Mapping residential property damage resulting from the August 23, 2011 Earthquake in Louisa County, Virginia to support recovery, research, and mitigation efforts

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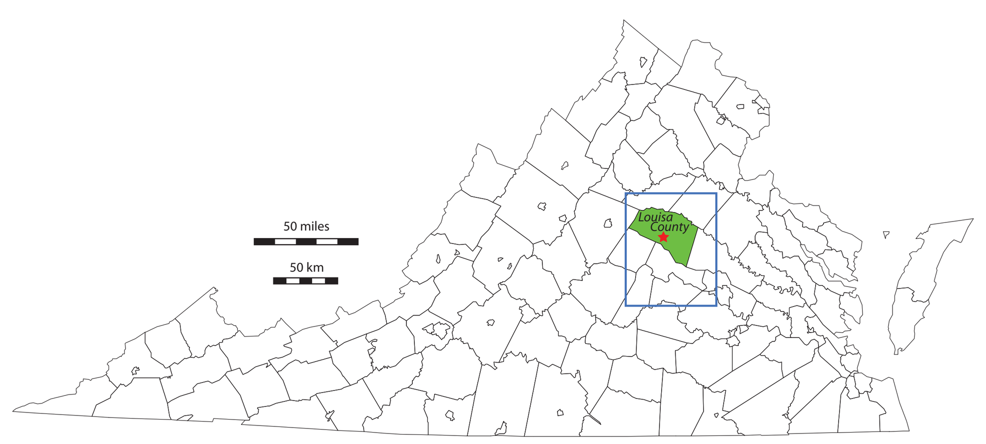
Abstract

The magnitude 5.8 earthquake that occurred near Mineral, VA on August 23, 2011 affected more than 1,500 residences in Louisa County and surrounding areas. Reported damage was to chimneys, building foundations, building frames, interior and exterior walls, windows, porches, carports, and water lines. In Louisa County, repair and replacement costs for residential property exceeded 21 million U.S. dollars. A preliminary map showing the distribution of property damage in the epicentral area was created by the Virginia Department of Mines, Minerals, and Energy (VA DMME) shortly after the earthquake to assist in recovery and aftershock monitoring efforts. Improved damage maps have been developed in collaboration with James Madison University to assist with recovery, research, and mitigation efforts that include locating the causative fault(s) and determining the geologic conditions that affect property damage in this region. Mapping the intensity of residential property damage for this earthquake was challenging because of the low density and irregular spacing of residences and the variability in residence size, style, age and method of construction. In addition, damage rankings from inspectors do not specify the type of damage that occurred and are not available for all residences reporting damage. Our approach uses data for approximately 100 structures that were collected by geologists from the VA DMME and the U.S. Geological Survey immediately after event in combination with reports of residential property damage from home-owners in Louisa, Fluvanna, Goochland, and Spotsylvania Counties, and damage rankings assigned by county and FEMA inspectors. Damage is mapped as zones of intensity based on the predominant type and level of damage and the percentage of homes reporting damage. The data suggest that the earthquake generated a Mercalli intensity of VIII at the ground surface, up-dip of the focus of the main shock.

Earthquake Background

- Occurred on August 23, 2011
- Magnitude 5.8, focal depth of 5 - 8 km (USGS, 2011; Chapman, 2012)
- Within central Virginia seismic zone
- Previously unknown fault
- Reverse motion on NE-striking, SE-dipping structure (Horton, 2012)
- No surface rupture
- Most widely felt earthquake in U.S. History
- Widespread property damage, but no fatalities



Sources of Damage Information

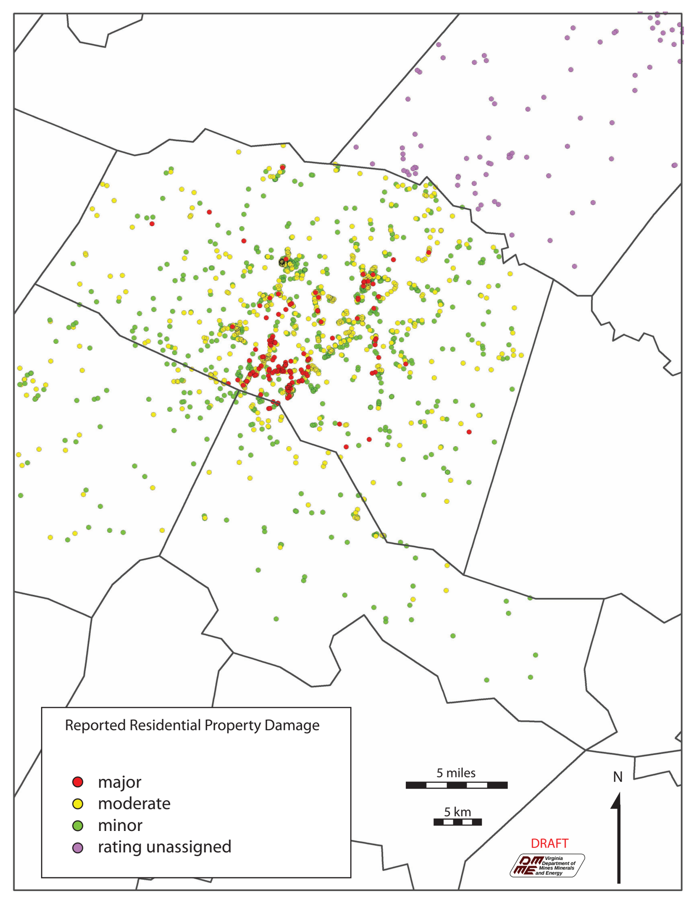
- FEMA Inspector damage ratings (451 residences)
- County Inspector damage ratings (897 residences)
- DMME site visits (101 residences)
- Self-description of damage by homeowner (1485 residences)

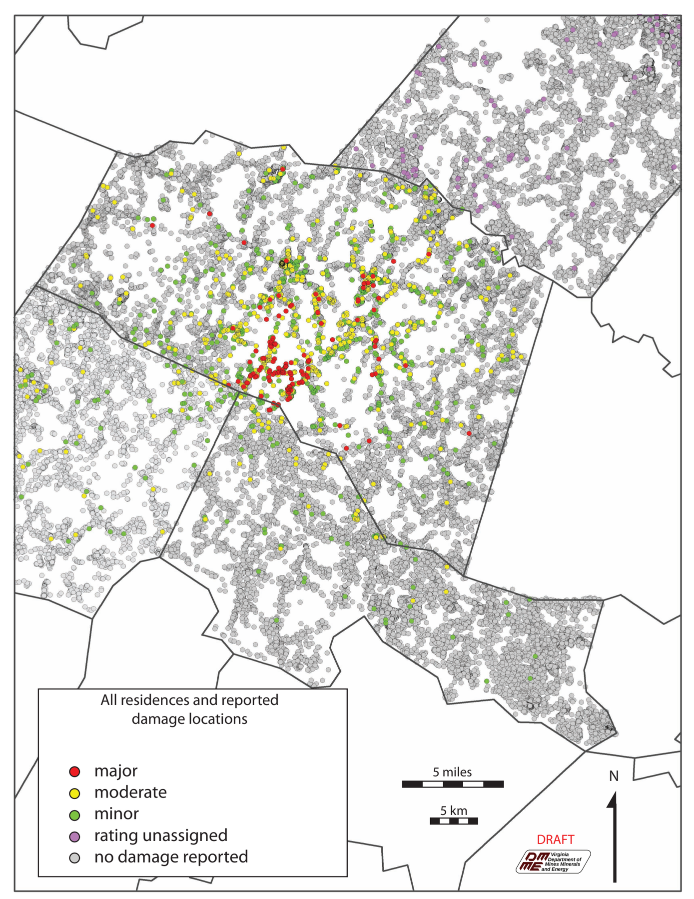
Damage Classification

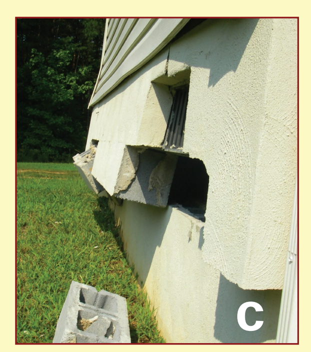
Damage Level	Criteria
Major (n=122)	- inspector rating of **major** or **destroyed**
Moderate (n=557)	- inspector rating of **affected**; AND self-description indicates foundation or building frame damage - self-description indicates foundation or building frame damage
Minor (n=778)	- inspector rating of **minor** - inspector rating of **affected;** AND self-description does **not** indicate foundation or building frame damage - self-description does **not** indicate foundation or building frame damage

A common classification system was needed in order to analyze data from various sources. Criteria for assigning levels are shown in in priority order.

Raw Data



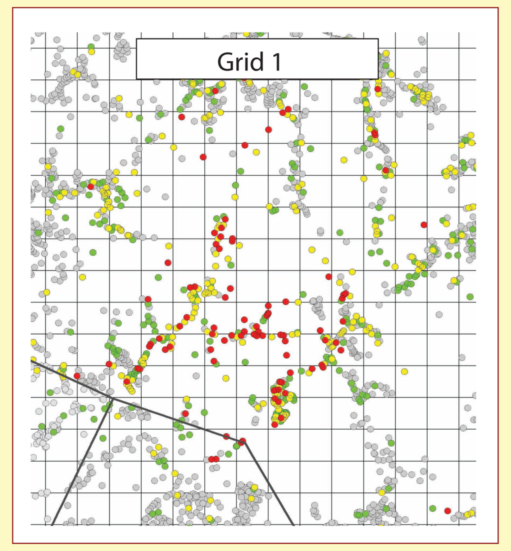




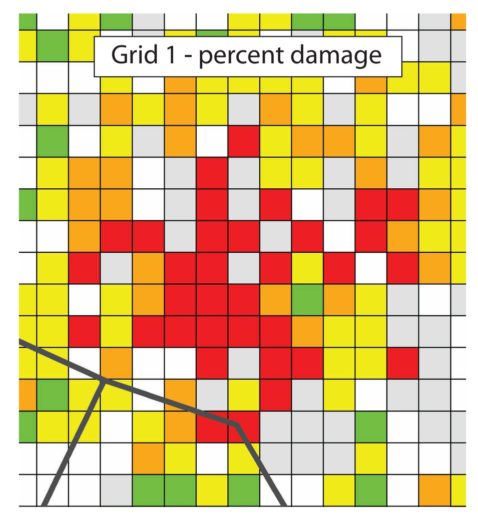
Photos: (a) VA DMME visited more than 100 damaged residences from 8/24/12 - 8/26/12; (b) chimney failure was common at all damage levels; (c) major damage to foundation; (d) major damage - house shifted on foundation; (E) moderate damage to foundation.

Grid Analysis

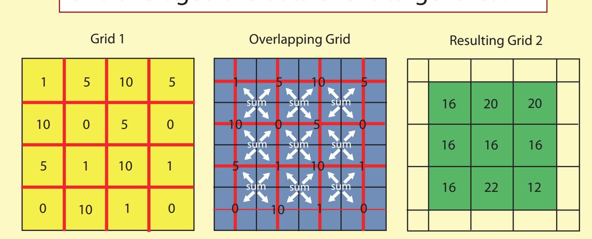
A 1 km grid was placed over the epicentral area. The total numbers of residences and residences reporting damage at each level were determined for each cell.

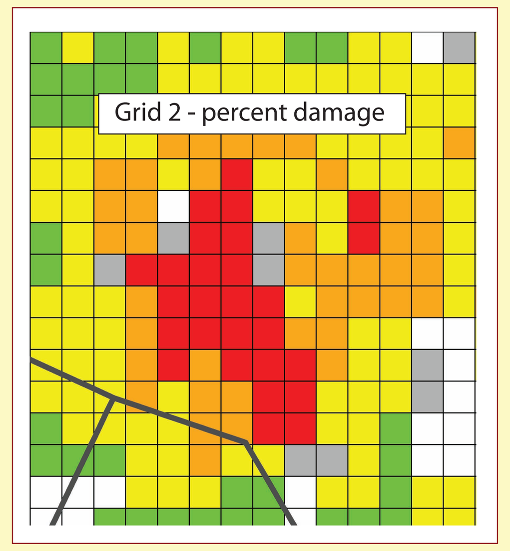


Cells were color-coded based on the percentages of residences reporting damage

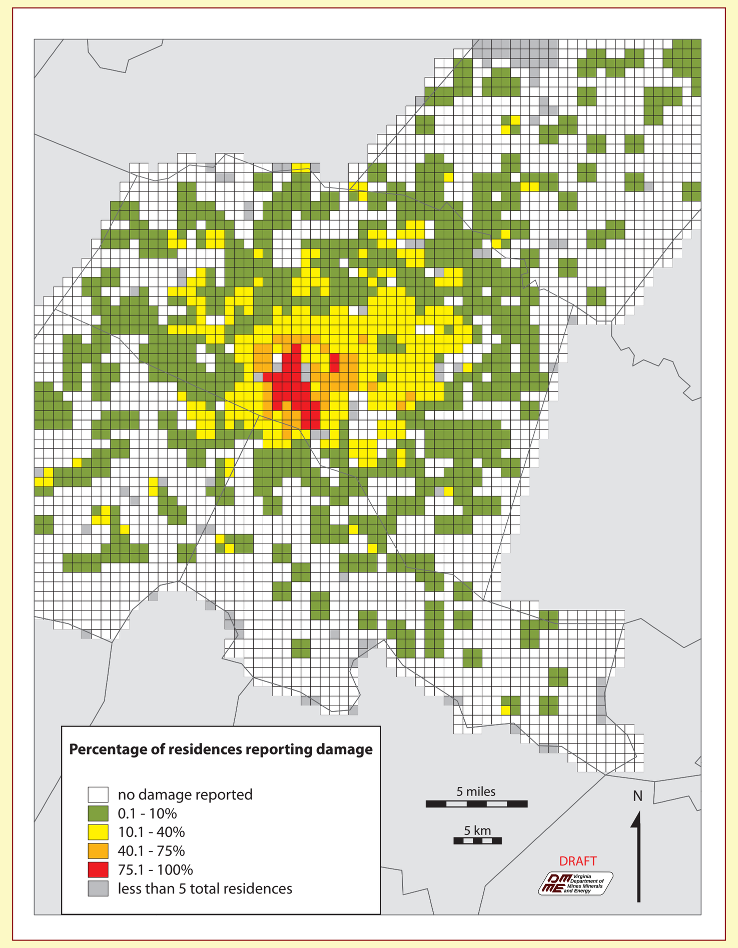


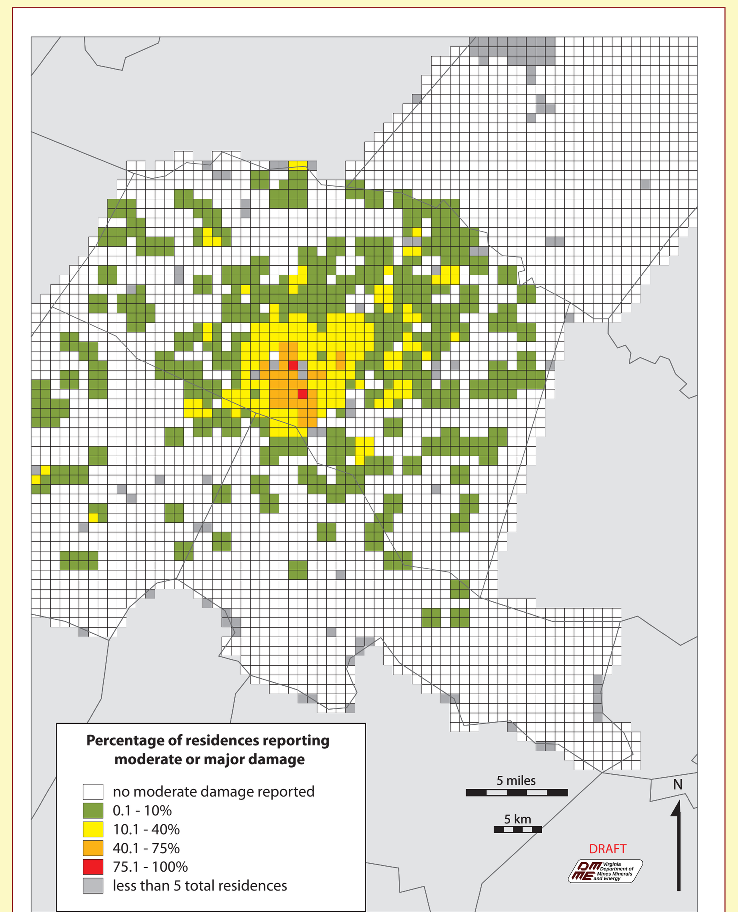
A second grid was overlapped with the first grid. Each cell in this grid was color coded based on the percentage of residences in the four intersecting cells from the first grid that reported damage. This reduced the impact of cells with few or no residences and averaged the data over a larger area.

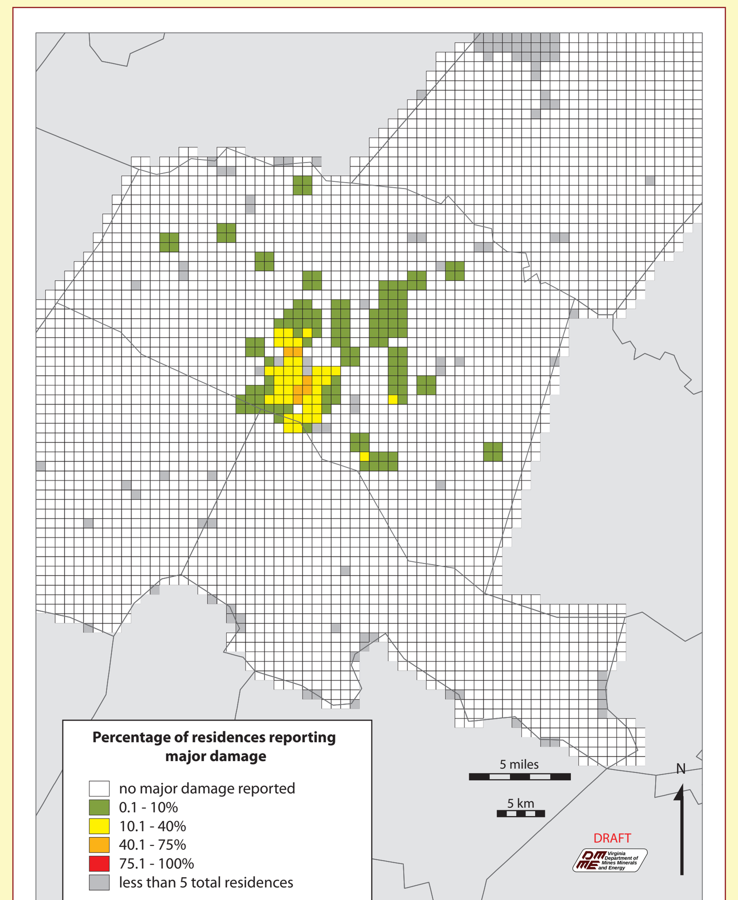




Grid Maps

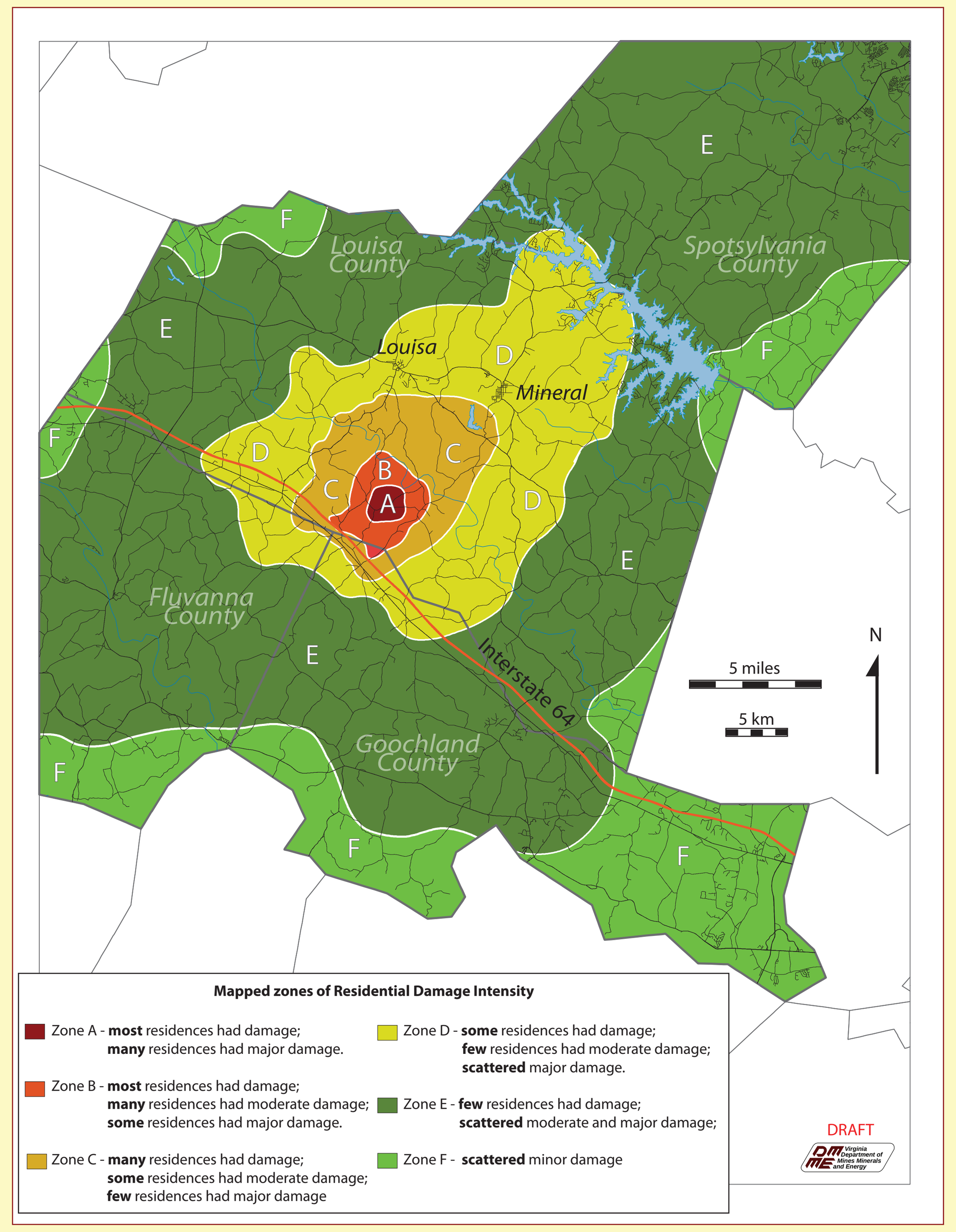




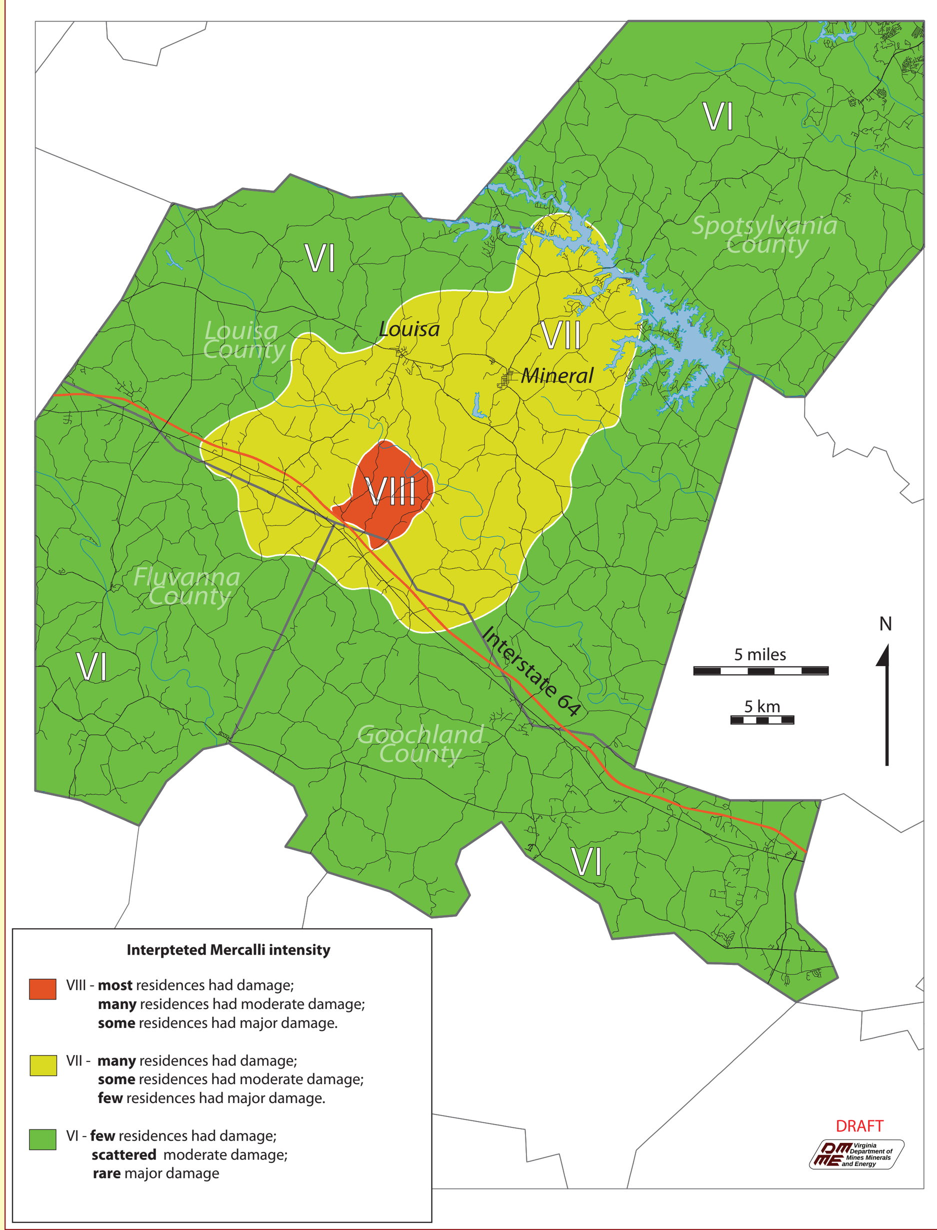


Intensity Maps

Raw data was used in combination with maps generated though the grid analysis to identify mappable zones of intensity, based on reported damage.



A Mercalli Intensity map was created based on the mapped zones of intensity, using the criteria of Stover and Coffman (1993).



Conclusions

Maps showing the intensity of residential property damage resulting from earthquakes can be made using damage ratings from building inspectors and descriptions of property damage from homeowners. Visiting a subset of affected residences is important in order to understand the type, frequency, and range of damage that occurred and to relate this damage to inspector ratings. The ability to map damage from future earthquakes would be improved if inspectors recorded the amount of building frame and foundation damage that occurred at each residence. A list of questions for homeowners reporting damage would help improve the usefulness of self-reported damage.

Data for the 2011 Virginia earthquake suggest that an area of approximately 40 sq. km experienced a Mercalli intensity of VIII; an area of approximately 600 sq. km experienced a Mercalli intensity of VII. The location of greatest residential property damage is up-dip from recalculated focus of the main shock (Chapman, 2012) along the causative fault plane, based on reported orientation of the fault plane (Horton, 2012).

Damaging earthquakes in the eastern U.S. are rare. Intensity maps from the 2011 Virginia earthquake provide a single example of the scope of damage possible, and may be useful for emergency simulation and planning purposes. These maps can also be used to determine the natural and man-made site conditions that affect damage, which has value for the mitigation of future impacts.

Acknowledgements

Mark Carter, David Spears, Dennis Feeney, and Lorrie Coiner participated in the field investigation of earthquake damage from August 24-26, 2012. Shelley Whitmeyer provided guidance to students compiling earthquake damage data. Martin Chapman, James Dewey, Wright Horton, Aina Carter, and Rich Harrison provided useful insights. Louisa, Spotsylvania, Fluvanna, and Goochland County staff provided GIS data and damage reports.

References

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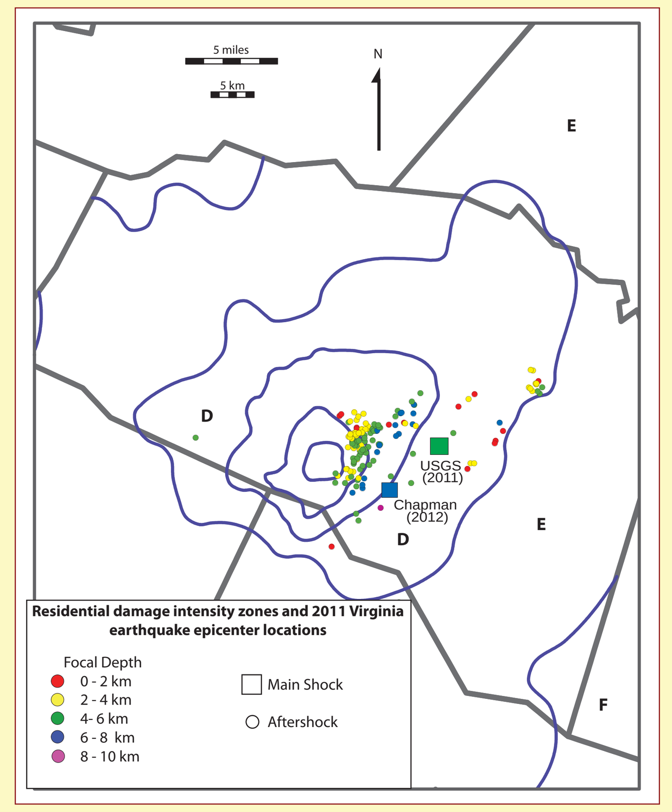
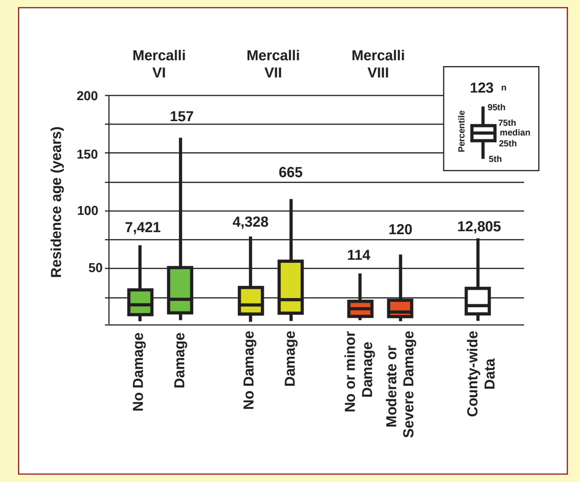
Horton, J.W., Jr., McNamara, D.E., Shah, A.K., Gilmer, A.K., Burton, W.C., Harrison, R.W., Carter, M.W., Herrmann, R.B., and Snyder, S.L., 2012, Preliminary analysis of magnitude 5.8 Virginia earthquake causative fault and subsidiary faults illuminated by aftershocks, Geological Society of America Abstracts with Programs, Vol. 44, No. 7, p. 381.

Stover, C.W., and Coffman, J.L., Seismicity of the United States, 1568 - 1989 (Revised), U.S. Geological Survey Professional Paper 1527, 418 p.

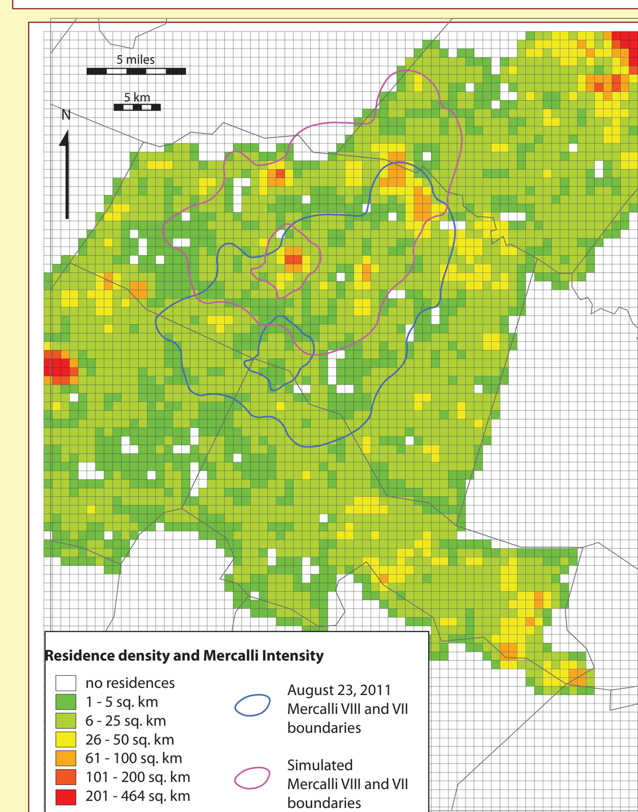
Derivative Products



Placing property damage in the context of other earthquake-related data, such as the locations of the main shock and aftershocks, can provide useful information. This map shows that the most intense property damage was west of the epicenter reported for the main shock (US. Geological Survey, 2011), the re-calculated epicenter (Chapman, 2012), and many of the aftershocks (U.S. Geological Survey, 2011). Based on the orientation and dip of the structure (Horton, 2012), and the recalculated focal depth of 8km (Chapman, 2012) the greatest damage occurred directly up-dip from the main shock in the location where the fault intersects the ground surface.



A damage intensity map allows for the analysis of property damage relative to other variables, such as home size, construction type, soil thickness and type, underlying bedrock, and water table depth. In this example, statistical variation in the ages of homes reporting different levels of property damage suggests that age was a factor in zones VI and VII, but was not a significant factor in zone VIII.



One possible application of the grid developed for this earthquake is to simulate the impact of a similar earthquake in a different location. Each cell of the grid developed for the 2011 Virginia earthquake has been assigned a percentage of damage for each level of damage. A simulated number of affected residences can be determined by counting the total number of residences in each cell at a new location and multiplying this count by the assigned percentages. There are many variables that will change from place-to-place, but this approach provides an general sense of the scope of damage that is possible, which should be useful for planning and training purposes. In this example, the area of greatest damage was moved 10 km north and centered on the town of Louisa.

Damage in Mercalli VII and VIII	Residences 2011 Event	Residences Simulated Event
Minor	619	422
Moderate	460	676
Major	118	451