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A Preliminary Inventory, Description, and Statistical Evaluation of Landslides in a Region of Projected Urban Development, Sheridan, Wyoming

By

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards or nomenclature

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A PRELIMINARY INVENTORY, DESCRIPTION, AND STATISTICAL EVALUATION OF LANDSLIDES IN A REGION OF PROJECTED URBAN DEVELOPMENT, SHERIDAN, WYOMING

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Introduction

In response to the national energy crisis, it is anticipated that the vast coal resources of the Powder River Basin will be developed at an ever-increasing rate over the next several decades. A report released by the Sheridan City Planning Commission (Peldo, 1975) stated that 12 energy companies are believed to have plans for coal development in the region, and that Sheridan and Johnson Counties would gain 30,000 people in the next two decades. It is evident that much urban and industrial expansion will take place in preferential areas in and near Sheridan and Buffalo.

In many of these areas, landsliding is common and undoubtedly will be a major hazard, hindering future development. Many factors in the existing physical environment contribute to slope instability. These include not only the geologic terrane but also climatic elements and topography. An exact understanding of what these factors are, and a knowledge of where, when, and how they are operating, are essential for optimum planning and development.

Reconnaissance in the vicinity revealed an area of approximately 300 square miles* southeast, south, and west of the city of Sheridan that has extensive slope failures. The failures occur mostly in poorly consolidated, fine-grained sedimentary rocks of the Wasatch and Fort Union Formations. Both formations dip slightly to the east, away from the Bighorn Mountain front. Some of the observed failures are undoubtedly old features that were activated in prehistoric time and may still be active today. However, many of the landslides are actively eroding present-day slopes, and generally consist of complexly deformed masses that are the result of slumping and earthflow movements. Individual moving masses sometimes coalesce, sometimes occur adjacent to or within older failed masses, or occur alone.

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*To convert square miles to square kilometres, multiply by 2.6.

As hazards, the slides already have caused considerable damage and concern among residents and various State agencies. Presently, the Wyoming Highway Department must contend with maintenance problems caused by slope failures on Highways I-90, U.S. 14, and U.S. 87 south and east of Sheridan. Sheridan County has made numerous repairs to roads damaged by slope failures south and west of Sheridan. The State Highway Department conducted geologic and slope-stability investigations along the right-of-way of Highway I-90, and used accepted techniques of slope design for highway construction where the slopes were determined to be unstable. The County Engineer of Sheridan County is also aware of the slope-instability problem but has not yet had to contend with it to any extent in housing developments. Much of the newer development presently is taking place on the high, flat, alluvial terrace surfaces west of the city of Sheridan. Effluent from septic tanks in these areas was accelerating instability along drainage slopes, but the installation of a sewage system has helped to alleviate the problem in the city of Sheridan. However, one slide on the north bank of Soldier Creek just north of Sheridan has already dammed and diverted the creek through the backyard of a local resident's property. Further damming of the stream, if accompanied by severe spring runoff, threatens to cause serious damage to at least one dwelling.

It is evident that slopes along major drainages west and south of Sheridan, esthetically ideal for development, are potentially unstable and remain a major factor that will hinder development.

The present landslide study undertaken by the U.S. Geological Survey is an attempt to aid local planning agencies in determining optimum land use by defining the natural and artificial conditions that influence slope stability, the areal distribution of active slides and potentially unstable slopes, and, if necessary, by developing criteria for better prediction and design capability.

The purpose of this preliminary report is fourfold:

1. To show the location of landslides and to define the problem of slope instability in the study area.
2. To present a representative overview of the existing landslides with regard to their types, distribution, geometry, and related factors in the physical environment.
3. To define some of the important conditions that influence slope stability.
4. To lay the groundwork for, and give direction to, future study.

This preliminary report includes an inventory map of the total study area showing the location of failed slopes, landslide descriptions, a brief statistical evaluation of geometric measurements made on selected failed slopes, and an assessment of engineering geology practice. More than 550 landslides have been mapped from aerial photos and by field reconnaissance mapping techniques over an area of about 200 square miles. Descriptions, including geometric measurements and descriptions of lithology, hydrology, structure, morphology, and recency of movement, were made for 22 of these mapped slides.

Acknowledgments

Data on existing landslides, logs from drill holes, slope-stability analyses, and slope profiles were obtained from William Sherman and Frank Morgando of the Wyoming State Highway Department. Walter Pilch, Sheridan County Engineer, contributed information about landsliding in the Sheridan area. The Texaco Petroleum Company granted permission for entrance onto their lands and supplied drill-hole data. Many local residents also granted access to their properties and provided useful information. Thomas Bullard of the U.S. Geological Survey assisted in the field investigations and compiled and reduced much of the data. Laboratory tests were performed by Eric Smirnow of the U.S. Geological Survey. The cooperation and help given by these individuals and organizations is greatly appreciated.

Geography

Location

The study area is in north-central Wyoming, and includes parts of Sheridan and Johnson Counties along the eastern front of the Bighorn Mountains and along the western margin of the Powder River Basin. The area is bounded on the west by steeply dipping Mesozoic and Paleozoic rocks and on the east by an arbitrary line approximately 5 to 10 miles* from the mountain front. The northern and southern extremes of the study area are represented by the drainages of Big Goose Creek and Piney Creek, respectively. Figure 1 shows the total study area

Figure 1.--NEAR HERE.

(the solid outline) in relation to the Bighorn Mountains and the towns of Sheridan and Buffalo.

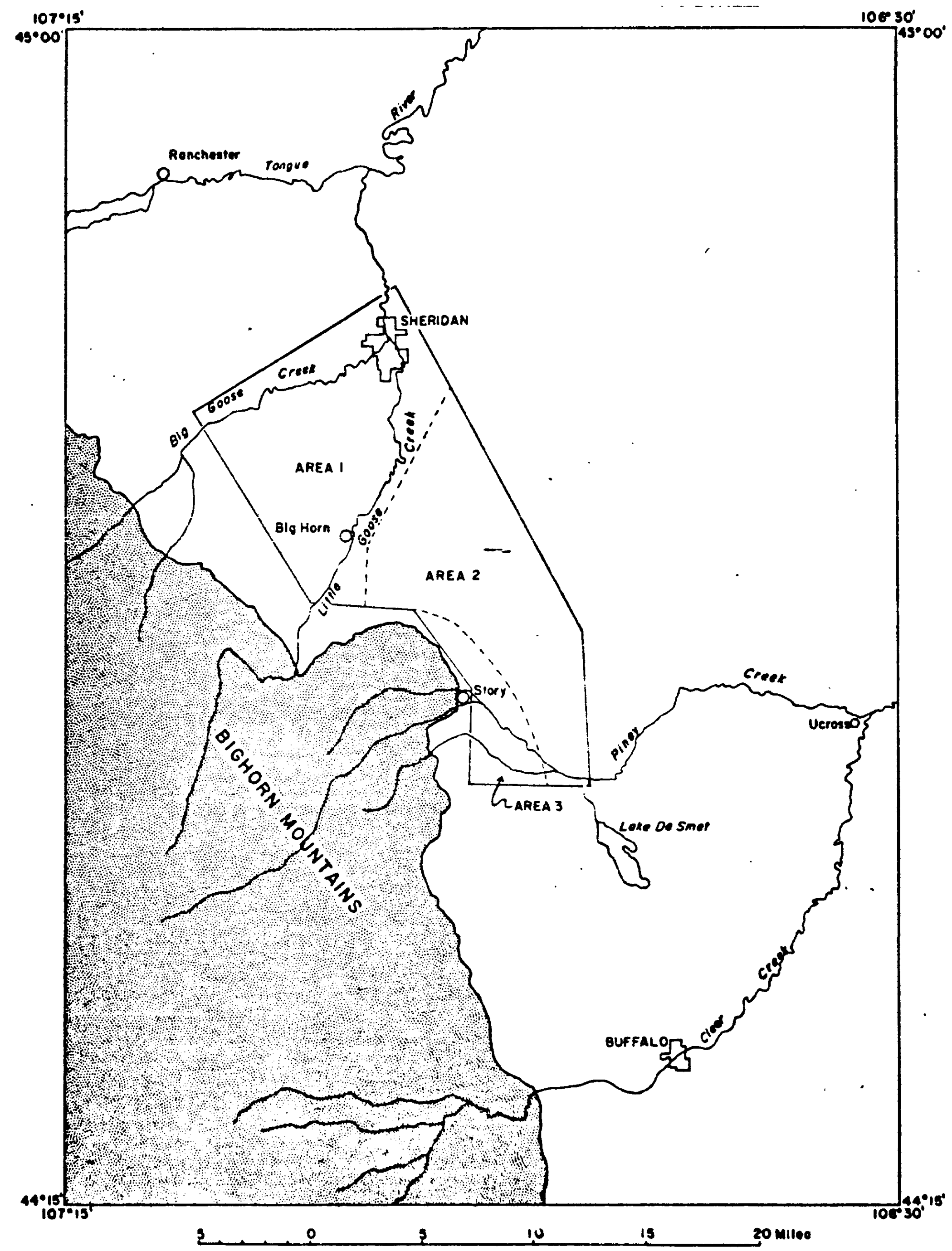
Topography and drainage

Two prominent topographic regions meet in the area: the eastern slope of the Bighorn Mountains and the westernmost part of the Powder River Basin. Landforms of both regions contribute to a varied topography.

A narrow belt of steep ridges and hogbacks, trending to the northwest, forms the mountain front of the eastern slope.

*To convert miles to kilometres, multiply by 1.6.

Figure 1.--Index map of the study area.



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To the east, a transitional zone of nearly flat erosional surfaces has been dissected by basinward-flowing streams, leaving gently sloping portions abutting the mountain front and high isolated remnants farther east. Rounded hills and nearly flat alluvial surfaces fill the many areas between, where the higher surfaces have been removed by erosion.

Local badlands are characteristic of the topography merging from the east. Red clinker, a highly resistant material resulting from the alteration of rocks overlying burned coal beds, caps many of the high buttes, ridges, and cone-shaped hills.

Perennial streams in the area include Big Goose, Little Goose, and Piney Creeks. Big Goose and Little Goose Creeks, located in the northern part of the study area, head in the mountains southwest of Sheridan and flow to the northeast. North and South Piney Creeks head in the mountains west of Story, Wyo., and merge east of Story, flowing southeastward.

Many of the tributaries in the eastern part of the area flow northwestward or southeastward into the major drainages, resulting in a rectangular drainage pattern.

Climate

The climate of the area is semiarid, with long cold winters and short hot summers.

Precipitation is generally greatest close to the mountains. The average annual precipitation at Sheridan is 15.79 inches.* April, May, and June are the months of greatest precipitation, and the mean for that 3-month period is 7.03 inches; a high of 15.81 inches was recorded in 1944. Heavy wet snows are common in the months of March and April and are often accompanied by strong winds and drifting snow. During the summer months, thunderstorms are generated over the mountains and frequently move northeastward, giving afternoon and evening showers to the Sheridan-Buffalo area. Tables 1 and 2, respectively,

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Tables 1, 2.--NEAR HERE.

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are records obtained from the National Climatic Center (1974) of monthly precipitation and snowfall for the years 1935 to 1974.

Temperature variations in the Sheridan area are great, especially east of the mountains. Temperature extremes of 106° F in July of 1954 and -41° F in December of 1919 have been recorded at the Sheridan weather station.

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*To convert inches to centimetres, multiply by 2.5.

Tables 1 and 2.--Records of total precipitation and snowfall (in inches) at the Sheridan, Wyoming, weather station (National Climatic Center, 1974).

Precipitation

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
1935	0.10	0.35	1.40	1.34	3.12	1.72	0.09	1.90	0.64	0.58	0.44	0.41	12.09
1936	0.76	0.85	1.48	0.88	0.15	2.18	1.07	0.19	0.88	1.82	0.38	0.50	11.14
1937	0.19	1.45	2.51	1.24	2.39	2.43	1.78	0.03	0.50	0.95	0.70	1.06	15.23
1938	1.03	0.31	1.00	1.34	6.82	2.29	1.36	0.30	0.04	0.41	1.23	0.85	16.98
1939	0.40	0.68	1.15	1.96	3.82	2.28	2.43	2.22	0.75	0.47	T	0.24	16.40
#1940	0.86	0.61	0.93	3.87	0.67	1.85	0.89	0.07	2.05	0.83	0.80	0.26	13.69
1941	0.19	0.10	0.42	3.87	1.52	1.37	1.94	1.15	2.04	1.30	0.48	0.80	15.18
1942	0.30	0.43	0.72	1.83	4.28	1.23	1.09	0.12	1.71	2.02	2.23	0.55	16.51
1943	0.70	0.58	0.81	1.61	3.93	3.72	1.83	1.88	0.34	0.87	0.75	0.78	17.85
1944	0.94	0.83	1.90	2.81	3.46	9.54	1.55	0.42	0.66	0.08	1.11	1.28	24.58
1945	0.44	1.03	1.53	1.41	2.29	4.26	0.26	2.00	3.02	0.69	0.97	0.79	18.69
1946	0.95	0.53	3.24	1.10	4.46	5.24	0.71	1.14	2.14	2.11	0.61	1.32	23.57
1947	0.55	1.15	1.31	1.89	2.59	5.02	0.30	0.52	1.89	1.09	2.13	0.43	18.87
1948	1.70	0.68	1.02	4.53	0.81	4.59	2.98	1.06	1.04	0.36	1.05	0.32	20.14
1949	1.61	0.41	1.15	2.30	2.83	2.30	0.36	0.10	1.48	1.99	0.94	0.50	15.97
1950	0.85	0.57	1.62	1.59	1.51	1.83	2.16	0.77	1.58	0.51	1.05	0.58	14.53
1951	0.55	0.24	1.20	1.41	0.93	2.06	1.97	1.13	3.08	1.37	0.15	0.68	14.79
1952	0.15	1.39	0.85	0.80	3.61	1.70	3.48	1.66	0.26	0.22	0.28	0.50	14.90
1953	1.14	1.53	0.77	1.53	2.08	1.92	0.13	1.21	0.77	1.51	0.91	0.85	14.35
1954	0.53	1.24	3.04	1.24	1.58	1.33	0.54	1.05	1.03	1.07	0.28	0.24	13.17
1955	0.89	2.68	2.72	4.52	4.17	1.76	1.42	0.52	0.71	1.21	1.19	2.03	23.82
1956	0.59	0.41	1.99	1.91	4.94	1.07	0.35	1.40	0.72	0.88	0.97	0.23	15.42
1957	0.41	0.53	1.23	3.26	3.63	4.39	0.31	1.31	1.11	1.61	1.15	0.23	19.17
1958	0.34	0.84	0.70	4.22	0.30	2.01	3.78	0.26	0.17	0.35	0.76	0.70	14.43
1959	0.32	0.45	0.80	1.72	1.46	2.07	0.08	0.13	0.60	1.48	0.90	0.31	10.32
1960	0.16	0.54	0.24	0.60	0.83	1.00	0.14	2.32	0.27	0.87	0.69	0.57	8.23
1961	0.12	0.98	0.61	1.20	2.95	0.49	1.31	0.15	2.56	2.83	0.73	0.74	14.67
1962	0.72	0.42	0.66	1.04	2.28	3.03	1.57	1.10	1.43	0.37	0.63	0.53	13.78
1963	1.31	0.83	0.55	4.80	1.54	4.71	0.51	0.42	1.33	0.52	0.65	0.91	18.08
1964	0.35	0.81	0.51	2.74	1.76	5.11	0.11	1.18	0.06	0.34	1.99	0.66	15.62
1965	1.18	0.72	0.70	0.65	2.12	2.15	0.93	0.68	1.75	0.02	0.22	0.24	11.36
1966	0.36	0.40	1.04	2.25	1.08	1.29	0.29	0.86	0.98	1.02	0.62	0.87	11.01
1967	0.61	1.28	1.19	2.51	1.33	6.11	0.22	0.70	1.56	0.88	0.84	0.98	18.20
1968	1.05	0.75	0.92	0.71	2.29	3.89	0.33	3.02	2.12	0.63	0.91	0.97	17.59
1969	1.11	0.18	0.40	1.84	1.79	2.44	0.47	0.24	0.09	1.47	0.99	0.51	11.53
1970	0.72	0.71	2.31	1.67	5.20	2.10	1.05	T	1.87	0.94	1.43	0.62	18.63
1971	1.43	1.17	0.62	3.83	2.45	0.28	0.21	0.52	0.90	3.16	0.71	0.52	15.80
1972	1.79	0.66	0.97	1.02	1.35	1.96	1.62	0.96	0.94	1.01	0.32	0.90	13.50
1973	0.35	0.39	1.41	4.05	0.51	2.21	0.64	0.47	2.79	0.81	0.70	0.80	15.13
1974	0.67	0.46	0.96	1.58	1.44	0.48	0.65	0.70	1.48	2.96	0.64	0.24	12.26
RECORD MEAN	0.77	0.69	1.19	2.12	2.52	2.39	1.18	0.82	1.39	1.26	0.81	0.65	15.79

Snowfall

Season	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Total
1935-36	0.0	0.0	0.0	5.0	6.3	3.0	10.8	11.7	15.2	0.9	0.0	0.0	52.9
1936-37	0.0	0.0	0.0	2.2	4.6	5.9	2.1	18.0	18.5	0.6	0.0	1.5	53.4
1937-38	0.0	0.0	T	T	8.2	9.1	8.3	3.5	8.3	5.2	0.4	0.0	43.0
1938-39	0.0	0.0	0.0	0.2	5.8	2.1	4.6	8.5	12.8	9.3	T	0.0	46.3
#1939-40	0.0	0.0	T	0.8	0.0	2.0	12.8	9.0	0.8	13.9	0.0	0.0	39.3
1940-41	0.0	0.0	0.0	0.0	5.9	6.7	4.4	2.6	5.1	2.2	T	0.0	26.9
1941-42	0.0	0.0	3.2	4.4	5.5	9.9	3.5	5.2	7.4	T	2.4	0.0	41.5
1942-43	0.0	0.0	0.6	1.8	24.0	5.1	6.8	9.9	10.4	T	11.0	T	69.6
1943-44	0.0	0.0	0.0	1.7	2.3	5.3	12.4	9.9	17.2	T	0.7	0.0	49.5
1944-45	0.0	0.0	T	T	7.6	11.8	5.4	12.5	2.7	5.6	T	0.0	45.7
1945-46	0.0	0.0	0.8	2.4	10.5	7.0	12.8	3.2	18.5	T	0.5	0.0	55.7
1946-47	0.0	0.0	0.0	6.1	8.6	13.4	5.8	15.4	13.3	4.9	0.6	0.0	68.1
1947-48	0.0	0.0	T	2.2	23.9	6.2	16.8	9.8	12.6	11.5	0.4	0.0	83.4
1948-49	0.0	0.0	0.0	T	5.3	5.4	22.9	8.1	13.8	3.3	T	0.0	58.8
1949-50	0.0	0.0	1.0	10.9	T	8.1	13.9	7.5	18.1	24.2	5.1	T	88.8
1950-51	0.0	0.0	0.6	2.7	9.8	10.0	11.3	6.7	21.6	7.3	0.0	3.2	73.2
1951-52	0.0	0.0	0.3	9.3	1.8	10.4	2.3	20.1	12.8	4.7	0.0	0.0	61.7
1952-53	0.0	0.0	0.0	0.3	7.0	6.4	7.6	26.1	8.2	13.1	2.5	0.0	71.2
1953-54	0.0	0.0	0.0	T	8.1	12.8	10.9	11.8	36.8	6.9	6.3	T	93.5
1954-55	0.0	0.0	2.0	10.2	1.1	3.4	8.4	35.0	29.1	39.5	0.0	0.0	128.8
1955-56	0.0	0.0	T	8.1	10.0	27.6	9.4	7.3	21.9	11.3	1.8	0.0	97.4
1956-57	0.0	0.0	0.0	1.2	8.2	4.3	9.5	11.1	15.4	19.2	T	0.0	68.9
1957-58	0.0	0.0	T	4.8	10.6	2.1	4.4	14.3	6.4	28.3	0.0	0.0	70.9
1958-59	0.0	0.0	0.0	2.0	3.0	8.8	6.4	8.6	6.8	10.3	T	0.0	45.9
1959-60	0.0	0.0	T	4.1	10.3	4.2	3.1	10.2	5.4	5.4	T	0.0	42.7
1960-61	0.0	0.0	0.0	T	6.9	14.1	2.8	8.8	0.8	4.1	0.0	0.0	37.5
1961-62	0.0	0.0	T	12.5	9.1	5.9	9.6	4.6	7.1	1.1	0.0	0.0	50.0
1962-63	0.0	0.0	2.3	T	4.1	6.8	23.9	13.1	6.7	6.7	0.0	0.0	63.6
1963-64	0.0	0.0	0.0	1.3	2.2	18.4	4.9	13.3	7.8	7.1	0.7	0.0	58.7
1964-65	0.0	0.0	T	0.0	25.8	9.4	11.8	12.5	12.8	3.7	4.7	0.0	80.7
1965-66	0.0	0.0	5.0	0.0	4.5	5.3	8.6	5.3	12.9	12.9	3.4	0.0	58.9
1966-67	0.0	0.0	0.0	4.4	11.1	14.6	12.1	20.4	16.5	23.0	7.5	0.0	109.6
1967-68	0.0	0.0	0.0	0.2	11.5	20.6	13.5	7.3	14.0	7.1	0.6	0.0	74.8
1968-69	0.0	0.0	0.0	T	6.9	15.3	15.0	3.0	4.9	6.7	1.3	4.0	57.1
1969-70	0.0	0.0	0.0	4.9	7.8	5.7	11.5	10.1	26.1	9.4	2.0	0.0	77.5
1970-71	0.0	0.0	9.5	0.9	11.3	10.0	15.6	15.7	7.5	5.2	T	0.0	75.7
1971-72	0.0	0.0	T	14.8	9.3	9.2	25.1	9.4	9.1	7.8	T	0.0	84.7
1972-73	0.0	0.0	3.6	2.6	1.4	15.6	7.8	8.2	16.1	37.5	1.4	0.0	94.2
1973-74	0.0	0.0	3.2	4.9	11.7	10.7	10.0	6.8	9.8	7.7	0.4	0.0	65.2
1974-75	0.0	0.0	0.3	2.0	4.4	4.7							
RECORD MEAN	0.0	0.0	1.0	3.6	8.4	9.7	10.3	11.0	12.8	9.9	1.6	0.2	68.5

Geology

Bedrock

The gently dipping beds of the Wasatch and Fort Union Formations constitute bedrock in the study area.

The Fort Union is exposed in the northwestern part of the area; it has been described by Lowry and Cummings (1966) as consisting of approximately 2,000 feet* of nonmarine dark shale, light-colored sandstone, and coal of Paleocene age. Surface exposures of the Fort Union in the study area reveal variable lithologies of light-brown silty shales, gray and blue clay shales, poorly consolidated lensatic sandstone and siltstone, and occasional thin beds of coal and carbonaceous shale. Water-well logs supplied by the State of Wyoming reflect similar lithologies to depths as great as 400 feet. The logs indicate that the thickness of individual shale beds is generally less than 30 feet, although a bed of dark shale approximately 130 feet thick was encountered in a well in sec. 8, T. 54 N., R. 83 W. Beds of sandstone, siltstone, coal, and carbonaceous shale are seldom thicker than 10 feet. The Fort Union rests conformably on the Lance Formation of Cretaceous age, and is overlain, in all but the northwestern part of the area, by the Wasatch Formation of Eocene age.

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*To convert feet to metres, multiply by 0.305.

The Wasatch Formation underlies approximately two-thirds of the study area, mostly south and east of Little Goose Creek. It has been mapped, in part, by Mapel (1959), and in part by Lowry and Cummings (1966). The Wasatch has been described by Lowry and Cummings as consisting of nonmarine deposits of light-gray to yellowish-gray sandstone and dark-colored shale and coal, grading and interfingering westward into conglomeratic members.

In the study area, the fine-grained facies of the Wasatch is characterized by beds of gray and brown carbonaceous shale and gray silty clay shale interbedded with coal, and lenticular siltstone and sandstone. Shale beds exceeding 50 feet in thickness are exposed in the central part of the area but thin rapidly to the west. The coarse-grained facies is found in the southwestern part of the study area and is characterized by greenish-gray sandy shale, siltstone, and lensatic coarse sandstone and conglomerate. The maximum thickness of the Wasatch Formation is about 1,200 feet (Taff, 1909).

Surficial materials

Flat-lying pediment, terrace, and flood-plain deposits of unconsolidated clay, silt, sand, gravel, and boulders cover much of the bedrock in the northern half of the study area. Less extensive deposits cover parts of the Wasatch Formation, to the south. Terrace and pediment deposits of the area are as much as 45 feet thick, and flood-plain deposits may be as thick as 100 feet (Mapel, 1959; Lowry and Cummings, 1966).

Colluvium in the area consists of loose deposits of soil, weathered bedrock, landslide material, and other surficial deposits which have moved downslope under the influence of gravity. The depth of the colluvium is variable and depends largely on the source of the material. Excluding landslide material, it probably seldom exceeds 10 feet in thickness (Wyoming State Highway Dept. unpub. drill-hole data).

Hydrology

Information contained in this section comes largely from the report by Lowry and Cummings (1966) on the ground-water resources of Sheridan County. It is supplemented by field observations by the authors and information supplied by residents of the area.

The principal aquifers are the sandstones and coals of the Wasatch and Fort Union Formations and the Quaternary alluvium which surfaces the pediments, terraces, and flood plains of the area. Well yields from the Wasatch and Fort Union are small, generally less than 10 gallons* per minute. Wells completed in sand and gravel deposits of Quaternary alluvium can yield greater than 100 gallons per minute, or more than 10 times the water yield from bedrock in the area.

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*To convert gallons to litres, multiply by 3.8.

The Wasatch and Fort Union Formations share similar hydrologic properties. Coal aquifers have fair continuity, but sandstone aquifers are lenticular; both are recharged locally by precipitation, irrigation, and surface water. The ground-water levels are generally at less than 100 feet; however, the depths of wells vary considerably because some of the aquifers are lenticular and not continuous. Local recharge from precipitation, irrigation, or surface water migrates through the unsaturated zone until it reaches the water table. Water in an aquifer perched upon a shale bed migrates laterally, influenced by any dip present. In the sharply dissected terrane of the study area, water commonly can migrate only short distances before the aquifer is truncated by a valley.

Lowry and Cummings (1966) reported that chemical analyses of water samples from the Fort Union and Wasatch Formations in Sheridan County indicate mostly sodium bicarbonate water types, with dissolved-solid contents ranging from 484 to 2,380 ppm in the Fort Union and from 160 to 6,620 ppm in the Wasatch. They further stated that the quality of water is probably affected by two chemical reactions as the water moves through the rocks: cation-exchange softening, and sulfate reduction. The cation-exchange reaction is believed to be the probable cause of a high percentage of sodium in the water of both formations. Carbon dioxide which originates in carbonaceous material can promote high sodium bicarbonate concentrations in water by dissolving calcium carbonate and increasing bicarbonate concentrations (Foster, 1950). The calcium ions made available in this process may be exchanged for sodium if they come into contact with cation-exchange materials.

Structure

The study area lies on the western edge of the Powder River Basin, adjacent to the anticlinal structure of the Bighorn Mountains.

The basin is a broad asymmetrical syncline whose axis roughly parallels the mountains a few miles east of the mountain front (Mapel, 1959). Basin sediments, which are early Eocene in age or older, are steeply upturned just west of the study area.

The Bighorn Mountains were uplifted during the Laramide deformation approximately 40 million years ago. The dominant structural style is one of basement-block faulting resulting from vertical tectonics (Prucha and others, 1965; Hodgson, 1965). Cenozoic tectonic elements related to the uplift include poorly developed, northwest-trending folds in the basin; high-angle and upthrust faulting at the mountain front; and east-west-trending, high-angle faults traversing both basin and uplift (Hoppin and Jennings, 1971).

In general, the basin sediments of the Fort Union and Wasatch Formations poorly preserve the record of faulting. There is some evidence of minor faulting in the Wasatch in the western part of the study area, and Mapel (1959) reported a fault to the south near Lake De Smet which may extend northwestward along Piney Creek.

The Wasatch Formation dips easterly 1 1/2° to 2° in the central, eastern, and southern parts of the study area and as much as 5° near the mountains to the west. Taff (1909) reported an easterly dip of about 4° for the Fort Union south of the Tongue River. Measurements made during this investigation indicate easterly dips of from 3° to 5° for the Fort Union in the study area.

Mapped landslides

Mapping procedures

Inventory mapping of the landslides was done on 1:24,000-scale topographic maps of the Sheridan, Hultz Draw, Beaver Creek Hills, Buffalo Run Creek, Big Horn, Story, and Banner quadrangles (fig. 2).

Figure 2.--NEAR HERE.

The landslides were located and mapped using aerial photographs and field reconnaissance from October 1974 to April 1975. The mapping was later transferred to a regional 1:50,000-scale topographic base map (pl. 1). Landslides less than 500 feet in their greatest dimension are represented as triangles with dotted centers. The dots represent the approximate centers of the slide masses. Landslides or landslide areas greater than 500 feet in their greatest dimension are represented by black outlines showing their size and shape.

The inventory map shows most of the areas of past landsliding and can be used as a general guide to slope stability under existing conditions. However, on a mapping project of this kind some of the existing landslides are unavoidably overlooked, either because they are too small (landslides smaller than 50 feet in their greatest dimension were not mapped) or because they are poorly defined or in an inaccessible area and are not covered by available aerial photographs. Consequently, it should not be assumed that areas without mapped landslides are necessarily devoid of landslide activity.

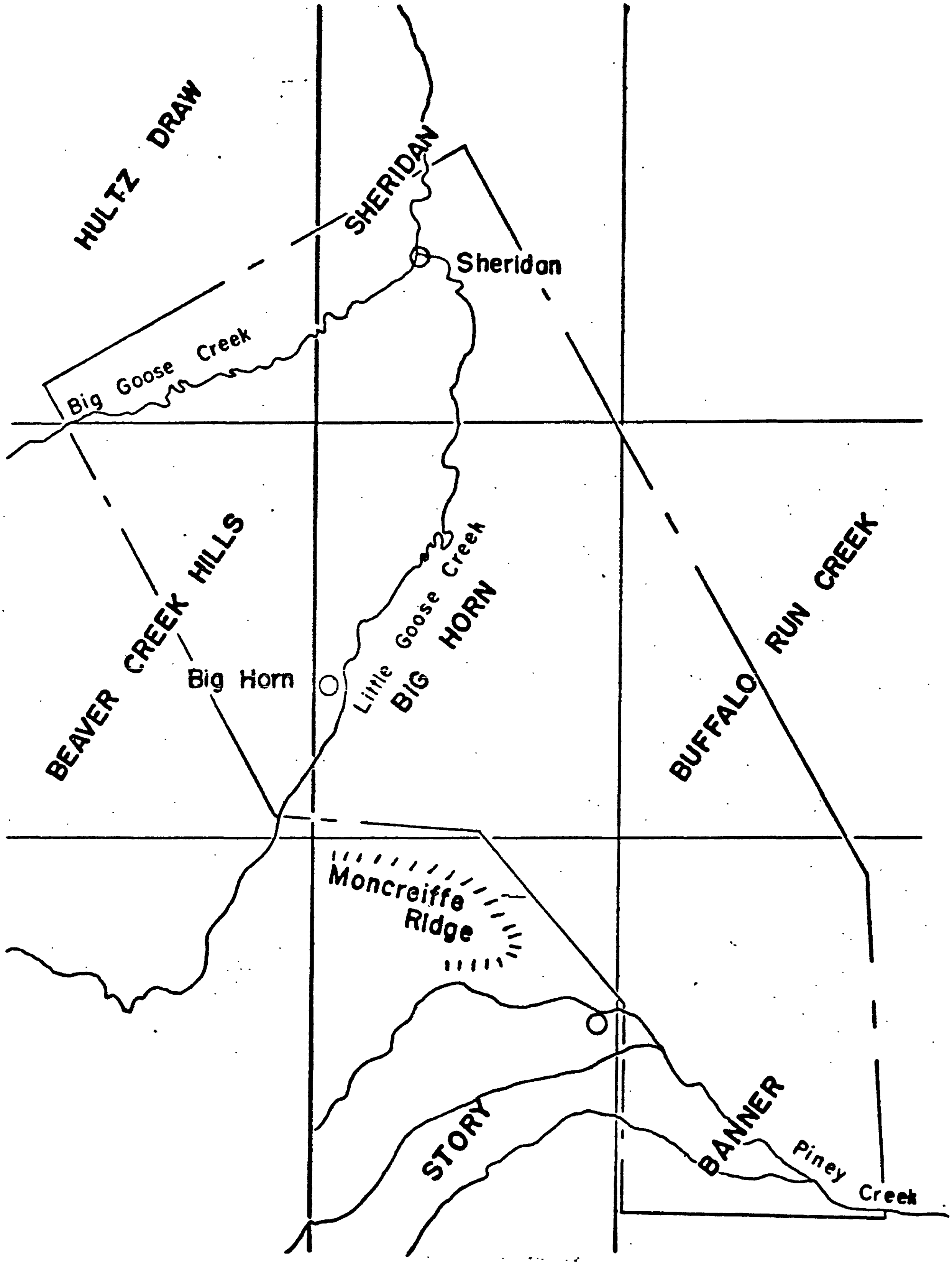

Figure 2.--Index to 7 1/2' quadrangle maps showing their relation to the study area.

Description of mapped landslides

In general, the landslides of the study area involve the slumping and earthflow types of movement described by Varnes (1958) in Highway Research Board Special Report 29. The two types of movement are present in most of the landslides, and in varying degrees. Figure 3 is a

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Figure 3.--NEAR HERE.

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generalized representation, taken from Varnes (1958), of a complex landslide involving slump- and earthflow-type movements.

During field reconnaissance, characteristic differences were noted between certain areas in the geology, landslide geometry, and dominant type of landslide movement. The total study area has been subdivided into three smaller areas on the basis of these differences (see fig. 1). The differences are in some cases subtle; however, it is believed that they reflect geologic controls on landsliding which, in some cases, are unique to each area.

Area 1

Area 1 is located in the northern part of the study area, and is characterized by extensive alluvial terrace surfaces which have been dissected by streams such as Soldier Creek and Big Goose and Little Goose Creeks. These streams and their tributaries have exposed the clay shales, silts, sands, and, occasionally, the coal beds of the Fort Union Formation, creating marginally stable slopes. Elevations vary from 4,800 feet near the mountains to 3,700 feet at Sheridan.

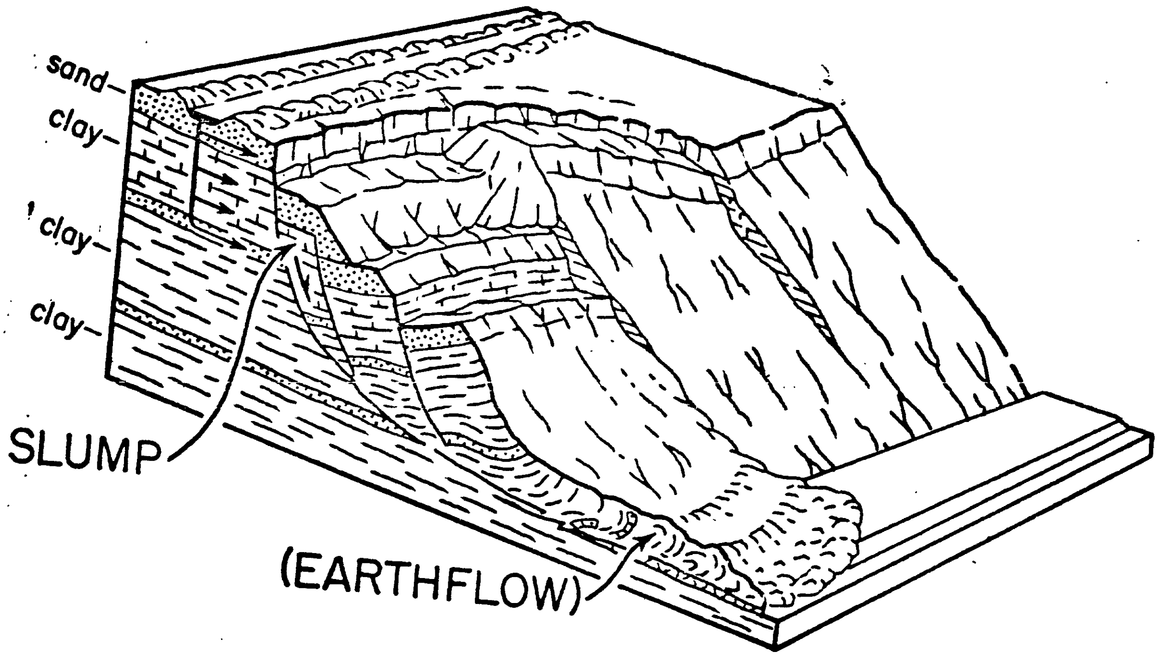

Figure 3.--Generalized diagram of a complex landslide involving slump- and earthflow-type movements (Varnes, 1958).

Many of the landslides of Area 1 are nearly as wide or wider than they are long, partly as a result of topographic controls and partly because of the dominant type of movement involved. Slump and slump/earthflow movements which involve the total length of slope are common.

Many of the slopes are topped by nearly flat alluvial terrace surfaces composed of gravels, sands, and silts as much as 45 feet thick (Lowry and Cummings, 1966). These surfaces act as storage units through which water is transmitted to the slope material below. Thin beds of coal, silt, and sand act as aquifers and transmit water to spring areas on the slopes.

Area 2

Area 2 of the study area is located south of Sheridan and includes areas of landslide activity adjacent to Interstate 90. The area is characterized by rounded hills and divides in the western and central parts, and by a semibadland topography in the eastern part, where many of the hills and buttes are capped by clinker. Total relief in the area exceeds 900 feet.

Bedrock in the area consists of the fine-grained, coal-bearing deposits of the Wasatch Formation. Prominent beds of carbonaceous shale, interbedded with silty clay, coal, sand, and silt, are occasionally exposed in ravines, gullies, and roadcuts, or on hillsides where vegetation and soil cover have been removed by landsliding or other erosional processes. In other places, fresh bedrock is covered by mantle material (soil, colluvium, and weathered bedrock) as much as 40 feet thick (Wyoming Highway Dept. unpub. drill-hole data). Many of the mapped slides in Area 2 involve carbonaceous shale beds and often head near a carbonaceous shale/sand-silt contact.

The individual landslides of Area 2 characteristically have a large flow component and are usually longer than they are wide. Most appear shallow as compared to the slides of Areas 1 and 3 and in some cases involve only the mantle material overlying bedrock (Wyoming State Highway Dept. unpub. drill-hole data). They seldom involve the total slope length, and this may reflect the effects of beds with varying susceptibilities to landsliding and varying hydrologic properties.

Spring areas are associated with coal seams in carbonaceous shales, with lenticular sands and silts, and with contacts between shales and sandier beds.

Area 3

Area 3 is adjacent to the rugged mountain front in the vicinity of Story, Wyo. It includes some of the coarse-grained sediments of the Wasatch Formation. The beds are, in general, thinner and much sandier than the fine-grained materials of Areas 1 and 2. Coal is exposed along Piney Creek in the southern part of the area, along Jenks Creek east of Story, and southeast of the Fetterman Monument near State Highway 87. A highly plastic clay usually underlies the coal beds and provides a surface that is very susceptible to sliding. The coal beds are proved aquifers in the area. Coal is associated with some of the landslides in the area, notably with the landslides along Sullivant Hill on the west side of Piney Creek, where it occurs near the base of the landslides. If the coal bed exposed southeast of the Fetterman Monument extends westward at the regional dip, it probably underlies the large slide mass northeast of the monument.

The landslides of Area 3 which involve the coarser grained sediments are mostly slumps involving little flow movement.

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Detailed descriptions of selected landslides

Purpose and method of selection

A total of 22 landslides in the study area were selected, studied, and sampled, in order to:

1. Obtain a representative overview of recent landsliding in the study area.
2. Collect detailed information on the lithology, hydrology, morphology, and age of individual landslides.
3. Determine pertinent physical properties of the materials involved.
4. Obtain a statistically representative sample of recent landslides in each of the three areas previously described.

A statistically representative sample of landslides from Areas 1, 2, and 3 was needed to test observed differences in landslide geometry, and to determine preferred directions of landslide movement, which in turn might reflect significant geologic controls. The representative sample was also needed to meet the first objective of obtaining a representative overview.

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In an effort to obtain statistically representative samples, mapped landslides from each area were numbered consecutively and selected by random draw, using a random number table. Only those landslides which were well defined were included; consequently, old landslides which were poorly defined and recent landslides whose boundaries were obscured by coalescing movements were not included. Nine landslides were selected from Area 1, 10 from Area 2, and 3 from Area 3. The selected landslides are identified by area and site number on the inventory map that accompanies this report.

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Presentation of photographs, profiles, and data

Photographs, field measurements and observations, and laboratory data were compiled for each of the selected landslides and are presented in sequence by area in Appendix 1. The first sheet of information on each landslide gives its location, elevation, associated formation, type and direction of movement, geometric measurements, surface profile, and photograph. The landslide sites were located using the U.S. Public Lands System of location, which specifies section, township, range, and divisions thereof. Elevations (at the crest of each landslide) were taken from a topographic map, then checked with an altimeter. Types of movement indicated are those described by Varnes (1958). If more than one type of movement is involved, the total movement is considered "complex." In those cases, the dominant type of movement is listed first. The nomenclature of the parts of a landslide used to define the lengths and directions which were measured is shown in the generalized diagram of figure 4. Following are

Figure 4.--NEAR HERE.

the geometric and directional measurements made on each landslide:

Slide direction. The azimuth of the direction of sliding measured from the center of the crown to the tip of the toe.

Total slide angle. The angle measured in a vertical plane between the horizontal and a line from the crown to the tip of the toe. It is an approximate measure of the original ground-surface slope if the landslide has not moved beyond the foot of the hillslope.

Slide length. The distance from the middle of the crown to the tip of the toe.

Scarp slope. The angle of the scarp slope measured in a vertical plane to the horizontal at the middle of the scarp.

Scarp length. The distance from the top of the center of the scarp to the head of the slide measured in the direction of sliding.

Scarp width. The distance between the sides of the slide where the flanks meet the scarp.

Greatest flank width. The greatest slide width from flank to flank.

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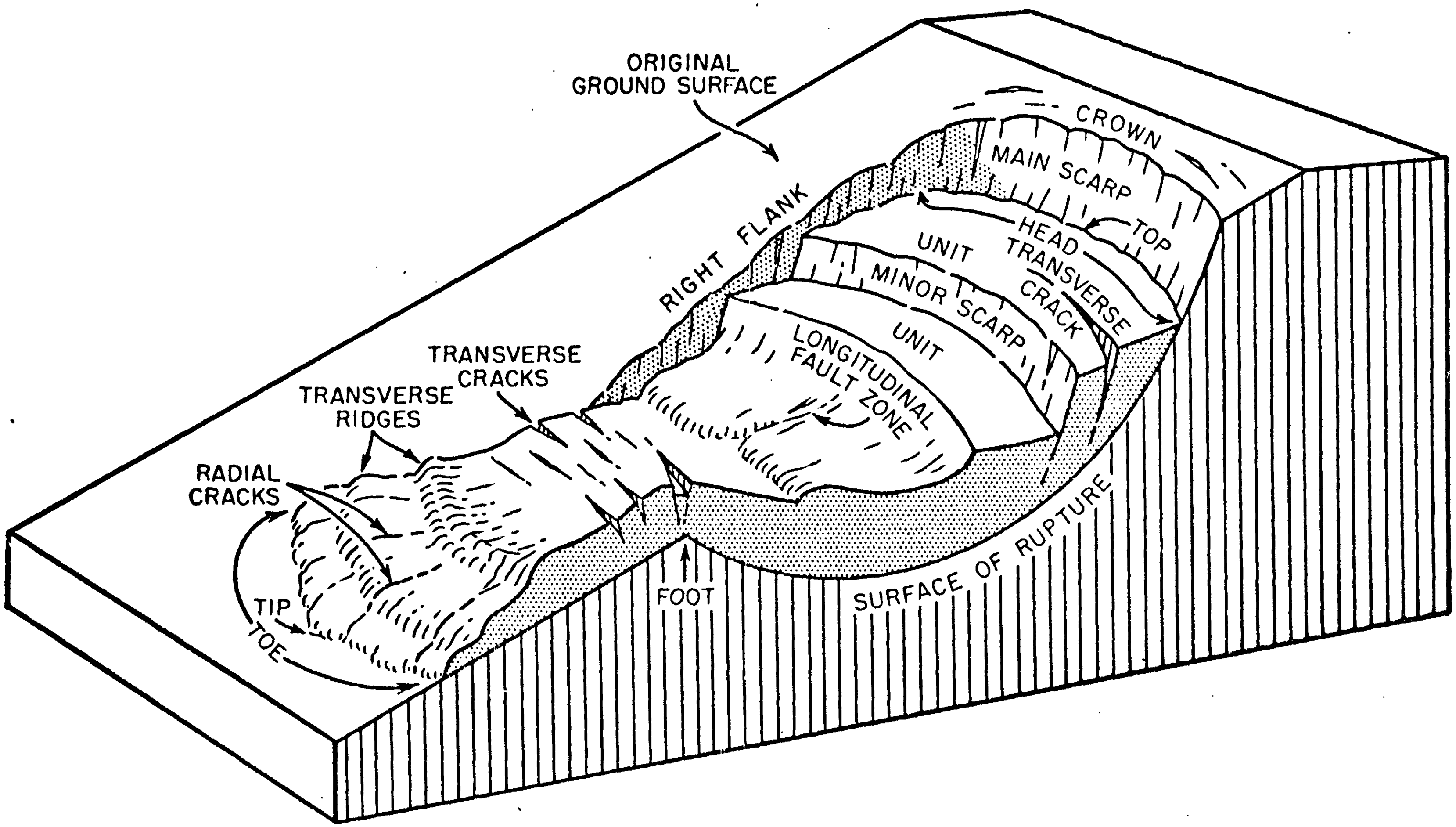

Fig. 4.--Nomenclature of parts of a landslide (Varnes, 1958).

Lengths were measured using a 100-foot cloth tape. Hand-held Abney levels were used to measure vertical angles, and a Brunton compass was used to determine the direction of movement.

Also given is an estimated slide depth, which is a rough estimate based on the geometry and geology observed in the field.

The undistorted profiles presented were measured by moving down the center of the slide mass and recording any slope changes greater than 1° for segments 10 feet long or longer. Vertical angles were measured downslope and then upslope to check within 1°.

Laboratory data and field observations are presented on the second information sheet for each landslide. All samples were collected at the surface, usually at the scarp, where bedrock is exposed. The samples had air dried somewhat during transport and processing prior to testing. Consequently, measured water contents are minimum values, probably slightly less than natural state.

The laboratory data include the liquid limit (LL), plastic limit (PL), and plasticity index (PI) for the indicated samples. Liquid limit is the water content at which the sampled material passes from a plastic to a liquid state. Plastic limit is the lowest water content at which the sampled material remains plastic, and plasticity index is the difference between the liquid and the plastic limits (Asphalt Inst., 1969).

Plastic materials deform easily in response to internal or external forces. If the water content is greater than the liquid limit, the material will flow like a fluid. If the water content is greater than the plastic limit but less than the liquid limit, the material can be plastically deformed. The plasticity index indicates the range of water content in which the material is in a plastic state. Many of the samples collected have a water content greater than their plastic limit, as indicated on the lab data sheets. NP on the data sheets indicates that the sample is nonplastic.

The grain-density values given represent the combined density of all the mineral grains in the total sample; they are useful in computing porosities and void ratios and they can be used to detect variations in lithology.

The size-analysis curves on the lab data sheets show the distribution and percentages of sand-, silt-, and clay-size particles that make up the sample. Some of the curves are discontinuous in the lower portion because the method used to determine the clay-size distribution is not sensitive to the lower size range.

Data analysis

Basic statistics on measured variables of landslide geometry are presented in table 3.

Table 3.--NEAR HERE.

As previously stated, an attempt was made to obtain a statistically representative sample of landslides in order to test observed differences in landslide geometry between areas. Ordinarily, if the variation in a statistical population, such as a population of landslides in a given area, is not known, an initial sampling is performed to determine the variability. This is necessary in order to determine the sample size needed to support any inferences or generalizations that may arise (Krumbein and Graybill, 1965). The number of landslides chosen for this study was limited by considerations of time and cost; consequently, it was hoped that the original number selected would prove adequate.

Table 3.--Statistical summary

[Leaders indicate data not calculated]

Variable	Area 1 (n = 9)			Area 2 (n = 10)			Area 3 (n = 3)		
	$\overline{X}$	S	R	$\overline{X}$	S	R	$\overline{X}$	S	R
Slide angle (degrees)-----	14	3	10-20	14	2.5	12-19	10	0.5	10-11
Slide length (feet)-------	304	253	104-933	263	70	125-370	319	111	203-424
Greatest flank-to-flank									
width (feet)------------	365	394	152-1,200	171	79	55-265	233	174	100-430
Scarp slope (degrees)-----	37	7	28-49	45	20	23-80	30	7	22-36
Scarp length (feet)-------	30	28	13-101	17	18	2-52	41	30	24-76
Scarp width (feet)--------	322	330	150-1,190	136	79	38-252	213	186	59-420
Length-width ratio--------	.99	.52	.43-2.03	1.85	.87	.90-3.2	---	---	-------

$\overline{X}$, Mean value.

S, Standard deviation.

R, Range of values.

n, Number of landslides.

In order to determine whether the statistical sample sizes (9 in Area 1, 10 in Area 2, and 3 in Area 3) were large enough to adequately estimate the true population means of the measured geometric variables, the formula of $n = \left[\frac{S t_{\alpha/2}(m)}{d}\right]^2$ was applied (Krumbein and Graybill, 1965); where

n is the sample size needed to estimate the mean,

S is the standard deviation,

$t_{\alpha/2}(m)$ is the upper Student's t value for probability $\alpha/2$ for m degrees of freedom, and

d is the desired closeness of the mean estimate to the true population mean.

The formula was applied for each of the geometric variables using the standard deviations listed in table 3, and t values at a 90-percent probability or confidence level.

In each case, with the exception of the variable "slide angle" in Areas 1 and 2, the value of n (the sample size needed) was larger than the number actually sampled. In those cases, a larger sample is needed before statistical inferences can be made with a high degree of confidence. Nonetheless, it should be noted that the mean values of length-to-width ratios shown in table 3 do reflect one of the characteristic differences between the landslides of Areas 1 and 2 observed in the field; that is, a higher mean length-to-width ratio for the landslides of Area 2. An awareness of this difference may lead to an understanding of unique conditions which cause and/or control landsliding in the respective areas.

Because the variability of slide angles in Areas 1 and 2 is low, the present sampling of those variables is adequate to estimate the true population means. In both cases, the probability is 90 percent that the mean-value estimate of 14° is within 2° of the true population means. As can be seen from table 3, the range of slide-angle values in Areas 1 and 2 is also similar. The highest value in each area (20° in Area 1 and 19° in Area 2) is from landslides on slopes with a westerly exposure. All of the other values are associated with an easterly component of slope direction and do not exceed 17 1/2°.

The basic statistics on the measurements made in Area 3 give a general idea of the variability in that area. However, statistical inferences cannot be made because the number of slides in the sample was too small to be representative.

During the course of the study, it was observed that most of the landsliding in the study area occurs on slopes with an easterly component of direction. Table 4 lists the number of mapped slides

Table 4.--NEAR HERE.

associated with each of the quadrants of slope exposure. This is done for the mapped slides of each area and for the study area as a whole. It can be seen that the number of mapped landslides in the northeast and southeast quadrants outnumber those in the westerly quadrants by nearly 3 to 1 in Area 1, 8 to 1 in Area 2, 4 to 1 in Area 3, and more than 4 to 1 overall.

Geologic and other factors which may account for the preponderance of landsliding on slopes in the northeast and southeast quadrants include the effects of the easterly dip of the beds, larger and/or more numerous catchment areas of moisture on easterly slopes, greater irrigation activity on easterly slopes, and the effects of microclimates associated with different slope exposures. The relative importance of these factors has not been determined; however, these and other factors are discussed in greater detail in the following sections on causes of landsliding.

Table 4.--Association of slope exposure and mapped landslides

Slope exposure	Number of landslides			
	Area 1	Area 2	Area 3	Total study area
NE------	72	178	36	286
SE------	79	85	7	171
NW------	32	13	7	52
SW------	22	22	5	49

NE (northeast)

SE (southeast)

NW (northwest)

SW (southwest)

General causes of landsliding

Changes in geometry and physical properties

On any slope there is a tendency for the slope mass to move downward and outward in response to gravitational forces. The gravitational forces generate a stress field within the mass that can be thought of as having two components: driving stresses and resisting stresses. When the stresses resisting movement within a slope mass are exceeded by the driving stresses, movement commonly takes place in a sliding or flowing manner. On a naturally stable slope, movement can occur when changes of geometry and physical properties within the slope mass alter the driving and resisting stresses. These changes can occur in many different ways as a result of changes in the physical environment. The changes may be due to natural processes or manmade disturbance, or both. In slopes considered to be marginally stable, the resisting stresses are approximately equal to the driving stresses, thus requiring very small changes to initiate significant movements. Some of the more common natural and manmade changes within a slope mass which contribute to landsliding are:

1. An increase in moisture content which causes a reduction in the resisting stresses and an increase in the driving stresses.
2. Undercutting or removal of part of the slope mass, in such a manner as to cause a reduction of the resisting stresses.

3. Rebound of the slope mass due to removal of overburden, causing a reduction in the resisting stresses.
4. Physical and chemical changes caused by natural weathering agents which reduce the resisting stresses.
5. Loading of the slope mass by adding water, debris, or manmade structures in such a manner as to increase the driving stresses.
6. Vibration of the slope mass due to seismic activity which causes a reduction in the resisting stresses and adds dynamic driving stresses.
7. Deformation due to long-term downslope creep which causes a reduction in resisting stresses.

These changes usually act in combination to promote landsliding, although all of them need not be involved. Some of the changes take place over a relatively short period of time; others are long term, involving hundreds or even millions of years.

Susceptibility

Important factors which control the susceptibility of a slope mass to landsliding include the composition and texture of the slope material, rock structure, and local topography.

Composition refers to the mineralogical makeup of the material. Some minerals have properties which greatly affect the susceptibility of a slope mass to landsliding. Certain types of clay shales, for example, react to moisture by swelling, because certain clay minerals, such as montmorillonite, adsorb water. This can result in a reduction of the binding forces which hold the material together, and possibly in increased gravity load. On the other hand, such clay shales may swell very little or not at all if they are strongly cemented by calcite, silica, iron oxide, or other cementing agents.

The texture of a soil or soil-like rock refers to the size of the individual grains or particles and their distribution. As used here, it also refers to the shape and arrangement of the constituents. Texture strongly influences physical properties such as packing of the particles, porosity, density, and permeability, and can affect the plasticity, swelling, and shrinkage of the material (Jumikis, 1962). Reorientation of clay particles in the direction of shear on slip surfaces has been found to contribute to a reduction in peak strength or resisting stresses (Skempton, 1964; Early and Skempton, 1972).

Structure refers to the large- and small-scale discontinuities in a rock or soil mass, such as faults, joints, bedding planes, slickensides, and unconformities. These discontinuities provide a path for water to enter the slope material and also act as surfaces of weakness along which failure can occur. The susceptibility of a slope mass to the changes of geometry and physical properties previously discussed can be highly dependent upon the orientation and relative position of discontinuities. Discontinuities that dip in the same direction as the slope can increase the sensitivity of a slope mass to any changes which decrease the resisting stresses or increase the driving stresses. For example, the effect of added moisture on such a surface of weakness may reduce the resisting stresses enough to initiate movement. In conjunction with the dip, the closer the strike of the discontinuity to the strike of the slope, the more susceptible is the slope mass to any critical changes. Other characteristics of discontinuities, such as extent, spacing, and surface irregularities, also affect slope stability. It must be noted that the slope behavior of soils is less dependent on large-scale discontinuities than is rock. Soil failures tend to occur within the intact soil mass, indicating a strong dependence on the properties of the intact soil (Schuster and others, 1975).

Topographic features such as local catchment areas of rain and snow concentrate moisture on certain slopes, increasing the moisture content of the slope mass and, at the same time, increasing its sensitivity to other critical changes. Slope exposure affects rates of snowmelt, water evaporation, transpiration, and the magnitude of temperature fluctuations on a slope area. This, in turn, affects the rate of erosion due to runoff, and the depth and degree of weathering.

A comprehensive study by Fleming, Spencer, and Banks (1970) deals with the behavior of clay shale slopes in general. Many of the factors considered in this study which relate to clay shale slopes are covered in that report in greater detail.

Dominant causes contributing to landsliding in the study area--probable and possible

Increased moisture content

In the study area, increased moisture content resulting from precipitation and irrigation practices is the most common short-term change that promotes landslide activity. Precipitation during the months of March and April often begins as rain, changing to a mixture of rain and snow or heavy wet snow. These snowstorms are often accompanied by strong winds which cause drifting on leeward slopes. Rapid snowmelt due to subsequent warming trends can add large amounts of moisture to slopes already wet, triggering slope failures. A heavy snowstorm in April of 1973 is reported by local residents to have greatly accelerated landsliding in the area. Reports of the unusually heavy snowfall are verified by data obtained from the National Climatic Center (1974), which indicate that 37.5 inches of snow fell in April of 1973, whereas 9.9 inches is average for that month. A comparable total snowfall for the month of April had not occurred since 1954, when 39.6 inches of snow fell (table 2). Additionally, heavy spring and summer thunderstorms can cause local increases in moisture content, which triggers landsliding.

The total impact of irrigation practices on slope stability in the area is difficult to assess. Lowry and Cummings (1966) stated that irrigation water is a major source of ground-water recharge in some areas. Some of this ground water is transferred by means of aquifers to slope areas, adding to the weight of the slope mass and weakening its resistance to movement. The association between irrigation and landsliding is conspicuous in Area 1, where most of the profiled landslides are downslope from unlined irrigation ditches or irrigated fields. Reports by local ranchers also attest to the association between the two.

Slope undercutting

Undercutting of slopes by streams and construction activity have been contributing factors to slope instability in the area. Profiled landslide No. 2 in Area 1 is a good example of a slope failure resulting in large part from undercutting by Big Goose Creek. A few of the slope failures along Interstate 90 in Area 2 and along State Highway 331 in Area 1 are, in part, related to the removal of slope materials in the process of road construction.

Slope rebound

Geologic evidence indicates that the Powder River Basin was covered by as much as 3,000 feet of sediment during Miocene time in the geologic past and has since been excavated by natural erosional processes to its present level (McKenna and Love, 1972). Certain types of clay shales subjected to overburden of this kind are thought to have large recoverable strain energy. It is known that removal of such an overburden from poorly bonded clay shales in the Dakotas and Montana has resulted in a high ratio of horizontal to vertical stress owing to volume changes associated with unloading conditions of no lateral strain (Terzaghi and Peck, 1967). Bjerrum (1967) has related this condition to a mechanism of slope failure (progressive failure) in certain types of clays and clay shales. The existence of significant recoverable strain energy in the unweathered clays and clay shales of the study area is suspected but has not been proved. Future study may reveal the condition to be a very important factor in slope stability in this area.

Weathering processes

Weathering processes have acted over a long period of time to distintegrate and loosen once-consolidated slope materials. In some localities of the study area, the weathered zone extends to a depth of several tens of feet (Wyoming State Highway Dept. unpub. drill-hole data). Freeze-thaw action has caused mechanical disintegration of near-surface material, while the chemical action of ground water has altered the condition of slope materials to greater depths, principally by oxidation, hydrolysis, and ion exchange. For example, the physical properties of clays are affected by the chemical and physical environment. Sodium-saturated montmorillonite exhibits greater expansion and lower permeability than calcium-saturated montmorillonite, and it is known that the strength properties of clays can be altered by the addition of chemicals in a process of ion exchange (Arora and Scott, 1974). Since cation exchange is thought to be a prominent chemical process affecting water quality in the study area (Lowry and Cummings, 1966), it may also be a process that has affected and is affecting the engineering properties of clays and clay shales in the area. Many of the landslides in the area appear to be shallow and may involve material no deeper than the weathered zone. Subsurface and geophysical exploration is needed to accurately determine landslide depths and their relation to the weathered zone.

Seismic activity

The contribution of seismic activity to slope instability in this area is not known, but the potential of seismic energy triggering slope failure does exist. Seismicity is known to be low, but one historic earthquake having a Modified Mercalli intensity of V (Micro Geophysics Corp., Golden, Colo., unpub. prelim. compilation of "Wyoming Historical Seismicity 1894-1974," 1975) occurred about 6 miles west of the town of Banner in 1925. Algermissen (1969) showed the area to be one of minor seismic risk in which minor damage can be expected. It is expected that there will be many low-intensity earthquakes that may affect the stability of slopes in the area. Data have been collected from seismically active areas (Morton, 1971; Castle and Youd, 1972) that demonstrate widely distributed slope failures in the vicinity of moderately intense earthquakes (Richter magnitude 6.4-6.6) in California. Similar slope failures may even be expected in the vicinity of much smaller intensity earthquakes, especially where the shaking ground consists of low-density, saturated, fine-grained materials that are highly susceptible to seismic energy absorption. For instance, Seed and Idriss (1970) reported that saturated soils whose standard penetration resistances are less than 6 blows per foot at a depth of 10 feet are subject to liquefaction when subjected to seismic acceleration of only 0.03 gravity. These accelerations are common in smaller earthquakes.

Engineering geology--slope stability

Past and present practice

Landsliding in the vicinity of Sheridan has not been dealt with as a major hazard except in specific slide areas found by the Wyoming Highway Department. In the past, slope-stability problems have been given very little consideration in the construction of new homes and buildings. Most of the slope problems associated with new development have been handled in a postconstruction remedial manner rather than in the initial design. The most thorough planning and preventive design have been accomplished by the Wyoming State Highway Department, especially in the construction of Highway I-90.

Construction practices for new housing developments in some cases have inadvertently contributed to slope instability. For instance, housing outside urban corporate limits generally relies on septic systems for sewage disposal. Even a large facility such as the Veterans' Administration Hospital north of Sheridan has a large septic system that discharges many gallons of water daily. The excess water supply adds to the ground-water gradient, and in places there are associated occurrences of unstable slopes adjacent to drainage valleys such as can be seen adjacent to Big Goose Creek, west of Sheridan.

Some homes in south Sheridan and on the northwest edge of town have been constructed adjacent to naturally unstable slopes that have been active within the historic past. Most of these homes have not been affected by recent activity except for those on the northwest edge of town. These homes were constructed on the toe of an old slide mass that is not well defined; old failure surfaces are healed and overgrown with vegetation and there is no clear ground evidence of present-day movement, yet frontyard retaining walls on the toe have been extensively damaged by differential movement. Also, fence lines and powerlines situated on the slope of the slide mass have deformed by rotation and downward and outward movement. We do not know whether foundation damage to the dwellings has occurred.

Highway construction and maintenance costs have been increased by landsliding. For example, the city of Sheridan has had to repair a water main and several road breaks caused by landsliding on Highway 331 along Big Goose Creek, southwest of Sheridan. In addition, repairs to the county road adjacent to Jackson Creek, west of Big Horn, were necessary because of landslide activity.

During construction of Interstate 90, the Wyoming Highway Department had to contend with landslide activity. The highway alinement south of Sheridan goes through an area of highly unstable natural slopes, where the geologic terrane consists of colluvium overlying carbonaceous clayey shales interbedded with silts and fine- to medium-grained sands, the beds dipping easterly about 1 1/2° to 3°. Conditions are ideal for the entrapment, storage, and slow migration of ground water along bedding planes to east-facing slopes, where the saturation of fine-grained plastic colluvium and weathered bedrock becomes inevitable. Highway construction undercut the already unstable natural slopes, creating hazardous conditions. The Wyoming Highway Department made extensive borings, geologic cross sections, and planetable maps, and conducted laboratory soils tests on samples along the I-90 alinement in order to determine the nature of the slope-stability problems and apply them as highway-design criteria. In very unstable areas, slope-stability analyses were performed and used in the design of cut-and-fill slopes. Since I-90 was finished, in 1970, there have been no road failures, but there have been failures in adjacent fill slopes that eventually may affect the pavement.

In addition, the State Highway Department has had to repair slide damage on Highway 87 northwest of Massacre Hill and Highway 331 west of Sheridan, and has removed slide debris from Highway 14 southeast of Sheridan.

Future practice

As discussed, the Wyoming State Highway Department has used modern techniques for the design and control of slopes in areas of instability. In addition, there exist several modern techniques--described in numerous references--that can be applied to specific slope problems in the area. A state-of-the-art evaluation of slope analysis and design by Johnson (1975) references most of these techniques.

It is not the intent of this preliminary investigation, however, to discuss engineering slope design but rather to point out the natural conditions and changes of these conditions that accelerate or retard failure processes. In future land-development and engineering practice, the critical changes of natural conditions should be considered and either avoided or modified by design to alleviate inherent instabilities.

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On the basis of our observations, we believe that many slopes in the studied area are susceptible to landsliding; the natural conditions having the most influence are:

1. The fine-grained and plastic nature of the bedrock and colluvial materials.
2. The shallow-dipping, sandy, silty, and carbonaceous aquifers interlayered between nonpermeable clay shales.
3. The natural moisture-collecting areas provided by terrace gravels, scarp depressions of existing slides, and the leeward side of natural or artificial slopes.
4. The sometimes heavy spring snows that are very wet and dense.
5. The easterly dip of the bedrock, which preferentially delivers ground water to easterly facing slopes and which makes bedding planes potential rupture surfaces on these same slopes.

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Construction contractors and planning officials involved in future development may avoid serious slope-stability problems by considering these factors in planning and design. Some of the considerations may be to:

1. Avoid construction on any slope until thorough field testing for soil behavior and hydrologic conditions is accomplished. Rigorous design criteria will probably be needed for many slopes, especially those facing in an easterly direction.
2. Eliminate natural catchment basins or provide drainage to keep foundation materials dry. Avoid creating catchment basins in excavation practice.
3. Determine hydrologic conditions in the vicinity of sandy, silty, and carbonaceous aquifers; drain, if possible. Avoid slopes directly underlain by coal or peat beds.
4. Avoid the sides of slopes where massive snowdrifts are known to occur, or provide adequate drainage.
5. Avoid steepening of slopes without adequate design criteria.
6. Avoid construction on slopes below active unlined irrigation ditches. Locations for new irrigation ditches should not be adjacent to land to be used for development unless the ditch is lined or routed so that leaking water cannot affect the hydrology of the development land.
7. Avoid the use of septic systems unless they can be placed in drainage areas where they will not affect ground-water gradients in the vicinity of unstable slopes.

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APPENDIX I

Information sheets for selected landslides

AREA 1-SITE 1

Location: SE 1/4 SE 1/4 sec. 16, T. 56 N., R. 84 W., Sheridan quadrangle

Formation: Wasatch

Elevation: 3820 ft

Type of movement: Complex - Earthflow/Slump

Direction of movement: S. 32° E.

SLIDE GEOMETRY

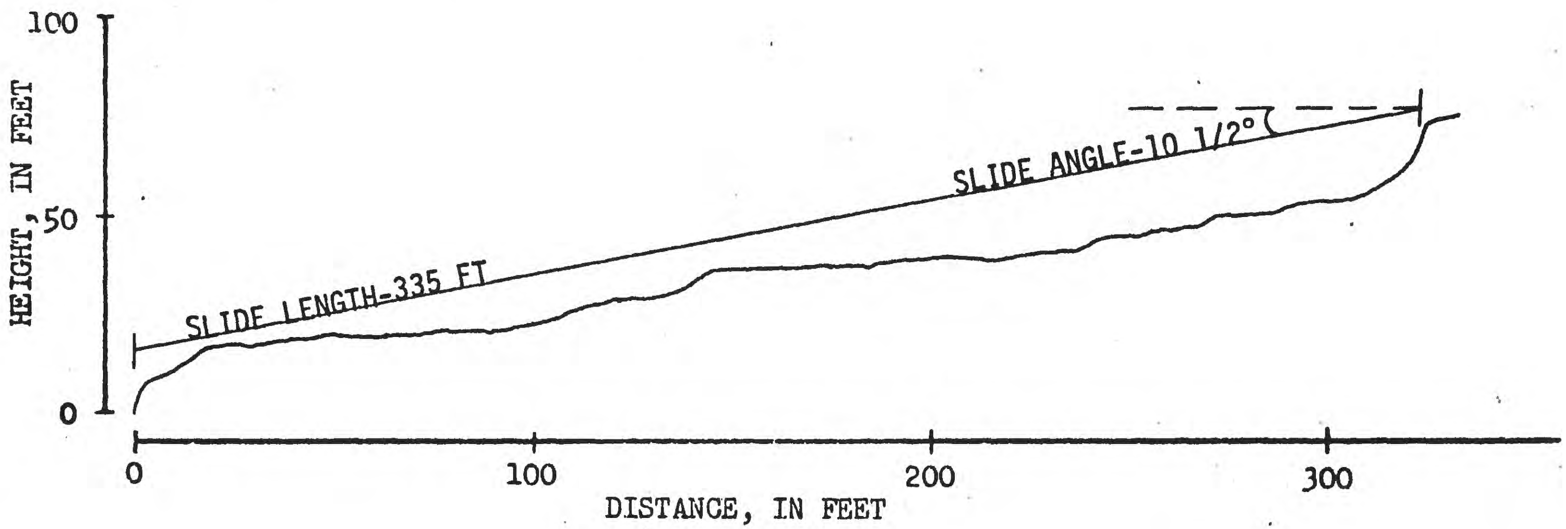
Greatest flank width 299 ft

Scarp width 236 ft

Scarp length 28 ft

Scarp slope 34°

Estimated slide depth 40 ft



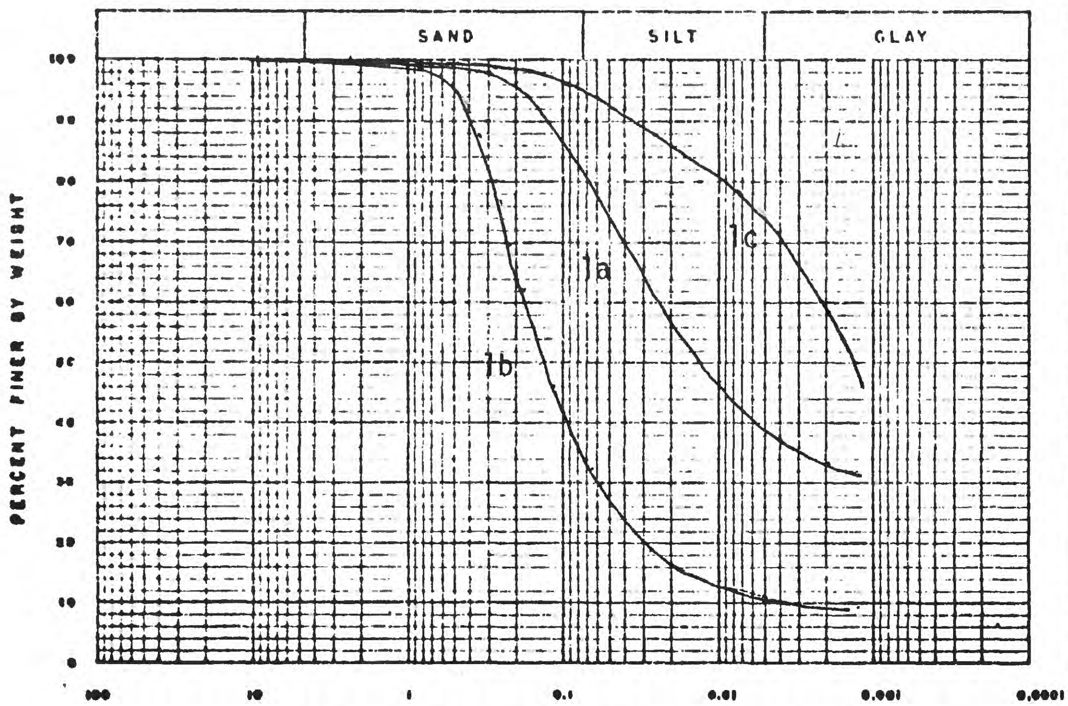
UNDISTORTED PROFILE

AREA 1 SITE 1

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density (grams-cm^3)
1a	Stream bottom	47	23	24	41%	2.67
1b	Base of scarp	NP	NP	NP	17%	2.66
1c	Base of scarp 15 ft below crown	60	46	14	66%	2.57

PARTICLE SIZE DISTRIBUTION CURVE



FIELD OBSERVATIONS: June 5, 1975

The slide mass was very wet--nearly saturated over most of its surface. Springs emanate from a variable lithology at the scarp base, especially from carbonaceous layers. Soldier Creek, below the slide, has been diverted by the toe of the slide.

The exposed portion of the scarp reveals a thin gravel cap underlain by weathered bedrock that grades downward from a medium sand to silt, clayey silt, carbonaceous shale, and peatlike beds. The capping terrace gravel extends northwestward, forming an extensive surface. Bedding dips easterly 1 1/2° to 3°.

Tangential fractures as much as 5 feet deep run parallel and near the scarp in the slide mass. These define downdropped slump blocks in the upper part of the slide. Radial fractures in the toe of the slide are also as deep as 5 feet.

An irrigation ditch located 15 feet above the scarp runs parallel to the failed slope and predates the slide by many years. A Veterans' Administration Hospital is located about a quarter of a mile to the northwest on terrace gravel and has an extensive septic system that affects the local hydrology.

Older sliding is evident on either side of the slide mass and on the slopes farther up the drainage.

AREA 1 SITE 1

FIELD OBSERVATIONS: June 5, 1975 (Continued)

Miscellaneous notes

A property owner whose home is located on land adjacent to the toe of the landslide reports that the majority of sliding took place after a heavy snow in the spring of 1973, and that subsequent constriction and diversion of Soldier Creek resulted in flooding during periods of heavy spring runoff.

Air photographs of the site, taken in 1967, show a grass-covered convex hillslope with a small failure at the foot of the hill, apparently caused by the undercutting action of Soldier Creek.

AREA 1-SITE 2

Location: SE 1/4 SE 1/4 sec. 32, T. 56 N., R. 84 W., Sheridan quadrangle

Formation: Fort Union

Elevation: 3840 ft

Type of movement: Complex - Slump/Earthflow

Direction of movement: N. 25° W.

SLIDE GEOMETRY

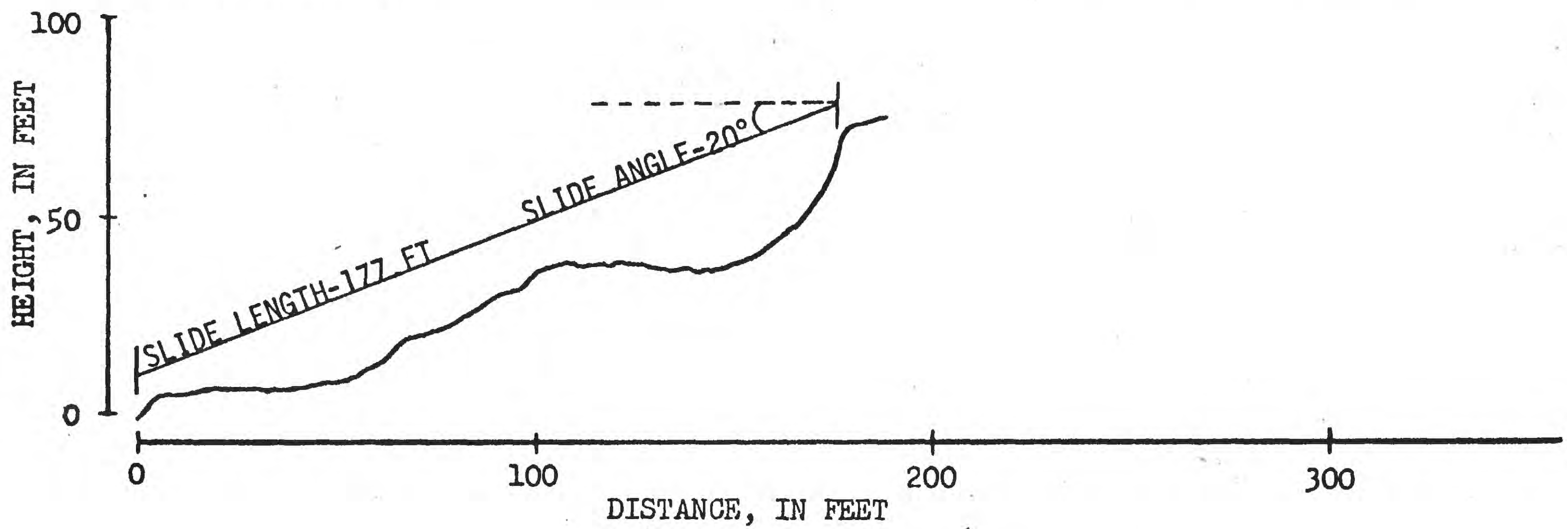
Greatest flank width 159 ft

Scarp width 158 ft

Scarp length 40 ft

Scarp slope 47 1/2°

Estimated slide depth 35 ft

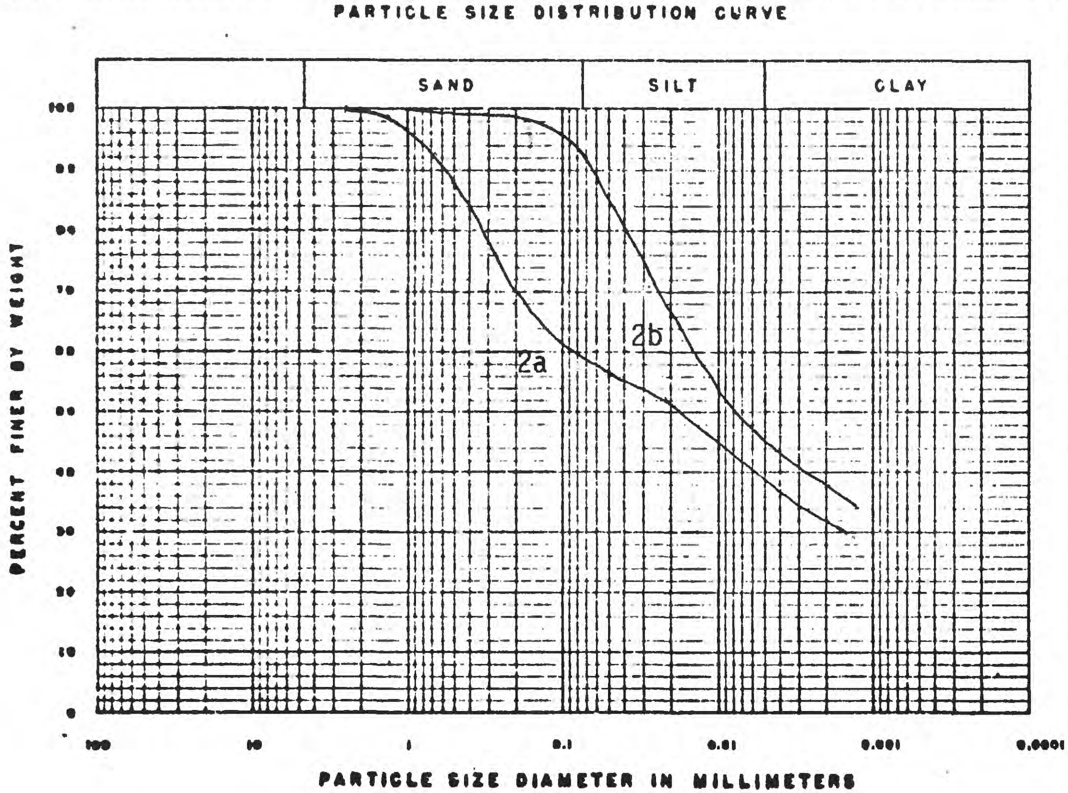


UNDISTORTED PROFILE

AREA 1 SITE 2

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density (grams-cm³)
2a	Top of scarp	NP	NP	NP	45%	2.41
2b	Middle of scarp	41	18	23	26%	2.69



FIELD OBSERVATIONS: June 6, 1975

Much of the surface of the slide mass was dry and crusted; however, the slide material was very wet 1 1/2 feet below the surface. Desiccation cracks in clayey zones are as much as 2 inches wide. Saturated zones and small springs at the scarp base, the middle of the slide, and the toe are associated with thin coal or carbonaceous shale beds. Goose Creek is actively undercutting the toe of the slide and adjacent parts of the hillside. An extensive terrace surface above the slide is irrigated at times.

The scarp exposes, from the top down, a variable clay shale and fine to medium sand sequence underlain by a thin carbonaceous shale bed. A thin coal bed, approximately 6 inches thick, is exposed on the flank near the middle of the slide and is underlain by a light-brown silty clay shale. Another coal bed at least 3 feet thick is exposed at stream level at the toe of the slide.

Large slump blocks in the upper part of the slide are well defined by shear fractures, while some flow movement is evident at the toe. A sequence of sliding is indicated by old scarps and slump blocks on either side of the measured slide mass. Bedding planes dip easterly 2° to 4°. Vertical fractures in the scarp face strike N. 30° W. and N. 70° W.

AREA 1 SITE 2

FIELD OBSERVATIONS: June 6, 1975 (Continued)

Miscellaneous notes

An examination of 1946 airphotos of the site reveals that the older failures took place prior to that time. The airphotos also indicate that irrigation had been taking place on the terrace surface above. The first evidence of the most recent movement appears in 1966 and 1967 airphotos.

A city of Sheridan water supply line is markered just behind the scarp of the profiled slide. The supply line may be endangered by future movement at the site.

AREA 1-SITE 3

Location: NE 1/4 SE 1/4 sec. 31, T. 56 N., R. 84 W., Hultz Draw quadrangle

Formation: Fort Union

Elevation: 3900 ft

Type of movement: Complex - Slump/Earthflow

Direction of movement: S. 50° E.

SLIDE GEOMETRY

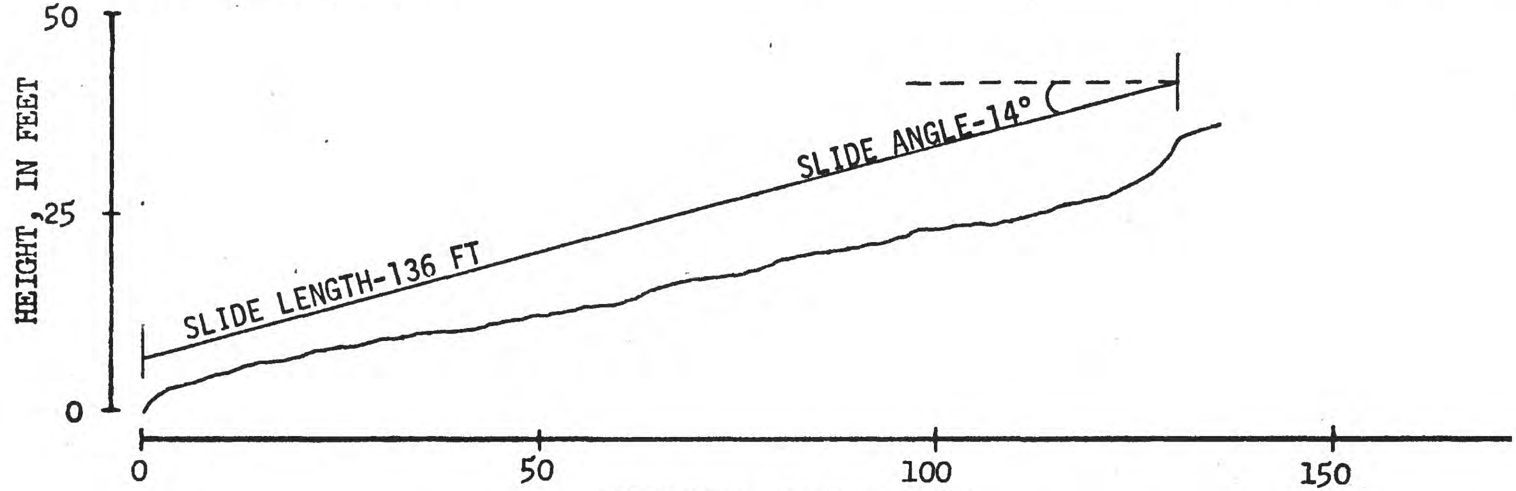
Greatest flank width 231 ft

Scarp width 190 ft

Scarp length 13 ft

Scarp slope 30°

Estimated slide depth 15 ft

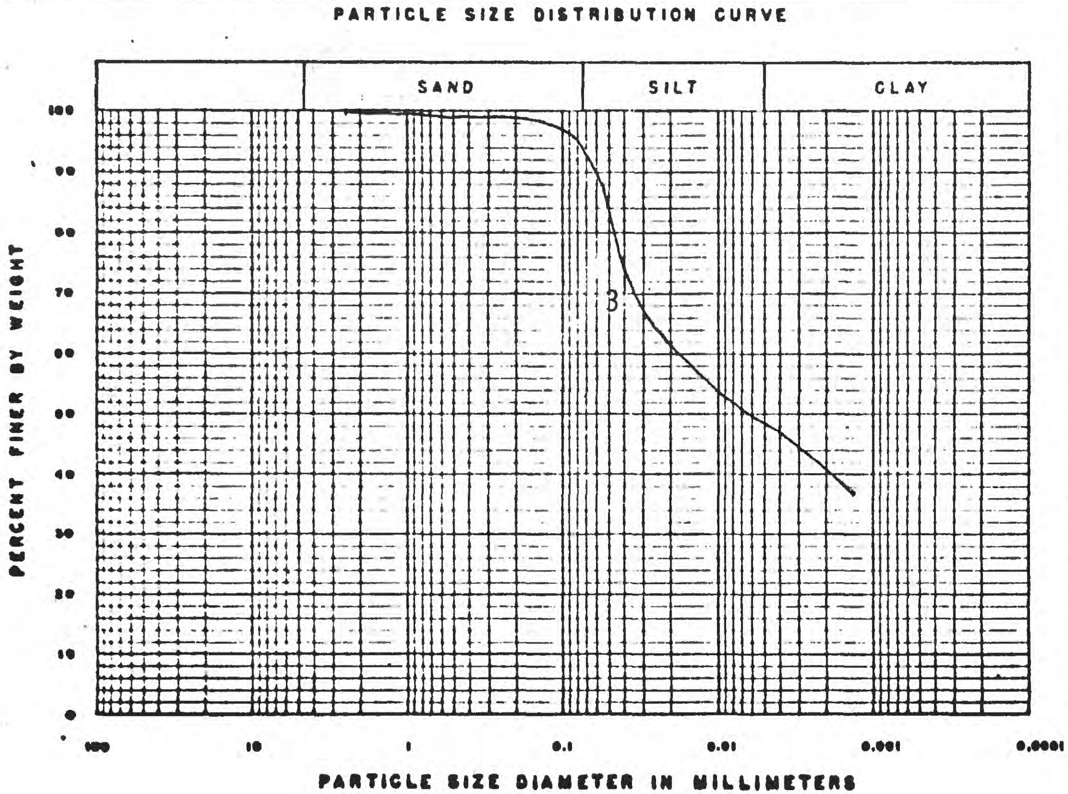


UNDISTORTED PROFILE

AREA 1 SITE 3

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density (grams-cm³)
3	Top of scarp	40	16	24	16%	2.67



FIELD OBSERVATIONS: July 8, 1975

The slide mass was damp to wet over most of the surface; some ponding occurs at the head of the slide where the mass is the wettest.

Two to 3 feet of gravel underlain by a silty clay shale is exposed at the scarp. The gravel is part of an irrigated terrace surface that extends for approximately three-quarters of a mile to the northwest.

Slumping is evident in the upper portion of the slide, as is some flow movement near the toe.

Fenceposts three-quarters of the way down the slide have been moved and tilted forward.

State Highway 331 has required maintenance in the past because of encroachment by the toe of the slide.

Miscellaneous notes

Air photographs of the site taken in July of 1946 show no slope failure. Airphotos taken in 1963 do show some movement, indicating that the movement was initiated sometime between those dates. Irrigation of the terrace to the northwest is evident in both the 1946 and 1963 airphotos.

AREA 1-SITE 4

Location: NE 1/4 NE 1/4 sec. 1, T. 55 N., R. 85 W., Hultz Draw quadrangle

Formation: Fort Union

Elevation: 3960 ft

Type of movement: Complex - Slump/Earthflow

Direction of movement: S. 20° E.

SLIDE GEOMETRY

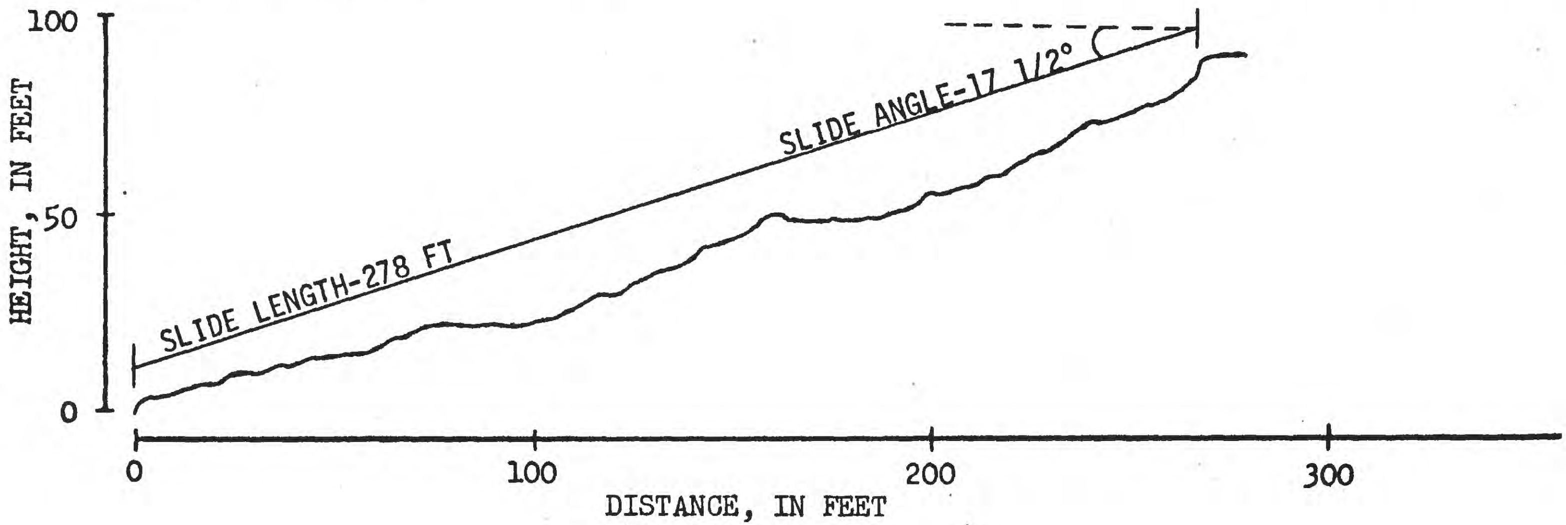
Greatest flank width 368 ft

Scarp width 326 ft

Scarp length 16 ft

Scarp slope 36°

Estimated slide depth 25 ft

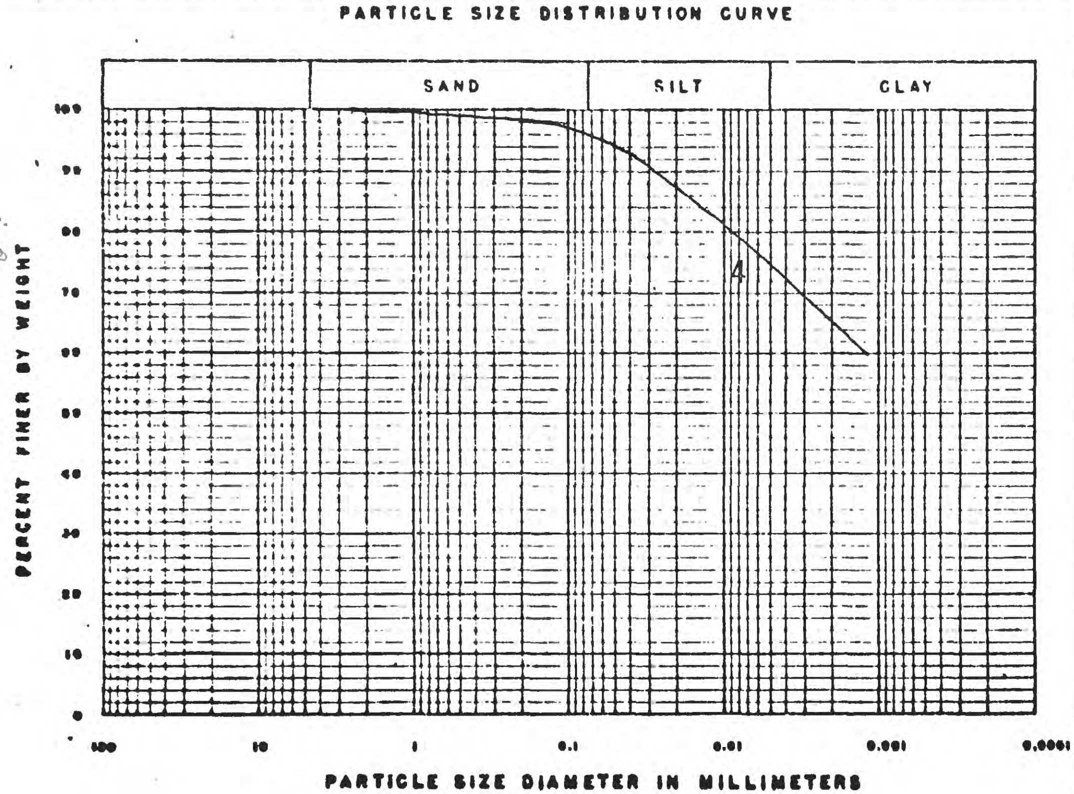


UNDISTORTED PROFILE

AREA 1 SITE 4

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density (grams-cm³)
4	Base of scarp	73	24	49	31%	2.67



FIELD OBSERVATIONS: July 8, 1975

Several areas of the slide mass are very wet. Ponding occurs at the head of the slide. Goose Creek runs near the toe but is not undercutting the present slope. An irrigated terrace surface extends northwest of the slide.

A silty clay capped by approximately 3 feet of gravel is exposed in the scarp. A relatively resistant sandy silt bed is exposed about halfway down the slide in the undisturbed material at either flank. Slump blocks occur in the upper half of the slide, and flow movement is predominant in the lower half.

Miscellaneous notes

Airphotos taken in 1946 show irrigation ditches on the terrace surface northwest of the failed slope. The recent landsliding is not apparent in the 1963 airphotos of the site, indicating that slide activity has occurred since that time.

AREA 1-SITE 5

Location: NW 1/4 NE 1/4 sec. 1, T. 55 N., R. 85 W., Hultz Draw quadrangle

Formation: Fort Union

Elevation: 3940 ft

Type of movement: Complex - Earthflow/Slump

Direction of movement: N. 64° E.

SLIDE GEOMETRY

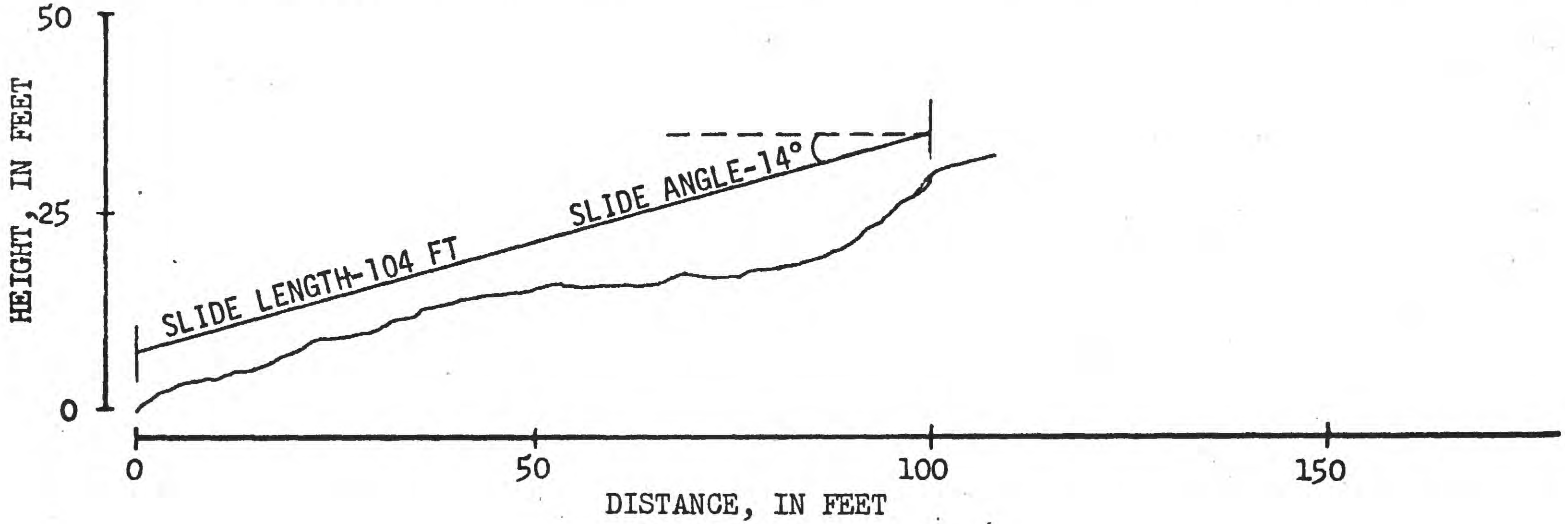
Greatest flank width 238 ft

Scarp width 220 ft

Scarp length 19 ft

Scarp slope 33 1/2°

Estimated slide depth 15 ft



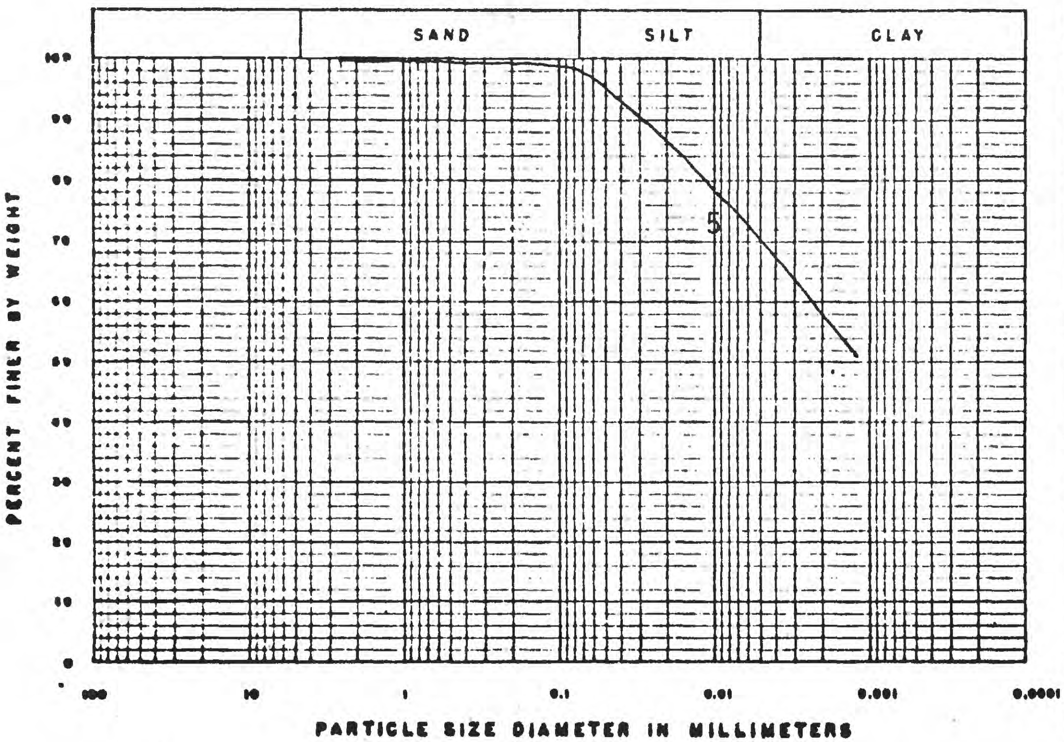
UNDISTORTED PROFILE

AREA 1 SITE 5

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density (grams-cm³)
5	Middle of scarp	61	21	40	23%	2.68

PARTICLE SIZE DISTRIBUTION CURVE



FIELD OBSERVATIONS: July 8, 1975

The slide was very wet at various places below the scarp, and standing water was observed at the head and the toe. An irrigated gravel terrace extends in a northwesterly direction above the slide.

The exposed scarp reveals a 2- to 4-foot gravel cap underlain by a blue-gray clay.

Miscellaneous notes

Airphotos taken in 1946 and in 1963 suggest possible irrigation of the terrace surface above the slide mass; however, little or no sign of the present slope failure is evident.

AREA 1-SITE 6

Location: NE 1/4 NE 1/4 sec. 28, T. 55 N., R. 85 W.,
Beaver Creek Hills quadrangle

Formation: Fort Union

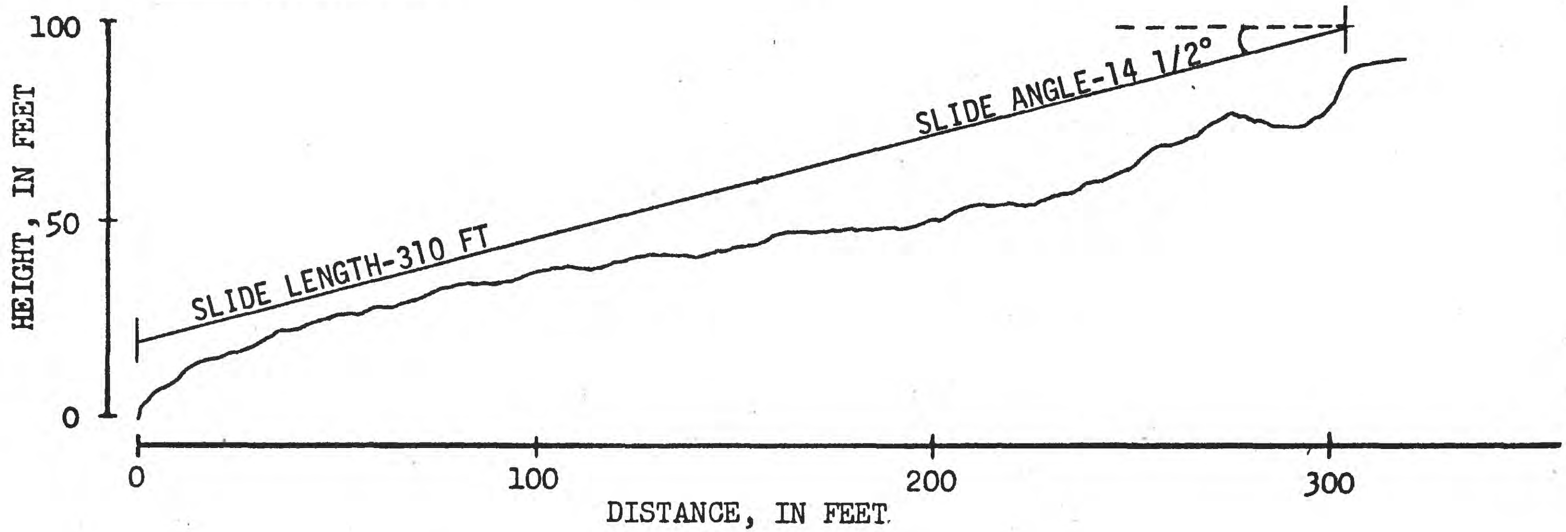
Elevation: 4575 ft

Type of movement: Complex - Earthflow/Slump

Direction of movement: N. 38° E.

SLIDE GEOMETRY

Greatest flank width	152 ft	Scarp slope	48 1/2°
Scarp width	150 ft	Estimated slide depth	20 ft
Scarp length	18 ft		



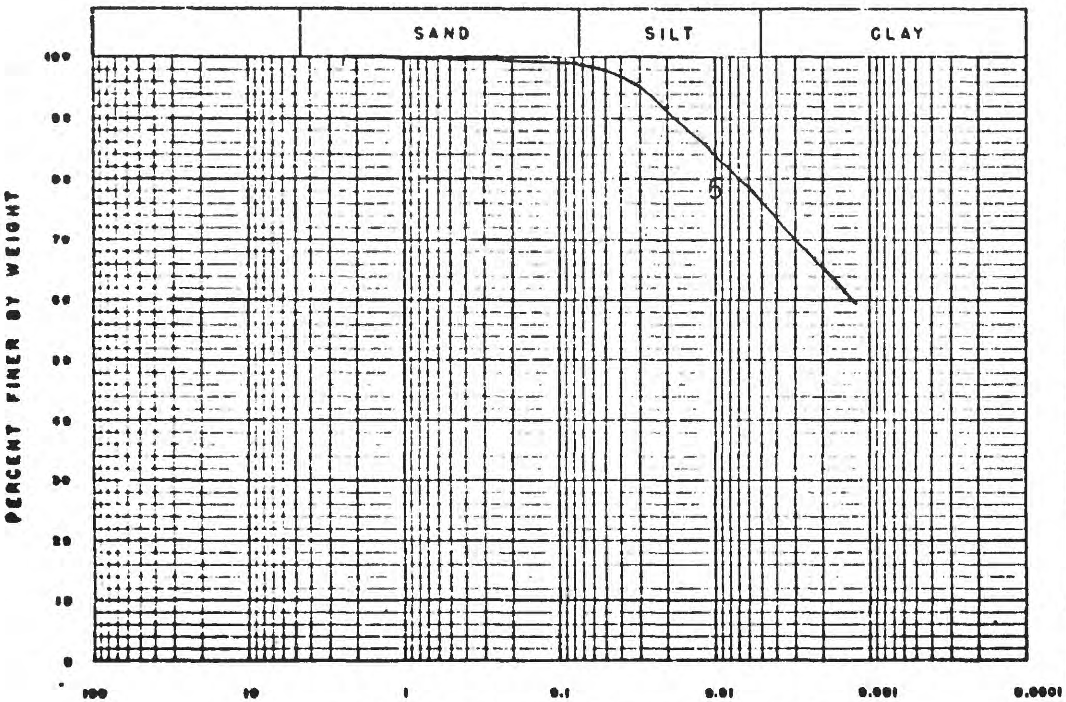
UNDISTORTED PROFILE

AREA 1 SITE 6

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density (grams-cm³)
6	Base of scarp	68	26	42	22%	2.71

PARTICLE SIZE DISTRIBUTION CURVE



PARTICLE SIZE DIAMETER IN MILLIMETERS

FIELD OBSERVATIONS: July 10, 1975

The slide is part of a large slide area composed of several coalescing earthflow/slump-type movements. The failure occurs in a small drainage on a hillside topped by a terrace surface that has been extensively irrigated. The surface of the slide was dry, with the exception of a zone just below the head, where ponding occurs.

Ten feet of terrace gravel is exposed in the scarp. Clay and carbonaceous shale beds are exposed in the scarp beneath the gravel.

Miscellaneous notes

Most of the failures of the slide area can be seen in airphotos taken in 1946, including the initial movement of the profiled landslide. The most recent movement of the profiled slide has taken place sometime during or since 1963.

A property owner reports that a considerable amount of activity occurred in the spring of 1968.

The airphotos of 1946 and 1963 clearly show irrigation ditches on the terrace surface previously mentioned. An irrigation ditch, which has cut a deep channel, parallels the slide area on the northeast side of the hill and has probably contributed to the wetness of the slide area below it.

AREA 1-SITE 7

Location: SW 1/4 NW 1/4 sec. 1, T. 54 N., R. 85 W., Beaver Creek Hills quadrangle

Formation: Fort Union

Elevation: 4465 ft

Type of movement: Complex - Earthflow/Slump

Direction of movement: N. 71° E.

SLIDE GEOMETRY

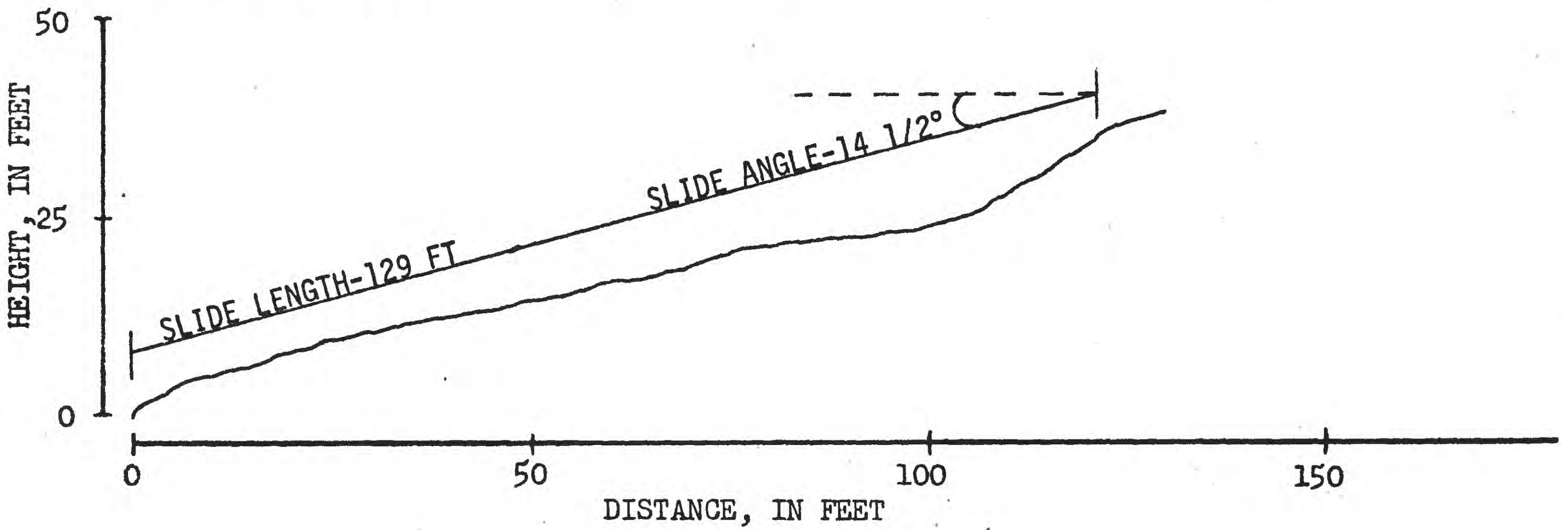
Greatest flank width 227 ft

Scarp width 227 ft

Scarp length 23 1/2 ft

Scarp slope 28°

Estimated slide depth 10 ft



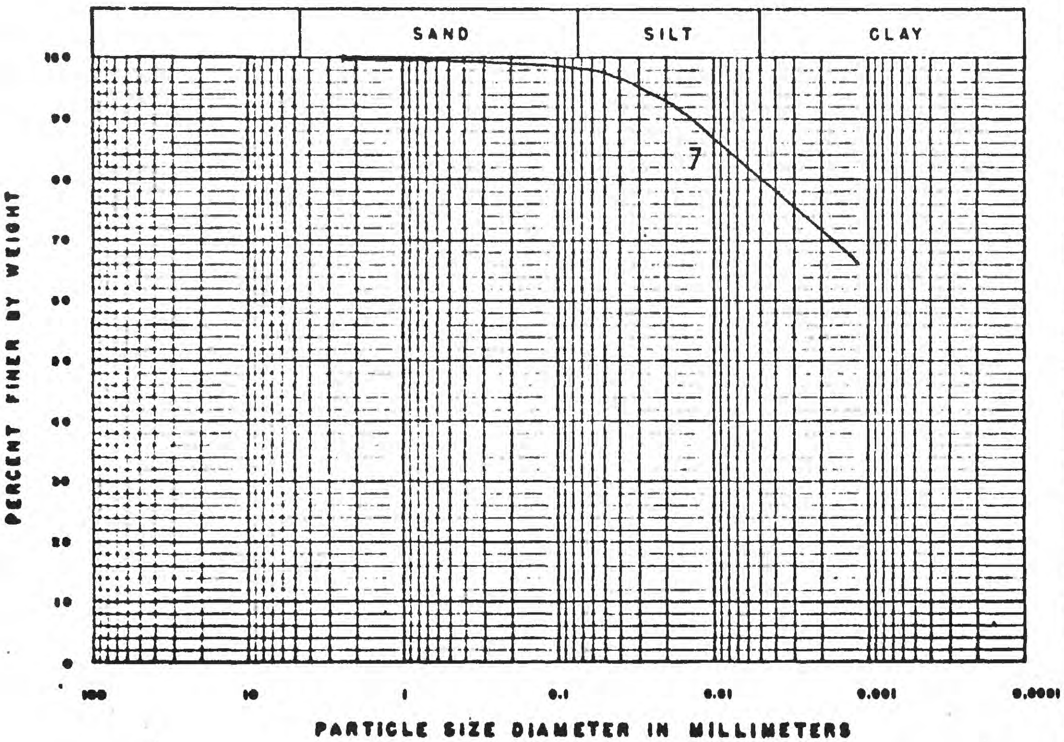
UNDISTORTED PROFILE

AREA 1 SITE 7

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density (grams-cm^3)
7	Middle of scarp	68	26	42	23%	2.68

PARTICLE SIZE DISTRIBUTION CURVE



FIELD OBSERVATIONS: July 10, 1975

The landslide is located on the side of a small knoll in an irrigated field. The main ditch of the irrigation system that supplies water to the field is located just above and behind the slide. A smaller ditch leading from the main ditch runs directly onto the failed slope. The irrigation system was not in use at the time of these observations and the surface of the slide mass was dry.

A silt to silty clay sequence is exposed in the scarp.

Miscellaneous notes

The irrigation system present today is evident in aerial photographs taken in 1946; however, little or no slope movement is shown. The profiled slide is evident in 1963 airphotos, indicating that the failure occurred sometime between 1946 and 1963.

AREA 1-SITE 8

Location: SE 1/4 SE 1/4 sec. 1, T. 54 N., R. 84 W., and SW 1/4 SW 1/4 sec. 6, T. 54 N., R. 85 W., Beaver Creek Hills quadrangle

Formation: Fort Union

Elevation: 4500 ft

Type of movement: Complex - Earthflow/Slump

Direction of movement: N. 12° E.

SLIDE GEOMETRY

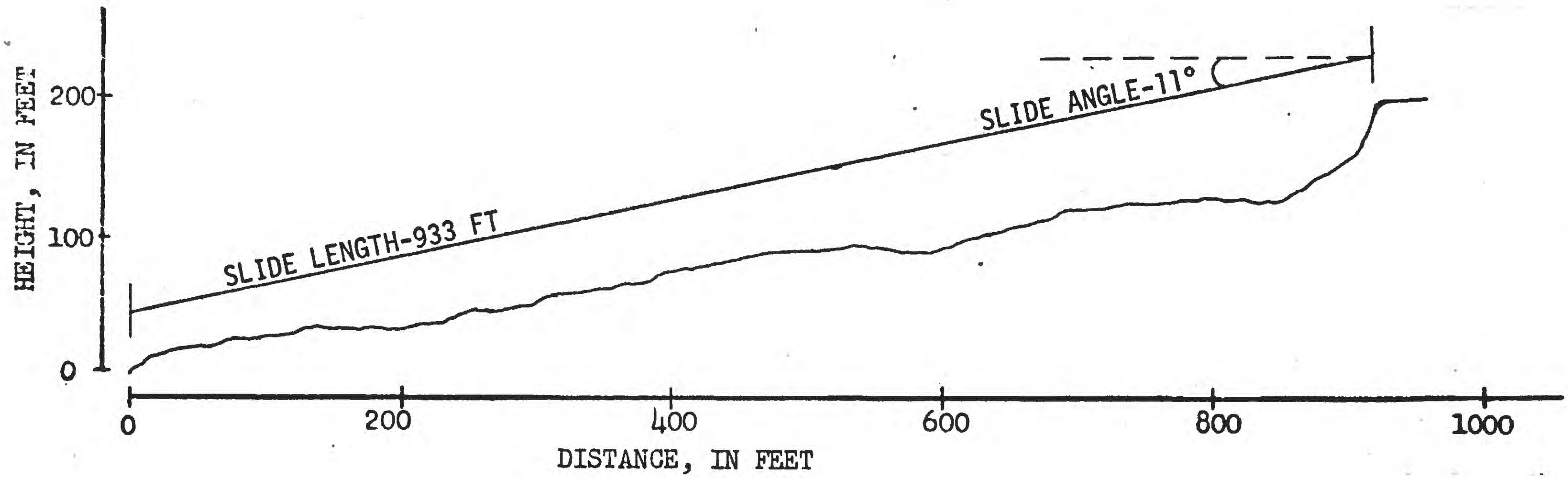
Greatest flank width 1400 ft

Scarp width 1190 ft

Scarp length 101 ft

Scarp slope 42°

Estimated slide depth 75 ft



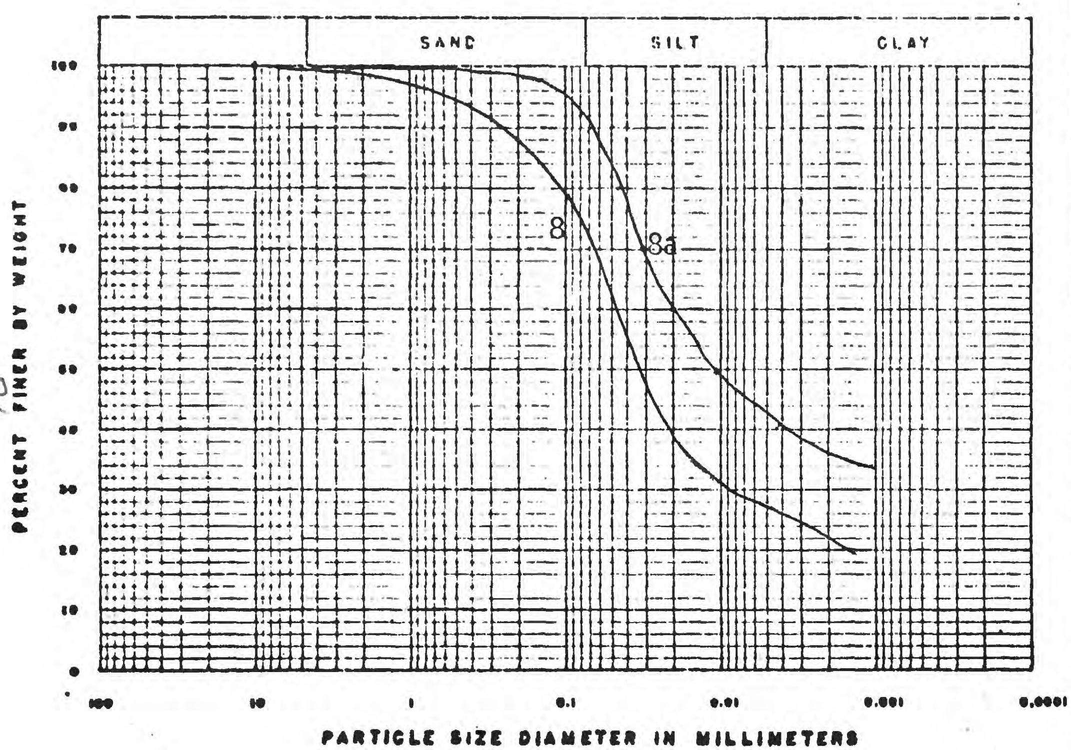
UNDISTORTED PROFILE

AREA 1 SITE 8

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density (grams-cm^3)
8	Base of scarp	30	21	9	22%	2.69
8a	Creek bottom	35	19	16	35	2.53

PARTICLE SIZE DISTRIBUTION CURVE



FIELD OBSERVATIONS: July 7, 1975

The scarp was wet near the base and much ponding was observed below the head of the slide. Jackson Creek is located at the bottom of the failed slope adjacent to the toe. An alluvial terrace gravel tops the hill and is exposed in the upper half of the scarp.

The scarp reveals a 6-inch-thick soil developed in, and underlain by, a lensatic gravel and coarse to medium sand as much as 6 feet thick, which in turn is underlain by a variable silt and silty clay shale. A gray to blue-gray clay shale is exposed in the creek bottom and forms a hard, slick, nearly impermeable surface beneath the running water.

A large slump block delineated by a minor scarp appears continuous across the width of the slide in the upper portion. Flow movement is dominant in the lower half of the slide.

Miscellaneous notes

Aerial photographs of the site taken in 1946, 1954, 1958, and 1963 suggest a sequence of slope failures that has enlarged the slide area by the incorporation of isolated smaller slides in larger, more recent movements. The latest movement may have involved all of the present slide area. The photographs clearly show that most of the recent sliding has occurred since 1954.

AREA 1 SITE 8

<u>FIELD OBSERVATIONS</u>: <u>July 7, 1975</u> (Continued)

<u>Miscellaneous notes</u> (Continued)

The occurrence of the landslide has been reported by Lowry and Cummings (1966), who presented photographs of the site for the years 1954, 1958, and 1961 showing its development. Lowry and Cummings stated that the landsliding "is due in part to the disturbance of the equilibrium caused by the rechanneling of the creek into the toe of the slope, and in part by the irrigation of land above the slope."

AREA 1-SITE 9

Location: NW 1/4 NW 1/4 sec. 7, T. 54 N., R. 84 W., Beaver Creek Hills quadrangle

Formation: Fort Union

Elevation: 4440 ft

Type of movement: Complex - Earthflow/Slump

Direction of movement: S. 49° E.

SLIDE GEOMETRY

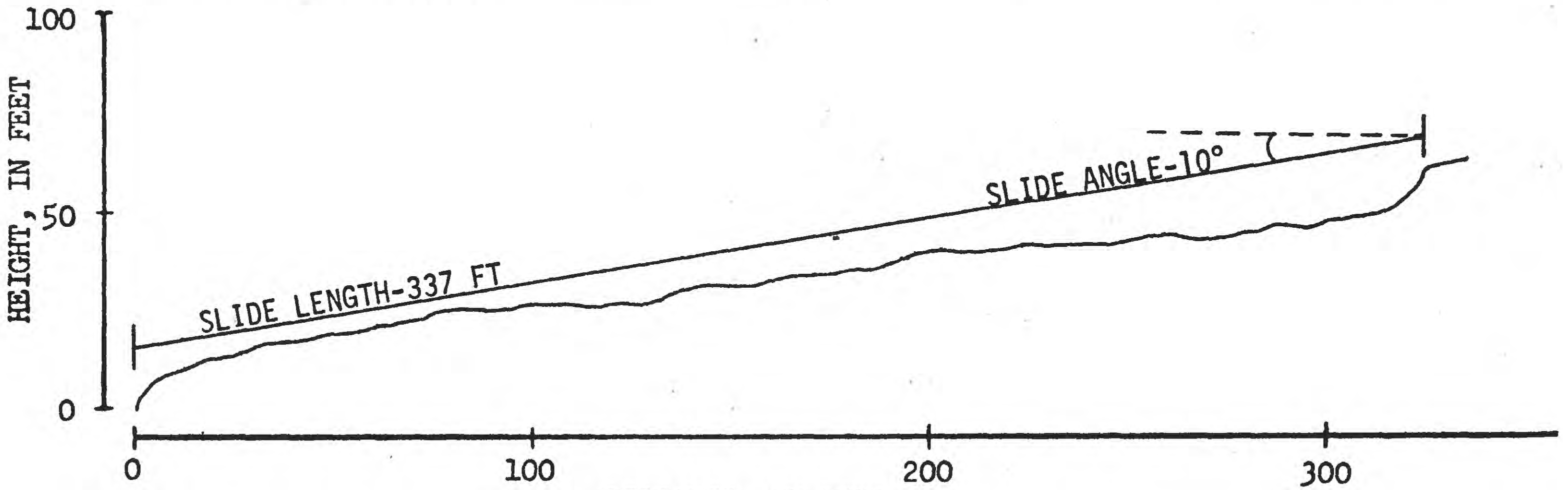
Greatest flank width 215 ft

Scarp width 201 ft

Scarp length 16 ft

Scarp slope 40°

Estimated slide depth 15 ft



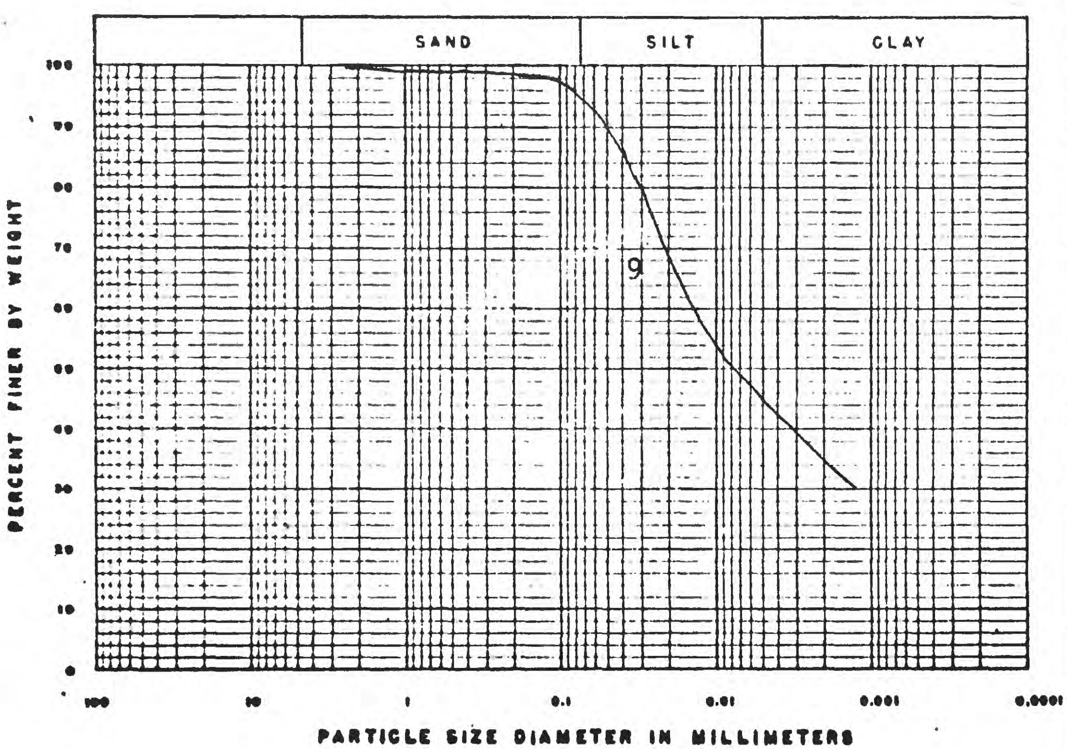
UNDISTORTED PROFILE

AREA 1 SITE 9

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density (grams-cm³)
9	Base of scarp	43	18	25	13%	2.72

PARTICLE SIZE DISTRIBUTION CURVE



FIELD OBSERVATIONS: July 10, 1975

The surface of the slide was dry and overgrown with weeds. No evidence of ponding was observed. An alluvial terrace surface extends to the northwest above and behind the slide mass; however, there is no indication of irrigation activity near the slide.

Two feet of silty sand underlain by a clayey silt is exposed in the scarp.

A new fence line running across the upper part of the slide shows no evidence of movement that would indicate fresh slide activity.

Miscellaneous information

Aerial photographs of the site indicate that the movement was initiated between 1963 and 1966. It is not clear whether or not irrigation has taken place on the alluvial terrace near the slide.

AREA 2-SITE 1

Location: NW 1/4 SW 1/4 sec. 6, T. 54 N., R. 83 W., Big Horn quadrangle

Formation: Wasatch

Elevation: 4505 ft

Type of movement: Earthflow

Direction of movement: N. 66° E.

SLIDE GEOMETRY

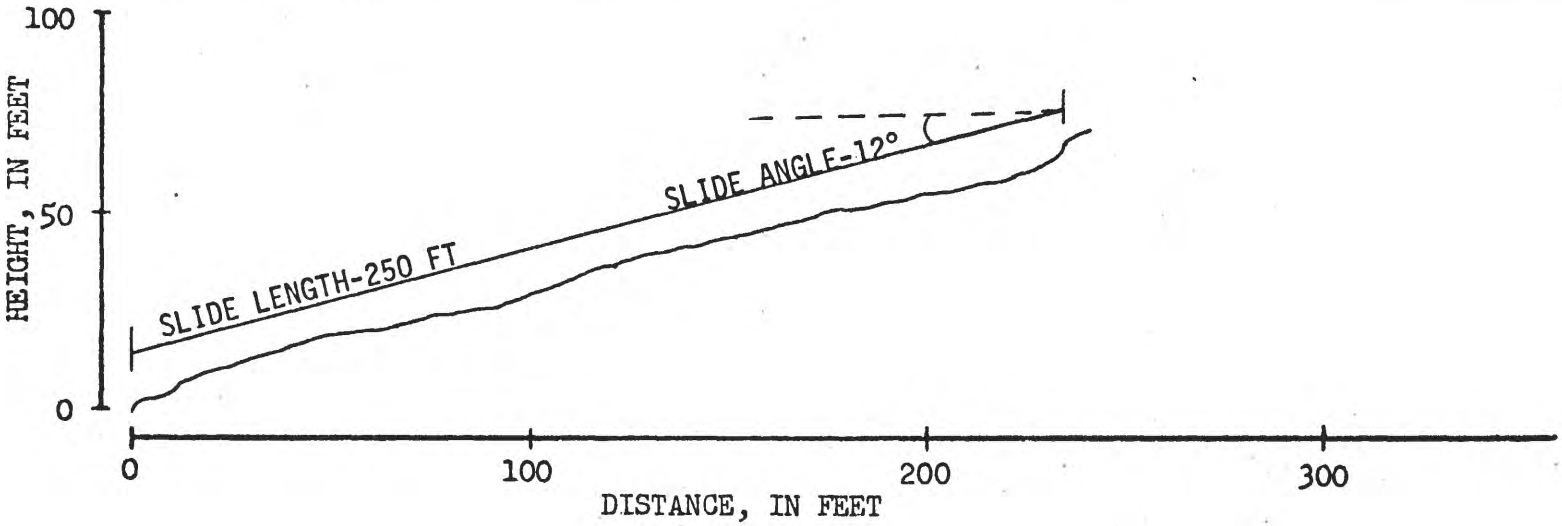
Greatest flank width 254 ft

Scarp width 252 ft

Scarp length 2 ft

Scarp slope 55°

Estimated slide depth 15 ft



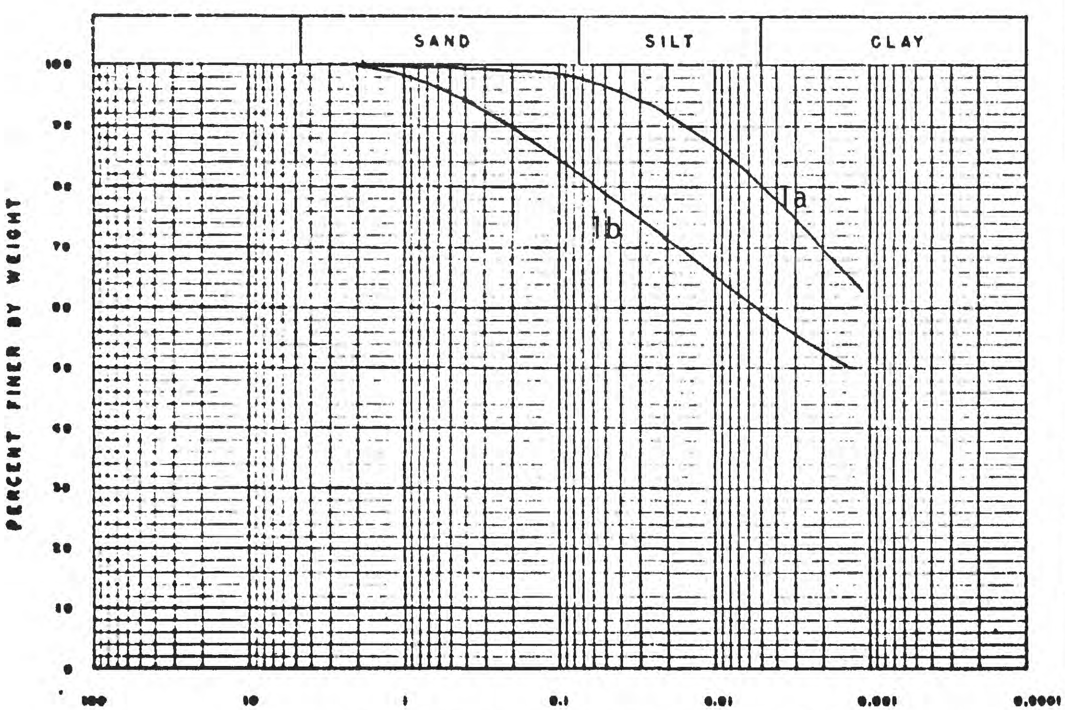
UNDISTORTED PROFILE

AREA 2 SITE 1

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density (grams-cm³)
1a	Base of scarp	74	26	48	26%	2.67
1b	Toe of slide	56	23	33	27%	2.64

PARTICLE SIZE DISTRIBUTION CURVE



FIELD OBSERVATIONS: May 28, 1975

The slide occurs at the head of a small drainage on a convex slope. It is well defined by a fresh scarp, pressure ridges at the flanks, and a hummocky surface; however, little displacement has occurred.

A silty clay is exposed at the base of the scarp and a clayey, sandy silt is exposed at the toe. A carbonaceous shale bed is exposed at the same elevation on a nearby slope and probably forms the bedrock of the failed slope.

The site is an effective catchment area for blowing and drifting snow as well as for other sources of moisture.

Bedding in the area dips 1 1/2° to 2° easterly.

Miscellaneous information

The property owner reports that the slide activity took place after a heavy snowstorm in April of 1974. He also reports that the failed slope has never been irrigated.

Aerial photographs of the site taken in July of 1966 give no indication of the present failure; however, color contrasts probably due to vegetative growth suggest unusual accumulation of moisture in that area.

AREA 2-SITE 2

Location: SE 1/4 SW 1/4 sec. 6, T. 54 N., R. 83 W.,
Big Horn quadrangle

Formation: Wasatch

Elevation: 4370 ft

Type of movement: Complex - Earthflow/Slump

Direction of movement: N. 52° E.

SLIDE GEOMETRY

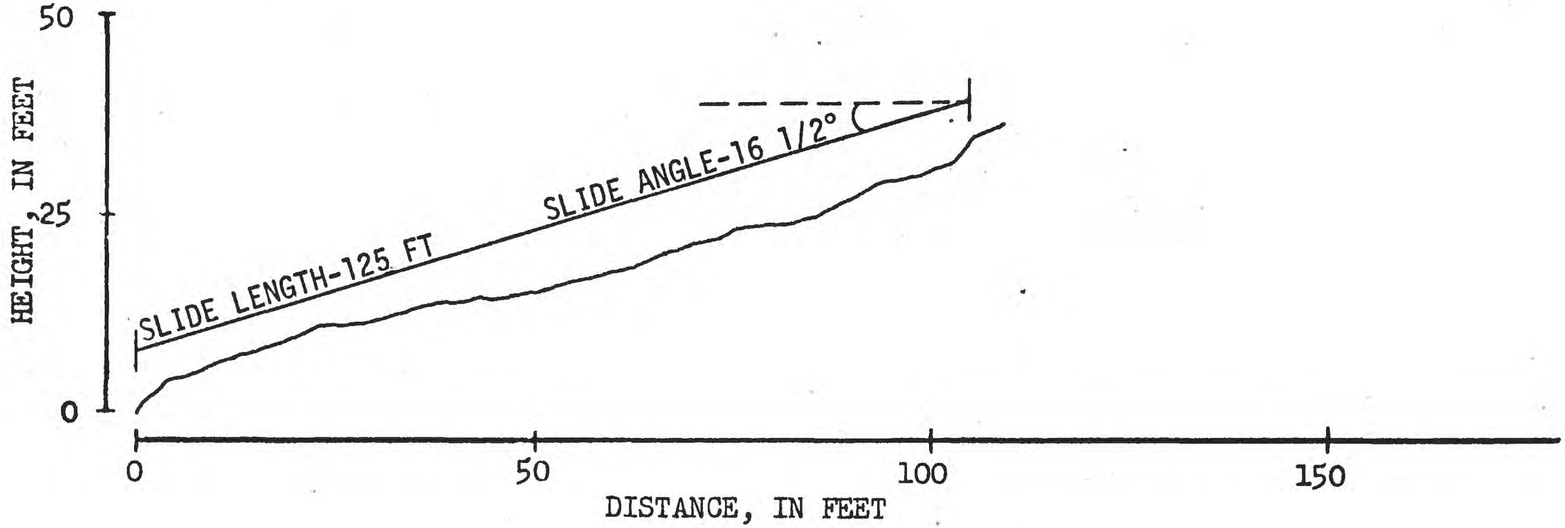
Greatest flank width 55 ft

Scarp width 38 ft

Scarp length 3 ft

Scarp slope 53°

Estimated slide depth 10 ft

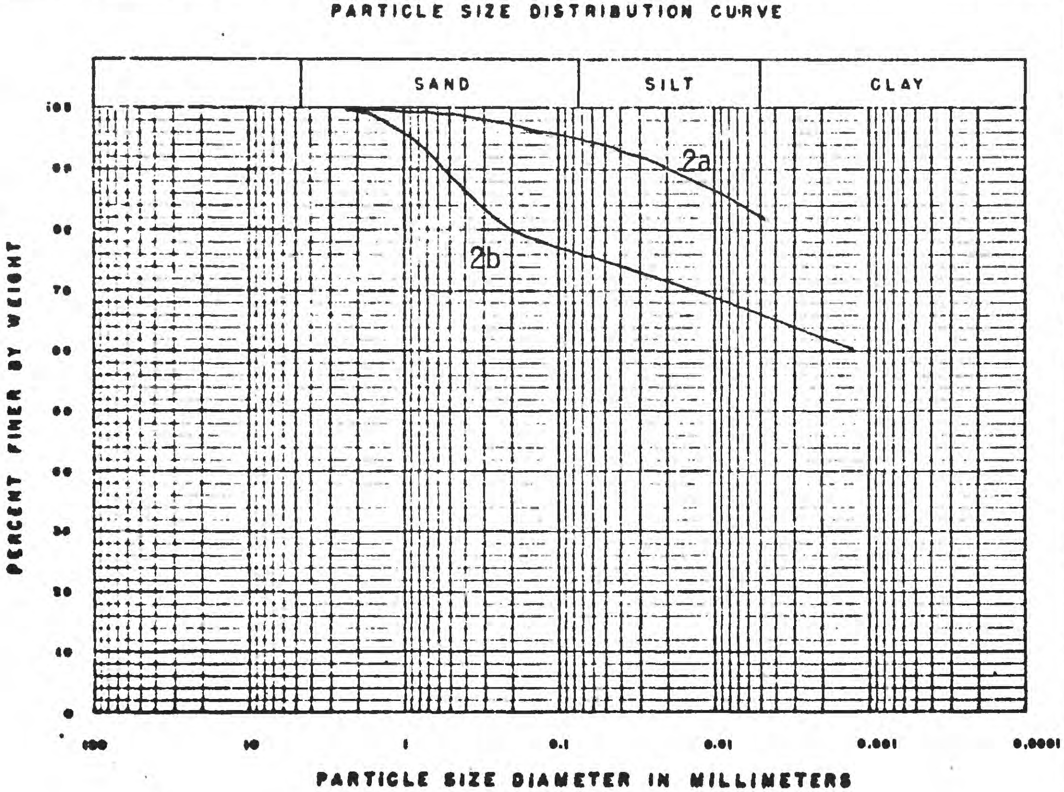


UNDISTORTED PROFILE

AREA 2 SITE 2

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density (grams-cm^3)
2a	Top of scarp	80	26	54	30%	2.71
2b	Top of scarp	58	26	32	32%	2.70
2c	Toe of slide	--	--	--	27%	2.66



FIELD OBSERVATIONS: May 28, 1975

Most of the surface of the slide was very wet. Ponding occurs near the middle of the slide.

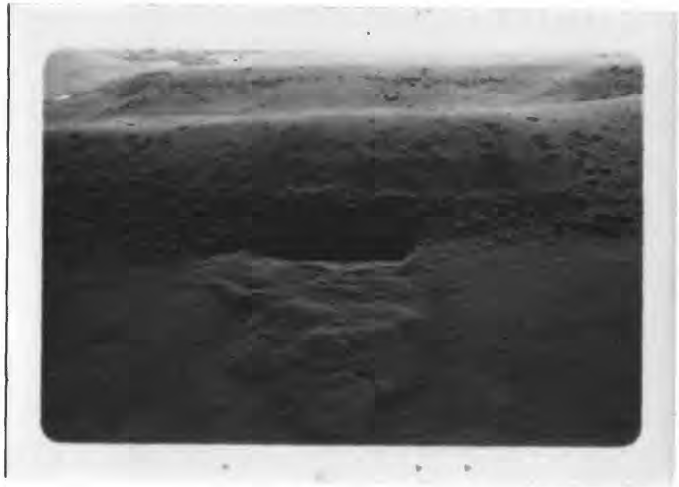
Three feet of exposed scarp revealed a thin soil underlain by a sandy, silty clay shale. Diggings from prairie dog holes adjacent to the slide indicate a lithology change from carbonaceous shale below the level of the scarp to a fine sand and silt above.

Several small slump blocks were observed in the upper part of the slide. Flow movement is dominant in the lower part.

Miscellaneous information

According to the property owner, the sliding took place after a big snowstorm in April of 1973.

Aerial photographs taken in 1966 give no indication of prior movement at the site.



AREA 2-SITE 3

Location: NW 1/4 NW 1/4 sec. 9, T. 54 N., R. 83 W., Buffalo Run Creek quadrangle

Formation: Wasatch

Elevation: 4370 ft

Type of movement: Earthflow

Direction of movement: Due west

SLIDE GEOMETRY

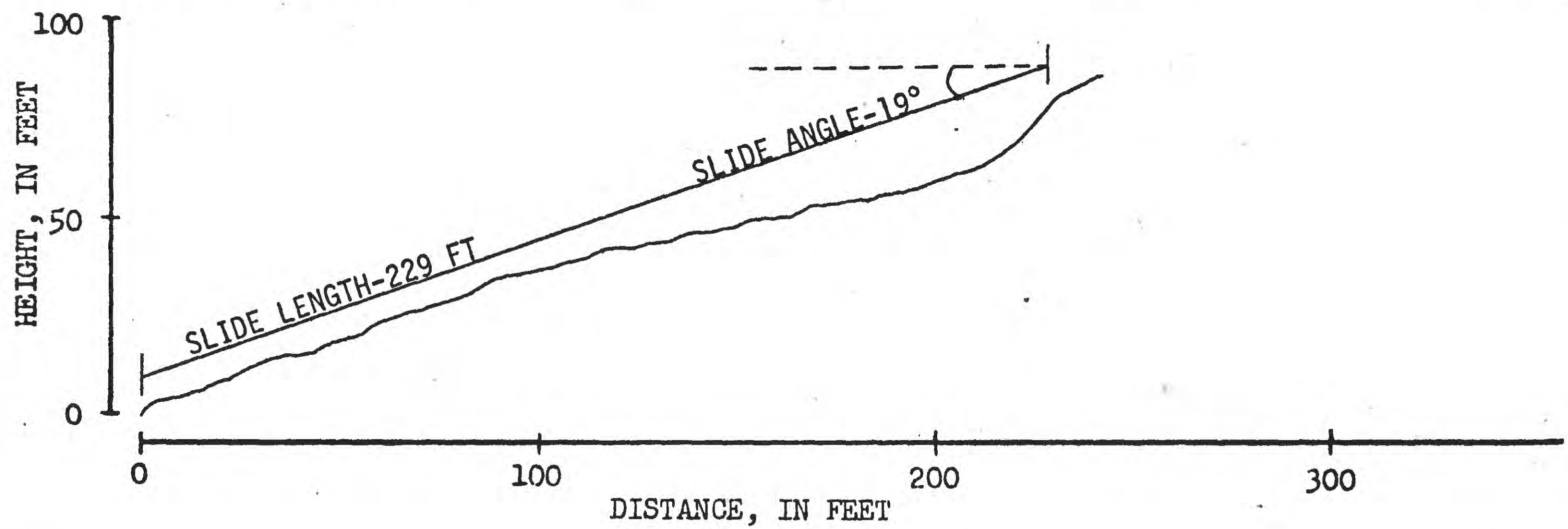
Greatest flank width 155 ft

Scarp width 152 ft

Scarp length 45 ft

Scarp slope 31°

Estimated slide depth 25 ft



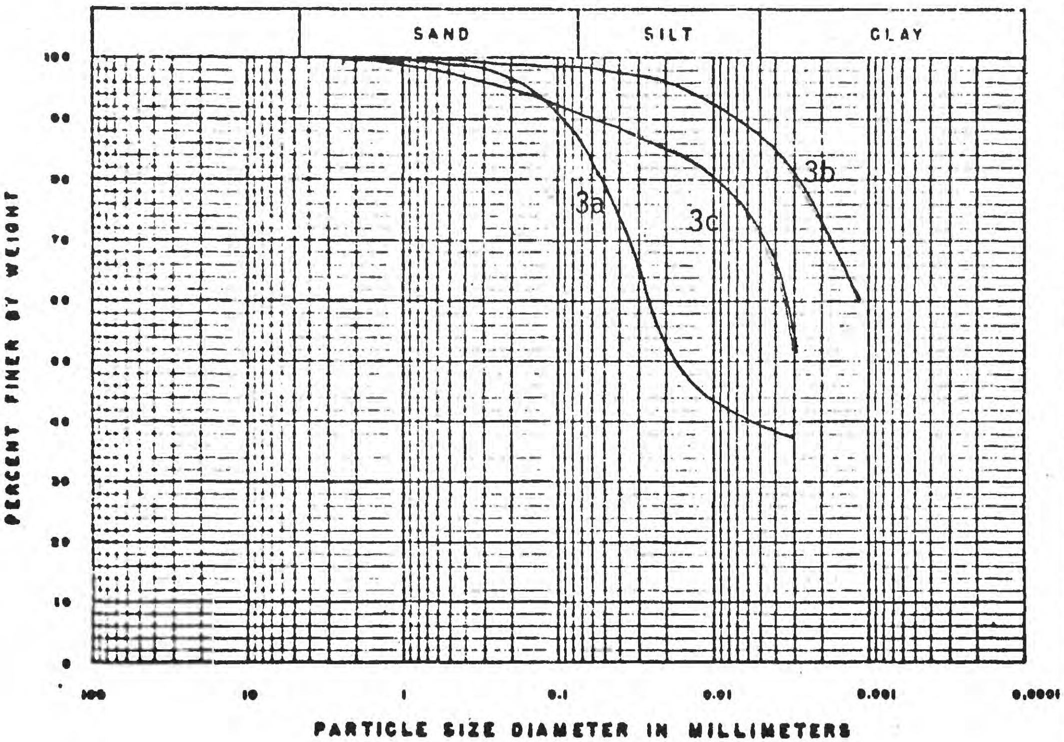
UNDISTORTED PROFILE

AREA 2 SITE 3

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density (grams-cm³)
3a	Top of scarp	61	27	34	27%	2.82
3b	Middle of scarp	61	37	24	45%	2.92
3c	Toe of slide	62	25	37	26%	2.77

PARTICLE SIZE DISTRIBUTION CURVE



FIELD OBSERVATIONS: May 30, 1975

The slide surface was dry and overgrown with grass and weeds. A line of vegetation on the upper part of the slope marks a break in lithology.

The scarp reveals a silty clay shale underlain by a thin bed of carbonaceous shale, followed by a clayey silt which in turn is underlain by more carbonaceous shale.

The fractures and depressions on the surface are partly filled and overgrown with vegetation. No evidence of fresh movement was observed. The slide appears stable.

Miscellaneous information

Aerial photographs taken in 1966 indicate that the slope failure had taken place prior to that time.

AREA 2-SITE 4

Location: NW 1/4 SW 1/4 sec. 7, T. 54 N., R. 83 W.,
Big Horn quadrangle

Formation: Wasatch

Elevation: 4470 ft

Type of movement: Complex - Earthflow/Slump

Direction of movement: N. 75° E.

SLIDE GEOMETRY

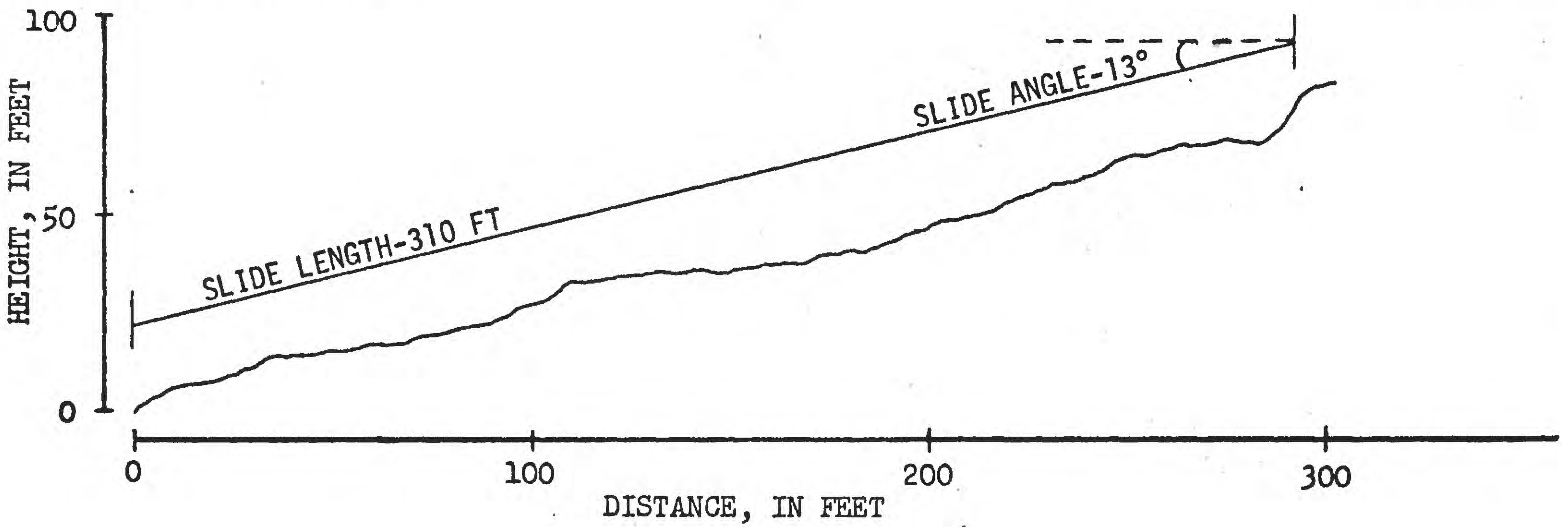
Greatest flank width 255 ft

Scarp width 98 ft

Scarp length 13 ft

Scarp slope 50°

Estimated slide depth 20 ft



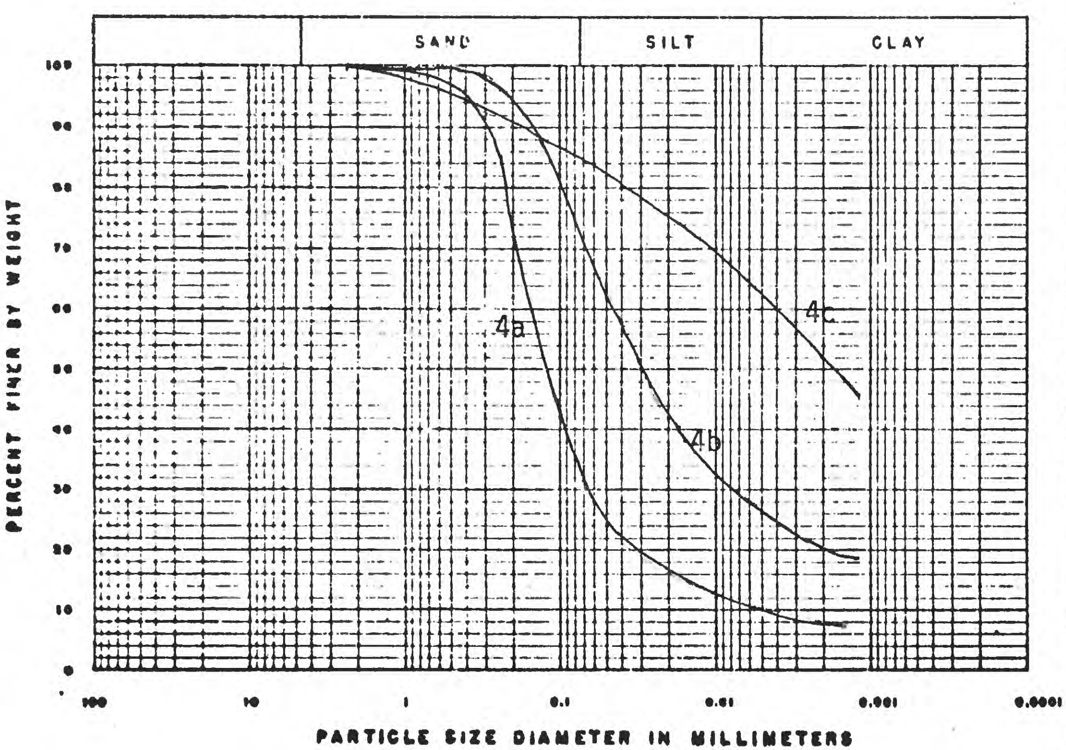
UNDISTORTED PROFILE

AREA 2 SITE 4

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density ($grams\text{-}cm^3$)
4a	Top of scarp	NP	NP	NP	15%	2.68
4b	Middle of scarp	31	20	11	13%	2.70
4c	Toe of slide	39	21	18	27%	2.70

PARTICLE SIZE DISTRIBUTION CURVE



FIELD OBSERVATIONS: May 30, 1975

The upper part of the slide surface was very wet. Ponding occurs at the toe. A spring line marked by bushes occurs on either side of the slide area at the elevation of the scarp. A small irrigation ditch has been overrun by the toe of the slide, and another irrigation ditch is located on the opposite side of the hill at or above the level of the scarp.

The scarp exposes 12 inches of soil underlain by 10 feet of tan to gray sandy silt, which grades downward into a dark-gray to green clayey silt.

Shear fractures spaced from 5 to 15 feet apart separate small slump blocks at the head of the slide. The surface of the lower portion is hummocky but relatively unbroken. Conjugate pairs of vertical fractures in the scarp strike N. 40° E., N. 60° E., N. 10° W., and N. 42° W. The fracture spacing is 1/2 inch to 2 inches. Bedding dips easterly 1 1/2° to 2°.

Miscellaneous notes

Aerial photographs of the site taken in 1966 show a slightly hummocky surface, indicating that a slope failure had been initiated prior to that time; however, most of the movement has occurred since 1966.

AREA 2-SITE 5

Location: NW 1/4 SE 1/4 sec. 16, T. 54 N., R. 83 W., Buffalo Run Creek quadrangle

Formation: Wasatch

Elevation: 4450 ft

Type of movement: Complex - Earthflow/Slump

Direction of movement: N. 64° E.

SLIDE GEOMETRY

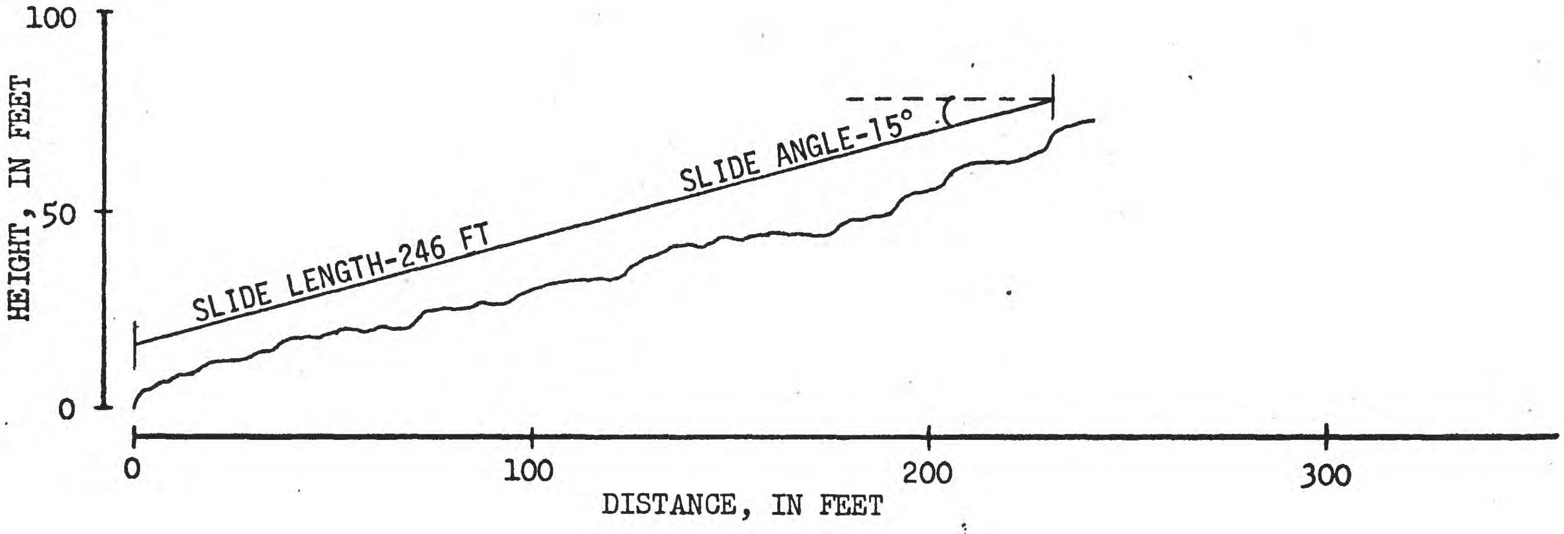
Greatest flank width 265 ft

Scarp width 240 ft

Scarp length 14 ft

Scarp slope 31°

Estimated slide depth 40 ft

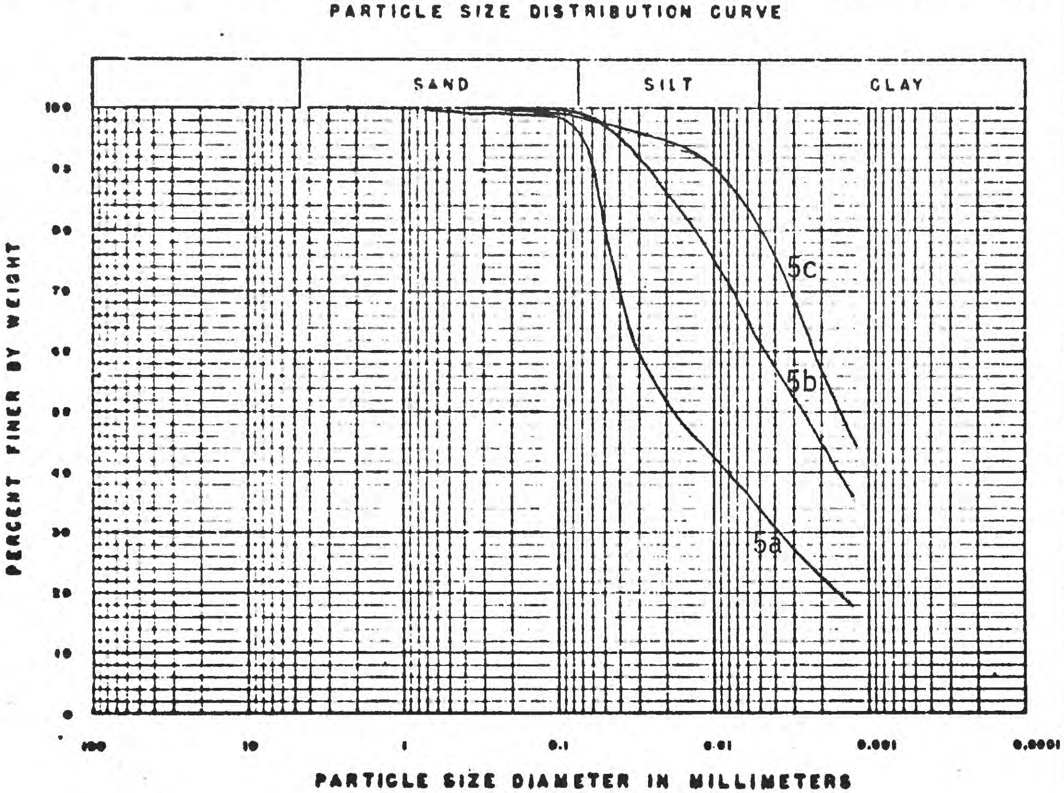


UNDISTORTED PROFILE

AREA 2 SITE 5

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density (grams-cm³)
5a	Top of scarp	30	21	9	19%	2.66
5b	Base of scarp	43	18	25	20%	2.69
5c	Toe of slide	60	27	33	29%	2.73



FIELD OBSERVATIONS: May 31, 1975

The slide occurs near the top of a slightly convex slope. Many older slides located at approximately the same elevation on the slope were observed on either side of the profiled mass.

The scarp was very wet, and exposed a clayey silt underlain by a carbonaceous shale. Carbonaceous shale and clay shale are exposed in fractures throughout the slide.

Slump blocks delineated by transverse fractures 15 to 50 feet apart occur in the upper half of the slide.

Miscellaneous information

Aerial photographs indicate that the sliding took place sometime between 1966 and 1974.

AREA 2-SITE 6

Location: SW 1/4 SW 1/4 sec. 15, T. 54 N., R. 83 W., Buffalo Run Creek quadrangle

Formation: Wasatch

Elevation: 4330 ft

Type of movement: Complex - Earthflow/Slump

Direction of movement: N. 80° E.

SLIDE GEOMETRY

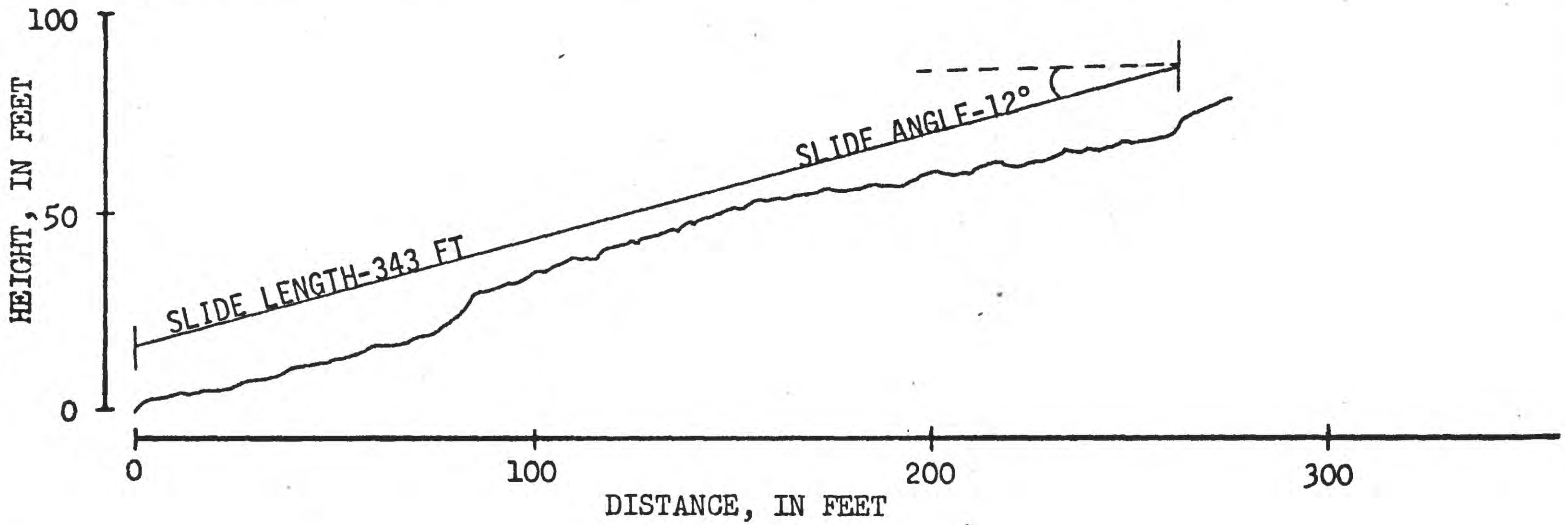
Greatest flank width 115 ft

Scarp width 74 ft

Scarp length 2 ft

Scarp slope 70°

Estimated slide depth 15 ft



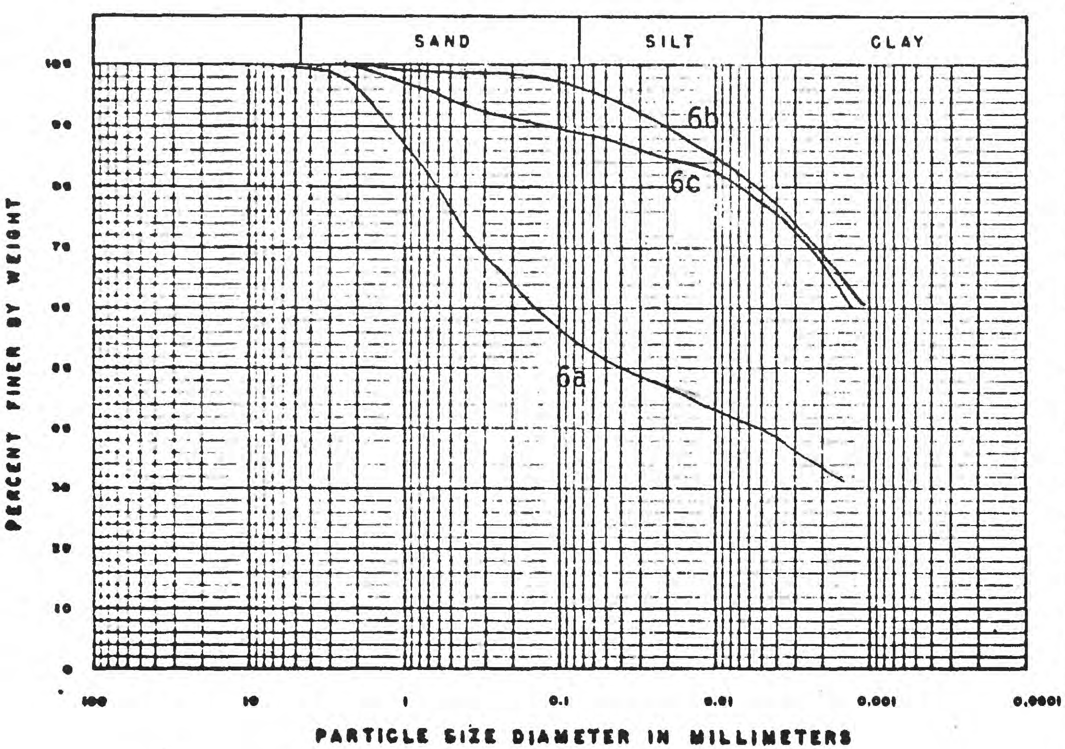
UNDISTORTED PROFILE

AREA 2 SITE 6

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density (grams-cm^3)
6a	Top of scarp	49	20	29	22%	2.68
6b	Middle of slide	91	53	38	52%	2.52
6c	Toe of slide	82	31	51	35%	2.71

PARTICLE SIZE DISTRIBUTION CURVE



FIELD OBSERVATIONS: May 31, 1975

Ponding was observed in the upper part of the slide. The toe of the slide runs into an irrigation ditch and a small creek (Prairie Dog Creek) at the foot of the slope.

A clay-rich, silty sand is exposed in the scarp. Carbonaceous shale and clay shale are exposed below the scarp along the flanks and at many places on the slide surface. Crystalline cobbles and boulders are mixed in with other debris on the surface of the slide.

Slumping and flow movement occurred in the upper half of the slide. Shear fractures with 30- to 80-foot spacing are associated with the slumping. A large slump with a slickensided scarp occurs three-quarters of the way down the slide and may represent more recent movement within the larger mass.

Miscellaneous notes

A property owner reports that the slide activity took place in the spring of 1973.

Aerial photographs taken in 1966 do not show the recent activity.

AREA 2-SITE 7

Location: NW 1/4 SE 1/4 sec. 3, T. 53 N., R. 83 W., Banner quadrangle

Formation: Wasatch

Elevation: 4700 ft

Type of movement: Complex - Earthflow/Slump

Direction of movement: N. 50° E.

SLIDE GEOMETRY

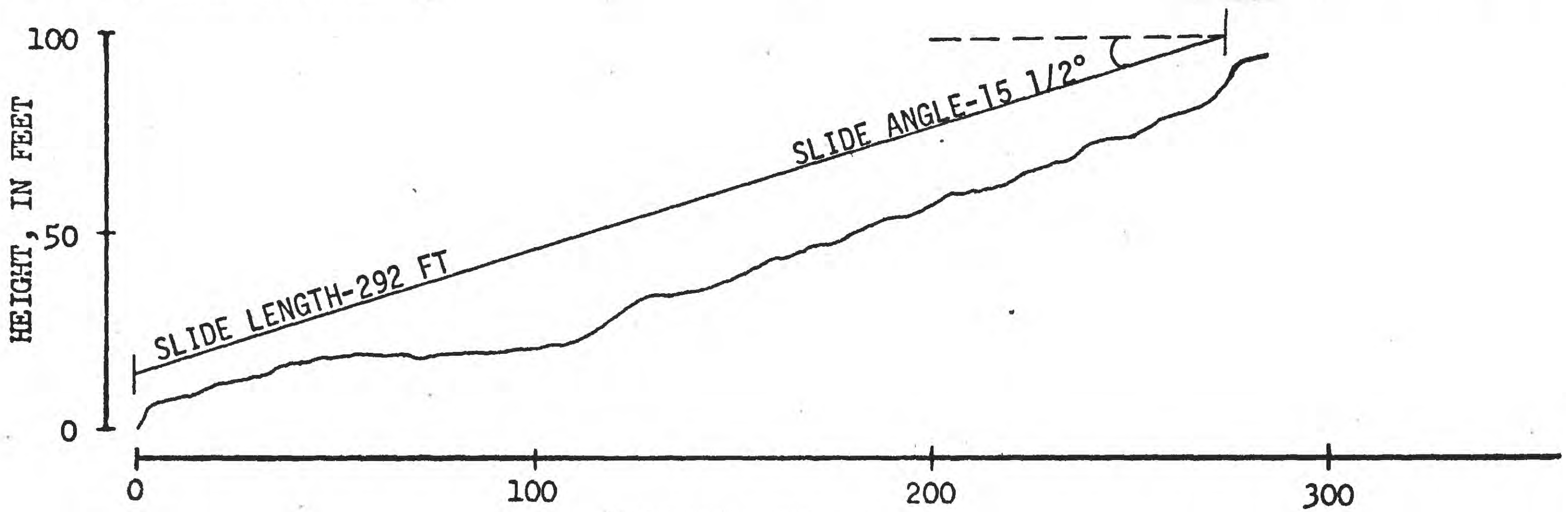
Greatest flank width 90 ft

Scarp width 88 ft

Scarp length 20 ft

Scarp slope 31 1/2°

Estimated slide depth 20 ft



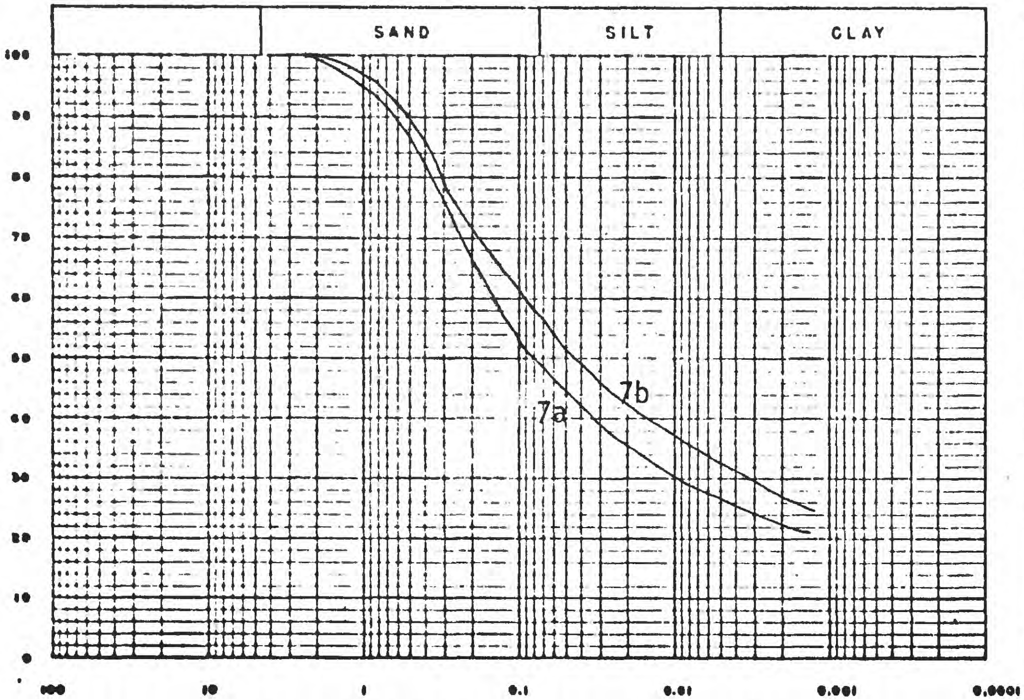
UNDISTORTED PROFILE

AREA 2 SITE 7

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density (grams-cm^3)
7a	Top of scarp	31	17	14	18%	2.67
7b	Toe of slide	32	19	13	19%	2.65

PARTICLE SIZE DISTRIBUTION CURVE



PARTICLE SIZE DIAMETER IN MILLIMETERS

FIELD OBSERVATIONS: May 31, 1975

The slide is overgrown with vegetation. Most of the depressions and fractures are filled in and obscured by grass and weeds. A spring-fed pond is located just above the toe. The rest of the slide surface was wet but did not appear saturated.

A sandy, clayey silt is exposed in the scarp, and a thin bed of silty sand is exposed on the hillside just above the scarp. A variable carbonaceous clay shale is exposed in a roadcut on the opposite side of the hill at approximately the same elevation as the slide.

Miscellaneous notes

The slope failure is evident in aerial photographs taken in 1966.

AREA 2-SITE 8

Location: NW 1/4 NE 1/4 sec. 11, T. 53 N., R. 83 W., Banner quadrangle

Formation: Wasatch

Elevation: 4600 ft

Type of movement: Complex - Earthflow/Slump

Direction of movement: S. 36° E.

SLIDE GEOMETRY

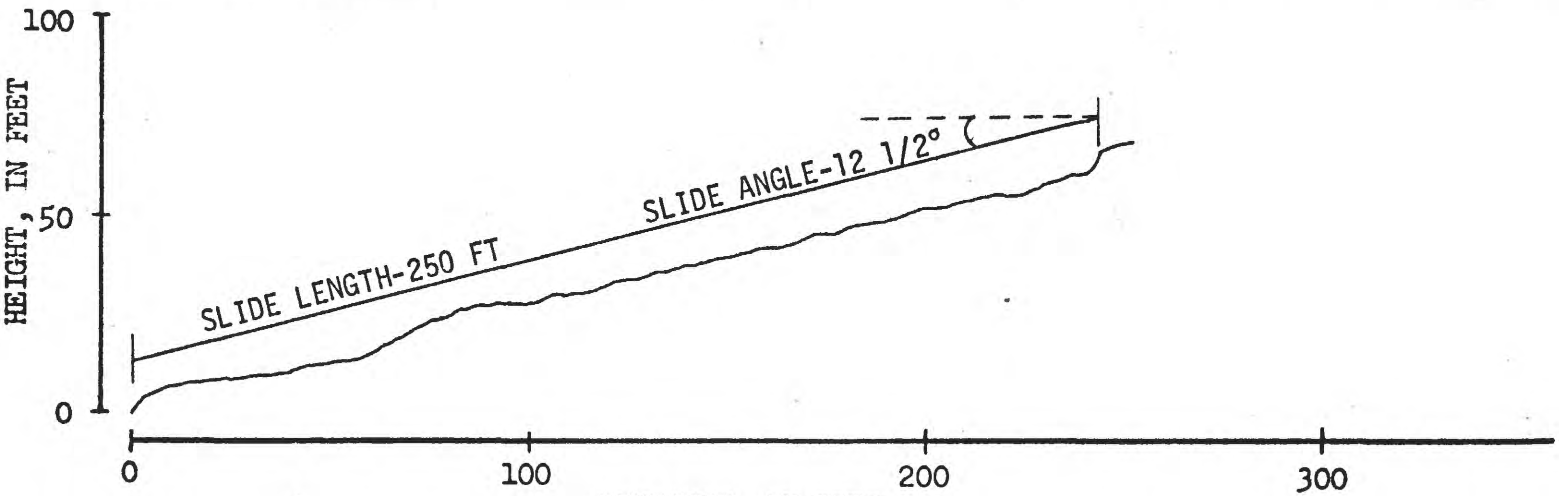
Greatest flank width 98 ft

Scarp width 38 ft

Scarp length 4 ft

Scarp slope 80°

Estimated slide depth 10 ft



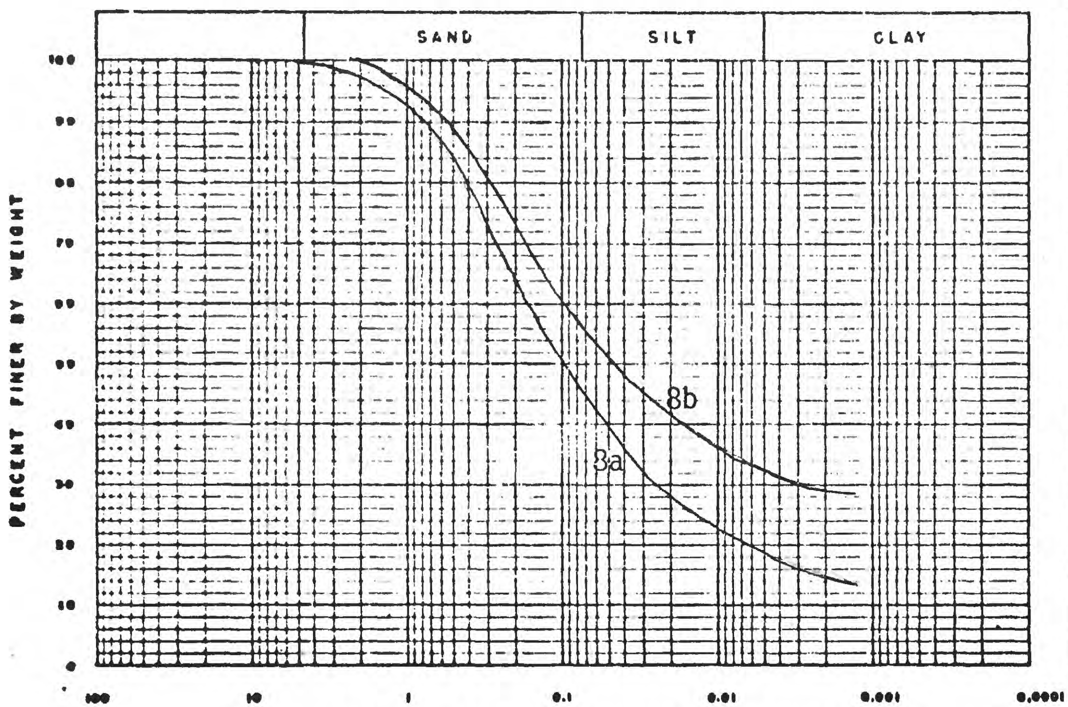
UNDISTORTED PROFILE

AREA 2 SITE 8

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density (grams-cm³)
8a	Top of scarp	NP	NP	NP	17%	2.68
8b	Toe of slide	22	21	1	23%	2.65

PARTICLE SIZE DISTRIBUTION CURVE



PARTICLE SIZE DIAMETER IN MILLIMETERS

FIELD OBSERVATIONS: May 29, 1975

The profiled slide heads in an older slide mass near the top of the slope.

A silty sand with minor clay was sampled at the scarp, and a clayey, organic, silty sand was sampled at the toe. Carbonaceous shale is exposed at the same elevation in a roadcut to the west, and clinker is exposed at the same elevation across the drainage to the south.

Miscellaneous information

Aerial photographs taken in 1966 show an old slope failure at the site. The profiled slide appears in 1974 photos, indicating that the recent activity took place between 1966 and 1974.

AREA 2-SITE 9

Location: SE 1/4 SE 1/4 sec. 11, T. 53 N., R. 83 W., Banner quadrangle

Formation: Wasatch

Elevation: 4670 ft

Type of movement: Earthflow

Direction of movement: N. 85° E.

SLIDE GEOMETRY

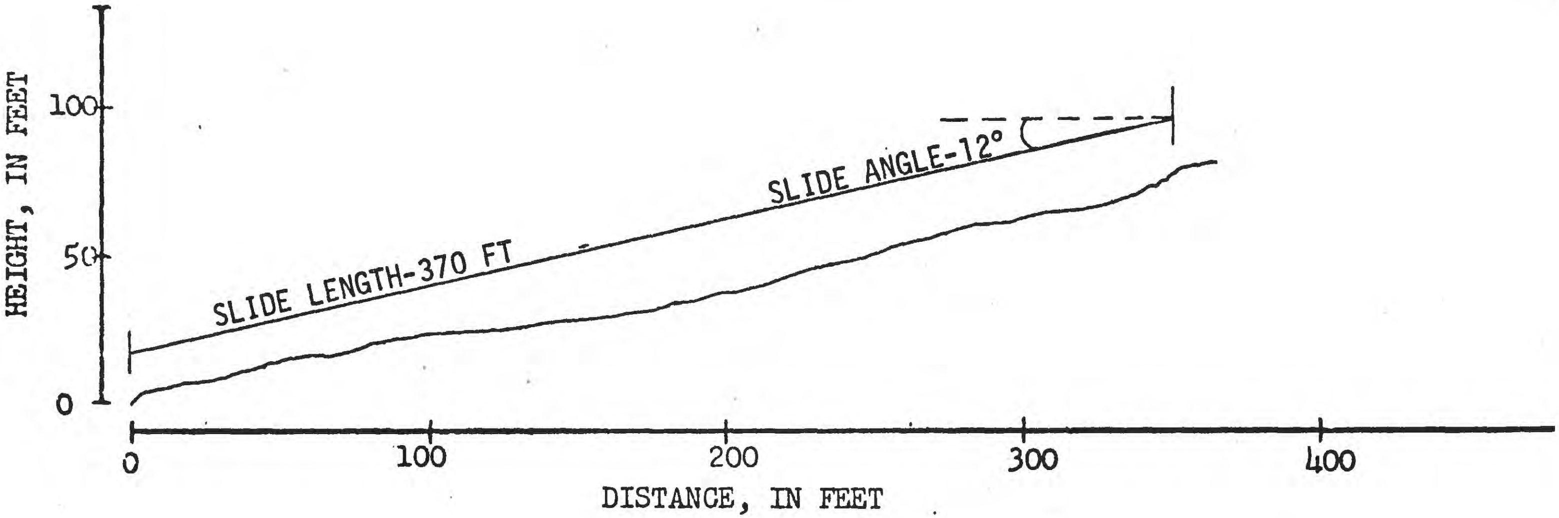
Greatest flank width 182 ft

Scarp width 179 ft

Scarp length 17 ft

Scarp slope 23°

Estimated slide depth 30 ft

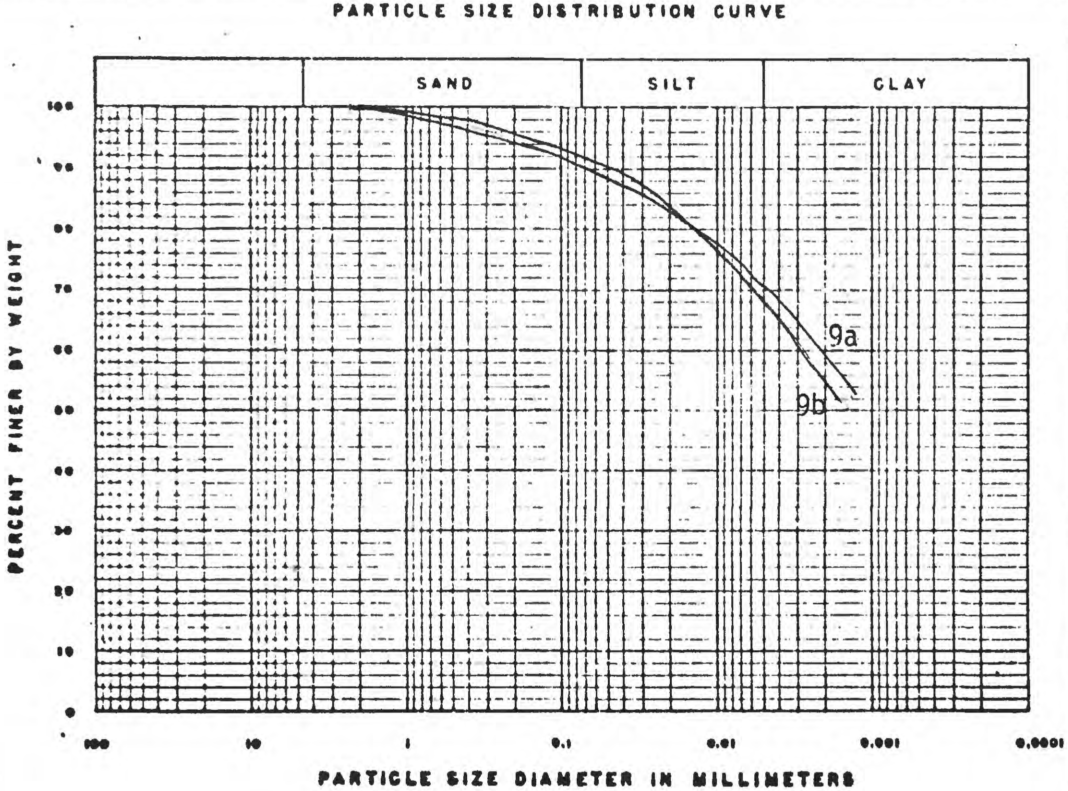


UNDISTORTED PROFILE

AREA 2 SITE 9

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density (grams-cm³)
9a	Top of scarp	37	25	12	30%	2.68
9b	Base of scarp	49	24	25	34%	2.70



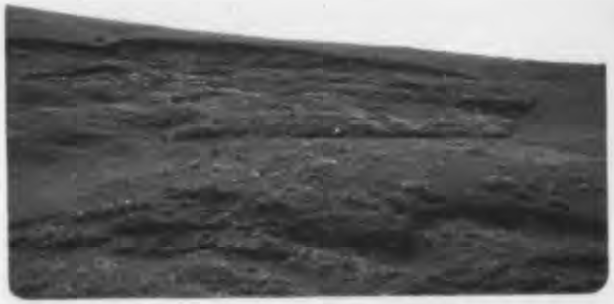
FIELD OBSERVATIONS: May 31, 1975

The profiled slide is not well defined because of little movement. There is very little broken ground other than a fresh scarp and tear fractures at the flanks. The rest of the movement is expressed at the surface as hummocky topography. Older sliding at the site is indicated by healed transverse fractures on the slide surface.

A silty, sandy clay was sampled at the scarp. Clinker is exposed at the same elevation across the drainage.

Miscellaneous information

Aerial photographs taken in 1966 show a spring line marked by vegetation and old landsliding just south of the site. It could not be determined whether the profiled landslide had occurred by that time or not.



AREA 2-SITE 10

Location: SW 1/4 SW 1/4 sec. 13, and SE 1/4 SE 1/4 sec. 14, T. 53 N., R. 83 W., Banner quadrangle

Formation: Wasatch

Elevation: 4660 ft

Type of movement: Earthflow

Direction of movement: N. 83° E.

SLIDE GEOMETRY

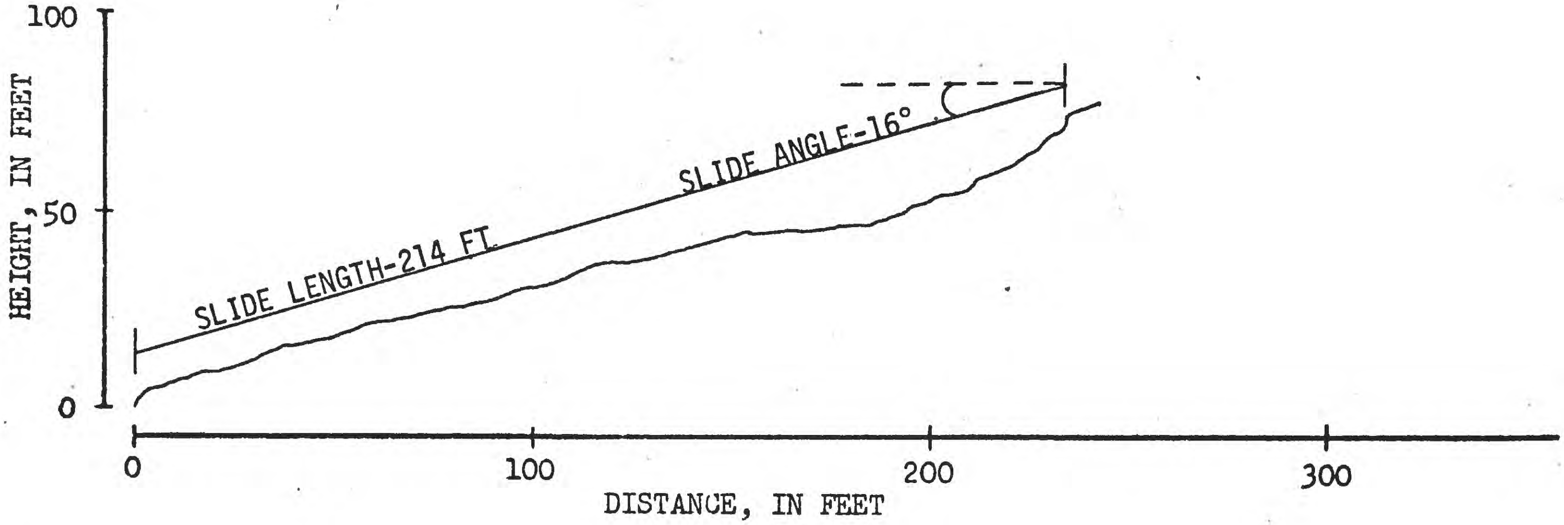
Greatest flank width 237 ft

Scarp width 197 ft

Scarp length 52 ft

Scarp slope 26°

Estimated slide depth 20 ft



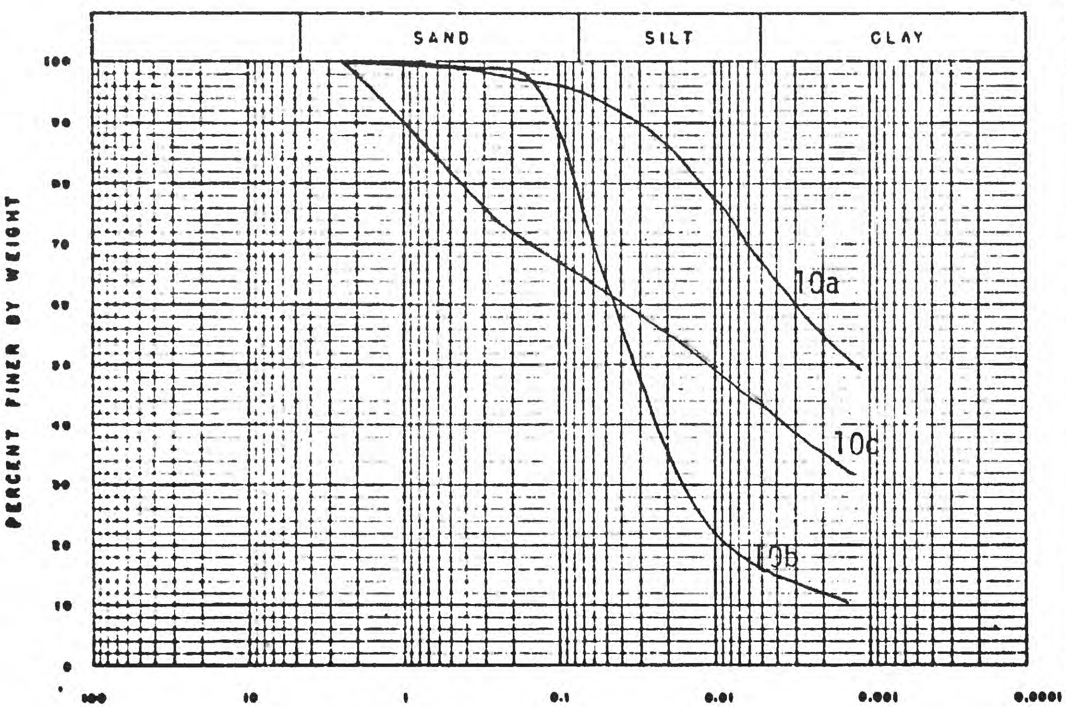
UNDISTORTED PROFILE

AREA 2 SITE 10

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density (grams-cm^3)
10a	Top of scarp	30	22	8	26%	2.70
10b	Base of scarp	NP	NP	NP	5%	2.74
10c	Toe of slide	31	23	8	31%	2.67

PARTICLE SIZE DISTRIBUTION CURVE



FIELD OBSERVATIONS: May 29, 1975

The profiled slide is part of a large slide area composed of several coalescing earthflow-type movements.

The surface material at the head and the toe appeared saturated.

The scarp reveals a silty, sandy clay grading downward into a clayey, sandy silt. A thin bed of sandy siltstone is exposed at the base of the scarp, and a silty clay and small chunks of clinker mixed with soil are exposed at the toe.

Tensional and shear fractures with 1- to 4-foot spacings were observed on the slide surface near the scarp.

Miscellaneous notes

Aerial photographs taken in 1966 and 1974 indicate that the recent slide activity took place sometime between those dates.

AREA 3-SITE 1

Location: SE 1/4 NW 1/4 sec. 4, T. 53 N., R. 83 W., Banner quadrangle

Formation: Wasatch

Elevation: 4590 ft

Type of movement: Complex - Earthflow/Slump

Direction of movement: N. 35° E.

SLIDE GEOMETRY

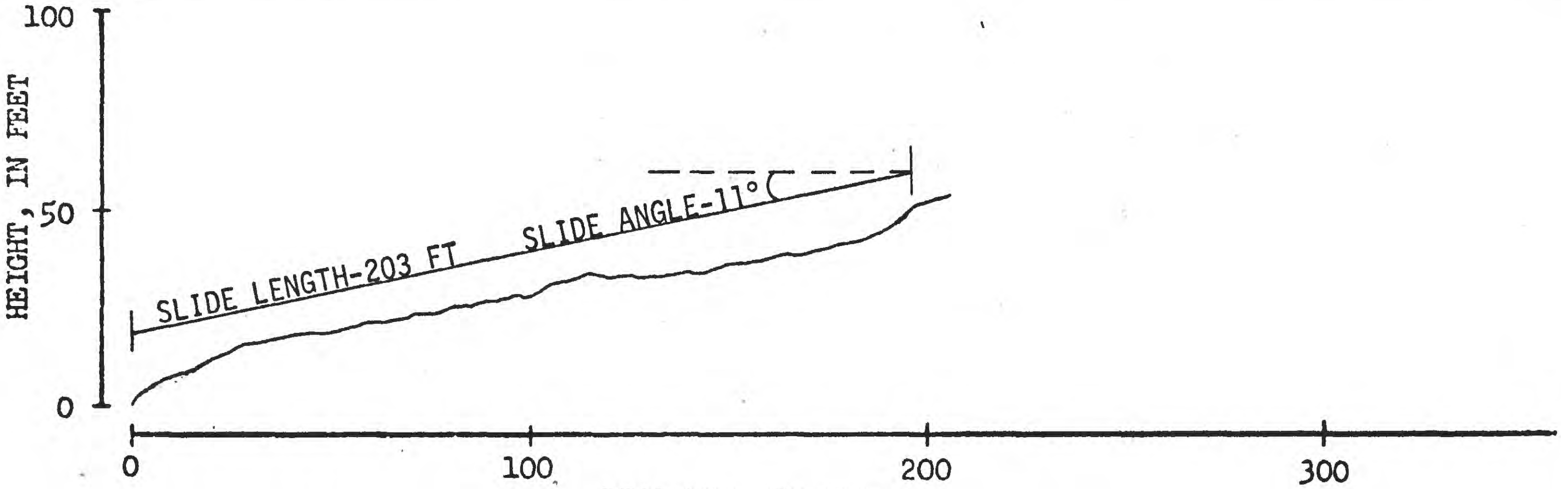
Greatest flank width 100 ft

Scarp width 59 ft

Scarp length 24 ft

Scarp slope 22°

Estimated slide depth 15 ft



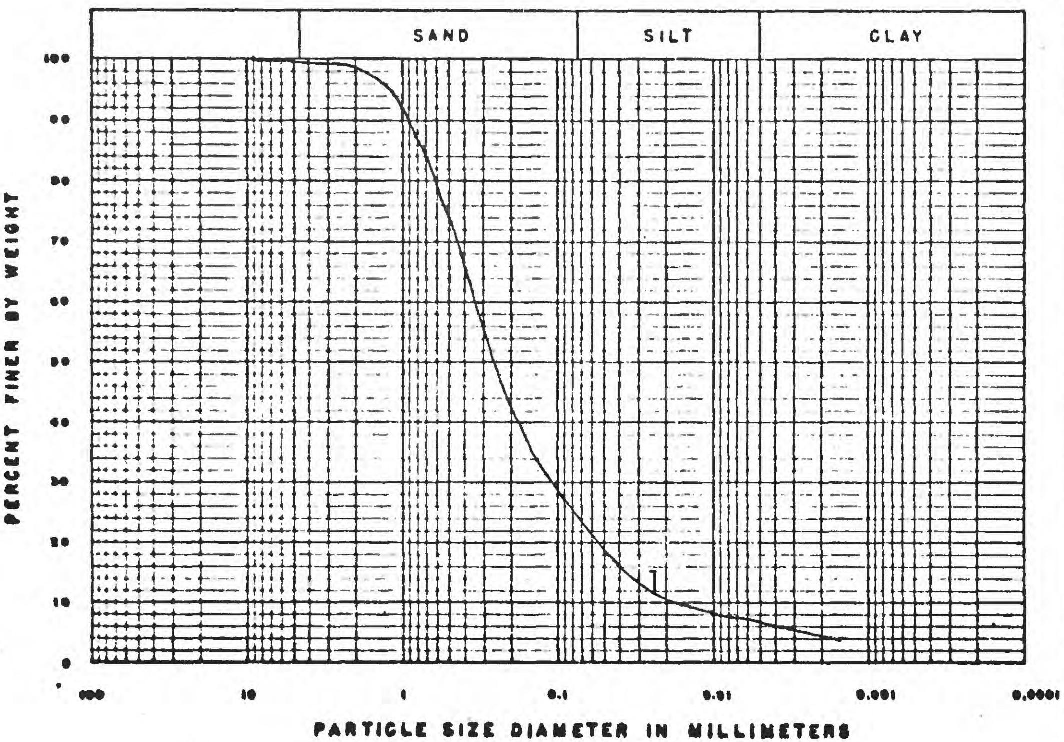
UNDISTORTED PROFILE

AREA 3 SITE 1

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density (grams-cm^3)
1	Top of scarp	NP	NP	NP	7%	2.66

PARTICLE SIZE DISTRIBUTION CURVE



FIELD OBSERVATIONS: June 4, 1975

The slide surface was dry and covered with weeds and grass. The scarp is vegetated three-quarters of the way up. Fractures and depressions on the surface are mostly filled and not well defined.

A lensatic, concretionary gravel is exposed at the top of the scarp. The scarp material below the gravel is predominantly a silty, fine to coarse sand.

State Highway 87 is located 200 feet to the east.

Miscellaneous notes

Aerial photographs taken in July of 1966 clearly show the profiled slide.

AREA 3-SITE 2

Location: NW 1/4 NW 1/4 sec. 9, T. 53 N., R. 83 W., Banner quadrangle

Formation: Wasatch

Elevation: 4600 ft

Type of movement: Complex - Slump/Earthflow

Direction of movement: N. 20° W.

SLIDE GEOMETRY

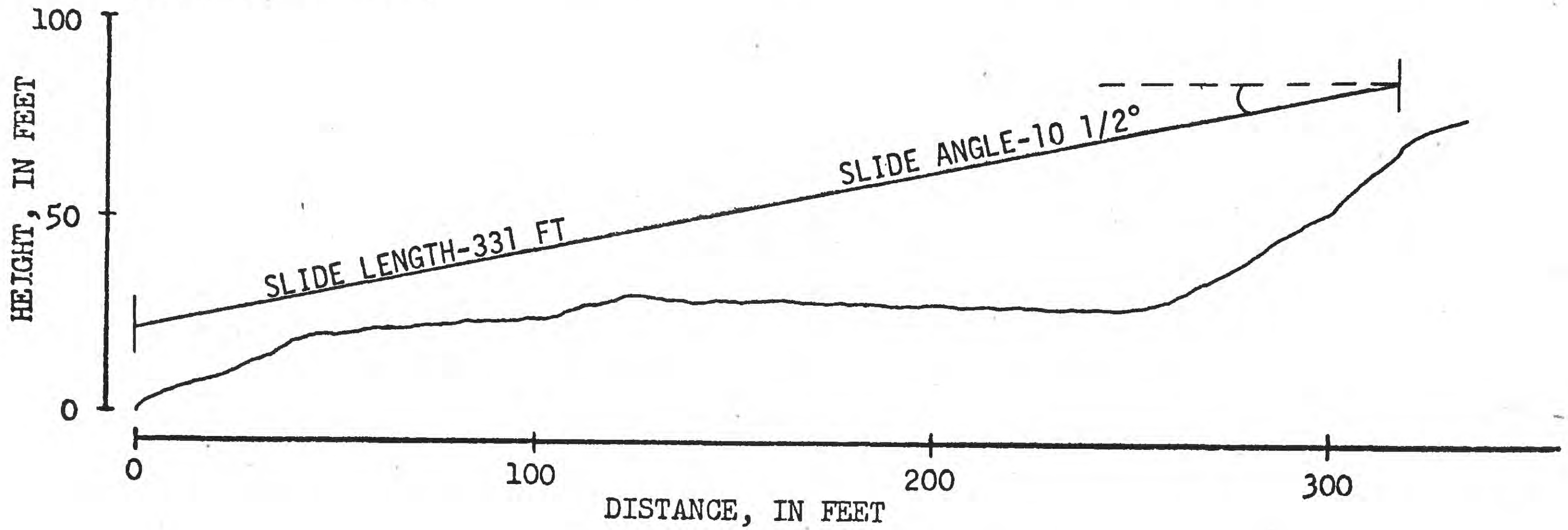
Greatest flank width 430 ft

Scarp width 420 ft

Scarp length 76 ft

Scarp slope 32°

Estimated slide depth 50 ft

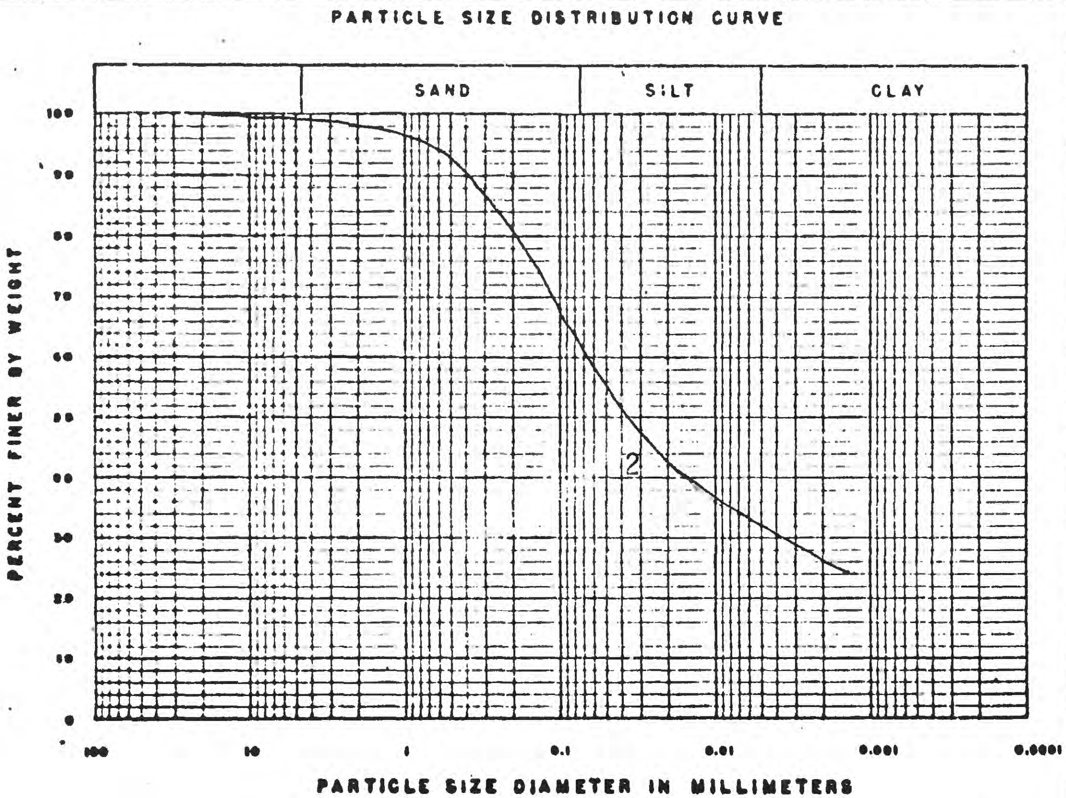


UNDISTORTED PROFILE

AREA 3 SITE 2

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density (grams-cm³)
2	Top of scarp	37	17	17	18%	2.68



FIELD OBSERVATIONS: June 5, 1975

The slide surface was wet and overgrown with vegetation. Jenks Creek runs close to the toe of the slide and actively undercuts the slope on the opposite side. The creek may have been diverted to its present course by the toe of the profiled slide.

The slide consists of a large rotated slump block in the upper half and small, poorly defined slump blocks and earthflow debris in the lower half. Fractures and depressions are filled and covered by bushes and weeds. No evidence of fresh movement was observed.

A 20-foot exposure across Jenks Creek reveals interbedded friable sands and silts, lensatic and concretionary coarse sands and conglomerates, and thin shale seams. A nearly vertical fault located on the east end of the exposure strikes N. 30° W. and is displaced at least 15 feet. Bedding dips 4° to 5° westerly.

Miscellaneous notes

The landslide is clearly shown in aerial photographs taken in 1966.

AREA 3-SITE 3

Location: SW 1/4 NW 1/4 sec. 26, T. 53 N., R. 83 W., Banner quadrangle

Formation: Wasatch

Elevation: 4750 ft

Type of movement: Complex - Slump/Earthflow

Direction of movement: S. 68° E.

SLIDE GEOMETRY

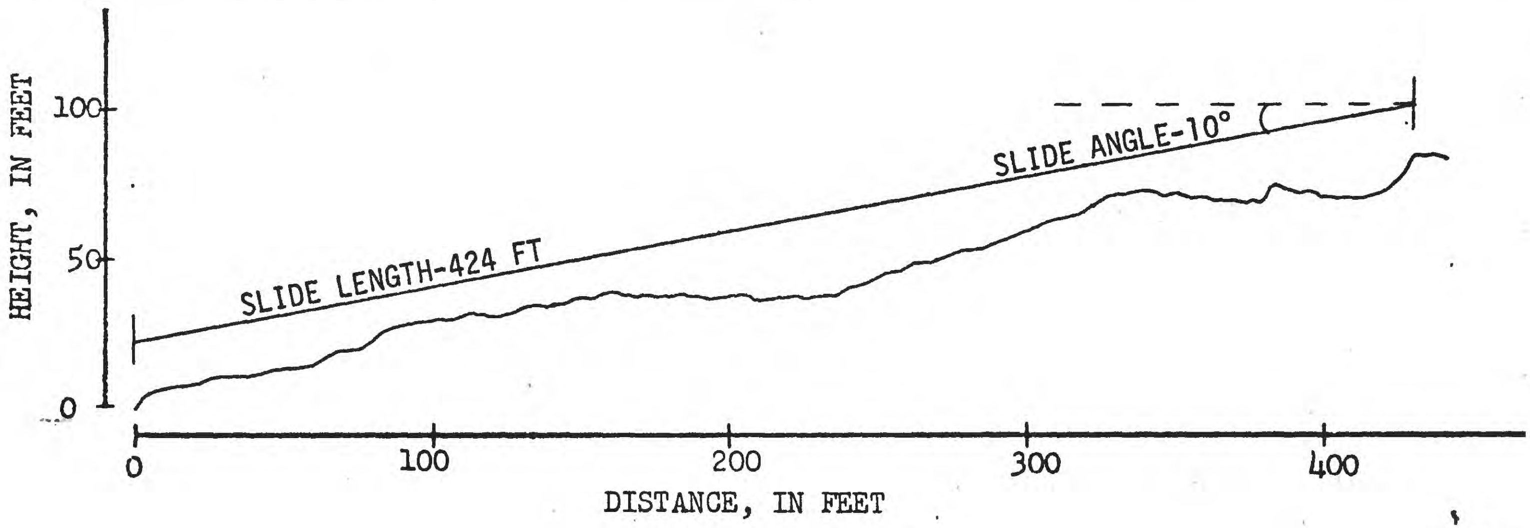
Greatest flank width 168 ft

Scarp width 159 ft

Scarp length 24 ft

Scarp slope 36°

Estimated slide depth 40 ft



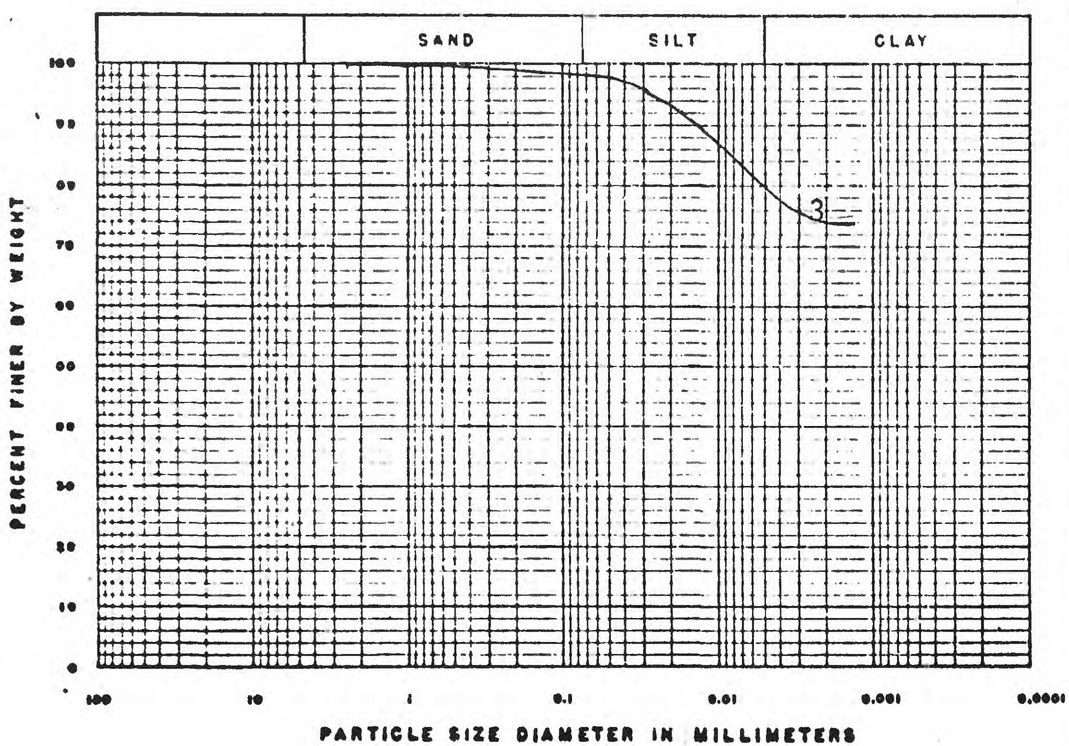
UNDISTORTED PROFILE

AREA 3 SITE 3

LABORATORY DATA AND FIELD OBSERVATIONS

Sample No.	Collection location	LL	PL	PI	Water content (percent)	Grain density (grams-cm³)
3	Toe of slide	77	35	42	36%	2.68

PARTICLE SIZE DISTRIBUTION CURVE



FIELD OBSERVATIONS: June 5, 1975

The slide is the result of recent movement on a slope that has a history of landslide activity. The hillside is scarred by numerous older slides. Hummocky landforms and the remains of old slope failures that have spilled out onto the Piney Creek flood plain can be seen to the northwest along 3 miles of slope.

The profiled slide had wet zones throughout, and ponding was noted above the toe. An irrigated alluvial terrace is located northwest of the slide.

Two slump blocks were observed in the upper part of the slide, where the slope is the steepest. Flow movement is dominant in the lower part, where the material has moved out beyond the foot of the hillslope.

The fresh scarp reveals a thin alluvial gravel cap underlain by sand, silt, and carbonaceous shale beds that dip 47° northward. Carbonaceous and clay shales are exposed at several places in the slide mass. Coal and peat were seen mixed with the flow debris in the toe.

Miscellaneous notes

Aerial photographs taken in 1966 and 1974 show that the landslide took place sometime between those dates.