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

LITE geology

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

"I saw ANOTHER meteor Shirley!!!. . .Shirley?"

This Issue:

Earth Briefs

Once Was Not Enough: Meteor Returns

The skies over New Mexico and Texas were busy on October 3, 1996, according to many witnesses who reported seeing bright lights or a fireball travelling to the north and east. Precisely an hour and forty-four minutes later, another intensely shining light streaked eastward over Southern California before it exploded with the force of as much as 100 tons of TNT. Physicist Mark Boslough of Sandia Labs in Albuquerque, and meteorite researcher John Wasson of UCLA, believe that the same meteor visited the United States twice that evening.

These scientists first became interested in the pair of celestial events after hearing news reports about a single flash of light that was seen from New Mexico to California. Thanks to alert viewers like Paul Bauer (see related story), they quickly realized that people in California saw a different flash. By interviewing eyewitnesses from all over New Mexico, Texas, and California, they were able to reconstruct the times and estimate the flight-paths for both visits.

The researchers realized that it might be possible to explain the times, locations, and directions of flight if both meteors were the same object. They suggested that the meteor had been travelling so fast that, when it broke apart as it passed over the boundary between New Mexico and the Texas Panhandle, its main fragment had enough momentum to be flung out toward space again. With its velocity slowed to about 18,000 mph, the fragment could not have escaped the Earth's atmosphere. Instead, it remained in our planet's orbit for almost a full revolution before breaking up over our western coast. For a while that October night, it seems we had a *second moon.*

After reentering the atmosphere over the Pacific Ocean, the meteor's track was visible and sonic booms were heard as it streaked eastward over California. Dozens of seismometers in this earthquake-prone state recorded the shock wave, and low frequency sound (infrasound) waves were picked up by an array of sensors that are designed to make sure that nuclear test ban treaties are not broken.

The fiery mass dropped some final glowing embers as far east as Owens Valley, CA. Scientists still have lots of data to collect and study to confirm this capture-and-reentry hypothesis. This kind of event is of great interest to scientists because it has never before been observed. They will make detailed analyses of a video tape recorded in El Paso, Texas, along with the seismic and infrasound recordings, and any photos, reports, and meteorite fragments that can be found.

This recent meteor appeared almost four years after a similar fireball burned through the sky in Peekskill, NY on October 9, 1992 (Lite Geology, Summer 1993). The New York meteor was easy to verify. On its pathway to Earth, a large fragment punctured the trunk of a 1980 Chevrolet Malibu that was parked in the owner's driveway. The meteorite was found nearly intact and still smouldering under the car.

Even if the capture idea is shown to be correct, scientists may have a harder time explaining other events that took place that same night. Their research has uncovered reports of many other bright meteors, fireballs and atmospheric explosions that took place all over the world within a few hours of the ones in the skies of the western U.S. One explanation is that Earth passed through debris from an asteroid that had recently broken up from a collision. Another suggestion is that an impact on the moon might have ejected some rocks toward the Earth. Whatever scientists ultimately conclude, there is no doubt that something interesting happened on Oct. 3.

Sources

Fire ball seen over Southwest...: Sandia Lab News, Albuquerque, New Mexico, issue for October 25, 1996, vol. 48, no. 22, pp. 1-2.

Cosmic debris makes dramatic entrance: Lite Geology, New Mexico Bureau of Mines and Mineral Resources, Summer 1993, pp. 1-2.

—story by S. Welch, NMBM&MR, and M. Boslough, Sandia National Laboratories

Have you ever wondered...

What Controls Summer Rainfall in the Desert Southwest?

David S. Gutzler
University of New Mexico

Cloudbursts, Droughts, and Monsoons

The American Southwest is an exceptionally arid environment in which the availability of fresh water profoundly affects the distribution and activities of all life. At high elevations, precipitation from winter storms creates an annual snowpack, feeding rivers that flow through the desert. Snowpack and rivers form a natural storage and transportation system for fresh water, augmented by dams and canals built by humans. Across much of the Southwest, however, ecosystems and people depend on summer rainfall for

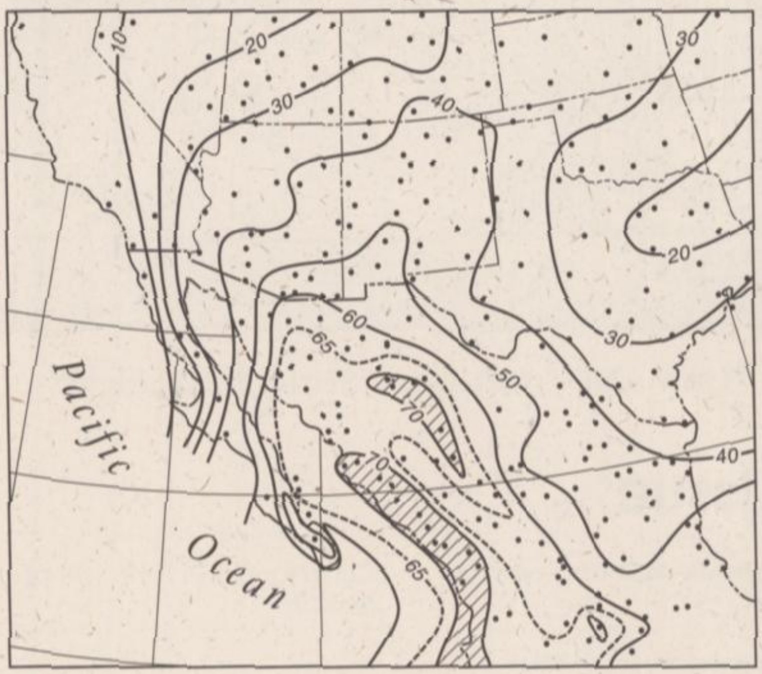

Figure 1—Percentage of the total annual precipitation falling in the three months of July, August and September. Dots represent the stations used in the analysis (modified from Douglas and others, 1993).

much of their supply of fresh water. As shown in Figure 1, most of Arizona and New Mexico receive more than 40% of the total annual precipitation in the three months of July, August, and September. Climate researchers are working to understand the large-scale processes that promote precipitation (or, as was the case in the first half of 1996, inhibit precipitation) in the desert Southwest, with an emphasis on summer rainfall. The ultimate goal of this research is to predict climate variations on seasonal to interannual time scales.

To understand why precipitation varies from year to year, we first need to consider the physical processes by which clouds and rain are formed. Air masses near the surface of the earth always contain at least a small quantity of water vapor, which evaporates from oceans, lakes, plants, and moist soils and is carried along by the wind. Clouds form when water vapor in the air **condenses** from a gas phase into liquid droplets or solid particles of ice. **Precipitation** (rain, snow, or hail) occurs when these droplets or crystals grow so large and weighty that they fall out of the cloud.

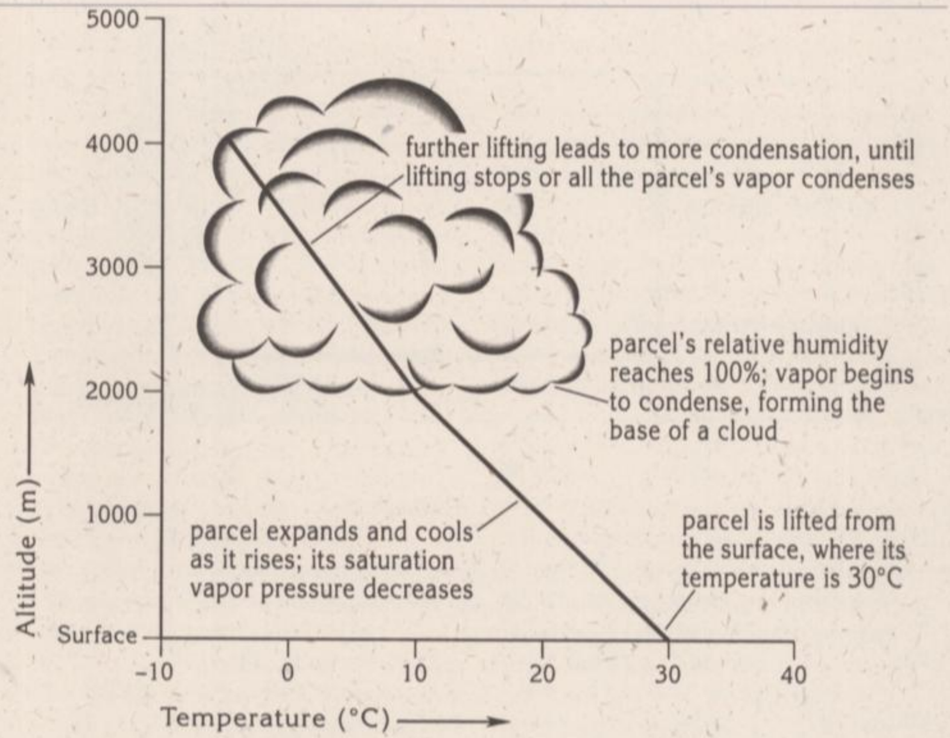

Figure 2—Schematic depiction of cloud formation caused by lifting. A parcel of rising air expands and cools, decreasing its saturation vapor pressure. When its saturation vapor pressure decreases to its actual water vapor pressure, (i.e. its relative humidity is 100%), the water vapor begins to condense, forming a cloud (modified from Moran and Morgan, 1994).

What causes atmospheric water vapor to condense?

The processes by which water changes phase in the atmosphere are extremely complicated and imperfectly understood, but some key physical principles are well-known. One such law of physics states that the **saturation vapor pressure** of water is a strongly increasing function of temperature. This is a more precise way of stating the familiar (but physically imprecise) phrase "warm air can hold more moisture than cold air." Thus clouds tend to form where a warm, moisture-laden airmass is cooled below the temperature at which the water vapor in the air reaches its saturation vapor pressure (then the **relative humidity** is, by definition, 100%).

At ground level, for example, moist air can be cooled to the temperature at which its water vapor starts to condense (such as when moist air blows over a snow- or ice-covered area) to form ground-hugging clouds that we call fog. Aloft, moist air can be cooled by lifting the air, because, as depicted in Figure 2, rising air expands and cools in response to the decrease in air pressure with increasing altitude.

In general, then, the two requirements for forming clouds in the air above the surface are (1) rising air, and (2) sufficient water vapor in the air. To understand how summer rainfall is modulated in the desert Southwest, we need to ask what would cause moist air to rise, and identify the source of moisture in the air. By considering these factors we may learn some clues that could lead to predicting the climatic conditions that modulate clouds and rain.

What causes air to rise?

Lifting can be forced by several different causes. *Orographic lifting* results when air is forced up over a mountain range by the wind; thus the upwind side of a mountain range receives more rain than the downwind side. *Frontal lifting* occurs along cold fronts and warm fronts associated with large cyclonic storm systems, when airmasses with different temperatures collide and the warmer air is forced up over the colder, denser air. This type of lifting is most prevalent in the winter, when such storm systems are most active.

In a previous edition of *Lite Geology* (Winter 1995, pp. 4–9), Dr. Charles Chapin explained that slowly-varying tropical Pacific Ocean surface

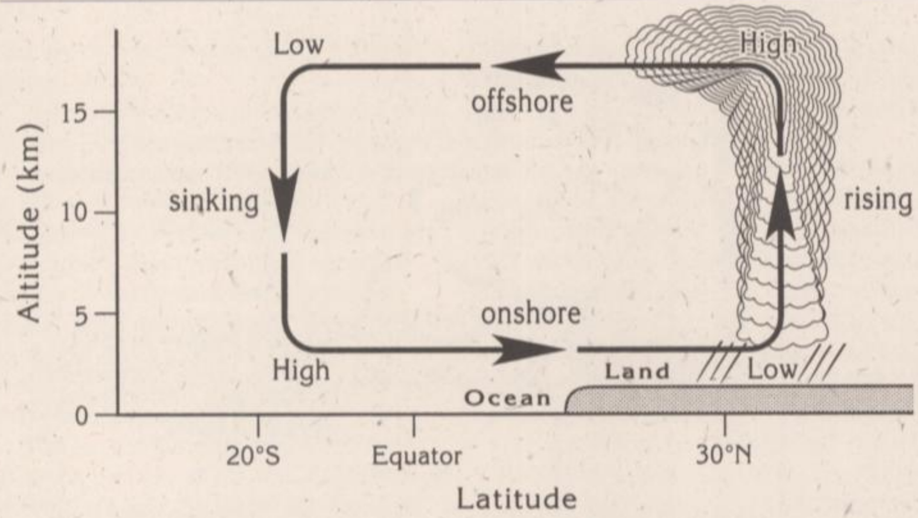

Figure 3—Schematic latitude-height cross-section of a summer monsoon circulation, modeled after the Southeast Asian summer monsoon. The land surface (to the north) has heated up relative to the ocean (to the south). The warm air above the land rises and the cool air above the ocean sinks.

Rising motion over the continent is amplified by the heat released as water vapor condenses in the clouds. Rising motion generates low (L) air pressure near the ground and high (H) air pressure aloft; sinking motion generates the opposite pressure conditions. Horizontal winds blow from high pressure to low pressure, generating low-level onshore flow and upper-level offshore flow, completing the circulation. (modified from Webster, 1987).

temperatures (warm "El Niño" and cold "La Niña" or "El Viejo") affect the winter and spring storm tracks over North America, changing the course of cyclonic storms and thereby providing a potential means for long-range prediction of cold-season precipitation. The light snowpack and general deficit of precipitation across the Southwest during the winter and spring of 1995/96 were consistent with the La Niña conditions that prevailed then.

In the summer, the lifting necessary to produce raindrops is mostly accomplished by yet another mechanism for lifting, called *convective forcing*. This occurs because the process of condensing water vapor releases heat to the surrounding air. The same process operates in reverse in a familiar situation: you need to add heat to a pot of liquid water in order to evaporate the water via boiling. Under the right environmental conditions, which occur principally on hot summer days, if a moist blob of air (meteorologists refer to such hypothetical blobs as "air parcels") is heated near the surface and rises enough to initiate condensation, the additional heat added to the parcel by condensation can be sufficient to make the parcel warmer than the surrounding air. If this happens, then the parcel will continue to rise (often rapidly and explosively), creating a summer convective thunderstorm. Very large droplets or (at altitudes higher than the freezing level) ice crystals can form in the intense updrafts of these storms, yielding copious precipitation for a short time until the storm plays itself out.

Individual thunderstorms are by nature spotty and fairly random relative to the rain produced by orographic or frontal lifting. Given sufficient moisture, thunderstorms can form from cloud-scale hot spots on the ground, which are very difficult to predict much in advance. Over the course of an entire summer, however, large-scale conditions that favor or inhibit thunderstorm formation might persist, or at least be potentially predictable. Thus, we have no realistic hopes of long-term prediction of individual thunderstorms, but we may be able to predict monthly or seasonal averages of thunderstorm activity.

What is the source of summer moisture?

Let us now consider the other requirement for cloud and precipitation formation: sufficient water vapor in the air. If the moisture source for summer thunderstorms is tied to an organized, large-scale circulation system, then by understanding the mechanisms controlling the circulation we might have some hope of characterizing and predicting summer rainfall variability. In the southwestern United States we are located on the fringe of such a circulation system: the Mexican monsoon.

What is a monsoon?

A monsoon is a seasonal, large-scale circulation system forced by differential heating of continents and oceans, illustrated schematically in Figure 3. The ocean has a large thermal inertia relative to land, which simply means that the same amount of energy input (in this case, from sunlight) will raise the temperature of a land surface more than the ocean surface. Therefore, the seasonal temperature variability of a continent is larger than the ocean. In the summer, the land heats up more than the ocean, the warm continental air tends to rise (forming clouds and precipitation) while the cooler oceanic air tends to sink, and onshore winds develop near the surface while offshore winds develop aloft to complete the circulation. In the winter, the continent-ocean temperature difference reverses and so does the associated circulation.

In some parts of the world, this fairly straightforward seasonal reversal of the large-scale circulation is strong enough to dominate the local climate. Monsoonal climates generally occur along continental margins in the tropics and subtropics where winter frontal-type storms are not very prevalent and ocean currents do not force a strong separate seasonal cycle in ocean temperatures. Another important factor is the existence of a high plateau or mountain range not too far from the edge of the continent, because a high-elevation land mass serves as a very efficient summertime heat source for the otherwise-cool air aloft, thereby driving a strong monsoon. The strongest and most famous such system is the Southeast Asian summer monsoon, the principal source of fresh water for more than a billion people on and around the Indian subcontinent.

Is there a true monsoon in the Southwest?

As suggested by the fraction of annual precipitation received in the summer months (Fig. 1), we certainly see the characteristic monsoonal summertime precipitation maximum here in the southwestern United States. The existence of a clear seasonal wind reversal is not so obvious, but recent evidence shows that a true monsoon system is anchored off northwestern Mexico, where winds abruptly turn northward up the Gulf of California in July, forcing tremendous convective activity along the western slopes of the Sierra Madre Occidental. The northward extent of this circulation system is still poorly resolved, but the balance of evidence suggests that rainfall during July and August associated with this monsoon circulation extends up at least as far as the southern portions of Arizona and New Mexico, and conceivably farther.

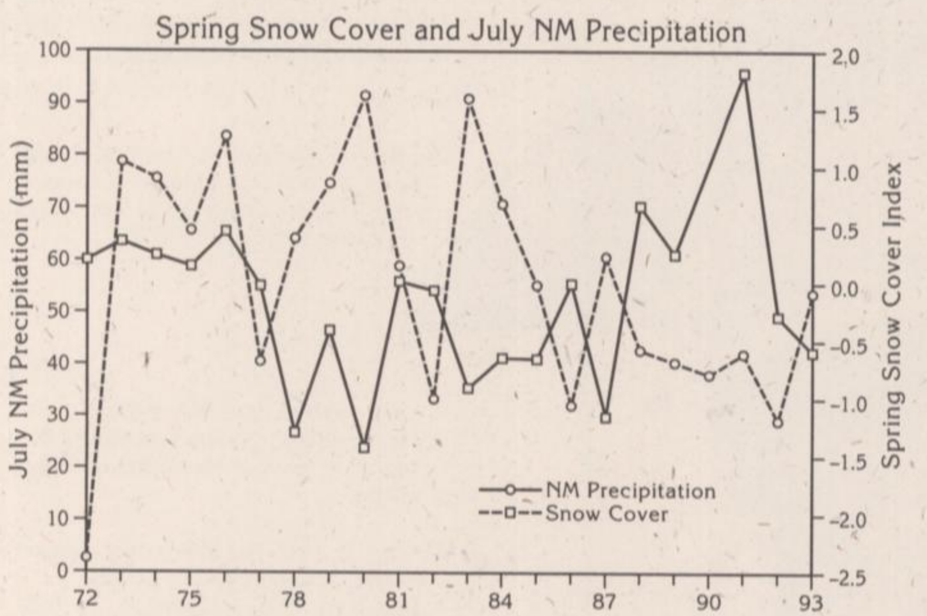

Figure 4—Year-to-year fluctuations of a dimensionless index of springtime snow extent in the American Rockies (dashed line), and July rainfall in New Mexico (solid line); units are in mm.

Predictability of monsoons

To the extent that our summer rainfall is associated with a large-scale monsoon system instead of randomly-forced individual thunderstorms, we stand a better chance of characterizing (and perhaps predicting) year-to-year, large-scale fluctuations of rainfall. An intriguing result of research aimed at forecasting the Southeast Asian summer monsoon is that the springtime snowpack across the Tibetan Plateau seems to modulate the amplitude of the following summer monsoon rains, such that heavy snowpack leads to a weak monsoon, and light snowpack leads to a strong monsoon. The reason for this is intuitively clear: excessive spring snow means cold continental temperatures that tend to linger even after the snow melts (because the land surface is still moist and cool from above-normal runoff), thus inhibiting the summertime land surface heating that drives the monsoon.

Jessica Preston, an undergraduate student at the University of New Mexico, and I have examined the possibility that interannual fluctuations in spring snow cover across the American Rockies might modulate summer rains in New Mexico, in analogy with the Tibetan snow–Southeast Asian monsoon relationship described above. We adopted an index of spring snow extent across the American Rockies derived by a Canadian scientist, Mr. Ross Brown, based on several decades of satellite observations. We compared the year-to-year fluctuations in the spring snow index with a time series of July monthly precipitation averaged over twenty-one stations distributed across New Mexico.

The comparison indicates that there has indeed been a tendency for above-normal springtime snow extent to be followed by below-normal rainfall in July in New Mexico over the past two decades, and below-normal snow extent to be followed by above-normal rainfall (Fig. 4). As you can see, the snow index is by no means a perfect predictor of July rainfall in New Mexico, but the results satisfy a formal statistical significance test, and they are suggestive enough to encourage us to explore the relationship in more detail using longer and more expansive data sets.

To be sure, even if the snow cover–summer rainfall relationship turns out to be real, it is only part of the larger climatic picture. Long-term droughts have occurred in the Southwest from time to time, and the reasons for such multi-year climate anomalies are very poorly understood. The tendency for 20th-Century drought episodes to occur about every other decade suggests that variations of solar luminosity could be an important forcing factor (solar variations have a 22-year periodicity), but a physical mechanism that explains how these rather modest solar fluctuations could result in large climate anomalies has not been demonstrated. We are really just beginning to understand the climate system well enough to consider the possibility of seasonal and interannual forecasting. Formulating such forecasts is a tremendously challenging and fascinating problem.

Glossary

condensation—The process by which water changes phase from vapor (gas) into liquid. Condensation *releases* heat.

evaporation—The process by which water changes phase from liquid into gas (the opposite process from condensation). Evaporation *consumes* heat.

precipitation—In meteorological usage, liquid water droplets or solid ice crystals that are weighty enough to fall out of a cloud toward the ground. Not all precipitation reaches the ground; some evaporates on the way down.

vapor pressure—The pressure onto a surface (which can be an imaginary surface in mid-air) exerted by a single gaseous species, e.g. water vapor. If the atmospheric water vapor pressure onto a liquid water surface is high enough, then the number of water molecules condensing onto the liquid surface equals the number of water molecules evaporating off the surface. At this pressure we say that the air is saturated, and the pressure at which this takes place is called the saturation vapor pressure.

relative humidity—A measure of water vapor in the air, expressed as the ratio:

$$\frac{\text{actual water vapor pressure}}{\text{saturation vapor pressure}} \times 100\%$$

The saturation vapor pressure (the denominator) increases rapidly as the temperature increases, so a relative humidity of 80% on a hot day indicates much more water vapor in the air than the same relative humidity on a cold day. Athletes at the Atlanta Olympics felt the effects of this!

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Moran, J., and Morgan, M., 1994, Meteorology—The atmosphere and the science of weather, Macmillan, 4th ed., 517 pp.

Webster, P., 1987, The Elementary monsoon; *in* Fein, J., and Stephens, P., (eds.), Monsoons: Wiley-Interscience, pp 3–32.

Celestial object reports

Because of the spontaneous nature of many celestial events, scientists sometimes rely on eyewitness reports from casual onlookers. New Mexico Bureau of Mines and Mineral Resources geologist Paul Bauer was one of the first persons to report the fireball to Mark Boslough, the scientist featured in the story on page one. Here is Paul's account of what he saw on October 3, 1996.

"Mark Boslough and I are friends, and knowing his interest in the celestial, I contacted him by e-mail the day after I saw the fireball....

The night of the fireball was clear and cloudless. That evening I was seated in a chair at homethat faced an eastern window. As the fireball came into view, my attention was immediately drawn, as it was very bright (much brighter than Venus at it's brightest) and trailed brilliant green sparklers (like the 4th of July type). It appeared to move slower than any shooting star that I had ever seen.

My first impression was that the bright object was a plane or something that was burning up and crashing. I jumped up and dashed out the door and onto the deck, expecting to hear an explosion as it crashed across the river. But, it had disappeared from view behind the cottonwood bosque without making a sound.

Mark later asked me to recreate the trajectory of the fireball. My report was important because I had viewed the object through a fixed frame of reference (the window frame). I sat in the same chair and used the window frame to mark the spots where the object had appeared and disappeared, and then measured my distance from the window, and the angles from the horizontal (using my handy brunton compass). Then I took an orientation (azimuth) on the direction that the window faces. Mark then calculated the approximate position and path of the fireball.

Mark later devised and tested a more precise method of calibrating meteor tracks that does not involve compasses or transits. He has asked me to make a time exposure, night sky photograph from the precise observation spot, and record the exact time of the photograph. When I get the print, I am to draw the trajectory with error bars. Using the stars, along with the time and location, both of which I can get extremely accurately with a global positioning system (GPS) unit, Mark will then use a computer to determine a trajectory.

According to Mark Boslough, good reports on meteor sightings are difficult to find. Here are a couple of examples:

"After UCLA put out a $5,000 reward for the first meteorite recovered from this event, they received dozens of rocks in the mail. So far they are calling them all *meteor-wrongs*."

"The New Mexico fireball passed almost directly over Roswell. When I was first trying to get names of eyewitnesses in that area I called the local TV station and sheriff's department with no luck. It occurred to me that some people might report what they saw to one of the two local UFO museums, so I called them to find out. They both told me the same thing: They got a lot of calls, but it was "just a meteor" so they didn't write down any information."

Dr. Nelson realized this was no ordinary meteor

Tremor Troop and *Seismic Sleuths* workshop series concluded for 1996–1997

Two *Tremor Troop* and two *Seismic Sleuths* workshops were conducted by staff from New Mexico Bureau of Mines and Mineral Resources (NMBM&MR), New Mexico Tech (NMT), and Los Alamos National Lab (LANL). The workshop series was sponsored by the New Earthquake Program of the New Mexico Department of Public Safety (NMDPS), with funding from Federal Emergency Management Agency (FEMA).

Ninety-three teachers from across the state attended the three-day courses, which were held in four different locations: Socorro (hosted by NMBM&MR), Los Alamos (hosted by LANL), Albuquerque (hosted by New Mexico Museum of Natural History), and Las Cruces (hosted by Las Cruces Public Schools). Teachers gained hands-on experience with the earthquake curricula and learned about the geology of New Mexico on field trips.

The primary instructors for the workshop series were Dave Love, Nelia Dunbar, Bill Chavez, Jamie Gardner, and Leigh House. Several classroom teachers who had experience with the curricula were invited to serve as facilitators at the workshops. Teacher-facilitators included Sue Ann Baranchick, Sue Abbott, Gary Lewis, Larry Rucker, Diana Lawton, Don Young, and Ernest Cummings. Others who helped as either coordinators or facilitators were Debra Pritchard and Bob Redden (NMDPS), Mike Price (Santa Fe Pacific Gold Corp.), Susan Welch and Lynn Heizler (NMBM&MR), and Alexis Lavine (LANL).

Dr. Jamie Gardner (A. R. G. G., Geologist at LANL) fields teachers' questions about the Española Basin of the Rio Grande rift and the local fault activity.

Dr. Bill Chavez (Associate Professor, New Mexico Tech) and Dave Love (Senior Environmental Geologist, NMBM&MR) discuss the fault offset along the Rio Grande fault south of Albuquerque.

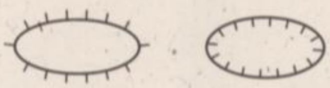
Dr. Nelia Dunbar (NMBM&MR Geochemist) explains the hydrovolcanic sequence at the Isleta Volcano south west of Albuquerque.

Tremor Troop participants listen to Dr. Jamie Gardner at Guaje Mountain fault, the site where LANL scientists excavated the first paleoseismic trench in the Jemez Mountains region. The trench revealed evidence for a Holocene (between 4,000 and 6,000 years ago) magnitude 7 earthquake.

to represent the topographic relief of an assigned portion of the state. These tiles will then be used to make molds, then concrete casts that will be placed together with hundreds of similar sections to form the final map sculpture. To become a partner in this project, contact Tish Morris at (505) 841–2822; or tish@darwin.nmmnh-abq.mus.nm.us.

oops!

In the summer 1996 issue of *Lite Geology*, we inadvertently reversed some terms and symbols in the map legend on page 4. Here is the correct designation for the terms **basin** and **uplift**. The contour line containing hachure marks *pointing inward* from the line indicates a basin, or depression. A contour line with hachures *pointing outside* from the line indicates an uplift. Remember, basins are "innies" and uplifts are "outies." We're sorry for the confusion!—ed.



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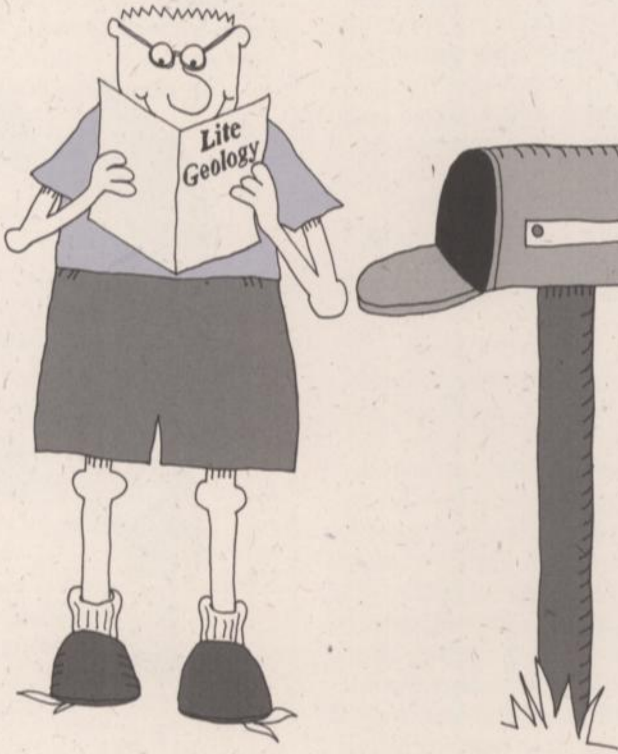
have you missed us?

You may have noticed that our production of *Lite Geology* has slowed over the past months. Funding cutbacks have forced us to stop printing (temporarily). Because we remain committed to the idea that *Lite Geology* should be free to New Mexico readers, especially teachers, we are looking for new funding sources to support this project. Please be patient; we're working hard to resolve the problem. If you have some creative funding ideas, or would like to become a financial sponsor, please contact *Lite Geology* at (505) 835–5112 or 835–5420. Thanks! —ed



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Lite Geology **Staff Information**
Editor: Susan J. Welch; susie@mailhost.nmt.edu
Geological Editors: Dr. Dave Love, Dr. Charles Chapin, Gretchen Hoffman, Dr. Nelia Dunbar
Graphic Designer: Jan Thomas
Cartoonist: Jan Thomas with inspiration from Dr. Peter Mozley
Editorial Assistant: Toby Click
Creative and Technical Support: NMBM&MR Staff

Mailing Address
New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801. Phone (505) 835-5420. For subscription information, please call or write. *Lite Geology* is printed on recycled paper.
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New Mexico Bureau of Mines and Mineral Resources
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