descriptions used to assign intensities to field interviews.

[MMI, Modified Mercalli Intensity, reprinted from Richter (1958). Each effect is described at the intensity level where it first appears and is most commonly and characteristically invoked. Bold text indicates descriptions that match the earthquake effects most frequently reported in our field interviews. The intensities are written as cardinal numbers because CDIs are reported as decimal intensities]

Intensity	Description
1 or I	Not felt. Marginal and long-period effects of large earthquakes.
2 or II	Felt by persons at rest, on upper floors, or favorably placed.
3 or III	***Felt indoors***. Hanging objects swing. ***Vibration like passing of light trucks. Duration estimated***. May not be recognized as an earthquake.
4 or IV	Hanging objects swing. ***Vibration like passing of heavy trucks***; or sensation of a jolt like a heavy ball striking the walls. Standing motorcars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range, wooden walls and frames creak.
5 or V	***Felt outdoors***; direction estimated. Sleepers awakened. Liquids disturbed, some spilled. ***Small unstable objects displaced or upset***. Doors swing, close, and open. Shutters, ***pictures move***. Pendulum clocks stop, start, and change rate.
6 or VI	***Felt by all. Many people frightened and run outdoors***. Persons walk unsteadily. Windows, dishes, and glassware broken. ***Knickknacks, books, and so on knocked off shelves. Pictures knocked off walls***. Furniture moved or overturned. ***Weak plaster and weak masonry cracked***. Small bells ring (church, school). Trees, bushes shaken visibly or heard to rustle.
7 or VII	Difficult to stand. Noticed by drivers of motorcars. Hanging objects quiver. Furniture broken. Damage to weak masonry, including cracks. Weak chimneys broken at roofline. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments). Some cracks in masonry of average construction. Waves on ponds; water turbid with mud. Small slides and caving along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

Building Damage

The earthquake damaged four buildings near the epicenter (figs. 1–3). The most severe damage that we observed was the partial failure (topping) of a brick chimney of the Taylor-Frey-Leavitt House Museum in East Waterboro (fig. 5; interview k, table 2), ~6 km west of the epicenter. Of three identical brick chimneys on the building, only one was damaged. The debris on one side of the building are shown in figure 6; the damage to the roof where the bricks hit it as they fell is difficult to see in the photograph, but was clearly evident from the ground below the building.

Figure 5. Damaged (red circle) and undamaged chimneys on the Taylor-Frey-Leavitt House Museum in East Waterboro, Maine, caused by the October 16, 2012, southern Maine earthquake.

Figure 6. Damaged chimney and brick debris at the Taylor-Frey-Leavitt House Museum in East Waterboro, Maine, caused by the October 16, 2012, southern Maine earthquake.

A homeowner in East Waterboro (interview j, table 2), a block away from the museum, reported a plaster crack in her wall (fig. 7) that ran along the wall behind an internal chimney and may have been caused by differential motion of the chimney and wall. Another homeowner near Waterboro (interview h, table 2) reported that a preexisting crack in his plaster wall was extended by ~8 centimeters (cm). No other building damage was reported to the field team.

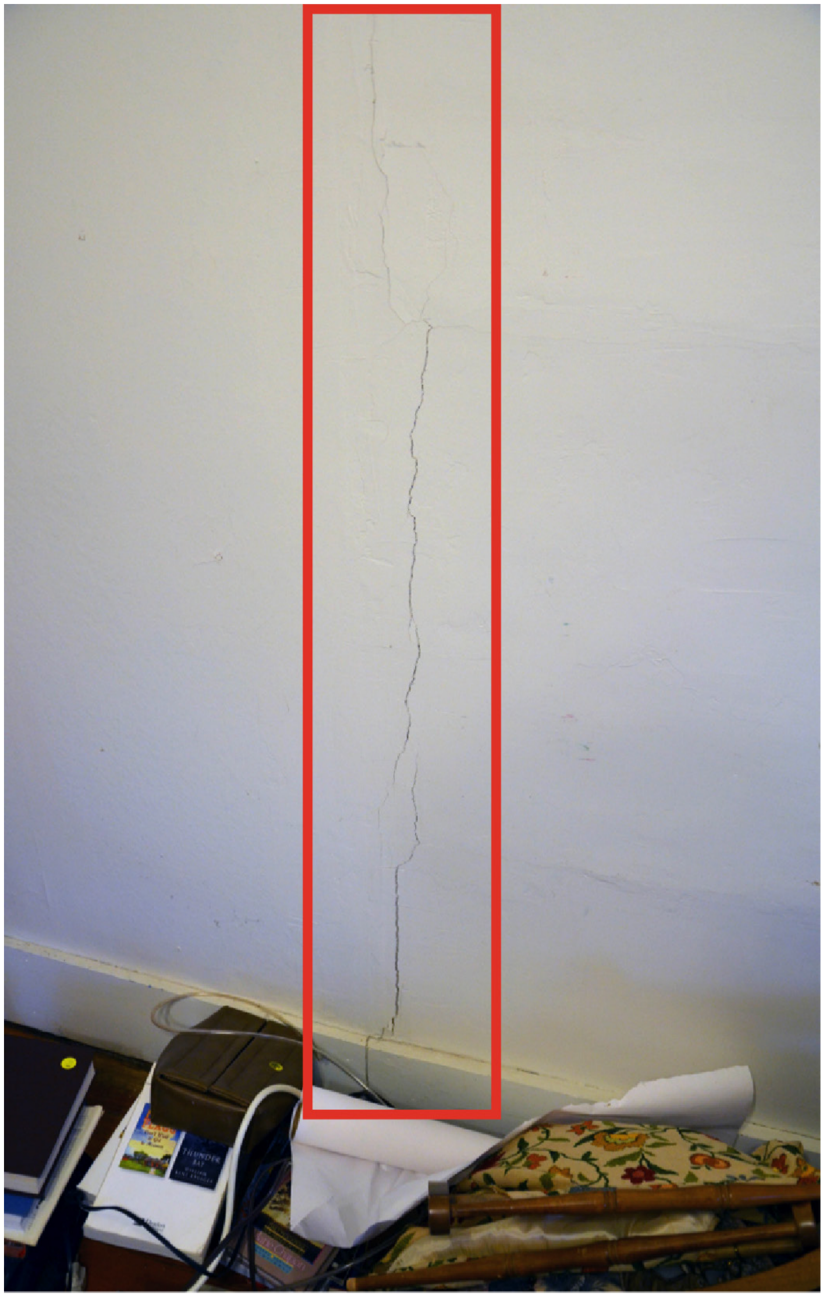

Figure 7. Crack in plaster on an interior wall of a wood-frame home in East Waterboro, Maine, caused by the October 16, 2012, southern Maine earthquake.

Shaking Effects

The earthquake occurred at 7:12 p.m. EST, when most residents were at home; a few people were at restaurants or outdoors. Many residents reported that small figurines and books were knocked off shelves, pictures were shaken from walls, and at one residence, a woodpile in the yard fell down (interview m, table 2). A store clerk in Cornish reported (interview a) that small items, such as canned goods, paper towels, and candles, were knocked off shelves in the store. Another resident reported (interview r) that his bed "jumped" while he was lying in it. One person reported (interview v) seeing the surface of a soccer field "ripple." The shaking caused 15–20 people in a restaurant to rush out of the building (interview u). Several residents of East Waterboro mentioned (interviews j, o) that their well water was cloudy for 1–2 days after the earthquake. These reports are consistent with MMI = 6.

Nearly all residents interviewed reported a loud sound and rumbling movement associated with the earthquake. The sound and initial shaking was commonly described to be like a freight train, a semitrailer, or a large truck. Other people reported that the earthquake sounded like an explosion (suggestive of a gas tank exploding), a plane crashing into the building, nearby construction work, or an off-balance washing machine. The perceived duration of shaking varied widely in the interviews (table 2) from 5 seconds to about one minute. The store clerk in Cornish reported (interview a) two distinct episodes of rumbling and ground motion. We considered the reports of shaking without other effects to indicate MMIs of 3–4.

Comparing the Field Intensities to the "Did You Feel It?" Intensities

The USGS DYFI ZIP-Code map (based on "Did You Feel It?" reports) in figure 1 is expanded around the epicenter of the earthquake in figure 8. The ZIP-Code CDIs in the epicentral area range from 3–5. We plot the intensities obtained from the field survey as colored dots on the shaded ZIP Codes of the DYFI map. Note that the color schemes for the two sets of intensities differ. The MMIs inferred from our interviews and the observed damage range from 3 to 6 but 4 to 6 in the epicentral area. The MMIs from the field survey add significant detail to the CDI map.

Outside the immediate epicentral area, the MMIs obtained from our field survey are similar to the CDIs. Both sets of intensities fall off to intensity 4 and 3 with increasing epicentral distance, and both sets are stronger to the west of the epicenter than to the east, although we conducted fewer interviews in the ZIP Codes to the east and southeast of the epicenter.

The two sets of intensities differ somewhat in the epicentral area. Overall, the MMIs from the field survey are slightly stronger than the CDIs. The intensities obtained from the seven sites in East and North Waterboro locate the strongest shaking 1–8 km west of the epicenter, mostly in the East Waterboro ZIP Code. The average CDIs for North Waterboro, East Waterboro, and Hollis Center are 5.2, 5.1, and 5.1, respectively.

We can gain some insight into the ZIP-Code average CDIs by considering the number of responses and the comments included in the DYFI reports. A total of 40 DYFI reports were received from 695 households in East Waterboro; that is, 5.7 percent of households responded. Two comments in the reports indicate that the earthquake slightly cracked sheetrock or foundations, and three comments mention objects "thrown" from shelves or furniture.

In contrast, 29 DYFI reports were received from 1,307 households in North Waterboro; that is, only 2.2 percent of households responded. Two comments indicated cracking, and none mentioned objects thrown from shelves. Similarly, 56 DYFI reports were received from 1,575 households in Hollis Center; that is, 3.6 percent of households responded. One comment said "things fell off of bookshelves and even some stacks of tires were toppled" and described cracking in the foundation and the garage floor. Another comment said things "fell in the shop," and a third comment described cracking in a garage floor.

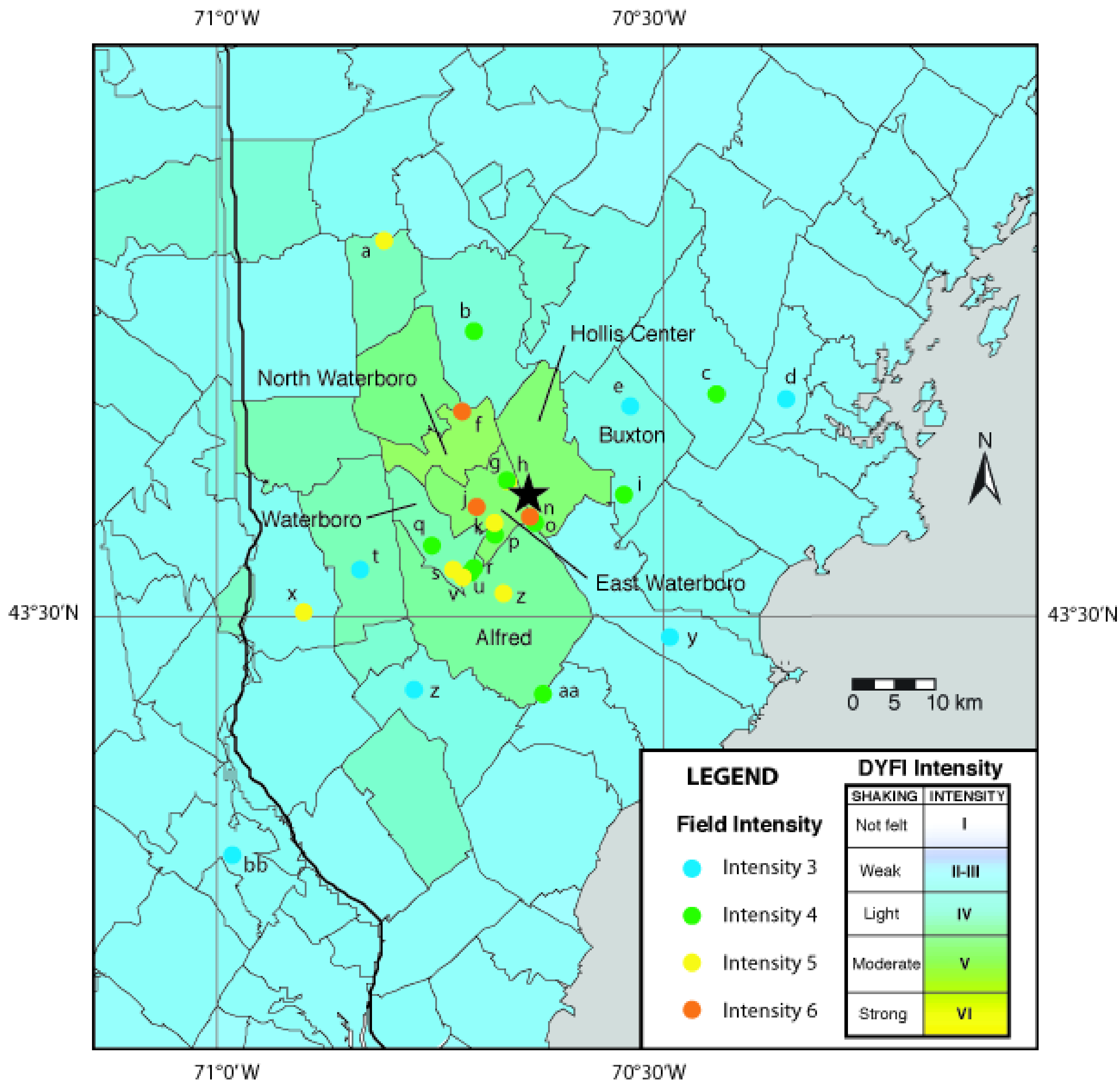

Figure 8. Epicentral area of the October 16, 2012, southern Maine earthquake, showing shaking intensities as recorded in resident interviews (colored circles), in comparison with the Community Decimal Intensity map, which is based on “Did You Feel It?” reports (background).

Farther from the epicenter, the 30 DYFI reports that were received from 805 households in Waterboro (3.7 percent) yielded an average CDI of 4.6. One comment mentioned cracks “in foundation.” In Alfred, the large ZIP Code to the south of the epicenter, 34 DYFI reports that were received from 2,839 households (1.2 percent) yielded an average CDI of 4.8. No comments from this ZIP Code mentioned cracks or objects thrown from shelves. In Buxton, the ZIP Code to the east of Hollis Center, 66 DYFI reports that were received from 1,655 households (4.0 percent) yielded an average CDI of 4.2. No comments mentioned cracks or objects thrown from shelves.

Thus, the East Waterboro ZIP Code has both the highest rate of DYFI responses (5.7 percent of households) and the most comments that describe cracking or objects thrown from shelves, but an average CDI of only 5.1. We note no apparent overlap of the field survey with DYFI: no DYFI comments described the damage that we observed or the reports that we obtained in East Waterboro. However, we neglected to ask the people we interviewed whether they had submitted DYFI reports.

The Taylor-Frey-Leavitt Museum was closed at the time of the earthquake, and the damage to this building was not reported to the DYFI Web site. This circumstance demonstrates an important difference between DYFI and field surveys. The DYFI Web questionnaire does not ask respondents to report damage to nearby buildings, in order to keep from multiply reporting these effects. The resulting DYFI reports represent only the direct experience of respondents; damage to unoccupied houses and houses without DYFI respondents is not reported. In our field survey, however, neighbors who were aware of damage to surrounding houses directed us to those houses.

Our field survey also provided an unexpected benefit to the DYFI Web site. The original CDI map for the earthquake showed CDIs of 3.3, 3.3, and 3.4 in three of the four ZIP Codes closest to the epicenter (Waterboro, East Waterboro, and Hollis Center, respectively). The numbers of DYFI reports received from these three ZIP Codes were wildly disproportionate—295, 355, and 922, respectively. When we pointed out these anomalies to Vince Quitoriano (USGS, Golden, Colorado), who maintains the DYFI Web site, he discovered that a computer error had mislocated 1,490 DYFI reports into these three ZIP Codes. Correcting this error yielded the DYFI ZIP-Code map shown in figure 8.

Inferring the Fault Plane from the Intensity Distribution

The moment-tensor inversions listed in table 1 constrain the mechanics of the earthquake. A block diagram of the epicentral area is shown in figure 9. The two nodal planes from the focal mechanism of the USGS waveform inversion are drawn as intersecting at the centroid depth of 7 km. In addition, we have drawn the geologic fault inferred from the geologic map of Maine (Osberg and others, 1985) as a plane dipping ~15° E. from the mapped fault trace. We note that despite the large uncertainty of the epicentral location (±2 km), the dip of these different planes implies that the earthquake did not occur on this older thrust fault.

We can use the intensity distribution shown in figure 8 to consider which nodal plane is the likely fault plane. The asymmetry of the intensity distribution around the epicenter, where intensities are stronger to the west than to the east, indicates that the earthquake ruptured westward, either updip on the nodal plane that dips steeply east or downdip on the nodal plane that dips shallowly west.

The area of strong shaking in East Waterboro corresponds to updip rupture on a fault plane that dips steeply to the east. As apparent in figure 9, updip rupture on this fault plane would focus seismic energy toward East Waterboro (immediately west of the epicenter). In the alternative model, downdip rupture on a fault plane that dips shallowly to west would produce a more nearly uniform intensity distribution in the epicentral area and a stronger east-west asymmetry of the intensity distribution at distances from 30 to 80 km. The directivity of the downdip rupture would be apparent only at distances where downgoing S-waves are efficiently reflected back to the surface.

We note that the directivity in the near-field intensities is weak, despite its clear expression in figure 8. A simple rule of thumb for relating intensity to ground motion is that one level of intensity corresponds to a factor of 2 in ground motion (Wald and others, 1999). Because the asymmetry of the intensity distribution of this earthquake is less than a whole level of intensity, the amplification of ground motion owing to rupture directivity is probably less than a factor of 2.

Although the intensity distribution in the near field of this small earthquake suggests that the nodal plane dipping steeply east is the more likely fault plane, we note that this choice is frictionally less favorable than the nodal plane dipping shallowly west. If the rupture occurred on such a high-angle reverse fault, it could represent reactivation of a normal fault that dates to the opening of the Atlantic ~200–180 Ma (Van Lanen and Mooney, 2007).

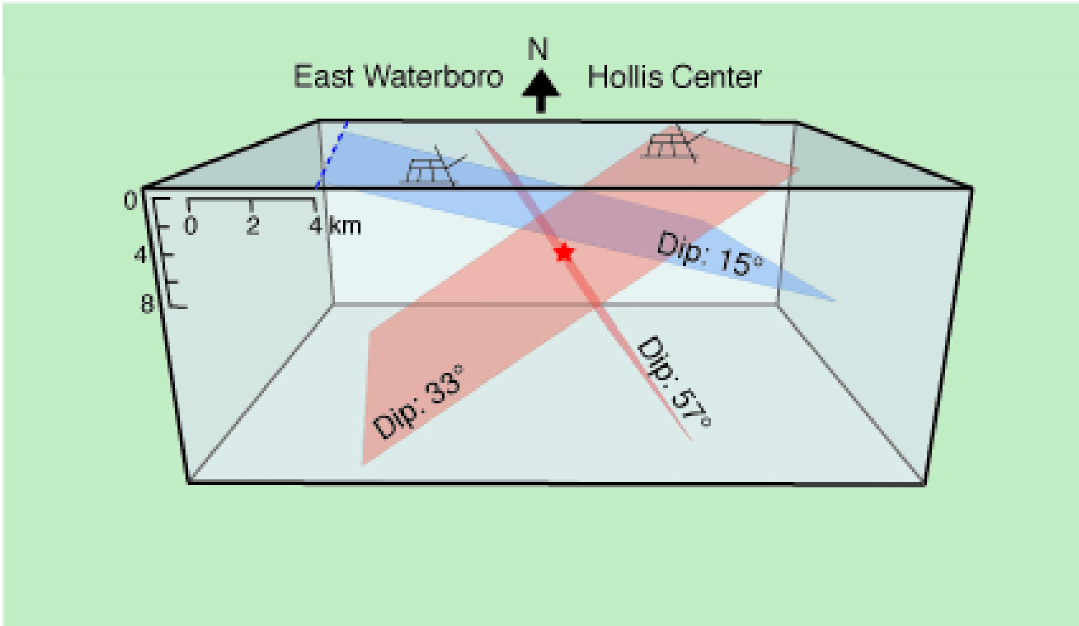

Figure 9. Block diagram of epicentral region of the October 16, 2012, southern Maine earthquake. Red star, earthquake centroid. Black grids, small towns of East Waterboro and Hollis Center, Maine. Orange planes, nodal planes from the U.S. Geological Survey moment-tensor inversion. Dashed blue line, main trace of fault mapped on geologic map of Maine (Osberg and others, 1985); blue plane approximates this fault. Horizontal exaggeration makes the fault plane and nodal planes appear to dip more steeply.

Conclusions

Residents of southern Maine experienced an M4.0 earthquake on October 16, 2012, that caused minor damage but no reported injuries. Our field study observed building damage that was limited to one broken chimney, two cracked plaster walls in East Waterboro, and one instance of extended chimney cracks. Common shaking effects reported to us included books and small objects being knocked from shelves, small pictures or paintings being shaken from walls, and in several places, turbid well water persisting for 1–2 days after the earthquake. These reports enabled us to locate an area of strong shaking 1–8 km west of the epicenter with an apparent MMI of 5–6, slightly higher than the maximum CDI of 5 reported on the USGS DYFI Web site.

The area of stronger shaking determined from our field survey suggests that the earthquake ruptured updip to the west on a fault dipping ~60° E. If this identification is correct, the earthquake should be interpreted as reactivating a fault that may have been active as a normal fault during the Mesozoic rifting of the Atlantic Ocean. We note that this localization of stronger shaking is not evident on either the DYFI ZIP-Code or geocoded maps, although the DYFI maps do show that the intensity is greater to the west than to the east of the epicenter.

The difference between these two sets of intensities in the epicentral area indicates that a brief field survey can yield critical intensity information for moderate earthquakes. The CDI maps fail to resolve the strongest shaking because they average DYFI reports over ZIP Codes and because sparse damage can go unreported. The minor damage that we observed and the strong shaking reports that we obtained in the epicentral area reinforce the utility of field surveys after moderate and large earthquakes in the Central and Eastern United States.

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