Richter magnitude scale

From Wikipedia, the free encyclopedia

The **Richter magnitude scale** (also **Richter scale**) assigns a magnitude number to quantify the size of an earthquake. The Richter scale, developed in the 1930s, is a base-10 logarithmic scale, which defines magnitude as the logarithm of the ratio of the amplitude of the seismic waves to an arbitrary, minor amplitude, as recorded on a standardized seismograph at a standard distance.

As measured with a seismometer, an earthquake that registers 5.0 on the Richter scale has a shaking amplitude 10 times greater than an earthquake that registered 4.0 at the same distance. As energy release is generally proportional to the shaking amplitude raised to the 3/2 power, an increase of 1 magnitude corresponds to a release of energy 31.6 times that released by the lesser earthquake.[1] This means that, for instance, an earthquake of magnitude 5 releases 31.6 times as much energy as an earthquake of magnitude 4.

- Magnitude 3 = 2 gigajoules
- Magnitude 4 = 63 gigajoules
- Magnitude 5 = 2,000 gigajoules
- Magnitude 6 = 63,000 gigajoules
- Magnitude 7 = 2,000,000 gigajoules

The Richter scale built on the previous, more subjective Mercalli scale by offering a quantifiable measure of an earthquake's size.[2]

In the United States, the Richter scale was succeeded in the 1970s by the moment magnitude scale. The moment magnitude scale is now the scale used by the United States Geological Survey to estimate magnitudes for all modern large earthquakes.[3]

Contents

Development

In 1935, seismologists Charles Francis Richter and Beno Gutenberg of the California Institute of Technology developed a scale, later dubbed the Richter magnitude scale, for computing the magnitude of earthquakes, specifically those recorded and measured with the Wood-Anderson torsion seismograph in a particular area of California. Originally, Richter reported mathematical values to the nearest quarter of a unit, but the values later were reported with one decimal place; the local magnitude scale compared the magnitudes of different earthquakes.[1] Richter derived his earthquake-magnitude scale from the apparent magnitude scale used to measure the brightness of stars.[4]

Charles Francis Richter, circa 1970

Richter established a magnitude 0 event to be an earthquake that would show a maximum, combined horizontal displacement of 1.0 µm (0.00004 in.) on a seismogram recorded with a Wood-Anderson torsion seismograph 100 km (62 mi.) from the earthquake epicenter. That fixed measure was chosen to avoid negative values for magnitude, given that the slightest earthquakes that could be recorded and located at the time were around magnitude 3.0. The Richter magnitude scale itself has no lower limit, and contemporary seismometers can register, record, and measure earthquakes with negative magnitudes.

M_L (local magnitude) was not designed to be applied to data with distances to the hypocenter of the earthquake that were greater than 600 km (373 mi.).[3] For national and local seismological observatories, the standard magnitude scale in the 21st century is still M_L. However, this scale cannot measure magnitudes above about $M_L = 7$,[5] because the high frequency waves recorded locally have wavelengths shorter than the rupture lengths of large earthquakes.

Later, to express the size of earthquakes around the planet, Gutenberg and Richter developed a surface wave magnitude scale (M_s) and a body wave magnitude scale (M_b).[6] These are types of waves that are recorded at teleseismic distances. The two scales were adjusted such that they were consistent with the M_L scale. That adjustment succeeded better with the M_s scale than with the M_b scale. Each scale saturates when the earthquake is greater than magnitude 8.0.

Because of this, researchers in the 1970s developed the moment magnitude scale (M_w). The older magnitude-scales were superseded by methods for calculating the seismic moment, from which was derived the moment magnitude scale.

About the origins of the Richter magnitude scale, C.F. Richter said:

> I found a [1928] paper by Professor K. Wadati of Japan in which he compared large earthquakes by plotting the maximum ground motion against [the] distance to the epicenter. I tried a similar procedure for our stations, but the range between the largest and smallest magnitudes seemed unmanageably large. Dr. Beno Gutenberg then made the natural suggestion to plot the amplitudes logarithmically. I was lucky, because logarithmic plots are a device of the devil.

— Charles Richter Interview, abridged from the *Earthquake Information Bulletin*, Vol. 12, No. 1, January-February, 1980.

Details

The Richter scale was defined in 1935 for particular circumstances and instruments; the particular circumstances refer to it being defined for Southern California and "implicitly incorporates the attenuative properties of Southern California crust and mantle."[7] The particular instrument used would become saturated by strong earthquakes and unable to record high values. The scale was replaced in the 1970s by the moment magnitude scale (MMS); for earthquakes adequately measured by the Richter scale, numerical values are approximately the same. Although values measured for earthquakes now are M_w (MMS), they are frequently reported by the press as Richter values, even for earthquakes of magnitude over 8, when the Richter scale becomes meaningless. Anything above 5 is classified as a risk by the USGS.

The Richter and MMS scales measure the energy released by an earthquake; another scale, the Mercalli intensity scale, classifies earthquakes by their *effects*, from detectable by instruments but not noticeable, to catastrophic. The energy and effects are not necessarily strongly correlated; a shallow earthquake in a populated area with soil of certain types can be far more intense in effects than a much more energetic deep earthquake in an isolated area.

Several scales have historically been described as the "Richter scale", especially the *local magnitude* M_L and the surface wave M_s scale. In addition, the *body wave magnitude*, m_b, and the *moment magnitude*, M_w, abbreviated MMS, have been widely used for decades. A couple of new techniques to measure magnitude are in the development stage by seismologists.

All magnitude scales have been designed to give numerically similar results. This goal has been achieved well for M_L, M_s, and M_w.[2][8] The m_b scale gives somewhat different values than the other scales. The reason for so many different ways to measure the same thing is that at different distances, for different hypocentral depths, and for different earthquake sizes, the amplitudes of different types of elastic waves must be measured.

M_L is the scale used for the majority of earthquakes reported (tens of thousands) by local and regional seismological observatories. For large earthquakes worldwide, the moment magnitude scale (MMS) is most common, although M_s is also reported frequently.

The seismic moment, M_o, is proportional to the area of the rupture times the average slip that took place in the earthquake, thus it measures the physical size of the event. M_w is derived from it empirically as a quantity without units, just a number designed to conform to the M_s scale.[9] A spectral analysis is required to obtain M_o, whereas the other magnitudes are derived from a simple measurement of the amplitude of a specifically defined wave.

All scales, except M_w, saturate for large earthquakes, meaning they are based on the amplitudes of waves which have a wavelength shorter than the rupture length of the earthquakes. These short waves (high frequency waves) are too short a yardstick to measure the extent of the event. The resulting effective upper limit of measurement for M_L is about 7[5] and about 8.5[5] for M_s.[10]

New techniques to avoid the saturation problem and to measure magnitudes rapidly for very large earthquakes are being developed. One of these is based on the long period P-wave;[11] the other is based on a recently discovered channel wave.[12]

The energy release of an earthquake,[13] which closely correlates to its destructive power, scales with the $^{3}\!/_{2}$ power of the shaking amplitude. Thus, a difference in magnitude of 1.0 is equivalent to a factor of 31.6 $(= (10^{1.0})^{(3/2)})$ in the energy released; a difference in magnitude of 2.0 is equivalent to a factor of 1000 $(= (10^{2.0})^{(3/2)})$ in the energy released.[14] The elastic energy radiated is best derived from an integration of the radiated spectrum, but an estimate can be based on m_{b} because most energy is carried by the high frequency waves.

Richter magnitudes

The Richter magnitude of an earthquake is determined from the logarithm of the amplitude of waves recorded by seismographs (adjustments are included to compensate for the variation in the distance between the various seismographs and the epicenter of the earthquake). The original formula is:[15]

$$M_{\text{L}} = \log_{10} A - \log_{10} A_0(\delta) = \log_{10}[A/A_0(\delta)],$$

where A is the maximum excursion of the Wood-Anderson seismograph, the empirical function A_0 depends only on the epicentral distance of the station, δ. In practice, readings from all observing stations are averaged after adjustment with station-specific corrections to obtain the M_{L} value.

Because of the logarithmic basis of the scale, each whole number increase in magnitude represents a tenfold increase in measured amplitude; in terms of energy, each whole number increase corresponds to an increase of about 31.6 times the amount of energy released, and each increase of 0.2 corresponds to a doubling of the energy released.

Events with magnitudes greater than 4.5 are strong enough to be recorded by a seismograph anywhere in the world, so long as its sensors are not located in the earthquake's shadow.

The following describes the typical effects of earthquakes of various magnitudes near the epicenter. The values are typical only. They should be taken with extreme caution, since intensity and thus ground effects depend not only on the magnitude, but also on the distance to the epicenter, the depth of the earthquake's focus beneath the epicenter, the location of the epicenter and geological conditions (certain terrains can amplify seismic signals).

Magnitude	Description	Mercalli intensity	Average earthquake effects	Average frequency of occurrence (estimated)
1.0–1.9	Micro	I	Microearthquakes, not felt, or felt rarely. Recorded by seismographs.[16]	Continual/several million per year
2.0–2.9	Minor	I to II	Felt slightly by some people. No damage to buildings.	Over one million per year
3.0–3.9		III to IV	Often felt by people, but very rarely causes damage. Shaking of indoor objects can be noticeable.	Over 100,000 per year
4.0–4.9	Light	IV to VI	Noticeable shaking of indoor objects and rattling noises. Felt by most people in the affected area. Slightly felt outside. Generally causes none to minimal damage. Moderate to significant damage very unlikely. Some objects may fall off shelves or be knocked over.	10,000 to 15,000 per year
5.0–5.9	Moderate	VI to VIII	Can cause damage of varying severity to poorly constructed buildings. At most, none to slight damage to all other buildings. Felt by everyone.	1,000 to 1,500 per year
6.0–6.9	Strong	VII to X	Damage to a moderate number of well-built structures in populated areas. Earthquake-resistant structures survive with slight to moderate damage. Poorly designed structures receive moderate to severe damage. Felt in wider areas; up to hundreds of miles/kilometers from the epicenter. Strong to violent shaking in epicentral area.	100 to 150 per year
7.0–7.9	Major	VIII or greater[17]	Causes damage to most buildings, some to partially or completely collapse or receive severe damage. Well-designed structures are likely to receive damage. Felt across great distances with major damage mostly limited to 250 km from epicenter.	10 to 20 per year
8.0–8.9	Great		Major damage to buildings, structures likely to be destroyed. Will cause moderate to heavy damage to sturdy or earthquake-resistant buildings. Damaging in large areas. Felt in extremely large regions.	One per year
9.0 and greater			At or near total destruction – severe damage or collapse to all buildings. Heavy damage and shaking extends to distant locations. Permanent changes in ground topography.	One per 10 to 50 years

(*Based on U.S. Geological Survey documents.*)[18]

The intensity and death toll depend on several factors (earthquake depth, epicenter location, population density, to name a few) and can vary widely.

Minor earthquakes occur every day and hour. On the other hand, great earthquakes occur once a year, on average. The largest recorded earthquake was the Great Chilean earthquake of May 22, 1960, which had a magnitude of 9.5 on the moment magnitude scale.[19] The larger the magnitude, the less frequent the earthquake happens.

Beyond 9.5, while extremely strong earthquakes are theoretically possible, the energies involved rapidly make such earthquakes on Earth effectively impossible without an extremely destructive source of external energy. For example, the asteroid impact that created the Chicxulub crater and caused the mass extinction that may have killed the dinosaurs has been estimated as causing a magnitude 13 earthquake (see below), while a magnitude 15 earthquake could destroy the Earth completely. Seismologist Susan Hough has suggested that 10 may represent a very approximate upper limit, as the effect if the largest known continuous belt of faults ruptured together (along the Pacific coast of the Americas).[20]

Energy release equivalents

The following table lists the approximate energy equivalents in terms of TNT explosive force – though note that the earthquake energy is released *underground* rather than overground.[21] Most energy from an earthquake is not transmitted to and through the surface; instead, it dissipates into the crust and other subsurface structures. In contrast, a small atomic bomb blast (see nuclear weapon yield) will not, it will simply cause light shaking of indoor items, since its energy is released above ground.

Approximate magnitude	Approximate TNT equivalent for seismic energy yield	Joule equivalent	Example
0.0	15 g	63 kJ	
0.2	30 g	130 kJ	Large hand grenade
1.5	2.7 kg	11 MJ	Seismic impact of typical small construction blast
2.1	21 kg	89 MJ	West fertilizer plant explosion[22]
3.0	480 kg	2.0 GJ	Oklahoma City bombing, 1995
3.5	2.7 metric tons	11 GJ	PEPCON fuel plant explosion, Henderson, Nevada, 1988
3.87	9.5 metric tons	40 GJ	Explosion at Chernobyl nuclear power plant, 1986
3.91	11 metric tons	46 GJ	Massive Ordnance Air Blast bomb
6.0	15 kilotons	63 TJ	Approximate yield of the Little Boy atomic bomb dropped on Hiroshima (~16 kt)
7.9	10.7 megatons	45 PJ	Tunguska event
8.35	50 megatons	210 PJ	Tsar Bomba—Largest thermonuclear weapon ever tested. Most of the energy was dissipated in the atmosphere. The seismic shock was estimated at 5.0–5.2[23]
9.15	800 megatons	3.3 EJ	Toba eruption 75,000 years ago; among the largest known volcanic events.[24]
13.0	100 teratons	420 ZJ	Yucatán Peninsula impact (creating Chicxulub crater) 65 Ma ago (10^8 megatons; over 4×10^{29} ergs = 400 ZJ).[25][26][27][28][29]

Magnitude empirical formulae

These formulae for Richter magnitude M_L are alternatives to using Richter correlation tables based on Richter standard seismic event (M_L=0, A=0.001mm, D=100 km). Below, Δ is the epicentral distance (in kilometers unless otherwise specified).

The Lillie empirical formula:

$$M_L = \log_{10} A - 2.48 + 2.76 \log_{10} \Delta,$$

Where A is the amplitude (maximum ground displacement) of the P-wave, in micrometers, measured at 0.8 Hz.

For distances D less than 200 km,

$$M_\mathrm{L} = \log_{10} A + 1.6 \log_{10} D - 0.15,$$

and for distances between 200 km and 600 km,

$$M_\mathrm{L} = \log_{10} A + 3.0 \log_{10} D - 3.38,$$

where A is seismograph signal amplitude in mm and D is in km.

The Bisztricsany (1958) empirical formula for epicentral distances between 4° to 160°:[30]

$$M_\mathrm{L} = 2.92 + 2.25 \log_{10}(\tau) - 0.001\Delta^\circ,$$

Where τ is the duration of the surface wave in seconds, and Δ is in degrees. M_L is mainly between 5 and 8.

The Tsumura empirical formula:[30]

$$M_\mathrm{L} = -2.53 + 2.85 \log_{10}(F - P) + 0.0014\Delta^\circ$$

Where $F - P$ is the total duration of oscillation in seconds. M_L is mainly between 3 and 5.

The Tsuboi, University of Tokyo, empirical formula:

$$M_\mathrm{L} = \log_{10} A + 1.73 \log_{10} \Delta - 0.83$$

Where A is the amplitude in micrometers.

See also

- 1935 in science
- Japan Meteorological Agency seismic intensity scale – does the same thing as the Mercalli Scale, but in different numbers
- Largest earthquakes by magnitude
- Mercalli intensity scale - Measures the intensity of an earthquake
- Moment magnitude scale
- Order of magnitude
- Rohn Emergency Scale for measuring the magnitude (intensity) of any emergency
- Seismic scale
- Seismite
- Timeline of United States inventions (1890–1945)#Great Depression and World War II (1929 –1945)

References

1. The Richter Magnitude Scale (http://earthquake.usgs.gov/learn/topics/measure.php)

2. Richter, C.F. (1935). "An instrumental earthquake magnitude scale" (PDF). *Bulletin of the Seismological Society of America*. Seismological Society of America. **25** (1-2): 1–32.
3. "USGS Earthquake Magnitude Policy (implemented on January 18, 2002)". United States Geological Survey. January 30, 2014.
4. Reitherman, Robert (2012). *Earthquakes and Engineers: An International History*. Reston, VA: ASCE Press. pp. 208–209. ISBN 9780784410714.
5. Woo, Wang-chun (September 2012). "On Earthquake Magnitudes". Hong Kong Observatory. Retrieved 18 December 2013.
6. William L. Ellsworth (1991). "SURFACE-WAVE MAGNITUDE (M_s) AND BODY-WAVE MAGNITUDE (mb)". USGS. Retrieved 2008-09-14.
7. "Explanation of Bulletin Listings, USGS".
8. Richter, C.F., "Elementary Seismology", ed, Vol., W. H. Freeman and Co., San Francisco, 1956.
9. Hanks, T. C. and H. Kanamori, 1979, "Moment magnitude scale", *Journal of Geophysical Research,* 84, B5, 2348.
10. "Richter scale". *Glossary*. USGS. March 31, 2010.
11. Di Giacomo, D., Parolai, S., Saul, J., Grosser, H., Bormann, P., Wang, R. & Zschau, J., 2008. "Rapid determination of the energy magnitude Me," in *European Seismological Commission 31st General Assembly,* Hersonissos.
12. Rivera, L. & Kanamori, H., 2008. "Rapid source inversion of W phase for tsunami warning," in *European Geophysical Union General Assembly,* pp. A-06228, Vienna.
13. Marius Vassiliou and Hiroo Kanamori (1982): "The Energy Release in Earthquakes," *Bull. Seismol. Soc. Am.* 72, 371-387.
14. William Spence, Stuart A. Sipkin, and George L. Choy (1989). "Measuring the Size of an Earthquake". *Earthquakes and Volcanoes*. **21** (1).
15. Ellsworth, William L. (1991). "The Richter Scale M_L, from *The San Andreas Fault System,* California (Professional Paper 1515)". USGS: c6, p177. Retrieved 2008-09-14.
16. This is what Richter wrote in his *Elementary Seismology* (1958), an opinion copiously reproduced afterwards in Earth's science primers. Recent evidence shows that earthquakes with negative magnitudes (down to −0.7) can also be felt in exceptional cases, especially when the focus is very shallow (a few hundred metres). See: Thouvenot, F.; Bouchon, M. (2008). "What is the lowest magnitude threshold at which an earthquake can be felt or heard, or objects thrown into the air?," in Fréchet, J., Meghraoui, M. & Stucchi, M. (eds), *Modern Approaches in Solid Earth Sciences* (vol. 2), *Historical Seismology: Interdisciplinary Studies of Past and Recent Earthquakes,* Springer, Dordrecht, 313–326.
17. "Anchorage, Alaska (AK) profile: population, maps, real estate, averages, homes, statistics, relocation, travel, jobs, hospitals, schools, crime, moving, houses, news". City-Data.com. Retrieved 2012-10-12.
18. "Earthquake Facts and Statistics". United States Geological Survey. 29 November 2012. Retrieved 18 December 2013.
19. "Largest Earthquakes in the World Since 1900". 30 November 2012. Retrieved 18 December 2013.
20. Silver, Nate (2013). *The signal and the noise : the art and science of prediction*. London: Penguin. ISBN 9780141975658.
21. Usgs Faqs (2014-01-15). "FAQs – Measuring Earthquakes". Earthquake.usgs.gov. Retrieved 2014-02-16.
22. "2.1 Explosion - 1km NNE of West, Texas (BETA)". United States Geological Survey. 19 June 2013. Retrieved 18 December 2013.
23. "The Tsar Bomba ("King of Bombs")". Retrieved 2014-07-06.
24. Petraglia, M.; R. Korisettar, N. Boivin, C. Clarkson,4 P. Ditchfield,5 S. Jones,6 J. Koshy,7 M.M. Lahr,8 C. Oppenheimer,9 D. Pyle,10 R. Roberts,11 J.-C. Schwenninger,12 L. Arnold,13 K. White. (6 July 2007). "Middle Paleolithic Assemblages from the Indian Subcontinent Before and After the Toba Super-eruption" (http://toba.arch.ox.ac.uk/pub_files/Petraglia2007Science.pdf). *Science* 317 (5834): 114–116. doi:10.1126/science.1141564 (https://dx.doi.org/10.1126%2Fscience.1141564). PMID 17615356.
25. Bralower, Timothy J.; Charles K. Paull; R. Mark Leckie (1998). "The Cretaceous-Tertiary boundary cocktail: Chicxulub impact triggers margin collapse and extensive sediment gravity flows" (PDF). *Geology*. **26**: 331–334. Bibcode:1998Geo....26..331B. doi:10.1130/0091-7613(1998)026<0331:TCTBCC>2.3.CO;2. ISSN 0091-7613. Retrieved 2009-09-03.

26. Klaus, Adam; Norris, Richard D.; Kroon, Dick; Smit, Jan (2000). "Impact-induced mass wasting at the K-T boundary: Blake Nose, western North Atlantic". *Geology*. **28**: 319–322. Bibcode:2000Geo....28..319K. doi:10.1130/0091-7613(2000)28<319:IMWATK>2.0.CO;2. ISSN 0091-7613.
27. Busby, Cathy J.; Grant Yip; Lars Blikra; Paul Renne (2002). "Coastal landsliding and catastrophic sedimentation triggered by Cretaceous-Tertiary bolide impact: A Pacific margin example?". *Geology*. **30**: 687–690. Bibcode:2002Geo....30..687B. doi:10.1130/0091-7613(2002)030<0687:CLACST>2.0.CO;2. ISSN 0091-7613.
28. Simms, Michael J. (2003). "Uniquely extensive seismite from the latest Triassic of the United Kingdom: Evidence for bolide impact?". *Geology*. **31**: 557–560. Bibcode:2003Geo....31..557S. doi:10.1130/0091-7613(2003)031<0557:UESFTL>2.0.CO;2. ISSN 0091-7613.
29. Simkin, Tom; Robert I. Tilling; Peter R. Vogt; Stephen H. Kirby; Paul Kimberly; David B. Stewart (2006). "This dynamic planet. World map of volcanoes, earthquakes, impact craters, and plate tectonics. Inset VI. Impacting extraterrestrials scar planetary surfaces" (PDF). U.S. Geological Survey. Retrieved 2009-09-03.
30. Al-Arifi, Nassir S.; Al-Humidan, Saad (July 2012). "Local and regional earthquake magnitude calibration of Tabuk analog sub-network, Northwest of Saudi Arabia". *Journal of King Saud University - Science*. **24** (3): 257–263. doi:10.1016/j.jksus.2011.04.001.

External links

- Seismic Monitor (http://www.iris.edu/seismon/) – IRIS Consortium
- USGS Earthquake Magnitude Policy (implemented on January 18, 2002) (http://earthquake.usgs.gov/aboutus/docs/020204mag_policy.php) – USGS
- Earthquake Energy Calculator (http://www.alabamaquake.com/energy.html)
- Perspective: a graphical comparison of earthquake energy release (https://www.youtube.com/watch?v=YXMKSOsv3QA) – Pacific Tsunami Warning Center

Categories: 1935 in science | 1935 introductions | California Institute of Technology | Seismic scales | Logarithmic scales of measurement

---