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PHOTO INTERPRETATION OF CLOSE-IN PHYSICAL EFFECTS OF AN UNDERGROUND NUCLEAR DETONATION

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ENVIRONMENTAL RESEARCH CORPORATION
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[This is a working paper for the transmission of ideas and exchange of information. The work herein represents the author's opinions and not necessarily those of the Corporation, and the results are preliminary and subject to revision in future reports.]

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ABSTRACT

Aerial photography provides a quick, economical and accurate technique for determining the surface changes caused by an underground nuclear detonation. Pre-shot and post-shot aerial photography was obtained for the Rulison detonation. These photographs were viewed stereoscopically in order to assess the surface changes associated with the Rulison detonation. The photo interpretation verified that no massive land slides or rock slides occurred as a result of the Rulison event. However, the interpretation revealed that 13 relatively small rock and soil movements occurred within 7 kilometers of Ground Zero. This study did not provide any information concerning physical effects beyond 7 kilometers.

PHOTO INTERPRETATION OF CLOSE-IN
PHYSICAL EFFECTS OF AN UNDERGROUND NUCLEAR EXPLOSION

INTRODUCTION

For each Plowshare experiment, examinations and recommendations are made for all slopes which might affect man-made structures if failure of the slope material occurs as a result of the experiment. As part of the Rulison experiment, however, the additional opportunity was presented to study the pre- and post-event condition of nearly every slope within approximately 7 km. of ground zero. This exercise was made possible by the examination of large-scale pre- and post-shot aerial photographs. Under normal conditions, aerial photography provides a permanent pre- and post-shot record of the terrain conditions at a reasonable cost. Because of the experimental nature of this effort, the coverage was limited to about 40 square miles.

The objective of this memorandum is to present the interpretation and analysis of the aerial photographs acquired before (26 August 1969) and after (25 September 1969) the Rulison detonation. After locating all of the close-in surface physical changes, an attempt is made to relate these to such factors as soil and/or rock type, the orientation of the slope location with respect to the detonation site, the estimated level of the input ground motion, and several other characteristics. Surface changes outside 7 km of the Rulison site are not discussed in this memorandum.

THE RULISON STUDY

GENERAL INFORMATION

It is not economically feasible to deploy recording instruments to document the ground motions at a large number of potential slide zones in unpopulated, irregular terrain, such as characterized by most of the immediate area surrounding the Rulison site. Aerial photography, however, provides a quick, economical and accurate technique for determining the surface changes associated with the detonation. These surface changes can be related to critical parameters such as distance from detonation, topography and geology. Ground motion data in the vicinity can be used to provide an approximation of the ground motions which the slide zones may have received. From such observations, more accurate predictions can be made of potential slide zones for future detonations.

The primary coverage (both pre-shot and post-shot) consisted of vertical, panchromatic photographs at a scale of 1:6000. This imagery was supplemented by low-altitude oblique photographs. Also, a third set of vertical imagery at a scale of 1:20,000 was obtained from the airphoto collection of the U. S. Department of Agriculture.

The large-scale (1:6000) coverage was flown in twleve strips in an east-west direction. During the data reduction stage, each strip of pre- and post-shot photographs was viewed stereoscopically with two-power magnification. The examination started with the southern-most flight line, and proceeded northward. The pre-shot imagery was examined first, followed by the post-shot imagery. Finally, the pre- and post-shot images were compared with the use of a stereoscope.

For each apparent surface change detected on the photos, the location was noted in three different forms:

1. the area was outlined on the imagery;
2. a notation was made of the film roll number and frame with a short description of the observable surface changes; and
3. the location was plotted on a 7-1/2 minute topographic quadrangle.

This procedure resulted in an accurate description of the extent, location, and type of surface change.

The changes observed in some areas were subtle and required additional study. These areas were checked at least three times to establish the final interpretation. For some areas, the interpretation was highly questionable, thus, the change in the area was not identified. Difficulties in interpretation generally were related to the quality of the imagery. For example, the major difficulty in interpreting the changes in many active or potentially active rock-slide or land-slide areas is related to the loss of imagery detail due to the high reflectivity of some of the sandstone-shale slopes. Additional pre-flight planning perhaps could have eliminated some of this deficiency in the imagery.

The basic assumption made in this analysis of pre-shot and post-shot imagery is that the relative change of close-in physical effects observed in the post-shot photographs represents a change induced by the Rulison detonation, rather than by some other phenomenon. The relatively small time interval (15 days) between each data acquisition and the detonation probably validates this assumption.

DESCRIPTION OF OBSERVED EFFECTS

The following paragraphs describe the surface changes resulting from the Rulison event as determined by examination of the pre- and post-shot aerial photographs. The location numbers preceding each description correspond to those used on the master location map (Figure 2-5) Table 2-1, contains specific data, such as distance and angle measurements, and the estimated values of ground motion for each location. It should be noted that the estimated peak resultant vector acceleration approximates or exceeds 1.0 g for all slide areas identified. However, small slides are known to have occurred at sites outside this zone of photo coverage where the peak resultant vector acceleration was less than 1.0 g (see report by John A. Blume & Assoc.)*. It should also be noted that the slide movements indicated in Figure 2-5 have a westerly direction.

The rock and soil movements detected by the photo analysis vary in relative degree. Although the photo interpretation verified that no "massive" landslides or rockslides occurred as a result of the Rulison event, the photo examination revealed that thirteen relatively small rock and soil movements occurred within 6.4 kilometers of ground zero. A description of each movement follows.

Location 1 - The largest rockfall occurred at this location. Figures 2-1 and 2-2 illustrate the appearance of the area before and after the event. This is an active rockfall area, and the ground motions from the Rulison event dislodged a section of weathered, unstable sandstone and shale. The rock fell from an essentially vertical slope, oriented nearly perpendicular to a radial line from ground zero. This rockfall and the dust it produced were visible from the observation point.

Locations 2, 3, 4, 5, 6 and 7 - Relatively small rockfalls were identified at each of these locations. Several additional areas representing probable rockfalls were also located, but these were not listed because of

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*John A. Blume and Associates, Structural Effects of the Rulison Event; John A. Blume Report, JAB-99-76, 1970.

Figure 2-1. Pre-Shot and Post-Shot Vertical Photographs of Location 1, Rulison Event.

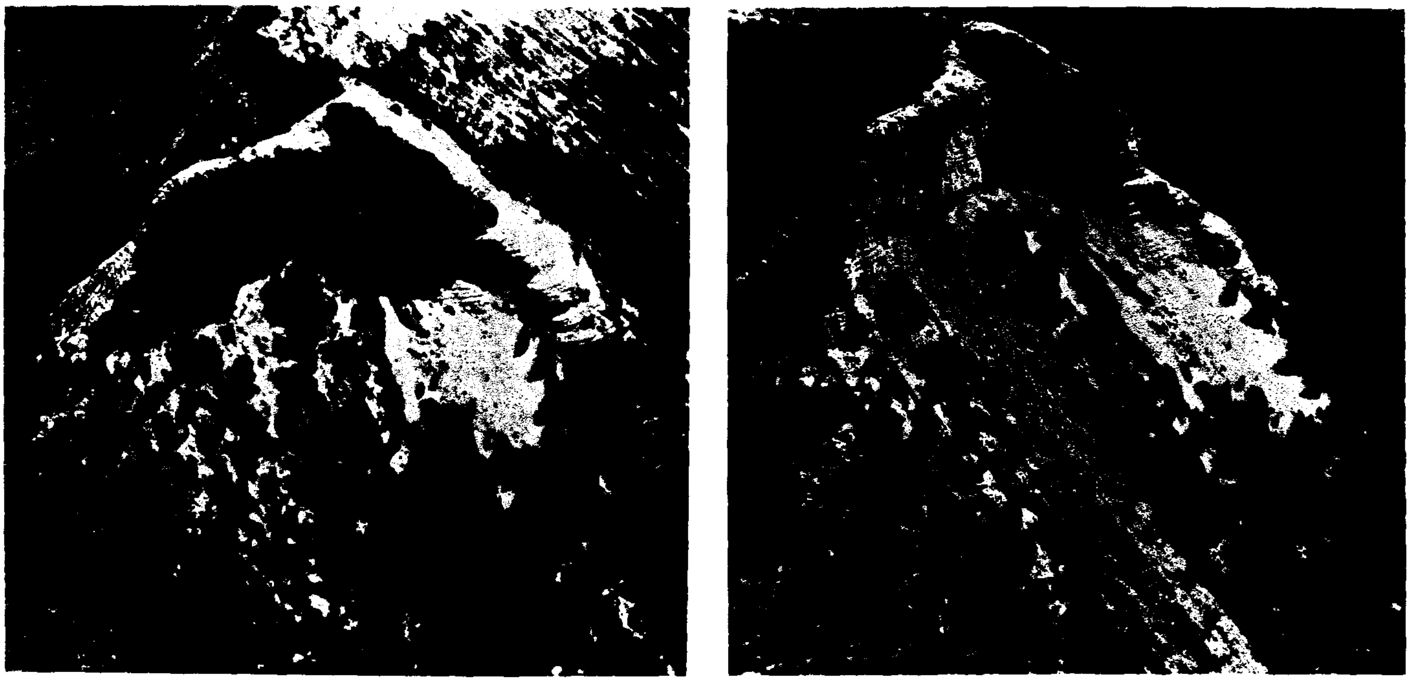


Figure 2-2. Pre-Shot and Post-Shot Oblique Photographs of Location 1, Rulison Event.

uncertainties in the interpretation. These six rockfall locations were grouped together, because the rockfalls all originated in the same sandstone bed. This sandstone bed can be traced on the photographs along the ridge at locations 5 and 6, and through the three ravines at location 2, locations 3 and 4 and location 7. The weathered, unstable sandstone is visible on the photographs as a thin band with very steep slopes within the interbedded sandstones and shales (see Figure 2-3). The interface at the bottom of this sandstone stratum appears to be quite wet, a factor which probably aided the rockfall process. This appears to be especially true at location 2, where a relatively recent slide has steepened the slope. An equally important factor which contributes to making this an active rockfall area is the relatively more rapid erosion of the exposed shale which underlies the sandstone. Undercutting was especially apparent at locations 5 and 6.

Location 8 - Several small rockfalls may have occurred along the active sandstone ridges near location 8. Uncertainties exist, however, due to overexposure of the photographs along some of these slopes. The area indicated as location 8 was listed, nevertheless, because of an unusual occurrence. Three large blocks of sandstone are located at the northwestern end of one of the ridges. Two of these blocks appear to have rotated several degrees in a clockwise direction. The blocks rest at the very end of a ridge which is very nearly perpendicular to a radial line from the shot-point. This orientation seems to be significant, for this rockfall is the only one observed south of the shot-point. Other causal relationships involving the ground motions and a combination of the elevations and joint pattern for locations 1 through 9 may be important, but are undetermined at this time.

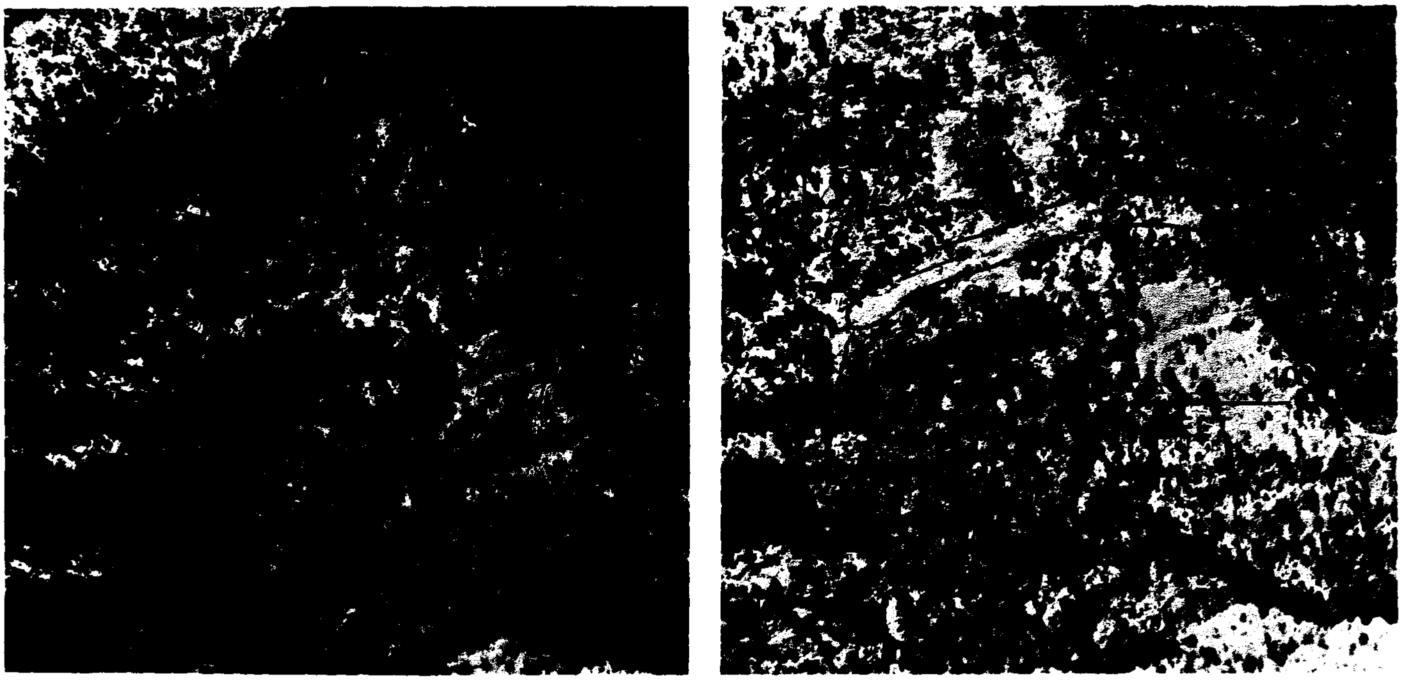


Figure 2-3. Pre-Shot and Post-Shot Vertical Photographs of Location 3 and 4, Rulison Event.

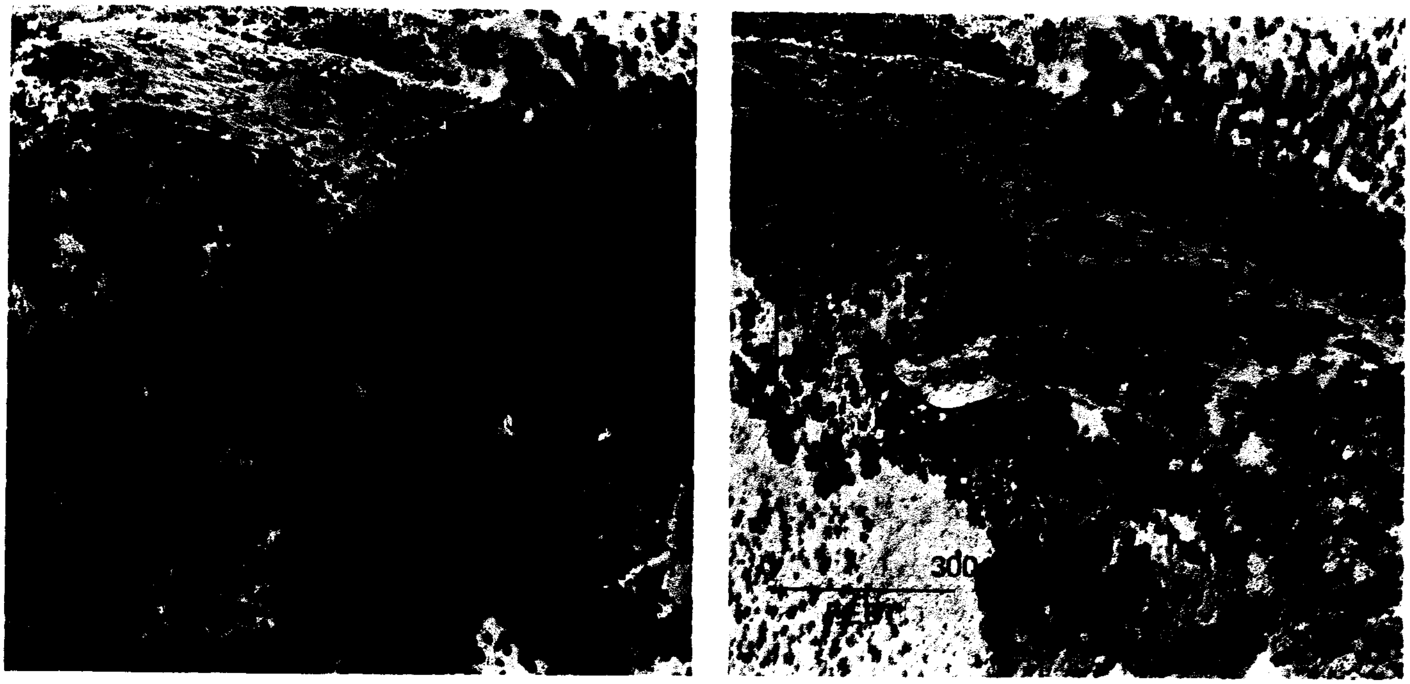
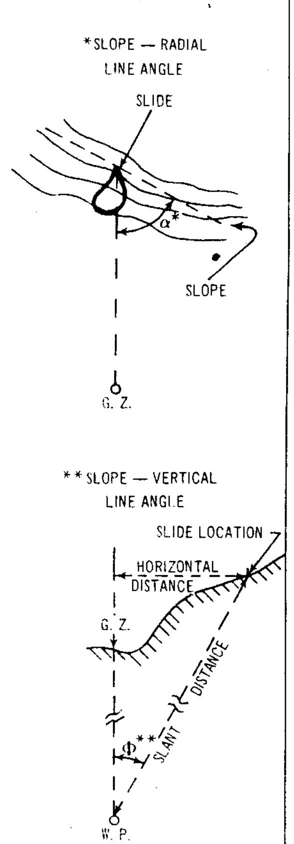


Figure 2-4. Pre-Shot and Post-Shot Vertical Photographs of Location 10, Rulison Event.

Table 2-1. Location and Ground Motion Data for Observed Surface Physical Effects

Location Number	Distance: Horizontal (km)	Distance: Slant (km)	Elevation Difference: Loc. to G.Z. (meters)	Elevation Difference: Loc. to W.P. (meters)	Azimuth from G.Z. (o)	Orientation of Slope: α* (°)	Orientation of Slope: Φ** (°)	Estimated Peak Particle Motion[b]: Acceleration (g)	Velocity (cm/sec)	Displacement (cm)	SLOPE ORIENTATION DIAGRAMS
1	3.35	4.30	120	2690	279	80	51.6	Z 1.7×10^{0} R 1.3×10^{0} T 9.1×10^{-1} V 2.5×10^{0}	3.7×10^{1} 3.3×10^{1} 2.5×10^{1} 4.8×10^{1}	9.2×10^{-1} 8.6×10^{-1} 6.6×10^{-1} 1.4×10^{0}	
2	4.34	4.82	-480	2090	283	59	64.6	Z 1.4×10^{0} R 1.0×10^{0} T 7.5×10^{-1} V 2.0×10^{0}	3.0×10^{1} 2.6×10^{1} 2.1×10^{1} 3.8×10^{1}	7.8×10^{-1} 7.2×10^{-1} 5.5×10^{-1} 1.2×10^{0}	
3	4.16	4.67	-440	2130	293	62	63	Z 1.5×10^{0} R 1.1×10^{0} T 7.8×10^{-1} V 2.1×10^{0}	3.1×10^{1} 2.7×10^{1} 2.1×10^{1} 3.9×10^{1}	8.0×10^{-1} 7.5×10^{-1} 5.6×10^{-1} 1.2×10^{0}	
4	4.23	4.73	-450	2120	294	73	63.4	Z 1.5×10^{0} R 1.1×10^{0} T 7.8×10^{-1} V 2.1×10^{0}	3.1×10^{1} 2.7×10^{1} 2.1×10^{1} 3.9×10^{1}	8.0×10^{-1} 7.5×10^{-1} 5.6×10^{-1} 1.2×10^{0}	
5	5.88	6.27	-410	2170	272	74	69.7	Z 7.9×10^{-1} R 6.1×10^{-1} T 4.5×10^{-1} V 1.1×10^{0}	1.8×10^{1} 1.6×10^{1} 1.2×10^{1} 2.3×10^{1}	4.9×10^{-1} 4.5×10^{-1} 3.5×10^{-1} 7.2×10^{-1}	
6	5.78	6.17	-410	2170	273	4	69.4	Z 8.4×10^{-1} R 6.4×10^{-1} T 4.7×10^{-1} V 1.2×10^{0}	1.8×10^{1} 1.6×10^{1} 1.3×10^{1} 2.3×10^{1}	5.1×10^{-1} 4.7×10^{-1} 3.7×10^{-1} 7.5×10^{-1}	
7	3.20	3.85	-430	2140	305	48	56.2	Z 2.2×10^{0} R 1.6×10^{0} T 1.1×10^{0} V 3.2×10^{0}	4.6×10^{1} 4.0×10^{1} 3.1×10^{1} 5.8×10^{1}	1.1×10^{0} 1.0×10^{0} 7.7×10^{-1} 1.7×10^{0}	
8	4.96	5.61	50	2620	239	68	62.1	Z 1.0×10^{0} R 7.8×10^{-1} T 5.6×10^{-1} V 1.5×10^{0}	2.2×10^{1} 2.0×10^{1} 1.6×10^{1} 2.8×10^{1}	6.0×10^{-1} 5.6×10^{-1} 4.3×10^{-1} 8.8×10^{-1}	
9	2.04	3.45	200	2780	0	2	36.2	Z 2.7×10^{0} R 2.0×10^{0} T 1.4×10^{0} V 4.0×10^{0}	5.8×10^{1} 5.0×10^{1} 3.8×10^{1} 7.2×10^{1}	1.3×10^{0} 1.2×10^{0} 9.2×10^{-1} 2.0×10^{0}	
10[a]	6.37	6.64	-680	1880	352	33	73.6	Z 7.5×10^{-1} R 5.7×10^{-1} T 4.2×10^{-1} V 1.0×10^{0}	1.6×10^{1} 1.5×10^{1} 1.2×10^{1} 2.1×10^{1}	4.6×10^{-1} 4.3×10^{-1} 3.4×10^{-1} 6.8×10^{-1}	
11	5.33	5.89	- 60	2510	61	67	64.8	Z 9.2×10^{-1} R 7.1×10^{-1} T 5.1×10^{-1} V 1.3×10^{0}	2.0×10^{1} 1.8×10^{1} 1.4×10^{1} 2.6×10^{1}	5.5×10^{-1} 5.2×10^{-1} 3.9×10^{-1} 8.2×10^{-1}	
12	6.07	6.68	200	2780	67	70	65.4	Z 7.3×10^{-1} R 5.6×10^{-1} T 4.1×10^{-1} V 1.0×10^{0}	1.6×10^{1} 1.4×10^{1} 1.1×10^{1} 2.1×10^{1}	4.5×10^{-1} 4.2×10^{-1} 3.3×10^{-1} 6.6×10^{-1}	
13	6.29	6.90	260	2840	65	66	65.8	Z 6.7×10^{-1} R 5.1×10^{-1} T 3.8×10^{-1} V 9.3×10^{-1}	1.4×10^{1} 1.3×10^{1} 1.0×10^{1} 1.9×10^{1}	4.2×10^{-1} 3.9×10^{-1} 3.1×10^{-1} 6.2×10^{-1}	



[a]NOTE: Slope material wet alluvium; all other locations sandstone/sandy shale.

[b]NOTE: Estimated Peak Particle Motion extrapolated from regression lines, observed Rulison data.

Z = vertical component; R = radial component; T = transverse component; V = Resultant vector.

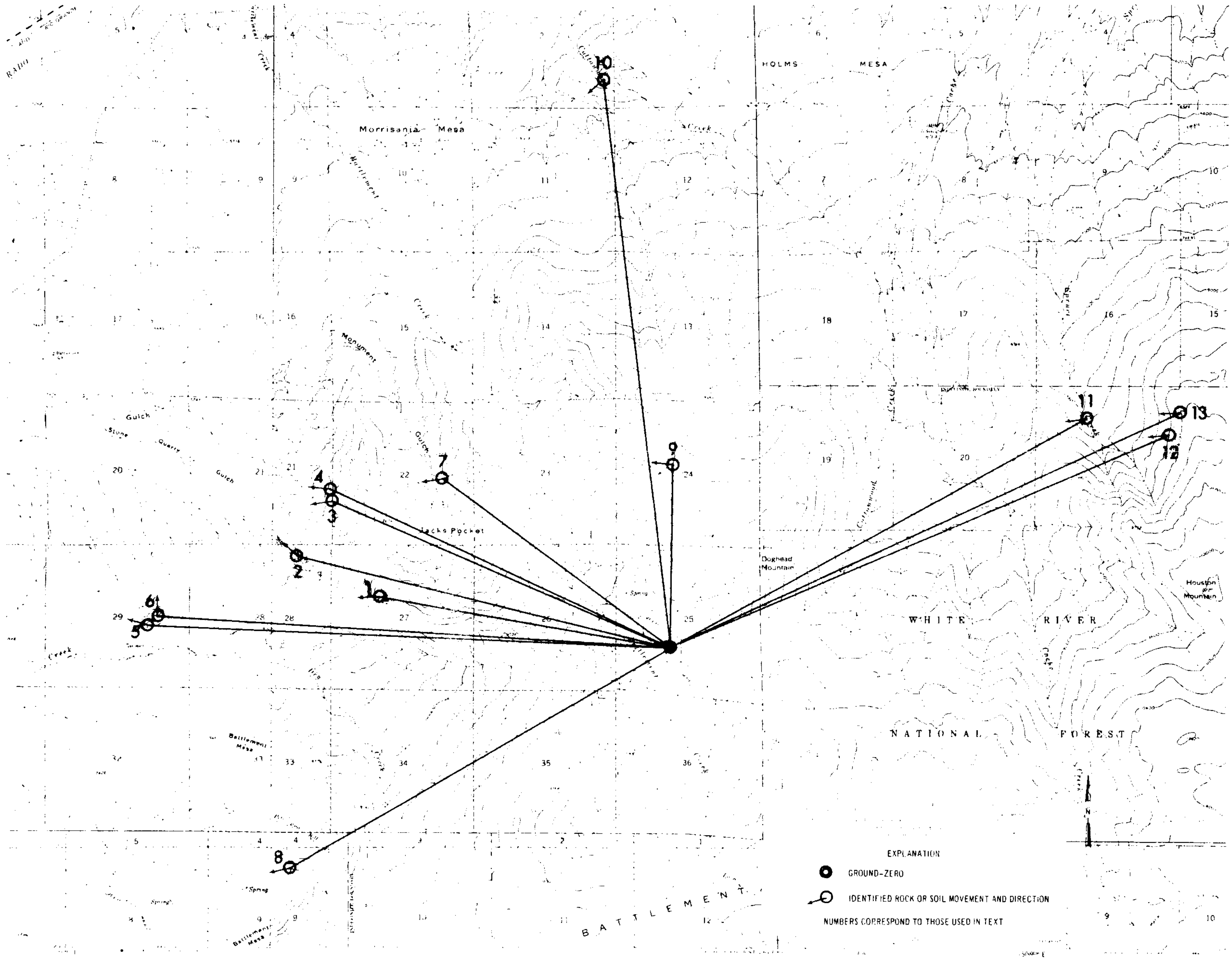


Figure 2-5. Area Map Showing Locations of Observed Surface Physical Effects

Location 9 - Several small rockfalls apparently occurred along the ridge near location 9. At the area indicated on Figure 2-5, one obvious rockfall is evident. The very steep slope and the weathered condition of the sandstone ridge were the primary factors contributing to the occurrence of this rockfall. The elevation and orientation of the joint pattern may also have had an influence.

Location 10 - At location 10, a substantial slide occurred in the Holmes Mesa area between the Lemon Ranch (Holmes Mesa) and Eames Orchard (Morrisania Mesa) recording stations (Figure 2-5). Although the general appearance of the area indicates good surface and vertical drainage, the photographs show several seepage bands in many of the gullies. The landslide at location 10 appears to have been influenced by one of the observed saturated layers (see Figure 2-4). The pressure of such saturated zones can cause landslides, even in areas which appear to be stable.

Locations 11, 12, and 13 - These locations are grouped together, because the changes are similar. At these locations, rocks have fallen onto what appears to be an infrequently used jeep trail. The rock movements are not significant in terms of size; however, the rocks are large enough to block easy passage by a vehicle.

The location of the Rulison event is shown in an oblique aerial photograph in Figure 2-6.

CONCLUSIONS AND RECOMMENDATIONS

Photo interpretation provides an economical means to acquire data which can be utilized to identify potential landslide and rockfall areas before a detonation and to document the occurrence of actual physical effects as a consequence of the detonation. Aerial photography permits an area of interest to be studied rapidly and economically, without encountering the difficulties experienced in normal field operations in rugged terrain.

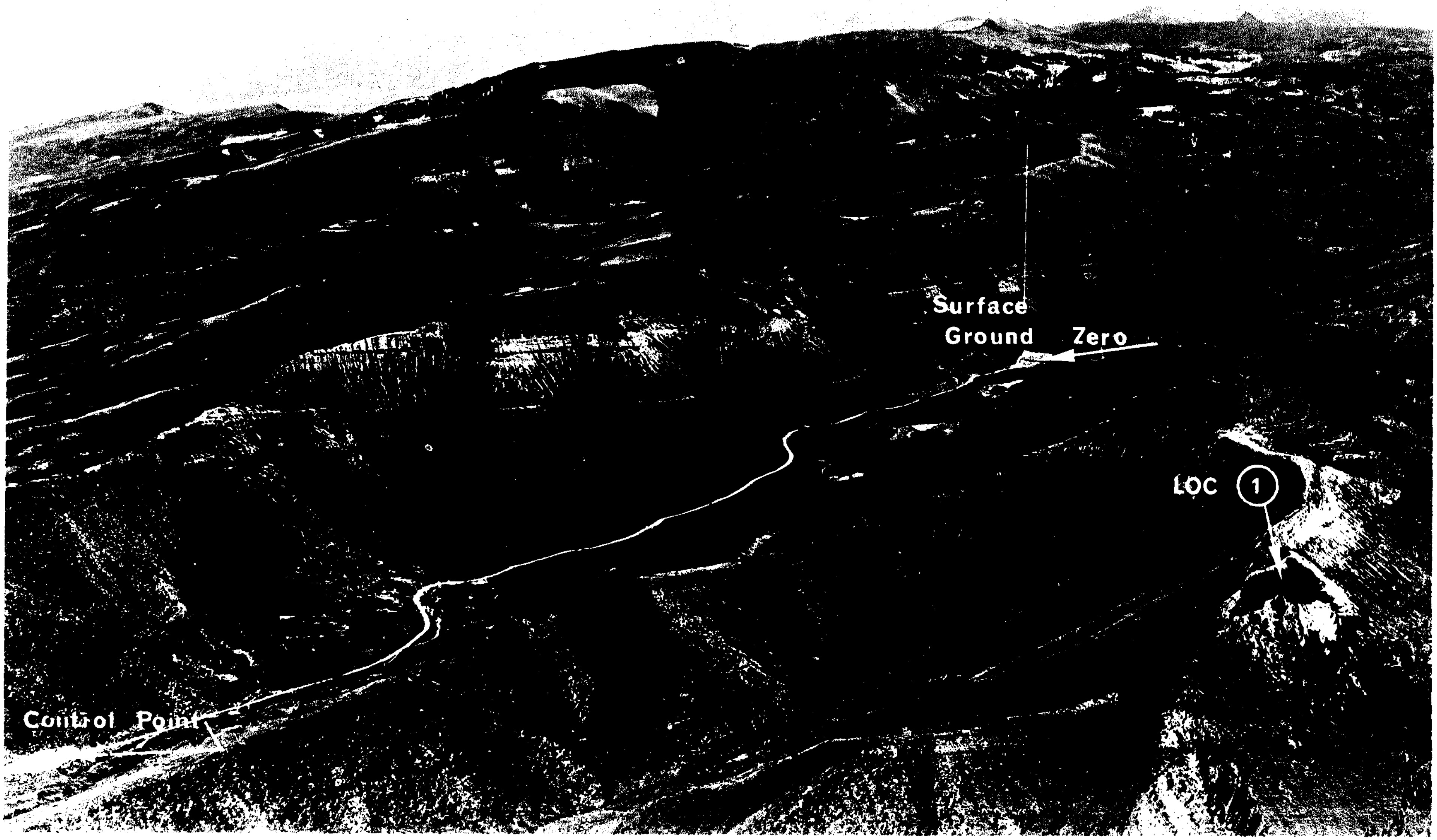


Figure 2-6. Oblique Aerial Photo of Rulison Event Vicinity (including Location No. 1 Slide Area).

The basic conclusions resulting from the study of pre-shot and post-shot photos of the area inside 7 km about ground zero are as follows:

1. No major rockfalls occurred within 7 km of ground zero as a consequence of the Rulison detonations.

2. A number of relatively small rockfalls and landslides were observed at various locations and appear to be related primarily to factors such as: (a) the slope condition, (b) the degree of saturation of interbedded layers, (c) the orientation of the location with respect to the detonation site, and (d) the level of the input ground motion. The estimated peak resultant vector accelerations approximated or exceeded one g at all but location 13, and even at this location, the estimated acceleration was 0.93 g. Because no ground motion records were available in these areas, no further detailed analysis was made to correlate rock falls with specific types of ground motion (frequencies, duration, etc.).

3. The slopes in the immediate areas of ground zero were unaffected. Even the man-made slopes adjacent to the drilling pad for the emplacement hole did not fail, in spite of substantial vertical ground motion at ground zero.

4. No observable slope failures occurred in the basalt landslide debris located south of ground zero.

   This is somewhat surprising, for much of this material has steep slopes, a high moisture content, and a history of past movement. Slope orientation also appears to have been of little significance, since the area contains slopes of nearly every orientation with respect to ground zero. The key factor seems to be the fact that the slant distance to the basalt debris was sufficiently great to cause a ground motion level which could be tolerated without sliding.

5. Most of the observed slides occurred in the interbedded sandstone-shale material which forms the rather steep ridges south of the Colorado River. The material of these ridges, although fairly competent, was highly fractured and weathered at the surface. Underlying moist shale seams add to the instability of the overlying sandstone. These factors, coupled with the relatively large input ground motions, led to landslides (refer to estimated ground motions for locations 2 through 7 in Table 2-1).

6. Unfortunately, the pre- and post-shot, large-scale photography did not extend beyond 7 km from ground zero. This study did not, therefore, provide any information concerning physical effects beyond 7 km.

7. By extending the aerial coverage and using the photography at an earlier pre-shot stage, some form of map could be prepared outlining areas of possible surface physical effects.

The Rulison exercise provides valuable information concerning the stability of slopes near ground zero for that particular event. This information could be quite useful for further tests at a nearby location or at any location with similar geologic conditions. This could, eventually, lead to the preparation of quite detailed, accurate landslide, or rockfall, potential maps for inclusion in prediction reports.

For future events, consideration should be given to obtaining pre- and post-shot aerial photographs for recording and studying physical effects. Advantage can also be taken of existing aerial photography in most parts of the United States (e.g., U. S. Dept. of Agriculture, U.S.G.S., U.S.A.F.), although the scale is usually smaller than was used in the present study.

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