Report on

A FIELD RECONNAISSANCE OF MANTLE INSTABILITY

on the

MANTI DIVISION OF THE MANTI-LASAL NATIONAL FOREST

and

AN ADJACENT PORTION

of the

FISHLAKE NATIONAL FOREST

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by

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I. INTRODUCTION

Scope

It is recognized that mantle instability is a limiting factor in resource and land use management on the Wasatch Plateau portion of the Manti-LaSal and Fishlake National Forests. This study was made to delineate hazard areas and to interpret, where possible, the degrees of hazard. The study area covers approximately 1,200 square miles and was mapped in a 2-month period during the summer of 1971. Thus, the study is a reconnaissance only and refinement is possible with further investigations. Two types of refinements can be made: (1) More detailed mapping to enable greater spatial resolution, and (2) subdivision of stability zones on the basis of the mechanisms of instability, e.g. block slides vs. slumps.

Early in the study it was realized that there would be three general ways to attack this project:

1. Map every slide. Determine if slides are active or fossil and, if fossil, indicate chances of reactivation.

2. Look at examples of the various landforms. If there are signs of activity, evaluate them and place all similar landform in the same class. For example, we have seen two fairly large landslides on the north-facing slopes of the canyons leading west from Joe's Valley; on this basis, every slope of this type would be classed as Zone 1 (unstable of its own accord).

3. Look at the various geologic formations and determine how they behave in general. The object here would be to tell the planner what types of problems he will encounter when working in a given formation.

This particular study was a combination of approaches 2 and 3, with an attempt to generalize from specific situations in such a way that meaningful mapping could be done using available 7½ and 15 minute quadrangles of the study area. This information was transferred to Ranger District maps for easier reference.

Purpose

This report has been prepared to alert the land managers to areas of slope instability. It is intended to be used only as a guide in the recognition of mass movement hazards to land- and resource-use management activities. A more detailed characterization of indicated problem areas should be considered basic to the design of specific management practices.

The four main sections of the report deal with: (1) A description of the study area in terms of its physiography and its geologic formations; (2) the stability classification system, stability zones, and a discussion of slide occurrence frequency; and (3) a detailed description of the subsections into which the study area was divided.

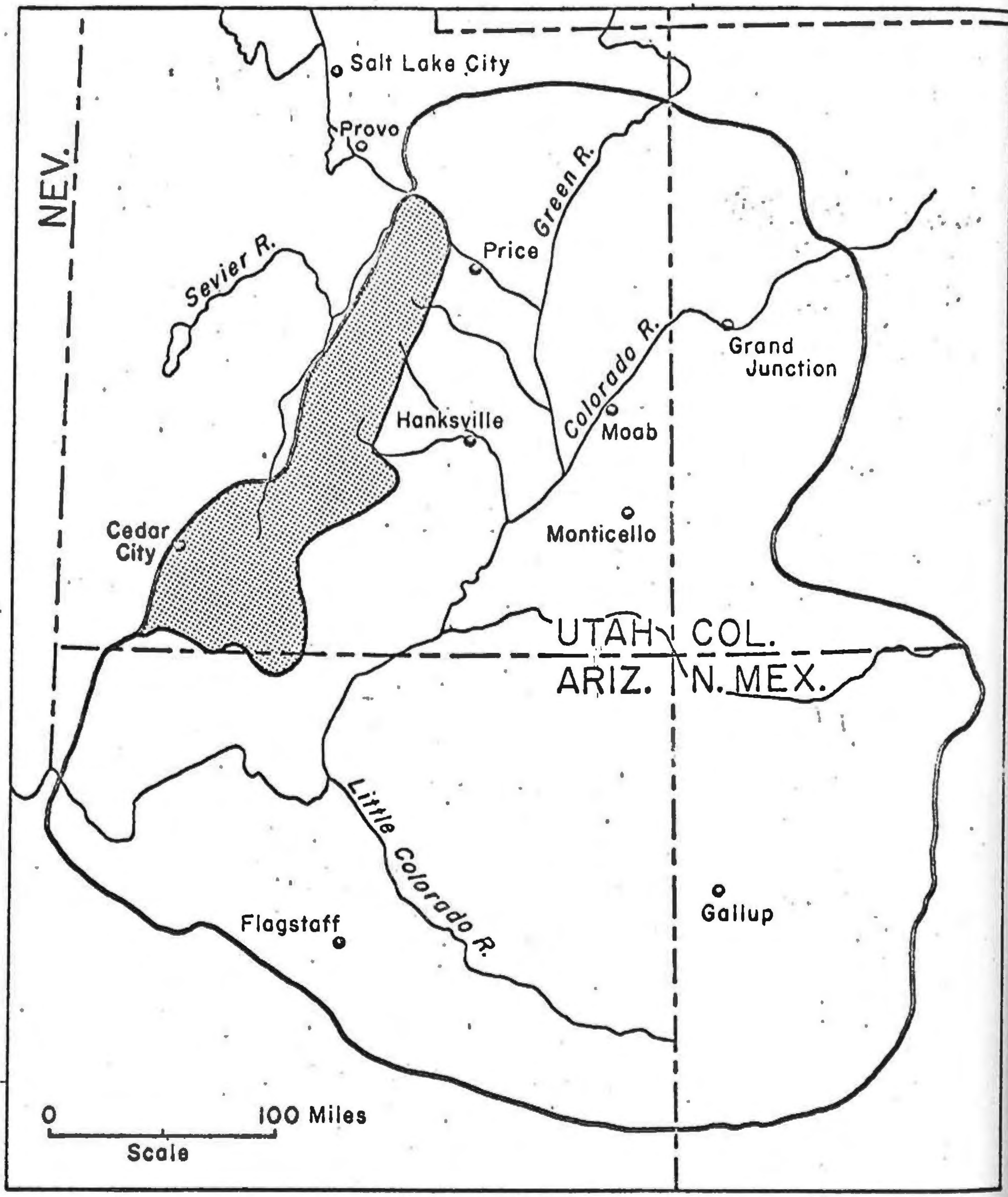

Figure 1. Outline map of Colorado Plateau Physiographic Province and High Plateaus Section.

II. DESCRIPTION OF THE STUDY AREA

Physiography

The first step in the study project was the delineation of areas of similar landscape, topography, and climate; i.e., physiographic units. This concept is not new, since the study area itself has been distinguished physiographically from nearby areas. The Wasatch Plateau, essentially the area of study, lies within the High Plateaus section of the Colorado Plateau physiographic province of the United States (figure 1). Thus, the process of stratification already established was extended within the study area. When this was done, six physiographic subsections were delineated as land type groups whose basically similar appearance suggested similar management problems (plates 1 and 2). These subsections are summarized as follows:

1. Lakes Subsection: (Landtype Area)

   The area is one of gently-rolling hills and valleys and is underlain by glacial till. It presents no major problems to land use. (Figure 2)

Figure 2. General view of Lakes Subsection. Cleveland Reservoir on the right and Miller's Flat Reservoir in the distance. Note the numerous potholes and several lakes enlarged by man.

2. High Plateaus Subsection:

Because of the flat-lying nature of the topography and the geology, this subsection poses no major problems. In its main portion along Skyline Drive, the only problem areas are the cirque headwalls which have been oversteepened by glaciation. (Figure 3)

Figure 3. General view of High Plateaus Subsection. The view is northeast towards Danish Knoll, showing flat areas separated by steep escarpments.

3. Ridge and Valley Subsection:

This area is characterized by long, steep slopes with narrow summit areas and V-shaped valleys. Topography here does not reflect geology. The major hazards would be minor sloughing if cuts were made in slopes, and major erosion if vegetation were removed by logging or over-grazing. (Figure 4)

Figure 4. Typical view of Ridge and Valley Subsection. This is the Left Fork of Huntington Canyon. The presence of the small cliffs indicate that this is part of the gradational boundary with the Eastern Clifflands Subsection.

4. Eastern Clifflands Subsection:

The steep nature of the topography and the alternation of sandstone and shale formations make this subsection extremely hazardous to block sliding, especially when the toes of slopes are cut away. (Figure 5)

Figure 5. General view of the Eastern Clifflands Subsection. Here in the area of the Emery County television tower, note the sharp upper border and the gradational lower border of this subsection.

5. Monocline Subsection:

This subsection's regional dip to the west and the underlying North Horn and Flagstaff Formations indicate that those activities which result in side cuts into the slopes will be hazardous, but that grazing and timbering will pose no major stability problems. (Figure 6)

Figure 6. General view of the Monocline Subsection. This view is taken north across Salina Canyon. Note how the eastern edge grades into the High Plateaus Subsection.

6. Rolling Basinlands Subsection:

Because this subsection is located on the sides of hills and is underlain by extensive areas of the North Horn Formation and fossil landslides, it presents the major problem in land management in the study area. The currently active slides in Bulger, Seely and Ferron Canyons indicate that human activity is not necessary to cause mass movement. (Figures 7 & 8)

Figure 7. View of Rolling Basinlands Subsection. This is between Ferron Canyon on the left and Ferron Mountain on the right. The canyon in the middle bottom closely resembles those canyons leading into Joe's Valley graben.

Figure 6. General view of the Rolling Basinlands Subsection in the area of North Dragon. Note the typical fossil landslide.

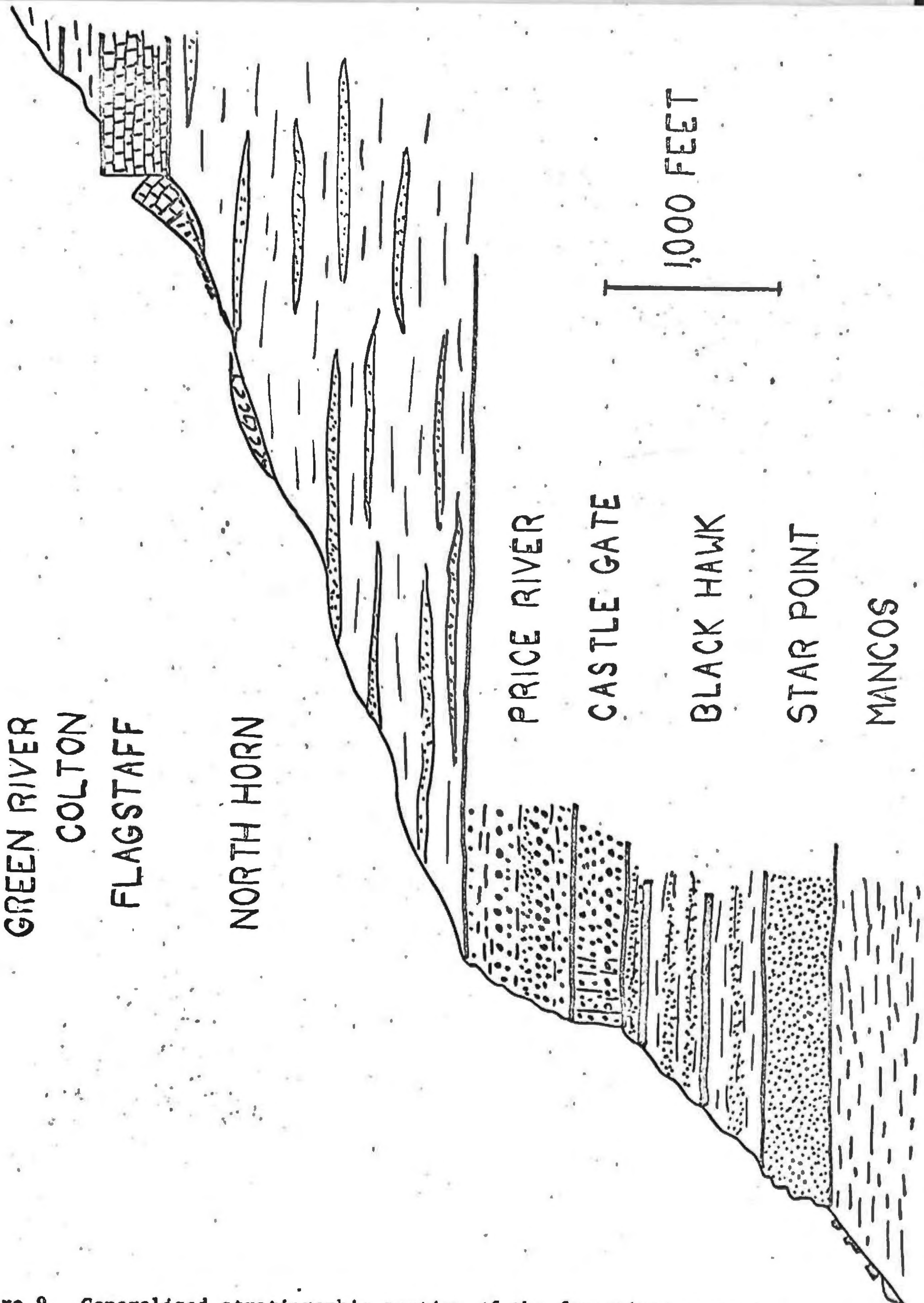

Figure 9. Generalized stratigraphic section of the formations present in the study area. Typical slopes for each formation are represented schematically.

Geologic Formations

The lithologies of the geologic formations and their stratigraphic positions are primary factors involved in the land-forming processes and, thus, in the development of the land stability characteristics of the study area. (Figure 9)

Masuk Member of the Mancos Shale--4000 feet: Uniform, massive gray marine shales of which only the upper part is exposed along the eastern boundary of the Forest. Because of the runoff characteristics, this formation tends to be rather barren and thus susceptible to severe sheet and gully erosion. Although not particularly susceptible to mass instability, this formation is slippery when wet and does provide lubrication for blocks of over-lying sandstone to slide on. (Figure 10)

Figure 10. Stratigraphic section from Masuk Shale to Castlegate Sandstone. The lower gray material is the Masuk with the vertical cliff immediately above it the Star Point Sandstone. Above this, the sloping area interrupted by several small cliffs is the Black Hawk Formation. The well-jointed vertical cliff at the top is the Castlegate Sandstone.

Star Point Sandstone--450 feet: Massive cliff-forming, buff sandstone, medium-to-fine-grained, found mostly in the Eastern Clifflands Subsection. Unlike the over-lying Castlegate Sandstone, this formation contains some interbedded shales which produce a steplike topography. Of itself, this formation is quite stable; however, the more rapid erosion of the under-lying Masuk Shale removes support by undercutting, which leads to block faulting. The blocks so produced then move down the shale-colluvial slopes as planar block glides. (Figure 10)

Black Hawk Formation--1500 feet: Medium-to-fine-grained, buff and gray sandstone, gray shale, coal; mostly found in the Eastern Clifflands and Ridge and Valley Subsections; major coal-producing formation in the area. Although not as unstable as is the North Horn Formation, the Black Hawk underlies several areas of active movement. In addition, it supplies abundant colluvial material which can be treacherous if not handled carefully. (Figure 10)

Castlegate Sandstone--300 feet: Massive, cliff-forming, gray sandstone, coarse-grained to conglomeratic; forms the top of the cliffs of the Eastern Clifflands Subsection in most places. In addition to producing massive cliffs, this formation is subject to severe jointing, which produces large boulders. Although the Castlegate is stable on its own, undercutting of the Black Hawk Formation beneath it removes support from the jointed cliffs. This results in block falls and subsequent sliding of the large blocks down the shale and colluvial slopes. (Figure 10)

<u>Price River Formation--600 feet</u>: Red to gray sandstone and conglomerate with varying amounts of shale. The appearance of this formation varies with geographical location. To the northwest, in the Ridge and Valley Subsection, it is a coarse, conglomeratic unit with minor amounts of shale. This material appears to be stable, presumably because of the paucity of shale. To the southeast, in the Rolling Basinlands Subsection, the size of the conglomerate decreases and shale interbeds appear. As a result, the topography changes from vertical cliffs to staircase forms, and the stability decreases as the proportion of shale increases. (Figure 11)

Figure 11. The Price River Formation in Joe's Valley. The steplike topography results from the alternation of sandstone and shale beds. The Castlegate Formation forms the cliff at the base of the hill.

<u>North Horn Formation--2000 feet</u>: Buff, gray, red sandstone, gray to variegated shale, conglomeritic, some limestone. This formation is probably the most important one in the study area because it is exposed over large areas and is extremely unstable. The shales which comprise a major component of this formation become highly plastic when wetted and are capable of extensive mass movement. Since the sandstones and limestones of this formation are not well indurated (cemented), they cannot act as stabilizing agents. (Figure 12)

south side of Harmonica Point

Figure 12. North Horn Formation. The location is the cliff ~~south~~ north east of Ferron Reservoir. The ponds and hummocky topography are caused by fossil landslides and the bare areas attest to the susceptibility of this type of terrain to gullying.

<u>Flagstaff Limestone--300 to 500 feet</u>: Gray, tan, white limestone with minor amounts of shale and sandstone; exposed mainly in the High Plateaus and Monocline Subsections. This formation is, in general, stable. However, where the slopes are oversteepened or where support has been removed from the base of a dip slope, the shale partings can form glide surfaces for movement of the limestone blocks. (Figure 13)

Figure 13. Flagstaff Formation near its type locality, Flagstaff Peak.

Colton Formation--0-500 feet: Varicolored to gray shale, buff to brown sandstone, some local limestone; exposed along the western border of the Forest at the base of the Monocline Subsection and along the lower part of Salina Creek. This formation is similar in lithology to the North Horn Formation and is thus potentially unstable if wetted. However, its major exposures are in the more arid portions of the study area so that it poses no immediate problem. (Figure 14)

Figure 14. Colton and Green River Formations. The Colton forms the red cliffs and is separated by a dip slope from the greenish-white Green River shale slopes behind.

Green River Formation--200 to 800 feet: Gray to green shale and white to tan limestone, minor amounts of sandstone and conglomerate. Because the lithology and geography of exposure are similar to those of the Colton Formation, it poses the same problems of potential instability. (Figure 14)

Quaternary Deposits: These deposits are quite varied because they reflect different parent materials. Their thicknesses vary, although each is generally less than 100 feet. Because of the mechanisms of their deposition and positions on the landscape, these deposits fall into four basic categories, each with different stability characteristics.

1. Alluvium - These are the most stable deposits because water-washing has removed the fine material, leaving behind sand and coarser material. Except for the pediments on the eastern edge of the Forest, these deposits are located in valley bottoms; hence, they are fairly stable.

2. Moraines - The major deposits are located in the northern end of Joe's Valley graben and in Manti and Six Mile Canyons. Although generally stable, these deposits may have North Horn shale cores and could show local instability. The lack of observable slides in the Lakes Subsection indicates that these deposits are stable at present.

3. Colluvium - Ubiquitous in the study area, these deposits vary greatly in their landslide potential. On gentle slopes they probably pose no serious problem; however, on steep slopes they can cause serious difficulties because they are generally more permeable than the underlying bedrock. In such instances, soil water may be concentrated at the base of the colluvium, forming a slip plane.

4. Landslides - This type of material is most common in the Rolling Basinlands Subsection, although it can be found anywhere within the study area. Because these slides have a shear plane at their bases, they can be reactivated at any time. Thus, these deposits are the most unstable of all materials on the Wasatch Plateau.

Table 1. Stability Classification Scheme.

	ZONE 1	ZONE 2	ZONE 3	ZONE 4
GEOLOGY	GREEN RIVER FLAGSTAFF NORTH HORN — LANDSLIDES	ALL SIX	FLAGSTAFF PRICE RIVER CASTLE GATE BLACK HAWK — GLACIAL MORAINES	FLAGSTAFF PRICE RIVER CASTLE GATE
SLOPES	ALL TYPES	ALL TYPES	MODERATE	FLAT
CLIMATE	HUMID	HUMID TO SEMIARID	HUMID TO SEMIARID	HUMID TO ARID
OUTSIDE INFLUENCE SUFFICIENT FOR SLIDING TO OCCUR	NATURAL CAUSES: RAIN, SNOW STREAM CUTTING VIBRATION	MODERATE ACTIVITIES: LOGGING, DAMMING ROAD BUILDING SHALLOW TRENCHING	EXTENSIVE ACTIVITIES: ROAD BUILDING DEEP TRENCHING OVER GRAZING CLEAR CUTTING	LITTLE OR NONE
MAXIMUM DEGREE OF SLIDING EXPECTED	MASS FAILURES	MASS FAILURES	FEW MASS FAILURES LIMITED SLUMPS BLOCK SLIDING	RARE LIMITED SLUMPS
UTILIZATION POTENTIAL	SCENERY LIGHT GRAZING	LIMITED TO NECESSARY ACTION, MODERATE GRAZING	MOST ACTIVITIES IN MODERATION	ESSENTIALLY UNLIMITED

III. STABILITY CLASSIFICATION

Classification Scheme

Once the study area had been divided into subsections it seemed reasonable to assume that geology might be the factor controlling land stability and that land within physiographic subsections could be classified on this basis. However, in the Ridge and Valley Subsection, for example, where there is not a direct relationship between topography and geology this system is not applicable. By combining geology, slope, aspect, and climate, however, it was possible to distinguish four classes of stability ranging from stable to highly unstable.

Table 1 shows this basic classification scheme on the first three horizontal lines (geology, slopes, and climate). It is important to note that the zones of relative stability are not mutually exclusive, but rather are reasonably distinctive when the characteristics are combined. The chart also describes, for each zone, the conditions that could cause sliding to occur. This does not imply that when such conditions exist, sliding will inevitably occur; it only means that when slides or potential slide areas were examined, the conditions listed were the minimum conditions which could trigger the sliding. The phrase, "maximum degree of sliding expected" indicates which types of slides are important in a management sense; of course, many types of movement are possible in each zone. The last line describes in general terms, the utilization potential of each zone. More detailed information on each of these points is included in the discussion of each physiographic subsection.

Thus, we have the outline for the description of the lands included within the Wasatch Plateau portion of the Manti-LaSal and Fishlake Forests and for the interpretation of this land in terms of multi-use planning.

The locations of the land stability zones are shown on Plates 3 through 7.

Stability Zones

Each area is first classified (see Table 1) as generally stable (zones 3 and 4) or generally unstable (zones 1 and 2). Then it is designated by a specific zone number depending on its relative stability or instability.

Zone 1.

Areas that are actively sliding or moving today, plus those areas in the physiographic subsection that have the same bedrock formation, climate, slope, and aspect. These are the most unstable areas and could become active and begin to move without human activity. (Figure 15)

Figure 15. Stability Zone 1. This is the area of Twelve Mile Canyon.

Zone 2.

Areas of dormant or fossil landslides. Areas underlain by the same geologic formations as areas of Zone 1, but with more favorable slope, aspect or climate; or areas with deep gullies which are cutting away the toes of slopes and may lead to landslides. These areas will probably become unstable if subjected to improperly designed construction activities. However, in some instances, they could be made stable by remedial engineering works. (Figure 16)

Figure 16. Stability Zone 2. This slump was found on the Ephraim road near the Great Basin Experiment Station.

Zone 3.

Areas of fluvially-dissected slopes underlain by the more stable formations of the region, however, because of the high slope angles and local gullying, small slumps and local sloughing might occur. Since these areas are relatively stable, remedial works are probably not necessary. (Figure 17)

Figure 17. Stability Zone 3. The area is Duncan Mountain.

Zone 4.

Flat-lying areas underlain by stable formations. No stability problems are anticipated in these areas. (Figure 18)

Figure 18. Stability Zone 4. The area is near Wildcat Knolls.

Slide Frequency

In this discussion of land instability, the concept of magnitude and frequency should be considered. This concept has been used for several years by meteorologists and by hydrologists. In short, it states that small events involving small volumes will occur frequently, whereas progressively larger events involving progressively larger volumes will occur with decreasing frequency. Thus, small floods occur more frequently than large floods. In the case of landslides, pertinent data must be collected for a considerable period of time before we can begin to predict magnitude and frequency. These data should include the following: Date of initiation, location, geology, slope angle, aspect, antecedent moisture contions, undercutting of toe and other predisposing conditions, and the volume of material involved.

In spite of a wealth of magnitude-frequency data, flood prediction is not always easy even though floods are the product of well-defined and increasingly visible phenomena and are restricted to a limited area - the stream channel and flood plain. On the other hand, landslides are not as geographically restricted as are floods, and their causes are not as obvious. The latter is because historic, geologic, and meteorologic factors are involved in varying degrees.

For the reasons described above, this study is primarily concerned with delineating areas susceptible to sliding of all types and, in a very rough way, with indicating the size of the expected slides. This study, however, says nothing about the timing of slides; they may occur tomorrow or they may not occur for 100 years.

Mechanisms of Mass Movement

There are four mechanisms which can initiate or trigger mass movements in susceptible areas, or reactivate fossil landslides. They are (1) the addition of weight near the top of a potentially unstable area, (2) removal of support from the toe, (3) saturation of the material with water so that internal friction is reduced, and (4) vibration of the material. Reducing this to fundamental principles, we can say that mantle stability exists when frictional forces exceed deforming forces, and instability exists when the converse is true. An equation for this will have the general form:

Deforming Forces		Resisting Forces	
W_1	$<$	$(W_2\phi + C)a$	stable
W_1	$>$	$(W_2\phi + C)a$	unstable

Where:

W_1 = weight of material tending to produce instability (component of gravity parallel to the slope)

W_2 = weight of material tending to produce stability (component of gravity normal to the slope)

C = cohesion of the material

ϕ = the internal angle of friction

a = area over which the friction operates

Any change that tends to reduce the value of the right hand side of the equation will lead to instability. This can be done by drastically reducing one of the factors or slightly reducing all of the factors.

Looking at the four mechanisms in this light, we can see that (1) causes instability by increasing the deforming forces; (2) causes instability by reducing the area over which the friction operates. Mechanisms (3) and (4) cause instability by reducing the coeficient of friction: (3) by lubricating the material and (4) by changing the type of friction from static to sliding.

Returning to the concept of magnitude and frequency, it becomes apparent that we are not looking at the variation of one factor with time, but rather at the variation of several factors and combinations of those factors, with time. Thus, until a catalogue of landslides, like the one described above, has been compiled over a period of years, we will be unable to quantify the probability of a landslide on a given landscape over a given period.

IV. DESCRIPTIONS OF THE SUBSECTIONS

The Lakes Subsection

This subsection, in essence the northern extension of the Joe's Valley graben, extends from Scad Valley divide on the south to Lower Gooseberry Reservoir on the north. To the east and west it is bordered by, but does not include, the long steep slopes that rise to the Ridge and Valley and Rolling Basinland Subsections. Spieker and Billings (1940, p. 1183) describe the region as follows: "The surfaces are hummocky and irregular, and are dotted with hundreds of small depressions, most of which are occupied by ponds and marshes except in very dry seasons. Postglacial erosion has hardly begun to modify these features."

The elevation of this subsection is generally around 9000 feet and rainfall averages 20 to 30 inches annually. Most of this area is underlain by the North Horn Formation, with the exception of some areas along the eastern border which are underlain by Castlegate Sandstone and the Price River Formation. The North Horn Formation here is mantled by glacial till which, because of its hummocky appearance, can be confused with fossil landslide topography. However, striated boulders, cirques, and U-shaped valleys indicate glacial, rather than landslide, action.

This subsection is relatively stable for several reasons: (1) the material was deposited by glacial action and not by landslides, (2) some of the clay and other fine material were washed from the deposits by glacial meltwater so that fewer potential landslide areas exist and, (3) the underlying topography consists of gently rolling, rather than steeply-sloped, hills.

As in landslide topography, there are numerous natural ponds and lakes. In contrast to sag ponds, however, these ponds rest on stable material and lie in or near the bottom of valleys rather than being perched on shoulders; thus, they can be, and have been, successfully enlarged for use as reservoirs. (Figure 19)

Figure 19. Cleveland and Miller's Flat Reservoirs (to the left). This is glaciated terrain with hummocky valley bottoms and U-shaped valleys (in background).

Despite the general stability of this area, there are some small earth flows and numerous seeps resulting from high ground-water levels and from drainage disrupted by glaciation. Therefore, although this subsection in general is suitable for most types of land use, the construction of surfaced roads should take these small areas of instability into account.

The High Plateaus Subsection

This subsection is located in the center of the map area and almost exclusively in the Manti-LaSal National Forest. Except for some outliers along Trail and South Horn Mountains, it is shaped like a large triangle, with its base at the southern edge of the Manti-LaSal and its apex near the Horseshoe. Altitudes here are generally above 10,000 feet and, thus, this subsection is the wettest and coldest of the study area. Precipitation is usually greater than 30 inches annually, much of it in the form of snow. The long winters with large diurnal fluctuations in temperature make frost wedging an important geomorphic process.

Most of this area is flat-lying and underlain primarily by Flagstaff Limestone; however, because of faulting, the North Horn Formation is exposed in isolated patches. Generally, then, this subsection is stable from a landslide point of view.

A combination of past and present processes has formed north-south trending narrow bands of instability on both sides of the Skyline Drive. Initially, slopes in these bands were over-steepened either by glacial headcutting (figure 3) or by faulting. They remain wet throughout most of the year because of the large drainage area above them and the large snow packs that accumulate on them each winter. Within these areas, instability is in the form of small-scale mudflows and block slides.

The border between the High Plateaus and the Rolling Basinlands is also unstable. Here, undercutting of the North Horn Formation beneath the nearly vertical cliffs of Flagstaff Limestone has led to block sliding (figure 20) and, in some areas, to large scale land slides (figure 27). It is in this border region that some of the large fossil landslides are located, and where repeated sliding can be expected in the future. The occurrence of large slides in this subsection, as opposed to the single block sliding in the Eastern Clifflands, results primarily from the difference in climate in the two regions, although plasticity of the shales may also be involved.

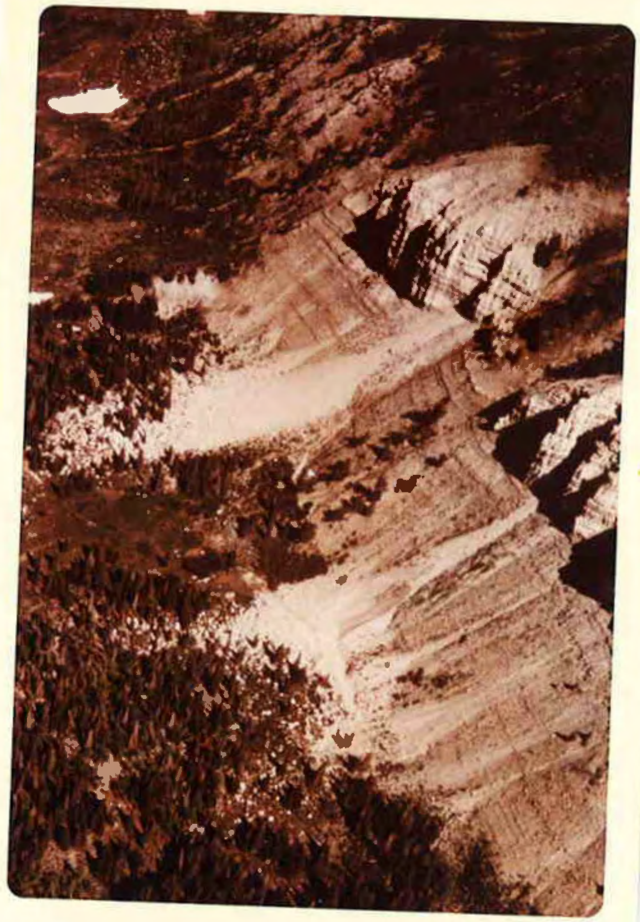

Figure 20. Block falls and debris slides along a Flagstaff escarpment. These are caused by undercutting of the North Horn Formation and are located on the south side of Heliotrope Mountain.

The recommendations for this subsection are fairly straightforward. In general, areas of high slope angle should be avoided in locating soil-and vegetation-disturbing activities. The relatively flat areas underlain by Flagstaff Limestone are suitable for most purposes, if the action of frost wedging is taken into account.

The Ridge and Valley Subsection

This subsection is located in the northern end of the study area. It has fairly sharp boundaries with the High Plateaus and Lakes Subsections to the south and has gradational boundaries with the Monocline near Milburn and with the Eastern Clifflands around the Star Point area. Elevations here range from 6000 to 9000 feet and the area is composed of narrow ridges and narrow V-shaped valleys. The topography is not angular as is the rest of the Wasatch Plateau, but rather is rounded like that of the Eastern United States (figure 4). Rainfall here averages 20-25 inches annually.

Structurally, this area is quite complex due to numerous faults and to its location at the junction of the Soldier Monocline dipping to the north and the Wasatch Monocline dipping to the west. These factors result in formations from Black Hawk to Green River being distributed throughout the area, both on ridge crests and at stream bottoms. Thus, unlike other subsections, the topography here does not follow the geology. The entire area has been dissected in a dendritic drainage pattern; the state of dissection could be described as late youth or early maturity in that there are small flood plains along parts of the stream valleys.

The geologic formations do not have the same outward expression in this subsection as they do in the rest of the study area; for example, Castlegate Sandstone is not a cliff-former here. For this reason it is necessary to consider each formation individually. The Castlegate and Black Hawk Formations are fairly sandy; the sand helps to increase drainage and to inhibit slipping of the plastic clays contained in these formations. Within this subsection the Price River Formation changes character drastically; to the east it is composed of pebble-sized material set in a clay matrix, and thus is similar to the underlying Castlegate and Black Hawk Formations. To the northwest, around the area of Smith's Reservoir and westward, it is composed of cobbles set in a sandy matrix and forms cliffs and slopes that are stable from a landslide point of view, but are subject to severe gullying and fluvial erosion.

The North Horn and Flagstaff Formations contain the same rock types as they do farther south and behave as they do in those locations. The Colton Formation is absent in this subsection. The Green River Formation is a heterogeneous mixture of conglomerate sandstones and bentonitic shales. Because of the rapid facies change, it is not practical to differentiate the various rock types at this level of mapping. In general, the Green River Formation is the most unstable in this subsection; in fact, the only active slide here is within this formation.

In the area of Little Clear Creek north of Indianola, there is a jumble of Cretaceous and Jurassic sedimentary rocks which appear to be similar in texture and stability to the Black Hawk and Castlegate Formations. Also in this area there are Tertiary extrusive igneous rocks that appear to be rapidly weathering to form clays. Thus, the steeper slopes of this material are classed as 2, while the gentle slopes are classed as 3.

Because the topography and, by inference, the erosional history, is entirely different here from that found elsewhere in the study area, it was necessary to further define the classification scheme so that the same zone definitions applied to the entire region. Thus, the zone descriptions were expanded as follows:

Zone 1: Slopes actively moving or similar in all respects to those that are moving.

Zone 2: Areas where land slips and mass failure could easily be induced by human activity.

Zone 3: Relatively stable slopes where extensive human activity could produce slope failure.

Zone 4: Very stable slopes; flat areas.

Although the large scale fossil landslides typical of zone 2 in other portions of the study area are absent from this subsection, the zone 2 designation has been given here to slopes that will likely produce numerous small scale failures, such as vegetative planar block glides and surficial sloughing, if human activities neglect the steepness of the slopes. In other words, these slopes are precariously balanced at present and any disturbance or steepening could lead to mass failure.

<u>Recommendations</u>. The Ridge and Valley Subsection is probably suitable for logging, as long as the steeper slopes are not severely cut up by a road network. In the area of watershed treatment shallow trenches would be feasible, but deep trenches would probably fail on the upslope side. Except on the ridge-crests and valley bottoms, recreational facilities are excluded by the steepness of the slopes. Road construction would have to be in full bench cuts. There would probably not be any large-scale slump failures resulting from road construction. However, persistent maintenance would be needed because of continual sliding of small sandstone blocks and vegetative planar block glides.

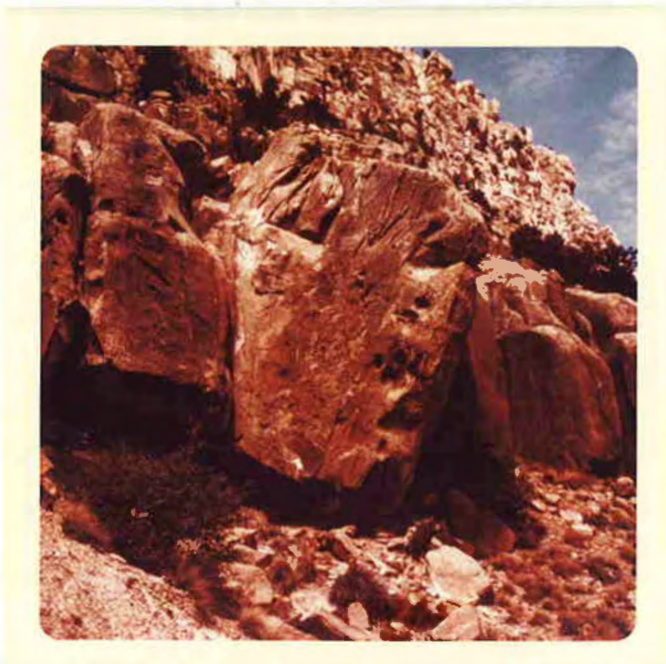

Figure 21. Undercutting of sandstone beds by shale. This process removes support from the sandstone beds, causing them to move downhill. The location is Ferron Canyon.

Figure 22. Road cut along U-29, 1/4 mile north of Joe's Valley Dam. Seepage along the base of the sandstone has removed shale and caused the sandstone block to move downhill.

The Eastern Clifflands Subsection

This subsection includes the 2000 foot cliffs facing Castle Valley and the canyons, such as Ferron, Straight and Huntington, extending westward into the Plateau. Because this subsection includes these canyons, it can be thought of as lying beneath the Rolling Basin-lands Subsection. This is important in considering interactions between these two subsections.

Geologic formations exposed here are, in vertical order upwards: the Masuk member of the Mancos Shale, Star Point Sandstone, Black Hawk Formation and Castlegate Sandstone. Thus, massive sandstone formations (Star Point and Castlegate) overlie shale formations (Masuk and Black Hawk). The prime physical erosion and movement in this subsection directly results from this arrangement: (1) erosion of the less resistant shale results in undercutting of the sandstone layers (figure 21), (2) because of jointing within the sandstone layer, blocks of sandstone may then fall upon the shale slope beneath, (3) once separated from the main sandstone layer, these individual blocks slide down the slope as a result of undercutting or wetting of the underlying shale and colluvium. Movement of the sandstone blocks is fairly slow under the normally arid conditions; however, undercutting by man or by water can speed the process. (Figure 22)

Although most of this subsection is rated as zone 2, the type of movement is distinct from that found in the Rolling Basinlands Subsection which is also ranked 2 in many places. Sandstone blocks in the Eastern Clifflands Subsection move by planar block glide, whereas movement in the Rolling Basinlands Subsection is mostly by earth flowage.

The Monocline Subsection

This subsection is located along the western border of the Manti-LaSal and Fishlake National Forests and extends from the southern end of the study area to Milburn. Its eastern boundary is gradational with the High Plateaus Subsection (figure 6). Elevations here range from 10,000 feet near the top of the plateau to about 6,000 feet in Sanpete Valley. In general, the average annual rainfall increases with elevation, being about 15 inches in the valley and 40 inches near the crest of the plateau.

As a result of folding and subsequent erosion, there are two quite different types and ages of topography in the Monocline Subsection (figure 23). The older surface, represented by the uplands between the canyons, is a surface without great local relief that follows bedding except where it is interruped by stoss slopes. Uplift of the Wasatch Plateau resulted in westward tilting of the Monocline. Subsequently, streams and glaciers have cut into the Monocline and developed a very rugged topography between remnants of the older surface. Because there are two types of topography, there are two types of instability problems in the area.

Figure 23. Monocline Subsection in the area of Six Mile Canyon. This photograph shows the two types and ages of topography.

Unlike the other physiographic subsections of the Wasatch Plateau where the formations are nearly flat-lying, here the bedding dips by as much as 20 degrees to the west. The Flagstaff and North Horn Formations each cover about half the area; the Colton and Green River Formations are exposed near the southern end of the study area. In addition, there are local deposits of glacial till in the stream valleys.

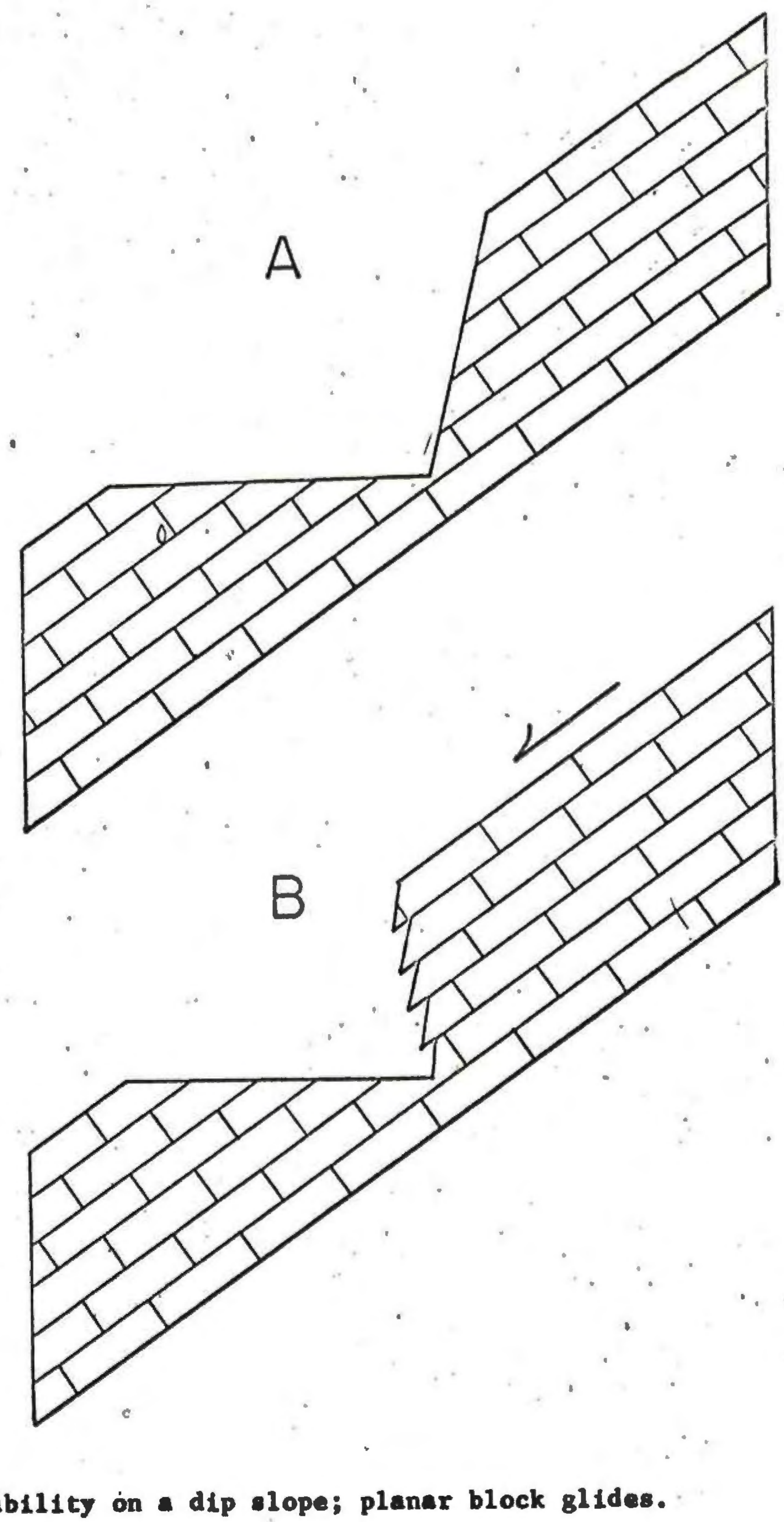

Figure 24. Instability on a dip slope; planar block glides.

In the flat interfluves the topography generally follows bedding planes; thus, these slopes are fairly stable especially where underlain by the Flagstaff Formation. However, no activity should be undertaken that involves extensive slope cutting, as this will remove the support from the base of the beds. Most of the beds have shaly partings between them and these can act as slip planes enabling an entire bed to glide downhill (figure 24). Other types of treatment that do not involve deep cuts would probably not produce harmful effects.

The glacial history of the rugged canyons, such as Twelve Mile and Six Mile, accounts for their oversteepened slopes and relatively flat floors mantled with till. As in the case of the Lakes Subsection, these till deposits are fairly stable except near their steep fronts and in stream gullies. In contrast, the canyon sides are generally unstable. Abundant moisture, high slope angles, dip slopes, and the stratigraphic characteristics of the North Horn Formation all contribute to the instability. (Figure 25)

Figure 25. Typical canyon side in the Monocline Subsection. This shows the fossil and active instability in the North Fork of Manti Canyon.

Although not within this subsection, Fairview Canyon (figure 26) exhibits most of the problems that can arise in the canyons to the south. In areas where road cuts have removed support from the toes of slopes, slumping probably will occur. In other areas where road fill has forced the stream to one side of the canyon, undercutting of the bank will produce debris slides. In both cases much sediment is placed in transport either directly, from material falling into the stream, or indirectly, from material being placed there in road-clearing operations.

Figure 26. Fairview Canyon road. Most of the cuts above the road are currently active, and in attempting to clear the road, the highway crews have dumped the debris on the downslope side producing the "talus cones" leading into Cottonwood Creek.

Rolling Basinlands Subsection

This subsection extends from, and is best developed at, the southern end of the project area, where along Interstate Highway 70 it occupies the entire width of the Fishlake Forest. To the north it is bounded on the west by the High Plateaus and on the east by the Eastern Clifflands. Still further north, in the area of Joe's Valley, the subsection is bounded both to the east and west by plateau surfaces. This special case is caused by the downdropping of the Joe's Valley graben. In the drainages of Ferron and Muddy Creeks, this subsection forms the gently rolling shoulders between the canyons of the Eastern Clifflands and the flat surfaces of the High Plateaus (figure 7). Elevations range from 6000 feet to slightly above 9000 feet. In general, the rainfall is between 20 to 30 inches annually.

The rolling nature of this subsection is a direct consequence of the underlying North Horn Formation, which in this area is composed mostly of shales. These are easily eroded, but because of their low cohesion they cannot form steep slopes; thus the stream drainages have a rounded cross-section. A second factor contributing to the rolling nature is the presence of numerous fossil landslides. Because the North Horn Formation and fossil landslides underlie most of this subsection, it is the most unstable subsection in the study area. The White Slides, Slide Lake, and the Clay Banks are examples of unstable areas underlain by North Horn. (Figure 27)

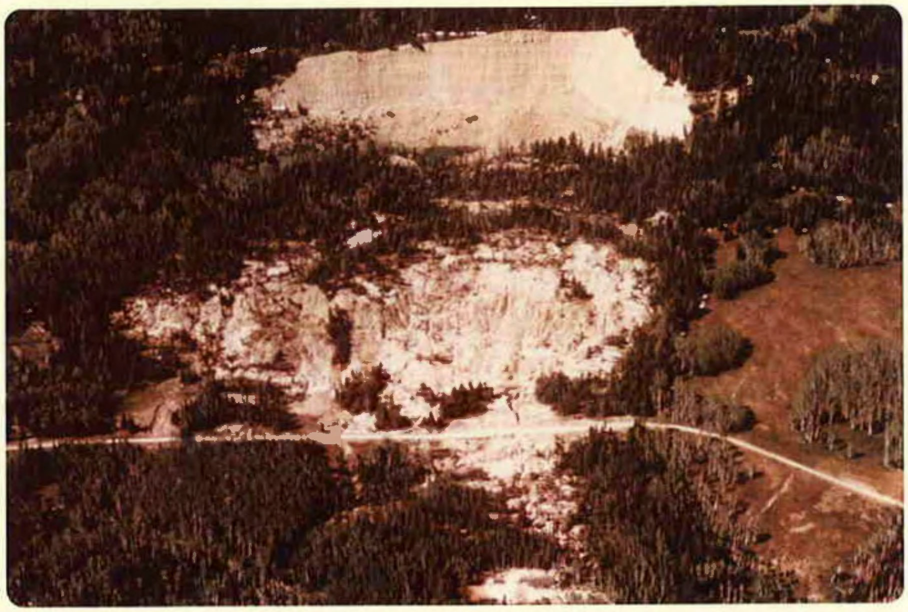

Figure 27. The White Slides. This area is an example of a large scale fossil landslide in the border region between the high plateaus and Rolling Basinlands Subsections.

Minor portions of this subsection are underlain by the Flagstaff and Price River Formations; these areas are fairly stable.

Because this subsection is centrally located and includes large areas of instability, several critical problems in land management should be considered. These problems are of general importance because they exist in other subsections, also.

1. The first of these problems is typified by the Bulger and Seely Canyon landslides. These are events of large magnitude and small frequency that pose recurrent and difficult problems in land utilization, since their effects extend far beyond their immediate areas. (Consult the special section concerning these slides on pages 39-41.)

2. Throughout this subsection, much of the land classed as zone 2 is subject to severe gullying. These areas are underlain by either the North Horn Formation or by fossil landslides composed of North Horn material. The gullying poses two problems: (a) The immediate one of excessive sedimentation in downstream reaches, and (b) the more insidious one of reactivation of fossil landslides by undercutting the toes of these slides. (See discussion of mechanisms of slide activation in plastic material.)

3. Another problem is posed by the utilization of the small lakes and ponds formed in the sag areas behind back--rotational slide blocks. Examples of these are the Grassey Flat Reservoir-Slide Lake area above Seely Creek, the Mary's Lake area above Swasey Creek, and the Willow Lake area in the upper Ferron Canyon drainage. Such areas provide two of the conditions which can reactivate slides: (a) Loading the head of the slide, here with a body of water, and (b) providing increased moisture within the body of the slide.

4. The border region between the Rolling Basinlands and High Plateaus Subsections forms a particularly hazardous area. Here, Flagstaff Limestone cliffs are continually being undermined by the more rapid erosion of the underlying North Horn Formation. Ground water, entering through the joints in the Flagstaff Limestone, lubricates the contact between the two formations and further contributes to the instability. The types of movement occurring here are block falls, block slides, debris flows, and rotational slumping (figures 12 and 20). This highly unstable area is of limited extent and could thus be left undisturbed.

For the three remaining problems certain recommendations can be made:

1. Although some major landslides cannot be prevented in a practical sense, corrective actions can be taken in the canyons leading westward from Joe's Valley Subsection. (See discussions on Bulger and Seely Canyon Slides.)

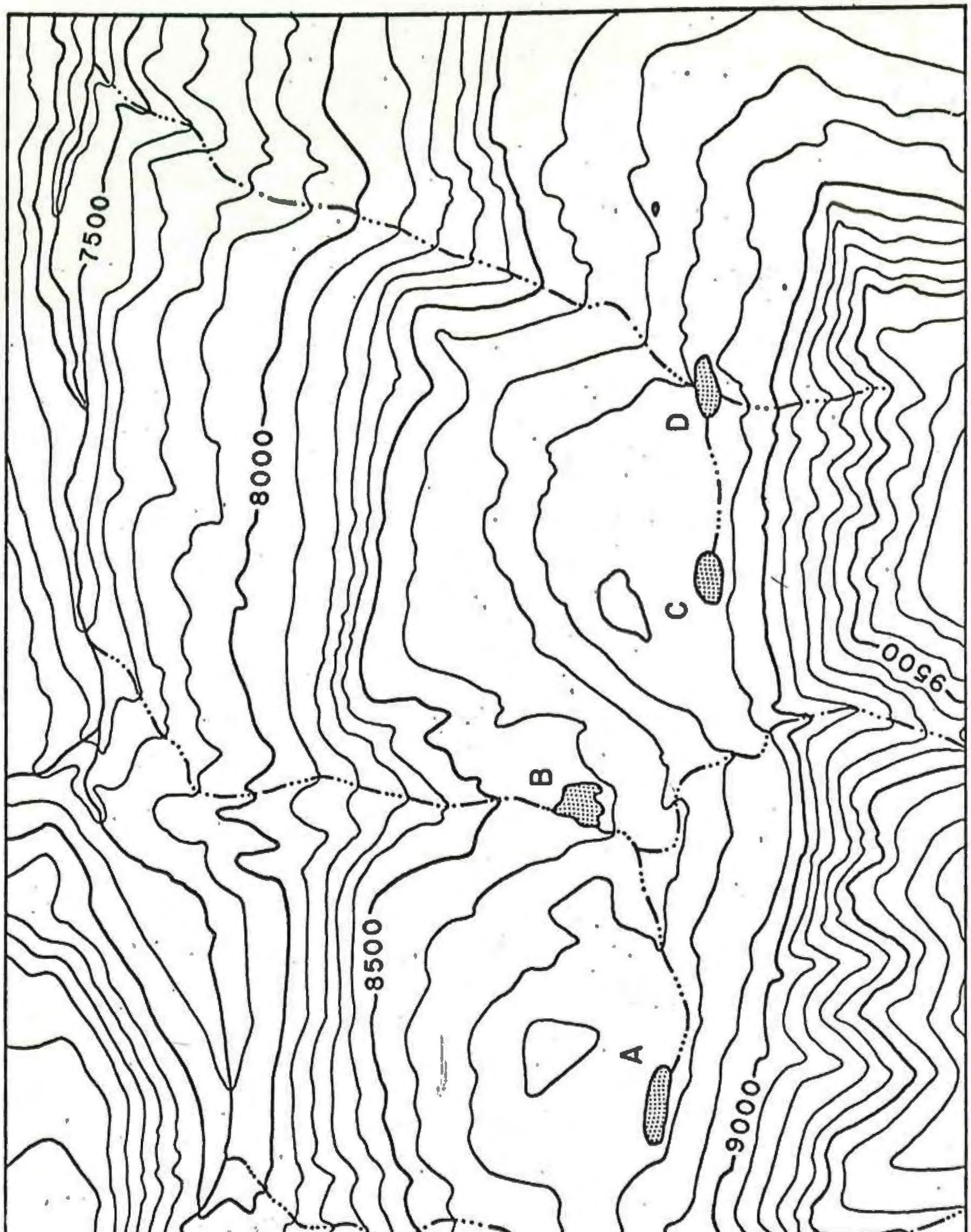

Figure 28. Idealized model for the location of ponds. (See caption with figure.)

2. One possible means of halting the gullying is to place gully plugs in severely eroded areas. These plugs should not be thought of as sediment traps, since they will probably be filled in the first storm; rather, they should be considered as temporary base levels to halt the process of downcutting.

3. a. In the area above Seely Creek only the ponds far removed from tributary gullies should be developed; those at the heads of gullies should be drained. (Figure 28)

   b. The proposed deepening of Willow Lake would be extremely hazardous. This lake is a sag lake formed behind a back-rotated slump block of the North Horn Formation. As shown by the adjacent White Slides area, this material is not only extremely plastic but is also subject to piping. Further complicating the situation is the fact that Willow Creek has cut a gully 200 feet lower than the lake level and within 1/4 mile of the lake. Continued head cutting will further remove support from the toe of this fossil landslide block.

We thus have three of the four conditions for reactivation of the landslide: (1) The lake acts as a weight at the head of the slide, (2) the hydrostatic pressure of the lake is wetting the material underlying the slide, and (3) headcutting of Willow Creek is removing support from the toe of the slide. The fourth condition, vibration, is a definite possibility, since the Great Basin to the west is seismically active.

Canyons Leading Westward from Joe's Valley. The canyons of this area include those between Potters Canyon and Swasey Creek. Near their mouths, these canyons are underlain by the Black Hawk, Castlegate, and Price River Formations and appear to be stable at this time. However, removal of the vegetative cover could lead to gullying of the Price River derivatives and thence to slumping.

Throughout most of their length, however, these canyons are cut into the North Horn Formation. As a result of the sinking of the graben which forms Joe's Valley, both the stream gardients and side slopes of these canyons have been oversteepened, leading to varying degrees of instability. In general, the south-facing slopes are covered with aspen and are hummocky, indicating that they are sites of fossil landslides. These slides comprise

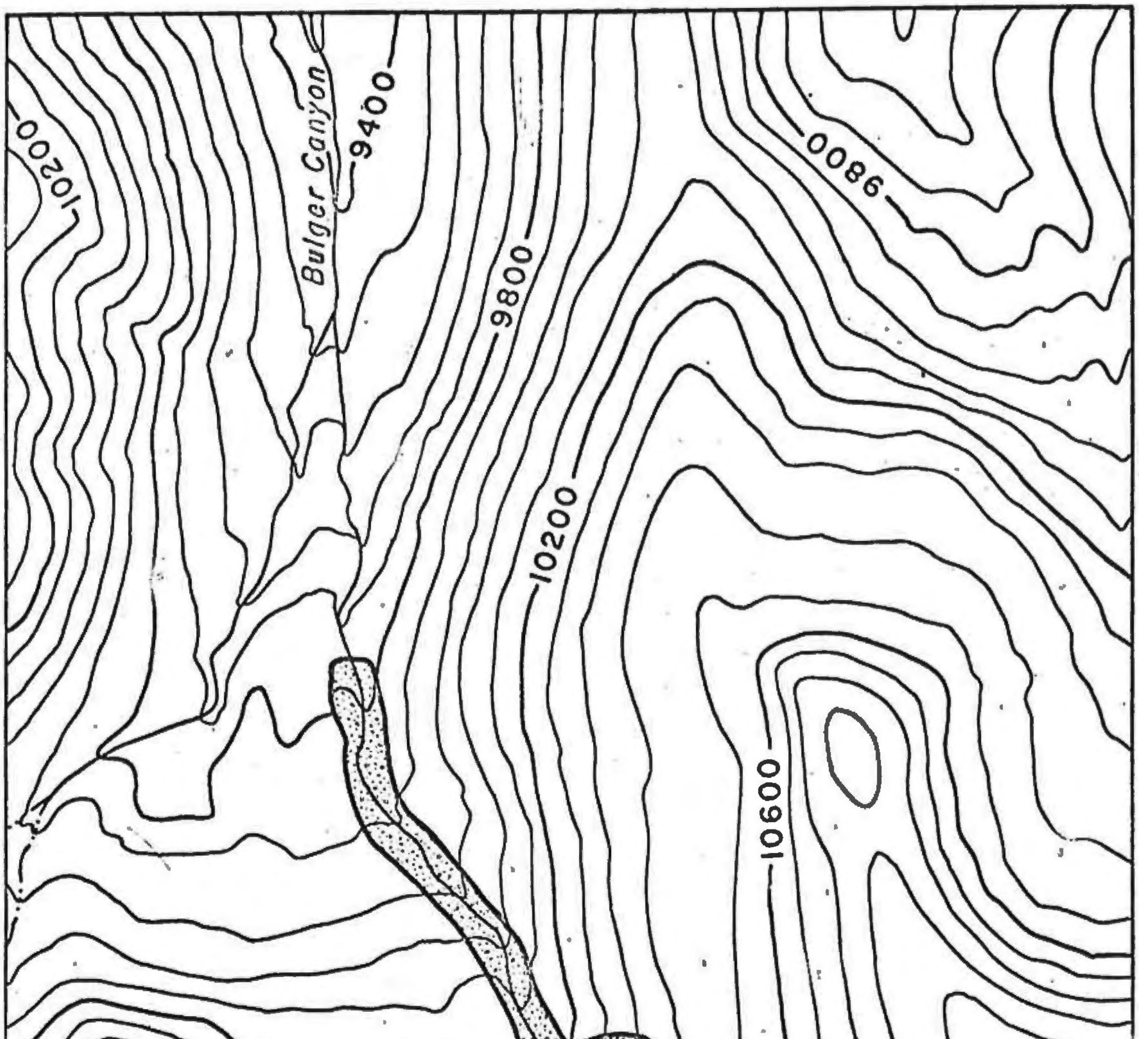

Figure 29. Map of the Bulger Canyon slide and mudflow.

several thousand cubic yards of material. Soil and vegetative disturbances, such as clear-cut logging which could lead to increased soil moisture (Bailey, 1971, p. 216-22), could result in gullying and ravelling of the slopes. In addition, situations which put an increased load on the heads of these slopes or undercut their toes could cause reactivation of the landslides. In Bulger Canyon slides have produced benches just above the stream gullies, and these could be used for low grade dirt locations. However, the slides which produced these benches could be reactivated by the same mechanisms listed above.

As opposed to the hummocky south-facing slopes, the north-facing slopes are generally straight and covered with mature stands of spruce and fir, giving an appearance of stability both in the field and on aerial photos. That this is not the case, however, has been shown by recent slides in Bulger and Seely Canyons (figures 29, 30 and 31). The slide in Bulger Canyon occurred in an area that appeared on aerial photos to be stable. Undercutting of the toe of the north-facing slope by rapid stream downcutting, and saturation of the bedrock and overlying colluvial material led to slumping of the slope (figure 32). In contrast to this, the area in which the Seely Canyon slide occurred appeared to be one of repeated slide activity in the past, as evidenced by 1957 aerial photos. Here, the downcutting of Seely Creek, plus the removal of material by an unnamed tributary has resulted in repeated activation of this slide (figure 30). Any development on these slump deposits should thus be done as far away as possible from tributary streams.

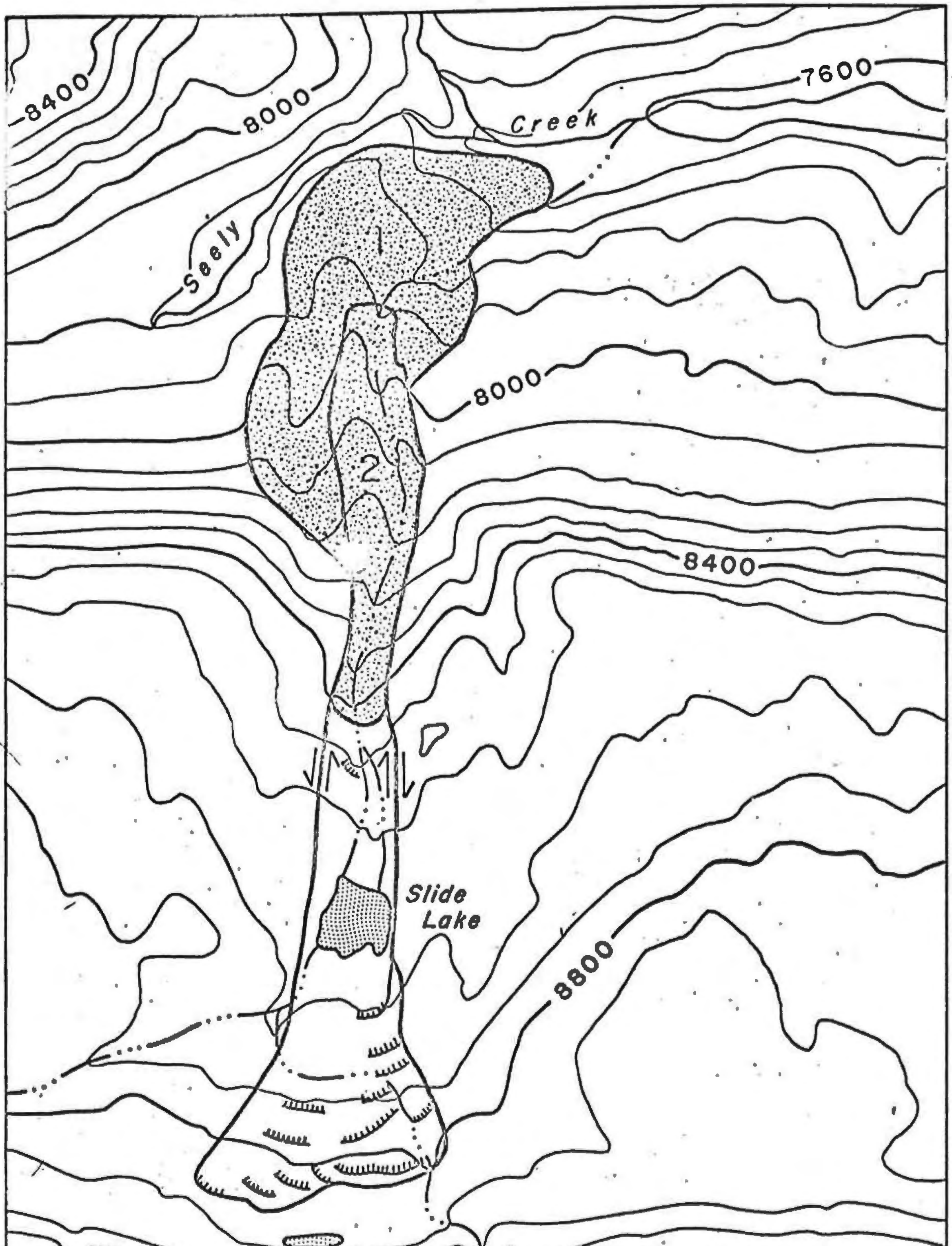

Figure 30. Map of the Slide Lake Slide.

Figure 31. Air photo of the Slide Lake slide.

Figure 32. Headward portion of the Bulger Canyon slide. The slump blocks near the head are coherent and the trees are upright. Whereas farther downslope the material has lost all its cohesion and the trees are lying on the ground.

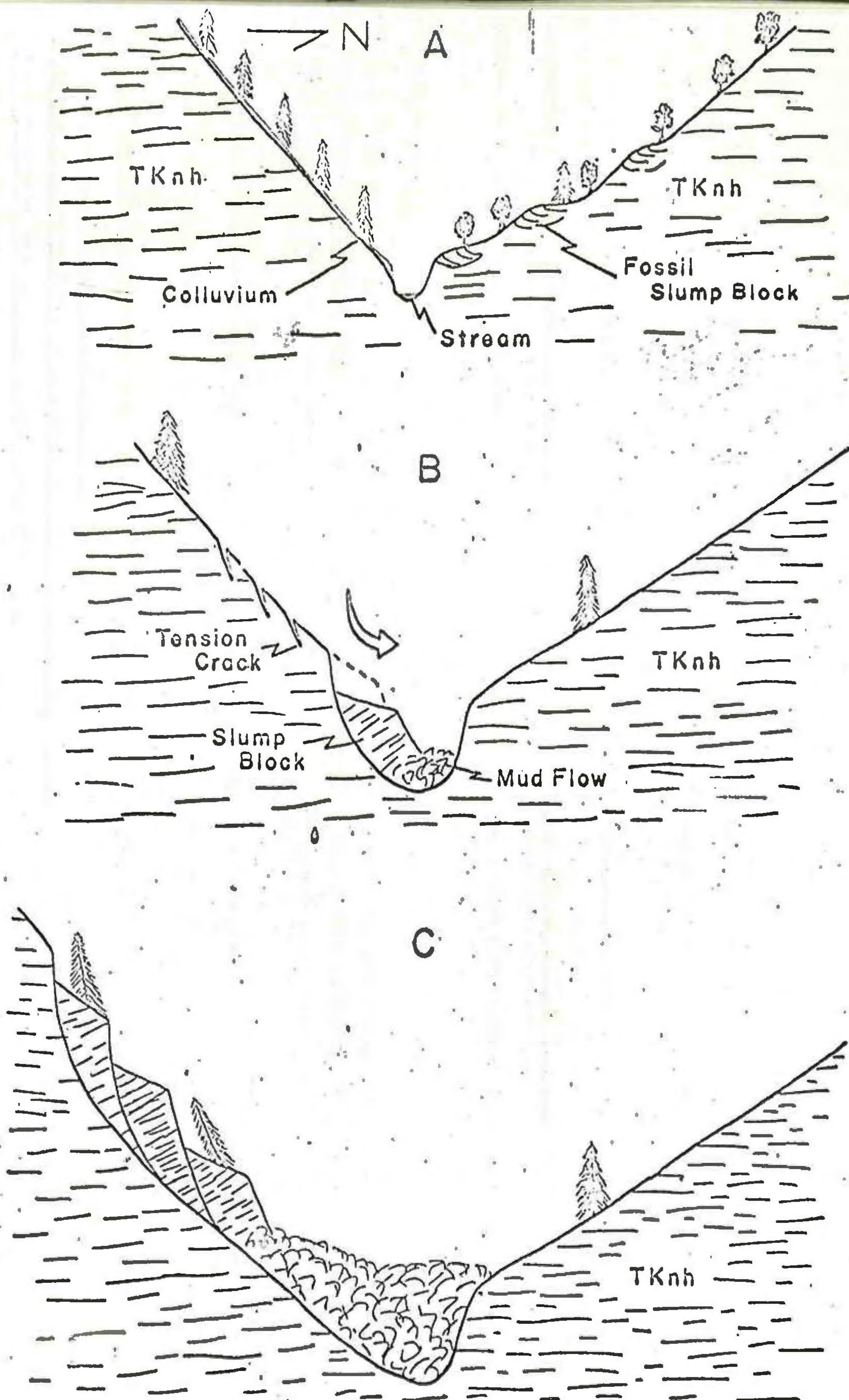

Figure 33. Generalized sequence for the development of slump blocks and mudflow.

Mechanisms of Activation and Mode of Movement of Slides. Several factors have combined to produce slumping in these canyons. First, throughout most of their length they are underlain by the North Horn Formation, and interbedded sequence of bentonitic (?) shales and sandstones. When water reaches these shales, expansion makes them heavy and slippery. The sandstone beds probably aid in this process by providing aquifers for the water to enter the shale beds. Second, these canyons are at altitudes between 7000 and 9000 feet, where the average annual precipitation is greater than 20 inches and a considerable snow pack is available to release moisture into the soil. The soils of the north-facing slopes are particularly wet since they receive little sunlight to dry them out. Third, because of the geologically recent tectonic uplift of the entire Wasatch Plateau and the downdropping of the Joe's Valley graben, the streams in these canyons have cut steep-sided canyons and presently are undercutting the toes of these slopes (A, figure 33). Fourth, the area immediately to the west is seismically active, so that there are numerous shock waves to trigger slumping.

By whatever combination of factors slumping is triggered, it begins at the base of the slope (B, figure 33) as a slump block 10 to 30 feet wide and about 100 yards long. The downward movement of the block removes support from the slope above and subjects that portion of the slope to tension stresses. In the Seely Creek slide, tension cracks were observed all the way up the slope from the area of active sliding to the ridge top divide (figure 34). These tension cracks may remain open for years and provide avenues for water to infiltrate and to lubricate the sole of the slide. Thus, it appears that once slumping starts at the base of these steep slopes, it will proceed intermittently, over a period of years, all the way to the top of the slope. (Figure 33)

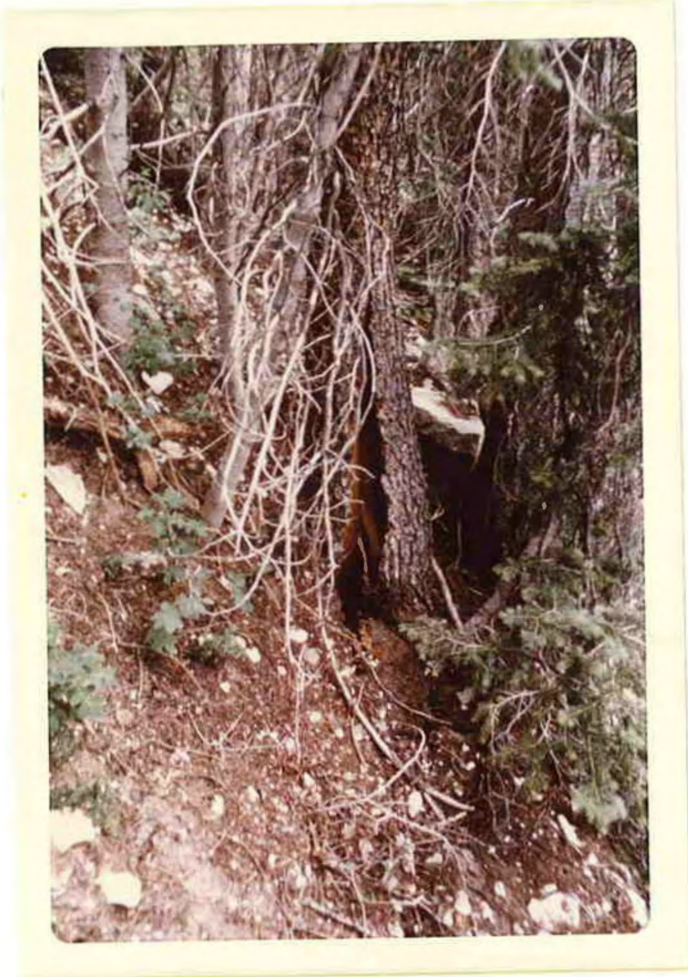

Figure 34. Tension crack at the headward portion of the Seely Creek slide.

The slumping of these slopes is hazardous, not only because slopes are disrupted and works of man can be damaged, but also because it provides thousands of cubic yards of material that can be carried by streams into Joe's Valley Reservoir. The downward movement of the slump blocks jumbles and disaggregates the toes of the slopes and places this jumbled material into the stream channels. The sudden influx of this material into the channel can cause a pond to form; water flowing from the pond goes over and through the slump material, converting it into a mudflow. The mudflow in Bulger Canyon was 3/4 mile long on July 2, 1971 and was still active. The absence of vegetation on the slump and the flowing of water primarily through, rather than over, the mudflow results in a maximum of sediment being transported by the stream. (Figure 35)

Figure 35. Middle portion of the Bulger Canyon mudflow.

Recommendations. Canyon slopes underlain by the North Horn Formation should be left undisturbed. Certainly no activity that either oversteepens a part of the slope or allows more water to enter the soil should be performed, as once these slumps and mudflows start they become too large to be controlled economically. It might be possible to decrease stream sediment load by seeding the surface of mudflows with grasses, possibly by air, thus providing material to hold the surface of the flow together. Such an action seems more favorable than the planting of trees, since these would be moved by the flow before they could root effectively. Events such as these slumps and mudflows should be considered high magnitude, low frequency events and treated as such.

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