Project: Geologic reconnaissance of the Zion Canyon landslide of April 12, 1995, Zion National Park, Washington County, Utah			Requesting Agency: Emergency Response
By: Barry J. Solomon	Date: 4-28-95	County: Washington	Job No: 95-08
USGS Quadrangle: Springdale East (73)			

INTRODUCTION

At about 9:00 p.m. on April 12, 1995, a landslide occurred on the west bank of the north fork of the Virgin River in Zion Canyon, Zion National Park (attachment 1). The landslide dammed the river and formed a pond about 20 feet (6 m) deep. About 1,000 campers were evacuated from the Watchman and South campgrounds downstream in case sudden dam failure initiated flooding. Drinking-water supplies were temporarily disrupted in the campgrounds and in the town of Springdale, 3 miles (5 km) south of the landslide. The river gradually cut around the toe of the slide and drained the pond, but caused no downstream flooding. As the river flowed around the slide it eroded the east river bank and washed out a 600-foot (180-m) section of the adjacent Zion Canyon Scenic Drive. The road was the only access for vehicular traffic to Zion Lodge, where more than 300 guests and lodge employees were stranded without water, sewer, electricity, or phone service. A one-lane, temporary road was cut into the slope on the east side of the river by park personnel for evacuation of the lodge, which was completed on the morning of April 14.

On April 13, 1995, the Utah Geological Survey (UGS) and Utah Division of Comprehensive Emergency Management (CEM) responded to this event. Fred May (CEM) and I arrived at the landslide at about 4:00 p.m. I was concerned with the geologic characteristics of the slide and its potential for renewed movement, as well as the condition of adjacent slopes and potential for new slides. Dr. May was concerned with damage assessment and coordination of emergency-response activities of the state of Utah. Upon arrival we inspected the landslide, attended a meeting of personnel from Zion National Park, and then met with Dave Keough, Regional Geotechnical Engineer for the Rocky Mountain Region of the National Park Service. After the meetings I participated in a helicopter reconnaissance of the landslide. On the morning of April 14, Dr. May and I continued our inspection of the landslide and checked to see if any additional movement had occurred overnight, and then walked about one mile (1.6 km) up the canyon to look for evidence of other slope failures. Prior to leaving the park, I discussed our observations of the landslide and recommendations for hazard reduction with Mr. Keough. His plan for remediation included: (1) excavation of the toe of the landslide and return of the river to its pre-slide position on the west side of the flood plain, (2) reconstruction of the road on a rebuilt embankment on the east side of the flood plain, and (3) construction of a ditch between the road and the cut face on the east canyon wall for collection of rock-fall debris. This report summarizes my observations and recommendations.

LANDSLIDE GEOLOGY

The landslide moved southeast from the face of Sand Bench, a 600-foot- (180-m-) high bluff at the base of a prominent sandstone cliff (attachment 1). The cliff rises another 2,200 feet (670 m) to an elevation of 7,043 feet (2,147 m) at the peak of The Sentinel. Prehistoric landslide deposits form the bulk of the bluff (Grater, 1945). A terrace on the upper surface of the bluff, part of the "high terrace remnants" identified by Coney (1959), developed in the late Pleistocene when the Virgin River was from 600 to 900 feet (180-270 m) above its present level.

The prehistoric landslide (attachment 1) detached from the face of The Sentinel and slumped beneath the terrace (Eardley, 1965), blocking Zion Canyon and creating an extensive lake (Grater, 1945). The canyon was first blocked about 4,000 years ago, an age determined by radiocarbon dating, measurement of varves in lake clays, and estimation of the rate of sediment transport in the river (Hamilton, 1979). The lake behind the prehistoric landslide dam was about 0.7 square miles (1.8 km^2) in area and at least 350 feet (115 m) deep during its early years (Hamilton, 1979). A radiocarbon date of 3,600 $\pm$ 400 years B.P. on plant carbon from non-lacustrine silt above the lake beds indicates when the dam was finally breached by the lake waters.

The prehistoric landslide is in the Lower Jurassic Kayenta Formation. The Kayenta consists of about 600 feet (180 m) of reddish-brown mudstone that is the source of numerous slope failures in the Zion Park region (Hamilton, 1978). The Kayenta overlies the Springdale Sandstone Member of the Lower Jurassic Moenave Formation. The Springdale Sandstone, about 150 feet (45 m) thick, forms a prominent ledge near the base of the bluff. The ledge is about at river level near the 1995 landslide. The Kayenta is overlain by the Lower Jurassic Navajo Sandstone, a uniform quartzose sandstone that reaches a maximum thickness of about 2,000 feet (600 m) in Zion Park. The Sentinel face is composed of Navajo Sandstone, which is capped by the Middle Jurassic Temple Cap Sandstone.

The 1995 landslide is the latest in a series of historical slope failures occuring in the prehistoric landslide. Grater (1945) noted two "major slides" in the complex, one in 1923 and the other in 1941, and another landslide reportedly happened during the Richter magnitude (M_L) 5.9 earthquake of September 2, 1992. That earthquake, with an epicenter 5 miles (8 km) southeast of St. George, Utah and 28 miles (45 km) southwest of Springdale, also triggered a large landslide with its basal slide plane in the Petrified Forest Member of the Upper Triassic Chinle Formation (Black and others, 1994).

The 1995 landslide is a complex slide with an earth slump at its head and an earth flow at its toe. The slide mass measures roughly 500 feet (150 m) from the main scarp to the toe, with a width of about 150 feet (45 m). Using a calculated surface area of 75,000 square feet (7,000 m^2) and an estimated average depth to the basal slide plane of 40 feet (12 m), the total volume of material involved is about 110,000 cubic yards (84,000 m^3). This is comparable to the volume of the 1941 landslide, estimated at 150,000 cubic yards (115,000 m^3) (Grater, 1945). The average gradient of the slope prior to the 1995 slide was 80 percent. The landslide has a clearly defined main scarp as high as 75 feet (23 m), and a sharp secondary scarp about 30 feet high (9 m), indicating that the upper part of the landslide moved in two coherent pieces. Several ground cracks are present on the southwest margin of the slide.

Cracks are also found in ancient slide debris on the steep west bank of the river about 2,000 feet (600 m) upstream. The lower part of the cracks are nearly vertical, in a zone about 2 feet (o.6 m) wide and 20 feet (6 m) tall, but curve northward in a gentle arc at the top of the zone. The cracks do not appear to penetrate deeply into the river bank.

Previous studies in the Springdale area (Harty, 1990; Hamilton, 1992; Black and others, 1994) noted a correlation between increased precipitation and landsliding, and this is apparently the cause of the 1995 landslide. Precipitation was 189 percent of average for the water year through April 14, 1995 in the Dixie region (verbal communication, Utah Climate Center). Weather records from Zion National Park show no precipitation in early April, immediately prior to the landslide, but precipitation was much higher than average during March. Average precipitation in March is 2.80 inches (7.11 cm), but 5.73 inches (14.55 cm) fell during March, 1995. Much of this, 3.40 inches (8.64 cm), fell during a six-day period early in the month, culminating in 1.06 inches (2.69 cm) of precipitation on March 6, 1995. This moisture rapidly infiltrates the porous and permeable prehistoric landslide debris. Seeps visible at the upper surface of the underlying Springdale Sandstone suggest that the sandstone-landslide interface is relatively impermeable. Accumulating moisture at the interface reduced cohesion and increased pore pressure in overlying fine-grained deposits, and slope failure followed.

HAZARD POTENTIAL AND RECOMMENDATIONS

Although landslide movement ceased by 4:00 p.m. on April 13, slope-stability hazards persist. Additional sliding is possible on the wedge of debris between the main and secondary landslide scarps, and near ground cracks on the landslide margin and upstream. Other potential hazards are related to the construction of the temporary road which cuts into prehistoric landslide debris on the east bank of the river, planned excavation of the 1995 landslide toe to return the river to its original course on the west margin of the flood plain, and reconstruction of the permanent road to Zion Lodge.

Failure of the cracked landslide margin and debris wedge may occur, but the volume of additional material subject to sliding is small compared to the original slide volume. The main scarp may also retreat farther upslope, contributing additional material. However, upslope retreat does not pose a threat to structures because there are none on top of the bluff. The slide mass should be closely monitored during the reconstruction phase to minimize the hazard of renewed slope instability.

Although the upstream cracks on the west margin of the river do not appear to penetrate deeply, they are also of concern. The cracks are on the near-vertical lower part of the hillside. Should portions of the hillside fail near the cracks, the upper slopes may be undermined and a larger landslide may occur. This area should be monitored after the reconstruction phase, particularly during periods of heavy precipitation.

The prehistoric landslide debris exposed during construction of the temporary road consists of an intact block of weathered and fractured Kayenta mudstone and siltstone that dips about 10 degrees southeast into the adjacent hillside. This dip increases the slope stability, but the cut slope should be reinforced once the permanent road bed is reconstructed and the temporary road abandoned to reduce the potential hazard of slope failure.

Hazard potential would normally be increased by excavation of the landslide toe, but a slope break in the landslide profile suggests that the toe has actually overridden the intact Springdale Sandstone ledge near the slope base. Thus, the bulk of the landslide may be reinforced by the ledge itself rather than by the toe of debris below the ledge. A buttress of granular material on the ledge would provide further reinforcement.

Care must be exercised during channel and road reconstruction to minimize disturbance because additional sliding might again impact the flow of the river and threaten workers and tourists. Additional investigation of the hazard potential is warranted before channel and road reconstruction begins, and design features should be incorporated to reduce the post-construction landslide hazard.

REFERENCES

Black, B.D., Mulvey, W.E., Lowe, Mike, and Solomon, B.J., 1994, Investigation of geologic effects associated with the September 2, 1992, St. George earthquake, Washington County, Utah, *in* Mayes, B.H., and Wakefield, S.I., compilers, Technical reports for 1992-1993 Applied Geology Program: Utah Geological Survey Report of Investigation 224, p. 66-81.

Coney, Peter, 1959, Elevated terraces in lower Zion Canyon, *in*

Coney, Peter, and Eardley, A.J., unpublished reports, Zion National Park Research Library, p. 78-79.

Eardley, A.J., 1965, Erosional history of Zion Canyon, *in* Coney, Peter, and Eardley, A.J., unpublished reports, Zion National Park Research Library, p. 1-32.

Grater, R.K., 1945, Landslide in Zion Canyon, Zion National Park, Utah: Journal of Geology, v. 53, no. 2, p. 116-124.

Hamilton, W.L., 1978, Geologic map of Zion National Park, Utah: Springdale, Utah, Zion Natural History Association, scale 1:31,680.

Hamilton, W.L., 1979, Holocene and Pleistocene lakes in Zion National Park, Utah, *in* Linn, R.M., editor, Proceedings of the first conference on scientific research in the National Parks: New Orleans, 1977 Conference, U.S. National Park Service and American Institute of Biological Science, p. 835-844.

Hamilton, W.L., 1992, The sculpturing of Zion: Springdale, Utah, Zion Natural History Association, 132 p.

Harty, K.M., 1990, Geologic investigation of a landslide in Springdale, Washington County, Utah, *in* Black, B.D., compiler, Technical reports for 1989-1990 Applied Geology Program: Utah Geological and Mineral Survey Report of Investigation 220, p. 94-96.