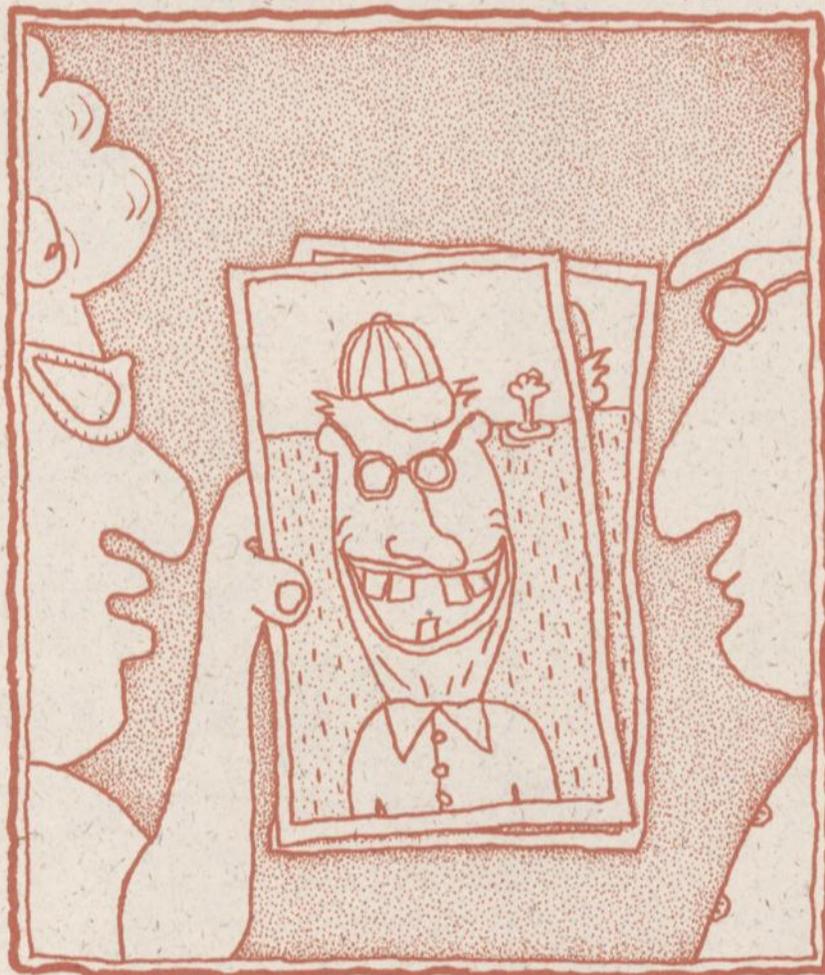


# L I T E geology

A quarterly publication for educators and the public—  
contemporary geological topics, issues and events



"I told you to take a picture of the  
GEYSER at Yellowstone—not the GEEZER."

## This Issue:

*Earth Briefs*—seismic shake-up  
causes geysers to wake up

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New Mexico Bureau  
of  
Mines and Mineral  
Resources  
(NMBM&MR)

## Earth Briefs

### Quake Shakes Thermal Lakes

This year in Yellowstone National Park, scientists have had a renewed opportunity to study the relationship between seismic events and the behavior of geysers. Geysers, or hot springs that erupt on an intermittent basis, are supplied with steam or hot water from reservoirs inside the rock.

These reservoirs consist of a **plumbing** system of fractures in the rock that convey hot ground water to geysers and hot springs. Changes in this plumbing, either by opening or closing of fractures, can change the flow of water to the geysers, affecting their eruption patterns. Earthquakes, such as the March 26, 1994 quake that rattled the Norris Geyser Basin in Yellowstone, can disturb the plumbing under geysers, resulting in changes in water temperatures and levels, and in the magnitudes and frequencies of geyser eruptions.

After the March earthquake, measuring 4.6 on the Richter scale, several geysers in the park have altered their behavior. Monarch Geyser, which had been sleeping for 81 years, woke up grumpy and threw rocks, mud, and water 15 feet into the air about once a day. In the early part of the century, before its dormancy, Monarch would shoot water up to 200 feet skyward, higher than most Old Faithful eruptions.

Following the same quake, Ledge Geyser erupted after a 15-year period of dormancy. In contrast, Steamboat Geyser, the largest geyser in the world, which sometimes erupts to a height of nearly 400 feet, showed signs of

reduced activity, and perhaps is heading for dormancy. Changes in geyser eruption patterns are common following an earthquake, and serve to illustrate that Yellowstone Park's geyser regions are a dynamic and complex weave of thermal and geologic processes.

A few scientists speculate that some geysers change their pattern of eruptions before earthquakes occur. If so, it might be possible to predict earthquakes using geyser behavior. This hypothesis is being tested by detailed monitoring of eruption behavior of a few geysers in Yellowstone. The outcome of the data collection awaits more earthquakes. The evidence from previous observations, however, is that the most noticeable changes in geyser behavior begin with earthquake shaking and changes in natural plumbing.

The known **geothermal** areas in New Mexico may be affected by earthquakes as well. Although there are presently no geysers in the Jemez Mountains or the Lightning Dock geothermal areas, changes in amounts and temperatures of water from hot springs and hot wells are documented in both areas and the water is hot enough to flash into eruption-causing steam under the right conditions. Earthquakes could change the plumbing systems to the geothermal fields. Hot water moving to the surface along a number of faults in Jemez Canyon has shifted through geologic time to its present location at Soda Dam. Remnants of previous travertine spring deposits along the canyon walls show where plumbing systems used to be active.

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—story by D. Love and S. Welch



Seismic Geyser evolved from a fumarole in 1963, spitting stones and killing trees with boiling water.



Castle Geyser cone in foreground, Giantess erupting beyond Firehole river, Upper Geyser Basin.



Lone Star Geyser



Castle Geyser in steam phase

photos by David Love, Senior Environmental Geologist, NMBM&MR

# Have you ever wondered...

## ...How Earthquakes are Measured?

**Richard Aster**

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Virtually everyone has seen press releases describing earthquakes around the world where the size of the earthquake has been quoted as a magnitude. What exactly does this refer to, and how do scientists assess and quantify the size of earthquakes?

As we saw in a previous article in *Lite Geology*, almost all earthquakes are caused by sudden fault slip in the brittle upper few hundred kilometers of the Earth. As most earthquake faults do not break the surface, most of what is known about earthquakes is inferred from observations of seismic waves that propagate away from the earthquake source region at depth and thus can be recorded at or near the Earth's surface.

The earliest semiquantitative method of assessing the size of earthquakes is the **intensity scale**, first developed by the British engineer Robert Mallet to assess the damage from a disastrous 1857 earthquake in southern Italy. The simple idea is to measure the intensity of shaking, as indicated by different types of structural damage. One can then plot on a map the intensity of shaking at different locations and contour the data to obtain a set of curves (isoseismal contours) that indicate approximately equal degrees of shaking (Fig. 1). An **isoseismal contour plot** thus gives an estimate of the spatial distribution of shaking. A twelve-point intensity scale was subsequently devised by the Italian geologist Giuseppe Mercalli in 1902, where the degree of inferred shaking ranges from I (detectable only with sensitive seismic instruments called seismometers) to XII (essentially total

destruction). The intensity scale used most often in North America, the **Modified Mercalli intensity scale**, was developed by H.O. Wood and F. Neumann in the early 20<sup>th</sup> century to fit construction conditions in California (California buildings have appreciably different features than European ones!). The intensity scale, despite its simplicity, is still a useful seismological tool today, particularly as a standard for assessing the size of historic earthquakes.

Isoseismal contours also may be used to estimate the location, depth, and size of an earthquake when no other data are available, as deeper

As an example of attenuation, note that the 1886 earthquake in Charleston, South Carolina (estimated magnitude 7.2) was felt over an area of approximately 8 million square kilometers, while the similarly-sized 1989 Loma Prieta earthquake was felt over only about 1 million square kilometers of California as a result of the more attenuating rocks of the west coast. The clearest examples of resonance and amplification effects are seen in cities. This is because many measurements of intensity can be made in a small region and because certain types of soft soil that amplify seismic disturbances, such as "reclaimed" wetlands, are common.

Recent examples of extreme local amplification include highly localized and very strong ground motions observed in Mexico City during the 1985 Mexico earthquake (in areas built on an ancient lake bed), during the 1989 Loma Prieta earthquake (in the Marina District of San Francisco), and the 1994 Northridge earthquake (in parts of Santa Monica, California).

The most commonly quoted measure of earthquake size is the **magnitude**. The original earthquake magnitude scale was developed by Charles Richter in 1935 for California. If you want to impress your friends, here is a strict definition of the **Richter Magnitude**:

*The base 10 logarithm of the maximum seismic-wave amplitude (in microns, or one one-millionth of a meter) recorded on a standard Wood-Anderson seismograph at a distance of 100 km from the epicenter, where the standard seismograph consists of a 5 gram mass suspended on a torsion wire with optical recording and electromagnetic damping. It has a period of 0.8 seconds and magnifies ground motion by a factor of 3000.*

Mathematically, the Richter, or local,

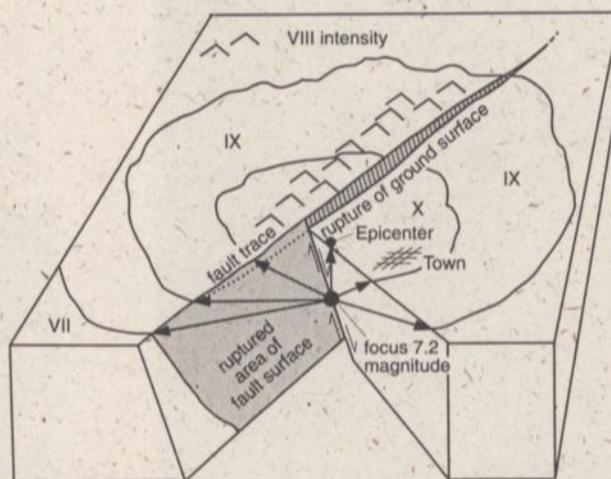


Figure 1—Diagram showing isoseismal contours, surface rupture, fault surface, focus, and epicenter.

events will generally affect a wider area with equal intensity. However, local ground shaking is highly influenced by near-surface and regional geology due to **attenuation** (the rate at which seismic wave energy is converted into heat by friction), **resonance** (local buildup of seismic wave amplitudes due to constructive interference), and **amplification** (soft materials which propagate seismic waves more slowly induce higher amplitudes to conserve energy).

magnitude is

$$M_L = \log_{10} (3000 u_{\max})$$

where  $u_{\max}$  is the maximum ground displacement in microns.

Because of the base 10 logarithm in the definition, each unit increase in magnitude reflects a ten-fold increase in ground motion. An increase of two magnitude units corresponds to a ground motion increase of  $10^2$  or 100. The instrument calibration is such that the maximum seismogram amplitude expected from a Richter magnitude 5 earthquake 100 km away is about 100 mm (Fig. 2). This corresponds to a maximum ground motion of about 33 microns, which is about 1/1000 of an inch. The expected ground motion for a magnitude 7, on the other hand, is 100 times greater (3300 microns or about 1/10 of an inch) which can easily be felt even 100 km away.

Note that earthquake magnitudes can be zero or negative, as the maximum ground displacement,  $u_{\max}$  of an  $M_L = 0$  earthquake is 1/10 that of an  $M_L = 1$  earthquake, and the ground displacement from an  $M_L = -1$  earthquake is just 1/100 that of an  $M_L = 1$  earthquake, and so on. Seismologists study earthquakes spanning the huge range of 11 orders of magnitude (magnitudes from approximately -2 to 8).

Despite its simplicity, the Richter magnitude doesn't do too bad a job of quantifying the relative size of earthquakes, particularly when there are many stations to provide measurements to average over.

Another scale that is used to measure earthquakes at local distances (typically less than 100 km) is the **duration magnitude**, which assesses how long the seismic waves rattle around in the crust of the Earth before they become indistinguishable from the background noise. Its formula is

$$M_d = \log_{10} (d) + q$$

where  $d$  is the duration in seconds and  $q$  is a factor used to make  $M_d$  approximately equal to  $M_L$ . The

duration magnitude scale is routinely used to assess the size of earthquakes in New Mexico by the New Mexico Tech Seismological Observatory.

The Richter magnitude was developed as a rough measure of earthquake size in California, where distances between earthquakes and seismographs are commonly not more than a few 10s of km. Many earthquakes around the world, however, occur in remote regions such as under the oceans and are thus recorded only at **teleseismic distances** of 100s to 1000s of km.

Distant large earthquakes produce two basic types of seismic waves that

can be seen on seismograms recorded virtually anywhere on the Earth with suitably sensitive instruments. Each of these waves has its own associated magnitude scale. Seismic **body waves** travel deep into the Earth's mantle and even through its core before reaching a particular station, while **surface waves**, travel near the Earth's surface. At teleseismic distances these two types of waves can be quite distinct on seismograms, in contrast with seismograms recorded close to the source, which are characteristically a more complicated superposition of body waves and surface waves. Surface waves are commonly the largest signals on a teleseismic record because they spread out over the (2-dimensional) surface of the earth, while body waves must spread out

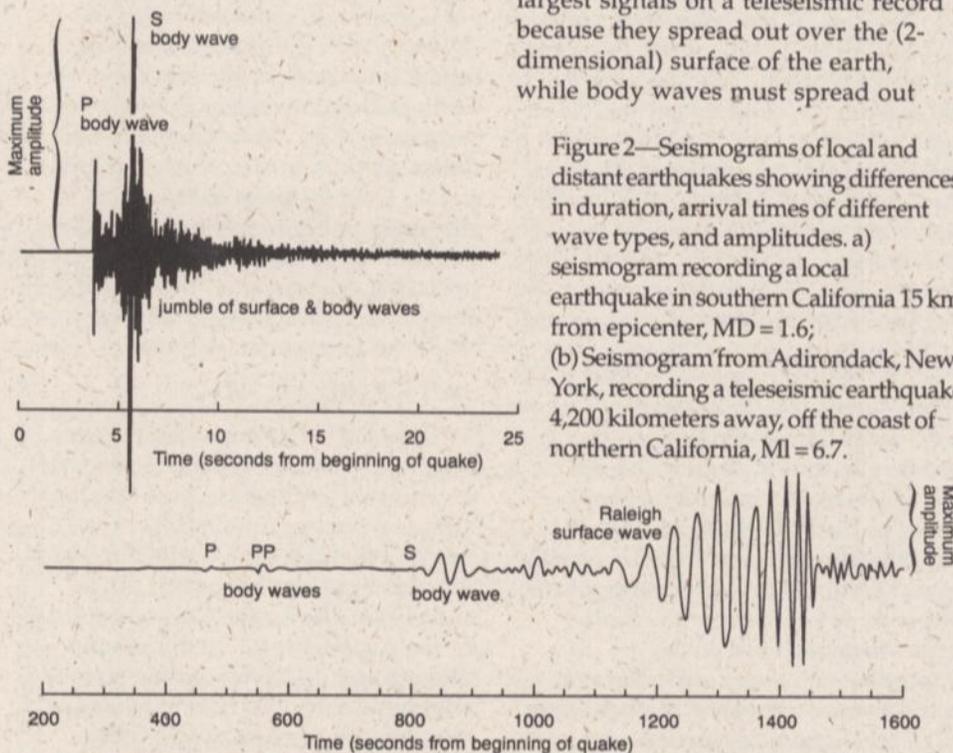


Figure 2—Seismograms of local and distant earthquakes showing differences in duration, arrival times of different wave types, and amplitudes. a) seismogram recording a local earthquake in southern California 15 km from epicenter, MD = 1.6; (b) Seismogram from Adirondack, New York, recording a teleseismic earthquake 4,200 kilometers away, off the coast of northern California, MI = 6.7.

Table 1—Moments and magnitudes of some famous earthquakes

	surface wave magnitude $M_s$	area of fault S (length x width)	average amount of slip $\bar{u}$ (m)	seismic scalar moment $M_0$ (N-m)	moment magnitude $M_w$
Northridge (1994)	6.6	20 km x 14 km	1.4	$1.2 \times 10^{19}$	6.7
San Francisco (1906)	8.2	320 km x 15 km	4.0	$6.0 \times 10^{20}$	7.9
Alaska (1964)	8.5	500 km x 300 km	7.0	$5.2 \times 10^{22}$	9.1
Chile (1960)	8.3	800 km x 200 km	21.0	$0.4 \times 10^{23}$	9.6

over the (3-dimensional) interior.

When thinking about these two types of waves, imagine dropping a stone into a pond. Sound waves from the impact (which you don't normally sense unless you are a fish) travel deep into the pond, while surface waves are seen traveling away along the air/water interface. The sound-like waves in seismology are body waves, and the concentric ripples moving away from the source (the rock) at the surface are surface waves. The **body wave magnitude**, is

$$m_b = \log_{10} (A / T) + Q$$

where the standard practice in the U.S. is to measure the maximum amplitude,  $A$ , in microns, of the initial teleseismic P-wave arrival,  $T$  is its period (typically less than 3 seconds), and  $Q$  is a term that depends on distance and source depth and minimizes the difference between  $m_b$  and other magnitude scales (there are always additive constants in these formulas for this reason, and why it's called  $m_b$  instead of  $M_b$ , no one seems to know). The **surface wave magnitude** is, similarly,

$$M_s = \log_{10} (A / T) + 1.66 \log \Delta + 3.3$$

where  $A$  is the maximum surface wave amplitude and  $\Delta$  is the source-to-receiver distance in degrees (e.g., a quarter of the way around the Earth would be  $D = 90^\circ$ ). Surface and body wave magnitudes may differ by up to several units, as shallower earthquakes release more energy near the Earth's surface and hence generate proportionately larger surface waves than deeper earthquakes. Surface wave magnitude values for several earthquakes are shown in Table 1.

Note that all of these magnitude scales, although useful, are purely empirical and relative. They also contain an additional problem in that, for technical reasons beyond the scope of this article, they don't do a very good job of discriminating between merely

big earthquakes and *really* big earthquakes, as we'll see. To obtain a more meaningful measure of earthquake sources we must look more closely at the physics of fault slip.

It turns out that when a fault slips, the mechanical process is equivalent to a force operating on a lever arm of some length, or a mechanical **moment** (the units are torque, or Newtons times meters). The **seismic scalar moment** of an earthquake is just the size of this torque, and is defined by

$$M_0 = \bar{u} S \mu$$

where  $\bar{u}$  is the average amount of slip on the fault,  $S$  is the area of the fault, and  $\mu$  is a scale factor with units of force per unit area, or pressure, called the **rigidity**. The rigidity describes how hard it is to bend the rocks in the earthquake source region with a shearing motion. Both  $\bar{u}$  and  $S$  can be estimated from modern seismograms and/or from ground rupture or aftershock patterns, while  $\mu$  is estimated from laboratory rock-squeezing experiments. The scalar moment defines a magnitude scale called the **moment magnitude**

$$M_w = 2/3 \log_{10} M_0 - 6.0.$$

Table 1 shows some surface-wave magnitudes and seismic moments for a few famous earthquakes. Note that the surface-wave magnitude ( $M_s$ ) values aren't all that different for the three very large earthquakes in the table ( $M_s$  is actually smaller for the Chile event than for the Alaska event) but the seismic moment and its corresponding moment magnitude show just how much larger mechanically the Alaska and Chile earthquakes were than the San Francisco event (the Chile event is just about as large an earthquake as the Earth is thought to be capable of generating!). As the seismic moment becomes more routinely estimated by earthquake monitoring agencies, you can expect to see the moment

magnitude reported more frequently in your favorite newspaper, especially for large earthquakes.

Because the seismic moment and the moment magnitude are determined by straightforward calculations from the dimensions and amount of slip on the fault and from the stiffness of the rocks around the fault, it is possible for **paleoseismologists** to estimate the size of earthquakes that may have occurred on faults in the past. Furthermore, seismologists can use the same technique to assess the size of an earthquake that may occur on a recognized fault in the future. To perform these calculations, it is necessary to estimate the length and width of the fault in question as well as the probable amount of slip and the rigidity of the rocks near the fault zone.

A final measure of the size of an earthquake is the total amount of energy released in the slipping of the fault. This is expressible in terms of the seismic moment as

$$E = M_0 (\bar{\sigma} / \mu) = \bar{\sigma} S \bar{u}$$

where  $\bar{\sigma}$  is the average shear stress (the force per unit area pushing the fault along in units of pressure) along the fault during the earthquake. Typically,  $\bar{\sigma}$  is on the order of 100 times the pressure of the atmosphere at the Earth's surface, or in metric units, about  $10^5$  Newtons per square meter. The energy released in a large earthquake is gigantic. For the Chile earthquake it is

$$E \approx 10^5 \times [800 \times 10^3] \times [200 \times 10^3] \times 21 \\ = 3.4 \times 10^{17} \text{ Joules}$$

For comparison, the energy released in a 1 megaton nuclear explosion is "only" about  $8 \times 10^{13}$  Joules, so a very large earthquake releases the energy equivalent to about 10,000 hydrogen bombs! Fortunately for the human race, most of this energy goes into fracturing and heating the rocks around the fault and only a few percent actually gets radiated away as seismic waves.

# Who really knows where stones come from?

If you have ever applied yourself to your garden in early spring, to dig out, once and for all, every rock—only to return the next season to find a new crop of rocks to pick out—you can understand why people ponder this universal problem. The June 1991 issue of the *Badger Common' Tater*, the magazine of the Wisconsin Potato and Vegetable Grower's Association, featured an insightful article on this dilemma. Excerpts from the article, "Where stones come from," by Justin Isherwood, are reprinted with permission and appear in italics. Justin Isherwood is a potato grower from Plover, WI, and is a regular columnist for the *Badger Common' Tater*.



magnitude 7 earthquake



magnitude 8 earthquake



magnitude 9 earthquake

Farmers often ponder where stones come from. It troubles some more than others, usually for the reason those who are not troubled do not own stony land.

Farmers think about stones because they have picked stones, picked them last year and the year before. Picked stones as far back as they can remember and their pa too. Every spring more stones, stones where none existed before...In the farmships why stones reappear every spring is routinely discussed. Village folk argue other things, troublesome subjects like national debt, greenhouse effect, and acid rain. Transitory things like apartheid, black holes and stock prices.

But in the glacial valleys, in the dim rural taverns late at night they talk stones and why stones come back to the fields year after year like migrating geese.

One farmer confesses he has taken to painting the rocks he picks because he swears they look like the ones he picked several years previous... He believes stones come back, how he throws 'em on a rock pile and they won't stay put, instead crawl off like wounded dogs to lick their wounds and return to the field...Stones have a homing instinct. Dump 'em in Romania, he says, and they'll find their way

back, which is why he is painting stones. Green one year, blue the next, white another. Some day when a blue stone shows up he will have his proof.

This is for the same reasons sea shells are found halfway up Mount Everest, the whole load of plate tectonics is driven by stones crawling their way home. If people had left stones plumb alone in the first place none of this would have happened. What with all the coal dug out of the ground and shipped thousands of miles away, the copper and iron ore and gold...the surface of the earth is crawling to beat heck.

There is always a scientist or two among any farm coven, and mythological stone lore sets them off. "...Stones don't think, crawl, or get squashed out of the ground. ...Ever feel the bottom of a rock? Colder than dirt, ain't it? Cold in May when the top of the rock is hot enough to fry sausages. Cold and wet. Sometimes after weeks of warm weather you find ice there. Tain't the ice that does it though, it's the dark side of that rock sucking water that does it. Frost heave won't get you any altitude even if you wait a thousand years. But the cold side of a rock sucking water day after day, season after season, brings rocks up from thousands of feet down. We ain't never gonna be free of stones. If it was frost alone, we'd have won the war a couple of generations ago. It ain't ice, it's them stones sucking water just like a hydraulic cylinder lifts the stones out of the ground."

We encourage our readers to write to us with scientific or humorous explanations about where stones—especially the reappearing kind—come from, or to share other stories of folk geology.

#### Source

Isherwood, J., (1991) Where stones come from, in Houlihan, T. (ed), *Badger Common' Tater: Wisconsin Potato and Vegetable Grower's Association*, Antigo, Wisconsin, v. 43, no. 6, pp. 38-39.

# Ancient Lakes: A Tool For Understanding Climatic Change

**Bruce Allen**

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One of the attractions of living in the southwestern United States is its dry air and clear, blue skies that seem to linger for weeks on end. Although thunderstorms bring sporadic rains during summer months, and cyclones bearing moisture from the Pacific Ocean sweep through the region during winter months, the overall climate of the Southwest is dry, a fact that is borne out by the scarcity of large, natural lakes in the region. Geological evidence indicates that such was not always the case. If we could travel back in time about 20,000 years, during the height of the last Ice Age, we would find that many of the intermontane basins in the Southwest were occupied by large lakes. These ancient lakes are called **pluvial** lakes because they formed when the climate was wetter than it is today.

New Mexico had several large, pluvial lakes. One such lake filled the bottom of the Estancia Valley, east of the Manzano Mountains in central New Mexico. The northern shore reached the outskirts of what is now Moriarty, NM (Fig. 1). At its maximum extent, Lake Estancia was about 40 miles long and 20 miles wide and covered the town sites of Estancia and Willard with almost 100 feet of water (Fig. 1). Today, a few miles east of Willard, NM, huge cup-shaped depressions, or **blowouts**, some a mile in diameter, have been carved by

wind into the old lake sediments. Highway 60 passes through the exposed remains of ancient Lake Estancia (Fig. 2). The blowouts now contain small, ephemeral salt ponds, or **playas**. Salt from these playas was harvested by the people of the Salinas Pueblos at Quarai and Gran Quivera.

Evidence for the expansion and contraction of ancient lakes provides

features such as beach ridges, spits, and sand bars that formed along the margins of pluvial lakes. Other more complete information about the rise and fall of lake level is obtained by studying the sediments that were deposited on the bottoms of the lakes. At Estancia, for example, when the lake was freshened and expanded in size,

aquatic worms and other bottom-dwelling organisms colonized the lake bottom and mixed the uppermost layer of the bottom muds in their search for food. Sediments that were deposited during highstands of the lake are relatively homogenous due to this mixing (called **bioturbation**). During lowstands of the lake, as salinity increased, bioturbating organisms were eliminated from the lake bottom, resulting in delicately laminated sediments.

Still another indicator of highstands and lowstands is the abundant remains of tiny crustaceans called **ostracodes** ("seed shrimp"). Ostracodes are used to estimate changes in the salinity of the lake in which they lived. Biologists studying modern ostracodes have determined that certain species of ostracodes can tolerate and even thrive in water that has high salinity. Other

species are able to tolerate only fresh water. Changes in the abundance and types of ostracodes in the deposits of Lake Estancia can be used to determine when the ancient lake was freshened and expanded in size, and when the

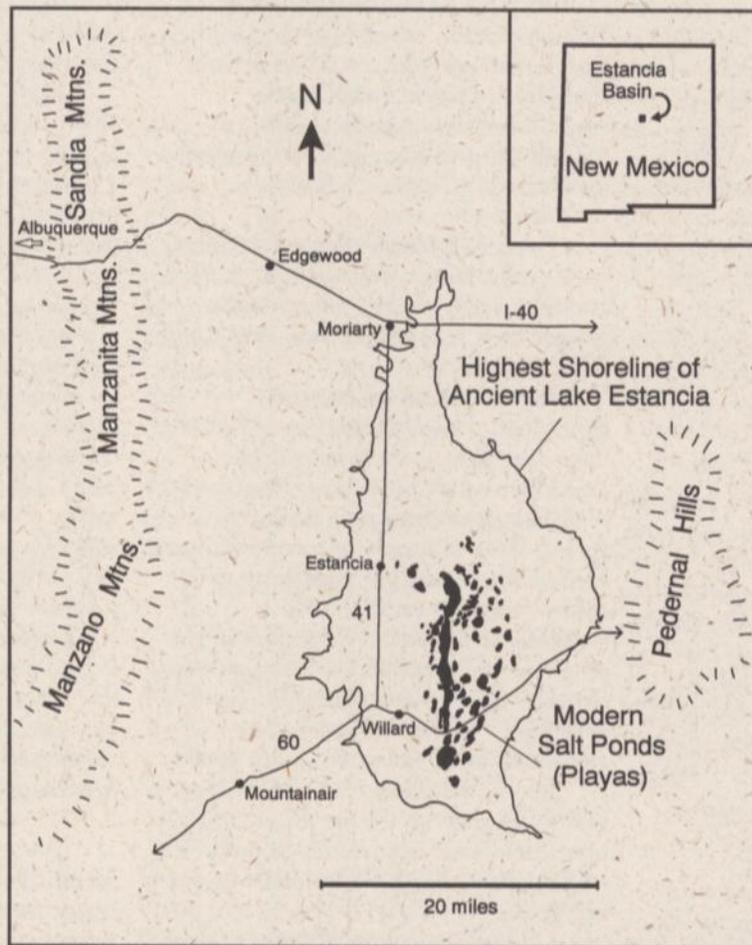


Figure 1. Map showing location of the Estancia basin and extent of former lake as indicated by stranded shorelines.

scientists with a powerful tool for understanding how the Earth's climate has changed over the past several tens of thousands of years. Past fluctuations in lake level can be documented by mapping the elevation of shoreline



Figure 2—Wind deflation of the central basin began ~8,000 years ago, resulting in the formation of numerous blowouts that presently contain ephemeral salt ponds, or playas.

water became salty during lowstands of the lake.

The climatic history of Lake Estancia, as recorded by its sediments, can be read in the walls of the many blowouts that excavated the floor of the old lake. The upper 15 feet of sediments exposed in the blowouts contains two thick beds of nearly pure clay that are bioturbated, indicating highstands of the lake. Radiocarbon dating of the older of the two clay beds tells us that the first highstand began suddenly about 20,000 years ago, forming the highest set of shorelines that now lie stranded along the margins of the Estancia Valley (Fig. 1). Then, just as suddenly, about 15,000 years ago, the climate changed dramatically and the lake dropped to a low elevation (Fig. 4), salinity increased, bioturbation stopped, and only the most saline-tolerant species of ostracodes survived in the lake water. This contraction of the lake lasted for about 1000 years and was followed by another rapid expansion beginning about 14,000 years ago (Fig. 4). This last major expansion of the lake, however, was not as extensive or long-lived as the earlier highstand, and by 12,000 years ago the lake began its final disappearance from the landscape.

The effects of dramatic changes in climate continued to be imposed on the floor of the Estancia Valley, and on other desiccated pluvial lake basins in the Southwest, long after the lakes dried up. The large blowouts cut into the lake sediments at Estancia (Fig. 2), for example, began to be excavated roughly 8,000 years ago as southwesterly winds blew across the abandoned lake bottom. Dried pellets of clay and gypsum, scooped out by the wind, were deposited nearby as giant dunes called **lunettes**, in reference to the crescent shape of the dunes. This process of "deflation" continued until the blowouts reached a depth of about 30 feet below the floor of the basin. An overall rise in the water table during the past few thousand years due to relatively wetter climatic conditions has reversed the trend towards deflation of the

basin floor, and the bottoms of the blowouts are beginning to fill in with sediment.

Some of the earliest attempts to estimate past climates were done in the mid-1900's by using the Estancia Valley and its shorelines to construct a **hydrologic-balance model**. In its simplest form, the hydrologic-balance model keeps track of the volume of water that enters and leaves the lake. Lake Estancia, as for many of the pluvial lakes in the Southwest, did not overflow and the removal of water from the lake was largely through evaporation from the lake surface. Inputs of water into the lake included direct precipitation on the lake surface, runoff from the surrounding drainage basin, and ground-water discharge. These early studies suggested that highstands were the result of both lower temperatures (lower evaporation rates) and increased precipitation.

A topic that is of great interest and importance today is how quickly large changes in climate, such as those recorded by Lake Estancia, may occur. The first good evidence that the Earth's climate has undergone large and abrupt changes in climate has come



Figure 3—Photograph of a blowout (large depression excavated by the wind) in the Estancia basin. Layered sediments in the wall of the blowout were deposited in ancient Lake Estancia during the last Ice Age.

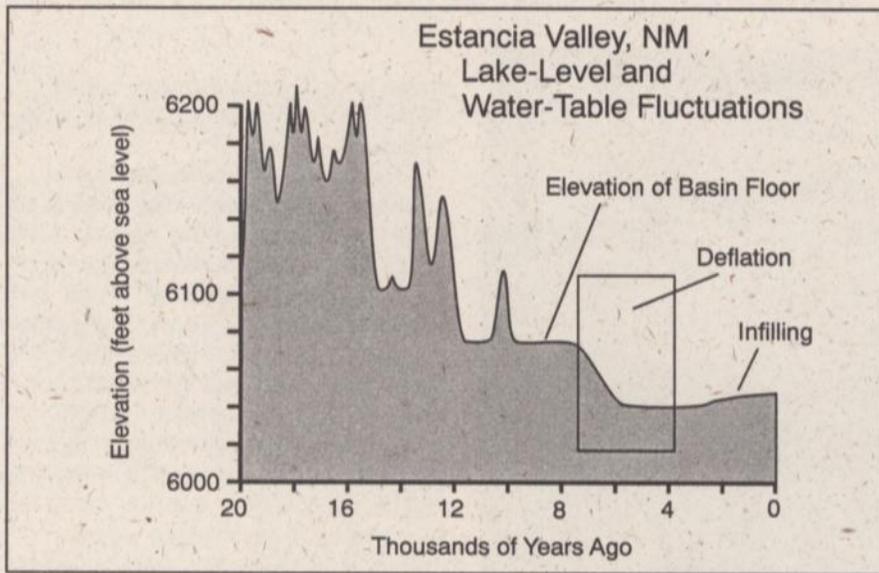


Figure 4—Fluctuations in lake level and water table in the Estancia basin occurred during the last 20,000 years. Notice a rapid rise in lake level ~20,000 years ago and a rapid fall ~15,000 years ago, followed by several other high lake stands.

from cores collected from the Greenland Ice Cap. Ice cores extend from the present back through the last Ice Age and indicate that dramatic shifts in temperature and other climatic variables, at that high latitude, occurred within a few years to a few decades. The abrupt shifts in climate suggest that the earth's climatic system is capable of "flipping" back and forth between relatively stable states in very short periods of time.

Our detailed study of the Estancia lake sequence suggests that rapid shifts in climate, similar to those recorded in high-latitude ice sheets, also occurred over the southwestern United States during the last Ice Age. The change from a low to a high lake stand about 20,000 years ago, for example, was accompanied by a large increase in the runoff of water and sediment being carried to the lake in stream channels. Suddenly, these streams began carrying large quantities of sediment, including sand-sized quartz grains, which were then spread out over the surface of the lake. Thin concentrations of quartz grains, found in muds far from shore, can be traced directly back to the stream channels that carried them. When this major runoff episode

freshened the lake, just as suddenly, ostracodes that live in fresh water reproduced in great numbers. The lake, during that single climatic episode ~20,000 years ago, rose to its high shoreline within a few decades and during the next 5,000 years it was sustained near its highest elevation by other brief episodes of increased precipitation (Fig. 4).

Although most of the moisture that reached Lake Estancia during brief episodes of increased precipitation probably came from the Pacific Ocean, it is unclear what may have triggered the sudden changes in precipitation.

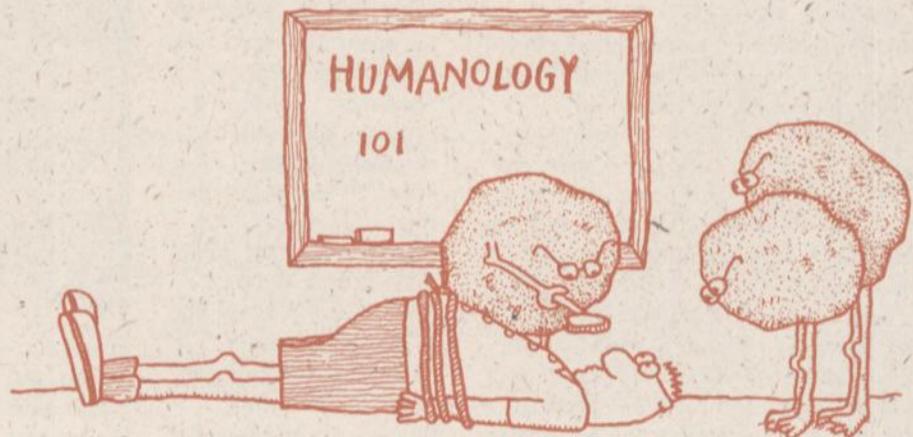
The accumulating evidence for large and abrupt changes in climate and for a metastable climatic system is causing climatologists to reconsider scenarios for global climate change. Prospects for "global warming" from the introduction of carbon dioxide into the atmosphere have been highly publicized, but the prediction of the magnitude and time-scale for such a human-caused event is hampered by an incomplete understanding of natural climatic variability. Records of paleoclimate from different parts of the world that resolve climatic changes on a time scale of decades, such as the one being reconstructed for Lake Estancia, will be needed in order to understand how the earth's climatic system operates and to predict future changes due to both natural variability and human activity.

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# high LITES

EARTH SCIENCE UPDATE

## Teacher Resources:

*How to Teach with Topographic Maps*, for grades 5 through 10, is a 24-page booklet containing student activities, and includes a topographic map by the U.S. Geological Survey. Teachers and students can learn to read topographic maps, and even construct a topo map of their own school yard. Contact: National Science Teachers Association, Publication Sales, 1840 Wilson Blvd., Arlington, VA 22201; phone (800) 722-6782 or (703) 243-7100. The price is \$7.95 plus \$3.75 shipping.

*Surface of the Earth* color-relief map poster measures 31 x 43" and is a computer-generated color image of the topography of the world. The price is \$20.00 which includes shipping (for U.S.A. orders). To order, request **Report MGG-5** from National Geophysical Data Center, NOAAE/GC4, 325 Broadway, Boulder, CO 80303-3328; phone (303) 497-6338.

*Creative Dimensions 1994 Catalog* of Science kits, materials and books lists an abundance of fossil and mineral activity and investigative kits. For a free copy of this catalog, write to: Creative Dimensions, P.O. Box 1393, Bellingham, Washington, 98227.

*Science Fare 1994 Catalog* offers a range of science supplies, including rock specimens and mineral study kits. For a free catalog, write to: Science Fare, 8246 Menaul Blvd NE, Albuquerque, NM 87110.

Note: Please mention *Lite Geology* when ordering any of the materials listed above.

## Upcoming Events

November 3-5, 1994  
*New Mexico Science Olympiad Fall Workshop* for teachers will be held on the campus of New Mexico Tech in Socorro. For More Information call Vannetta Perry, (505) 835-5678.

November 18 and 19, 1994

*The Fall Conference of the New Mexico Science Teachers Association and New Mexico Math Teachers Association* will be held in Albuquerque at the Hilton Hotel. For more information, contact Cindy Lauster, 11520 Paseo del Oso NE, Albuquerque, NM 87111.

## Lite Geology evolves:

*Lite Geology* began as a small Earth-science publication designed and scaled for New Mexico. Our subscription list has grown tremendously during the past two years, and now includes a large number of out-of-state readers. In order to keep up with the demand for this publication from outside of New Mexico, we will charge **\$4.00 per year for out-of-state readers**, which covers the cost of printing and mailing *Lite Geology*. The subscription year begins with the Fall issue, and ends with the Summer issue to correspond with the academic year. This current issue, **Summer 1994, is the last of the free issues** that you will receive if you reside outside of New Mexico. We thank all of our readers for their enthusiastic support, and hope that all of you will continue to subscribe. If you have questions about your subscription, please call Theresa Lopez at (505) 835-5420. Thanks! —ed.

## Lite Geology

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\*\*Beginning with the Fall 1994 issue, out-of-state subscribers will be charged \$4.00 per year to cover printing and mailing costs.

## geologist studies hot springs...

As a follow-up to our last issue, we have continued to explore earthquakes. We hope that our readers will be more able to interpret news about earthquakes—why they occur, how they are measured, and how they influence local geology, such as in the geyser fields of Yellowstone. Although New Mexico does not have geysers to explore, there are a few geothermal areas in the state that have hot springs. The NMBM&MR has about a dozen publications that discuss New Mexico's geothermal resources. These Bulletins, Circulars, and Hydrologic Reports are listed in the current price list available through the NMBM&MR Publications Office, (505) 835-5410. See you next issue!

Lite Geology Staff



hot springs

# LITE geology

is published quarterly by New Mexico Bureau of Mines and Mineral Resources (Dr. Charles E. Chapin, *Director and State Geologist*), a division of New Mexico Tech (Dr. Daniel H. Lopez, *President*).

**Purpose:** to help build earth science awareness by presenting educators and the public with contemporary geologic topics, issues, and events. Use *Lite Geology* as a source for ideas in the classroom or for public education. Reproduction is encouraged with proper recognition of the source. *All rights reserved on copyrighted material reprinted with permission within this issue.*

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