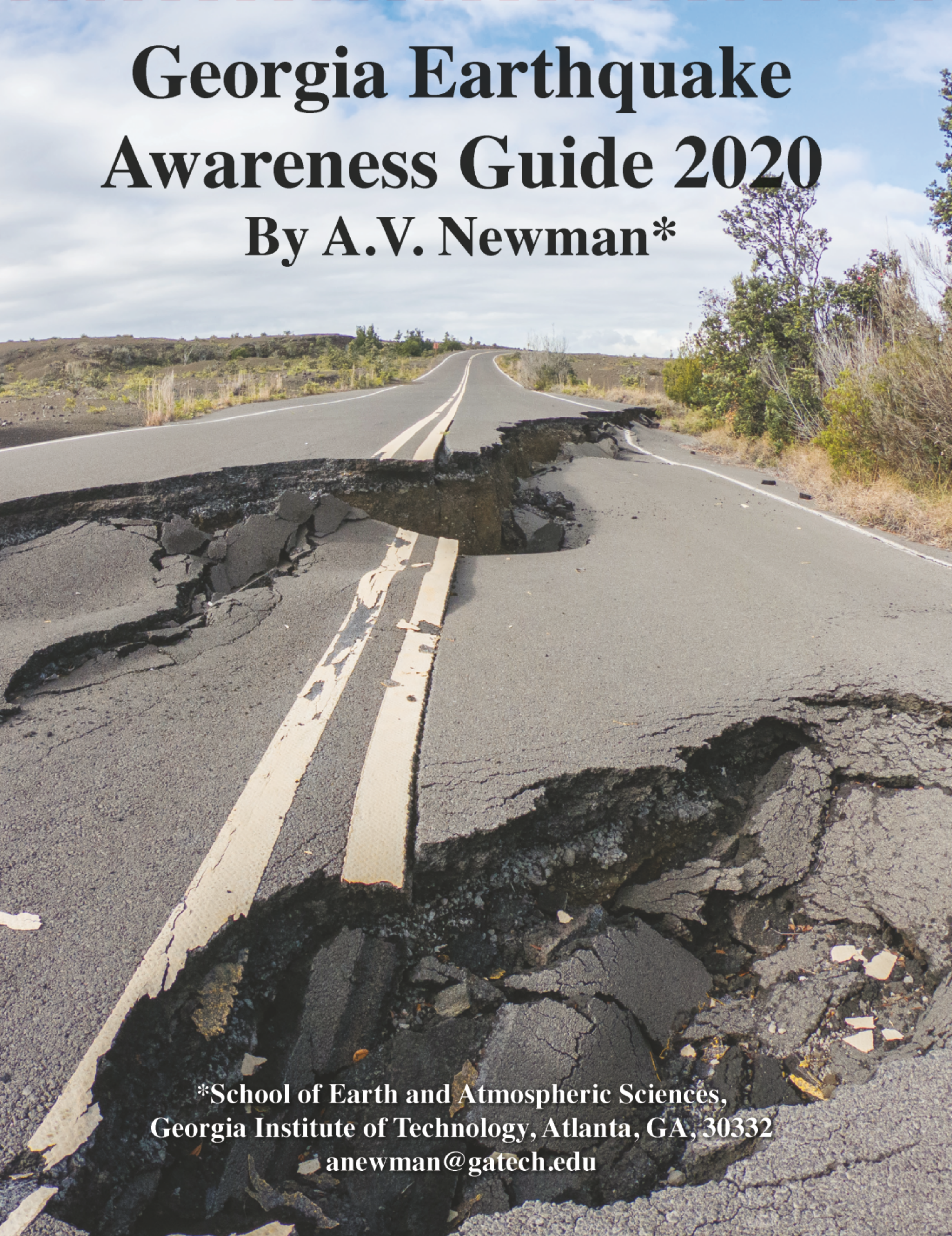
# Georgia Earthquake Awareness Guide 2020

## By A.V. Newman*



*School of Earth and Atmospheric Sciences,
Georgia Institute of Technology, Atlanta, GA, 30332
anewman@gatech.edu

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## 1. Introduction:

Earthquakes most often occur along well-known faults along the edges of constantly moving tectonic plates such as the San Andreas Fault in California. However, far away from plate boundaries, intraplate earthquakes can still occur due to stresses that are often not well understood. Georgia, like other states east of the Rocky Mountains, experiences these earthquakes (Fig. 1). Because these events are potentially damaging, they are an important consideration even if the likelihood of a dangerous event occurring may be small.

## 2. Earthquake Basics:

***Earthquakes are:*** strong ground shaking events caused by the sudden failure of the earth's crust releasing energy built up in the form of stress. Almost the same thing occurs when you bend a pencil and it breaks—stress is rapidly and possibly violently released due to the stress associated with bending the material.

***Earthquake shaking is measured:*** using extremely sensitive instruments called seismometers that record the tiniest vibrations of the earth. With a network of these instruments, scientists are able to identify the timing, location, size, and other physical aspects of earthquakes. Because seismic waves (waves generated by earthquakes) travel through the earth at known speeds, we identify their location and timing by identifying when the waves arrive at individual stations. The magnitude of an earthquake is determined by the amplitude of shaking recorded at seismometers after correcting for distance. The waves recorded from a magnitude 4 earthquake are about 10 times larger than a magnitude 3 that is the same distance away. In the hours after an earthquake, the reported magnitude may change because of additional measurements from other seismic stations, and because other methods may be applied to improve the result.

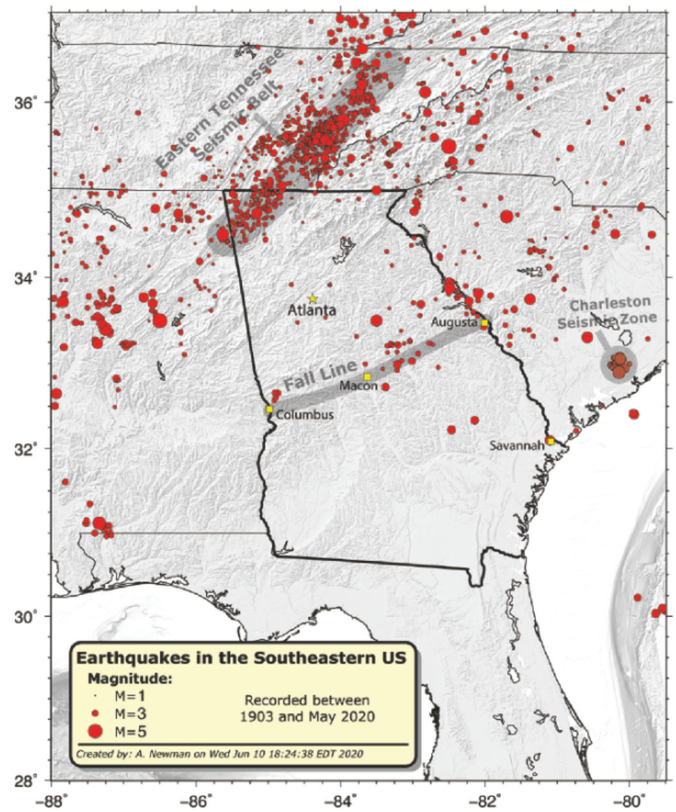


Figure 1: Earthquake activity in and around Georgia. Red events are those cataloged by the US Geological Survey between 1903 and May 2020 (ANSS, 2020), Most events are between magnitude 2 and 3.

Magnitudes are currently measured using a number of methods, which all have advantages for different events in different environments. However, because the methods are all designed to correspond to the original "Richter Magnitude", results are similar. The alternative magnitude types include body-wave, surface-wave, moment-, duration, but are generally referred to as simply "Magnitude" to avoid confusion with non-seismologists. **Appendix I** gives a descriptive comparison of the effects observed for events with different magnitudes.

***Earthquake deformation is measured:*** using a number of other instruments, including GPS, that record how the ground around a particular fault or region changes over time. Near active plate boundaries, the tools can be used to measure very small changes in the shape of the surface of the Earth as motions on the order of 1-inch per year load faults. When the faults are known, rates are fast enough to be measured, and data are available, scientists use these data to better understand how often, and even where earthquakes are more likely even without substantial historical data on a fault's behavior. In the eastern U.S., this is difficult however, as motions are generally too small to see significant changes associated with fault loading. Thankfully, this too means that earthquakes are less frequent here.

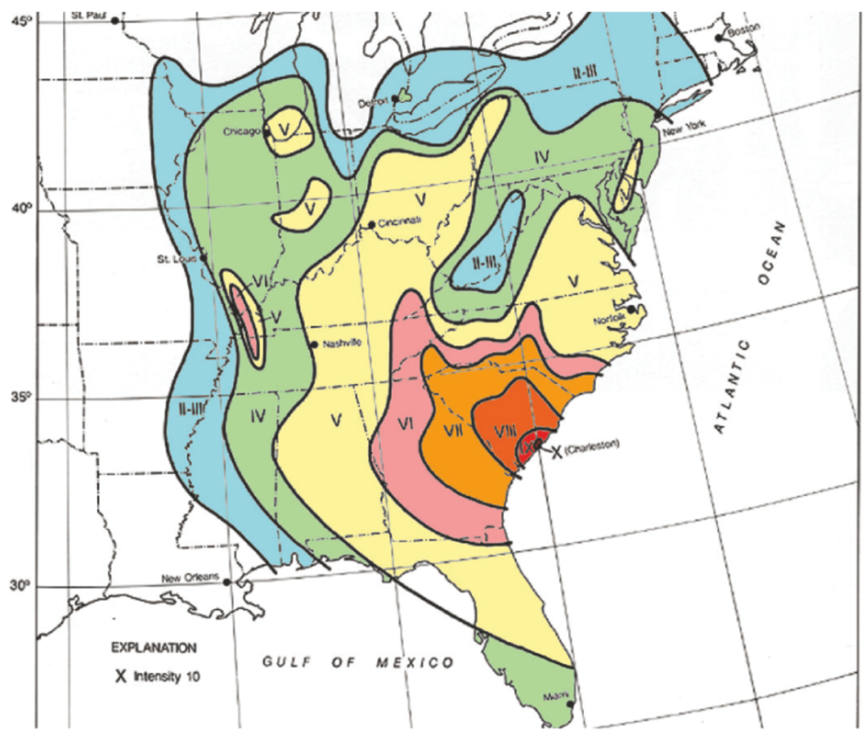


Figure 2: Modified Mercalli intensity map describing the ground shaking and damage from the 1886 Charleston, South Carolina earthquake. A few chimneys fell even in Atlanta, and shaking was felt as far away as Milwaukee (McKinley, 1887), with local amplification in sediment rich shorelines and river valleys. The precise magnitude of this event is unknown because seismometers did not yet exist, but information such as these reports of ground shaking were used to get modern estimates between magnitude 6.6 and 6.9. (Image after Stover and Coffman, 1993).

***Earthquake damage:*** caused at a specific site is measured by its intensity, and a single earthquake will have a range of intensity values that become smaller with distance. Intensity is incredibly useful, because it describes the extent of ground motion and damage across a

Identifying Earthquakes: by their shaking is easy when events are large and nearby, however smaller earthquakes and more distant ones may be very difficult to observe, and many small ones are never recorded sufficiently to locate, determine the magnitude, and catalog.

region better than earthquake magnitude alone. We can estimate ground motion from an expected earthquake, but we need to consider not just the size of the event, but also how close it was, the local variations in the ground shaking changes (called attenuation), the orientation of the fault, how deep it occurred, and the amount of stress relieved during the rupture. Earthquake intensities are also valuable for evaluating the size of historic earthquakes that occurred before the seismometer was invented. These include all past large earthquakes in the eastern United States.

The modern earthquake damage scale used by seismologists is called the Modified Mercalli Intensity Scale and is detailed in **Appendix II**. The intensity scale extends from I (felt by only a few people) to XII (total destruction). Like earthquake magnitudes, Mercalli III shaking is thought to be about 10 times less than Mercalli IV shaking. Roman numerals are used to prevent confusion with magnitudes, and to highlight assumptions about accuracy since intensity estimates often have an uncertainty of plus or minus one unit. In addition to the earthquake parameters, the intensity of shaking also depends strongly on the local crustal structure and soil conditions. The eastern US is mostly extremely old and thick crustal rock with much less damage than seen at plate boundaries, because of this, an earthquake can be felt up to ten times further away than in places like California. Soft deep sediment is also associated with higher intensities than hard soils or near-surface rock. So, in river valleys and sediment rich coastal flatlands like Savanah, earthquake intensities are expected to be much larger. By combining information on the size and location of an earthquake with knowledge of local soil conditions, an Emergency Manager may be able to identify areas more to have been damaged following an earthquake. The high magnitude 6 earthquake that occurred in Charleston, South Carolina in 1886, caused substantial damage to the city and was felt across the eastern U.S., including places like Milwaukee, Wisconsin (**Fig. 2**).

***Predicting Earthquakes:*** is incredibly considered by many seismologists to be impossible. While scientists are learning more and more about the physics that control earthquakes, there are still too many fundamental questions about earthquake behavior that limit the potential to accurately predict events. However, improvements in the scientific understanding and measurements have made great headway. Through geologic studies of past earthquakes, and recent technological advancements in measuring ground deformation, and determining the history of past large events, the ground deformation that leads to earthquake failure can be imaged at plate boundaries around the globe. This information can identify how fast individual plate boundaries can build up to release an earthquake of a certain magnitude, giving a potential long-term (50 -500 year) forecast. Regrettably, it does not give us any definitive information on precisely when, or even what year, the projected earthquake will occur. In the eastern U.S., our historic records of earthquakes are unfortunately too short, and measurement techniques are not precise enough yet to observe such small intraplate motions, making long-term earthquake recurrence estimates lousy, particularly outside of regions that have had recent observed large earthquakes, including the New Madrid, Missouri and Charleston, South Carolina regions. Though not very likely, we cannot neglect the possibility of a large magnitude 7 earthquake occurring within Georgia during our lifetime.

At present, no reliable pre-earthquake warning is available, nor likely in the near future. Though some tools have been used as earthquake precursors, they're not physically understood, and more often than not occur without a subsequent large earthquake. Thus, to avoid unnecessary cost or a "boy who cried wolf" scenario, where the population becomes desensitized and begin to ignore warnings, these methods have been deemed too unreliable for activating emergency response. Unfortunately, the social media is full of charlatans that claim otherwise.

***Identifying Earthquakes:*** by their shaking is easy when events are large and nearby, however smaller earthquakes and more distant ones may be very difficult to observe, and many small ones are never recorded sufficiently to locate, determine the magnitude, and catalog.

Very small temblors, those less than about magnitude 2.5, are difficult to identify without previously experiencing one. Sometimes a resident will mistake other not-so obvious vibrations with an earthquake and call emergency services. These sources include thunder, heavy trucks, sonic booms, nearby construction, falling objects, quarry blasts, a bad compressor in an air conditioner or refrigerator, water hammer in the pipes, or an unbalanced washing machine. With the exception of quarry blasts, these sources are easy to distinguish from earthquakes. Earthquakes within 30 miles (about 50 km) usually start with a jolt, build rapidly for a couple of seconds, and then decay. Shaking can be longer if the event is larger magnitude; up to a minute or more for very large events. The actual motion felt for a typical Georgia earthquake lasts only a few seconds. A small earthquake is sometimes described as a muffled dynamite explosion because the ground vibrations are also transmitted through the air. A small earthquake would likely be felt throughout a neighborhood, so talking to neighbors would discount sources with a single residence. Presently, the seismic network in Georgia is limited, thus it is possible that some of these earthquakes will not be registered.

Larger earthquakes are usually immediately identified because they are both recorded by regional networks and felt by people who have previously experienced earthquakes. Most transplants from California identify these earthquakes immediately. Because earthquakes in the Eastern U.S. are a novelty and large earthquakes affect a wide area, it should be expected that emergency services would receive a high volume of calls.

Residents living near a quarry may be familiar with the vibrations from quarry blasts, which feel very much like small earthquakes. When earthquakes occur in the vicinity of quarries, local seismograph records are necessary to distinguish them from quarry explosions. If the events happen at night and in a range of sizes, they are unlikely to be quarry blasts, and may be earthquakes. Quarry blasts are usually detonated between 12 PM and 5 PM on a regular schedule; they also tend to be about the same size. If the vibrations from a quarry blast seem too large, the State Fire Marshal may be contacted for more information, or to help determine if the vibrations exceed legal limits.

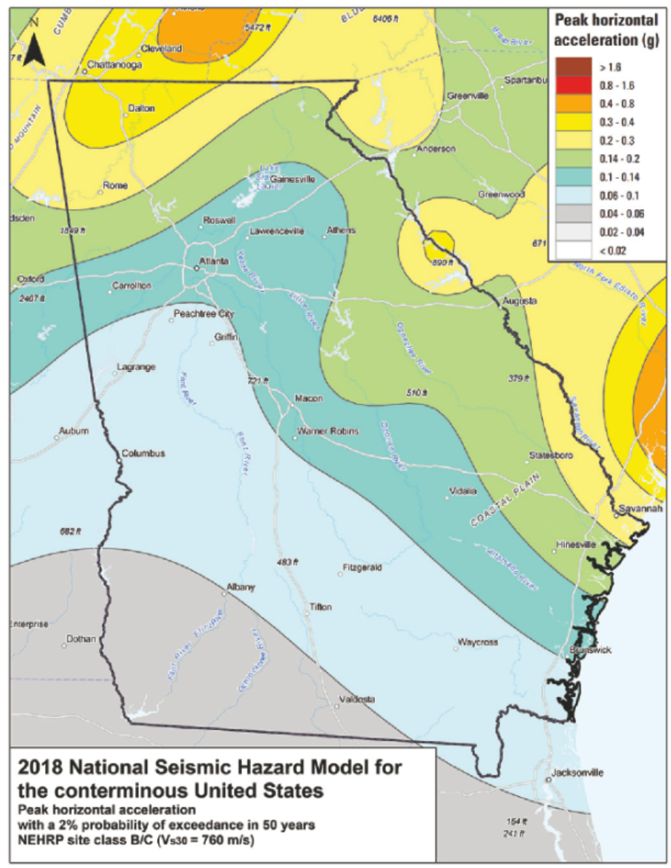


Figure 3: USGS estimated seismic hazards in and around Georgia. The map shows the low probability (2% in 50 years) of reaching a certain level of ground shaking, as described by horizontal ground acceleration. Northwestern Georgia, Augusta, and the Coastal area extending from Savannah, northward are considered at the greatest risk, with much of it being at greater than 2% chance of 0.2 g (yellow region) in the next 50 years. The national map and source information is described in Fig. 5.

## 3. Earthquake Hazards in Georgia:

Earthquakes are much less common in the Eastern United States than in California, with most events not being felt by local populations. This leads to a complacency that may be unwarranted. Many are unaware of the last large event that struck Charleston, South Carolina in 1886, killing almost 60 people and devastated the city (**Fig. 2**). Unfortunately, earthquakes in the Eastern U.S.

are very efficient at transmitting seismic energy over large distances, such that the damage area of a magnitude 6 here is comparable to a magnitude 7 in the western U.S. It is not clear why that earthquake occurred there, and a future similar event may occur anywhere in Georgia.

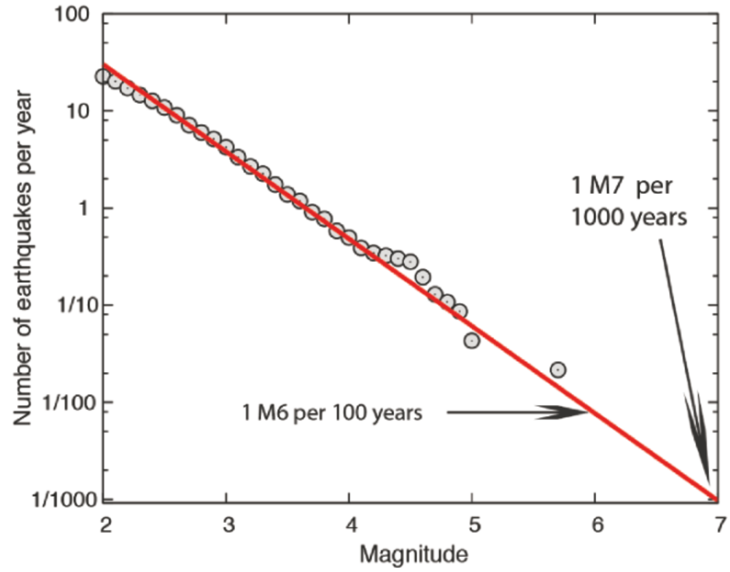


Figure 4: Using the earthquakes recorded in and around Georgia since 1962 (ANSS, 2010; range=30°-36.5°N, 79.5°-88.3°W) the long-term estimated return period of larger earthquakes can be estimated. A magnitude 6 is expected about every 100 years, and a magnitude 7 about every 1000 years.

Earthquakes may be felt in any area of Georgia, but the region surrounding northwestern Georgia has experienced the most earthquakes in recent history. Earthquakes large enough to cause damage could be felt in most, if not all, of Georgia's counties. Based on current and historical seismicity (**Fig. 1**) three zones of somewhat distinct seismic activity are apparent in Georgia. The least active area extends from the Coastal Plain of South Georgia below Columbus and on past Montgomery Alabama, where almost no activity is observed. One modest, about magnitude 3.6 earthquake, did occur, however near Jacksonville in the year 1900. The northern half of Georgia is more seismically active, with earthquakes occurring along two distinct bands. The most prominent is the Eastern Tennessee Seismic zone. The second band is less active but extends along the "Fall Line" from Macon to the South Carolina border, just north of Augusta. The threat of a larger earthquake from the Tennessee Valley seismic zone, and from a repeat of the Charleston Earthquake outside our borders are thought to comprise the largest risk to counties within Georgia (**Fig. 3**).

E***arthquakes in Northwest Georgia:***
occur primarily along the Eastern Tennessee Seismic Zone (ETSZ), which runs along the western Appalachian Mountains and extends from West Virginia down to the Alabama-Mississippi Border. In the Eastern US, the ETSZ is second only to the New Madrid Seismic Zone in terms of seismic activity. Earthquakes here typically occur between 0 and as much as 15 miles below the surface and outline a very long (200 miles or more) roughly linear zone. These similarities between the ETSZ and the New Madrid suggest that ETSZ could sustain an event similar to the dev-

astating 1811-1812 earthquakes, but since no such event has been recorded by seismometers, nor reported by western settlers, its hazard is considered less. This area currently experiences about one magnitude 4.0 earthquake about every 5 to 10 years. Such an event is generally perceived as a startling vibration that may rock objects off shelves and may cause some cracking of plaster. A magnitude 4.4 occurred here as recently as December 2018.

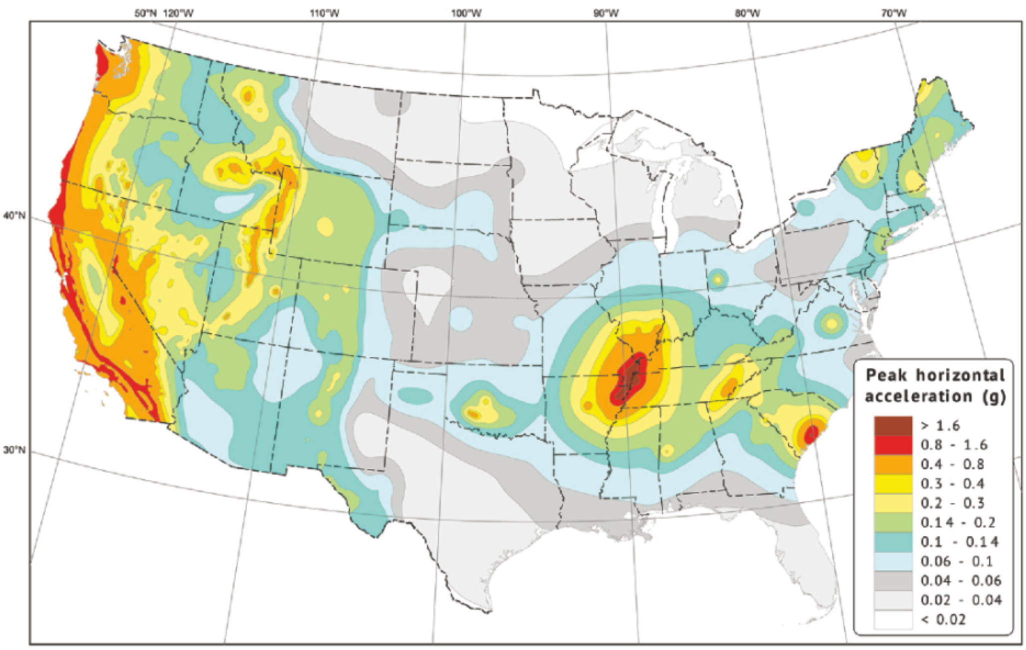


Figure 5: The National Seismic Hazard map defining the level of shaking that has a 2% probability of occurring in 50 years around the United States (the expected shaking an area might feel once every 2500 years). You can detailed seismic hazards for specific frequencies of ground shaking at individual locations at https://earthquake.usgs.gov/hazards/interactive .(Image from Peterson et al., 2019).

***Earthquakes in Central and South Georgia:*** are more scattered than in the ETSZ, and do not define any convincing faults. There are some large faults such as the Brevard Fault that runs through north-central Georgia, however these known faults are not considered to be active and show no ongoing microseismicity (small earthquakes). Instead most of these events may be on smaller faults that are buried beneath soil. The central band of seismicity occurs near the “Fall Line”. The line is not a fault, but a surface feature that distinguishes more rocky and hilly terrain in the north due to piedmont of the Appalachian mountains, from the very flat lying sediment filled south of Georgia which was formed as our coastline receded to its current position over the last 100 million years. Earthquakes here tend to be quite small and can be affected by changes in the water levels at reservoirs, which are common there. Many of these earthquakes are very small but occur within 3 km of the surface making them more easily felt and heard. They often occur in an earthquake swarm, so that many may be felt over a time period of 1 to 3 months. In the Piedmont, they are most common in areas of weakly fractured granitic rock. The Piedmont experiences about one magnitude 4 event every 20 years, which will likely be both felt and heard, potentially with many foreshocks and aftershocks. In the immediate epicentral zone, plaster and cement block walls will crack, merchandise may fall off store shelves, and minor structural damage may occur in buildings not designed to withstand earthquake forces. A magnitude 4.3 occurred about 30 miles north of Augusta, back in 1974, and more recently, a magnitude 3.2 was felt widely in Augusta, GA in June of 2017.

Earthquakes in the Coastal Plain of southern Georgia are too sparsely distributed to define a pattern but pose the second largest long-term hazard to Georgians. This hazard is dominated by the repeat of the 1886 Charleston earthquake (discussed below). While we don't know the likelihood of such a repeat near or along coastal Georgia, the potential cannot be entirely discounted.

***Earthquakes outside Georgia's borders:*** are a potential threat to populations within the state as strong ground shaking does not stop at the border. Historically, the Charleston earthquake of 1886 and the New Madrid earthquakes of 1811-12 have caused as much damage in Georgia as all the earthquakes occurring within the state. In current models for earthquake hazard, these distant earthquakes provide the greatest threat (**Fig. 3**). In most of Georgia the Charleston earthquake of August 31,1886, knocked over chimneys, broke windows, and cracked plaster. The Charleston earthquake is estimated to be between magnitude 6.6 and 6.9, similar in size to the "World Series", or Loma Prieta earthquake of October 18, 1989 (magnitude 6.9). A repeat of this event today would likely be far more devastating due to population growth. The earthquake would be felt far beyond Charleston, and possibly causing damage to poorly built and unreinforced structures as far away as Atlanta (see **Fig. 2** for the historical extent of the event).

Though the precise magnitudes of the 1811-1812 New Madrid earthquakes cannot be known without direct seismic records, many reports suggest that at least one of the four large earthquakes in the sequence was extremely strong modern estimates for the sequence are between magnitude 7.0 and 7.8. The events were devastating and caused massive changes to the landscape that are still visible today. The Mississippi River changed its course, the land surface sunk to form new lakes and violent shaking snapped off trees. At the time, settlements were sparse and limited to log cabins, thus the loss of life was minimal. However, if a similar event were to occur today, extensive damage would be expected throughout a very large region, and the risk would be much greater and because population density is now quite high; loss of life may be substantial. While these events are considered more likely to occur along zones of currently active seismicity (including the New Madrid, eastern Tennessee, and Charleston regions), it is possible that the next large event occurs outside of one of these zones. Again, we are fortunate that such devastating earthquakes are rare in the eastern US.

On average, major events like Charleston and New Madrid have the potential to occur about once every 100 years across the eastern United States. The probability that such an event could occur near enough to Georgia to cause substantial damage is about one in a thousand, for any given year (**Fig. 4**). The areal extent of damage could be much like that experienced in Georgia during the 1886 Charleston earthquake, but the risk may be greater because of increased infrastructure and population. Depending on where the next event occurs, damage could be quite high. For reference, the area of major damage and potential for deaths from the 1886 Charleston earthquake (defined by region within Modified Mercalli Intensity VIII and higher), covered an area extending more than 100 miles from the epicenter. More details on the Modified Mercalli Intensity Scale are covered in section 2 (Earthquake Damage) and Appendix II.

***Seismic Hazard Mapping:*** is currently used to evaluate the long-term probability of strong ground shaking any area may sustain. At present, these remain the only non-speculative way to assess hazard from earthquakes. These data can be combined with other information (such as population density, soil conditions, and infrastructure) to determine the risk that these hazards pose. Hazard maps rely heavily on the historical and ongoing measurements of seismicity, though in some parts of western US new information about fault motions are now also being included. Because such fault motions are too small to be observable in the eastern U.S. presently, only prior earthquake information is used. In these maps, hazard is expressed in terms of the probability of experiencing a certain level of shaking and are reported in terms of acceleration relative to the gravity, g (This is the same as the G-Force described during flight). Seismic hazards are obviously greater in areas of higher seismic activity, but the effects of large distant earthquakes are also considered. The example in **Fig. 5** defines the level of shaking that has a 2% probability of occurring in 50 years around the United States. Also, in a statistical sense, this is the level of vibration one should expect to experience about once every 2500 years. The U.S. Geologic Survey seismic hazard maps are frequently updated due to improved understanding of earthquake behavior, and recent versions are used by the Building Seismic Safety Council to inform building code regulations (Multi-Hazard Mitigation Council, 2019). The seismic hazard indicated by these maps is greatest in northwest Georgia, decreases in the Piedmont and is minimal in the Coastal Plain south of Savannah. Predicted seismic hazard is again greater toward and in coastal South Carolina, showing the continued influence of the 1886 Charleston earthquake and ongoing activity (Blow-up of Georgia in **Fig. 3**).

## 4. Planning for Earthquakes:

***Emergency Response to Earthquakes:*** can be divided into those for small, moderate, strong, large, and great earthquakes. In all cases, the first task is to determine the size and location, of the event because these parameters will determine the extent and location of emergency services that will be needed. Unlike hurricanes and other weather-related disasters, there will be no opportunity for advanced preparation or mobilization. The impact on individual communities are detailed depending on the approximate size of the event below.

*Small earthquakes* are of magnitude less than 2.5. These are typically felt only within 15 km of the epicenter and typically contained within one or two counties. These could generate calls to emergency response agencies, particularly in central Georgia where these events occur closer to the surface and are felt more strongly. If the event is part of a typical Piedmont earthquake swarm, such as in the Norris Lake Community swarm of 1993, the continuing occurrence of minor seismicity may cause alarm. Actions, such as town meetings, may be needed to explain the events to the population. Also, the time following an earthquake or during a swarm provides a good opportunity to instruct the population in methods to minimize damage and injury during earthquakes, particularly because earthquake swarms are often followed by isolated events as large as the largest event in the swarm. Swarms are very poor indicators of a larger earthquake.

*Moderate earthquakes* are those with magnitudes between 3 and 5. These will be noticed by almost everyone in the area and will be felt as far away as 100 to 200 miles. Twitter and local Emergency Managers may become swamped with calls, but the news media will usually be quick to distribute information on the identity and size of these earthquakes. Some weak structures may experience minor damage, such as cracked plaster and items knocked off shelves, and in rare incidences there may be some minor structural damage, such as brick facings falling off buildings. Life threatening situations are rare for these moderate events, and any associated emergencies should be easily handled as routine events.

*Strong earthquakes* are those with magnitudes between 5 and 6. These will be widely noticed and will cause widespread minor damage in well-built structures. A few structures will suffer moderate to major damage and could require examination for safety, but major damage will be rare. Again, life-threatening situations would be restricted to the immediate epicentral zone and to weak structures that are located on poor foundational material. These events will be possibly felt up to 600 miles away. As with moderate earthquakes, the news media will distribute information about the felt area and damage areas. Some efforts are needed to control traffic in damage areas, and some disruption to traffic may be caused by damage. In rare cases, a bridge or road structure may be damaged. The possibility of damage after the earthquake from fires is possible. In the eastern United States, water heaters and furnaces are not routinely protected against falling over which could start fires.

*Large earthquakes* are those with magnitude 6.5 and larger. The Charleston, 1886, and New Madrid, 1811-12, earthquakes are of this size. Expect extensive damage and loss of life within 30 miles of an earthquake. Outside this zone of major damage, to 150 miles, the effects will be like those of the large earthquakes. Buildings will need to be examined for safety because these large earthquakes may have aftershocks that can cause more damage, particularly to weakened structures. Many people will be displaced from their homes and field or tent communities will need to be set up and maintained for 1 to 2 months. Transportation may be interrupted by broken rail lines and bridges. Also, clutter from buildings in the intensely damaged areas could inhibit rescue efforts. A systematic search of collapsed buildings will have to be undertaken to find survivors. The probability for the repeat of an event like Charleston, 1886, somewhere in the eastern United States is about 25% in the next 25 years. (one chance in 1000 per year in Georgia). Such an event near any large metropolitan area in the southeastern U.S. and outside of Atlanta would likely see a rapid temporary to long-term influx of people to Atlanta.

***Seismic monitoring:*** of significant earthquakes in the United States is coordinated by the U.S. Geological Survey (http://earthquake.usgs.gov). This includes most earthquakes larger than magnitude 3.5 and those that are felt widely. For small local earthquakes, it is generally necessary to rely on data from a nearby regional network. In Georgia, The Georgia Institute of Technology maintains a small distributed Educational Seismic Network (http://geophysics.eas.gatech.edu/GTEQ). The University of Tennessee, University of North Carolina at Chapel Hill, and the University of South Carolina maintain seismic stations surrounding Georgia. Also, the Center for Earthquake Research and Information at Memphis State University maintains a Southern Appalachian Regional Network. These networks generally record events of magnitude greater than 2 and routinely distribute information on these events directly to the U.S.G.S., and the public.


Figure 6: Knowing what to do and training others is the single best way to minimize the loss of life during an earthquake. This simple information can be printed and posted in most workplace, school, and public environments as a tool for educating Georgians. Flyers in English and Spanish, as well as for those using accessibility devices can be found at: https://www.earthquakecountry.org/.

**5. Preparedness Tips and Strategies:**

*Individual and Family Preparedness:* is the best insurance against earthquake damage. Of the things to do, the single most important is to eliminate those risks in the home that could cause significant damage to people or property during an earthquake. When the earth shakes in an earthquake, falling objects can cause injury or start a fire. Many of the hazards associated with falling objects can be eliminated or minimized before an earthquake strikes. Many general preparedness guidelines will help prepare for an earthquake as well and can be found at https://www.ready.gov). For preparing your home, the Federal Emergency Management Agency has a useful guide as well (https://www.fema.gov/earthquake-safety-home).

**Around the house:**

- Secure cabinets, bookcases and mirrors to wall studs.

- Consider strong latches for cabinet doors, keeping contents better secured during strong shaking.

- Avoid installing tall bookcases near beds since the often heavily loaded structure could fall causing significant injury or death.

- Strap any gas or electric water heater to wall studs.  A broken gas line can cause a fire, while a knocked over or ruptured tank could cause water damage or scalding.

- Secure any expensive electronics to walls, tables or desks.
- Store hazardous or flammable materials safely.  If a container of flammable liquid spills during an earthquake, any source of flame may ignite the fluid and start a fire.

- Consider having chimneys, roofs, and walls checked for stability.  Bricks from chimneys and wall facings if not secured can fall and cause significant damage or injury.

- Bolt house to foundation if possible.  Houses in the southeast are built to stand-upright and may not withstand shaking.  Loss of contact with the foundation is a major source of damage in many large earthquakes.

**For individuals and family members:**

- Develop a disaster plan.  This includes identifying a muster area should your home be unreachable, identifying an out-of-area contact that everyone can check in with.  Keep in mind, cellular service may not be reliable during a time of crisis.
- Keep important documents (insurance policies) up to date and safe.
- Be prepared for 3-days of self-sufficiency.  This is also good preparation for inclement weather and other disasters.  Have on hand a flashlight, extra batteries, a charged battery pack for mobile phones, a portable radio, first aid kits, fire extinguisher, and 1 gallon of water per person for 3 days (https://www.ready.gov/water).
- Learn what to do during a large earthquake: **"Drop, Cover and Hold On"** is

the simple solution to minimize the risk of being hurt or killed during an earthquake (**Fig. 6**).

  - ***Drop*** to the ground fast onto your hands and knees, otherwise the earthquake shaking may knock you down uncontrollably.
  - ***Cover*** yourself below a strong table or desk. Falling objects and collapsing structures cause many of the injuries and deaths during an earthquake. Additionally, cover your head and face to protect them from broken glass and falling objects. If no sheltering surface is near, move to a wall, crouch inward towards your knees.
  - ***Hold*** onto the table or desk and be prepared to move with it. Holding your position until the shaking stops. If unsheltered, hold onto the back of your neck and head, protecting it from falling debris.
- ***<u>Do not</u>*** run outside during the shaking or use the stairways or elevators. The entranceways of buildings and homes are particularly dangerous because of falling bricks and debris.

- Know what to do following a large earthquake.
  - After tremors stop, vacate premises immediately until it is safe to return.
  - Look for and eliminate fire hazards that can cause further damage.
  - Follow your disaster plan to locate and communicate with family and loved ones.
  - Check your building for cracks and structural damage.
  - Take photos to record damage before you clean up or make repairs.
  - Move valuables to a safe weatherproof location.
  - Review your insurance coverage and report claims promptly.
  - Collect inventory records, appraisals and photographic records.
  - Use licensed professionals to conduct inspections and repair your home.
  - Look for ways to better prepare your home for earthquakes as you repair or rebuild.

**Earthquake Insurance:** is available as a rider to most home insurance policies. To be effective, they should protect the homeowner against the most likely damage expected from a small or distant earthquake, such as the failure of brick facing. These riders vary in price depending on the deductible and company pricing practices. Clearly, a high deductible would protect mostly against a very rare large earthquake that might cause more than 10-20% damage to your property (dependent on deductible). The cost vs. peace-of-mind needs to be weighed for any such purchase.

## 6. Associated hazards:

Earthquakes can cause a host of other damaging hazards, including landslides, fire, and tsunami.

***Landslides:*** (including rock falls, debris and mud flows, and slumps), frequently occur in sloping regions without an earthquake due to weather, vegetation, and soil conditions, with most occurring following strong periods of heavy rainfall. As soils become oversaturated with water, or when water in weathered cracks in surface rocks freeze, they can break away and start a runaway affect downhill. Strong shaking from an earthquake during periods of heavy rainfall often triggers these events. There is well-documented history of earthquake-related landslides in Georgia, however, landslides do occur here naturally (mostly in the foothills of the Appalachians), thus when a strong earthquake shakes the region, landsliding is a natural likely outcome that can block roads and limit access for emergency responders in high sloping regions.

***Fire:*** is a dominant risk within city environments following any very strong shaking because of the potential to snap gas lines, down power lines, or a host of other smaller electrical malfunctions associated with strong shaking. For this reason, along with preparing for aftershocks, one of the best ways to mitigate the damage from a large earthquake, is to quickly assess and put out fires, particularly in areas most likely to spread into population centers.

***Tsunami:*** waves occur frequently following extremely large and sudden shifts on the seafloor. The most common cause is from a large undersea earthquake, but they too can come from submarine landslides, volcanic eruptions, and even strange weather events offshore. Fortunately, Georgia doesn't have much seismic activity in our immediate offshore region, and no history of destructive tsunami waves within our borders. However, this does not mean we are completely safe. Waves from distant large earthquakes and volcanic eruptions, possibly occurring in the northeastern Caribbean, may still reach Georgia, but the likelihood is considered very low.

## Appendix I. Descriptive comparison of earthquake magnitudes with observed effects

The rate at which earthquakes have occurred in Georgia is shown in Fig. 5. We experience a magnitude 3.0 every year or two and a magnitude 4.0 every 8 years.

The best way to estimate the area of potential damage is to use the observed relation between magnitude and area of intensity VII. Modified Mercalli Intensity VII is the lowest level of shaking at which damage requiring some emergency response would be expected. The relation for the eastern United States is approximately, Log10(AVII)= M - 2. The intensity VII area for a magnitude 4.0 is 100 square kilometers (a radius of 5.6 km or 3.5 mile) and a magnitude 6.0 is 10,000 square kilometers (a radius of 56 km or 35 mile).

**Magnitude:**

**M0:** Earthquakes that occur at shallow depths in the Piedmont are occasionally heard by people when they are within a few miles of the epicenter. Their sounds are like a distant cannon. These are usually ignored.

**M1:** Earthquakes that occur at shallow depths in the Piedmont are usually heard by people when they are within a few miles of the epicenter. These and smaller earthquakes are rarely reported by people in areas of northwest Georgia where the earthquake focus is deeper.

**M2:** Earthquakes are typically described as large quarry blasts by residents in the Piedmont. Vibrations are felt near the epicenter. People in northwest Georgia occasionally report vibrations from events of this size.

**M3:** Earthquakes (e.g. Augusta, Georgia, June 20, 2017; M3.2) are maximum intensity III in northwest Georgia and up to V in the Piedmont. Vibrations are like a heavy truck. They can feel and sound like an explosion. Sometimes two shakes are felt, with the first a higher frequency vibration (P-wave) and the second following within a few seconds a rocking vibration (S- and Surface waves). In the Piedmont, they sound like a cannon. The vibration decays with time.

**M4:** Earthquakes (e.g. Decatur, Tennessee, December 12, 2018; M4.6) have maximum intensities in the VI to VII range. These events are just large enough to cause some minor damage in the epicenter area and groceries may fall off shelves. Felt over many counties, typically out to a distance of 100 miles.

**M5:** Earthquakes (e.g. northcentral Alabama, January 18, 1999) are noted for widespread damage. The Sharpsburg earthquake was particularly noted for damage to chimneys. Intensity VI and higher within a radius of 30 miles. Felt over many states, a radius of over 300 miles.

**M6:** Earthquakes (e.g. Louisa, Virginia, August 23, 2011; M5.8) are characterized by intensity VIII and higher near the epicenter. The Massena earthquake was felt from Canada south to Maryland and from Maine west to Indiana. It caused property damage estimated at $2 million. Many chimneys required rebuilding, and several structures were unsafe for occupancy until repaired. Residents of St. Lawrence County reported that many water wells went dry. At Massena, 90 percent of the chimneys were destroyed, or damaged and house foundations, plumbing, and masonry were damaged severely. Cracks formed in the ground, and brick-masonry and concrete structures were damaged.

**M7:** Earthquakes (Charleston, South Carolina, August 2, 1886; M~6.6-6.9) generate intensities of IX and above. Effects in the epicentral region include more than 1,300 square kilometers of extensive cratering and fissuring. Damage to railroad tracks, about 6 kilometers northwest of Charleston, included lateral and vertical displacements, formation of S-shaped curves and longitudinal movement. Strong alarming vibrations are felt. Many buildings will sustain damage, a few will fall or be rendered useless. Some lives will be lost in collapsed buildings or in fires following the earthquake. Communications and transportation will be interrupted significantly.

## Appendix II. Modified Mercalli Intensity Scale of 1931 (Abridged)
## Modified Mercalli Intensity Scale

**I:** Shaking felt except by a very few under especially favorable circumstances.

**II:** Shaking felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

**III:** Shaking felt quite noticeably indoors, especially on upper floors of buildings, but most people do not recognize it as an earthquake. Standing motorcars rock slightly. Vibration like a passing truck. Duration estimated.

**IV:** During the day, felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, and doors disturbed; walls make a creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably.

**V:** Shaking felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.

**VI:** Shaking felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

**VII**: Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures. Some chimneys broken. Noticed by persons driving motorcars.

**VIII:** Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, and walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed.

**IX:** Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

**X:** Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from riverbanks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.

**XI:** Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

**XII:** Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

## Appendix III. Glossary of terms

**Acceleration:** Rate of change in velocity with time. In earthquake ground shaking, acceleration is measured relative to the acceleration of gravity (g).

**Active Fault or Active Seismic Zone:** A fault that has exhibited movement in recent time and that is expected to move in the future. The movement may be indicated by earthquakes in a seismic zone or by displacements within the last 10,000 years of young soil or other deposits along a fault trace.

**Aftershocks:** Smaller earthquakes following a large event and occurring in the same fault zone. Generally, aftershocks decrease in magnitude and frequency-of-occurrence with time.

**Aseismic Region:** A region lacking earthquakes and assumed to lack a potential for future earthquakes.

**Capable Fault:** A fault that is considered active for seismic hazard computations.

**Creep:** Slow slip along a fault without producing earthquakes.
**Crust of the Earth:** The top 30 km of the Earth that is brittle and the area of occurrence of most earthquakes. Mid-crustal depths represent the strongest part of the Earth's crust and are at depths of 10 to 20 km.

**Duration:** The duration of strong shaking is the time interval between the first and last peaks of strong (usually felt) ground motion.

**Eastern United States:** All states in the continental United States east of the Rocky Mountain Front, approximately Longitude 105° West.

**Earthquake:** The sudden release of stress along a fault and the resulting vibrations of the earth. The vibrations propagate away from the epicenter.

**Earthquake Prediction:** An earthquake prediction is a qualified determination of the magnitude, location, and time of a future earthquake. Such qualifications must be beyond the expectations from ongoing background activity. Predictions can be broken down into short-term (hours to days), intermediate term (weeks to months), or long-term forecasts (years to decades).

**Earthquake Swarm:** An earthquake swarm is a prolonged series of small events. In a swarm, earthquake activity usually increases until the largest event occurs.

**Epicenter:** The location on the earth's surface directly above the focus (or hypocenter) for an earthquake.

**Fault:** (or Fault Zone) a zone of weakness or fractures in the earth along which the two sides have been displaced relative to each other parallel to the fracture. The total fault offset may range from centimeters to kilometers.

**Felt Reports:** Documentation of perceived shaking as felt by individuals affected by an earthquake. For historic earthquakes, these come from old surveys, books, and newspaper accounts. Modern felt reports include rapid assessments recorded over the internet. Within the US, if you feel an earthquake, it is quite helpful to go to the USGS "Did You Feel It?" website (https://earthquake.usgs.gov/data/dyfi ) and report the shaking you felt.

**Focal Depth:** The depth below the surface of the hypocenter, the point where an earthquake initiates movement.
**Focal Plane:** The area of movement on a fault during an earthquake. The Focus may be any place on the focal plane.

**Focus:** (or hypocenter) The place at which rock failure commences in an earthquake.

**Foreshocks:** Smaller earthquakes preceding a large event and occurring in the same fault zone.

**Hazard Map:** A map showing locations of areas where a defined level of vibration is expected to be felt in a given time period. For example, areas where an acceleration of 0.1 g or greater would be expected once every 450 years.

**Hypocenter:** see Focus.

**Intraplate Earthquake:** Earthquake that occurs in the interior of recognized tectonic plates, often not associated with major active fault zones. All eastern United States earthquakes are intraplate earthquakes.

**Intensity:** A measure of ground shaking obtained from the damage done to built structures, changes in the earth's surface and felt reports. The Modified Mercalli Intensity scale measures intensity in Roman Numeral units from I (felt slightly) to XII (total damage).

**Isoseismal:** Lines that surround zones in which an earthquake generated a given intensity.

**Magnitude:** Earthquake magnitude is an instrumental determination of the relative size of an earthquake. The Richter Magnitude was the first commonly used measure of earthquake size. All subsequent magnitude scales are tied to the Richter magnitude scale. Magnitudes released in news reports are often referred to as Richter Magnitude, although that term can only be applied strictly to southern California earthquakes.

**Microseism:** Weak, almost continuous seismic waves or earth noise; often caused by surf, ocean waves, wind, or industrial activity.

**New Madrid Seismic Zone:** An area of continuing seismic activity along the Mississippi River in Tennessee and Missouri. Also, the location of the epicenters of the four largest New Madrid earthquakes of 1811-12.

**P-wave:** The primary or fastest wave traveling away from a seismic event through the earth. and consisting of a train of compressions and dilatations of the material.
Plate Tectonics: The Earth's crust consists of many rigid plates, such as the North American Plate. Plate Tectonics is the description of plate movement and interaction that explains earthquakes, volcanoes, and mountain building as consequences of horizontal surface motions of rigid portions of the Earth's crust.

**San Andrea fault zone:** A zone of movement between the North American Plate and the Pacific Plate, extending through southern California.

**S wave:** The secondary, or shear, seismic wave, traveling more slowly than the P wave, and consisting of elastic vibrations that are transverse to the direction of travel.

**Surface Waves:** Seismic waves that are confined to the earth's surface. Surface wave velocities are less than S-wave velocities.

**Seismicity:** Generally, the occurrence of earthquakes in space and time. Usually given as the number of earthquakes of a given magnitude in a specified time, such as the number of zero magnitude events per year.

**Seismogram:** The record of an earthquake written by a seismograph.

**Seismograph:** An instrument for recording the motions of the Earth's surface.

Seismologist: Scientist trained in interpreting ground motion from earthquakes and in using the waves from explosions to determine the structure of the Earth. Seismologists are found in major universities and in the oil industry.

**Seismology:** The study of earthquakes, seismic sources, and wave propagation through the Earth.

**Seismometer:** The sensor part of the seismograph.

**Tectonic Earthquakes:** Earthquakes resulting from sudden release of energy stored by deformation of the Earth's tectonic plates.

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