Lite Geology

Ancient Tsunamis

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An artist's interpretation of a giant meteorite entering the ocean. *Don Davis, NASA*.
http://solarsystem.nasa.gov/multimedia/display.cfm?IM-ID=2306

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Ancient Tsunamis from Meteorite Impacts: Evidence, Interpretation, Modeling, and Controversy

Nelia Dunbar

Large tsunamis are devastating events and have been in the public eye in the past 10 years because of the terrible tsunami-related devastation caused by the Great Sumatra earthquake in 2004 and the Great East Japan earthquake in 2011. Because of these recent events, the association between tsunamis and extremely powerful earthquakes is strong in peoples' minds. Tsunamis, which are trains of waves produced by displacement of large bodies of water, can be produced by seismic disturbance of the sea floor. However, lots of other natural events can cause water displacements to take place both in the ocean or in large lakes. Some of these include underwater volcanic eruptions, glaciers calving, underwater landslides, and landslides that enter a body of water. Some of the most enormous tsunamis that Earth has ever experienced may be related to large meteorites, or bolides, that fall into the ocean. The relationship of bolide impacts to tsunamis, particularly the impact at the Cretaceous–Tertiary (K–T) boundary (~65 million years ago) that caused the mass extinction of dinosaurs, has been suggested by a number of geologists, but is not without controversy.

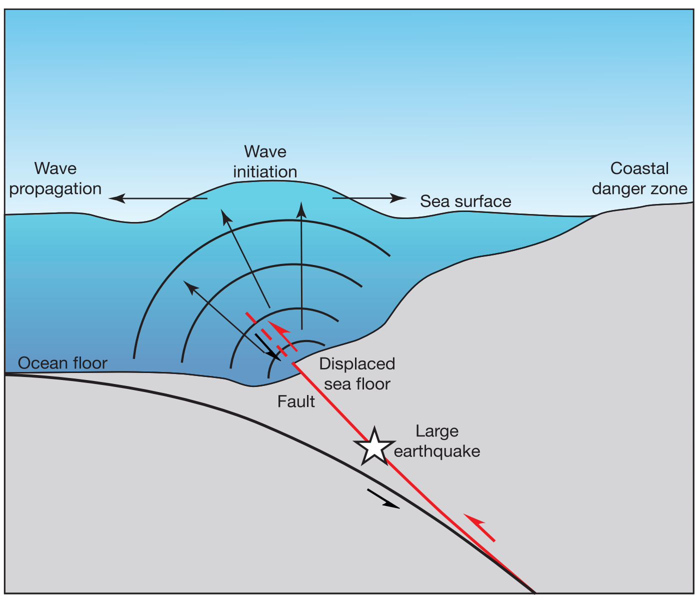
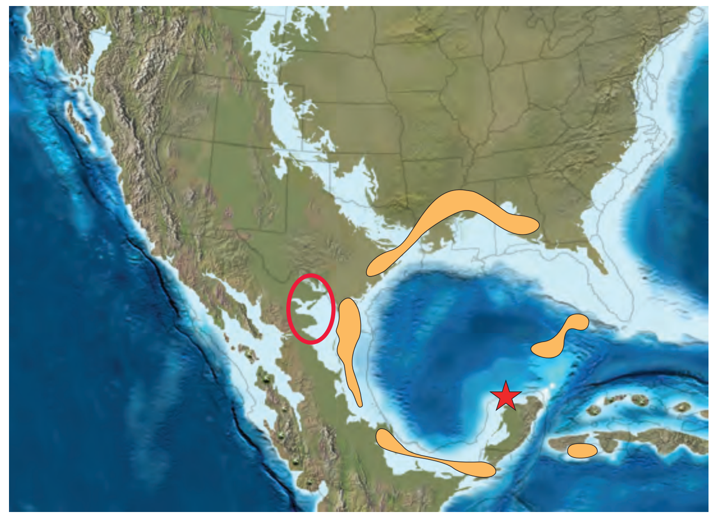


Diagram of a large thrust earthquake and resultant water displacement, similar to the Japan and Sumatra earthquakes. *Source: the Geological Survey of Canada.*

A major mass extinction of life on Earth occurred around 65 million years ago, at the boundary between the Cretaceous and Tertiary geological periods. At that time, about half of the genera existing on Earth became extinct, marine reptiles, flying reptiles, and dinosaurs, among others. Evidence for a bolide impact causing this event was first discovered in the 1980s, based on the presence of anomalous abundances of platinum group elements, particularly iridium, in rocks at the K–T boundary. These elements are enriched in meteorites, and the "iridium anomaly" was attributed to a 10-kilometer-wide (6-mile-wide) body impacting Earth. This theory is supported by the presence of shocked minerals and spherules in rocks of K–T boundary age, which can be related to a major impact. The idea of a major bolide impact

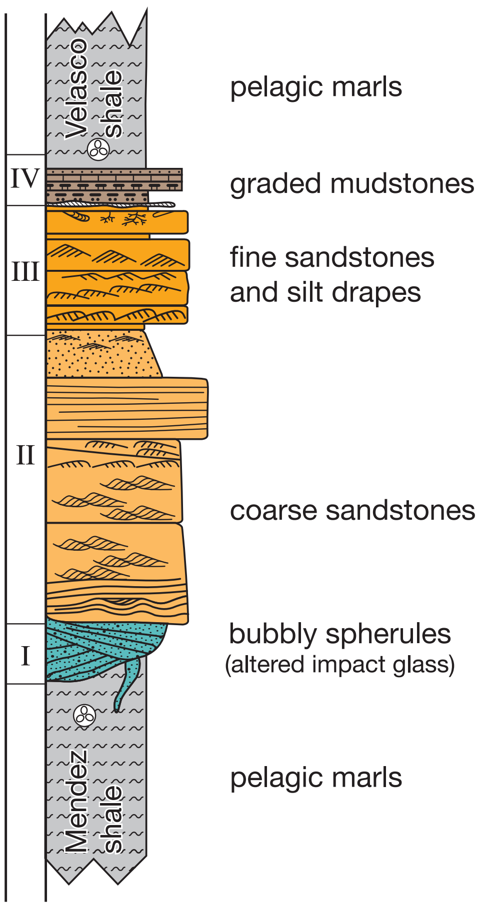


Map of the Gulf of Mexico showing land/ocean areas at the K–T boundary, the location of bolide impact (red star), outcrop area for the sandstone complex (orange areas). Dark-blue areas represent deep ocean, light blue or white represent shallow seas, and brown/green represent continent. The outline of the present-day continental landmass, and state boundaries in the United States and Mexico are also visible as gray lines. The approximate location of the La Popa Basin is shown as the red outline. *Base figure from Ron Blakey, Colorado Plateau Geosystems, Inc., with bolide impact, sandstone outcrops and La Popa Basin outline from Smit et al. 1996, Lawton et al. 2005, and personnel communication from T. Lawton (2011).*

was further strengthened in the early 1990s by the discovery of a 180–300 kilometer (112–186 mile) diameter crater in the Yucatan region of Mexico, which, based on size and age, is a strong candidate for the site of the impact. This impact structure, dubbed "Chicxulub" (pronounced CHEEK-shoo-loob) is now widely, although not universally, accepted as the site of an extinction-causing bolide impact.

The idea of an enormous tsunami at the K–T boundary came about because of the presence of an unusual sandstone unit found at a number of localities around the margins of the present-day Gulf of Mexico, at more or less concentrically arranged distances of between 700 and 1,000 kilometers (435 and 622 miles) from the proposed impact site. Many scientists noticed the complicated, multi-layered sandstone deposit, ranging between 5 centimeters and 9 meters (2 inches and 29 feet) thick, interbedded with shallow-water sediments such as clay, chalk, or marl. Although on land today, the sandstone is interpreted to have been deposited in a marine environment, probably in around 200 meters (656 feet) of water. Sea level was higher at the time of the K–T impact, creating a much larger Gulf of Mexico than exists today. The location and approximate age of the sandstone, as well as the presence of impact-related debris in some beds, suggested a possible link between the deposit and the bolide impact. However, the details of the possible depositional mechanism of the sandstone were not apparent until the sandstone had been studied by several groups of scientists.

This complicated sandstone, known as the "K–T sandstone complex," was first recognized in the 1930s and described as being a sequence of bedded shallow-water or nonmarine deposits in the midst of a sequence of marine shelf clay, marl, or chalk. Further study of the sandstones by a number of workers showed that in many localities, the sandstone has a consistent set of layers that are interpreted to represent separate geological events. The lowest unit of the sandstone, called



Representative section of the four depositional units in a typical K–T sandstone complex. From Smit et al. 1996.

"Unit I," is made of material ripped up from underlying formations, some foraminifera (tiny marine organisms with carbonate shells), small clasts of angular limestone, glauconite pellets that probably formed on the continental shelf, fish and gastropod fossils, and spherules interpreted to be related to the impact. Little layering is observed, apart from some channel-fill crossbedding, and no burrowing is seen, suggesting no biological activity within the bed. Unit II is composed of a stack of sandstone lenses, made up of foraminifera (some shallow-water varieties), terrestrial lithic grains, macrofossils, plant debris, and wood. This unit also contains some mudballs made of spherulites and limestone fragments. Water current directions as indicated from the sandstone lenses are widely variable, with a range of as much as 180°. Unit III is composed mostly of fine-grained sandstone with some silt/mud layers, and contains elevated iridium, as well as impact-related spherules. Unit IV is typically composed of thinly bedded calcareous siltstone and mudstone.

The composition and structure of these deposits are consistent with formation from a bolide impact and subsequent tsunami. Unit I is interpreted to be material thrown into the air by the impact (limestone clasts, material from underlying formations, foraminifera, and glauconite), as well as some material melted by the force of the impact and turned into tiny glass droplets (spherules). This debris was deposited onto the sea floor, and then reworked into existing channels or scours. Unit II contains a wide variety of sedimentary structures associated with high energy currents that were traveling in a range of directions. The composition of the material in this sandstone implies derivation from onshore areas (plant debris, terrigenous sediment, shallow-water foraminifera), but some was also of local origin. The structures in the sedimentary package, as well as the derivation of the material, suggest that this unit was deposited by up-surge and back-surge of several very large tsunami waves. Unit III is also interpreted to be tsunami-related but deposited when the waves were diminishing in strength. The iridium-rich composition of this horizon indicates that impact-related fallout was settling in the ocean at this time. Researchers have noted that the coarse-grained impact-related ejecta found in Unit I is decoupled from the iridium fallout, suggesting that the iridium was carried as finer-grained particles, and therefore settled more slowly. Unit IV, the finest-grained material, is thought to have settled out when the tsunami-related currents had subsided to the point that fine-grained material could no longer remain suspended in the water. The sediments deposited just above the K–T sandstone complex are depleted in foraminifera, suggesting that the timing of mass extinction closely coincided with deposition of these sediments.

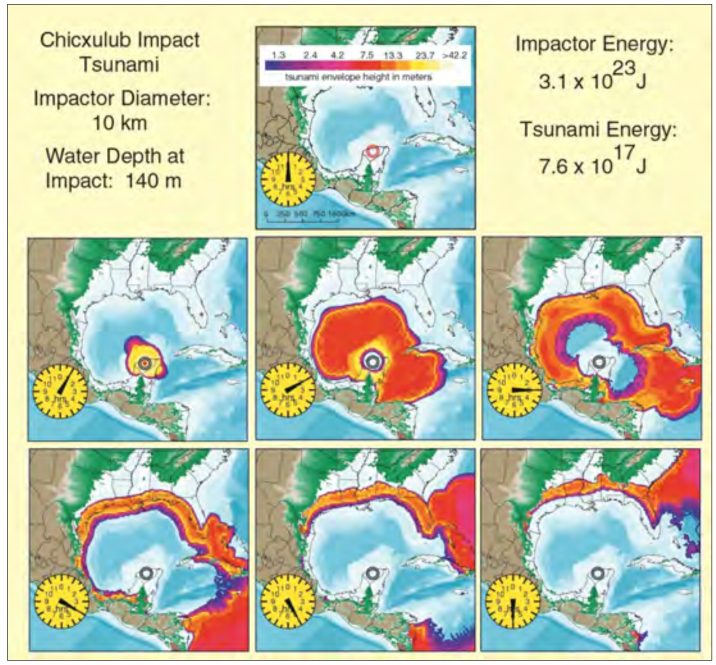
One criticism of this model is the presence of Cretaceous fossils in strata that are speculated to have been deposited at the K–T boundary. However, research on deposits in northeastern Mexico provide additional insight into the tsunami process, and have helped to address this problem. These deposits come from areas that would have been in shallower water at the time of the Chicxulub impact and provide additional information about how the tsunami process mobilized and re-deposited sediment. The rocks in the La Popa

Basin of northeastern Mexico contain a wide variety of marine fossils from shallow nearshore and deeper-water environments, as well as recently discovered dinosaur bones and teeth. The rocks also contain features that indicate they were deposited by turbulent, high-energy flow moving in a southerly to southeasterly direction. Some of these deposits are interpreted to be related to tsunami-induced backflow, which mobilized large amounts of nearshore and terrestrial sediment, transporting it to a deeper-water setting, where it was deposited as the sandstones described above. This sedimentary process, which is comparable to the backflow formed by hurricanes along the Texas Coast, may also be analogous to the process that transported houses, boats, and people from onshore to offshore environments during the 2004 and 2011 Sumatra and Japan tsunamis. The presence of dinosaur remains adds a piece of information to the tsunami process. In addition to eroding deltaic and coastal estuary environments, these remains imply that the above-water coastal plain was also swept by water, and debris from this area was included in the backflow.

In order to better understand the behavior and size of an impact-related tsunami, researchers have produced numerical models that predict the size and distance traveled of waves related to the K–T bolide impact. These models break the tsunami down into four parts. First, when the meteorite

The gastropod (snail) in the mudstone clast is in sediments from the La Poppa Basin. An example of a nearshore shallow-water (probably estuarine) fossil dragged offshore, with a lot of bivalve shells and the odd black spherule. The 5 peso coin is 2.5 cm (1 inch) across. *Image and caption courtesy of Tim Lawton.*

entered the atmosphere it would have produced a shock wave that impacted the ocean. This shock wave could have caused a tsunami. Second, when the meteorite hit the ocean and ocean floor, it would have created a mass of debris, called ejecta, which moved away from the impact point. The outward motion of this wave of ejecta could have generated a tsunami, called a "rim wave." Finally, and as it turns out, most importantly, water rushing into the crater formed by the impact and then rushing back out, can form tsunamis. These waves are called, respectively, the "receding" and "rushing"



Visualization of a tsunami associated with the Chicxulub impact.
From: **http://www.es.ucsc.edu/~ward/chix.jpg**

waves. Models show that a very important factor in the size of the tsunami is the water depth into which the meteorite fell. For an estimated water depth of 200 meters (656 feet), the "receding" wave, which they suggest occurred first, would have had a height of roughly 50 meters (164 feet), and taken 10 hours to propagate to its farthest point. The next wave, the "rushing wave" may have had a height of as much as 200 meters (656 feet). Models suggest that this, the largest wave, penetrated inland as far as 300 kilometers (186 miles), reaching the Rio Grande and Mississippi embayments. The wave may have reached as much as 300 meters (984 feet) above sea level in some places, although the average was around 150 meters (492 feet). This modeling, both of the pattern of wave behavior (a receding wave followed by a rushing wave) and the magnitude of the wave, is consistent with observations in the geological record discussed above.

As is the case with many geological ideas, not all scientists are in agreement about the idea of a giant tsunami associated with a bolide impact at the K–T boundary. The arguments against this interpretation mainly hinge on the origin and chronology of the unusual sandstone deposits in Mexico. Some researchers suggest that the deposits were formed by debris flows triggered by the Chicxulub impact, rather than being tsunami-related. Others suggest that the sandstones were formed by normal geological depositional processes at a time when sea level was briefly lowered, generating coarser-grained sediments with more terrestrial debris. The interpreted presence of biologically reworked zones within the sediment package plays into these arguments. Others argue that the sandstone deposits predate the meteorite impact, based on the presence of Cretaceous fossil assemblages.

However, detailed and compelling counter-arguments have been presented to many of these points by the pro-tsunami scientists, and as research continues, new information and interpretations will provide further input to this discussion.

Additional Reading

Alvarez, L. W., Alvarez, W., Asaro, F., and Michel, H. V., 1980, *Extraterrestrial cause for the Cretaceous-Tertiary extinction—experimental results and theoretical interpretation*: Science, v. 208, pp. 1095–1108.

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Lawton, T. F., Shipley, K. W., Aschoff, J. L., Giles, K. A., and Vega, F. J., 2005, *Basinward transport of Chicxulub ejecta by tsunami-induced backflow, La Popa basin, northeastern Mexico, and its implications for distribution of impact-related deposits flanking the Gulf of Mexico*: Geology, v. 33, pp. 81–84.

Smit, J., Ryder, G., Roep, T. B., Alvarez, W., Montanari, A., Claeys, P., Grajales-Nishimura, J. M., Bermudez, J., Fastovsky, D., and Gartner, S., 1996, *Coarse-grained, clastic sandstone complex at the K/T boundary around the Gulf of Mexico; deposition by tsunami waves induced by the Chicxulub impact?*: Geological Society of America, Special Paper 307, pp. 151–182.

Warning Systems Minimize Tsunami Casualties Douglas Bland

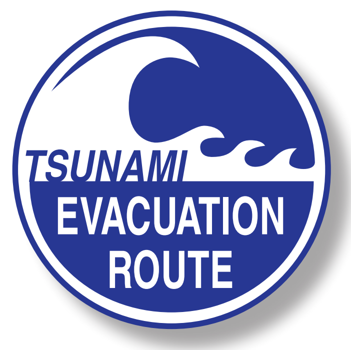
Tsunamis, especially large ones, frequently cause massive destruction and loss of life. Devastation from the March 2011 Japanese earthquake paled in comparison to that from the subsequent tsunami, although warnings saved many lives. Accurate warnings and effective preparedness are the best tools to minimize tsunami casualties. In the United States, the West Coast, Hawaii, and Alaska are the most vulnerable areas. Are we ready?

Rapid data analysis from seismometers around the globe can determine earthquake magnitude (size) and location. Large, shallow undersea quakes are the most likely to generate tsunamis. Once such an event is detected, tsunami warnings are immediately issued for nearby coastal areas. Tsunamis can propagate for thousands of miles across the open ocean, arriving hours after the earthquake. Therefore, distant locations are put on alert while further data analysis and modeling are performed. A network of more than 50 buoys operates across the planet, with most in the Pacific Ocean. These buoys measure actual wave heights, allowing greater accuracy in predicting the size and timing of tsunamis at landfall.

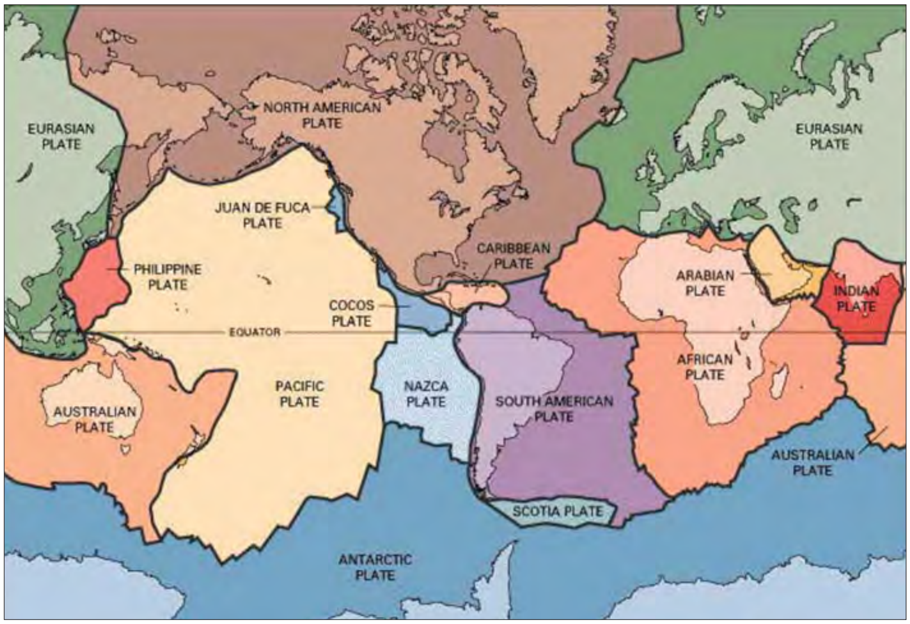
To avoid danger, be aware if you are in a potential tsunami-impact zone, and if so, what you can do to escape. If warned of impending danger, act quickly. Many vulnerable areas have sirens, notification procedures, and evacuation routes for times when a warning is issued. Very large quakes and tsunamis similar to those in Japan in 2011 and in Indonesia in 2004 have occurred on the Cascadia fault zone that extends from offshore to underneath the U.S. Pacific Northwest Coast, most recently in A.D. 1700. When (not if) such an event occurs again, huge tsunamis will arrive in less than 30 minutes. Buildings, roadways, and bridges may be damaged by the quake, making automobile escape difficult or impossible. What then? Another option is vertical evacuation. Head for the nearest hill that is at least 35 feet above sea level, on foot if necessary. If you can not reach a hill, find a sturdy building that is at least three stories high, and climb to at least the third story. Knowing what to do may save your life.

Web links for additional information:

- **Western States Seismic Policy Council (WSSPC): http://www.wsspc.org/resources/tsunami.shtml**
- **National Oceanic and Atmospheric Association (NOAA): http://www.tsunami.noaa.gov/warning_system_works.html**
- **West Coast and Alaska Tsunami Warning Center: http://wcatwc.arh.noaa.gov/**
- **Pacific Tsunami Warning Center: http://ptwc.weather.gov/**



Earth Briefs—Our Ever-Changing Earth Douglas Bland



Map of major and certain minor tectonic plates. *Image courtesy of USGS.*

Did you know that 325 million years ago New Mexico was located on the equator where Brazil is now, and much of the state was covered by an ocean? In fact, over the eons any particular spot in our state has alternated between being underwater, part of a coastal plain, or on a continental upland. What causes the state to move around the globe, shorelines to move hundreds of miles, and mountain ranges to grow and then disappear?

The surface crust and uppermost mantle of Earth (the lithosphere) are composed of eight major and dozens of minor solid plates floating on a plastic layer in the upper mantle (the asthenosphere). These plates move relative to each other by sliding apart and generating new crust at the plate boundaries, sliding sideways past each other, crashing together, or by one plate slipping under another. Rates of movement vary but average a few inches per year. However, this movement does not occur continuously, like a car creeping down a road at about the speed that your fingernails grow. Instead the plate boundaries remain frozen for years, with stresses building up. Then a section of the boundary fault zone tears apart, causing an earthquake. Over millions of years the slow creep and more dramatic movement on faults adds up, shifting plates across the surface of the planet, or thrusting the land skyward to form a mountain range, or dropping fault blocks down to form basins. Bit by bit, the surface of the planet is changed.

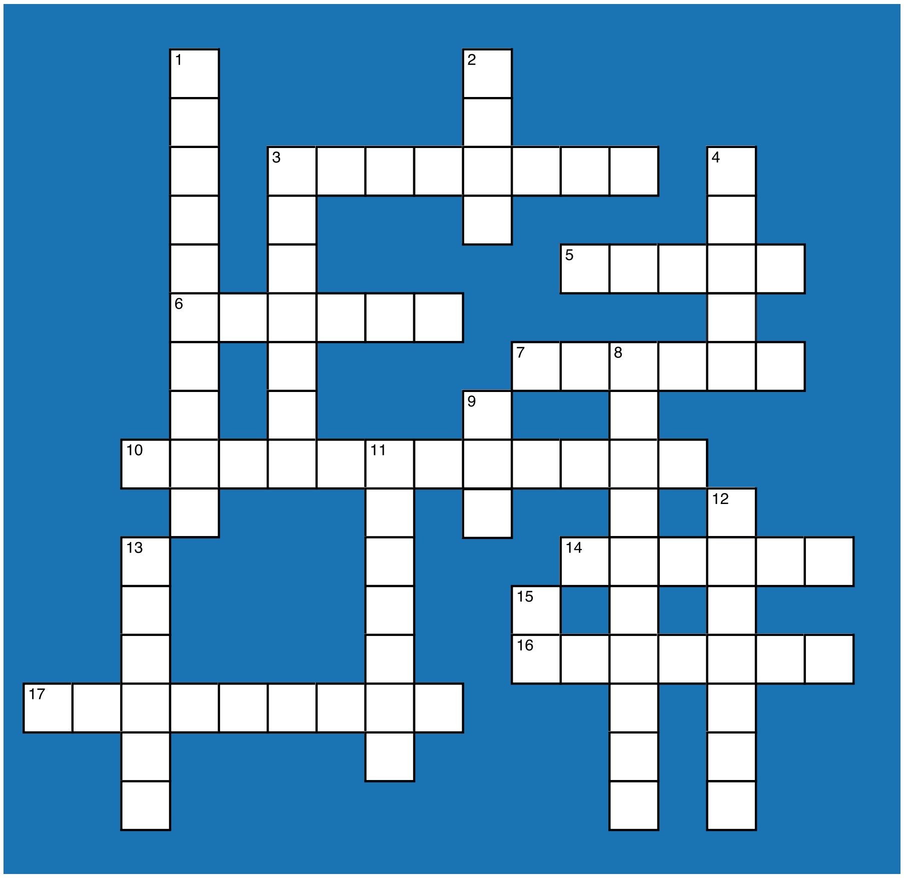
The shape of Earth was altered on March 11, 2011, when a monster earthquake shook Japan. The magnitude 9.0 temblor occurred on a fault where the Pacific tectonic plate is sliding to the west under the North American plate. This plate wraps around from North America to include northeast Russia and northern Japan. A section of the fault about 250 miles long by 90 miles wide ruptured, with the epicenter (the location on the surface of Earth above where the earthquake began) located about 80 miles east of the city of Sendai, Japan. The earthquake occurred at a depth of about 6 miles.

Scientists estimate that 100 feet or more of movement may have occurred on this huge low-angle fault, called a mega-thrust. Parts of Japan's largest island, Honshu, moved about 8 feet eastward. Preliminary modeling indicates that areas of the sea floor may have risen 10 feet or more, causing a displacement of sea water that generated a series of giant waves, or tsunami, that devastated Japan's coastal areas. Tsunami waves estimated at more than 30 feet high surged as far as 6 miles inland. Other surface locations near the fault sank, or subsided. Some coastal areas of Japan subsided more than 2 feet, which enhanced the destruction caused by the tsunami. The waves spread out and caused lesser damage all around the Pacific Ocean, including California. Eight thousand miles from the earthquake, the tsunami even caused 50 square miles of the Sulzberger ice shelf in Antarctica to break off into several giant icebergs. This portion of the ice shelf had been stable since at least 1965.

Earthquakes are only one of several mechanisms that alter the surface of Earth. Others include erosion, sedimentation, and volcanism. Together, these processes create Our Ever-Changing Earth, which is the topic of Earth Science Week this year, sponsored by the American Geological Institute on October 9–15, 2011. For more information on Earth Science Week, visit **http://www.info@earthscienceweek.org**

Crossword Puzzle

Douglas Bland and Nelia Dunbar



Across

3. tiny glass droplet

5. country impacted by the 2011 mega-earthquake

6. structure formed by meteorite impact

7. material thrown out of meteorite impact site

10. tiny marine organisms

14. type of earthquake that can form a tsunami

16. waves produced by displacement of water

17. dinosaur killer

Down

1. large meteorites can cause this

2. type of shallow-water sediment

3. area impacted by the 2004 mega-earthquake

4. piece of rock, like angular limestone

8. one cause of tsunami

9. type of wave formed by ejecta

11. Platinum group element

12. location of giant meteorite impact

13. another term for meteorite

15. Cretaceous–Tertiary abbreviation

The answers to the clues are located in the Ancient Tsunamis from Meteorite Impacts article in this issue of *Lite Geology.*

The solution to the puzzle is found on the last page of this issue.

New Mexico's Most WANTED MINERALS

Virgil W. Lueth

DOLOMITE

A 3-inch-tall aggregate of dolomite crystals $(Ca,Mg)CO_3$. NMBGMR Museum No. 10927. *Photo courtesy of Debra Wilson.*

DESCRIPTION: Dolomite is a carbonate mineral commonly confused with calcite. Perfect crystals form rhombohedrons, but the mineral is usually found as deformed rhombs displaying curved faces, or as crystal aggregates forming saddle-shaped crystals. It can also take columnar, stalactitic, granular, or massive forms. The mineral displays typical rhombohedral cleavage. It is relatively soft, with a Moh's Hardness of 3.5–4.0, so it can be scratched easily with a metal point, and is slightly harder than calcite. It reacts sluggishly with weak hydrochloric acid; a powdered sample reacts more vigorously. It comes in a variety of colors, commonly white to reddish- or greenish-white, but also red, green, brown, gray, and black.

WANTED FOR: The mineral is most commonly used as a building or ornamental stone. Sometimes it is added to cement to produce particular properties. It is also used in the production of magnesia (MgO). The replacement of calcite by dolomite in limestones produces a change in volume, creating significant porosity and permeability in rocks that often become petroleum reservoirs.

HIDEOUT: A major rock-forming mineral, most abundantly formed by diagenesis (alteration) of limestone, called dolomitization. It can precipitate directly from sea water in hypersaline environments. It is a common mineral in metamorphic environments, especially when associated with certain hydrothermal ore deposits. It is also found in carbonatites and many ultramafic rocks.

LAST SEEN AT LARGE: New Mexico has dolomite in various hideouts. Most famous are the 1-inch, near octahedron-shaped, individual crystals in gypsum near Lake Arthur (Chaves County), a rare and unique occurrence. Flat, hexagonal-shaped pseudomorphs after aragonite, (they also fluoresce an orange color) from Puerto de Luna (Guadalupe County) are also very collectable. Crystals of dolomite are reported from the Organ Mountains (Doña Ana County) and Hansonburg district (Socorro County). Silver dendrites are encased in dolomite in the Black Hawk district (Grant County). Another unusual occurrence is dolomite geodes south of Cabezon (Sandoval County).

ALIASES: Pearl spar, brown spar.

New Mexico's Enchanting Geology

Paul Bauer and Douglas Bland

WHERE IS THIS?

Photo courtesy of Paul Bauer, New Mexico Bureau of Geology and Mineral Resources.

The 14-mile segment of NM–68 along the Rio Grande between Velarde and Pilar is a scenic stretch of the river that skirts the base of notoriously unstable slopes of fractured Precambrian bedrock, talus, and landslide debris. The cliffs are the result of millions of years of movement on the Embudo fault zone, which has juxtaposed young basalts and sediments of the Taos Plateau against Precambrian metamorphic rocks of the Picuris Mountains.

This area is a classic example of the ever-changing landscape in New Mexico. Rock falls, rockslides, and debris flows are common hazards to motorists, especially along the Pilar cliffs. In September 1988, five people were killed and 14 injured in a passenger bus that crashed into a falling 11,600 pound basalt boulder near the village of Embudo. On the evening of July 25, 1991, after several days of hard rain, 11 debris flows and many rockslides and falls caused a 5-mile stretch of NM–68 between Pilar and the Taos County line to be closed for 19 hours. Although 20 cars were trapped along the highway, there were no reported injuries. The largest debris flow on the highway was approximately 100 feet wide and 8 feet deep. The most spectacular rock fall was a giant 360-ton garnet schist boulder that rolled 1,000 feet down the cliffs at nearly 50 mph, creating a 45'x15'x15' impact crater in the highway before careening across the Rio Grande at Big Rock Rapid. Boatmen have affectionately named this rock "Baby Huey" after the dimwitted, diaper-draped duck of cartoon fame. Such rock falls have created many of the exciting rapids on this section of Class III to IV whitewater known as the Racecourse.

In response to the rock falls, in 1991 several thousand feet of Swiss-made, energy-absorbing rock fall protection nets were installed above the road. Although the netting is highly effective at stopping small boulders, the rolling and sliding Big Huey boulder would have exceeded the capacity of these nets by about 160 times.

Baby Huey is located at 36° 14' 37", 105° 49' 42.5" (NAD83), and can be seen from a pullout on NM–68 near mile marker 26, just downstream of the Glenwoody Bridge.

Classroom Activity Susie Welch

THE MERCALLI SCALE: CALLING STATION KWAT

The following lesson summary was excerpted from "*Seismic Sleuths: Earthquakes—A Teacher's Package for Grades 7–12*". The full lesson is available online at the link at the bottom of this article. The purpose of the activity is to first learn the difference between earthquake measurements according to the **Richter scale**, expressed as magnitude, and the **Modified Mercalli scale**, expressed as intensity. Then, students will read from a script of radio callers' comments following an earthquake. They will find the callers' locations on a local map and look up intensity values based on the reports of earthquake effects at those locations. Drawing lines that connect points of equal intensity creates an isoseismal map, which is a contour map that shows areas of greatest impact. These maps can be useful to building engineers when developing building codes that account for potential risk for damage from earthquakes.

There are many news reports about the M 5.8 earthquake in Virginia on August 23, 2011, that contain personal accounts from people who experienced the shaking and observed damage. These reports can be downloaded from the Internet from various news sites to create a current event, real world exercise similar to KWAT. Eyewitness stories from the quake can be correlated to intensity values from the Modified Mercalli scale, which then can be plotted along with isoseismal lines onto a local or regional map.

Rationale

Students need to know how seismologists establish earthquake intensity in order to understand how much damage earthquakes can cause and how building codes are developed.

Focus Questions

How do seismologists determine the intensity of an earthquake?

Objectives

Students will:

1. Interpret the Modified Mercalli scale and assign values on the basis of descriptions by citizen observers during and after a quake.

2. Use the assigned values to construct an isoseismal map.

Teacher Background

When an earthquake occurs, we often hear news reporters describing it in terms of magnitude. Perhaps the most common question at a news conference is "What was the magnitude of the quake?" In addition to calculating the magnitude of an earthquake, however, we can describe the effect it had at a particular location by measuring its intensity. Magnitude and intensity are both measures of an earthquake, but they describe different characteristics. Each measurement has its uses.

Magnitude is a measurement of the amplitude of the earthquake waves, which is related to the amount of energy the earthquake releases. Magnitude is calculated from the size of the earthquake waves arriving at a seismic station. The most commonly used scale for magnitude is the Richter scale, developed by Charles Richter in 1935. The Richter scale is a logarithmic measurement of the maximum wave amplitude recorded at a seismograph station, corrected for distance from the epicenter.

Intensity is a measure of the effect that the vibration had on natural and human-made structures. The most common measurement of intensity is the Modified Mercalli Intensity scale, originally developed in 1902 by Giuseppi Mercalli, an Italian geologist. Wood and Neumann adapted it to "modern" conditions in 1931. The intensity scale ranges from I, the lowest perceptible intensity, to XII, the greatest intensity. Intensity is a function of many variables, including magnitude, depth of the earthquake, distance from the earthquake, local geological conditions, and local construction practices. Generally speaking, the intensity felt at a given location will increase with increasing magnitude, decreasing depth, decreasing distance from the earthquake, and a decrease in the quality of construction. If an earthquake is shallow, its intensity will be greater. If it affects an area built on soft sediments, such as landfills or sedimentary basins, the intensity will also be greater. A single quake will produce a range of intensities that typically decrease with increasing distance from the earthquake. An **isoseismal map** illustrates this range. Intensity is more useful than magnitude as a measure of the impact that an earthquake had at any given location.

Source: Unit 3.3, *Sizing Up Earthquakes—Activity One: The Mercalli Scale: Calling Station KWAT in Seismic Sleuths: Earthquakes—Teacher's Package for Grades 7–12*; 1995 with update in 2009; American Geophysical Union and Federal Emergency Management Agency, pp. 161–166 and 171–176.

Access and download this lesson at:
http://www.fema.gov/library/viewRecord.do?id=3558

Modified Mercalli Scale

MM intensity	PERCEIVED SHAKING	DAMAGE
I	Not felt except by a very few under especially favorable circumstances.	None
II	Felt only by a few persons at rest especially on upper floors of buildings. Delicately suspended objects may swing.	None
III	Felt quite noticeably indoors; especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration like passing of truck. Duration estimated.	None
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing automobiles rocked noticeably.	None
V	Felt by nearly everyone, many awakened.	Very light—Some dishes and windows broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.
VI	Felt by all, many frightened and run outdoors.	Light—Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight.
VII	Very strong. Everybody runs outdoors.	Moderate—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 cars.
VIII	Severe—Persons driving cars disturbed.	Moderate to heavy—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. Chimneys, factory stacks, columns, monuments, walls may fall. Heavy furniture overturned. Sand and mud ejected in small amounts. Change in well water.
IX	Violent	Heavy—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	Extreme	Very heavy—Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks.
XI	Extreme	Extreme—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	Extreme	Extreme—Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.

PROFILE OF A NEW MEXICO EARTH SCIENCE TEACHER

Claudine Rood is a 6th grade science and language arts teacher at Eagle Ridge Middle School in Rio Rancho, New Mexico. She has taught 15 years at the middle school level in Rio Rancho and is certified in science, language arts, and special education. She is the content leader at Eagle Ridge Middle School for the science department as well as the lead teacher for the LASER i3 Project through the Smithsonian Institution's National Science Resources Center, which is the first major research project to study the effects of inquiry on student learning.

In addition to her regular class load, Claudine teaches a program called Starbase La Luz, sponsored by Kirtland Air Force Base. She was named *Teacher of the Year* in 2003 through the Aerospace Foundation, which sponsors a set of classroom newspapers. Claudine has been an active participant in the summer geology workshop, Rockin' Around New Mexico since 2004.

Educational background:

B.A. in Elementary Education; Minor in Science, University of New Mexico

M.A. in Special Education, University of New Mexico

Specialties in teaching: I emphasize integration of technology into the curriculum including the use of an interactive white board, a Classroom Performance System (CPS; enabling students' electronic responses to lessons), a document camera, and Interwrite pad devices. I am able to instruct students who have severe disabilities because I teach science with hands-on activities that make the lessons easier to understand. I also incorporate language arts skills into my science classes by having my students do a lot of writing, mainly in their field notebooks, where they write about their observations and what they have learned.

Why do you think it is important that students learn about earth science? I believe that students should learn about earth science because it relates to their lives now. How our planet has come to be the way it is today relates to what it will become in the future. Learning about Earth's past will help people understand how to increase awareness and prepare for changes to come such as earthquakes, volcanic eruptions, changes in weather patterns, etc.

Do you use any of the lessons and resources from Rockin' Around New Mexico in your classroom?
The exercise we do at Rockin' that I use is FEMA's Seismic Sleuths lesson, "Sizing up Earthquakes: Calling Station KWAT" to illustrate how seismologists can use citizen reports after an earthquake to assign intensity values using the Modified Mercalli scale and assess damages at various locations near the earthquake site. See page 10 for further description. I use many of the other Rockin' lessons and always display posters and rocks and minerals for my students. I love all the resources that the workshop provides for us and also the shared ideas from other teachers.

Claudine Rood conducts a soil test during the 2008 session of Rockin' Around New Mexico in Socorro. *Photo courtesy of Jennifer Whiteis.*

How did you decide to become a science teacher? While I was studying to get an associate's degree so I could open a day care center, my friend challenged me to get my teaching degree instead. Because I preferred to take science classes over other subjects, I ended up with a lot of science content, which I enjoy teaching.

Have you always enjoyed geology? My high school earth science teacher made the subject a lot of fun. Then, when I moved to New Mexico I wanted to learn more about the beautiful landscapes. I hiked into Canyon de Chelly in Arizona with a group of scouts. It was an amazing canyon, just like a little Grand Canyon. I also hiked the trail in the Grand Canyon from Havasu Falls Campground at the bottom of the canyon to the top. That trip was so great, we actually went twice!

What other ways do you enjoy science on your days off? I ride in hot air balloons all the time. When the Albuquerque Balloon Fiesta rolls around in October I'll do a mini lesson on how balloons fly because it ties into teaching about density. Our family includes my husband and two children, and we enjoy camping at the lakes in northern New Mexico. We have raised all kinds of pets including cats, dogs, rabbits, dart frogs, ferrets, and fish, although our mini zoo has decreased over the past few years.

How easy is it to network with professionals in the scientific community to support science teaching in New Mexico? I feel it is difficult to network with other science teachers, but attending workshops and trainings such as Rockin' really helps with that effort. Now that we have access to social networks such as Facebook, it is easier to stay in contact with professionals.

Are you aware of any of your former middle school students who went into science or engineering? One of my students became an FBI agent, and several others are now teachers.

What is your favorite activity in earth science? *Edible Plate Tectonics*, explained at the Web site below, is a creative lesson to show the students the types of plate boundaries and what happens at them. For each student you will need one graham cracker, one fruit roll-up, a large spoonful of frosting, a plastic knife, and a piece of wax paper. The cracker represents continental crust, and the roll-up represents oceanic crust.

1. Spread the frosting on the wax paper to serve as the ductile upper mantle, then place different combinations of the cracker and roll-up on the frosting to represent the different boundaries.
2. Roll-up and roll-up slide apart, representing a divergent boundary (mid-ocean ridge).
3. Roll-up and cracker pushed together, representing a convergent boundary (creates volcanic mountains).
4. Cracker and cracker slide past each other, representing a transform boundary (causes earthquakes).
5. Slightly wet one edge of each cracker, then push together to represent a convergent boundary (creates big mountains).

http://www.windows2universe.org/teacher_resources/teach_snacktectonics.html

What is your favorite Web link?
This Web site is a great resource for videos:
www.unitedstreaming.com

Student Assignment: Go to this Web site to learn about the three types of rocks and a little about the rock cycle. This interactive site includes an assessment at the end. Please complete the assessment and print out your results.
http://www.learner.org/interactives/rockcycle/index.html

What are your favorite resources? Mobile laptop lab, which I use all the time when I can get it checked out.

Do you have any advice or suggestions for other earth science teachers? Always make it relevant to the students' lives and as interactive as possible. Take them out into the field and let them experience science first hand, not just through a book.

What is your favorite geologic feature in New Mexico? That's hard to pick because our state is so rich in geology, but I would have to go with the volcanoes, especially the Valles caldera.

Rockin' Around New Mexico: A Summer Geology Workshop for Teachers

Susie Welch

Summer 2011 Jemez Springs Workshop Summary

The New Mexico Bureau of Geology conducted a 3-day teacher workshop on July 5–8, 2011, in Jemez Springs, New Mexico, to cover topics including: 1) geology of local seismic, volcanic, and geothermal features relating to the Valles caldera; and 2) seismic hazards in New Mexico along with discussions on safety and survival for schools. A total of 28 teachers from grade levels K–12 attended the workshop. This group represents most grade levels with more than half of the participants teaching at middle school and high school levels.

About half of the teachers attending were registered for the one hour of graduate credit offered through the Masters of Science for Teachers program at New Mexico Tech.

Sessions for 2011:

- A field trip to see a seismometer station on Jemez Pueblo, along with discussion on geothermal resources in the Jemez area.
- Field trip to White Mesa trails near San Ysidro to hike along a spectacular anticline with faulting. Teachers also collected gypsum crystal specimens.
- Presentation on explosive volcanism that relates to the Valles caldera.
- Sieving exercise with samples from pumice outcrop to determine eruptive mechanisms of deposits through particle-size analysis.
- Presentation on status of the Las Conchas fire and an introduction to fire ecology, followed by discussions on how this area will look next year (affects of fire on the local landscape, geology, and forest habitat).
- Driving tour to the Valles caldera overlook to see effects of the still-burning Las Conchas wildfire in the Jemez Mountains on July 7th, the day after NM–4 was re-opened to public traffic.
- Discussions on the resurgent domes of the Valles caldera, their eruptive history and potential for future eruptions.
- Implications for seismic activity in the future with hazard and safety preparedness activities, including earthquake drop, cover, and hold drill.

Ojito overlook. Colorful red siltstones and mudstones of the Triassic Petrified Forest Formation are exposed about 4 miles southwest of San Ysidro and just north of the Ojito Wilderness Area. The juniper covered mound in the middle distance is composed of recent travertine deposits from active warm springs. *Photo courtesy of Linda Brown, 2011.*

Our Partners: Rockin' Around New Mexico is built around partnerships between the New Mexico Bureau of Geology/New Mexico Institute of Mining and Technology, New Mexico Department of Homeland Security and Emergency Management, New Mexico Geological Society, and other agencies and private companies that provide funding support and expertise. For 2011, we also cooperated with the Valles Caldera National Preserve/Science Education Center and the New Mexico Mining Association.

Ojito hike. Participants in the 2011 Rockin' Around New Mexico teacher's workshop walk across gypsum deposits of the 159 million-year-old Todilto Formation. Gypsum from this formation at the White Mesa mine 3 miles to the northwest is made into wallboard at a plant in Bernalillo, 20 miles to the southeast. *Photo courtesy of Linda Brown, 2011.*

Las Conchas burn area. Picture was taken west of the Valles caldera on NM Highway 4, looking east. The Las Conchas fire burn area is visible along the ridge on the right (south) side of the road. *Photo courtesy of Linda Brown, 2011.*

Pumice deposit. Pumice deposits at a roadcut on NM Highway 4, southwest of the caldera. Layers of ash fall (gray upper and lower layers) and ash flow (white middle layer) deposits are visible. These units were sampled for the pumice sieving exercise to determine clast-size distribution, which will differentiate between the two types of deposits. *Photo courtesy of Linda Brown, 2011.*

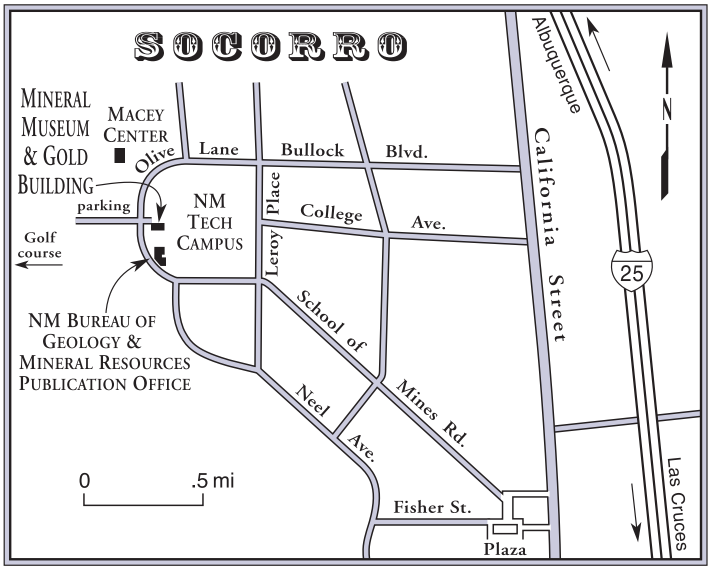
Rockin' Around New Mexico 2012

Dates for Summer 2012: July 9–12

Location: Jemez Springs, New Mexico

We are returning to this location in 2012 to study some of the geologic sites that were closed this season because of the Las Conchas fire, and to evaluate the recovery of burn areas after one year. Contact Susie Welch by e-mail at **susie@nmt.edu** to get on the notification list for the 2012 Rockin' workshop registration.

Short Items of Interest to Teachers and the Public



THE MINERAL MUSEUM ON THE CAMPUS OF NEW MEXICO TECH IN SOCORRO, NEW MEXICO

Hours:

8 a.m. to 5 p.m., Monday through Friday

10 a.m. to 3 p.m., Saturday and Sunday

Closed on New Mexico Tech holidays

The Mineral Museum is located in the Gold Building on the campus of New Mexico Tech in Socorro. The bureau's mineralogical collection contains more than 16,000 specimens of minerals from New Mexico, the United States, and around the world, along with mining artifacts and fossils. About 2,500 minerals are on display at a time.

For teachers and other groups, we offer free tours of the museum. We like to show off our home state minerals, as well as give students an idea of how minerals end up in products we use every day. Museum staff can also identify rocks or minerals for visitors. Please call ahead to ensure someone will be available. For more information on the museum, please visit our Web site at: http://geoinfo.nmt.edu/museum/

Dr. Virgil W. Lueth
Senior Mineralogist and Curator
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Bob Eveleth
Senior Mining Engineer and Associate Curator (emeritus)
beveleth@gis.nmt.edu
575-835-5325

To Schedule a Museum Tour, Contact:

Susie Welch
Manager, Geologic Extension Service
susie@nmt.edu
575-835-5112

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UPCOMING EVENTS FOR TEACHERS AND THE PUBLIC

National Earth Science Week

October 9–15, 2011

Take part in Earth Science Week 2011! American Geological Institute, which sponsors Earth Science Week (ESW), encourages people everywhere to explore the natural world and learn about the geosciences. "Our Ever-Changing Earth," the theme of ESW 2011, engages young people and the public in learning about the natural processes that shape our planet over time. Request your Earth Science Week Planning Toolkit with cool resources and ideas about how to plan your own celebration online at: http://www.earthsciweek.org/

Fall Conference for Environmental and Science Educators

October 20–22, 2011
Farmington, New Mexico

This year's conference will held at Piedra Vista High School in Farmington. The theme of the conference is "Soar to Greater Heights: Connecting Earth and Education." Pre-conference field trip topics include archaeology, mining reclamation, geology, the Bisti wilderness, and paleontology. Session topics will address the connection between science and environmental education. The conference opens with an insightful keynote speech by renowned Navajo physicist Fred Begay. Find out more about the conference and register at New Mexico Science Teachers Association Web site:
http://www.nmsta.org/

Teacher Resources:

School Earthquake Safety

Recent earthquakes have prompted discussions about safety preparedness. These quick references will increase your awareness and prepare for an earthquake or other disaster.

Drop, Cover and Hold On! is the earthquake safety drill that you can practice with the staff and students at your school. Visit **http://www.dropcoverholdon.org/**

Federal Emergency Management Agency (FEMA) provides excellent information on what to do before, during, and after an earthquake:

Before:
http://www.fema.gov/hazard/earthquake/eq_before.shtm

During:
http://www.fema.gov/hazard/earthquake/eq_during.shtm

After:
http://www.fema.gov/hazard/earthquake/eq_after.shtm

FEMA recommends having an emergency evacuation kit for your classroom containing a first aid kit, food and water, tools, tarps, and other supplies. See the list at:
http://www.fema.gov/plan/prepare/basickit.shtm

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