

# PHYSICS TODAY

## Italy's chain of earthquakes poses a forecasting challenge

To develop better hazard maps that will help protect buildings and save lives, scientists are poring over data on the string of Italian quakes that have occurred this year.

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Over the past several months, Italy has experienced a series of destructive earthquakes, which illustrate how the country is splitting geologically along the Apennines, a mountain range that forms the north–south spine of the Italian peninsula.

The first quake, of magnitude 6.2, occurred on 24 August near the mountain town of Amatrice, about 120 km northeast of Rome. Almost 300 people were killed, and thousands were left homeless. Amatrice's historic center, with buildings dating from the Middle Ages, was destroyed. Aftershocks continued for months. On 26 October, magnitude 5.5 and 6.1 earthquakes occurred about 30 km to the north. The temblors knocked down electrical and telephone lines, damaged buildings, and frightened local residents already unnerved by continuing earthquakes.

Four days later, on 30 October, the strongest earthquake to date, magnitude 6.6, struck close to the historic walled town of Norcia, 20 km north of Amatrice. The town's 14th-century basilica of San Benedetto collapsed, leaving just the façade standing. Fortunately, because many residents of the area had been evacuated due to the recent earthquakes, no lives were lost. However, damage was widespread. "Everything has been destroyed," one local mayor said. "The towns no longer exist."



A magnitude 6.2 earthquake on 24 August caused buildings to collapse in Pescara del Tronto, located about 15 km from the epicenter. Credit: Marco Garbin, CRS–OGS, Trieste, Italy

The earthquakes came as no surprise. Similar sequences have been relatively common in the region, which was also shattered by a series of three large quakes in 1703. But unlike three centuries ago, scientists now have the tools to analyze the ground shaking and assess the possibility of further damage. The work is vitally important for helping Italy's national and local governments rebuild damaged areas and prepare for future earthquakes.

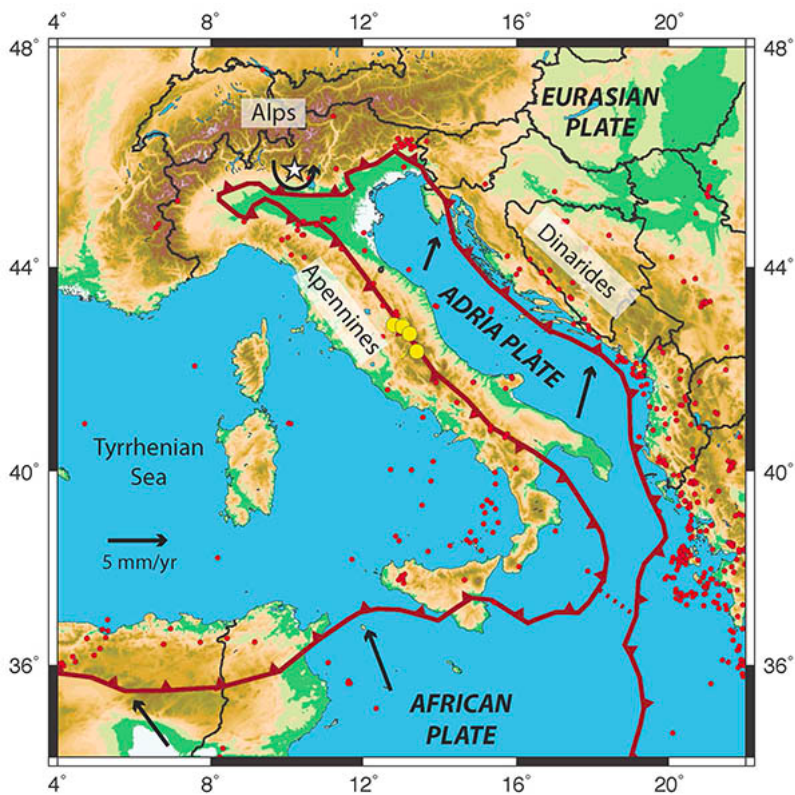
### Battle of the microplates

Italy's complicated geological setting underlies the region's seismic activity. For the past 100

million years, the African plate has been moving northward relative to the Eurasian plate (see diagram below). The collision between the two plates built the Alps and gave rise to a number of distinct crustal blocks, or microplates, which jostle between the two major plates. The Adria microplate, which contains the Adriatic Sea, looks like a finger driven into the Eurasian plate. It is bordered on the west by the Apennines and on the east by the Dinarides, a mountain chain that runs along the east shore of the Adriatic.

Adria and Eurasia have had a complex history of interactions. Starting about 15 million years ago, the Tyrrhenian Sea, west of Italy, opened by seafloor spreading. Italy rotated counterclockwise relative to Eurasia, and Adria subducted southwestward under Italy, all of which combined to raise the Apennines. About 2 million years ago, spreading ceased in the Tyrrhenian Sea, and the subduction stopped. As a result, Italy west of the Apennines became part of Eurasia, and Adria began moving northwestward with respect to Eurasia.

All that jostling explains a lot about earthquakes in Italy. Positions measured with high-precision GPS data show Adria rotating counterclockwise about a rotation pole in the southwestern Alps. That motion causes extensional earthquakes in the Apennines, where Adria is diverging from Eurasia, and compressional earthquakes along the southeastern Alps and Dinarides, where Adria is colliding with Eurasia.



Italy lies in an active geological zone. Red lines are plate boundaries, red dots are earthquakes with magnitude greater than 5 that have occurred since 1966, and yellow dots are epicenters of the 2016 earthquake series and the 2009 L'Aquila earthquake. The arrows show plate motions with respect to Eurasia. The Adria plate rotates with respect to Eurasia along the pole indicated by the star.

The Apennine earthquakes occur on a network of short (30–40 km in length) faults that formed about a million years ago, relatively recently by geological standards. Over time, fault systems become smoother as short faults merge into longer ones. Because earthquake magnitudes are controlled by fault length, the strongest earthquakes on the Apennine faults have magnitudes between 6 and 7. Instead of growing stronger, the earthquakes on one fault segment often trigger earthquakes or a nearby fault, because the change in the stress field after an earthquake makes a nearby fault more prone to slip.

The process of fault interactions by stress transfer is thought to be why Apennine earthquakes occur in progressive sequences, much like a series of falling dominoes. The recent activity can be viewed as a northward-propagating sequence that started with the 2009 magnitude 6.3 earthquake that destroyed the city of L'Aquila, about 50 km south of Amatrice. Italian seismologists were charged with manslaughter for allegedly providing inaccurate information about the earthquake danger, though they were ultimately acquitted.

### Playing the game of chance

The burst of activity over the last seven years illustrates the challenge Italy faces in dealing with earthquakes. Defending society against earthquakes is a high-stakes game of chance against nature in an uncertain world. It involves the scientific challenge of assessing the hazard—estimating what levels of shaking should be expected and how often—and the societal challenge of mitigating or reducing the resulting losses.

Both challenges are complex. Italy's current seismic hazard maps were developed using a probabilistic approach, which predicts the level of shaking that should be exceeded either 2% or 10% of the time over a 50-year period. The maps show the Apennines as an area of high seismic hazard. However, ground shaking for the 30 October event was significantly more severe at several sites than the maps predicted. A deterministic approach to hazard mapping, which specifies the largest potential shaking to expect, better matched the observations of most severe shaking.

Because earthquake hazard mapping has only been developed in the past 40 years, and large earthquakes are relatively rare, seismologists do not yet understand the accuracies and uncertainties of the maps. Programs are under way in Italy and other countries to assess and improve hazard mapping, since governments use the maps to develop building codes for earthquake-resistant construction. That's especially important in Italy, which is full of historic buildings that are not particularly structurally sound and very expensive to retrofit.

Although major earthquakes rarely occur at any given place, Italy as a whole has had more than its fair share. In addition to the 2009 and 2016 events, the country has experienced at least three other destructive quakes in the last two decades. All that seismic activity demonstrates the need for seismologists, earthquake engineers, social scientists, and public officials to work together to assess and mitigate earthquake hazards. As those experts raise and debate the hard questions, they will work toward better protection against quakes.

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