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RECONNAISSANCE STUDY OF THE APRIL 12, 1995, LANDSLIDE IN ZION CANYON, ZION NATIONAL PARK, UTAH

by

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Introduction

At about 9:00 p.m., April 12, 1995, a large landslide occurred on the west valley wall of Zion Canyon on the North Fork Virgin River, Zion National Park, Utah (fig. 1). The slide dammed the river, but the dam was soon overtopped. Erosion caused by the overflowing river caused partial failure of the dam, resulting in a local flood that destroyed about 600 ft of the National Park Service (NPS) highway in the canyon as well as parallel utility conduits. About 430 people were trapped at Zion Lodge, upstream from the landslide, until an emergency detour road was carved from the east wall of the canyon adjacent to the new course of the river.

The costs of this landslide and the resulting damming and flooding can only be roughly estimated at this time, but they are (and will be) substantial. The minimum direct cost of rebuilding the highway to former standards (which involves moving the river nearly back to its original course) has been estimated at $750,000 (David Keough, Highway Engineer, Rocky Mountain Region, National Park Service, personal commun., 1995). This figure does not include the already-incurred cost of constructing an emergency outlet road on the east side of the river by which people were evacuated from Zion Lodge or the cost of installation of new public utility conduits (electricity, sewer, water) along the yet-to-be-reconstructed highway. In addition, it has been estimated that indirect losses to the economy of southern Utah will approximate $1 million for each day that the highway through Zion Canyon is closed during reconstruction (Steve Holder, Chief Ranger, Zion National Park, personal commun., 1995). It is anticipated that the partially reconstructed highway will be available for one-lane traffic by the 1995 Memorial Day weekend, but that the finished highway will not be ready for at least a couple of months.

We conducted a reconnaissance study of the landslide on Friday afternoon, April 14, and Saturday, April 15. Late Friday afternoon, we met with Don Falvey, and discussed our first impressions based on a short visit. Falvey informed us of what had been accomplished thus far in terms of remedial effort. Early Saturday morning, we met with Falvey, Lopez, Keough, and a few Park personnel in a briefing by Keough of proposed plans for reconstruction. The rest of Saturday was spent examining the slide, the breached dam, and the river.

Geology

The North Fork Virgin River has eroded Zion Canyon into rocks of the Lower Jurassic Navajo sandstone and the Kayenta formation, the Upper Triassic (?) Moenave formation, and the Springdale member of the Upper Triassic Chinle formation (Grater, 1945; Hamilton, 1987, 1992). These units consist mainly of sandstone and siltstone. However, the Springdale member includes shale and mudstone, which when saturated, have a low shear strength and are susceptible to slope failure. About 4,000 yr ago, the river eroded down into the Springdale member which probably served as a failure surface when "a great slide from The Sentinel [fig.1; a 7,000-ft peak west of the canyon] blocked the mouth of the canyon" about 4,000 yr ago (Hamilton, 1992). This slide (fig. 2) can probably be classified as a Toreva block ("A slump block consisting essentially of a single large mass of unjostled material which, during descent, has undergone a backward rotation toward the parent cliff......." (Bates and Jackson, 1980)). The slide block dammed the river impounding a lake about 2 3/4 mi long (fig. 1). The original dimensions of this landslide were about 1 1/4 mi long (parallel to the valley) and 3/4 mi wide. About 3600±400 yr ago, the large natural dam breached, draining the lake and splitting the original slide block into two parts that are separated by the river (Grater, 1945; Hamilton, 1987, 1992). The larger remnant currently is about 1 mi long along the river and 1/2 mi wide; its top surface forms a ledge about 600 ft above the river on the west side of the canyon. The smaller remnant is a narrow strip of landslide material immediately east of the river. The channel cut into the landslide by erosion from the released impoundment and subsequent erosion by the river for about 3,600 yr forms the entrance to the present Zion Canyon.

In 1923 and 1941, rock slides of sufficient size to destroy whole sections of the Zion Canyon highway and to dam the river occurred along the canyon wall of the large western block of slide materials (Grater, 1945). In both instances, some of the loose debris from the older slide mass moved down, damming the North Fork Virgin River for a short time. These local slides probably were triggered by local toe erosion of the Toreva block slide by the river and (or) heavy precipitation. The exact locations of the 1923 and 1941 events are uncertain, but they probably were within 1/4 mi of the current slide and one of them may have been at exactly the same location.

Current Landslide and Dam

The current landslide (figs. 3 and 4; volume approx. 300,000 yd^3) seems to be similar to the 1923 and 1941 events. It occurred in broken-up rock (Navajo sandstone and Kayenta formation) at the edge of the old slide block that forms the west valley wall of Zion Canyon (fig. 1). It can be classified as a debris slide (Varnes, 1978). The slide consists of two blocks of debris separated by an intermediate scarp. The materials exposed in the flank of the upper main scarp are rock fragments in a sandy gravelly matrix (fig. 5) derived from the rock units disrupted by the prehistoric sliding. It measures about 700 ft along the river and approximately 900 ft (horizontal distance) from the head of the slide to its toe in the river. The elevation difference between the top of the headscarp and the toe of the slide at the river is about 550 ft.

The slide occurred and dammed the river a little after 2100 hr on Wednesday, April

12, 1995. By means of a hydrograph (fig. 6) of river flow taken at a gaging station near Park Headquarters, about 1 mi downstream, we estimate that partial failure of the landslide dam occurred in about 1 1/2 hr. In this partial failure, the upper 10 ft of the approximately 25-ft-high dam was removed by erosion, resulting in a flood crest of only about 1 ft at the gaging station. However, the flood immediately downstream from the dam must have been several times as great. It did considerable damage to the canyon highway for a couple of hundred yards downstream, removing the pavement and eroding large gullies in the subgrade (fig. 7). No damage was caused at the campgrounds in the vicinity of Park Headquarters or in the city of Springdale, about 2 mi downstream.

The probable cause of the 1995 landslide consists of two elements: (1) saturation of shale and mudstone layers within the old landslide mass and (2) toe erosion by the river along the base of the old slide mass. Heavy precipitation and resulting high runoff during the winter of 1995 contributed to both of these elements. Cumulative precipitation measured at Zion Park Headquarters for January, February, and March 1995 totaled 15.22 in., almost equaling the average annual precipitation of 15.23 in. for the period 1928-1980 (Hamilton, 1992). This high amount of precipitation probably raised the water table within the remnant of the old slide mass and in the saturated shale and mudstone layers within the Springdale member; however, the majority of the slide mass appeared to be dry. A seep was observed at the SW margin of the lower block of the landslide, probably from the sandstone unit of the Springdale member which outcrops at the margin of the landslide and possibly extends beneath the landslide. Because of elevated pore pressures, the shear strength of these landslide materials was reduced. The reduced shear strength, combined with erosion at the base of the canyon wall due to fairly high river levels during the spring, led to the landslide.

Remedial Design Alternatives

The proposal to relocate the river and rebuild the highway will be difficult because: (1) the canyon is so narrow, (2) unstable old landslide material forms both canyon walls at the site, (3) the toe of the current landslide is located in the pre-landslide river channel, and (4) the river currently is carrying enough water at a high level with rapid enough velocity to inhibit construction.

Several remedial alternatives have been suggested. The one that seems the most promising has been formulated by David Keough, Highway Engineer, Rocky Mountain Region, NPS. Keough presented this reconstruction plan at the April 15th meeting with NPS officials. According to the Keough plan, the highway (with a 30-ft-wide paved surface) will be rebuilt at about the present position of the river (figs. 4 and 8) It will be separated from the cut-face of the present emergency roadway in the old landslide material of the east valley wall by a 12-ft-wide ditch for collection of rocks that fall from above the cut face.

This plan will necessitate moving the river from its current channel back to a position approximating that of the pre-landslide channel (fig. 2). This will require minor excavation into the toe of the current landslide to relocate the river. The cut slope should be analyzed for slope stability by NPS geotechnical engineers. Both sides of the future river channel (the cut in the toe of the slide and the riverward face of the highway fill) will be protected from erosion by geogrid or gabion walls faced with a 6-ft-thick section of rip rap. A possible option would be to place the entire new highway structure on an erosion-resistant subgrade consisting of boulders larger than 1 ft in diameter.

Although this proposed reconstruction solution will provide protection against erosion by the river, it will present only minimal resistance to possible recurring movement of the landslide due to the load upslope. Thus, as a precautionary measure, it will be necessary to monitor the landslide for even small movements during construction.

Other options that were discussed and dismissed are as follows:

(1) Bridging the river and toe of the landslide with a viaduct -- This option was considered to be too expensive, and the resulting viaduct would possibly clash with the natural beauty of the canyon.

(2) Cutting the new road farther into the east wall of the canyon (i.e., moving it farther away from the current toe of the landslide and leaving the river in its current location) -- Because the steep east wall of the canyon is made up of disturbed old landslide material, this solution would possibly induce new landslide activity on the east wall of the canyon. In addition, the east wall at the site is so steep that the necessary excavation volume would be considerably larger that for the Keough plan, which cuts only into the relatively flat toe of the landslide. Thus, excavation costs would be considerably higher.

(3) Making a vertical cut into the toe of the slide and restraining this cut and the material behind it by means of a large retaining wall -- Although this solution would provide additional room for the river and the new highway, a retaining structure large enough to restrain much of this landslide in a cut would be prohibitively expensive. However, the minimal wall envisioned by Keough will help if the cut is not too high and is laid back at a flat enough slope.

(4) Drainage of the slide -- We feel that it would not be possible to drain this slide mass to the extent that no other remedial measures are required. Subsurface drainage would be very expensive and might not be effective. However, it might help to install simple drainage ditches to catch water above and on the slide and transport it to the river; thus, some rainwater can be prevented from infiltrating the slide mass. For maximum effectiveness, these ditches should be lined with an impervious material.

Future Role of the USGS in Landslide Hazards in Zion Canyon

The USGS could be of help to the NPS in Zion National Park in either: (1) the immediate reconstruction phase, or (2) long-term planning for evaluation and mitigation of landslide hazards in Zion Canyon.

Immediate Reconstruction Phase:

USGS personnel could serve as (1) general geologic consultants or (2) technical advisors to a program for monitoring potential movement of the slide mass during reconstruction. Monitoring should include the use of registered (i.e., with surveying targets positioned) aerial photos that should be taken soon, and continuing monitoring of the landslide during construction.

Although we have not discussed this with Park Service officials, there is a possibility that NPS would fund such technical support.

Long-term Landslide Hazard Evaluation:

We feel that the NPS would possibly be more interested in this approach, and might possibly support a 2-yr program of landslide hazard evaluation for Zion Canyon between the highway junction and the mouth of Birch Creek. Such a study would include:

(1) large-scale geologic mapping of critical parts of the old landslide mass,

(2) slope-stability analysis of the currently active slide and of critical slopes along both sides of the canyon, and

(3) Evaluation of hazards due to other types of landslides, i.e., rockfalls and debris flows.

We note that Bob Scott of the Branch of Central Regional Geology has already discussed the possibility of a similar program with Don Falvey, Superintendent, Zion National Park. Falvey showed considerable interest, and we feel that there would be a good chance of NPS funding for such a project if they received a proposal from the USGS. We feel that this general plan can best be conducted by a two-person USGS team consisting of a landslide expert and a structural geologist. A logical approach might be to achieve cooperation between the Branch of Earthquake and Landslide Hazards and the Las Vegas Urban Corridor Study (the successor to BARCO, which is now winding down).

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Figure Captions

Figure 1. Map of Zion Canyon and vicinity showing location of remnants (shaded) of the prehistoric slide from the flanks of The Sentinel and of the April 12, 1995, debris slide (arrow). Extent of the lake caused by the prehistoric landslide is indicated.

Figure 2. View looking southward of back-rotated blocks of Navajo sandstone (center)

displaced by the prehistoric landslide which moved from The Sentinel (right) to Zion Canyon (left) about 4,000 years ago.

Figure 3. Looking upslope at the April 12, 1995, debris slide. Main scarp is visible in the upper center of photograph and rocky landslide deposit is visible in the lower center.

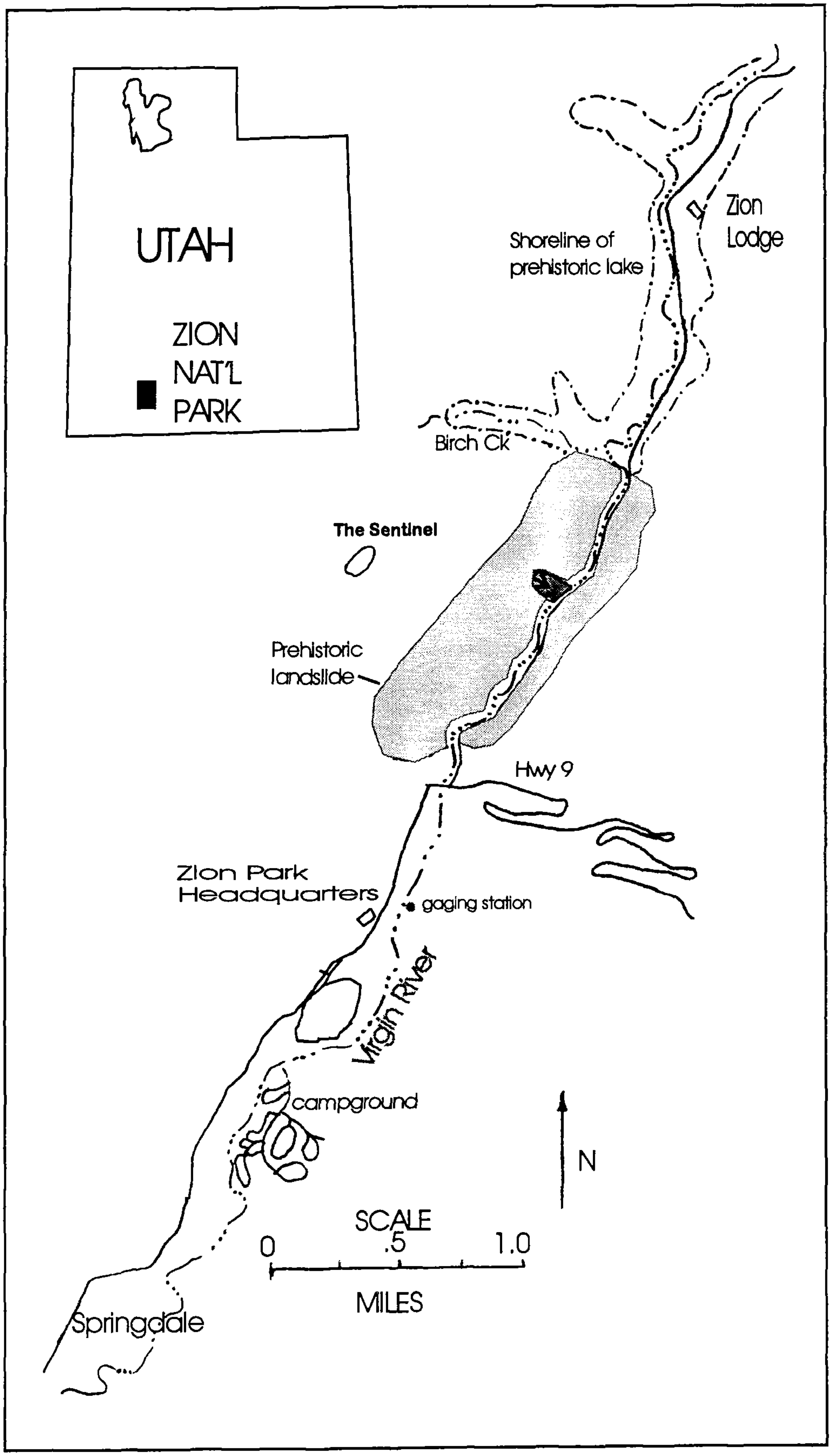
Figure 4. Map of Zion Canyon showing size and shape of the April 12 debris slide and the impoundment (shaded area) that remained behind it after partial breaching on April 12, 1995. Inset shows enlarged diagram of landslide and the location of the original channel of the Virgin River (dotted line). Contour interval is 160 ft.

Figure 5. Scarp along right flank of upper slide block. Slope of ground surface (upper left) is about 30°. Steeply inclined striations indicate direction of movement of about 3.5 ft. The scarp exposes rock fragments in a sandy gravelly matrix derived from the rock units disrupted by prehistoric sliding. Pencil (lower center) indicates approximate scale.

Figure 6. U.S. Geological Survey hydrograph on the North Fork Virgin River for April 11-13, 1995. This hydrograph is from a gaging station located near Park Headquarters approximately 1 mi downstream from the landslide (fig. 1).

Figure 7. Erosion damage to Zion Canyon highway downstream from the landslide as a result of flooding due to partial failure of the landslide dam.

Figure 8. View looking downslope along the April 12 landslide from the top of the main scarp. The North Fork of the Virgin River has been displaced by the landslide against the east wall of the canyon where an emergency road has been cut into the slope. The remnant of the impoundment behind the landslide dam can be seen to the left. Vehicles along the road provide scale.



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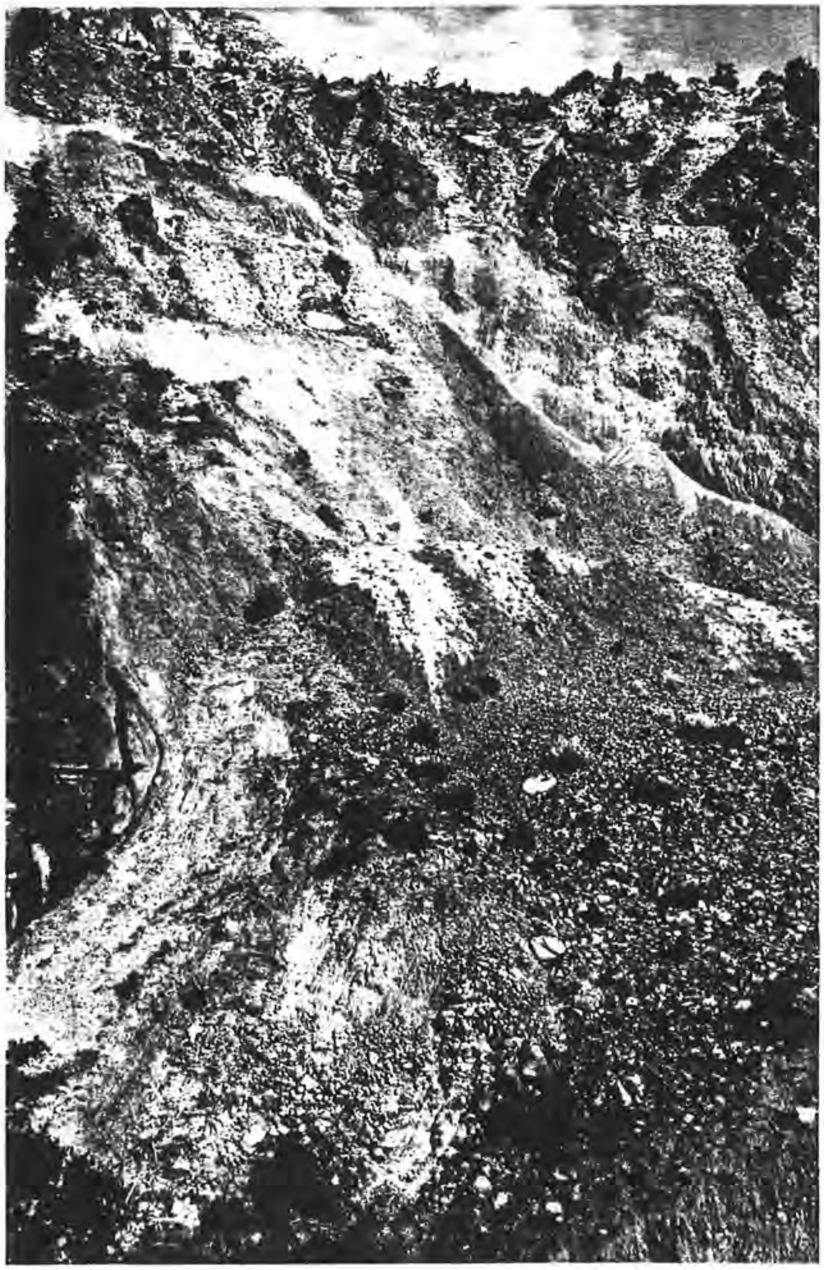

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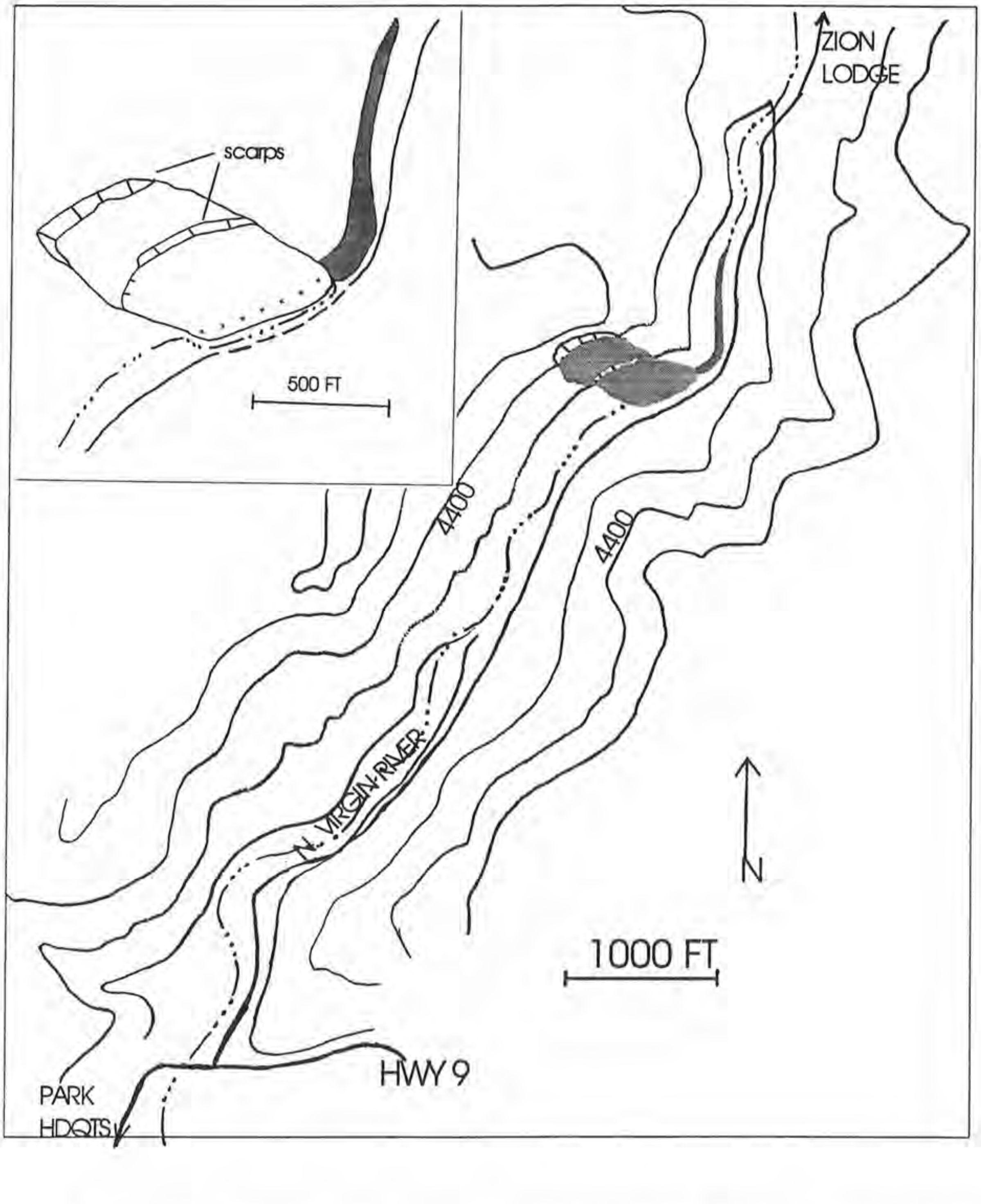

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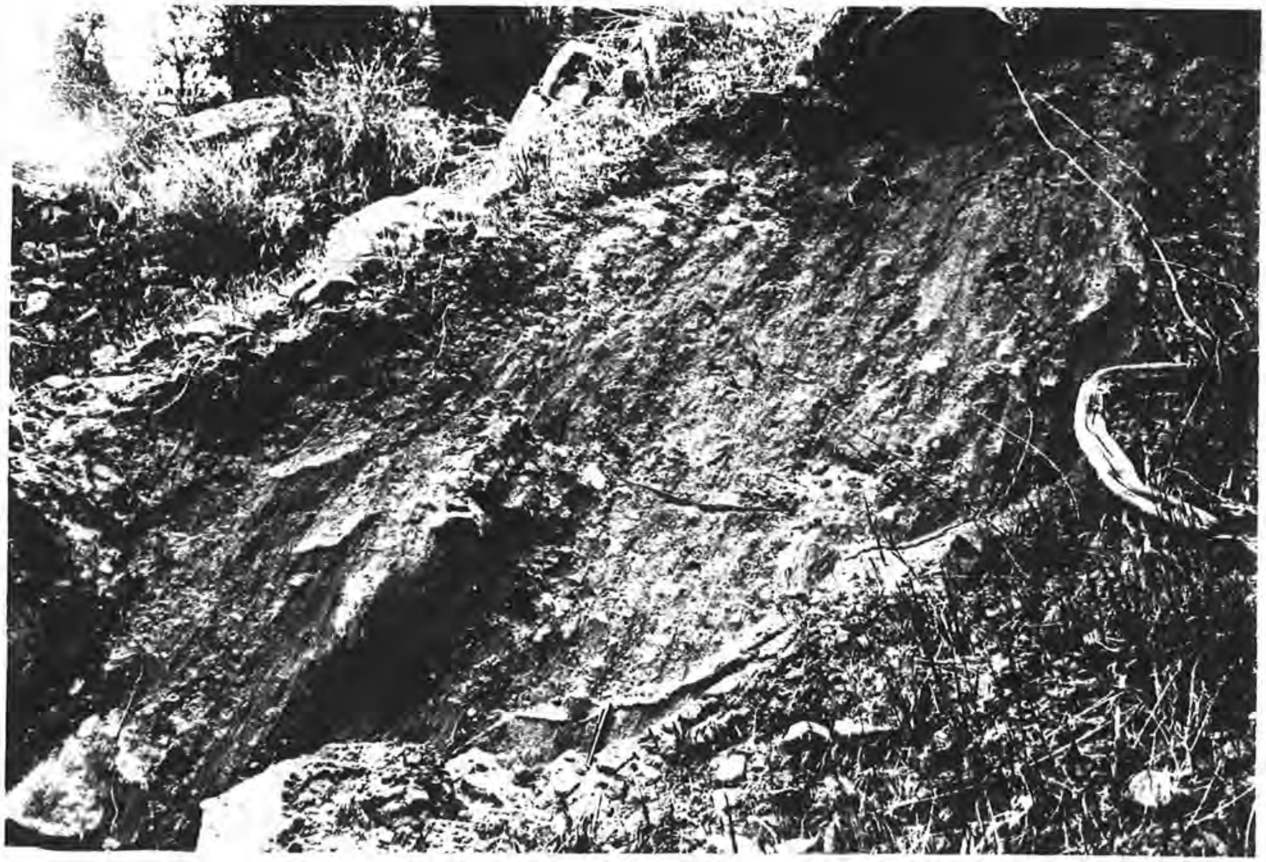

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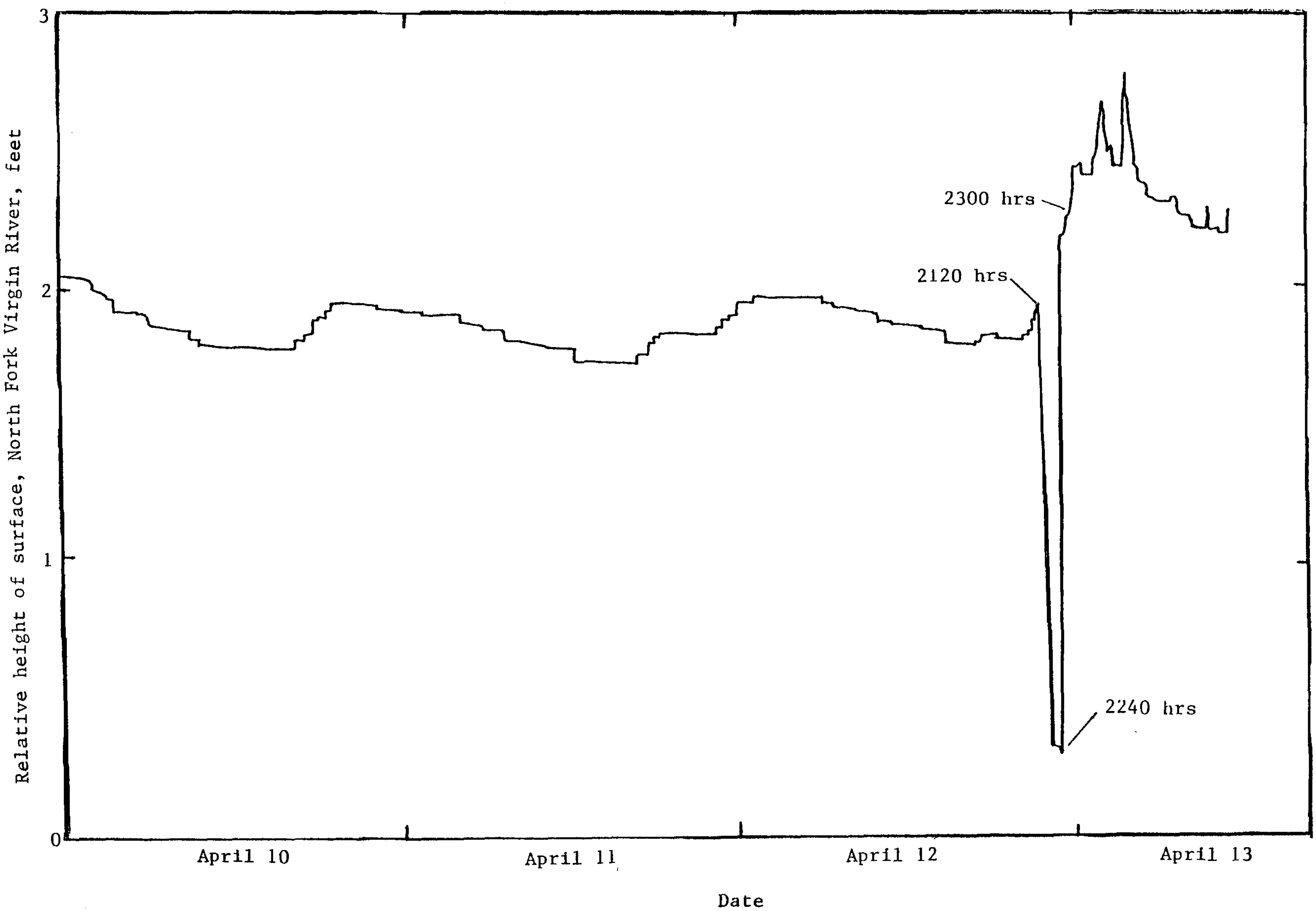

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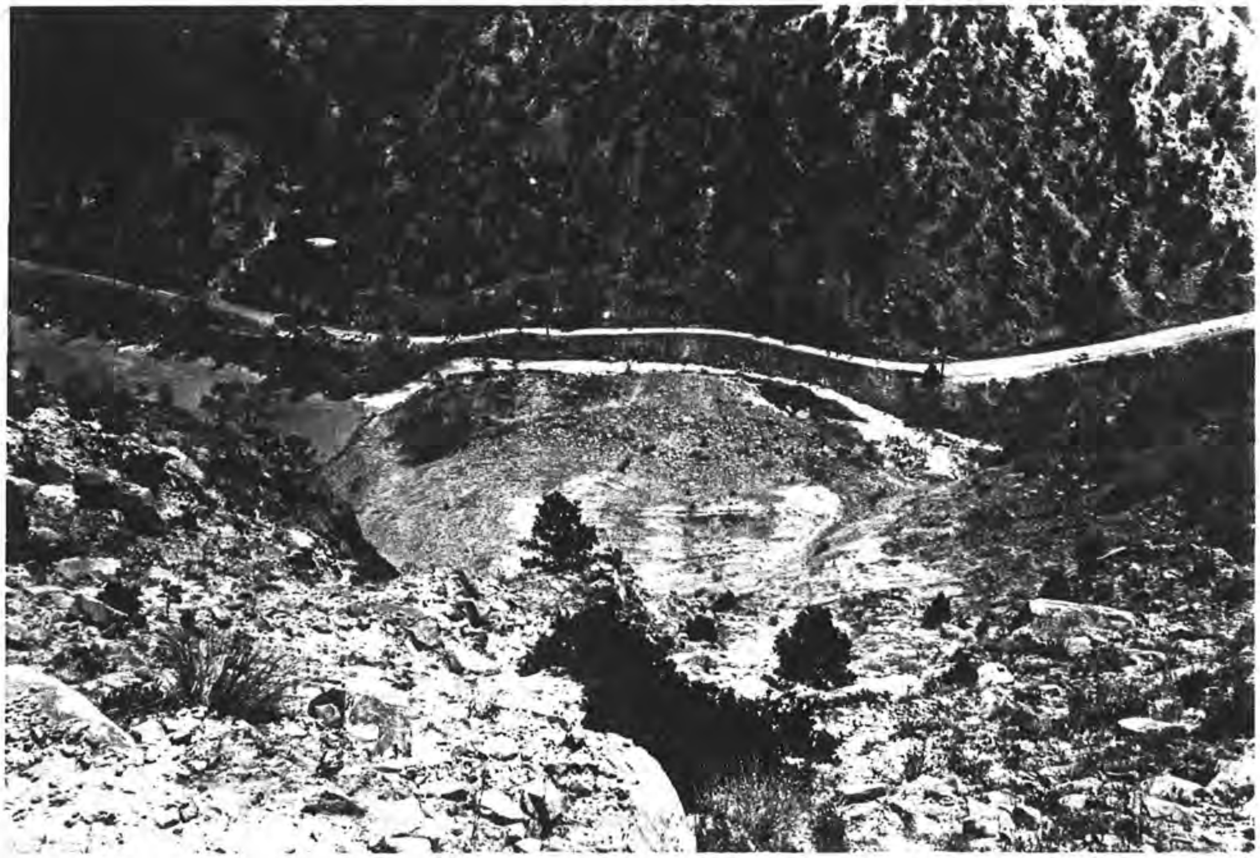

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