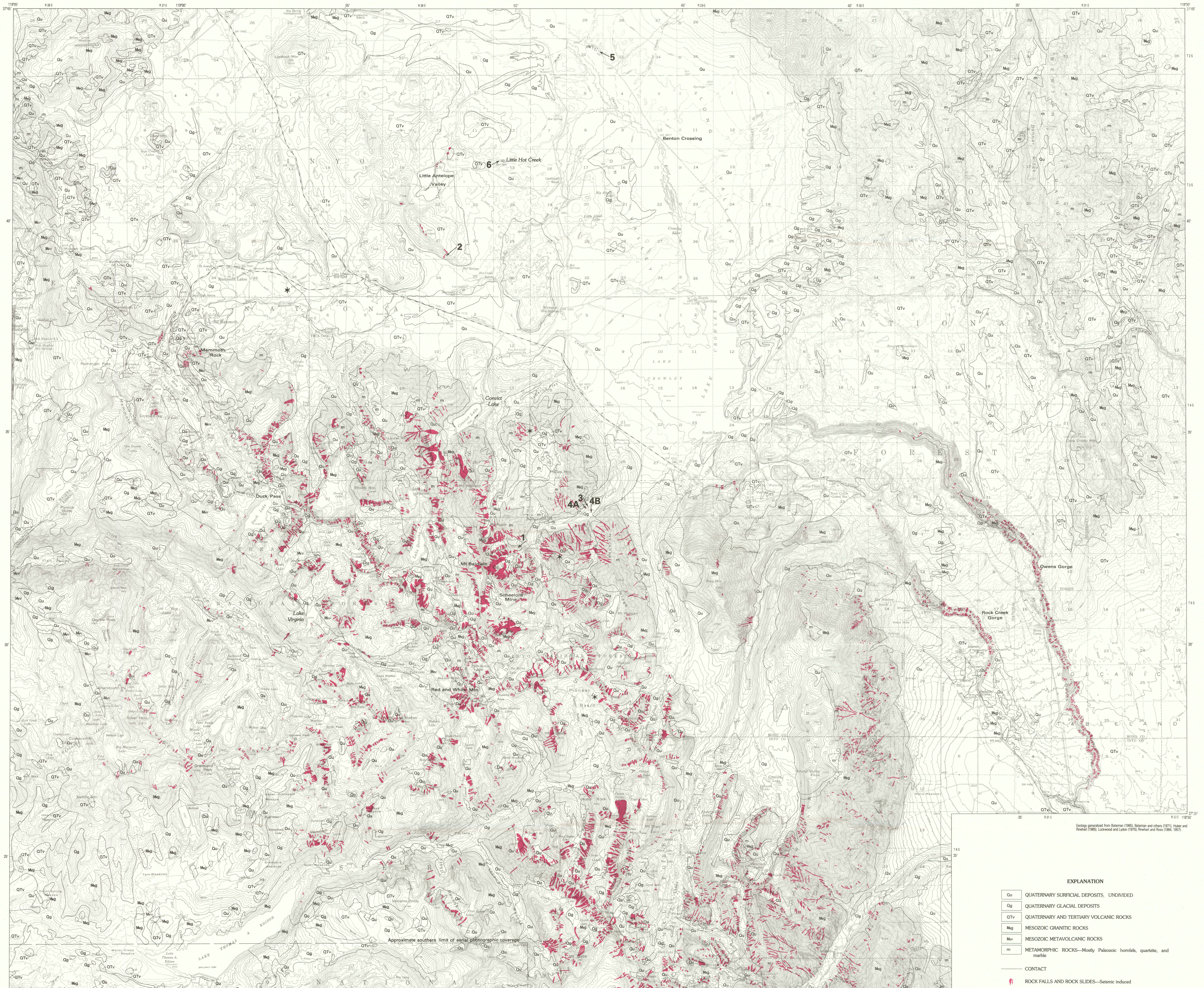


EXPLANATION

Qu	QUATERNARY SURFICIAL DEPOSITS, UNDIVIDED
Qg	QUATERNARY GLACIAL DEPOSITS
QTv	QUATERNARY AND TERTIARY VOLCANIC ROCKS
Mzg	MESOZOIC GRANITIC ROCKS
Mzv	MESOZOIC METAVOLCANIC ROCKS
m	METAMORPHIC ROCKS—Mostly Paleozoic hornfels, quartzite, and marble

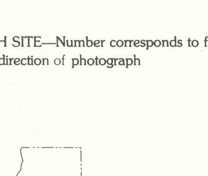
CONTACT

ROCK FALLS AND ROCK SLIDES—Seismic induced

FISSURES—Caused by liquefaction-induced lateral spread failures

EPICENTERS FOR THE SEISMIC EVENTS—$M_L \geq 6.0$; approximately located

PHOTOGRAPH SITE—Number corresponds to figure in text. Arrow indicates view direction of photograph



INTRODUCTION

The May 25-27, 1980, Mammoth Lakes, California, earthquake sequence triggered several thousand landslides throughout an area of approximately 2500 km². The landslides extended from Owens River Gorge on the east to Yosemite Valley about 42 km to the west (Wieczorek, 1981) and from Mount Darwin about 8 km south of the map area to 5 km northwest of Benton Crossing on the north. The series of four earthquakes had magnitudes of 6.0 or greater (Archuleta and others, 1982; epicenters shown on map) and more than 200 aftershocks of magnitude 3.0 or greater.

The landslides from this earthquake sequence were almost exclusively rock falls and rock slides; however, six seismic-induced failures were due to liquefaction. The failures ranged in size from toppling of a few small rocks to rock-fall avalanches of more than 200,000 m³ (fig. 1). The largest of the rock-fall avalanches, which occurred on the east side of Mount Baldwin (fig. 1), travelled about 1 km from its source. Extensive snowfields still existed at the time of the earthquakes and provided smooth low-friction slopes, thus lengthening the slide paths of many of the rock avalanches.

The areas depicted as failures on the map include the scarp area, debris path, and deposit for rock-fall and rock-slide sites. The failures were mapped from two sets of aerial photography taken July 1980: (1) 1:18,000-scale vertical black and white photographs contracted for by the U.S. Geological Survey and (2) approximately 1:12,000-scale black and white U-2 photographs taken by the Nevada Air National Guard in Reno. Field checking was done throughout the mapped area except in the extreme southwestern part.

ROCK FALLS AND SLIDES

Rock falls and slides occurred within a variety of lithologies. Paleozoic metamorphic rocks, Mesozoic granitic rocks, Mesozoic metavolcanic rocks, Pliocene to Holocene volcanic rocks, and Pleistocene glacial moraine deposits all shed material from slopes varying in steepness from 35° to vertical and overhanging. Most slopes contributing to rock falls and slides were in excess of 50°.

PALEOZOIC METAMORPHIC ROCKS

Paleozoic metamorphic rocks within the area affected by the earthquake compose part of a roof pendant within the Mesozoic granitic rocks of the Sierra Nevada batholith. The metamorphic rocks crop out over an area of about 70 km² and consist of quartzite, hornfels, marble, and slate (Rinehart and Ross, 1964). They strike northwest, extending from Mammoth Rock in the north to near Red and White Mountain to the southeast. These rocks were the most susceptible to seismic-induced landslides, primarily because the rocks are extensively fractured and are exposed on steep slopes. As was the case in all other rock types that produced failures, rock debris was concentrated in gullies and deeply incised fractures that transect cliff faces. In many cases, such as on the eastern slopes of Laurel Mountain, several large rock-fall avalanches channeled along gullies produced debris lobes extending down into Convict Canyon from Sevehah Cliff.

Of all the metamorphic assemblages, the most susceptible to producing rock falls and slides was the Mount Baldwin Marble. This susceptibility is primarily due to its extensively fractured nature enhanced by intense chemical weathering and alteration along fractures. The largest rock falls from the earthquake sequence were from the eastern flank of Mount Baldwin along the contact of the Mount Baldwin Marble and the Round Valley Peak Granodiorite at the head of the cirque opposite the Scheelore mine (fig. 1).

MESOZOIC GRANITIC ROCKS

Granitic rocks that failed range in composition from granodiorite to quartz monzonite. These rocks were extremely variable in their susceptibility to rock-fall failures. Where the granitic rocks contained closely spaced fractures, rock falls and slides were nearly as numerous and closely spaced as those within the Paleozoic metamorphic rocks.

Fracture orientation was also an important factor in rock-fall failure in the granitic rocks. There were striking examples of fracture control on rock-fall susceptibility. On the northwest-trending ridge underlain by the Round Valley Peak Granodiorite, approximately 1.5 km north-northeast of Lake Virginia, the northeast slopes are steeper than the southwest slopes, yet most rock falls occurred on the southwest slope. This difference in failure occurrence is apparently due to prominent southwest-dipping fracture surfaces along which the rocks failed.

The weathering characteristics were also a major factor in the failure of granitic rocks; deeply weathered rocks were especially prone to rock falls and slides. Examples of such failures were present along Rock Creek Gorge. Failures from extensively weathered and highly fractured roadcuts and natural slopes in the Triassic Wheeler Crest Quartz Monzonite were numerous along old U.S. Route 395 (new U.S. 395 is not shown on map) and were responsible for its closure for several days.

MESOZOIC METAVOLCANIC ROCKS

The behavior of the Mesozoic metavolcanic rocks in producing rock falls and slides was similar to that of the granitic rocks. The metavolcanic rocks in the earthquake-affected area consist of slightly metamorphosed latite, latite tuff, metamorphosed volcanic sediment, hornfels, and volcanic breccia (Rinehart and Ross, 1964). Where massive, these rocks (exposed mainly in the Mammoth Crest area) produced few failures. Where they are extensively fractured or weathered, they produced numerous rock falls and slides, such as on Mammoth Crest east of Duck Pass.

YOUNGER VOLCANIC ROCKS

Pliocene to Holocene volcanic rocks that failed are mainly located along the walls of Owens River Gorge, Rock Creek Gorge, and along steep slopes of rhyolite within Long Valley. In Owens River and Rock Creek gorges these rocks are rhyolitic tuffs (Bishop Tuff of Gilbert (1938)) and basalts. In Owens River Gorge, the Bishop Tuff displays a lower pink massive unit with columnar jointing and an overlying white poorly cemented densified tuff (Gilbert, 1938). Few rock falls occurred within the lower massive tuff; most failures came from the overlying poorly cemented tuff. Most of the rock falls were thin (less than 2 m thick).

Several widely scattered rock falls occurred throughout Long Valley in various rhyolitic lithologies. One such failure occurred as a large single block of reddish-brown flow-banded rhyolite that rolled down from steep cliffs about 1 km north of the Mammoth School. The rock is approximately 10 m × 5 m × 5 m and is clearly visible from U.S. 395 (fig. 2). Numerous failures also occurred in similar rhyolite from cliffs along Hot Creek near the public access to the hot springs and forced their closure for a short time.

Rocks fell from low cliffs composed of tuffaceous rhyolitic lacustrine deposits (Cleveland, 1962) at the northern margin of Little Antelope Valley and were also found as scattered small rock falls within the rhyolitic material north toward Little Hot Creek. The rock falls near the northeast margin of Little Antelope Valley are composed of tuffaceous diatomaceous earth that has extremely low density and is hydrothermally altered.

PLEISTOCENE GLACIAL MORAINES

Pleistocene glacial moraines produced rock falls in several localities. Steep (35°-40°) glacial moraines with rounded granitic boulder clasts (many with diameters greater than 2 m) formed some of the most hazardous rock falls. On the northeast slopes of McGee Mountain above old U.S. Route 395 and in the McGee Creek drainage along the McGee Creek road, boulders from steep lateral moraines narrowly missed dwellings as they rolled and bounded down the slopes. The McGee Creek pack station suffered a demolished corral fence from one such granite boulder (fig. 3) while the house itself was narrowly missed by a slate boulder that came from bedrock above the lateral moraine (fig. 4A, B). Inspection of the moraine slopes showed that numerous large granitic boulders had been partly dislodged from their surrounding matrix where they now rest in various degrees of metastability.

LATERAL SPREAD LANDSLIDES

Liquefaction of saturated noncohesive sediments produced lateral spreads in five main areas. At Convict Lake, shoreline lacustrine sediments consisting of gravel and coarse-grained sand underwent cracking and lateral displacement lakeward. About 50 m of shoreline were affected near the south end of Convict Lake campground. Also at Convict Lake, the delta sediments at the lake inlet slumped due to liquefaction.

Approximately 5 km northwest of Benton Crossing, Holocene alluvial sediments underwent liquefaction and lateral spreading. Large cracks with up to 0.5 m separation occurred along the boundary of the Owens River flood plain over a length of about 1 km (fig. 5). Similar failure occurred along the west margin of the Owens River flood plain about 1 km to the west. In Little Antelope Valley, tuffaceous alluvial sediments developed lateral spreading cracks both along the margin of the valley-flood plain and in the center of the valley near natural springs.

The liquefaction of thermal spring deposits at Little Hot Creek was unusual. High pore pressure in calcareous, hot, saturated mud composed of uniform spherical silt-sized particles developed during seismic shaking and resulted in as much as 10 m of downslope displacement of the surficial grassy mat covering much of the hot spring deposits. The surficial material underwent movement in rug-like fashion in places; in other places it tore as it slid down a slope of approximately 5° toward Little Hot Creek (fig. 6).

SUMMARY

The most abundant landslides from the Mammoth Lakes earthquake sequence were rock falls and rock slides. Rock falls occurred on slopes in excess of 50°; the minimum slope for rock slides was approximately 40°-45°. Paleozoic metamorphic rocks were the most susceptible to failure. Mesozoic granitic rocks of the Sierra Nevada batholith and Mesozoic metavolcanic rocks were slightly less susceptible. The susceptibility of the respective rock types is governed by their fracture and slope characteristics. Of prime importance is the openness (or dilatation of the rock mass) of fractures on a given slope. The most susceptible slopes were steep cliffs and narrow ridges where numerous open fractures existed. The one rock type in which fracture characteristics did not play a major role in rock-fall failure was the uppermost weakly cemented ash-flow tuff unit of the Bishop Tuff. Here, the weakly cemented nature of the rock allowed failure through previously intact rock with equal or greater facility than along previously existing fractures.

Because of their great runout distances, single rounded boulders shaken loose from glacial moraines proved to be the type of failure most hazardous to areas of habitation. The shape of such boulders allows them to roll easily and thereby develop sufficient momentum for many of them to become airborne for much of their travel distance.

Liquefaction-induced lateral spreading failures were due to the unconsolidated nature of saturated sandy alluvial deposits along the Owens River and lacustrine sand and gravel at Convict Lake.

Because of the sparse population throughout most of the area affected by rock falls and rock slides, similar future earthquakes pose little hazard to residences. However, during peak recreation use in summer months, many of the steep, narrow canyons, such as Convict Canyon, would be extremely dangerous to hikers or campers from rock falls and rock slides during an earthquake.

ACKNOWLEDGMENTS

The authors wish to acknowledge the cooperation of the Reno Nevada Air National Guard and to thank them for providing aerial reconnaissance photographs of the landslide-affected area. We wish to express our appreciation to the U.S. Forest Service (Inyo National Forest) for making helicopter support available and for providing helpful information immediately after the earthquakes.

REFERENCES CITED

Archuleta, Ralph J., Cranswick, Edward, Mueller, Charles, and Spudich, Paul, 1982, Source parameters of the 1980 Mammoth Lakes, California, earthquake sequence: Journal of Geophysical Research, vol. 87, 30 p.
Bateman, Paul C., 1965, Geology and tungsten mineralization of the Bishop district, California: U.S. Geological Survey Professional Paper 470, 208 p.
Bateman, Paul C., Lockwood, John P., and Lydon, Phillip A., 1971, Geologic map of the Kaiser Peak quadrangle, central Sierra Nevada, California: U.S. Geological Survey Geologic Quadrangle Map 894, 1:62,500.
Cleveland, George B., 1962, Geology of the Little Antelope Valley clay deposits Mono County, California: California Division of Geology, Special Report 72, 28 p.
Gilbert, C. M., 1938, Welded tuff in eastern California: Geological Society of America Bulletin, vol. 49, p. 1829-1862.
Huber, N. King, and Rinehart, C. Dean, 1965, Geologic map of the Devil's Postpile quadrangle, Sierra Nevada, California: U.S. Geological Survey Geologic Quadrangle Map 437, 1:62,500.
Lockwood, John P., and Lydon, Phillip A., 1975, Geologic map of the Mount Abbot quadrangle, central Sierra Nevada, California: U.S. Geological Survey Geologic Quadrangle Map 1155, 1:62,500.
Rinehart, C. Dean, and Ross, Donald C., 1964, Geology and mineral deposits of the Mount Morrison quadrangle, Sierra Nevada, California, with a section on A gravity study of Long Valley by Pakiser, L. C.: U.S. Geological Survey Professional Paper 385, 106 p.
———1957, Geology of the Casa Diablo Mountain quadrangle, California: U.S. Geological Survey Geologic Quadrangle Map 99, 1:62,500.
Wieczorek, G. F., 1981, Rock falls in Yosemite Valley from the Mammoth Lakes, California, earthquake sequence of May 25-27, 1980: Geological Society of America Abstracts with Programs, v. 13, no. 2, p. 114.

Figure 1.—Oblique aerial photograph of rock-fall avalanche approximately 1 km in length occurring in cirque wall on east flank of Mount Baldwin.

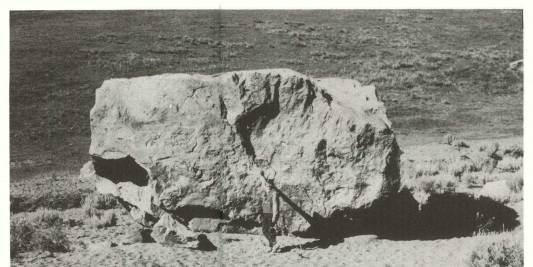


Figure 2.—Rhyolite block that fell during the earthquake sequence. Rock is located approximately 1 km north of Mammoth school and is plainly visible from U.S. 395.

Figure 3.—Granitic boulder shaken loose from lateral moraine above McGee Creek pack station.

Figure 4A.—Remains of mature cottonwood adjacent to McGee Creek pack station. Tree was hit by disk-shaped slate boulder rolling on edge.

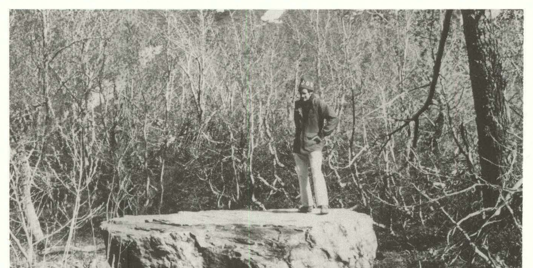


Figure 4B.—Slate boulder found over 50 m to south of demolished cottonwood.

Figure 5.—Fissures resulting from lateral-spread failure in alluvial sediments of edge of Owens River flood plain. Failure affected a 1-km section of flood plain approximately 5 km north of Benton Crossing.

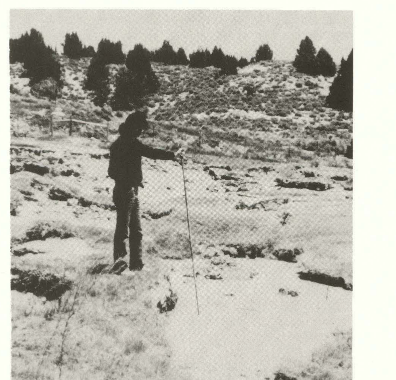


Figure 6.—Fissures resulting from lateral-spread failure in hydrothermal deposits at Little Hot Creek. Grass-covered topsoil has slid in rug-like fashion exposing hot calcareous mud (light area in which rod has been inserted).

LANDSLIDES FROM THE MAY 25–27, 1980, MAMMOTH LAKES, CALIFORNIA, EARTHQUAKE SEQUENCE

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