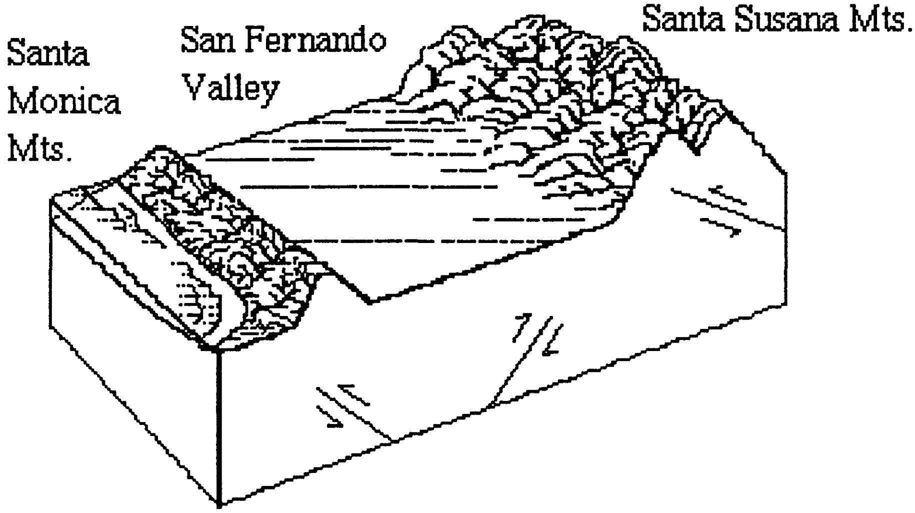
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

The Northridge, California, Earthquake of January 1994:

A computer animation and paper model

by
Tau Rho Alpha* and Ross S. Stein*

Open -file Report 94-214



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Menlo Park, CA 94025

Description of Report

* Note: In the diskette version (HyperCard stack) additional information can be viewed by clicking on an astrisk (*) or **bold type**.

This report illustrates, by means of computer animation, and paper model, how three different earthquakes, the 1971 San Fernando, the 1987 Whitter Narrows and the 1994 Northridge, behaved and what type of movement there was on the three blind faults. The report is intended to help students and others visualize what caused the earthquakes, and the shaking and movement of the ground. By studying the animations and the paper model, students will come to understand earthquakes and that the potential consequences of earthquakes are numerous and serious. Included in the diskette version of this report are the templates for making a paper model, instructions for its assembly, a fault map and discussion, and animations showing the movement that resulted from the three different earthquakes. Each animation is accompanied by sound. If no sound is heard change the memory of HyperCard to 4500K. To change the memory available to HyperCard quit this stack. Highlight the HyperCard program icon "get info" from File Menu. Change the "memory requirements" to 4500K, start this stack again. The paper version of this report includes everything except the animations.

Description of Report

Requirements for the diskette version are: Apple Computer, Inc., HyperCard 2.2™ software, and an Apple Macintosh™ computer with high-density drive. If you are using System 7, I recommend using at least 3 MB of RAM with 4500K of memory available for HyperCard. To change the memory available to HyperCard quit this stack. Highlight the HyperCard program icon "get info" from File Menu. Change the "memory requirements" to 4500K, start this stack again.

Purchasers of the diskette version of this report, which includes all of the text and graphics, can use HyperCard 2.2™ software (not supplied) to change the model (by adding geologic patterns, symbols, colors, etc.) or to transfer the model to other graphics software packages*.

To see the entire page (card size: MacPaint), select "Scroll" from "Go" menu and move the hand pointer in the scroll window. If you are experiencing trouble with user-level buttons, select "message" from the "Go" menu. Type "magic" in the message box and press return. Three more user-level buttons should appear.

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to go to that section
of the report

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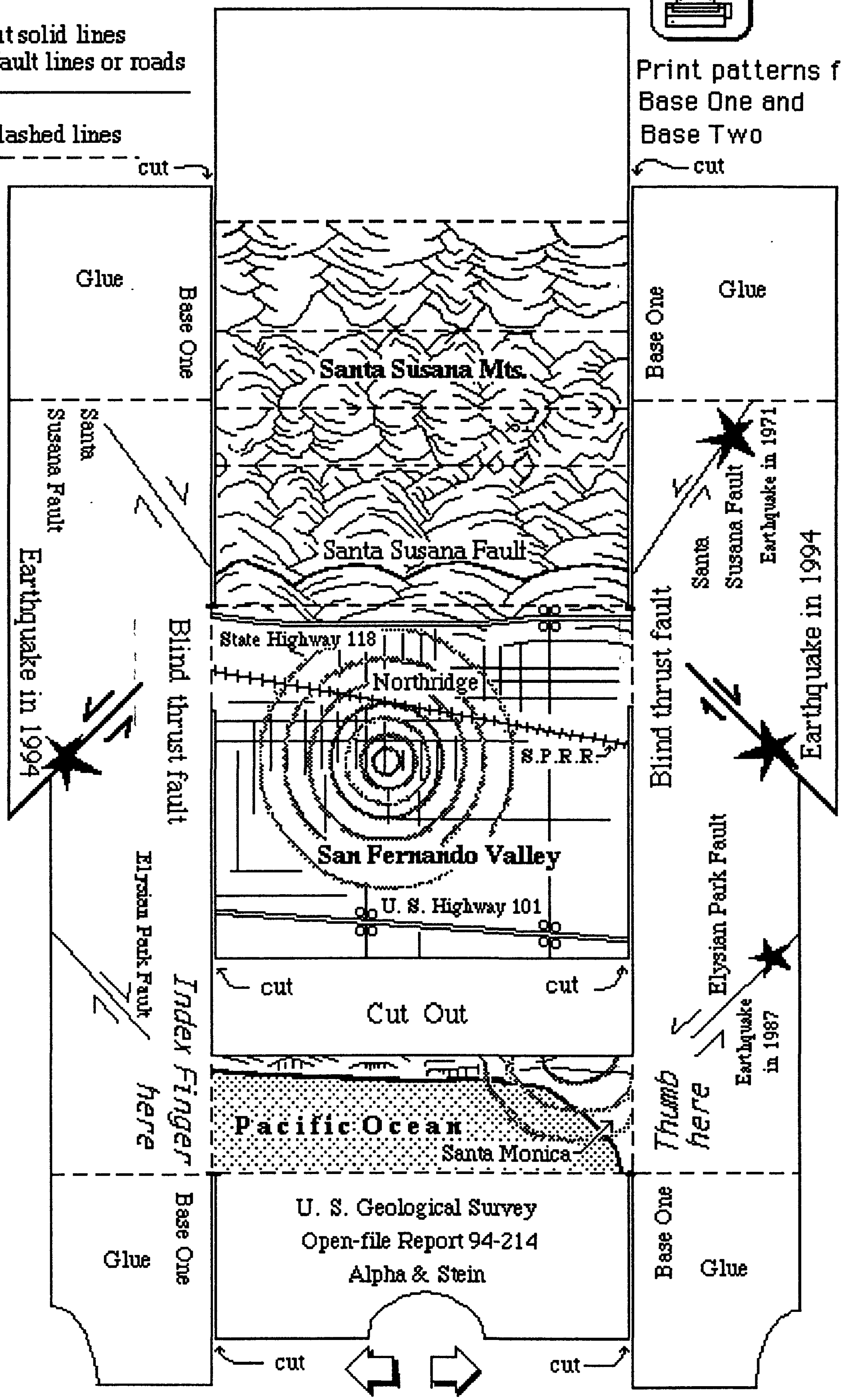
Base One

Cut solid lines except fault lines or roads

Fold dashed lines

Print patterns for Base One and Base Two

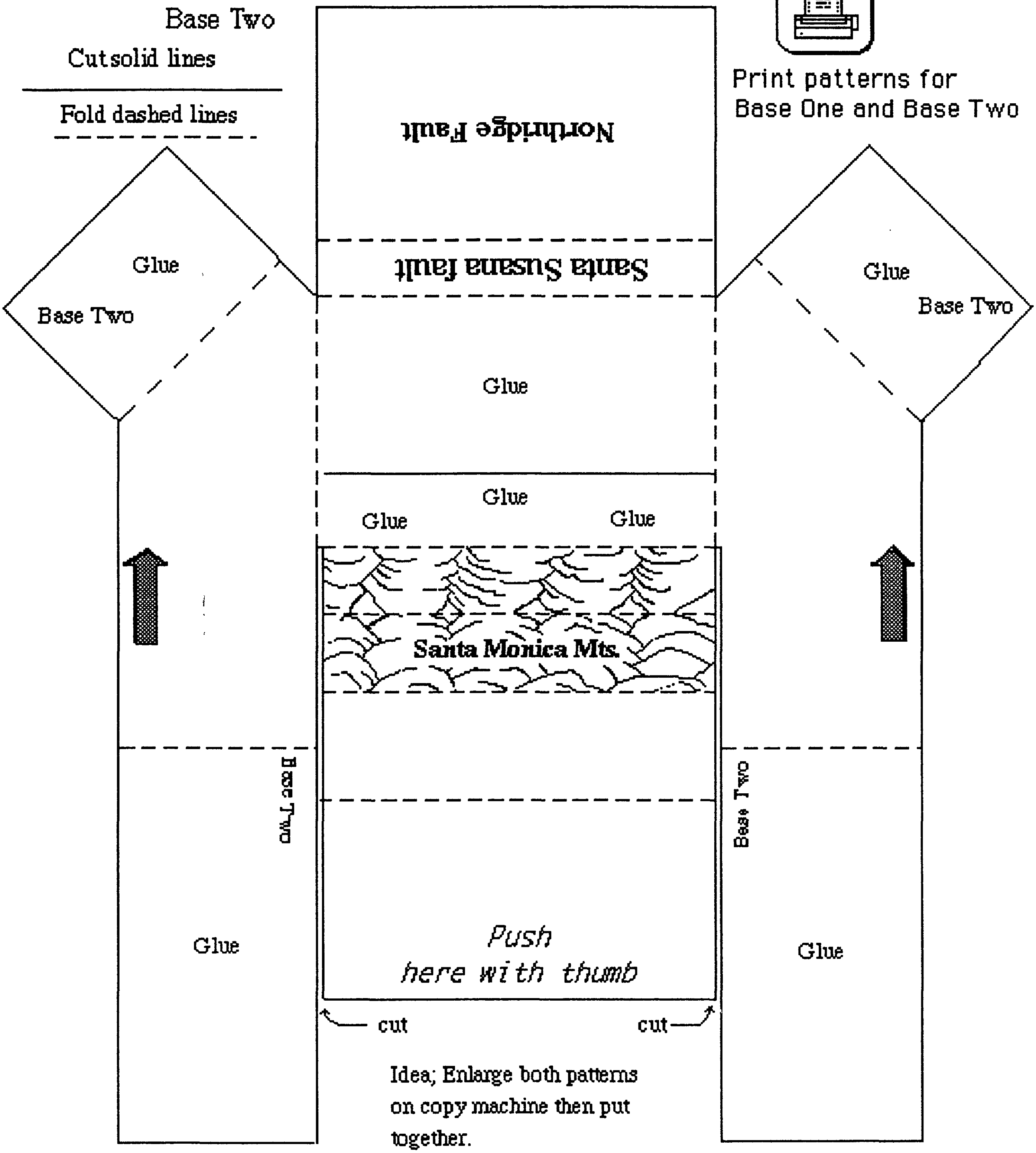


Print patterns for
Base One and Base Two

Base Two

Cut solid lines

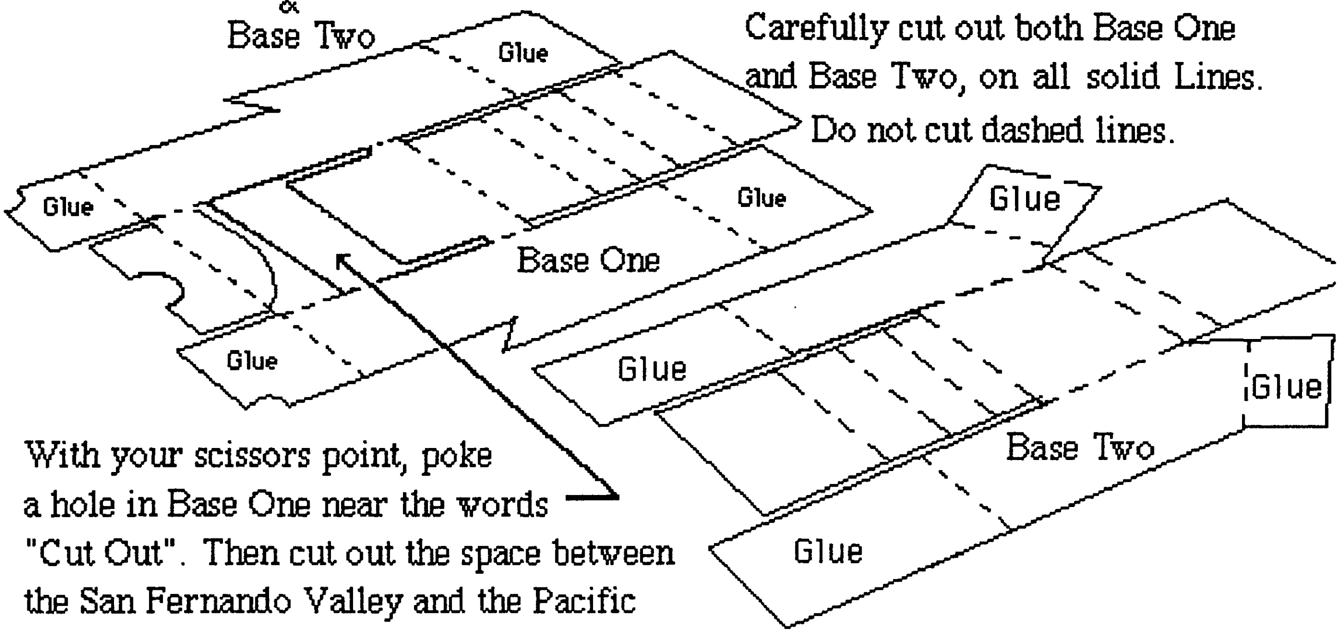
Fold dashed lines



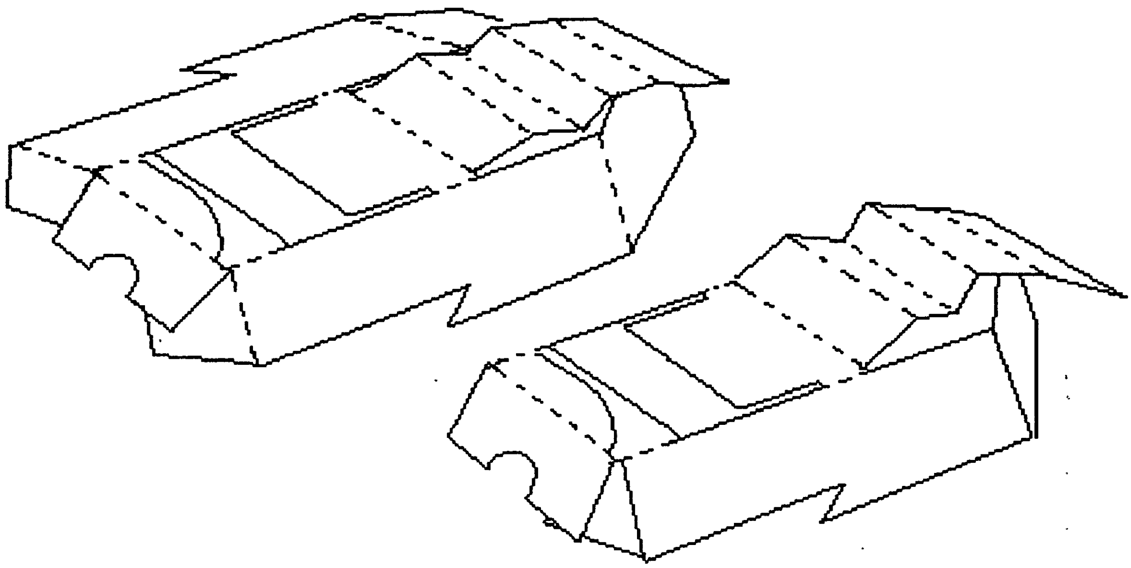
Idea; Enlarge both patterns
on copy machine then put
together.

Base One
&
Base Two

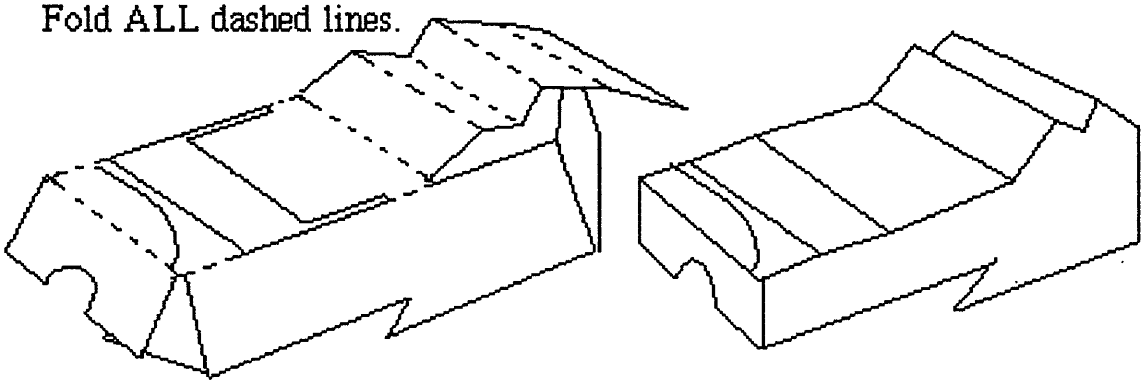
Carefully cut out both Base One and Base Two, on all solid Lines. Do not cut dashed lines.

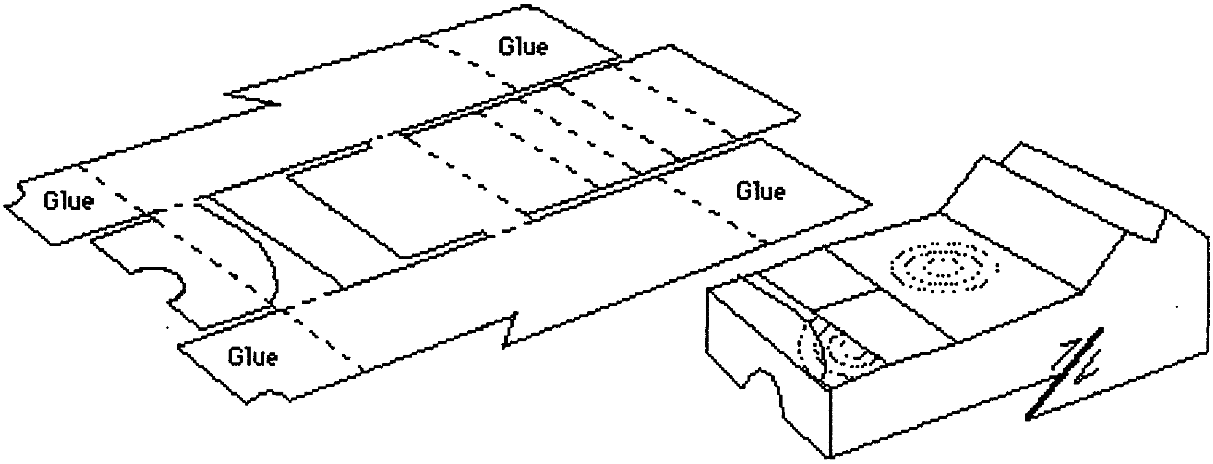


With your scissors point, poke a hole in Base One near the words "Cut Out". Then cut out the space between the San Fernando Valley and the Pacific Ocean. This is where the Santa Monica Mts. from Base Two will fit.



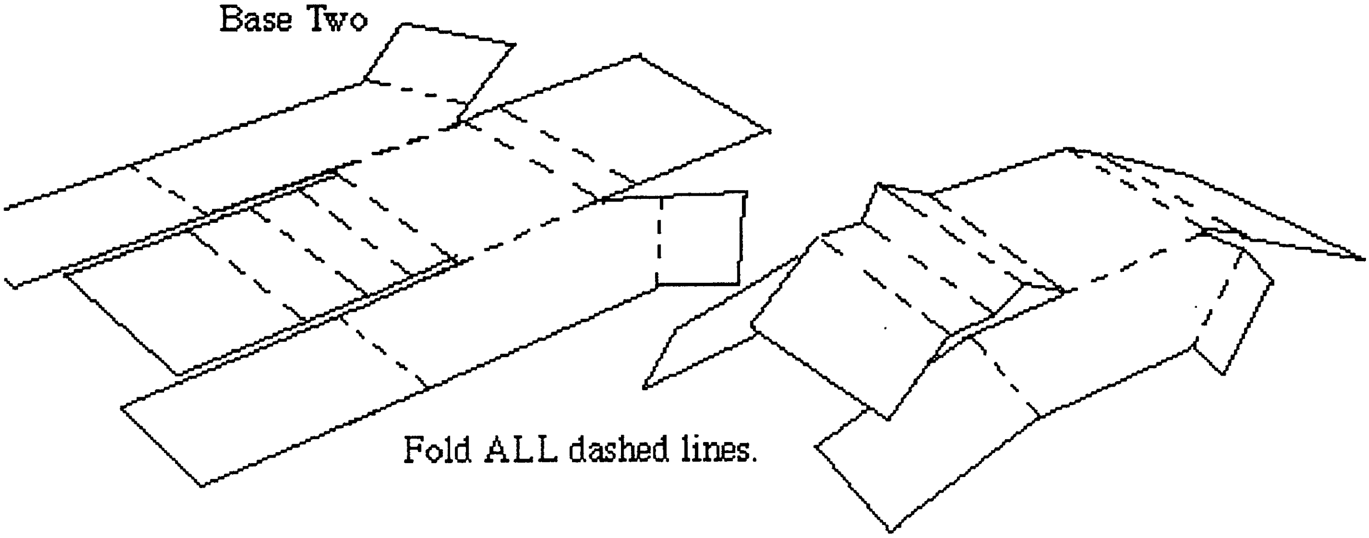
Fold ALL dashed lines.





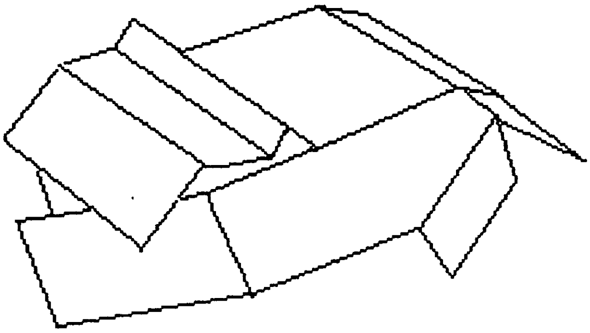
Place Base One on scrap paper. Glue the four tabs carefully to make Base One. All tabs marked "Glue" will fit behind solid ends of base.

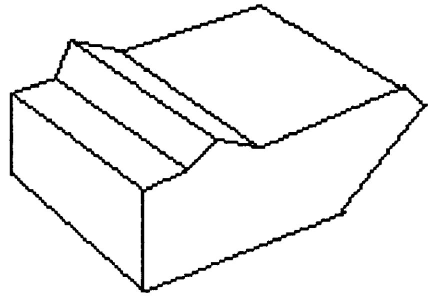
Base Two

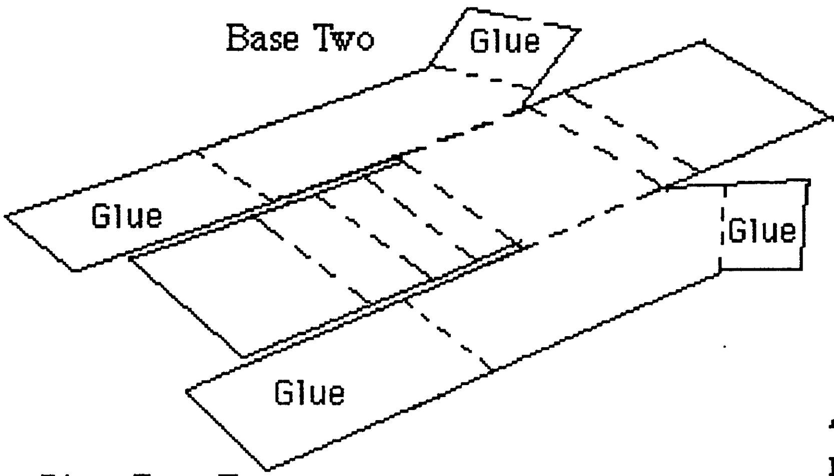


Fold ALL dashed lines.

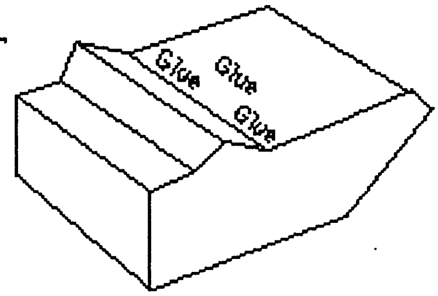
Base Two



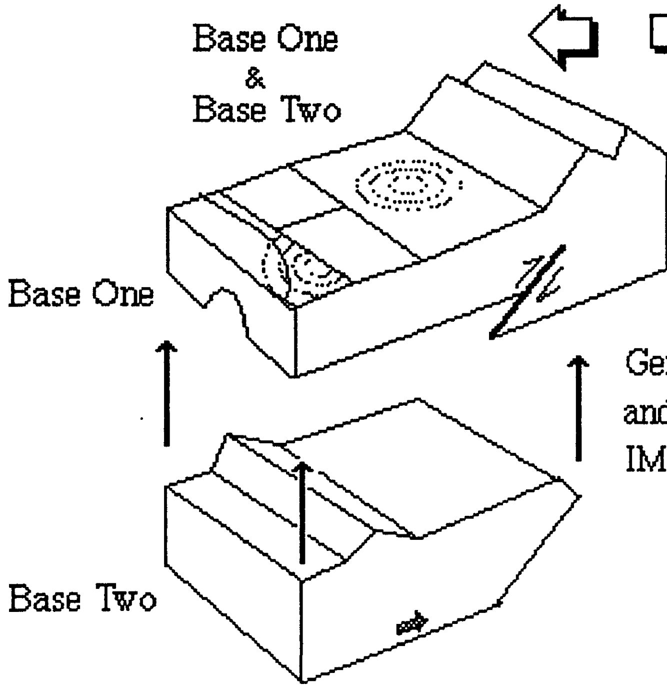




Place Base Two on scrap paper.
Glue the four tabs carefully
to make Base Two.



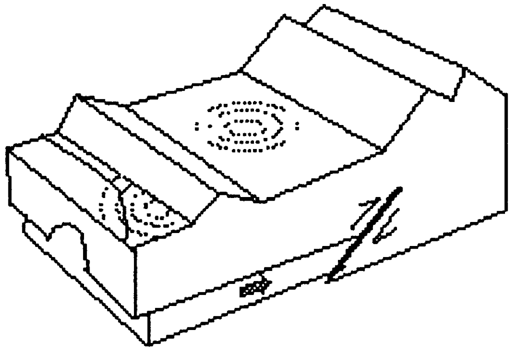
Add glue to the area
marked "Glue Glue Glue"
behind the Santa Monica Mts.



Now you have two glued parts.

Gently fit Base Two under Base One and push Highway 101 onto the glue. IMPORTANT: let dry.

Model of
Northridge earthquake



Hold the front sides of Base One between thumb and index finger of one hand. With the thumb and fingers of the other hand gently and slowly push Base Two back, creating an up-and-down earthquake in the San Fernando Valley. —Wait for animation.—

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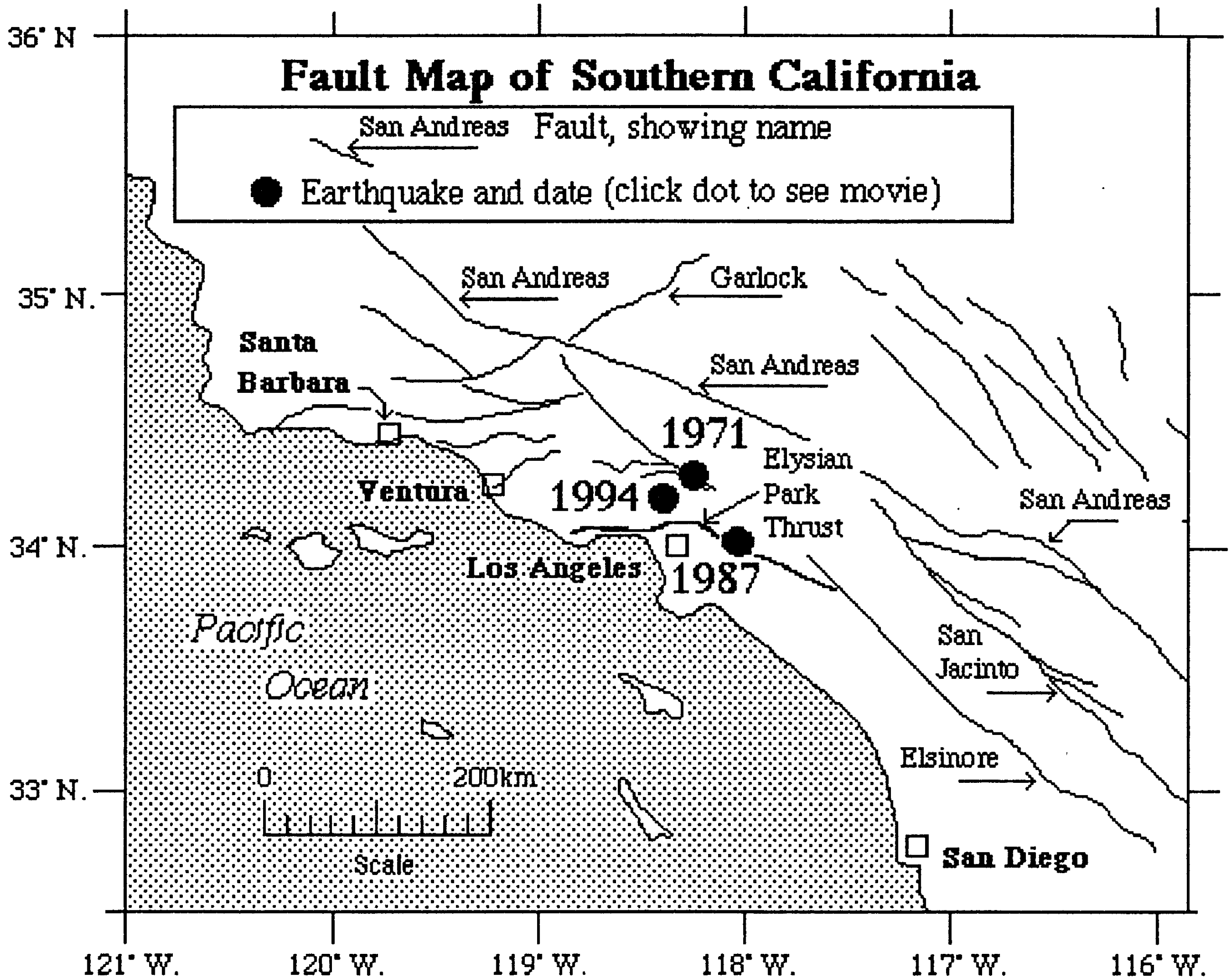
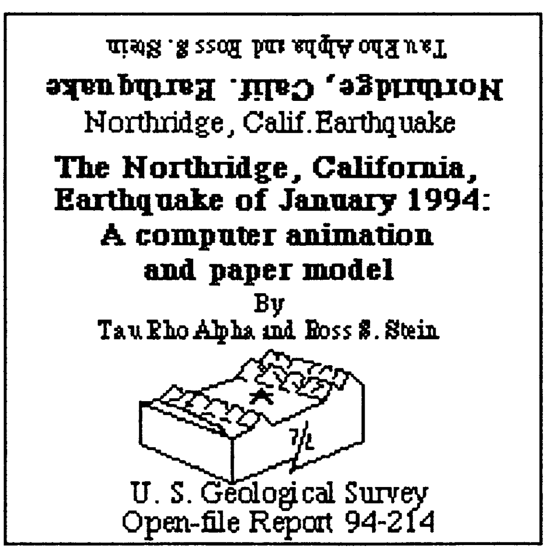
Educator's Guide: Northridge California Earthquake 1994 Summary





Cover for Disk

Educator's Guide Continued : Northridge California Earthquake 1994 Summary

Summary

The most damaging earthquake in the history of the United States struck the northern flank of the Los Angeles basin on January 17, 1994. The magnitude-6.7 Northridge earthquake occurred on a **"blind"** or buried thrust **fault**, inclined to the south, rooted under the San Fernando Valley and extending north under the Santa Susana Mountains. The earthquake raised the mountains and the northern San Fernando Valley by about 1 foot (0.3 m). The previously unidentified fault extends under and abuts against the fault plane that broke in the same-size 1971 San Fernando earthquake. The Northridge earthquake is the fifth in a series of moderate events (M>5) to strike the northern Los Angeles basin since the 1987 Whittier Narrows earthquake. All of these earthquakes have been related to a broad system of **thrust faults** that accommodate compression of the crust and produce uplift of the Santa Susana, Santa Monica, and San Gabriel Mountains that rim the northern Los Angeles basin.

Educator's Guide Continued :
Northridge California Earthquake 1994 Summary

Rupture of the fault.- The base of the fault that ruptured in the Northridge earthquake slips at a steady rate of just 1/4 inch (6 mm) per year. But in just a few seconds, the rate of fault slip sped up (**"accelerated"**) to 6,000 miles per hour (9656 km/h). This sudden slippage of the fault is known as an **earthquake**. At this speed, it took just 6 seconds for the fault to unzip ("rupture"). During this brief time, the two sides of the fault slipped past each other about 4 feet (1.2 m). It took another several seconds for the seismic waves to travel outward from the fault and to reach the Earth's surface. The waves traveled across the San Fernando Valley in about 10 seconds. The shaking became weaker in the Santa Monica Mountains, probably because the rock is stronger there, and became strong again in the city of Santa Monica, where the waves bounced (or "**reverberated**") at the edge of the deep, sediment-filled Los Angeles basin.

Imagine a drawer that becomes stuck. You push and it won't budge. So you push very hard, and it slams into the chest of drawers causing the dresser to shake and producing sound. Faults, too, tend to be "stuck" most of the time. Eventually, the stress acting on them is greater than their strength, and they become unstuck, producing the sudden fault motion. The sound waves that travel through the earth's crust (called "**seismic waves**") cause the shaking that is the principal hazard of an earthquake.

Shaking of the Earth. The strong shaking (acceleration) experienced was about 70 percent stronger than expected for an earthquake of magnitude 6.7, and the shaking was also greater than was measured during the 1971 San Fernando earthquake, which had the same magnitude. It is possible that the shaking was stronger because the fault slipped a large amount over a small area, or because of reverberations in the San Fernando Valley, but the reason for the strong shaking is still a mystery.

Educator's Guide Continued :
Northridge California Earthquake 1994 Summary

When an **earthquake rupture propagates** toward a site on the ground, the shaking is significantly larger, a phenomenon known as "**directivity**".
This is why sites to the north of the fault in the Santa Susana Mountains experienced some of the strongest shaking. The Sylmar Hospital was such a site, located northeast of the fault. Ironically, the original Sylmar Hospital building was destroyed in the 1971 San Fernando earthquake by ground motion that was probably also enhanced by directivity. In 1971 the rupture moved up from depth and toward the hospital from the north, and in 1994 the rupture moved up and toward the hospital from the south. So the hospital was unlucky enough to be in the wrong place for both earthquakes. Sadly, 14 hospitals were damaged during the Northridge earthquake, and thus were not operational after the earthquake. This would have created a medical crisis if the earthquake had occurred during the weekday rush hour, because many more people would have been injured.

Educator's Guide Continued :
Northridge California Earthquake 1994 Summary

The Northridge Earthquake. One of many in southern California.- The 1971 San Fernando, 1987 Whittier Narrows, and 1994 Northridge earthquakes are all magnitude 6.0 (or greater) shocks that lie within 25 miles of each other. Are they related? It appears that the 1971 San Fernando shock increased the stress on the Elysian Park thrust fault on which the Whittier Narrows shock occurred, and also on the unnamed fault on which the Northridge earthquake took place. Because all three faults produce earthquakes that repeat infrequently-perhaps once every thousand years–the small increase in stress caused by the 1971 earthquake likely advanced the occurrence of the 1987 and 1994 shocks.

Are the thrust earthquakes related to the San Andreas fault 30 miles to the northeast of Northridge? The thrust faults along which the 1971, 1987, and 1994 earthquakes occurred are the result of a big bend in the San Andreas fault. The bend causes crumpling, or "compression" of the Earth's crust nearby, giving rise to the thrust faults. Motion on the thrust faults, in which one side of the fault slides over the other, relieves the compression. This portion of the San Andreas fault last ruptured in 1857, and it has had earthquakes roughly 100-200 years apart during the past 13,000 years. Thus the San Andreas itself is due for a great earthquake, although the event might not come for another 50-100 years.

Educator's Guide Continued : General earthquake information

Earthquakes. An **earthquake** is a sudden shaking or vibration in the Earth caused by sudden release of slowly accumulated strain. Most earthquakes result from movement between the large rigid blocks of rock, or **plates**, that compose the Earth's surface. This movement occurs on **faults**, the boundaries between blocks of rock.

The slow churning motion of the hot molten rock in the mantle, far beneath the Earth's surface, drives the plates, causing them to move up or down against each other, away from each other, or to slide past each other along faults. It is difficult for one plate to slip against another because of the great forces pressing them together. Consequently, the plates often do not slip freely in constant slow motion; instead, they slip in a jerky fashion. Each jerk causes an earthquake. This continuous motion of the Earth's plates is called **plate tectonics**.

This report illustrates the motion of plates sliding past each other along what is known as a **"blind" thrust fault.** A "blind" thrust is a buried fault that is inclined to the Earth's surface and is deep enough that it does not reach the surface. The relative motion on the fault is such that one side of the fault moves upward and the other down, but the movement does not cause visible offset at the surface.

Before an earthquake, the tectonic forces that drive the plates cause the rock in the vicinity of a fault to distort and bend. Energy is stored in the rock as it deforms, in much the same way as energy is stored in a rubber band as it is stretched. This energy is called **elastic energy**. When the forces exceed the strength of the rock along the fault, the fault suddenly slips, just as the stretched rubber band snaps back to its original shape when it is let go. The point on the fault at which slip first occurs is the **hypocenter** of the earthquake. The point on the surface of the Earth directly above the **focus** is the **epicenter** of the earthquake. The area of slip on the fault grows rapidly outward from the focus and may extend upward to the surface of the Earth.

Educator's Guide Continued :

Slippage on a fault. When the fault slips, the elastic energy stored in the rock is released as **seismic energy** in the form of **seismic waves** or earthquake waves. These waves spread outward from the fault. Close to the earthquake fault, the seismic waves can be strong enough to knock people to the ground. The waves are weaker the farther one is from the earthquake fault. Consequently, shaking is usually greatest near the source of the earthquake.

There are two classes of seismic waves: **body waves,** which travel at high speed through the deeper, denser rock within the body of the Earth, and **surface waves,** which travel at a slower speed through rock near the Earth's surface. The body waves arrive earlier than the surface waves. There are two types of body waves: **P-waves**, which are similar to sound waves, and the slower but more damaging **S-waves**. P-waves travel about 4.8 to 8.0 km (3 to 5 miles) in one second, while S-waves travel about 3.2 to 4.8 km (2 to 3 miles) in one second. Surface waves are slower still and can cause even more damage due to their greater duration.

Earthquake Damage.-Earthquakes can cause severe and widespread damage to weak or unreinforced buildings or structures. Movement associated with the earthquake may cause landslides and (or) tear apart buildings, roads, and pipelines built above the fault. Such damage can be spectacular, but it is usually limited to the vicinity of the earthquake.

The collapse of highway overpasses and several new parking garages were the most dramatic building failures caused by the Northridge earthquake. The highway overpasses that collapsed were identified as weak before the earthquake and were scheduled for seismic strengthening ("**retrofitting**"). The damage to these older overpasses was strikingly similar to that resulting from the 1971 San Fernando earthquake. In contrast, highway overpasses retrofitted since the 1971 San Fernando earthquake performed well and did not fail.

Educator's Guide Continued :

Most damage results from strong shaking during the passage of seismic waves, which spread out from the fault over a large region. Shaking may be severe enough and long enough to collapse weak buildings, overturn furniture, topple water heaters and storage tanks, and collapse unsafe dams. These effects can result in further damage through fires resulting from broken gas mains and fallen electric wires, the loss of water to fight fires because of broken water mains, oil spills caused by failure of storage tanks, and flooding resulting from dam failure. Shaking can also cause landslides. These in turn can damage buildings, roads, and pipelines built on slide areas or downhill from them. An earthquake can cause a seismic sea wave, or **tsunami**. Such waves can be as large as 30 m (100 feet) high. If they occur when the tide is high, they can sweep inland into a town and destroy harbor facilities and buildings.

People can do many things to protect themselves and their homes from earthquakes. They can fasten tall, heavy objects in their homes to walls so they will not fall in an earthquake. Houses can be inspected to make sure the foundations, walls, and chimney are built to withstand the effects of possible shaking. When choosing where to live, a family can ask city or county officials what areas are subject to earthquake faulting, strong earthquake shaking, or landsliding. Finally, a family can plan what each member will do if an earthquake occurs while at home or while away from home, such as at school or at work.

Educator's Guide Continued :

Vocabulary one of two pages

acceleration A change in velocity or speed. A car accelerates from 0 to 60 miles per hour, for example, in about 10 seconds.

"blind" thrust fault A "blind" thrust fault does not cut the surface of the Earth. See thrust fault, next page.

directivity Seismic waves concentrate and build in the direction the rupture is moving, and they diminish and spread out in the direction opposite to the rupture propagation. When you hear a train coming toward you, the pitch is higher than when it is going away from you. This is often called the Doppler effect.

body wave A seismic wave that travels through the interior of the Earth and is not restricted to any boundary surface.

earthquake A sudden motion or trembling in the Earth caused by the abrupt release of slowly accumulated strain.

elastic energy The energy stored within the Earth during elastic deformation.

epicenter That point on the Earth's surface which is directly above the focus of an earthquake.

fault A surface or zone of rock fracture along which there has been displacement.

focus That point on a fault at which the sudden break resulting in an earthquake begins.

hypocenter That point on a fault where the earthquake begins.

plate tectonics The Earth's surface is composed of large, semirigid sections (plates) about 50 km (30 miles) thick that float across the mantle, with seismic acivity and volcanism occuring primarily at the junctions of these sections.

plates Large, nearly rigid, but still mobile segments of blocks about 50 km (30 miles) thick involved in plate tectonics, that include both crust and some part of the upper mantle.

Educator's Guide Continued :

Vocabulary two of two pages

Propagation of an earthquake rupture. The fault unzips from one end to another at about 6,000 mph, each side of the fault moving in opposite directions by several feet.

P-wave (or primary waves) That type of seismic body wave which is propagated by alternating compression and expansion of material in the direction of propagation.

retrofitting Bracing and reinforcing a structure so that it resists shaking during an earthquake.

reverberate The back-and-forth movement of the seismic waves. Echos are caused by reverberated sound waves.

rupture plane The surface along which each side of the fault moves.

seismic energy The energy that is released as vibrations during an earthquake.

seismic waves Waves produced by an earthquake, including both body waves and surface waves.

surface waves A seismic wave that travels along the surface of the Earth.

S-wave (or secondary waves) That type of seismic body wave which is propagated by a shearing motion of material perpendicular to the direction of travel.

thrust fault A fault that is inclined to the earth's surface; when it moves, the crust is pushed together, with one side moving upward and the other down.

tsunami A sea wave produced by any large-scale disturbance of the sea floor, usually by a submarine earthquake or by submarine landslide.

Educator's Guide Continued :

Questions for further study

Discuss possible solutions to these problems with your class.

1. Why do earthquakes happen?

2. Do earthquakes happen at or near the same place more than once?

3. Does a "blind" thrust fault appear on the surface of the Earth?

4. Does the hypocenter of an earthquake occur on the surface of the Earth?

5. What is plate tectonics?

6. As of today, can scientists predict when an earthquake will happen?

7. Several cities are located in the San Fernando Valley. What are some of the problems or hazards the citizens might have living in such an active earthquake area?

Activity

Investigate some historic earthquakes and report on them.

Educator's Guide Continued :

Easy Reading

Gates, George O., 1990, Safety and survival in an earthquake: U.S. Geological Survey General Interest Publication. 11 p. (also available in Spanish)

Shulty, Sandra S., and Wallace, Robert E., 1990, The San Andreas Fault, U. S. Geological Survey General Interest Publication, 16 p.

Simkin, T. , Tilling, R. I. , Taggart, J. N., Jones, W. J. , and Spall, H., compilers, 1989, This Dynamic Planet: World Map of Volcanoes, Earthquakes, and Plate Tectonics: U. S. Geological Survey, Reston, VA, in cooperation with The Smithsonian Institution, Washington, D. C.

U. S. Geological Survey, 1990, The severity of an earthquake: U.S. Geological Survey General Interest Publication, 15 p.

Walker, Bryce, 1982, Earthquake: Time-Life Books, Alexandria, Virginia, 176 p. (A factual, well-illustrated account of earthquakes and their effects, written for a layperson.)

Ward, Peter L., and others, 1990, The Next Big Earthquake in the Bay Area may come sooner than you think: U. S. Geological Survey in cooperation with other public service agencies, 23 p. (Includes an especially good list of additional reading and sources of more information)

Yanev, Peter I., 1991, Peace of mind in earthquake country: Chronicle Books, San Francisco, California, 218 p. (A discussion of earthquake hazards and practical steps to take before, during, and after earthquakes.)

Educator's Guide Continued :

Further Reading

Bolt, Bruce A., 1988, Earthquakes: W. H. Freeman, New York, 282 p. (A scientific primer on earthquakes, their causes, measurement, precursors, and effects.)

Gere, James M., and Shah, Haresh C., 1984, Terra non firma: W. H. Freeman, New York, 203 p. (An elementary scientific discussion of earthquakes and how to prepare for them.)

Kimball, Virginia, 1988, Earthquake ready: Roundtable Publishing, Santa Monica, California, 225 p. (A practical guide on how to prepare for earthquakes.)

Nance, John J., 1988, On shaky ground: America's earthquake alert: Avon Books, New York, 440 p. (An absorbing, factual narrative of earthquake disasters and scientists' efforts to understand and cope with earthquakes.)

The National Science Teachers Association, 1988, Earthquakes: a teacher's package for K-6th grades: The National Science Teachers Association, 280 p. (Excellent for hands-on activities to teach children about earthquakes.)

Pakiser, Louis C., 1990, Earthquakes: U.S. Geological Survey General Interest Publication, 20 p.

Stein, Ross S. and Yeats, R. S., 1989, Hidden earthquakes, Scientific American, Vol. 260, p. 48-57. (June 1994.)

Additional Models

Alpha, Tau Rho, 1989, How to construct two paper models showing the effects of glacial ice on a mountain valley: U. S. Geological Survey Open-File Report 89-190 A&B (Available as a 3.5-in. MACINTOSH disk or a 30-p. report)

Alpha, Tau Rho, Lahr, John C., and Wagner, Linda F., 1989, How to construct a paper model showing the motion that occurred in the San Andreas fault during the Loma Prieta, California, earthquake of October 17, 1989: U. S. Geological Survey Open-File Report 89-640A&B (Available as a 3.5-in. MACINTOSH disk or a 10-p. report)

Alpha, Tau Rho, and Lahr, John C., 1990, How to construct seven paper models that describe faulting of the Earth: U. S. Geological Survey Open-File Report 90-257 A&B (Available as a 3.5-in. MACINTOSH disk or a 40-p. report)

Alpha, Tau Rho, 1991, How to construct four paper models that describe island coral reefs: U. S. Geological Survey Open-File Report 91-131A&B (Available as a 3.5-in. MACINTOSH disk or a 19-p. report)

Alpha, Tau Rho, and Gordon, Leslie C., 1991, Make your own paper model of a volcano: U. S. Geological Survey Open-File Report 91-115A&B (Available as a 3.5-in. MACINTOSH disk or a 4-p. report)

Additional Models Cont.

Alpha, Tau Rho, Page, Robert A., and Gordon, Leslie C., 1992, Earthquake effects, a computer animation and paper model: U. S. Geological Survey Open-File Report 92-200A&B (Available as a 3.5-in. MACINTOSH disk or a 4-p. report)

Alpha, Tau Rho, Starratt, Scott W. and Chang, Cecily C., 1993, Make your own Earth and tectonic globes: U. S. Geological Survey Open-File Report 93-380a&B (Available as a 3.5-in. MACINTOSH disk or a 14-p. report)

Alpha, Tau Rho, and Stein, Ross S., 1994, Make your own paper model of the Northridge, California, earthquake, January 17, 1994: U. S. Geological Survey Open-File Report 94-143 4p.

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