ShakeAlert® activities for formal and informal learning settings

Magnitude and Intensity

How are they different, yet related?

Version 03/22/22

OVERVIEW

Magnitude and intensity are different, yet related concepts. The size of an earthquake, or magnitude, is a single value that measures the energy released at the source of the earthquake rupture. Earthquake scientists calculate magnitude based on measurements made from seismic and geodetic instrumentation. Seismic intensity is a measure of the strength of shaking at a specific location. Seismic intensity is determined based on seismic instrumentation (instrumental intensity) or on the effects on people and the built environment (community intensity). Magnitude is a single value, while intensity is a range of values that depend on location. (See Vocabulary in Appendix A for more information.)

Three learning options of different lengths (5, 15, and 45+ minutes) provide opportunities to understand the differences between an earthquake's magnitude and shaking intensity. The 5-minute option compares an earthquake's magnitude and intensity to the wattage and brightness of a light bulb. The 15-minute activity engages learners with the key variables that affect the intensity of earthquake ground shaking. Finally, in the 45-minute activity learners delve deeper into the intensity scale through analysis of earthquake experience narratives.

Why is it important to learn about an earthquake's magnitude and intensity? An important tool for earthquake mitigation is the ShakeAlert® Earthquake Early Warning (EEW) system for the West Coast of the U.S. which detects significant (magnitude 4+) earthquakes quickly so that alerts can be delivered to people and automated systems often before shaking arrives (intensity). ShakeAlert delivery partners incorporate magnitude and shaking intensity thresholds to determine whether to send ShakeAlert-powered alerts.

OBJECTIVES

Learners will be able to:

- Explain that magnitude is a single value that measures the energy released at the source of the earthquake's rupture.
- Explain that the intensity of shaking describes the severity of an earthquake.
- Understand that analyzing the personal accounts of shaking following an earthquake can be used to calibrate the intensity of official USGS ShakeMaps.

Beginner

5 min | 15 min | 30–45 min

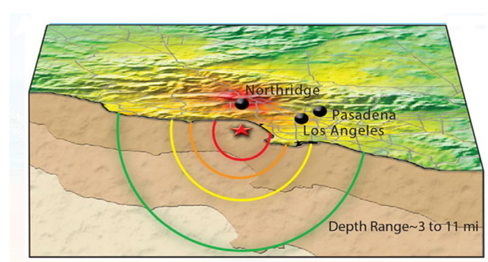
Large Group | Small Group

Demo | Materials

Time: 5-, 15- and 45-minute guided activities that can be adapted for audience and venue.

Audience: This can be done with novice and experienced geoscience learning groups.

Subject: Natural Hazards: Earthquakes, Geoscience.



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MATERIALS

Materials for the 5-minute activity:

- Light bulbs: At least 3 different wattages (different physical sizes might be helpful too, such as 25-40 W refrigerator light bulbs and 100-300 W light bulbs).
  - Optional: Small lamp and extension cord (if needed) to reach an outlet, and a small towel or hot pad to change the light bulbs.
  - Optional: Flashlights with different battery strengths may be substituted.
- APPENDIX B—USGS ShakeMaps: Intensity of earthquake ground shaking.
  Print Example A, ShakeMaps for Ridgecrest, California, that shows two earthquakes of different magnitudes two days apart Print in color.
  Tip: Laminate or use clear plastic page protectors to help preserve maps for reuse.
- Optional: Light Intensity smart phone app. (See inset box below.)
- Optional: Data or computer projection if using maps with a larger group.

Materials for the 15-minute activity:

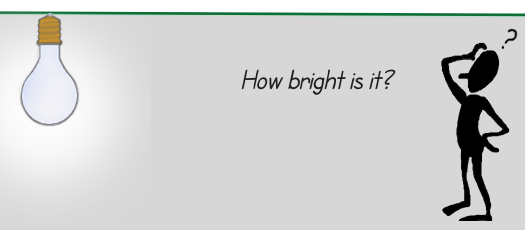
- USGS ShakeMaps printed in color for every group of learners:
  - APPENDIX B—Intensity of earthquake ground shaking.
  - Optional: Laminate or use clear plastic page protectors to help preserve maps for reuse.
- Data or computer projection if using maps with a larger group.

Materials for the 45-minute activity:

Print enough copies of the following for each table group:

- APPENDIX C—Modified Mercalli Intensity of Shaking Scale. One scale for each table group.
  Note: Must be printed in color.
- APPENDIX D—Northridge, California ZIP code map (activity copy). One map for each table group.
  Note: Maps can be printed in black and white.
- APPENDIX E—Earthquake Experiences Narratives. One set for each table group. (Printed in black and white.)
- Optional: Laminate or use clear plastic page protectors to help preserve maps for reuse.

- Set of 9 colored pencils that will match the colors in the Modified Mercalli Intensity Scale: violet, light blue, aqua, green, yellow, gold/amber, orange, red, and magenta. Note: Crayons may be substituted but are more difficult to use.
- The following maps could be computer projected or printed in color for a data projector or provided one per table group:
  - APPENDIX F—Northridge, California ZIP Code Map (Answer Key)
  - APPENDIX G—USGS "Did You Feel It?" Northridge, California Intensity Map
  - APPENDIX H—ShakeMap of the 1994 Northridge, California Earthquake
  - APPENDIX I—Combined "Did You Feel It?" and Seismic Sensor "ShakeMap" Locations
  - APPENDIX J—USGS Macroseismic Intensity Map
  - Optional: Laminate or use clear plastic page protectors help preserve printed maps.



Use your smartphone to measure light intensity!

Download a light-sensor app onto your smartphone (some are free) and measure light from different light bulbs in different parts of the room. Learners will be able to quantify differences in the light's brightness (*lumens*) between different light bulbs at specific distances.

RELEVANT MEDIA RESOURCES

Animations:

- *Earthquake Intensity- Introduction to 4 modules*:
  5 short animations show how seismic intensity is controlled by four main factors.
- *Take 2: Magnitude vs. Intensity* (1:55) Is seismic intensity really different than an earthquake's magnitude?

Website Resources:

- *USGS "Did You Feel It?" Scientific Background*
- *USGS "Did You Feel It?" Report an earthquake*
- *USGS "Did You Feel It?" Summary Maps*

ACTIVITIES AND DEMONSTRATIONS

IF YOU HAVE 5 MINUTES

Did You Know?

- Did you know that an earthquake's magnitude and intensity can be compared to a light bulb?

A light bulb is a great analogy with the location within the Earth called the hypocenter where the earthquake begins (Figure 1a). The magnitude, or size, of an earthquake is like the wattage of a light bulb (Figure 1b). Just as the wattage represents the amount of power of the light bulb, the magnitude is related to the total amount of energy released by the earthquake source.

The intensity, or shaking level, is like the amount of light from a light bulb that is received at any spot in a room (Figure 1c). A low wattage light bulb will make one area of the room bright with high intensity light, but it will leave the distant areas of the room dim with low intensity light.

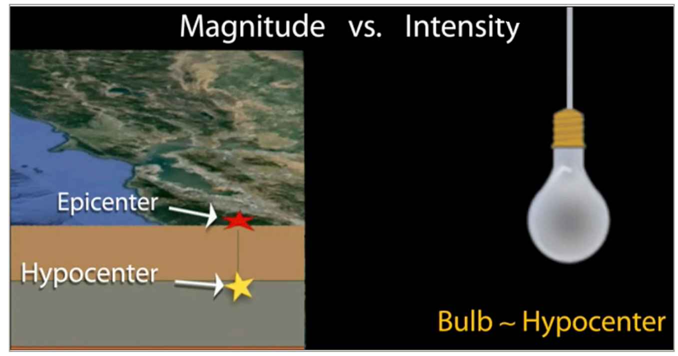
Prepare for the 5-minute activity

- Before demonstrating the activity, watch the animation Take 2: Magnitude vs. Intensity (1:55) for a short introduction to this activity. The animation could be shown at the end of the activity if time permits.
- Assemble at least three light bulbs of different wattages: low, medium, high (or flashlights with different battery sizes).
- Optional: Use a small lamp to demonstrate the amount of light from different light bulbs in a darkened room. An extension cord might be needed as well as a towel or hot pad to change light bulbs.
- Show APPENDIX B Example A which compares ShakeMaps of two earthquakes in Ridgecrest, California, either:
  - a) Print maps for learners.
  - b) Optional: For larger groups, use a data projector with the maps or computer projection system.

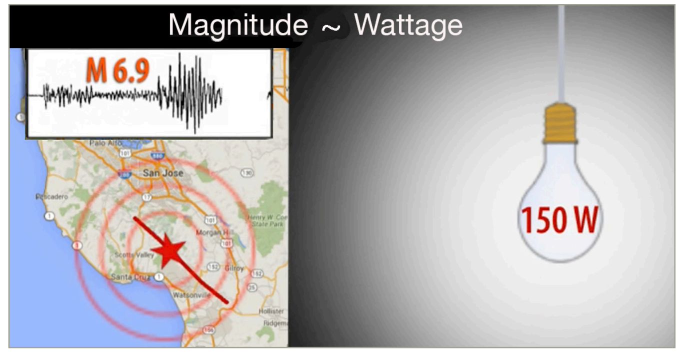
Directions

1. Hold up one light bulb and explain the analogy with an earthquake:
   - a. Hypocenter - Location of the light bulb
   - b. Magnitude - wattage
   - c. Intensity - amount of light that is received at any spot in a room.
2. Optional: If you have a small lamp, demonstrate two different concepts:

1A



1B



1C

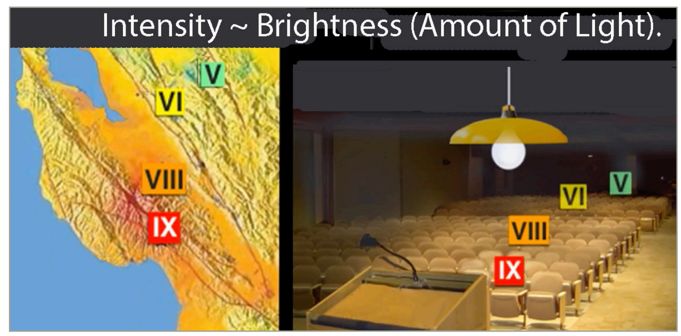


Figure 1: Screen shots from the animation, "Earthquake Intensity" ; timecodes in parentheses.
***1A:** Magnitude vs. Intensity: Using a light bulb to model the hypocenter of an earthquake. (Minute 1:06)*
***1B:** Earthquake magnitude represented by a light bulb's wattage. (Minute 1:16)*
***1C:** Earthquake shaking intensity represented by the amount of light from a light bulb that is received at any spot in a room. (Minute 1:43)*

   - a. Use the different wattage bulb to model different earthquake magnitudes. Note: Be sure to use a towel or hot pad to change the bulb since they could be hot. If you aren't using a lamp, you can point out a specific ceiling light fixture in your room as an example of a fixed earthquake magnitude.
   - b. Using a single bulb, model that the intensity of light diminishes with distance from the light source, no matter the wattage (magnitude). Remember, earthquake intensity means intensity of ground shaking.

Questions for Discussion:

- If a night light of 4–7 watts represented an earthquake, what magnitude do you think it might be, small or large? (*Answers vary, but a small earthquake of M2.5–M3.*)
- What type of lights do you think would represent a great earthquake, such as one with a magnitude of M8 or greater? (*Answers vary, football stadium flood lights.*)
- What characteristics of the light bulb would impact the intensity of light (brightness) that you would see? (*Answers will vary. Some examples might include if the light bulb surface is clear or frosted, colored or filtered by a lampshade.*)
- Since the amount of light varies so greatly in these examples, what are the implications for ground shaking during a real earthquake? (E*arthquake shaking can potentially be catastrophic, affecting both the natural world, as in landslides and liquefaction from water-saturated soils, and to the built environment, and resultant loss of life. Earthquake early warning can provide valuable seconds to take protective actions that can mitigate physical harm due to shaking.*)

3. Now, let's apply the analogy of a 25-watt and a 100-watt light bulb to two actual earthquake events two days apart in the city of Ridgecrest, California on July 4th and July 6th, 2019. Show the ShakeMaps for these earthquakes in Appendix B.
   a. Identify the maps as ShakeMaps. These maps show the intensity of ground shaking based on the Modified Mercalli Intensity (MMI), shown on the left of the map.
   b. The MMI scale uses Roman numerals to distinguish categories of earthquake shaking. The color palette moves from low intensity (light shaking), in the cool violet/blue colors, to higher intensity (violent shaking), in the deep red/magenta colors.
   c. Examining the maps, we notice that the two earthquakes occurred at the same location and depth.

Questions for Discussion

- Is there a difference in the magnitude of these two earthquakes? (*The July 4th earthquake near Ridgecrest, CA was M6.4, while the July 6th earthquake was M7.1.*)
- How does this difference in earthquakes affect the intensity of shaking, and the ShakeMaps? (*The July 4th M6.4 earthquake had light to very-strong ground shaking and the July 6th M7.1 had light to severe ground shaking.*)
- What changed in the size of the area affected by shaking between the two earthquakes? (*The larger magnitude earthquake shook a larger area. On July 6, 2019, a M7.1 earthquake created eleven times as much energy as the M6.4 earthquake with strong shaking extending approximately 40 miles from the epicenter. The July 4, 2019 a M6.4 earthquake produced strong shaking up to approximately 25 miles from the epicenter. Just like the light bulb analogy, the larger wattage light bulb casts brighter light in more places throughout a room.*)
- In your own words, explain the differences between earthquake magnitude and intensity using lightbulbs as an example. (*Answers will vary.*)

Optional: Show the "*Take 2*" animation at the end if time permits.

IF YOU HAVE 15–20 MINUTES

Did You Know?

- Did you know that an earthquake has one magnitude but can have many intensities of ground shaking?

Earthquake magnitude is a quantitative measurement of the size of the earthquake. The magnitude is expressed as one number. An earthquake's intensity is a measure of the amount of shaking at a particular location and varies from place to place (Figure 2).

This activity explores the four key factors that affect the amount of ground shaking experienced in an earthquake. The four factors* include:

- the *magnitude* of the earthquake,
- the *distance* from the epicenter,
- the *depth* to the hypocenter, and
- *local rock and soil conditions* at the location where shaking occurs.

[*See *Earthquake Intensity- Introduction to 4 modules.*]

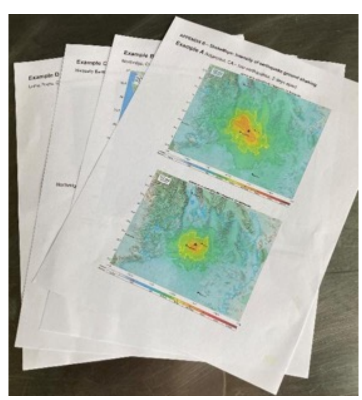


Figure 2: Set of 4 Learner activity ShakeMaps representing factors affecting intensity of ground shaking (Appendix B).

Without sharing what the factors are in advance, challenge learners to discover four key factors influencing the intensity of earthquake ground shaking, one factor for each page of maps. Learners will use either paper or computer projected maps to study the ShakeMaps using clues, along with the Modified Mercalli Intensity (MMI) scale of earthquake shaking, as a reference. Learners then discuss their ideas and why they think each factor is significant.

Instructor Preparation

Note: Depending on the instructional setting, maps may be used either on a computer, or printed on paper.

- Computer projection: Have Appendix B—Intensity of Earthquake ground shaking Learner Version ready to show. (4 pages illustrating the four factors.)
- Print **color** copies and create map sets for each learner group in Examples A–D from APPENDIX B that illustrate the four factors influencing intensity of ground shaking.
  - Optional: Laminate or use clear plastic page protectors to help preserve maps.

Procedure

1. Distribute one set of four ShakeMaps to each group of learners or prepare in advance a slide deck of maps from APPENDIX B ready to use with a computer projection system for a larger group of learners.
2. Explain that ShakeMaps provide a reference for the strength of earthquake shaking over a region where an earthquake has occurred. The degree of shaking depends on four key factors that they will discover by analyzing four maps. Check for understanding by pointing out the components of one of the maps: top banner has date, time, magnitude, and location of the earthquake and depth to the hypocenter; X and Y axis shows the latitude and longitude; the scale bar is shown in the top left; and along the bottom is the Modified Mercalli Intensity (MMI) scale.
3. (8 minutes) Ask each group to answer Questions a–c for each page of ShakeMaps. Optional: Write the four factors that affect intensity (bulleted list on the previous page) on the board.
   a. What factors do you think influence shaking intensity in each map? (*Answers vary. The maps show that even for a single earthquake, shaking intensity in different places. Answers should include magnitude [Example A], distance from the epicenter [bullseye pattern of Example B best exemplifies this factor], depth to the hypocenter [Example C], and rock and soil conditions [Example D].*)
   b. What clues helped you discover the factor? (*Answers vary. See "Explanation of map characteristics" (at right). Answers should include MMI color scale, area covered by the intensity contour lines, and shape of the contour lines and data included on the ShakeMaps.*)
   c. Why is each factor important in determining earthquake shaking intensity? (*Each factor plays a unique role in determining shaking intensity. See each characteristic described below.*)
4. Reconvene the groups and discuss each ShakeMap factor Examples A–D by asking groups to share their answers to the questions. Assist with terms that learners might miss and add additional information about each factor and map using the following "*Explanation of map characteristics*" as a guide:

Explanation of map characteristics:

Example A—Magnitude: Two earthquakes near Ridgecrest, California two days apart provide an excellent comparison of how different magnitudes affect the intensity of ground shaking for the same area (Figure 3). On July 4, 2019 a M6.4 earthquake produced strong shaking up to 40 km from the epicenter. On July 6, 2019, a M7.1 earthquake created eleven times as much energy as the M6.4 earthquake with strong shaking extending up to 70 km from the epicenter.

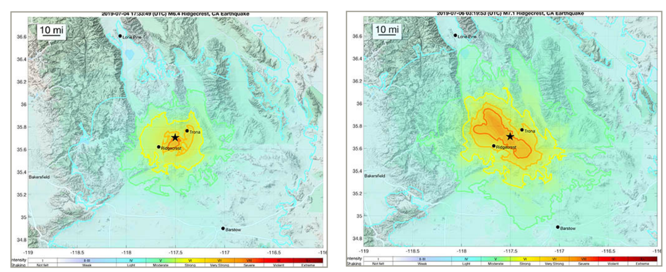
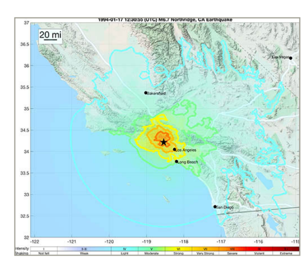


Figure 3: ShakeMaps for the two earthquakes near Ridgecrest, CA. Left: July 4, 2019, M6.4. Right: July 6, 2019, M7.1. Page-size maps are in Appendix B, Example A.

Example B—Distance from the Epicenter: In this example, we use a ShakeMap for the January 17, 1994 M6.7 earthquake near Northridge, California (Figure 4). While all of the maps illustrate the decrease in shaking intensity with distance from the epicenter, this ShakeMap illustrates the "ideal" bullseye map concentric pattern with intensity decreasing with distance away from the epicenter.

Figure 4: (right) ShakeMap for the 1994 M6.7 Northridge earthquake. Page-size map is in Appendix B, Example B.



Example C—Depth to the Hypocenter: In this example we compare two earthquakes of nearly the same magnitude having different depths to the hypocenter (Figure 5).

The February 28, 2001 M6.8 earthquake near Nisqually, Washington occurred at a depth of 52 km (Figure 6). The ground shaking was "strong" on the Mercalli scale, lasting 45 seconds and extended 200 km from the epicenter. By comparison, the January 17, 1994 M6.7 earthquake near Northridge, California occurred at a much more shallow depth of 18 km with just 10–20 seconds of ground shaking with significant (lower end of severe on the MMI scale) shaking felt 30 km from the epicenter.

The damage was strikingly different: The Nisqually earthquake had one fatality, 400 injured and 1–4 billion dollars in damages while the Northridge earthquake had 57 fatalities, 9,000 people injured, 22–76 billion dollars in damages (recalculated in 2001) and left 125,000 people homeless. The Northridge earthquake was the costliest earthquake disaster in U.S. history.

The reason for the differences in severity of ground shaking was the depth at which the earthquake occurred, e.g. the distance from the hypocenter to the epicenter. As the depth of the hypocenter, the energy attenuates (dissipates) by the time earthquake waves reach the surface. So deep earthquakes generally have lower intensities.

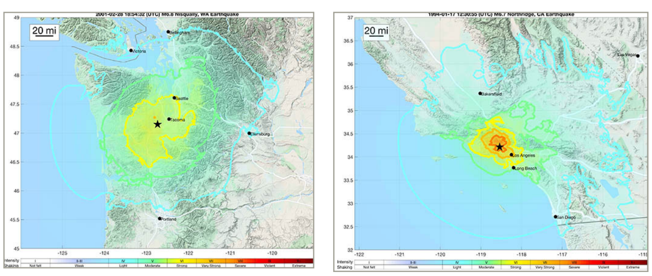


Figure 5: ShakeMaps for the two earthquakes show the difference in intensity based on depth to the hypocenter. Left: 2001 M 6.8 Nisqually quake. Right: 1994 M6.7 Northridge earthquake. Page-size maps are in Appendix B, Example C.

Example D—Local rock and soil conditions: The October 17, 1989 M6.9 Loma Prieta earthquake was on the San Andreas fault roughly 56 miles south of San Francisco and 10 miles northeast of Santa Cruz, near Mt. Loma Prieta in the Santa Cruz Mountains. The depth to the hypocenter was 11 miles. Shaking lasted from 10–20 seconds.

The ShakeMap (Figure 6) shows intense to severe ground shaking in:

- Bay muds and soft sediments surrounding the San Francisco bay (the red/magenta colors surrounding the bay area),
- Sediments in the Salinas and San Joaquin river valleys (the yellow colors follow the valleys).

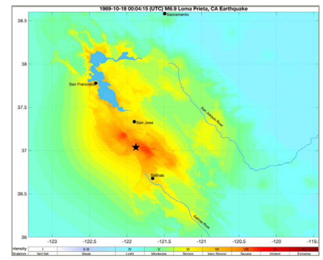


Figure 6: (right) ShakeMap for the 1989 M 6.9 Loma Prieta earthquake. Page-size map is in Appendix B, Example D.

Why was that? Thick layers of soft rocks and soils amplify ground shaking from an earthquake. Seismic waves travel faster through hard rocks than through softer rocks and sediments. As the waves pass from hard rock to soft rock, they slow down and get larger in amplitude as the energy piles up. Softer soils amplify ground motion (Figure 7).

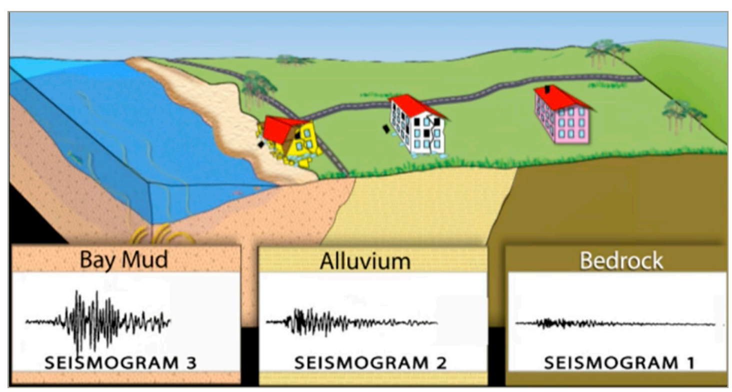


Figure 7: This image helps interpret how intensity of ground shaking depends on the type of subsoils using seismograms. Screen shot from the animation, "[Earthquake Intensity]" (Minute 6:52)

5. Conclusion: We have discovered that the intensity of earthquake ground shaking is influenced by four critical factors. Fortunately, the impact of large future quakes can be reduced by advances in understanding seismic activity and structural engineering, improved construction practices, land use zoning, and better emergency response preparation.

It is also important to remember that whenever the ground shakes due to an earthquake, take protective actions to Drop, Cover and Hold On. ShakeAlert earthquake early warning (see inset at right) can provide seconds of warning to take additional protective actions.

Find out more about ShakeAlert here.

Activity Extension: If time permits, the instructor may have learners explore USGS ShakeMaps to discover additional information.

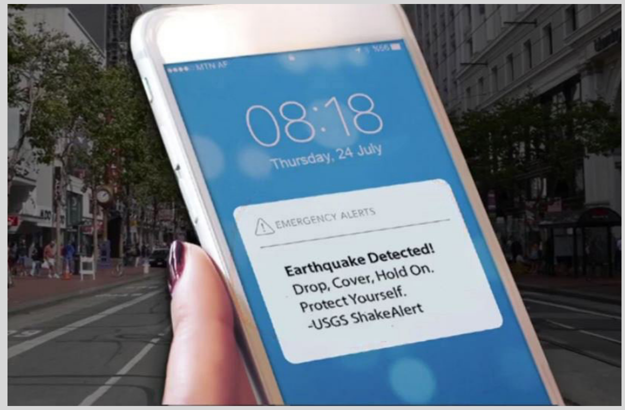
To access the ShakeMap overlays:

a) click on the ShakeMap to enlarge,

b) click on the map layer icon (stack of 3 layers top right),

c) select from the dropdown list provided

d) scroll or use maximize/minimize to focus on a specific area.



ShakeAlert-Powered Alert Delivery

The ShakeAlert system detects the initial P wave from an earthquake and estimates the magnitude and intensity of ground shaking for a given region. In some cases, the system attempts to characterize an earthquake with less than one second of ground motion data. If the earthquake meets a minimum magnitude, the system issues a ShakeAlert Message. ShakeAlert distribution partners (e.g., an app provider or transportation agency) use this Message to develop and deliver alerts to regions that could experience shaking at or above a predetermined ground shaking intensity. For example, users of a cell phone app who may feel MMI 3 (weak shaking) or greater, could receive a ShakeAlert-powered alert for earthquakes estimated to be magnitude 4.5 or greater (see Appendix C).

From time-to-time adjustments are made to thresholds but only after careful testing and evaluation by the USGS with input from alert delivery partners. All adjustments to ShakeAlert-powered alert delivery thresholds are made with the goal of optimizing public safety.

IF YOU HAVE 45 MINUTES*

Did You Know?

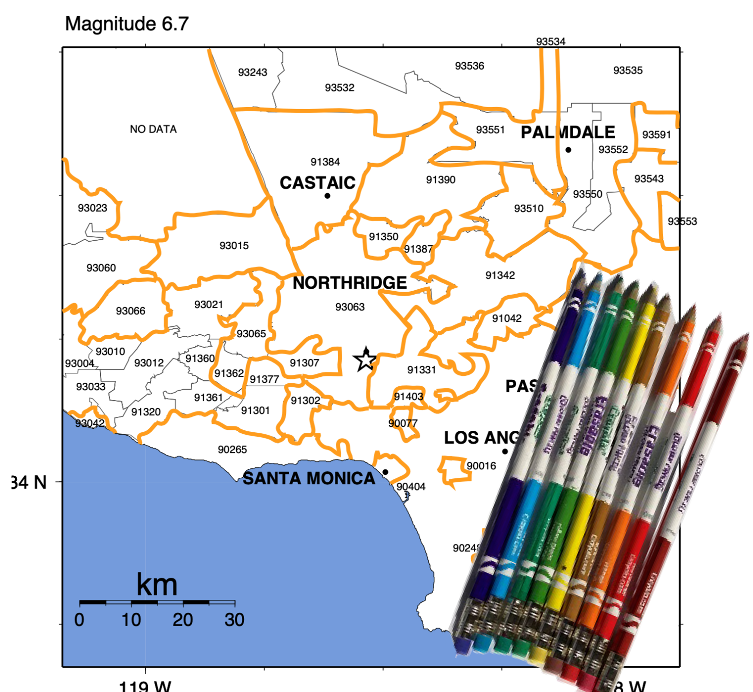
- Did you know that ShakeMaps can be based on data gathered from seismic instrumentation and from the people who live and work in the community?

There are two main types of ShakeMaps. The difference in the ShakeMaps is based on the nature of the data used for each product. The USGS ShakeMaps are primarily based on measurements of ground motion as recorded by seismometers. In contrast, "*Did You Feel It?*" (DYFI) collects information from people who felt an earthquake and uses this information to create maps that show what people experienced and the extent of damage.

In this activity, learners read personal narratives of what people experienced during the historic Northridge earthquake (Appendix E). Using the Modified Mercalli Intensity (MMI) scale, learners choose a specific MMI level of shaking from Roman numeral I to X for each narrative (Appendix C). Learners color and create an intensity map (Figure 8 and Appendix D), based on the location of the narrative (in terms of ZIP Code) with the MMI color palette (Appendix D). Learners then compare their created maps with the answer key (Appendix F) and the official USGS "*Did You Feel It?*" Map (Appendix G). Three additional maps (Appendix H, I and J) add increasing detail by revealing different aspects of the same event. Appendix H shows a color blended, area-wide composite ShakeMap of the event. Appendix I shows DYFI and seismic sensor locations color intensity side by side. Appendix J illustrates the geophysical (rock, soil and topographical effects of ground shaking) in a regional map.

Instructor Preparation

- Read the "Did You Feel It?" Scientific Background which explains how the USGS uses community-reported earthquake experiences to create their Community Internet Intensity Maps. On the other hand, scientists use point location measurements of the ground motion recorded by seismometers to create the USGS ShakeMaps. The color-coding on the intensity maps both share the same palette and values. In areas with both seismic instruments and human "sensors", DYFI intensities are used to calibrate the equations used by ShakeMap to convert ground motions (as measured by sensors) into intensity.
- Print enough copies of the following for each table group:
  - APPENDIX C—Modified Mercalli Intensity of Shaking Scale. One scale for each table group. Note: Must be printed in color. Optional: Laminate or use clear plastic page protectors to help preserve maps.
  - APPENDIX D—Northridge, California ZIP Codes (activity copy). Note: Activity maps can be printed in black and white.
  - APPENDIX E—Earthquake Experiences Narratives
- Assemble sets of 9 colored pencils (preferred), or crayons to supply one set for each table group that will match the colors in the Modified Mercalli Intensity Scale: violet, light blue, aqua, green, yellow, gold/amber, orange, red, and magenta.
- The following maps could be computer projected or printed in color for a data projector or provided one map per table group:
  - APPENDIX F—Northridge, California ZIP Code Map (Answer Key)
  - APPENDIX G—USGS Did You Feel It Northridge, California Intensity Map
  - APPENDIX H—CISN ShakeMap of the 1994 Northridge, California Earthquake
  - APPENDIX I—Combined "*Did You Feel It*" and Seismic Sensor "ShakeMap" Locations
  - APPENDIX J—USGS Macroseismic Intensity Map



INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy

Figure 8: M6.7 Learner activity ShakeMap for the January 17, 1994 M6.7 Northridge, California earthquake by ZIP codes. Map in Appendix D.

* This 45-min activity was adapted from the USGS activity: Magnitude vs. Intensity, developed by Lisa Wald & Wendy Shindle.

Directions

1. Ask learners if anyone has ever been in an earthquake? Spend a few minutes letting learners share their personal experiences, videos they have seen, family-stories, etc.
2. Describe the [USGS sponsored "Did You Feel It?" website] where anyone who felt an earthquake can report their experiences. This site provides rapid reporting that scientists use to help fill in the gaps of actual seismogram reporting for ShakeMap.
3. Distribute for each table group:
   - Learner activity ZIP Code-based ShakeMap (black and white)
   - Modified Mercalli Intensity Scale (printed in color)
   - Earthquake Experiences Narratives
4. Ask learners to create their own MMI color scale on the bottom of their ZIP code map using their color pencils. Try to match the actual MMI color scale as closely as possible.
5. Assign Earthquake Experiences Narratives to each group. Note: there are 29 narratives that can be assigned.

   Two suggestions:

   a. Assign four (4) or more narratives to each learner group. The group reads each narrative, decides which MMI shaking level they feel is appropriate, and then color in their ZIP Code map. After ~10 minutes, each group reports the results of their ZIP Codes and the other groups add colors to their own maps.

   b. Assign each group to read as many narratives as they can within the allowed time. In a 45-minute class, allow ~30 minutes. After reading each narrative, the group decides which MMI shaking level they feel is appropriate, and colors in their ZIP Code map.

   Note: The goal is to help students understand that social data (information given by people) is important to earthquake science.

5. Reengage by asking learners what they noticed in the maps they created.

   Questions for Discussion
   - What impressed you most about the narratives? (*Answers vary, but should reflect both factual as well as emotional impact of the earthquake experience*.)
   - Was there a pattern to the colors in the ZIP codes? (*Intense shaking (darkest reds) is felt closest to the epicenter and shaking intensity decreases (toward cooler, blue colors) farther away from the epicenter*.)

6. Reveal the completed ZIP Code answer key (Appendix F) using a data projector or a computer projection system.

   Questions for Discussion
   - Are there any surprises in this map? (*Answers vary*.)
   - Why do you think there are areas of intense shaking farther away from the epicenter? (*Answers vary, but most likely due to highly localized underlying soil conditions within the San Fernando Valley and Los Angeles Basin*.)

7. Show the "*Did You Feel It?*" Northridge, California Intensity Map (Appendix G).

   Questions for Discussion
   - This map was originally created over 25 years ago. What do you notice about it? (*Answers vary but may include: the colors are not continuous, there were over 10,000 responses, 6051 responses plotted in 361 blocks, and that maximum shaking was severe at level IX*.)

8. Now let's look at a CISN (California Integrated Seismic Network) ShakeMap for the same earthquake (Appendix H) which is based on seismometer-recorded data of ground shaking amplitude.

   Questions for Discussion
   - What do you notice about this ShakeMap created by the California Integrated Seismic Network? (*The colors are continuous, and the colors more uniformly move from intense reds near the epicenter to cooler, less intense colors further away*.)

9. The next map (Figure 9) combines the last two; it displays both *"Did You Feel It?"* data and seismic sensor data (Appendix I). In this map, "DYFI?" symbols are circles and seismic sensor symbols are triangles.

   Questions for Discussion
   - Which shaking intensity colors do most of the circles and triangles match? (*The colors of the triangles and the circles match well at locations closer to the epicenter, where shaking is severe*.)

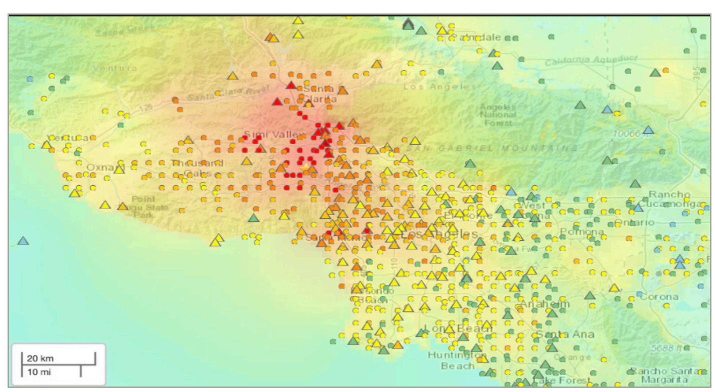


Figure 9: Combined Did you Feel It and USGS Seismic Sensor ShakeMap Location. Map and explanation are in Appendix I.

- Which shaking intensity colors do many of the circles and triangles not match? (*Most DYFI circles and seismic sensor triangles did not match further from the epicenter, where the shaking is at the lower end of the scale. DYFI reports often gave a higher rating than the seismic sensors.*)
- Why do you think that might be? (*Answers vary. Higher MMI levels reported in DYFI? reflect changes to the built environment, while lower MMI levels reflect greater variation in individual felt perceptions. In general, people tend to inflate what they felt during an earthquake. For example, people might say that shaking lasted for 30 seconds, when in fact, shaking lasted for just 10 seconds*.)

10. Finally, let's look at the USGS Macroseismic Intensity map (Appendix J). This map shows additional detail that reveals important factors that affect ground shaking intensity. Review the four factors that affect ground shaking. (Ask learners what they are, if they have done the 15-minute activity!) The factors are magnitude, distance from the epicenter, depth to the hypocenter, and local rock and soil conditions.

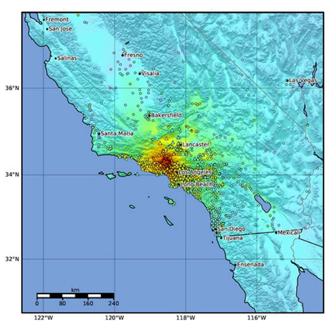


Figure 10: USGS Macroseismic Intensity map. Map and explanation are in Appendix J.

Questions for Discussion

- What factors that affect the intensity of ground shaking do you see in this map? (*Factors are distance from the epicenter, depth to the hypocenter, and local rock and soil conditions*.)
- What do you notice about any patterns to the colors, especially strong (yellow colored) shaking? (*The yellow color of strong shaking follows valleys which drain into the Los Angeles basin where softer soils and sediments intensify ground shaking.*)

APPENDIX A — VOCABULARY

Attenuate—decrease in wave size, or amplitude, away from the source. When you throw a pebble in a pond, it makes waves on the surface that move out from the place where the pebble entered the water. The waves are largest where they are formed and get smaller as they move away. Seismic waves attenuate away from the earthquake source.

Did You Feel It? (DYFI)—a community-science project led by the USGS that collects information from people who felt an earthquake and creates maps that show what people experienced and the extent of damage.

Epicenter—the point (map location) on the Earth's surface directly above the hypocenter (or focus) of an earthquake.

Hypocenter—commonly termed the focus, this is the point within the earth where an earthquake rupture starts. It is directly below the epicenter and generally between 1–50 km depth, but can be as deep as 600 km in subduction zones.

Intensity—a number (written as a Roman numeral) that describes the severity of an earthquake in terms of its effects on the earth's surface and on humans and their structures (i.e., what is experienced).

Lumen—a unit of measure for the brightness of light. The lumen is a measure of the total quantity of visible light emitted by a source per unit of time.

Magnitude—a number that characterizes the relative size of an earthquake. Magnitude is based on measurement of the maximum motion recorded by a seismograph.

Modified Mercalli Intensity (MMI) Scale—commonly used intensity scale that assigns a number describing the perceived severity of an earthquake in terms of its effects on the earth's surface and on humans and their structures. (See Intensity.)

Seismogram—the real-time record of earthquake ground motion recorded by a seismograph.

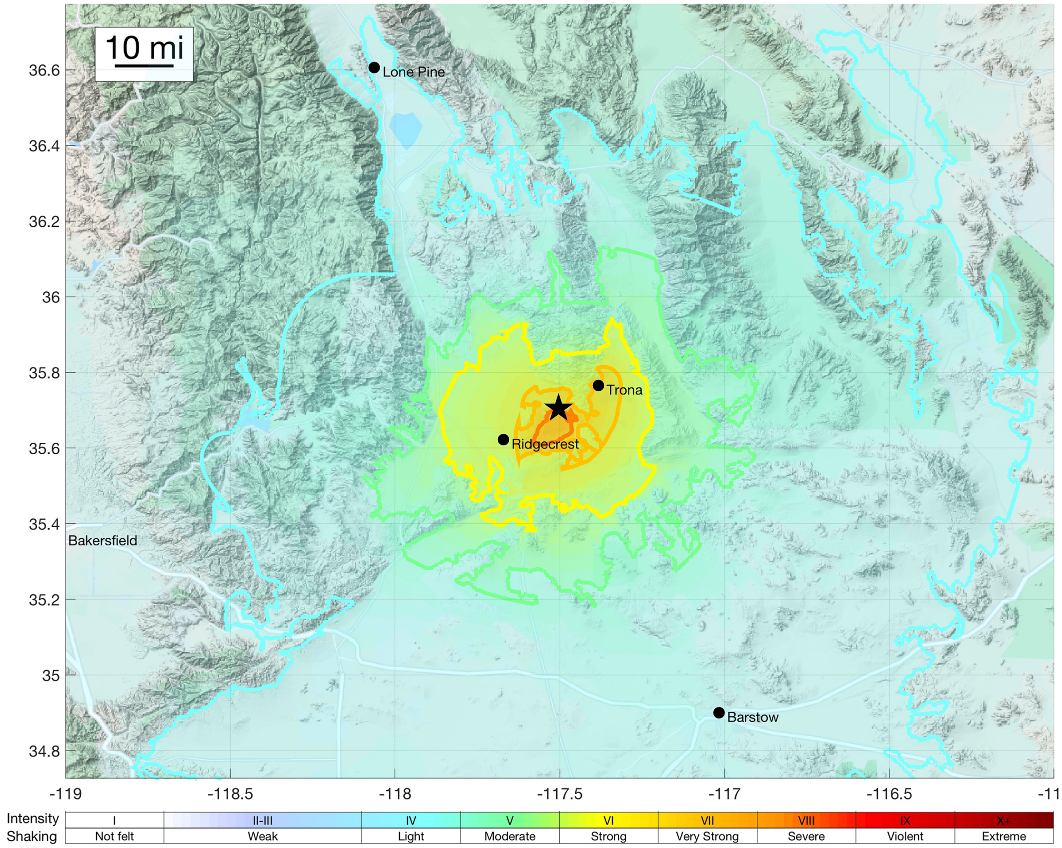
ShakeMap—is a product of the USGS Earthquake Hazards Program in conjunction with the regional seismic networks. ShakeMaps provide near-real-time maps of ground motion and shaking intensity following significant earthquakes.

Wattage—a measure of electrical power in units of watts, e.g., the operating power of a lamp or other electrical appliance expressed in watts.

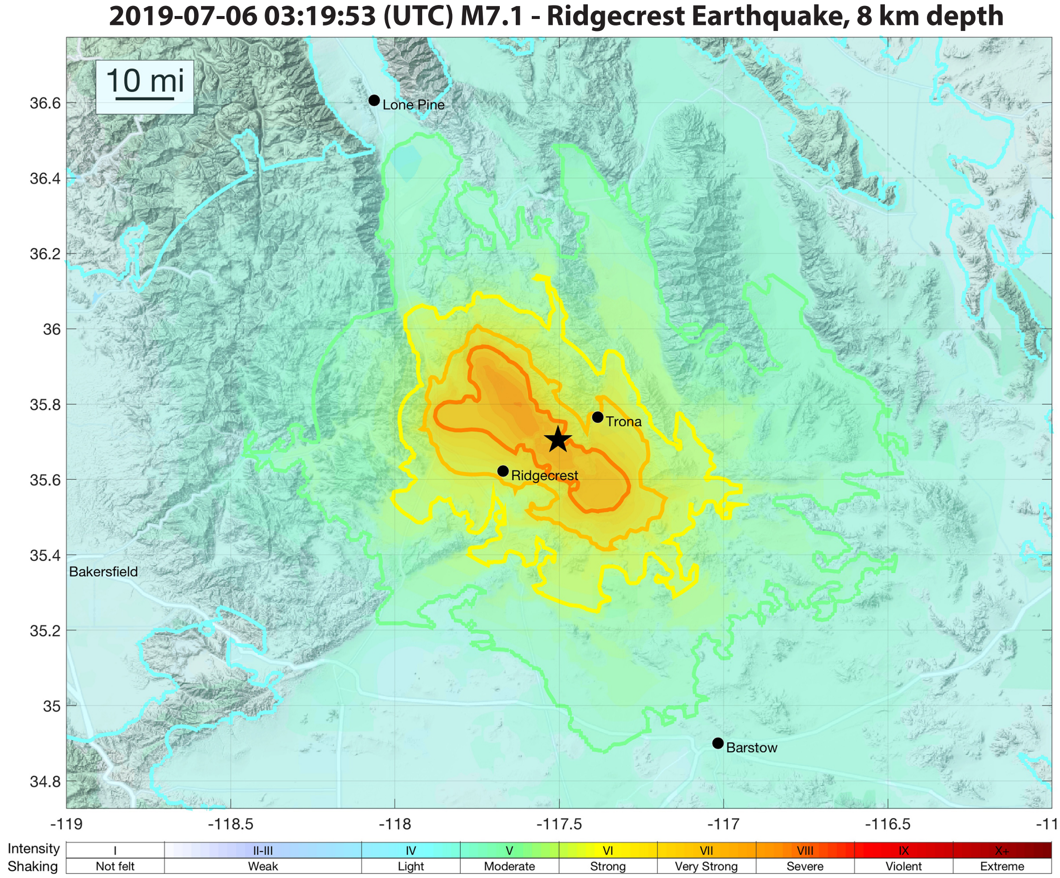
APPENDIX B—ShakeMaps: Intensity of earthquake ground shaking

Example A: Ridgecrest, CA—two earthquakes, 2 days apart.

2019-07-04 17:33:49 (UTC) M6.4 - Ridgecrest Earthquake, 10.5 km depth

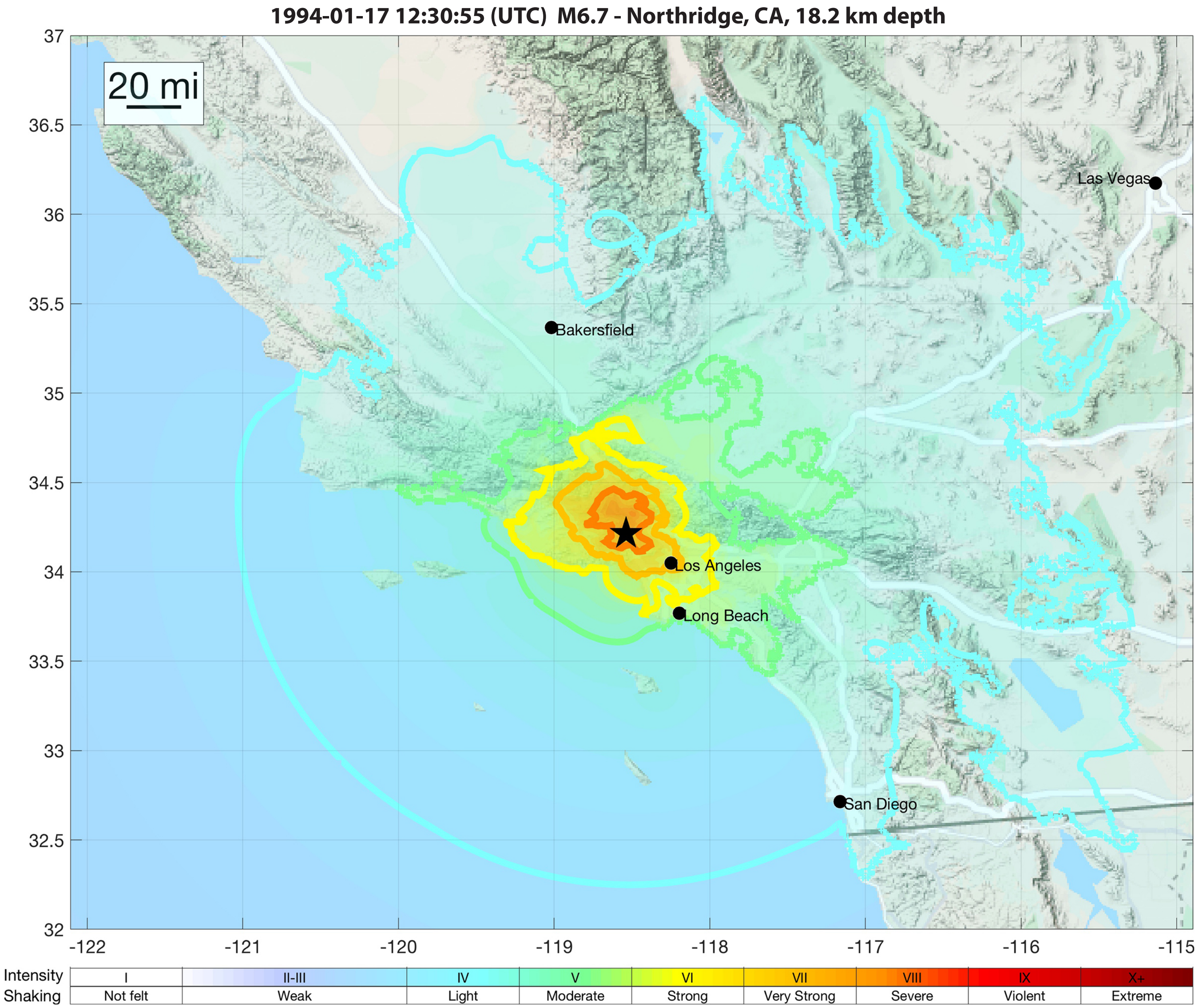


2019-07-06 03:19:53 (UTC) M7.1 - Ridgecrest Earthquake, 8 km depth



(Appendix B cont.)

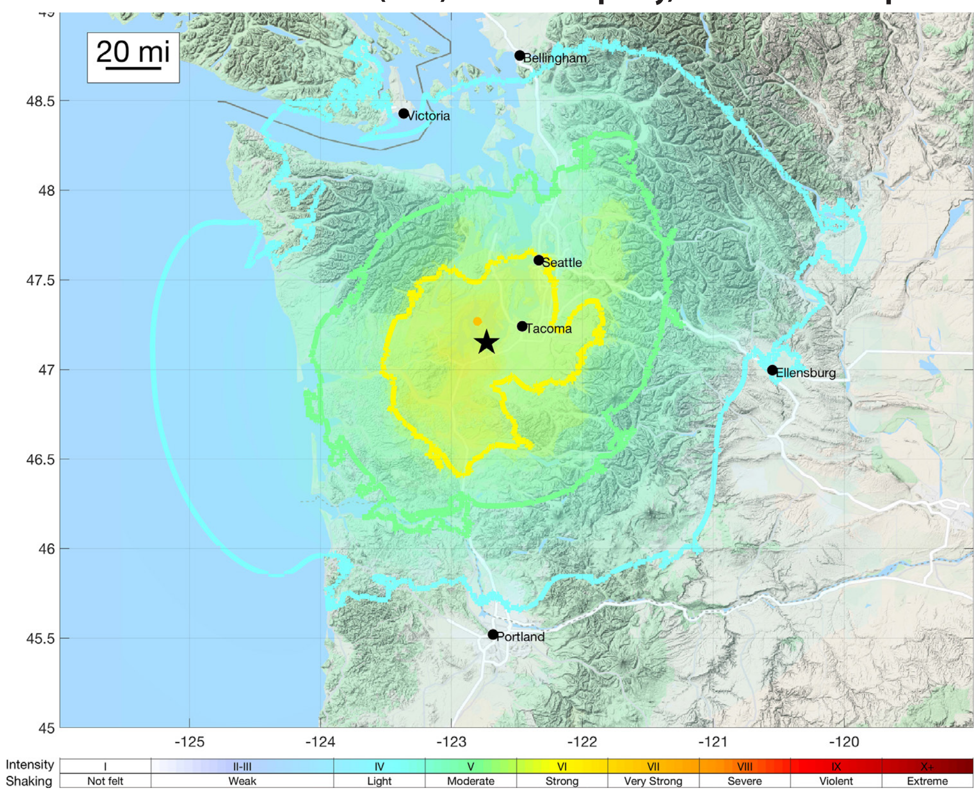
Example B: M6.7 Northridge, California Earthquake January 17, 1994



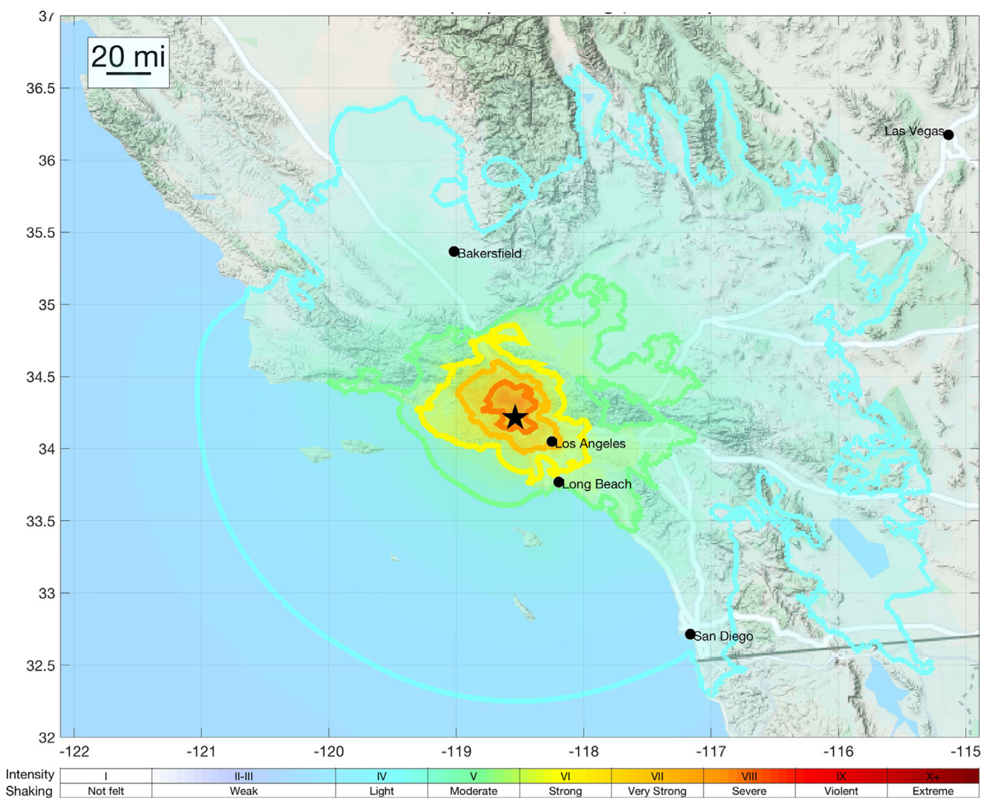
(Appendix B cont.)

Example C: Two earthquakes with similar magnitudes (M6.8 and M6.7)

2001-02-28 18:54:32 (UTC) M6.8 - Nisqually, WA 51.8 km depth

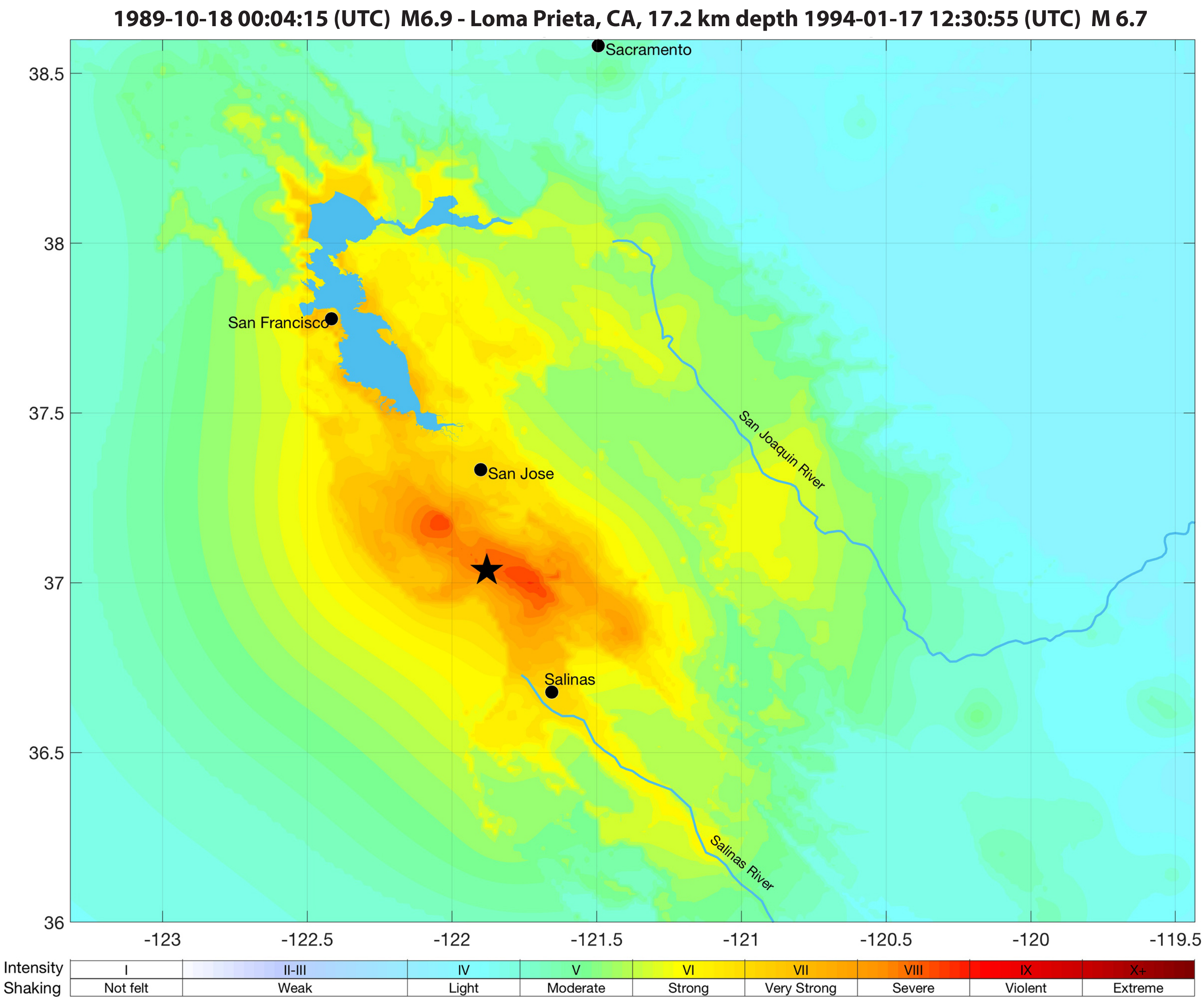


1994-01-17 12:30:55 (UTC) M6.7 - Northridge, CA, 18.2 km depth



(Appendix B cont.)

Example D: M6.9 Loma Prieta, California Earthquake October 18, 1989



APPENDIX C—Modified Mercalli Intensity Scale

Intensity	Shaking	Description/Damage
I	Not felt	Not felt except by a very few under especially favorable conditions.
II	Weak	Felt only by a few persons at rest,especially on upper floors of buildings.
III	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

APPENDIX D—Northridge, California ZIP Code Map

INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy

Directions:

1) Color the Intensity Scale at the bottom of the map…using your color pencils to match the MMI color scale as closely as possible…with a different color for each intensity.

2) Then color in the map to reveal which areas had the most shaking in the Northridge earthquake.

Small zip code areas have been combined in many cases and are represented by one zip code. The resulting ShakeMap in this exercise is representative of the actual shaking distribution, but not exactly accurate for each individual zip code.

APPENDIX E—Earthquake Experiences Narratives

93065, 91362, 91367—I was driving home from work and it felt like I had a flat tire. I pulled off the road to check and as I stopped the car I saw the chimney on a nearby house collapse. It fell right on a new Lexus that was parked in the driveway.

93012, 91361, 91360, 93033, 93004, 93021, 93010, 91320— I had just gotten up to give my baby daughter her bottle when I felt a violent jolt. I knew we were having an earthquake so I tried to run into her room to get her but it was so hard to walk! I could hear things outside falling and hitting the ground, and all of the pictures in the hall were falling and breaking. I was so scared!

90248—I am a nurse at a local hospital. I was attending to Mr. Jones when I first felt the earthquake. He woke up and we watched a glass of juice on his bedside table slide back and forth-I caught it before it tipped. Most of the patients woke up-let me tell you, it was a long night!

90265—My parents were out of town visiting my brother at college so my best friend John and I decided to have a party. The party was pretty much over and we were doing damage control in the back yard when I felt something weird. I thought it was just me but then everything started to shake. I mean, even the pool had waves in it and the water was spilling out over the edges! And so much stuff in the house had fallen over and broken you couldn't even tell we had a party!

91387—I work the late shift at Denny's. I was outside on my break when I felt the first shake. Then everything started shaking so hard I could even hear the bushes rattling! The people inside felt it too. Their plates and glasses were shaking and bouncing and a bunch of them came running outside. I don't know where they thought they were going to go; it was shaking outside too!

93510—I am from Virginia and I was in California visiting my grandchildren. In the very middle of the night, I woke up and felt a strange rumbling. Then things started to shake a bit and my grandson ran into my room and told me to stand in the doorway, that we were having an earthquake. Well, that door was swinging back and forth and I told him that I would stay right where I was. Thank you very much! I wasn't going to get knocked out by some door and have to be taken to the hospital in my nightclothes!

91706—I am a really heavy sleeper and I didn't even wake up, but my husband was up getting a snack and he said he felt it. He said the dishes in the cupboard rattled and he could see the hanging plants swaying.

91042—I am a seismologist with the USGS and my first thought when I felt the earthquake was "I'm going to work tonight!" My husband and I watched as several picture frames slid off the mantle, and then we ducked under the table. We had to hold on because the table was trying to slide away. Lots of our dishes were broken and we have a lot of cracks in the walls to fix.

90016—I was sleeping soundly when I was suddenly thrown out of bed. I could hear my kids crying and I was trying to run, trying to get to them. The walls were shaking and cracking, and pieces of plaster were falling from the ceiling. I could barely stand. The noise was deafening. By the time I got to my kids and got them outside the whole thing was over. We have a lot of damage to our house but not as much as our neighbors. Their house partially collapsed.

91331—I'm a night watchman at an apartment complex. It was pretty late, and everything was real quiet. I was making my rounds when I felt a strong jolt-it almost knocked me off my feet! I ran out into the middle of the street and it's a good thing I did too! Bricks were falling off of the building and the trees were shaking so hard that branches were breaking and falling off. All of the parked cars around me were shaking and bouncing and the car alarms were all going off.

91384—My daughter had just arrived home (WAY past her curfew) and we were arguing in the den. When we felt the shaking we just stared at each other. The sound of a glass smashing snapped us out of it. We both ran to the China hutch where I keep my mother's china-it was just about to tip over! We held it up and we could hear other things around the house falling and breaking. Needless to say I wasn't worried about the curfew violation any more!

93015—I was up late working on a briefing when I first felt the earthquake. It didn't seem too bad at first so I stayed put to see if it would get worse. It did! I tried to get up and could barely stand. I remembered that you're supposed to get under a table if it's a bad earthquake so I got down on my hands and knees and crawled under my table. Just as I got under there my big bookcase fell and smashed on the table. If I had still been sitting there it would have crushed me.

93543—We were out of town when the earthquake hit. Of course, we were scared for our friends and family and for our home. We called our son and he said that everyone was alright, but they had a lot of structural damage to their house, and had lost some personal items. We called the neighbors and they gave us a grocery list of damage to our house chimney broken at the roofline, cracks in the masonry, fallen bricks, stuff like that. I'm afraid to go home and see the damage inside.

93532, 93243, 93536—My husband woke me up yelling that we were having an earthquake. As we ran in to the kitchen I could hear the plates and cups banging and rattling, and all of the pictures were falling off the walls. We grabbed the dog and all got under the table. I knew we were going to be alright because our house is retrofitted and all of our things are secured, but I was worried about my mom and dad.

93060, 93023—I was asleep when the earthquake came. I was so scared and I didn't know what to do. The house was shaking so bad that I couldn't even walk. My dad came into my room and got me and we got under the table. We could see the refrigerator sliding back and forth across the kitchen with its door opening and shutting and all of the stuff falling out onto the floor. Our TV went flying across the room and smashed into the wall. All over we could hear things breaking. Then the lights went out. After it stopped and we went outside we could see all of the other people outside too. They were crying and looking around. Part of our apartment building fell down and now those people have to find another place to live. We might have to too.

93591—I was just finishing a great Tom Clancy novel when I felt the earthquake. At first I thought it was a passing truck but then I noticed that the blinds were swinging a little bit. I thought about calling my buddy to see if he had felt it but it was late and I was pretty sure it wouldn't have woken him up.

93551—I was sleeping over at my friend's house when the earthquake came. We were supposed to be asleep but we were telling stories so we felt it first. She said that her family had an earthquake plan and we were supposed to go into the dining room and get under the table. It was kind of scary because all of the furniture was moving around and her dad's computer fell on the floor and broke, but I wasn't really scared because her mom and her dad said that we were prepared and we'd be okay.

91377, 91301—I was driving home from my late shift when it felt like the car wasn’t driving normally. Then I noticed dirt sliding down the steep side of the ditch next to the road. I stopped the car on the side of the road and got out. That’s when I noticed the new cracks in the concrete wall on the other side of the ditch. By that time the shaking had stopped, so I got back in my car and drove home.

93552, 93535, 93550—I was working on my computer when the earthquake struck, and it was scary. My desk chair was rolling back and forth across the floor, and all the pictures fell off the bookshelves. My computer almost fell off the table too!

91342—I had fallen asleep watching TV when I felt a tremendous jolt. Things were things flying through the air and I ran to get under cover. There was a huge crash and part of my ceiling fell in. My chimney had collapsed!

91302—It was exam week and I was coming home late from the library when I felt the shaking. I had to run into the middle of the street to get away from the tree branches. They were breaking off and falling all around me!

90404—I was out of town for the earthquake, but my neighbor says our house has sustained a lot of damage. It fell off the foundation. I guess we shouldn’t have put off that retrofitting.

93066—I thought the earthquake was great! What a ride! Our panel walls fell down, and we have some damage to the masonry, but it was such a fun experience! I can't wait to tell my friends back east!

91350—I'm a bus driver on the graveyard shift. I thought I must have blown out a tire because it was so hard to drive. I pulled over to the side of the road and turned my head just in time to watch the old factory tower fall down!

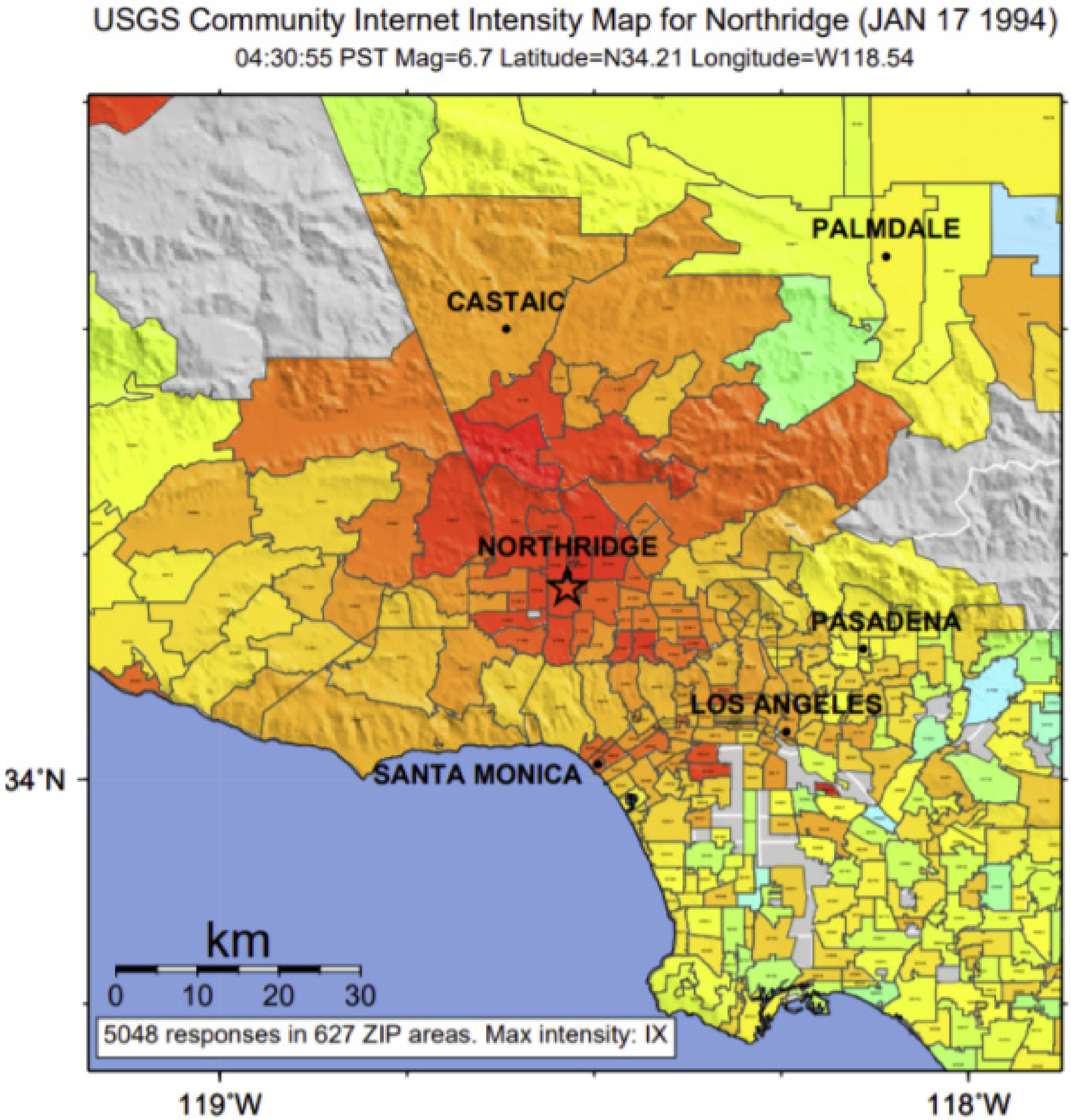
91390—Our big surprise from this earthquake was the next morning when we went outside and saw big cracks in the hillside behind our home. Scary!

90240—My wife woke me up and asked me if I felt anything. I told her the only thing that I felt was her shaking me! She said she thought we were having an earthquake, and when I stopped and listened I could hear the glasses in the kitchen rattling and clinking. There was an earthquake-and a pretty big one! Who knew?

93553—I was sleeping when I felt the first jolt. I got out of bed but it was hard to stand. I was amazed by all the noise-car alarms were going off, things were falling and breaking, and the church bells across the street were even ringing! Can you imagine? Those things are huge!

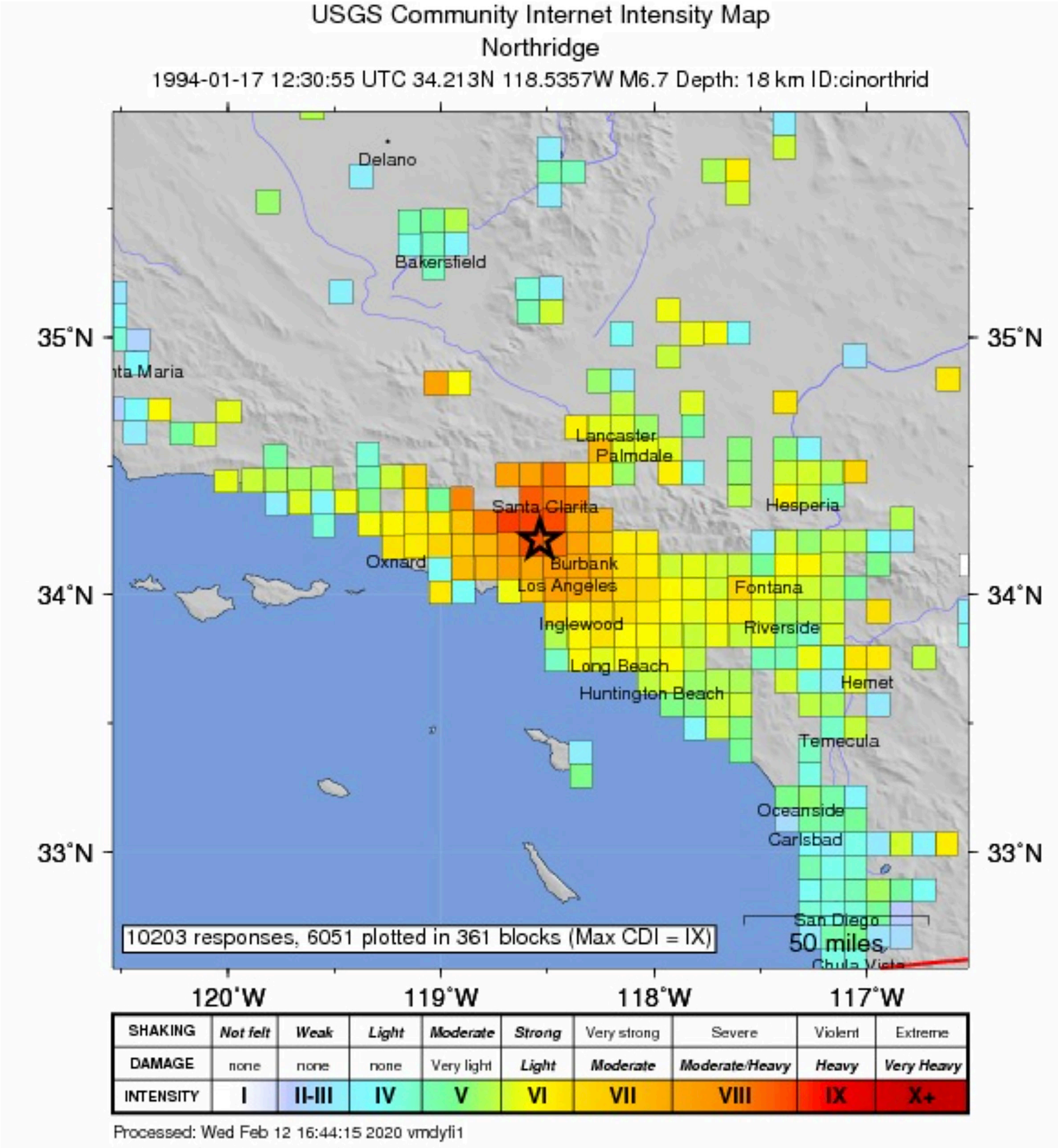
91403—I had just gotten up to go to the bathroom when the earthquake came. It was unbelievable. It threw me off my feet. My roommate and I ran to get underneath the dining room table. As I was running I saw my computer flying through the air. Once we got under the table we held on for dear life! It felt like it lasted forever but really it was only a few seconds. Once it stopped we went outside and saw the mess. Pipes had broken and everything was flooding, there were little sand volcanoes in the front yard. There was lots of damage to people's houses and chimneys but everyone on our block was uninjured. It was the most frightening experience of my life.

93063—I was at a soccer game when the ground started shaking really hard. Our whole team was really scared, and most of us sort of fell to the ground because it was so hard to stand up. It was really weird when some sand sprayed up from a couple of places in the field. When the shaking stopped, we saw some of the houses on the street looking lopsided, with collapsed porches. There was even one that had collapsed!



https://pubs.usgs.gov/fs/fs030-01/images/Northridge.jpg

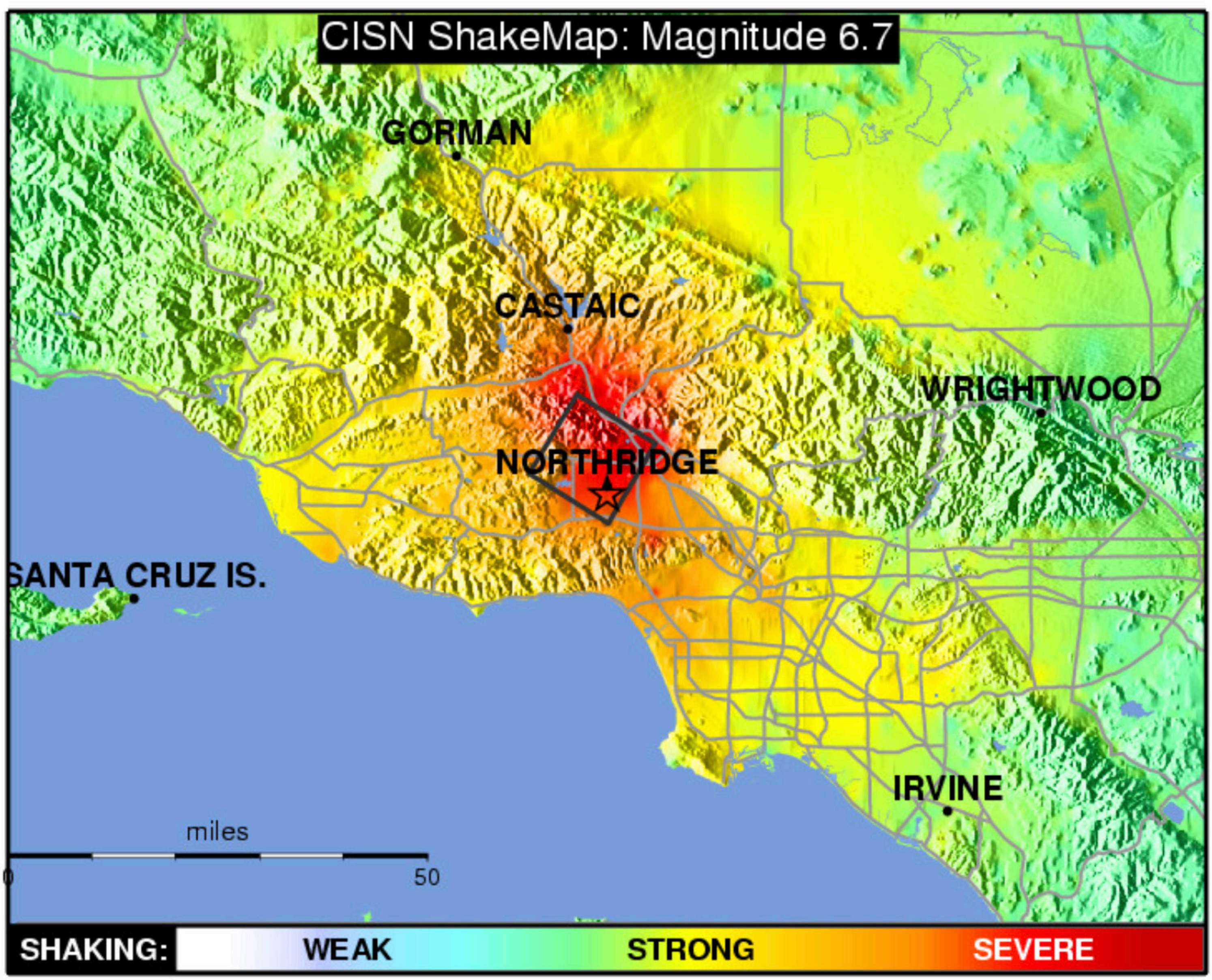
APPENDIX G—USGS Did You Feel It? Northridge, California ShakeMap



https://earthquake.usgs.gov/earthquakes/eventpage/ci3144585/dyfi/intensity

APPENDIX H—CISN ShakeMap of the 1994 M6.7 Northridge, CA Earthquake

A ShakeMap of the 1994 Northridge, CA earthquake. A ShakeMap is a near-real-time seismic network product that helps guide emergency response efforts within minutes of a strong earthquake. The California Strong Motion Instrumentation Program (CSMIP), a California Geological Survey program, manages more than 1,300 strong motion instruments statewide that contribute data to ShakeMap. Visit the California Integrated Seismic Network to see the 1994 M6.7 Northridge earthquake ShakeMap and related products.



Map Version 15 Processed Thu Feb 1, 2007 03:11:01 PM PST,

Image Source: California Integrated Seismic Network https://www.conservation.ca.gov/cgs/earthquakes/northridge

APPENDIX I—Combined *Did you Feel It* (circles) and *USGS Seismic Sensor* (triangles) ShakeMap Locations

DYFI color palette coding and values are made to be compatible and consistent with ShakeMap. However, the difference between the intensity maps is in the nature of the data used for each ShakeMap product.

ShakeMap is primarily based on point location measurements of the ground motion as recorded by seismometers. Seismic intensity is calculated from these recordings by analyzing the records for peak ground acceleration, the largest value of acceleration recorded during the earthquake by a seismometer.

In contrast, DYFI maps are based on direct reports of earthquake effects by people in the area instead of seismometers. In some regions, the ShakeMap—particularly those within an area with few seismic stations—incorporates DYFI reports to help constrain the shaking levels in addition to employing seismic stations, fault locations, and surficial geology for site amplifications.

In areas with both seismic instruments and human “sensors”, DYFI intensities are used to calibrate the equations used by ShakeMap to convert ground motions (as measured by sensors) into intensity.

DYFI is Community Science! Anyone who has felt earthquake ground shaking can report their experiences by entering “Report it Here—Tell Us!” on the USGS website .

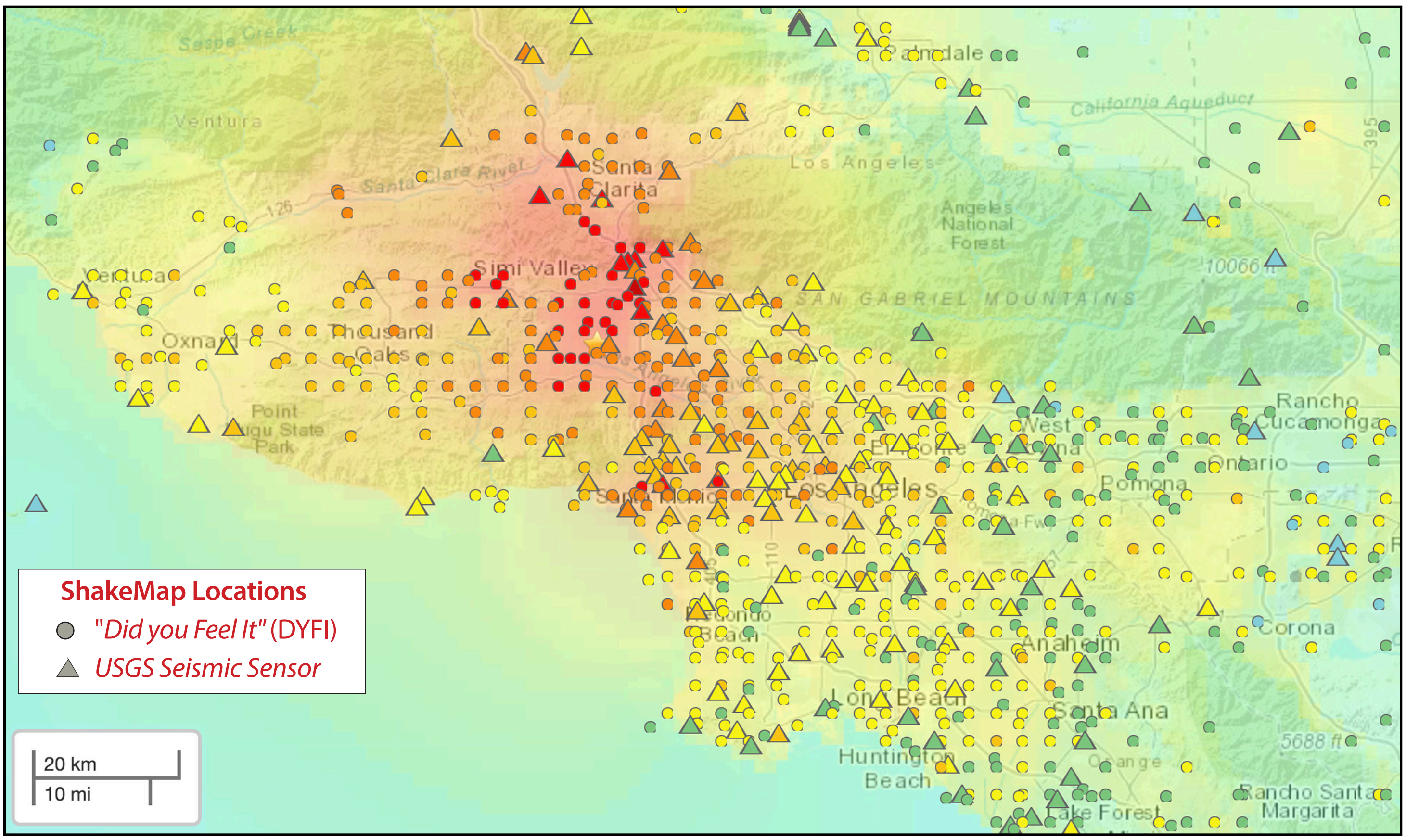


Image source link here.

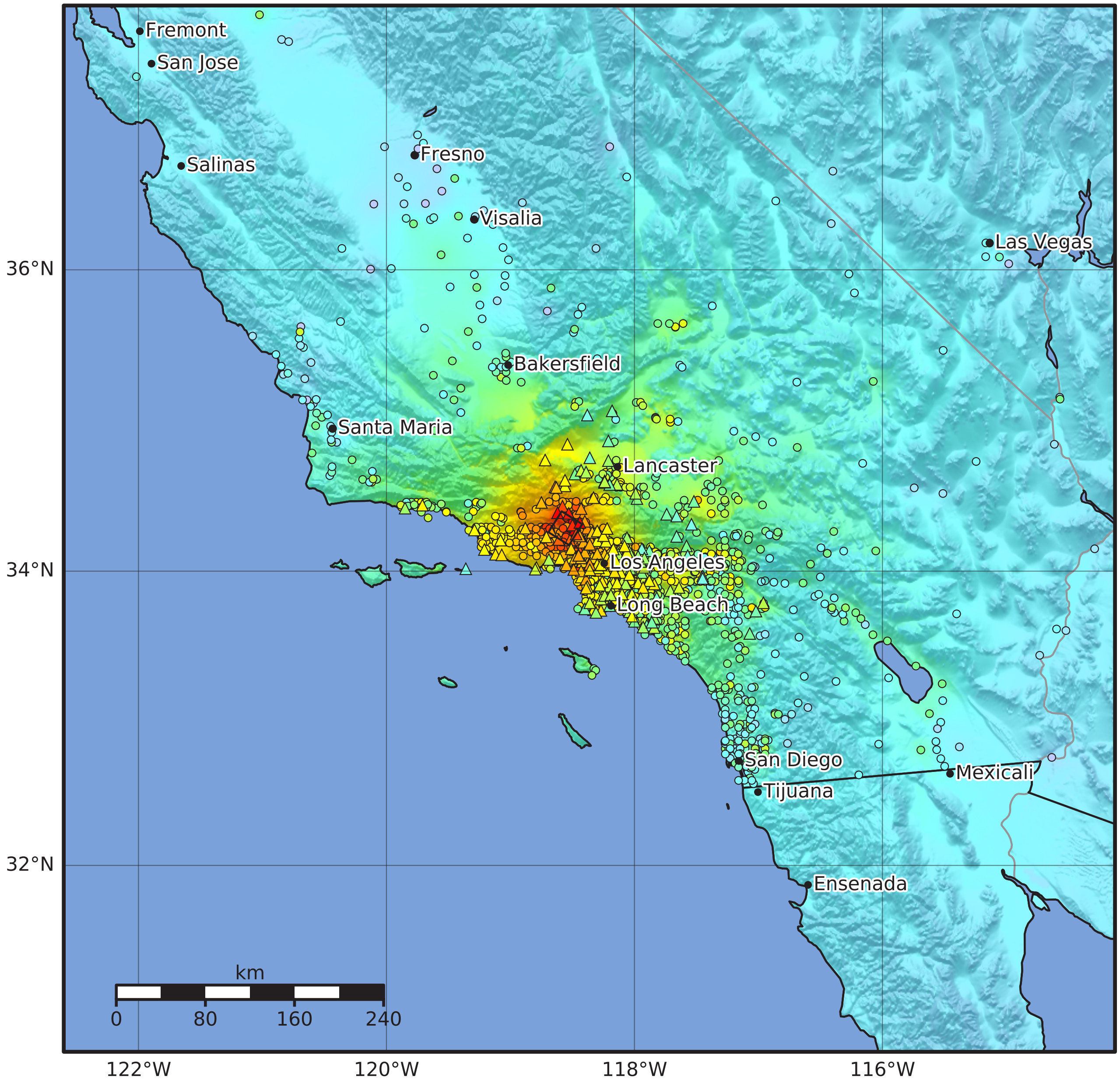
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.0464	0.297	2.76	6.2	11.5	21.5	40.1	74.7	>139
PGV(cm/s)	<0.0215	0.135	1.41	4.65	9.64	20	41.4	85.8	>178
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based on Worden et al. (2012) Version 1: Processed 2020-06-03T00:39:44Z

△ Seismic Instrument ○ Reported Intensity ★ Epicenter ▭ Rupture

APPENDIX J—USGS Macroseismic Intensity Map

Macroseismic Intensity Map USGS
ShakeMap: 1km NNW of Reseda, CA
Jan 17, 1994 12:30:55 UTC M6.7 N34.21 W118.54 Depth: 18.2km ID:ci3144585



SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.0464	0.297	2.76	6.2	11.5	21.5	40.1	74.7	>139
PGV(cm/s)	<0.0215	0.135	1.41	4.65	9.64	20	41.4	85.8	>178
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based on Worden et al. (2012) Version 1: Processed 2020-06-03T00:39:44Z

△ Seismic Instrument ○ Reported Intensity ★ Epicenter ▭ Rupture

Image source link here

APPENDIX K— NGSS Science Standards & 3 Dimensional learning

Earth and Human Activity

MS-ESS3-2 Performance Expectation:

Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects. MS-ESS3-2

[Clarification Statement: Emphasis is on how some natural hazards, such as volcanic eruptions and severe weather, are preceded by phenomena that allow for reliable predictions, but others, such as earthquakes, occur suddenly and with no notice, and thus are not yet predictable. Examples of natural hazards can be taken from interior processes (such as earthquakes and volcanic eruptions), surface processes (such as mass wasting and tsunamis), or severe weather events (such as hurricanes, tornadoes, and floods). Examples of data can include the locations, magnitudes, and frequencies of the natural hazards. Examples of technologies can be global (such as satellite systems to monitor hurricanes or forest fires) or local (such as building basements in tornado-prone regions or reservoirs to mitigate droughts).]

Science and Engineering Practices

Analyzing and Interpreting Data

Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.

- Analyze and interpret data to determine similarities and differences in findings.

Disciplinary Core Ideas

ESS3.B: Natural Hazards

Mapping the history of natural hazards in a region, combined with an understanding of related geologic forces can help forecast the locations and likelihoods of future events. (MS-ESS3-2)

Crosscutting Concepts

Patterns

Graphs, charts, and images can be used to identify patterns in data.(MS-ESS3-2)

Connections to Engineering, Technology, and Applications of Science

Influence of Science, Engineering, and Technology on Society and the Natural World

- The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus technology use varies from region to region and over time.

Incorporated Research Institutions for Seismology

IRIS

FACILITATE. COLLABORATE. EDUCATE.

Founded in 1984 with support from the National Science Foundation, IRIS is a consortium of over 100 US universities. In partnership with its Member Institutions and the scientific community, IRIS manages and operates comprehensive, high-quality geophysical facilities that enable exciting discoveries in seismology and the Earth sciences. IRIS programs contribute to scholarly research, education, earthquake hazard mitigation, and the verification of a Comprehensive Test Ban Treaty.